Holistic Research Perspectives

Volume 13

KVM. Prof. Dr. R. Ganesan

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On an Inventive Plane Innovation Tends to Infinity

- KVM. Prof. Dr. R. Ganesan

Foreword

The advancements in globalization are happening at a fast pace. This necessitates the focus on research that needs to be periodically conducted on multidisciplinary and interdisciplinary domains to understand the new dimensions for gaining growth through various kinds of innovations to address future challenges and demands. The development of any nation and globe is guaranteed only through laudable contribution of its intellectual capital across all spheres. Moreover, enhancement of knowledge is the need of the hour and only ray of hope for prosperity. It is possible through enabling and encouraging the research acumen of human resources who are the vital constituents of the aforesaid intellectual capital. Furthermore, these intellectual resources are very much required to bring in an overall socio-economic development.

Today, congregation of various research approaches, theoretical perspectives and pragmatic views are quite indispensable. This in turn enhance the socio-economic sustenance and bring in a holistic growth within the global society. Keeping these aspects in view, this edited book has included selective book chapters in science, management, arts and humanities to facilitate the understanding through integrated learning. In furtherance, 'NFED Publishers' conveys to the publishing community that it is very much conscious and cautious about quality rather than quantity. The contributions made by each author in this edited book are unique, as they adopt different scientific approaches in presenting their respective book chapters.

I view this edited book titled 'Holistic Research Perspectives – Vol.13' as one of the important resources with useful information that provides an impeccable knowledge sharing for research communities.

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

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

Sd/-

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Preface

Today, the research studies and approaches have to be multidimensional in nature. Also, it should bring in a phenomenal change and holistic development in the society. For instance, any nation's development depends mainly on its knowledge potential. These knowledge sources are to focus more on interdisciplinary and multidisciplinary researches for achieving a comprehensive growth. In furtherance, the aforesaid research avenues have to concentrate more on societal upliftment, economic wellbeing and eco-friendly environment. This is possible only through creating an irrefutable scientific platform and encouraging burgeoning researchers towards socio-environmental and technology-management innovations.

The present edited book titled 'Holistic Research Perspectives Vol.13' envisions in its mission of congregating the book chapters on various disciplines of study viz. geophysical aspects, public administration, applied psychology, medical education, entrepreneurship development, mathematical applications, neuromarketing techniques and medical education for gaining an effective socio-economic transformation.

This edited book by itself is a learning platform, which emphasizes on knowledge sharing among research communities across the nation. It is to be noted that any scientific innovation is possible only through conducting periodic research. The results and observations discussed in the book chapters provides an overall understanding of research happenings, which are quite necessary to address the future global challenges.

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

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

Jai Hind!!!

Sd/-

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Contents

Structural Controls on Groundwater Contamination in the Crystalline Terrain of Musi River Basin, Telangana, India – An Integrated Geophysical and Geospatial Approach

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Abstract

Rapid urbanization and industrial expansion in Hyderabad, India, have transformed the Musi River into a major conduit for untreated domestic and industrial effluents, significantly degrading surface and groundwater quality. The present research study examined the structural and hydrogeological controls governing contaminant migration along the Peerzadhiguda–Valigonda corridor of Musi River basin within the crystalline hard-rock terrain of Deccan Plateau. An integrated approach combining Electrical Resistivity Sounding (VES), Magnetic Anomaly modeling, IRS P6–LISS IV remote sensing and groundwater quality assessment has been employed to delineate subsurface architecture and identify preferential flow pathways. Resistivity cross-sections revealed a three-tier aquifer system comprising a shallow conductive soil/clay layer, a weathered and fractured granitic aquifer extending to depths of 15–20 m and a compact crystalline basement encountered at approximately 40–43 m in the southern sector. Magnetic anomaly modeling identified high-intensity peaks corresponding to basic intrusive dykes and major structural discontinuities trending NW–SE and NE–SW. Strong spatial correlation between magnetic depth models and geoelectrical sections confirmed that dyke–granite contact zones and fracture intersections function as high-permeability tectonic conduits. Moreover, comparative analysis of upstream and downstream traverses indicated an asymmetrical tectonic framework with a southward-dipping basement block exhibiting

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enhanced structural penetration and increased groundwater vulnerability. Also, the integrated Groundwater Quality Index (GQI) mapping demonstrated a clear spatial coincidence between structural intersections and high-toxicity zones, confirming that contaminant migration is structurally controlled and extends beyond the shallow weathered zone into the fractured basement. This study established a robust structural–hydrogeological model for assessing groundwater vulnerability and managing pollution in rapidly urbanizing hard-rock environments.

Keywords: Groundwater Contamination, Structural Controls, Hard-rock Aquifer, Electrical Resistivity Sounding (VES), Magnetic Anomaly, Musi River Basin.

Introduction

Hyderabad, the fifth largest city in India in terms of population and geographical extent, which has experienced unprecedented urban expansion over the past few decades. This rapid growth has placed under most environmentally stressed metropolitan regions in the country, ranking among the most polluted cities in India. Unplanned and accelerated industrialization, coupled with intense urbanization, has generated severe environmental challenges, particularly concerning water resources. The River Musi, which flows through the heart of Hyderabad and bifurcates the twin cities of Hyderabad and Secunderabad has become central to this environmental crisis. The Musi River, a major tributary of the Krishna River, originates from Ananthagiri Hills of the Ranga Reddy district, approximately 90 km west of Hyderabad and traverses nearly 170 km before joining the Krishna River at Wadapally in Nalgonda district.

Historically, the river flowed over lateritic formations of the Deccan Traps and across granitic plains, acquiring excellent physicochemical quality and even medicinal value. For centuries, it sustained diverse cultures along its banks and contributed significantly to the socio-economic development of region-from the era of Qutb Shahi rulers to the modern industrial age. Today, the river supports more than 13 million people and irrigates nearly one lakh hectares of agricultural land downstream, particularly during the monsoon season. However, the pristine character of Musi River has drastically deteriorated. As the river enters western periphery of Hyderabad, it receives large volumes of untreated industrial effluents, domestic sewage and municipal wastewater. Industrial clusters located along the western flank of the city discharge effluents indiscriminately into the river system (Blessy et al., 2019). In addition to this, partially treated and untreated sewage from households and sewage treatment plants (STPs) is continuously released into the river channel. Consequently, the river now carries high loads of suspended and dissolved contaminants, characterized by foul odor, discoloration, elevated chemical concentrations and increased density. The environmental degradation is not confined to surface water alone.

The downstream of Hyderabad, hundreds of farmers depend on the perennial flow of Musi River for irrigation, cultivating vegetables and other crops over extensive agricultural lands. Often, irrigation water consists of untreated or partially treated wastewater, raising serious concerns regarding soil quality, crop safety and human health. More critically, wastewater

irrigation coexists with groundwater extraction in the same areas. This interaction has resulted in progressive deterioration of groundwater quality in local aquifers, particularly marked by rising salinity and fluctuating pH levels. Groundwater contamination in Hyderabad has become widespread due to continuous infiltration of domestic and industrial pollutants, exacerbated by poor urban planning and inadequate waste management infrastructure. In the crystalline hard-rock terrain of Telangana, groundwater occurrence and movement are governed predominantly by secondary porosity. Structural discontinuities such as fractures, joints, faults and dykes serve as preferential pathways for subsurface fluid migration. These tectonic features facilitate the downward and lateral transport of contaminants from the polluted river into underlying aquifers. Although previous investigations have documented groundwater quality deterioration along the Musi River corridor (Subramani et al., 2010; Blessy et al., 2019), a significant research gap persists in identifying and mapping the specific structural conduits responsible for contaminant migration, particularly along the Peerzadhiguda–Valigonda stretch.

The present study addresses this critical gap by investigating wastewater quality along a 40 km transect downstream of Hyderabad and examining the lateral and vertical extent of groundwater contamination. An integrated methodological framework combining Remote Sensing (IRS R2 LISS-IV data), Total Magnetic surveys and Electrical Resistivity investigations has been employed. Moreover, by correlating geomorphological features observed at the surface with subsurface geophysical anomalies, wherein present study aims to delineate fracture networks and structural pathways that control pollutant leakage into aquifers. The ultimate objective is to develop a scientifically robust structural model that enhances understanding of contaminant transport mechanisms and provides a foundation for sustainable groundwater management and pollution mitigation strategies in rapidly urbanizing hard-rock environments.

Literature Review

Groundwater systems in crystalline basement terrains are strongly influenced by structural architecture, where fractures, foliations and fault zones govern both groundwater storage and subsurface flow dynamics. Pradhan et al. (2022) demonstrated that structural discontinuities in crystalline rocks significantly control the development and thickness of weathered zones, which directly influence aquifer transmissivity and groundwater availability. Their study emphasized that structural mapping integrated with geophysical investigation provides a reliable framework for identifying groundwater-bearing zones in hard-rock terrains. Similarly, Rajaveni et al. (2017) highlighted the importance of geological and geomorphological controls on groundwater occurrence in the crystalline terrains of Telangana. Using remote sensing and GIS-based techniques, the study showed that lineament density, structural intersections and geomorphological features significantly influence groundwater recharge and distribution (Jogu & Gardas, 2025). These findings reinforced the importance of integrating structural, geophysical and geospatial datasets to understand groundwater behaviour in hard-rock aquifers. Groundwater contamination in crystalline hard-rock terrains presents complex hydrogeological challenges due to the dominance of secondary porosity and structural controls. Unlike sedimentary aquifers, groundwater occurrence and migration in granitic terrains are largely governed by fractures, joints, shear zones and intrusive contacts, which function as

preferential flow pathways (Chandra et al., 2006). In rapidly urbanizing regions, such structurally controlled aquifer systems are highly vulnerable to anthropogenic contamination, particularly where untreated wastewater infiltrates fractured bedrock systems. Blessy et al. (2019) reported the elevated concentrations of heavy metals in groundwater downstream of Hyderabad, attributing contamination to prolonged wastewater irrigation and infiltration along structurally weak zones. Similarly, Subramani et al., (2010) emphasized that hydrogeochemical facies evolution in Southern Indian hard-rock aquifers reflects strong anthropogenic influence superimposed on lithological controls. Recent investigations highlighted the importance of integrating geophysical and geospatial techniques for delineating structurally controlled aquifers. Naresh Kumar et al. (2023) demonstrated that multi-influence factor (MIF) models combined with remote sensing datasets that significantly enhance groundwater potential mapping in granitic terrains. Chandra et al. (2006) further established that electrical anisotropy derived from resistivity measurements correlates strongly with mapped lineaments, confirming that deep-seated fracture zones can be reliably identified through integrated analysis. Moreover, their findings reinforced the reliability of magneto-electrical correlation techniques in mapping subsurface structural discontinuities.

Magnetic methods have proven particularly effective in delineating intrusive bodies and fault-controlled contacts within crystalline terrains. The research study conducted by Ali et al. (2025) demonstrated that combined magnetic and resistivity modeling improves basement configuration estimation and fracture characterization in hard-rock settings. Analytical signal and tilt derivative processing of Magnetic Anomaly data enhance the identification of lithological boundaries and tectonic contacts, which frequently correspond to groundwater conduits. An emerging concept in crystalline hydrogeology is the so-called “Yield Paradox”, whereas groundwater productivity does not necessarily correlate with fracture density but rather with fracture connectivity and weathering intensity. Studies on fractured crystalline aquifers indicated that groundwater productivity depends primarily on fracture connectivity and weathering development rather than fracture density alone (Singhal & Gupta, 2010). This interpretation is supported by interaction-based vulnerability models developed for the Musi River basin by Mondal and Chandrapuri, (2025), who demonstrated that structurally intersecting zones exhibit significantly higher contamination indices compared to areas with comparable fracture density but lower connectivity.

Hydrogeochemical modeling studies have also strengthened the understanding of structural influence on pollutant migration. Groundwater contamination in the Musi River basin is strongly influenced by hydrogeochemical processes and subsurface structural controls, facilitating the movement of pollutants through fractured hard-rock aquifers beyond the shallow weathered zone. In a subsequent entropy-based vulnerability assessment, Chandrapuri et al. (2026) confirmed that structural intersections are statistically associated with high groundwater pollution risk zones. These findings collectively indicated that contamination in hard-rock terrains cannot be explained solely by surface anthropogenic loading but must be interpreted within a tectonic–hydrogeological framework.

At a broader scale, several studies emphasized on the importance of integrating remote sensing, GIS and geophysical techniques for groundwater exploration in hard-rock terrains. Such

integrated approaches significantly improved delineation of fractured aquifers and groundwater potential zones (Srivastava et al., 2012). Similarly, Adimalla et al. (2024) quantified the impact of urban sprawl on groundwater chemistry in the Hyderabad–Yadadri industrial corridor, emphasizing the urgent need for structurally informed groundwater management strategies. Despite these advancements, a significant research gap persists in establishing direct spatial correlation between surface lineaments, subsurface magnetic basement structures, geoelectrical fracture zones and groundwater quality indices within a unified structural model. Most previous studies have examined hydrochemistry, geophysics and remote sensing independently. Comprehensive magneto-electrical–geochemical integration aimed at identifying deep-seated tectonic conduits controlling contaminant migration remains limited, particularly along the Peerzadhiguda–Valigonda stretch of the Musi River. The present study addresses this gap by employing a fully integrated geophysical, geochemical and geospatial framework to delineate structurally governed contaminant pathways in the crystalline basement. By correlating Magnetic Anomaly modeling, Electrical Resistivity Soundings, lineament extraction and Groundwater Quality Index mapping, the study advances understanding of tectonic control on groundwater vulnerability in rapidly urbanizing hard-rock terrains.

Need & Significance

Rapid urbanization and industrial expansion in and around Hyderabad have significantly altered the hydro-environmental balance of Musi River basin. The river currently acts as a major conduit for untreated domestic sewage and industrial effluents, leading to progressive deterioration of both surface and groundwater quality. Several investigations have reported elevated concentrations of heavy metals and other chemical contaminants in groundwater along the Musi River corridor, largely attributed to wastewater irrigation and uncontrolled industrial discharge (Blessy et al., 2019; Adimalla et al., 2024). In the crystalline hard-rock terrains of Deccan granitic province, groundwater occurrence and movement are predominantly governed by secondary porosity features such as fractures, faults, joints, shear zones and intrusive contacts. These structural discontinuities regulate groundwater storage, transmissivity and flow dynamics, and can also act as preferential pathways for groundwater movement in hard-rock terrains (Chandra et al., 2006; Jogu & Gardas, 2025). Also, recent research further emphasized on the critical role of structural architecture in controlling groundwater systems within crystalline basement terrains. Pradhan et al. (2022) demonstrated that structural features including foliations, fractures and fault zones significantly influence the development and thickness of weathered zones thereby determining groundwater storage potential and transmissivity. Similarly, Rajaveni et al. (2017) highlighted the importance of geological structures, lineaments and geomorphological characteristics in regulating groundwater occurrence in the hard-rock terrains of Telangana using remote sensing and GIS-based analysis. These studies collectively indicated that understanding the structural framework is essential for accurate groundwater assessment in crystalline environments.

Despite these advancements, most studies in the Musi River basin have primarily focused on hydrochemical characterization or isolated geophysical investigations. Comprehensive studies integrating geophysical, geochemical and geospatial datasets to delineate structurally

controlled contaminant migration pathways remain limited. Therefore, an integrated multidisciplinary approach combining magnetic anomaly analysis, electrical resistivity investigations, remote sensing and groundwater quality assessment is required to identify tectonic conduits responsible for contaminant transport. The present study addresses this gap by establishing a structural-hydrogeological framework to evaluated groundwater vulnerability along the Peerzadhiguda-Valigonda stretch of the Musi River basin, thereby contributing to sustainable groundwater management in rapidly urbanizing hard-rock environments.

Objectives

- To investigate the structural and hydrogeological controls governing groundwater contamination and its relationship along the Peerzadhiguda–Valigonda stretch of Musi River basin
- To identify the various faults, fractures and basic intrusive dykes through Magnetic Anomaly modeling and structural interpretation
- To map geomorphological units and extract lineaments from remote sensing data and correlate them with subsurface structural features

Methodology

An integrated multidisciplinary approach has been adopted to investigate structural controls and hydrogeological characteristics along the Musi River stretch from Perzadiguda to Valigonda, Telangana. The methodology combines geological mapping, remote sensing, magnetic and electrical geophysical surveys, hydrochemical analysis and GIS-based spatial integration to evaluate tectonic influences on groundwater occurrence and contamination. The study area is predominantly underlain by Archaean granitic rocks (pink and grey granites) intruded by dolerite dykes and intersected by major lineaments trending NE–SW, E–W and N–S. Satellite imagery and Survey of India toposheets were interpreted to delineate geomorphological units such as pediplains, residual hills, valley fills and flood plains. Lineaments have been extracted through visual interpretation and correlated with mapped shear zones and fracture systems to establish the structural framework for subsequent analysis.

Magnetic Anomaly data were acquired using a Proton Precession Magnetometer (Model-600) along systematic east–west traverses across the Musi River. Measurements were recorded at a station interval of 100 m and a traverse spacing of 500 m, ensuring uniform spatial coverage. A total of 1260 stations were occupied and positional accuracy was maintained using GPS. The data were corrected for diurnal variation and the International Geomagnetic Reference Field (IGRF). Magnetic anomaly maps were generated to identify intrusive bodies, lithological contacts and structural discontinuities. Electrical resistivity investigations were conducted through 80 Vertical Electrical Soundings (VES) using an SSR-MP1 resistivity meter with Schlumberger configuration. The maximum electrode spacing (AB/2) was extended up to 150 m to probe deeper subsurface layers. Apparent resistivity values have been calculated using standard geometric factors and interpreted through manual curve matching and IPI2WIN software. The results provided layer resistivities and thicknesses, enabling preparation of iso-resistivity maps, pseudo-sections, geoelectric cross-sections and depth-to-basement models.

Low resistivity zones (<30 Ωm) were interpreted as weathered or fractured aquifer zones, whereas high resistivity zones (>100 Ωm) indicated compact crystalline basement.

Hydrochemical investigations included analysis of 46 groundwater samples collected during pre-monsoon and post-monsoon seasons (2018–2019). Field measurements of pH and EC have been carried out in situ and laboratory analyses are performed using ICP-MS at CMET, Hyderabad. Major ions, trace elements and pollution indicators were analyzed and indices such as SAR, PI, RC and GWQI are computed accordingly. Spatial distribution maps have been prepared to delineate contamination zones. All datasets are integrated within a GIS environment by overlaying magnetic anomalies, resistivity patterns, lineament density and hydrochemical distribution maps. Zones where geophysical anomalies coincided with elevated contamination indicators were interpreted as structurally influenced groundwater pathways. Cross-sectional analysis along selected traverses validated the continuity of inferred faults and fracture systems. This integrated approach enhances reliability in identifying subsurface structural elements and assessing their hydrogeological significance.

Study Area Profile

The River Musi is situated in Deccan Plateau in the state of Telangana, southern India. It originates in the Ananthagiri Hills of Vikarabad district, approximately 70 km upstream of Hyderabad city. From its source, the river flows eastward through Hyderabad and eventually joins the Krishna River at Wadapally in Nalgonda district, nearly 200 km downstream (Ensink et al., 2008). Geologically, the Musi River originates in basaltic terrain of the Deccan Traps, characterized by rugged topography and then flows downstream across granitic formations of Proterozoic age. The present study area encompasses the Hyderabad–Valigonda stretch of the Musi River basin, lying between 78°35′30″ E to 78°57′30″ E longitude and 17°15′00″ N to 17°31′30″ N latitude, covering parts of Ranga Reddy and Nalgonda districts of Telangana State. The total geographical extent of study area is approximately 894.79 sq. km (Figure 1). The topography of the region is undulating, with a gentle regional slope towards the southeast, which controls the natural drainage pattern and groundwater flow direction. Elevation ranges from a maximum of about 473 m to a minimum of approximately 317 m above mean sea level. This variation in relief influences surface runoff, infiltration characteristics and subsurface water movement. The study area is well connected by a network of state and national highways, facilitating accessibility for field investigations and data collection. The availability of transportation infrastructure supports systematic geological, hydrogeological and geophysical surveys conducted in the region.

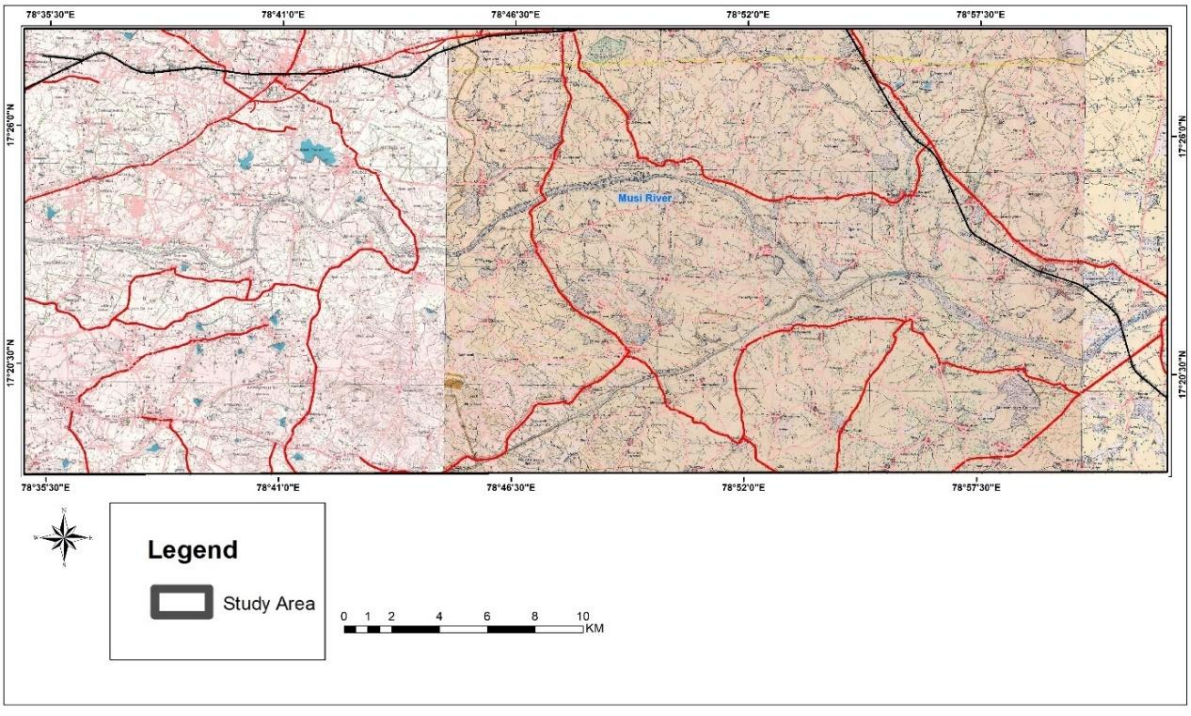

Figure 1: Location Map of Study Area

Study Area Geography

The study area (Figure 2) is dominantly underlain by granitic terrain comprising various Archaean granitoids that form part of the Peninsular Gneissic Complex (PGC). These granitoids display colour variations ranging from red to light pink and are locally associated with older schistose metamorphic rocks. The region also records multiple phases of magmatic and tectonic activity, evidenced by the intrusion of basic dykes of Proterozoic age. On the basis of field observations and petrochemical characteristics, granitoids in the area are broadly classified into two principal suites: Adamellite–Granodiorite and Granite (Bhaskar Rao et al., 1991). The Peninsular granites are broadly classified into pink and gray varieties. Gray granites are generally medium-to-fine-grained and exhibit relatively low primary porosity and permeability. In contrast, pink granites are medium-to-coarse-grained and are commonly affected by fractures and fissures. These structural discontinuities enhanced secondary permeability and create favorable pathways for groundwater movement within the granitic aquifer system, particularly in hard-rock terrains of Telangana (Kumar et al., 2016).

The granitoid complex is also marked by pegmatitic segregations and numerous aplite and quartz–feldspathic veins, indicative of late-stage magmatic differentiation. Quartz veins occur extensively throughout the region and are occasionally associated with minor shearing, reflecting tectonic adjustments after emplacement. Basic intrusive bodies, including amphibolite, dolerite, gabbro and pyroxenite, occur as dykes that cut across the granitoid formations. These dykes typically vary in width from approximately 7 to 50 meters and extend for several kilometers, though local discontinuities are observed. They are generally massive,

compact and predominantly doleritic in composition. The overall geological framework of the study area, compiled from Geological Survey of India, (2010) (District Resource Map), is presented in Figure 2. This map illustrates the spatial distribution of lithological units and structural features that significantly influence the hydrogeological characteristics of the Musi River basin.

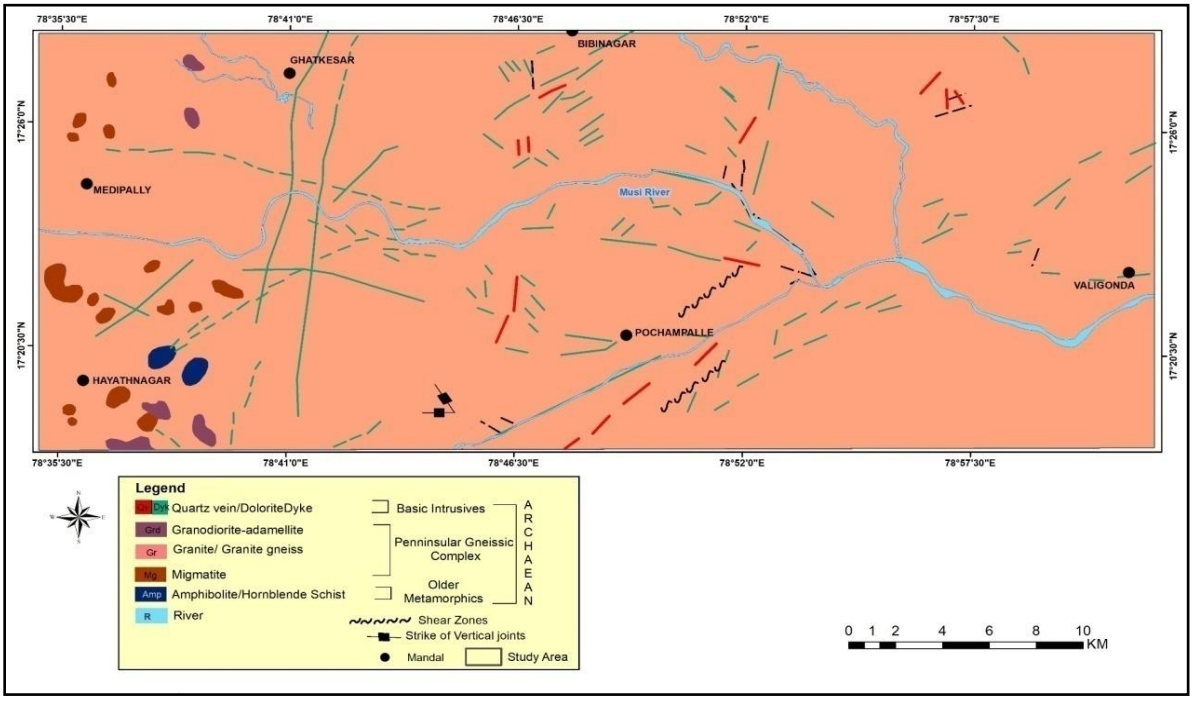

Figure 2: Geology Map of Study Area

Source: GSI-District Resource Map, 2010

Results

Correlation of Geophysical, Remote Sensing & Geochemical Data

The characterization of hard-rock aquifers requires an integrated, multidisciplinary approach that connects surface geomorphological features with subsurface hydraulic structures. Although remote sensing is conventionally used for land-use and lithological mapping (Chandra et al., 2006; Srivastava et al., 2012; Jogu & Gardas, 2025), its effectiveness significantly increases when combined with geophysical and geochemical datasets. The integration of geomorphology, Groundwater Quality Index (GQI) and formation resistivity (Figure 3.a-c) in the present study provides a high-resolution spatial framework for identifying contaminant migration pathways. Overlay analysis reveals a clear spatial association between specific geomorphic units and zones of elevated toxicity.

Quantitative interpretation of Vertical Electrical Sounding (VES) data acquired from 80 locations delineates a two-layer subsurface configuration. The upper layer consists of a

weathered zone extending to an average depth of approximately 15 m, underlain by a fractured basement characterized by joints and secondary porosity. Lineament analysis derived from IRS R2 LISS-IV imagery indicates dominant NW–SE and NE–SW structural trends. These trends showed strong correlation with computed electrical anisotropy values, suggesting structural control over groundwater flow (Singhal & Gupta, 2010). The identified lineaments represented tectonic features such as faults, fractures and lithological contacts that act as preferential conduits, regulating the hydrogeological behavior of crystalline basement.

A noteworthy observation from the integrated analysis is the presence of a "Yield Paradox" within the granitic terrain. Areas exhibiting comparatively lower fracture density, particularly within moderately weathered granites, demonstrated higher groundwater yields and support relatively denser vegetation cover than intensely fractured but barren zones. This indicated that fracture connectivity and intensity of weathering exert greater influence on groundwater storage and movement than fracture density alone. The results emphasized that in hard-rock settings, this observation reflected a well-known phenomenon in fractured crystalline aquifers where groundwater productivity depends more on fracture connectivity and degree of weathering rather than fracture density alone (Singhal & Gupta, 2010). The study further substantiated the predictive capability of remote sensing when validated through integrated geophysical analysis.

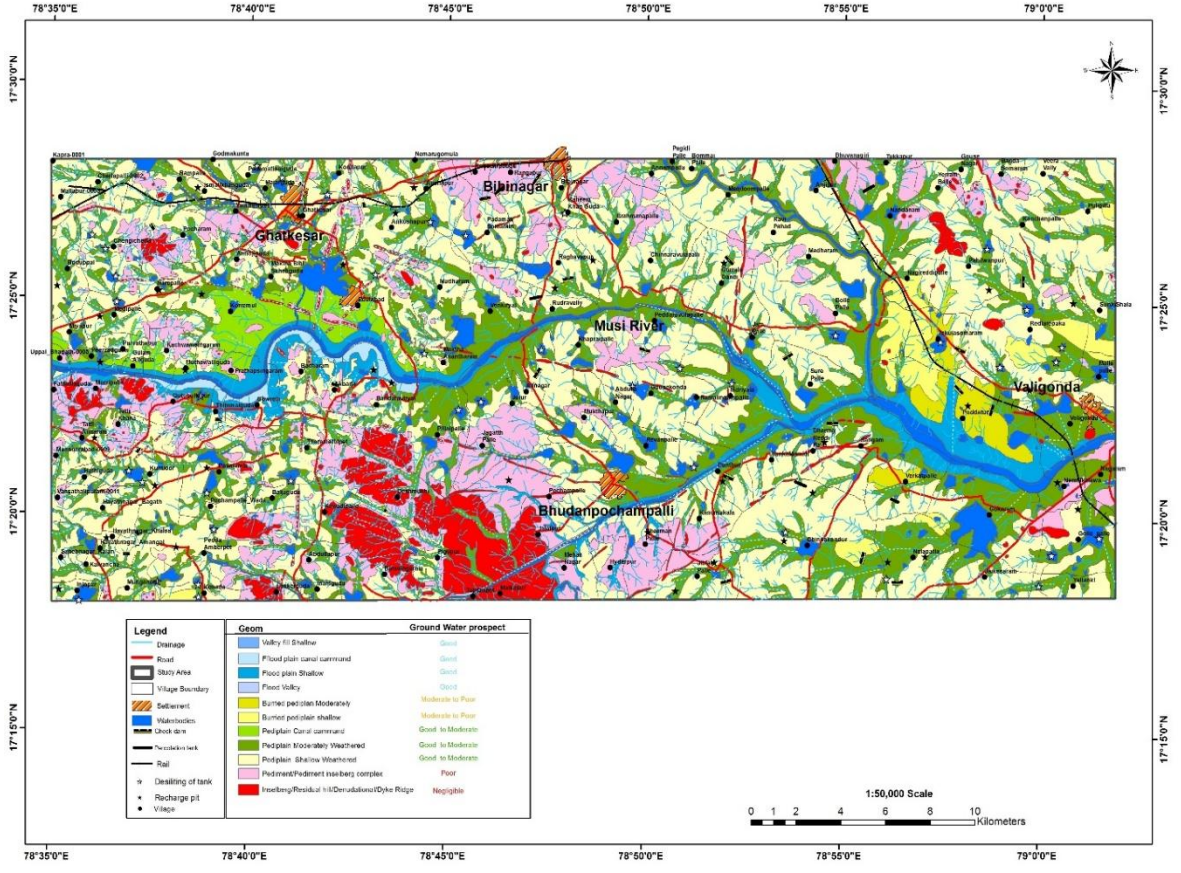

Figure 3a. Geomorphology Map from Remote Sensing

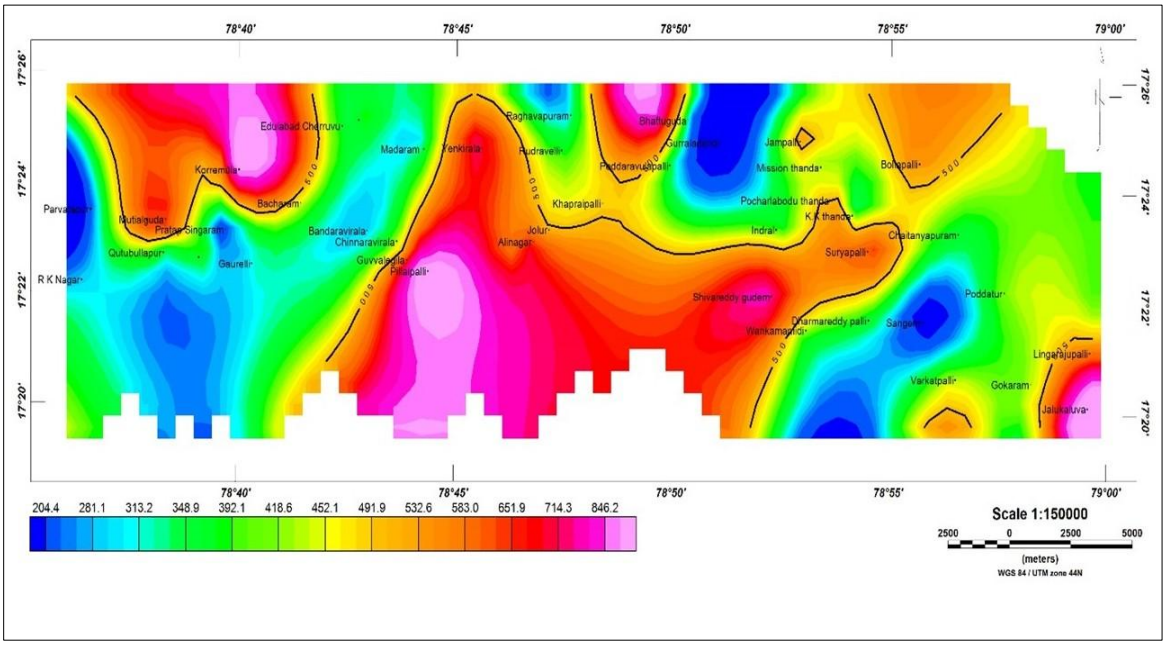

Figure 3b. Ground Water Quality Index from Geochemical studies

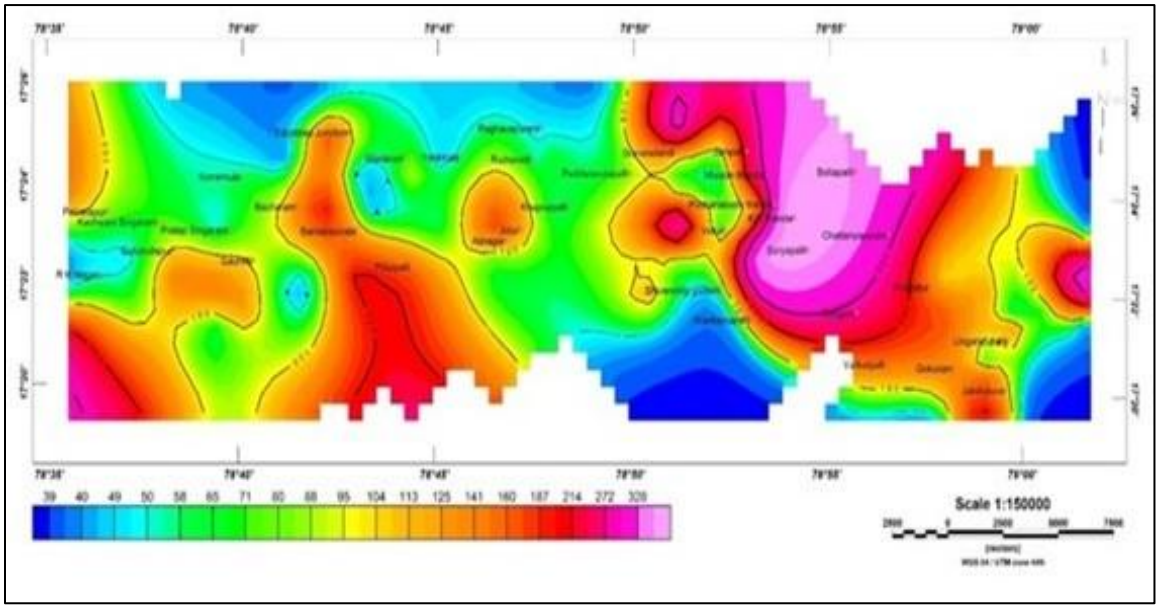

Figure 3c. Formation Resistivity from Geophysical Method

Integrated Structural & Magnetic Correlation

Structural elements interpreted from surface investigations were superimposed on Magnetic Anomaly derivative maps, particularly the analytical signal and tilt derivative maps, to validate the subsurface structural configuration (Figure 4b). These magnetic enhancement techniques

effectively delineate lithological boundaries and structural discontinuities, enabling correlation between surface lineaments and deeper crustal features. The integrated analysis demonstrated a strong spatial correspondence between mapped surface lineaments and subsurface magnetic anomalies. Prominent structural trends, predominantly oriented in NW–SE, N–S and NE–SW directions, align closely with identified faults, fractures and dyke intrusions. This structural continuity from surface to depth indicates a well-developed tectonic framework governing the crystalline basement.

Notably, zones exhibiting elevated contamination levels along the Musi River corridor coincided with the intersection of these structural features. The faults and fractures function as high-permeability pathways, facilitating vertical and lateral migration of pollutants into underlying aquifers. This integrated structural–magnetic correlation confirmed that subsurface tectonic architecture plays a decisive role in controlling groundwater vulnerability within the Peerzadhiguda–Valigonda stretch (Figure 4.a-c).

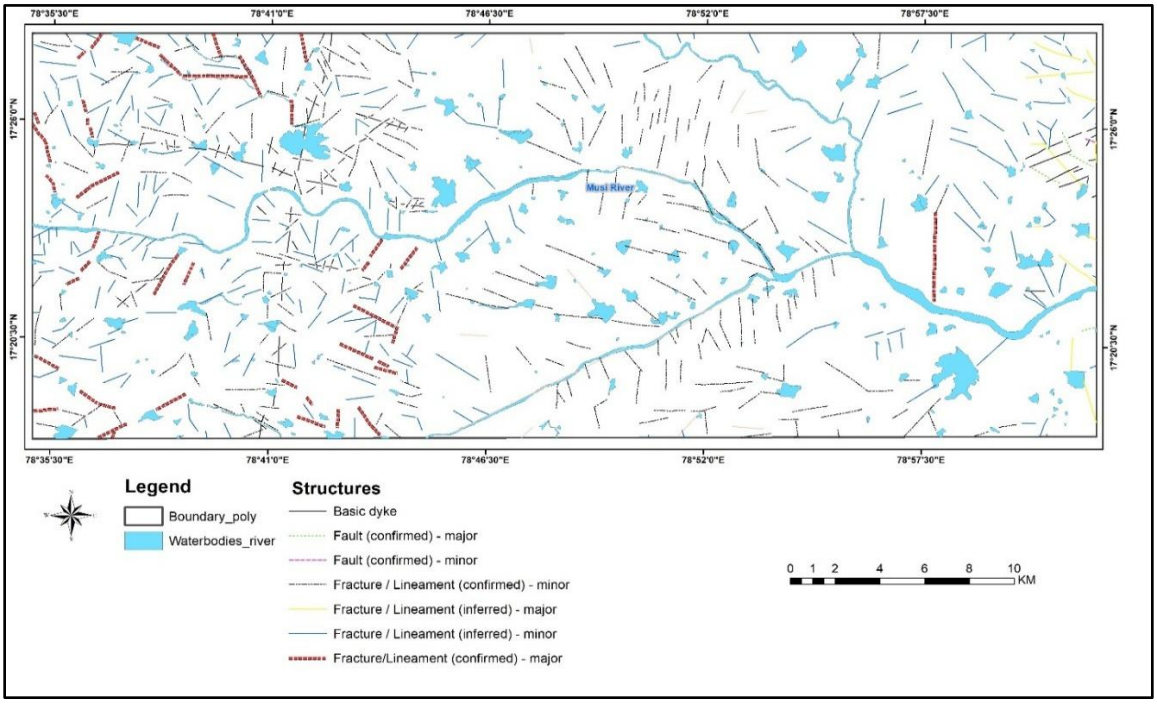

Figure 4a. Lineaments Derived from Remote Sensing

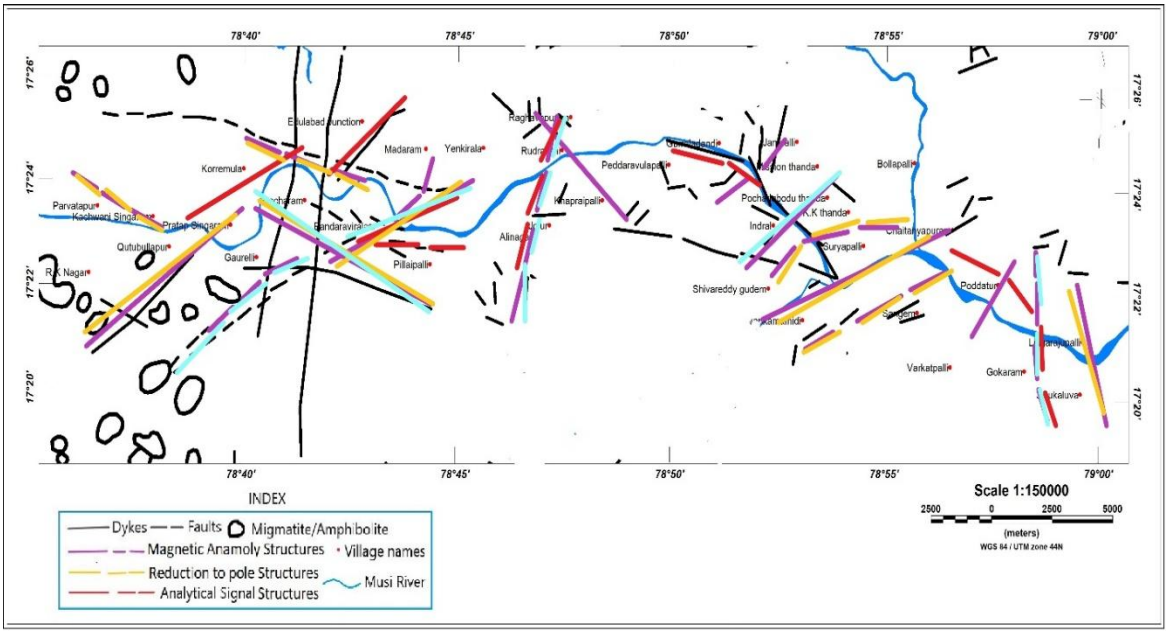

Figure 4b. Structural Lineaments Map Inferred from Magnetic Anomaly

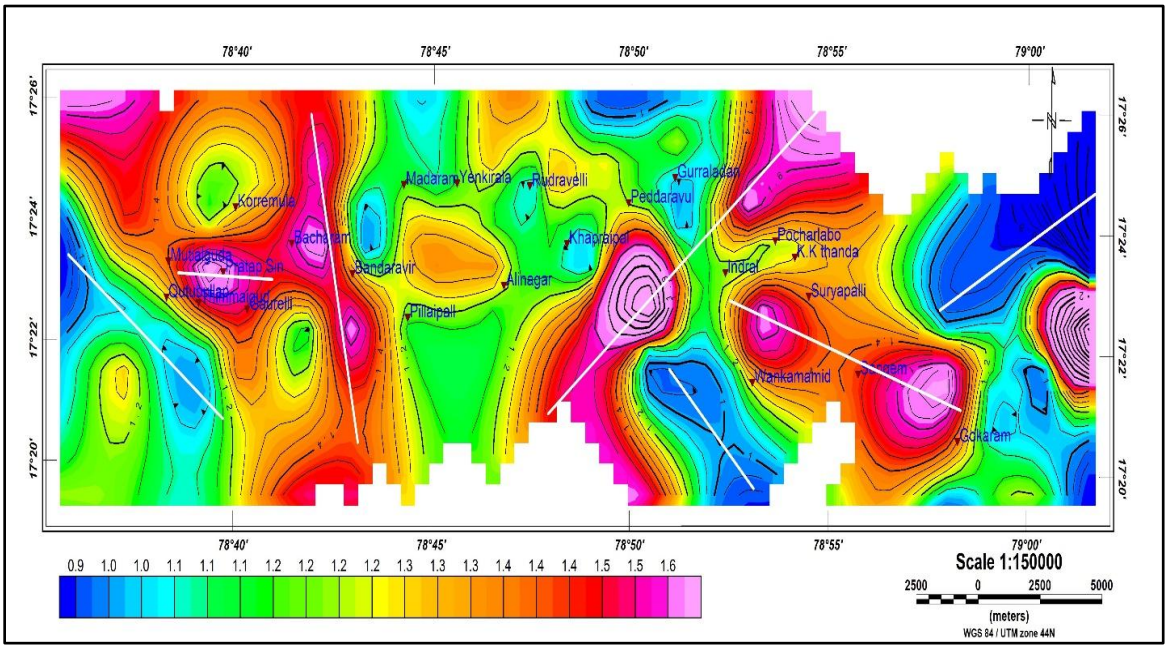

Figure 4c. Electrical Lineaments Derived from Anisotropy Map

Integrated Magneto-Electrical Correlation

To delineate subsurface heterogeneity and structural controls, high-resolution electrical resistivity and magnetic surveys were conducted along two traverses-Northern Traverse (NT) and Southern Traverse (ST)-parallel to the Musi River banks. Resistivity data have been

processed using IPI2WIN software to generate geoelectrical cross-sections that define vertical and lateral lithological variations. Simultaneously, magnetic data are modeled using Geosoft software to estimate depth-to-basement configurations and identify structural discontinuities. The integrated interpretation revealed a strong correspondence between deep-seated magnetic basement structures and high-permeability zones identified in the electrical resistivity sections. Magnetic anomalies spatially coincided with fractured and weathered zones in the resistivity models, confirming the presence of structurally controlled conduits within the crystalline basement. These conduits facilitated preferential subsurface flow and enhance the potential for contaminant migration (Mondal & Chandrapuri, 2025& Naresh Kumar et al., 2023).

Northern Traverse (NT): Upstream Structural Characteristics

The Northern Traverse extends approximately 56 km along the north bank of Musi River from west to east. The geophysical response along this traverse indicates a structurally disturbed framework, reflecting significant tectonic influence. Surface elevation gradually decreases eastward, consistent with the regional slope and river flow direction. Interpretation of Vertical Electrical Sounding (VES) data, processed using IPI2WIN, delineates a semi-weathered granitic layer with thickness varying between 5 m and 20 m. Enhanced weathering in this zone is likely influenced by continuous infiltration from the perennial flow of Musi River. Beneath this layer lies the Archean gray granite basement, intersected by deep-seated faults and joint systems clearly reflected in the pseudo-resistivity sections (Figure 5a, b). Magnetic anomaly profiling (Figure 5c) identifies significant positive peaks at Korremulla (~300 nT) and Bacharam (~400 nT), indicating the presence of basic intrusive dykes, most likely gabbroic or pyroxenitic in composition. A broad magnetic low observed between 12 km and 50 km corresponds to a thickened basic intrusive body, within which sharp magnetic gradients suggest the presence of a major fracture or fault zone. Magnetic responses ranging from –200 nT to –400 nT effectively delineate contacts between alkali feldspar granites and gray granites. The depth-to-basement model generated from magnetic data correlates closely with the geoelectrical sections, confirming that these tectonic features function as high-permeability corridors. Although minor spatial displacements occur between datasets, the integrated interpretation clearly demonstrated that deep-seated structural discontinuities govern groundwater flow and potential pollutant migration along the northern bank.

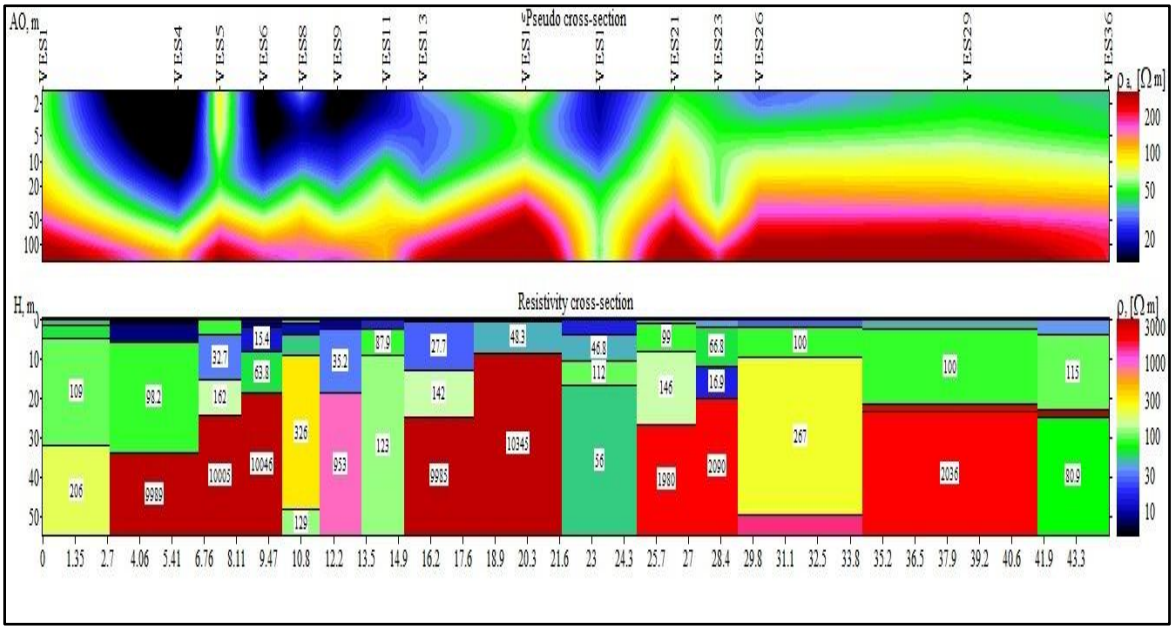

Figure 5a. Resistivity Pseudo-Section and Resistivity Cross Section

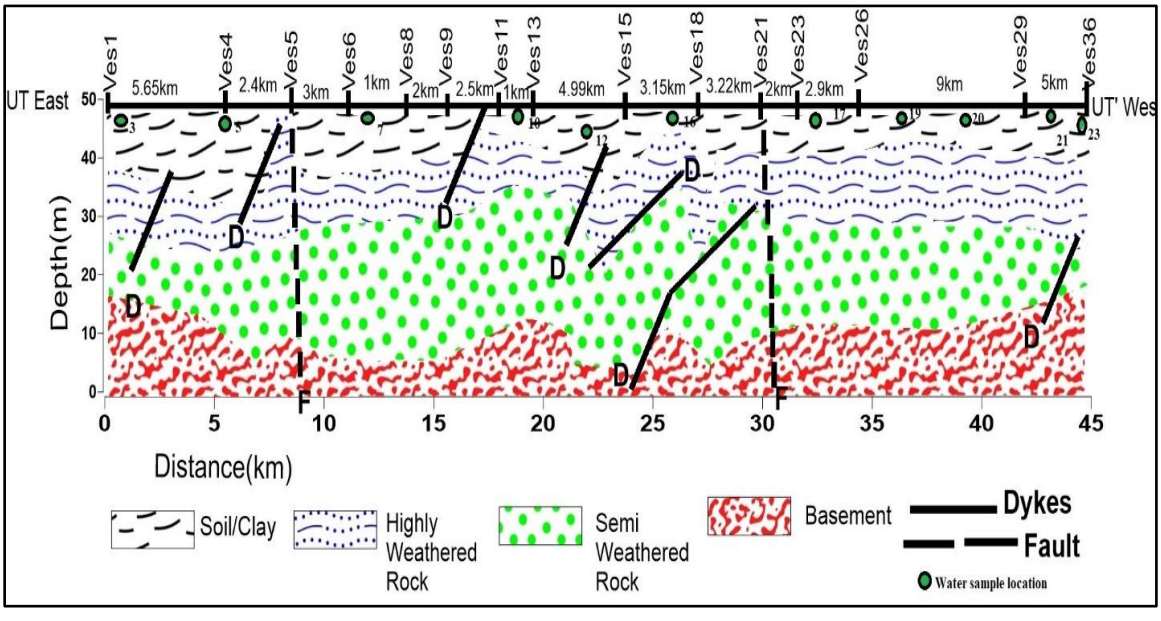

Figure 5b. Geological Cross Section

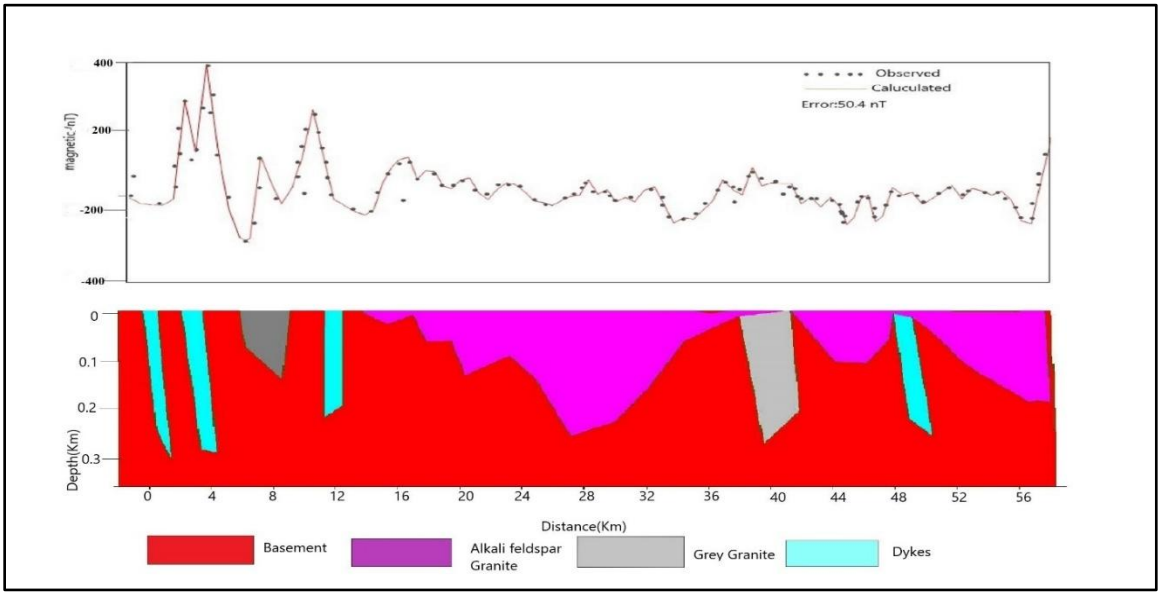

Figure 5c. Total Magnetic Anomaly Traverse and Magnetic Model along North Traverse-(NT) Upstream from Parvathapur to Valigonda

Southern Traverse (ST): Downstream Structural Analysis

The Southern Traverse extends approximately 52 km along the south bank of the Musi River and includes fifteen VES stations. Similar to the northern segment, geophysical responses indicated a tectonically influenced subsurface framework. Pseudo-resistivity cross-sections (Figure 6a) revealed minimal development of topsoil or clay cover across much of the traverse. At stations VES 43, 71 and 75, an abrupt increase in near-surface resistivity values (>100 Ωm) is observed. This anomaly is interpreted as evidence of near-surface faulting or dyke intrusion.

Geoelectrical modeling (Figure 6b) indicated a thin veneer of erosion-derived clay accumulation overlying a semi-weathered granitic layer ranging from 5 m to 20 m in thickness. The crystalline basement is encountered at depths of approximately 42–43 m, with basement topography deepening eastward in alignment with the regional slope. This basement is characterized by extensive jointing and fracture systems, forming high-permeability pathways that enhance groundwater circulation and facilitate contaminant transport. Magnetic anomaly profiling (Figure 6c) identifies positive peaks at Pratapsingaram (~200 nT) and Gaurelli (~300 nT), signifying basic intrusive bodies such as gabbro or pyroxenite. Conversely, pronounced magnetic lows ranging from –200 nT to –400 nT at Gaurelli, Sangem and Jalukaluva delineate the gray granite basement. The magnetic depth model (Figure 6c) further highlights sharp intrusive features between 12 km and 50 km, corresponding to major fracture and fault zones within the thickened basic intrusive body. The strong correlation between magnetic and geoelectrical datasets confirms that these structural lineaments exert primary control over the hydrogeological vulnerability of the southern bank, acting as preferential conduits for groundwater flow and pollutant migration.

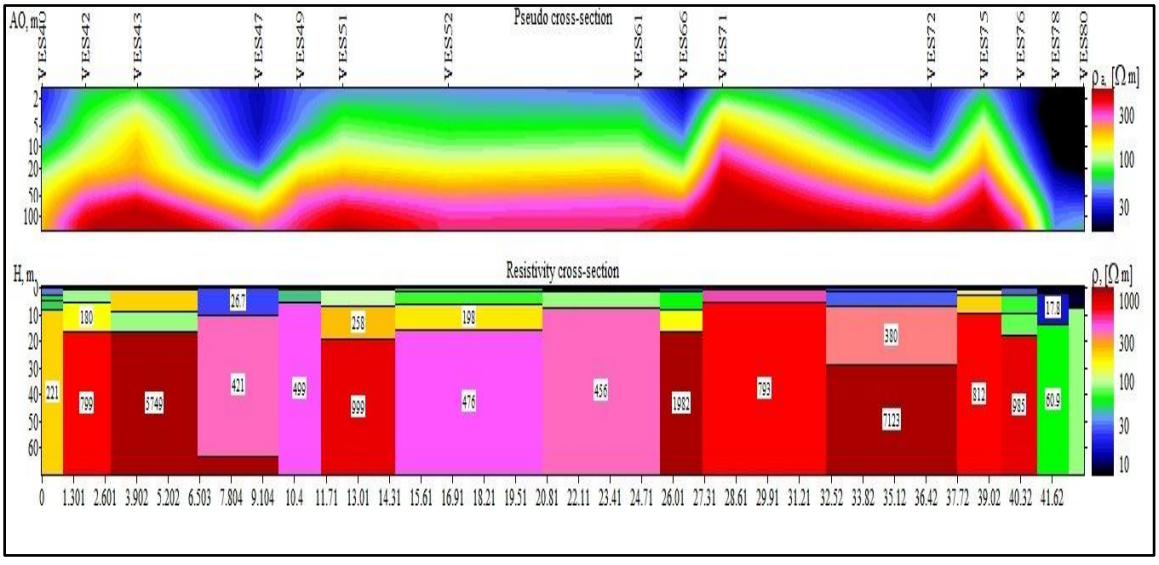

Figure 6a. Resistivity Pseudo-Section and Resistivity Cross Section

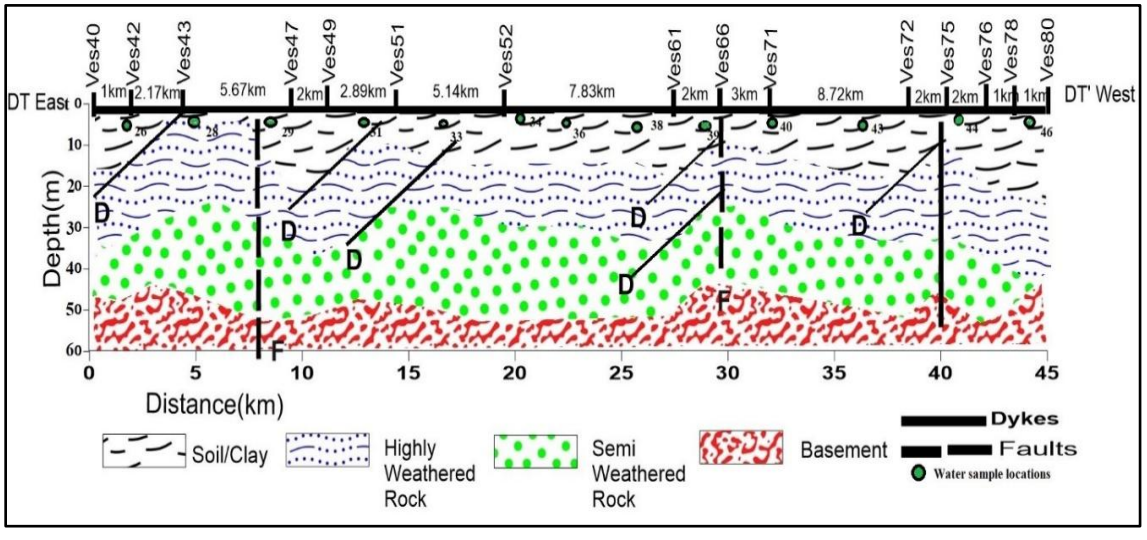

Figure 6b. Geological Cross Section

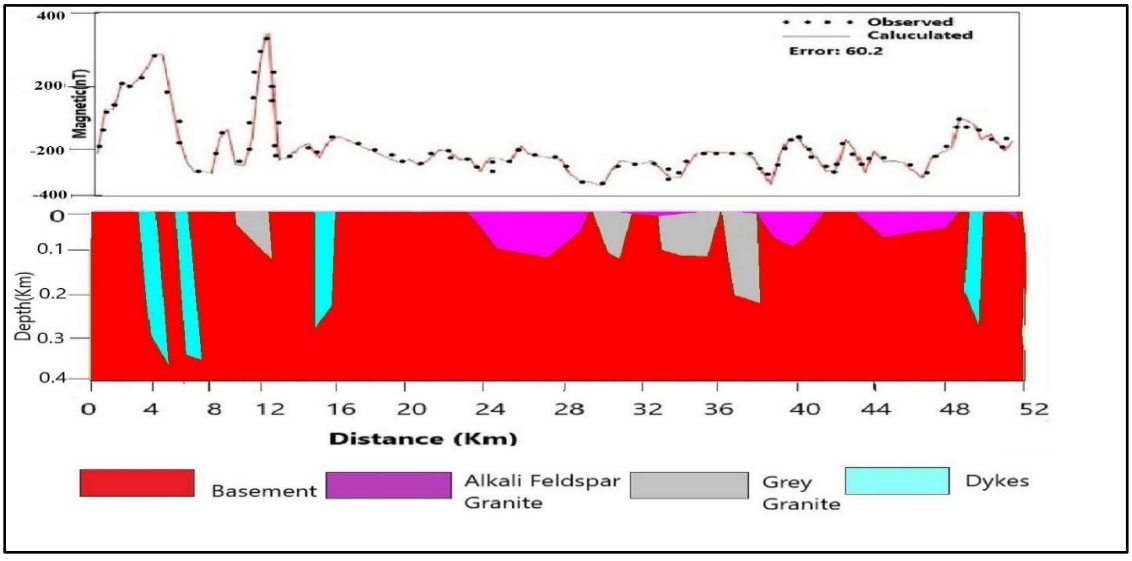

Figure 6c. Total Magnetic Anomaly Traverse and Magnetic Model along North Traverse-(NT) Downstream from Parvathapur to Valigonda

Discussion

The findings of the present study strongly indicated that groundwater contamination within the Peerzadhiguda–Valigonda corridor is structurally controlled, with faults, fractures and intrusive contacts functioning as preferential pathways for pollutant migration. This interpretation is consistent with earlier hydrogeological investigations in crystalline terrains, which emphasized the dominance of secondary porosity in regulating groundwater flow (Chandra et al., 2006; Singhal & Gupta, 2010). In hard-rock aquifers, transmissivity is largely governed by fracture connectivity rather than fracture density alone, a phenomenon widely reported in fractured crystalline aquifers where groundwater productivity is governed more by fracture connectivity than fracture density (Singhal & Gupta, 2010). The present results corroborated this concept, as zones with interconnected fracture systems demonstrate both higher groundwater productivity and increased vulnerability to contamination.

The strong spatial correlation observed between magnetic anomalies, resistivity discontinuities and elevated Groundwater Quality Index (GQI) values further confirms tectonic control over contaminant transport. Similar structural–hydrochemical linkages have been reported in the Musi River basin and other crystalline provinces of India (Mondal & Chandrapuri, 2025). These studies demonstrated that contaminant plumes preferentially migrate along deep-seated structural intersections, enabling pollutants to bypass the shallow weathered zone and infiltrate fractured basement aquifers. The present study extends this understanding by integrating Magnetic Anomaly modeling with geoelectrical cross-sections, thereby validating the continuity of structural conduits from surface lineaments to basement depths. Magneto-electrical integration has been widely recognized as an effective approach for delineating lithological contacts and fault-controlled aquifer systems (Ali et al., 2025). The high-amplitude magnetic anomalies (300–400 nT) identified in the study area correspond to basic intrusive

bodies, consistent with previous geophysical interpretations in the Deccan granitic terrain (Srivastava et al., 2012). However, rather than acting as impermeable barriers, the dyke–granite contact zones appear to function as structurally weakened interfaces that enhance vertical permeability. Comparable observations have been reported in hydrogeophysical studies of fractured crystalline basements in Southern India (Subramani et al., 2010; Naresh Kumar et al., 2023).

Hydrochemical evidence further strengthens the structural control hypothesis. Elevated EC, TDS and heavy metal concentrations observed downstream are aligned with mapped structural intersections, supporting the findings of Blessy et al. (2019) and Adimalla et al. (2024), who documented anthropogenic contamination in structurally vulnerable zones of the Hyderabad industrial belt. Also, study conducted on entropy-based vulnerability modeling by Chandrapuri et al. (2026) demonstrated that structural intersections significantly increase groundwater pollution risk. Thus, the present results align with emerging consensus that groundwater degradation in hard-rock urban basins is not merely a function of surface pollutant loading but is fundamentally governed by tectonic architecture. Overall, the integrated framework adopted in this study advances previous research by explicitly correlating geomorphological lineaments, magnetic basement structures, resistivity-defined fracture zones and hydrochemical indices within a unified structural model. This multidisciplinary approach strengthens the interpretation that tectonic discontinuities act as dominant controls on contaminant migration in crystalline terrains.

Suggestions

- Structural intersection zones and dyke-granite contact areas should be designated as groundwater vulnerability zones and subjected to strict environmental regulation.
- Industrial discharge and untreated wastewater release near identified fault and fracture systems must be strictly controlled and continuously monitored.
- A structural-based groundwater monitoring network should be established along major lineaments to track contaminant migration trends.
- Artificial recharge structures should be avoided in highly fractured and structurally weak zones to prevent accelerated pollutant infiltration.
- Structural–hydrogeological vulnerability maps should be integrated into urban planning and groundwater management policies for sustainable resource protection.

Conclusion

The integrated geophysical, geochemical and geospatial investigation carried out along the Peerzadhiguda–Valigonda corridor of Musi River basin demonstrated that groundwater vulnerability in the crystalline hard-rock terrain is fundamentally controlled by tectonic architecture rather than solely by surface anthropogenic loading. Electrical resistivity soundings delineate a three-tier aquifer system comprising a shallow conductive soil–clay layer, an intermediate weathered and fractured granitic aquifer zone extending to depths of approximately 15-20m and a deeper compact crystalline basement encountered at depths of about 40-43m, particularly along the southern traverse. Magnetic Anomaly modeling identified

high-amplitude anomalies corresponding to basic intrusive bodies such as gabbro and pyroxenite dykes, while derivative analysis confirms the presence of major structural discontinuities trending NW–SE, NE–SW and N–S. The strong spatial correspondence between magnetic basement structures, resistivity-defined fracture zones, extracted surface lineaments and elevated Groundwater Quality Index values substantiates that dyke–granite contact zones and fracture intersections function as high-permeability tectonic conduits facilitating vertical and lateral contaminant migration. A notable observation is the "Yield Paradox", wherein groundwater productivity and vulnerability are governed more by fracture connectivity and weathering intensity than by fracture density alone. Comparative analysis between the northern (upstream) and southern (downstream) segments revealed an asymmetrical tectonic framework with a southward-deepening basement block exhibiting enhanced structural penetration and increased hydrogeological susceptibility. Overall, the study established a scientifically robust structural–hydrogeological model confirming that contaminant infiltration within the Musi River corridor is structurally governed, with tectonic discontinuities acting as preferential pathways enabling pollutants to bypass the shallow weathered zone and penetrated deeper sections of the fractured crystalline basement. The integrated methodological framework adopted in this study provides a reliable basis for groundwater vulnerability assessment and sustainable resource management in rapidly urbanizing hard-rock environments.

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Comparative Analysis on Aizawl's Journey Towards Becoming a Smart City: Challenges and Opportunities

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Abstract

This study explores how the Smart City Mission (SCM) has been carried out in Aizawl, Mizoram, against the backdrop of India's fast-paced urban growth and economic development. Given the city's strategic position, growing population and tourism potential, there is a clear need for comprehensive urban planning strategies. The present research evaluates on how funds have been distributed among projects focused on enhancing infrastructure, strengthening digital governance and promoting environmental sustainability. Although several promising initiatives were undertaken, the findings revealed that Aizawl has not yet fully achieved its vision as a smart city due to ongoing challenges such as socio-economic inequalities and inefficiencies in governance. The study highlighted the need for sustained efforts, policy reforms and consistent engagement to successfully realize the goals of 'Smart Cities Mission' in Northeast India.

Keywords: Smart City Mission, Urbanization, Ministry of Housing & Urban Affairs (MoHUA), Aizawl City.

Introduction

Modern urban areas are under a great deal of strain because of the growing population. Civic authorities are responsible for addressing a wide range of challenges such as - 'air pollution, transportation systems, sanitation, water availability and public safety'. Sustainable solutions are therefore desperately needed (Bahadur, 2009). The Government of India has responded by launching 'Smart Cities Mission (SCM)', which aims to create 100 Smart Cities across the country. Aizawl, known for its charming scenic setting, is the capital of Mizoram. It is the key part of Aizawl District and selected in the third round of SCM in June 2017. According to the 2011 Census, Aizawl accommodates nearly 30 percent of state's population, making it the

largest urban center in Mizoram with regards to both population and geographical extent. The state itself ranks seventh in India in terms of urbanization according to the 'Summarized Projects of Aizawl Smart City, 2020'.

Table 1: Round-Wise List of 100 Cities Selected Under Smart Cities Mission

S. No.	Jan-16	May-16	Sep-16	Jun-17	Jan-18
	Round 1	Fast Track	Round 2	Round 3	Round 4
1	Bhubaneswar	Lucknow	Amritsar	Thiruvananthapuram	Silvassa
2	Pune	Warangal	Kalyan- Dombivali	Rajkot	Erode
3	Jaipur	Dharamshala	Ujjain	Naya Raipur	Diu
4	Surat	Chandigarh	Tirupati	Amaravati	Biharsharif
5	Kochi	Raipur	Nagpur	Patna	Bareilly
6	Ahmadabad	NT Kolkata	Mangaluru	Karimnagar	Itanagar
7	Jabalpur	Bhagalpur	Vellore	Muzaffarpur	Moradabad
8	Visakhapatnam	Panaji	Thane	Puducherry	Saharanpur
9	Solapur	Port Blair	Gwalior	Gandhinagar	Kavaratti
10	Davanagere	Imphal	Agra	Srinagar	Shillong
11	Indore	Ranchi	Nashik	Sagar	
12	NDMC	Agartala	Raurkela	Karnal	
13	Coimbatore	Faridabad	Kanpur	Satna	
14	Kakinada		Madurai	Bengaluru	
15	Belagavi		Tumakuru	Shimla	
16	Udaipur		Kota	Dehradun	
17	Guwahati		Thanjavur	Tiruppur	
18	Chennai		Namchi	Pimpri-Chinchwad	
19	Ludhiana		Jalandhar	Bilaspur	
20	Bhopal		Shivamogga	Pasighat	
21			Salem	Jammu	
22			Ajmer	Dahod	
23			Varanasi	Tirunelveli	
24			Kohima	Thoothukudi	
25			Hubballi- Dharwad	Tiruchirappalli	
26			Aurangabad	Jhansi	
27			Vadodara	Aizawl*	
28				Prayagraj	
29				Aligarh	
30				Gangtok	

Source: Ministry of Housing and Urban Affairs (MoHUA), 2023-2024

Literature Review

The existing literature on 'India's Smart Cities Mission (SCM)' provides important insights into its conceptual foundations, governance mechanisms and implementation challenges. Lalruatdiki & Nath (2025) examined the implementation of SCM in Aizawl and highlighted the unique governance and infrastructural challenges faced by hill cities. Their study also compares Aizawl with other Northeast cities such as Gangtok and Shillong, emphasizing the

importance of geographically sensitive planning, though their analysis requires stronger empirical support. From a broader policy perspective Nallapaneni et al., (2018) conceptualized smart cities in India through the "3-C framework"—competence, convenience and cleverness. They argued that despite strong policy ambition, the implementation of smart city initiatives faces several structural challenges such as weak institutional coordination, leadership limitations, technological gaps and insufficient citizen participation. Moreover, by adopting a critical socio-political perspective, Saha (2020) revealed that the Smart Cities Mission largely continues project-based and market-driven development models rooted in earlier urban planning paradigms. According to Saha, this approach risks reinforcing socio-spatial inequalities and may marginalize local democratic institutions if citizen participation remains limited. Focusing specifically on Northeast India, Malsawmtluanga and Sadashivam (2022) analysed the progress of Smart City Mission in Aizawl and identified several constraints such as limited fund utilization, institutional challenges and infrastructural limitations. Moreover, their findings suggested that unless implementation strategies are more inclusive and context-sensitive, the mission may result in uneven urban development outcomes. Together, these studies highlighted that while Smart Cities Mission offers important opportunities for urban modernization, its success depends significantly on governance capacity, local institutional strength and context-specific planning approaches.

Need & Relevance

Smart city research in India has largely focused on metropolitan regions, while geographically constrained hill cities in Northeast India remain under-studied. Scholars such as Saha (2020) and Nallapaneni et al. (2018) have highlighted structural governance and implementation challenges within the Smart Cities Mission, but limited empirical attention has been given to smaller urban centres like Aizawl. Similarly, Malsawmtluanga and Sadashivam (2022) emphasized that hill cities face unique infrastructural and administrative constraints that require context-specific urban development models. Furthermore, by examining Aizawl's experience under the SCM, this study contributes to the existing literature by providing insights into smart city governance in geographically complex regions, which is a sheer necessity for enhancing livelihood of people. Also, the present study gains relevance in helping to bridge the gap between national policy ambitions and local implementation realities while offering policy implications for inclusive and sustainable urban development in Northeast India.

Objectives

- To examine the vision, strategy and implementation of the Smart Cities Mission in Aizawl focuses on inclusivity, sustainability, infrastructure and digital governance
- To evaluate its effectiveness in addressing urban challenges and position Aizawl's performance within the broader Northeast regional context.

Methodology

This study adopts a mixed-method research design for examining the implementation, progress and challenges of the 'Smart Cities Mission' in Aizawl. The quantitative component relies on

secondary data obtained from official sources such as SCM reports of the 'Ministry of Housing and Urban Affairs (MoHUA)', 'Aizawl Smart City Reports (2020 & 2024)', 'RTI responses from Aizawl Smart City Pvt. Ltd.', 'Standing Committee Report on Housing & Urban Affairs (2023-24)' and data from the 'Census of India'. The quantitative data relating to project numbers, financial allocation, completion status and sectoral distribution have been analyzed using tabular analysis, percentage comparison and regional comparative analysis across Northeast smart cities.

The qualitative component involves content analysis of policy documents, governance frameworks, institutional arrangements and digital governance initiatives associated with the Smart City Mission. This analysis is further supported by peer-reviewed academic literature and policy reports. A comparative regional perspective is incorporated to situate Aizawl's performance within the broader Smart City landscape of Northeast India by comparing project progress, financial utilization and sectoral priorities across selected cities. The scope of the study is confined to projects approved and implemented up to 2025. Although primary field surveys are not included, the integration of RTI-based evidence with official government data strengthens the reliability and analytical depth of the present research.

Smart City Mission in Northeast India

In India's north-eastern states, the MoHUA has designated ten cities under 'Smart City Mission'. The Smart City Report 2024 states that around ₹7,737 crores have been allocated for 360 projects that have been started in these cities. The selection of these cities is a component of India's larger plan to create 100 Smart Cities, which aims to improve the quality of life through strategic and technologically advanced solutions, strengthen essential urban infrastructure and foster a clean and sustainable environment. The allocation of funds and projects by state showed notable variance. Between Itanagar and Pasighat, the two cities in Arunachal Pradesh, 75 projects totalling approximately ₹1,033 crores have been allocated. Around ₹945 crores have been invested in 22 projects in Guwahati, Assam and ₹513 has been allocated for 97 projects in Imphal, Manipur.

Aizawl, on the other hand records that despite having a relatively large number of projects, nearly 45 percent of its total financial allocation is allocated to on-going projects. This points to a strategic focus on area-based development and long-term, capital-intensive infrastructure, which is in line with the complicated topography, land limitations and construction difficulties typical of hill-city settings. The case of Aizawl emphasizes on the need for region-specific planning and execution strategies within national urban missions and the shortcomings of standard implementation frameworks.

Table 3 provides additional insights derived from the examination of central financial assistance claimed and subsequently used under SCM. The region as a whole showed a high level of fund utilization, which suggests enhanced institutional capacity and financial governance. In contrast to Sikkim, which has used more than 92 percent of the claimed funds, wherein Assam and Tripura have utilized all of the central assistance. Nonetheless, comparatively lower levels of utilization in Arunachal Pradesh, Manipur, Meghalaya and

Mizoram—especially in cities like Aizawl, Shillong and Imphal—indicated slower fund absorption, which is mostly caused by limited project complexity, longer implementation timelines and terrain-related limitations.

Together, the project distribution, completion status and financial utilization analysis shows that although the Smart City Mission has advanced significantly in the Northeast, results differ significantly between states and cities. In order to achieve more sustainable and balanced urban development in line with the Smart City Mission, these variations highlight the significance of implementing context-sensitive, adaptable implementation and financing strategies, particularly for hill cities.

Table 2: City-Wise List of Completed and On-Going Projects Under SCM (North Eastern States)

State / City	Total		Completed		Ongoing	
	Project	Amount	Project	Amount	Project	Amount
Arunachal Pradesh	**75**	**1032.11**	**59**	**669.52**	**16**	**362.59**
Itanagar	32	520.61	24	406.85	8	113.76
Pasighat	43	511.5	35	262.67	8	248.83
Assam	**21**	**754.65**	**20**	**745.74**	**1**	**8.91**
Guwahati	21	754.65	20	745.74	1	8.91
Manipur	**27**	**513.02**	**20**	**251.57**	**7**	**261.45**
Imphal	27	513.02	20	251.57	7	261.45
Meghalaya	**13**	**517.41**	**10**	**453.41**	**3**	**64**
Shillong	13	517.41	10	453.41	3	64
Mizoram	**45**	**508**	**32**	**277.64**	**13**	**230.36**
Aizawl	45	508	32	277.64	13	230.36
Nagaland	**40**	**689.3**	**40**	**689.3**	**0**	**0**
Kohima	40	689.3	40	689.3	0	0
Sikkim	**55**	**1660.99**	**48**	**1453.22**	**7**	**207.77**
Gangtok	29	743.75	24	672.14	5	71.61
Namchi	26	917.24	24	781.08	2	136.16
Tripura	**77**	**807.54**	**77**	**807.54**	**0**	**0**
Agartala	77	807.54	77	807.54	0	0

Source: Ministry of Housing and Urban Affairs (MoHUA), 2025

Table 3: Central Financial Assistance Claimed and Utilized Under SCM, Since Inception of Mission (North Eastern States)

NE States	Total Central Assistance Claimed	Utilization of Central Assistance Claimed
Arunachal Pradesh	**978**	**858.31**
Itanagar	488	392.6
Pasighat	490	465.71
Assam	**490**	**490**
Guwahati	490	490
Manipur	**398.13**	**347.63**
Imphal	398.13	347.63
Meghalaya	**490**	**432.8**
Shillong	490	432.8
Mizoram	**490**	**386.62**
Aizawl	490	386.62
Nagaland	**490**	**472.98**
Kohima	490	472.98
Sikkim	**978**	**899.83**
Gangtok	488	446.51
Namchi	490	453.32
Tripura	**490**	**490**
Agartala	490	490

Source: Ministry of Housing and Urban Affairs (MoHUA), 2025

Table 4: City-Wise Physical Progress: Smart City Mission in Northeast India

Name of the City	Rank	No. of Projects	Amount (Crores)
Agartala	89	75	808
Aizawl	94	43	513
Gangtok	95	38	1,216
Guwahati	96	22	945
Imphal	97	23	513
Itanagar	92	32	521
Kohima	59	40	689
Namchi	72	25	1,255
Pasighat	86	43	512
Shillong	93	17	765
Total		**360**	**7737**

Source: Nezine, 2024

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Vision of Aizawl Smart City Mission

The Aizawl Smart City proposal outlines the following vision: "Aizawl will be a resilient, sustainable and inclusive city by celebrating its culture and nature and utilizing its human capital through technology". The city's profile and this vision statement are very similar in a number of ways – 'Summarized Projects of Aizawl Smart City, 2024'.

This vision leverages Aizawl's topography, pleasant climate and rich cultural and historical legacy to strengthen its identity as a healthy and environmentally sustainable city. Delivering basic urban services and amenities including electricity and water, street light, storm drainage, transportation, managing traffic and vehicle parking, development of housing & market centres and management of waste remain a significant challenge for the city. Therefore, the vision focuses on transforming Aizawl into a livable urban city.

While the population's literary rate is high, the vision also considers the human capital that is currently available, pointing out that the skills and diversity needed to contribute to tertiary economic activities are lacking. It is expected to promote economic sustainability by creating large number of programs for skill development and job opportunities by constructing different facilities and providing amenities.

Targets of Aizawl Smart City Mission

The objectives of the 'Aizawl Smart City Mission' are as follows (Government of Mizoram, 2024):

1. **Promote Aizawl's Identity, Culture & Natural Environment**: Aizawl holds a great administrative significance as the capital of Mizoram. Multimodal transportation, such as air, road and rail, connects the city to other parts of India and makes it accessible throughout the year. Also, in this area Aizawl is an essential trade gateway. Moreover, due to its cultural legacy and pristine natural surroundings, the city has a significant amount of tourism potential and welcomes more than five lakh domestic visitors each year. The city's festivals and fairs attract tourists by showcasing its vibrant cultural heritage, alongside historical monuments and charming landscapes.

2. **An Inclusive Society**: Aizawl stands out for its diversity of tribal communities, which include both material and intangible cultural components. In order to attract tourists, smart city development should prioritize promoting indigenous culture. This goal will be accomplished by setting up a variety of eateries, cafes, stores and booths to display the buildings' historical artefacts. The growth of all social groups is necessary for social inclusion and these include that.

(a) Access for All: The innovative and well-planned approaches ensured that smart cities are accessible to persons with disabilities. Accessibility is made easier by integrating universal design principles into urban infrastructure. The use of tactile surface variations with clear signage systems helps independent mobility for persons with disabilities. The creation of city-

level non-motorized transportation zones encourages sustainable mobility. There will also be smooth and unhindered mobility in parts of the historic city. Also, incorporating housing-addressing systems, street numbering and signage will improve accessibility even more.

(b) Institutional Strengthening & Reforms: The delegation of functional powers stated in the '12th Schedule as per 74th Constitutional Amendment Act (1994)' and ongoing reforms will improve the efficacy and efficiency of city administration. The 'Aizawl Municipal Corporation' already operates an e-governance framework that can be further utilized to improve delivery of services along with greater transparency and accountability, while the 'National Informatics Center' has introduced an accrual-based accounting system. To promote inclusive access to benefits, priority should be given to developing e-portals that enable interactive, two-way communication between authorities and citizens. Additionally, establishing 'Government-To-Citizen (G2C) centers' equipped with digital connectivity and reliable centralized data backup along with security measures would help in faster grievance redressal. The city's public transportation system ensures the safety of both locals and visitors.

(c) Affordable Housing: Citizens, including the 'economically weaker sections' are provided with affordable housing. The population's housing needs were to be addressed by this initiative.

(d) Economic Sustainability

(i) The main aim is to create a base for sustainable economy base by strengthening the city's human capital, which can be done through creation of skill development centres, organizing construction initiatives and developing key infrastructure such as multi-utility facility centres (MUFCs), command and control centres, start-up hubs, centres for business facilitation, trade and exhibition spaces. Overall, these initiatives are designed to create significant employment prospects for the population.

(ii) Financial sustainability can be strengthened by expanding revenue such as user fee, adopting public–private partnerships, leveraging land monetization and charges for public infrastructure improvement. Additional measures such as transfer of development rights, premiums for regulatory relaxations or increased floor space index - FSI and floor area ratio - FAR, taxation on vacant land, pooling mechanisms for land and regularization of structures in accordance with municipal laws and regulations also play a vital role. Grant-in-aid, credit ratings and municipal bond issuance will also be sought. Priority will be given on strengthening the capacity to manage an extensive range of smart city projects and to effectively realize the benefits they generate.

(e) Fostering Resilience: Improving the city's resilience in terms of disaster management, urban environmental sustainability and service delivery is the main goal of the 'Aizawl Smart City Mission'. Increased solar energy use, the creation of green spaces, efficient management of solid and liquid wastes, encouraging rainwater harvesting, constructing retaining walls, creating smart infrastructure and setting up disaster management facilities are some ways to accomplish this. Together, these actions increase Aizawl's ability to endure and adjust to precarious circumstances.

Aizawl Smart City - Key Components

The following are the main components of Aizawl Smart City initiative from the **'**Urban Development & Poverty Alleviation Department, Government of Mizoram, 2020' and 'Summarized Projects of Aizawl Smart City, 2020'.

1. Improving the city's landscape, urban planning and mobility to increase its vitality, safety and connectedness. These include the following aspects:
a) Improvements to the streetscape, including bollards for a common street concept, signage, light poles, hardscape, landscape and pedestrian right-of-way, as well as facade improvements in the 'Bara Bazaar' market area.
b) Improving pedestrian pathways, carriageways, constructing foot over-bridges, enhancing road junctions and implementation of smart parking systems to improve overall walkability and mobility in the area.
c) Establishing multi-utility facilitation centres at five locations, equipped with public amenities, skill development services and platform for addressing citizens' grievances.
d) Developing key infrastructure projects such as the Aizawl tourism corridor, cultural centre and sports complex for the city, trade facility and exhibition spaces and a skill development/incubation centre.
e) Ensuring safety and security through the provision of trauma and emergency services, along with CCTV and e-surveillance systems.
f) Upgrading the Mizoram State Museum, setting up a digital library and piloting digital classrooms in 29 schools as part of smart education initiatives.

2. Several essential elements are involved in improving urban infrastructure:
(i) Provision of potable water supply and wastewater management systems, including the installation of smart meters, electronic billing mechanisms and ensuring uninterrupted 24×7 water supply across the region. This also involves implementing water quality monitoring systems, developing large-scale rainwater harvesting ponds and canals and introducing open as well as underground drainage systems within the Area-Based Development zone.
(ii) Upgrading and reconstructing stormwater drainage networks is also a key requirement.
(iii) As a pilot initiative, integrated solid waste management should incorporate ICT-based solutions such as reverse vending machines and community bins enabled with RFID tags.
(iv) Addressing energy and environmental issues involves creating power distribution network in the underground by replacing overhead lines.
(v) The infrastructure improvements include deployment of solar-powered LED street lighting systems.

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Table 5: No of Projects Under Aizawl Smart City Mission

S. No	Project Name	Cost as Per Agreement
1	New Age Learning Centre	3,13,94,700.00
2	Smart Classroom	7,54,11,339.00
3	Solar Mini Mast/Semi High Mast	3,43,43,500.00
4	Solid Waste Management Instead of Multi Utility Facility Centre	26,41,00,000.00
5	Construction of Outdoor Youth Recreation Gym	1,09,87,364.00
6	Sustainable Landfill	4,06,06,100.00
7	Entrepreneurship Development Centre, Incubation Centre and Start up Hub	4,06,08,100.00
8	Multi Utility Sports Centre (Brigade Field, Aizawl)	2,00,00,000.00
9	5G/Smart Ambulance	6,98,60,000.00
10	Renovation of Mizoram Secretariat Building at MINECO	2,00,00,000.00
11	Fire Fighting Vehicle & Equipment	4,46,73,000.00
12	Pelican Crossing System	58,00,000.00
13	Traffic Bollards Flexible Fixed	23,83,861.00
14	Steps Stair Improvement	4,43,49,080.00
15	On-Road Smart Parking including CCTV, Boom	13,38,04,858.00
16	Multi-Utility Pole and Urban Services including cabling, etc.	14,64,99,664.00
17	Urban Landscape- Avenue Plantation to increase green cover and Bio Remediation plants pollution absorbing plants	9,72,75,900.00
18	Energy Efficiency - LED Street lighting with digital hoarding	7,49,67,017.00
19	Improved Energy Efficiency Solar LED Street Lighting	8,72,20,000.00
20	Refurbishing of Mizoram State Museum	1,72,55,800.00
21	Setting up of Digital E-Library	1,44,88,040.00
22	Procurement of Sanitary Napkin Vending Machine and Incinerator	1,97,75,400.00
23	Road Side Drinking Water Kiosks	1,17,35,360.00
24	Tourist Guidance Centres	19,46,601.00
25	Street Vending Zone – Creating vending Zones with Basic Facilities modular kiosks	43,57,632.00
26	Reverse Vending Machines Pilot Projects	83,79,419.00
27	Integrated Command Control Centre	1,19,20,96,894.00
28	Energy Efficiency for Solar LED lighting with digital hoarding	2,70,02,016.00
29	Construction of Smart Street at Upper Khatla	3,28,21,300.00
30	Upgradation of Tourist Lodge, Chaltlang, Aizawl	18,11,98,427.00
31	Common Bio-Medical Waste Treatment Facility	7,65,49,035.00
32	Construction of playground at Zemabawk	24,94,72,960.00
33	Construction of playground at Edenthar	7,91,58,468.00
34	Construction of playground at Zuangtui	14,60,14,377.00
35	Construction of playground at Chite	8,65,73,160.00
36	Construction of playground at Tuivamit	6,74,74,543.00
37	Construction of playground at hlimen	6,59,23,380.00
38	Construction of futsal ground at Zemabawk Mitla Mual	5,95,08,334.00
39	Construction of Multipurpose Ground at High Field, Zarkawt	15,08,52,082.00
40	Construction of Playground at Durtlang	17,87,84,000.00
41	Construction of City Centre Bara Bazar, Aizawl	40,35,46,870.00
42	Construction of Chaltlang Sports Multipurpose Hall	13,52,10,000.00
43	Procurement of Medical Equipment of Civil Hospital, Aizawl	4,08,36,000.00
44	Pavement of Approach Road to Edenthar Playground	86,90,639.00

Source: RTI Application answered by State Public Information Officer Aizawl Smart City Pvt Limited

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Projects Under Aizawl Smart City Mission

As indicated in Table 5, the 'Aizawl Smart City Mission' covers 44 projects with budget allocations ranging from ₹58 lakhs for the 'Pelican Crossing System' to ₹119.21 crores for the 'Integrated Command and Control Centre (ICCC)'. This distribution highlights the digital governance and real-time urban management. Infrastructure development remains a central priority as provided by eight playground projects, such as those in Zemabawk, Durtlang and Chite, which together account for over ₹100 crores. These efforts underline a commitment to promoting sports, community development and youth participation. Additionally, major investments in commercial and recreational infrastructure, including the 'City Centre Bara Bazar (₹40.35 crores)' and 'Multi-Utility Sports Centre (₹2 crores)' highlights the significance towards urban transformation.

The mission's two core themes are sustainability and technology. Environment-focused initiatives such as sustainable landfill management (₹4.06 crores), solar-powered LED street lighting (₹8.72 crores) and urban landscaping (₹9.72 crores) reflect Aizawl's commitment to eco-friendly urban development. At the same time, projects like biomedical waste treatment (₹7.65 crores), vending machines for sanitary napkins (₹1.97 crores) and provision of firefighting vehicles (₹4.46 crores) addresses the critical public health and safety needs, supporting holistic urban growth. Smaller-scale interventions, including street vending zones (₹43.57 lakhs) and traffic bollards (₹23.83 lakhs), which highlights the attention to localized urban issues and everyday challenges faced by residents. The inclusion of guidance centres for tourists (₹19.46 lakhs) and restoration of Mizoram Secretariat (₹2 crores) further demonstrates administrative strengthening and tourism development. Overall, the distribution of projects reflects a strategic approach that emphasizes digital infrastructure, environmental sustainability and inclusive public services, while ensuring balanced development across Aizawl's neighbourhood.

Table 6: Sector-Wise Details of Projects Under SCM

S. No	Sectors of SCM	Total No. of Projects	Cost of Projects
1	Economic Infrastructure	932	12973.04
2	Environment	151	2715.27
3	Smart Energy	694	14263.15
4	Smart Governance	680	17808.82
5	Smart Mobility	1737	41623.06
6	Social Infrastructure	898	13022.29
7	Vibrant Public Spaces	1408	12261.96
8	WASH (Water, Sanitation & Hygiene)	1545	49621.47

Source: Ministry of Housing and Urban Affairs (MoHUA), 2025

The Table 6 highlights the sector-wise distribution of projects under the 'Smart City Mission', revealing clear investment priorities**.** WASH **(**Water, Sanitation & Hygiene) emerges as the most capital-intensive sector, with the highest financial allocation (₹49,621.47 crores) across 1,545 projects, reflecting the Mission's emphasis on basic urban services. Smart Mobility

records the largest number of projects (1,737) and substantial investment, indicating a strong focus on urban transport and connectivity. Significant allocations to Smart Governance and Smart Energy underscore the growing importance of digitalization and energy efficiency in urban management. In contrast, the **e**nvironment sector receives comparatively limited investment, pointing to a relative under-emphasis on ecological interventions within the' Smart City Framework'.

Findings & Discussion

The analysis revealed that implementation of Smart Cities Mission in Northeast India remains uneven and comparatively slower than the national average. Most cities in the region, including Aizawl, fall within the lower tier of national rankings in terms of physical progress. Similar observations have been highlighted by Prajapati (2023) and Hoque & Prakash (2023) who have noted that institutional constraints and geographical limitations significantly affect smart city implementation in smaller urban centres. The vision of the Aizawl Smart City Mission emphasizes inclusivity, sustainability and resilience. While this vision aligns well with the city's socio-cultural and environmental context, the study indicated a gap between policy aspirations and on-ground outcomes. In furtherance, the existing urban challenges such as water supply limitations, traffic congestion, drainage problems and housing shortages continue to affect the city. This reflects broader concerns raised by Saha (2020) regarding the disconnect between policy rhetoric and practical urban transformation.

Project allocation patterns in Aizawl showed a strong emphasis on digital governance, recreational infrastructure and urban beautification initiatives. The Integrated Command and Control Centre (ICCC) represent the largest single investment, indicating a strong technological orientation. However, relatively lower investment in essential services such as affordable housing and storm-water drainage raises questions about sectoral prioritization. Singh and Upadhyay (2022) similarly argued that technology-centric approaches may overlook fundamental urban service needs in many Indian smart cities. Digital governance initiatives including smart parking systems, e-libraries, CCTV surveillance and 5G-enabled emergency services demonstrate important progress toward technology-enabled urban management. These initiatives have contributed to improved monitoring, service delivery and administrative efficiency. Nevertheless, the effectiveness of such initiatives remains dependent on institutional coordination, maintenance capacity and citizen accessibility.

Environmental sustainability initiatives such as solar LED lighting, urban landscaping, sustainable landfill development and rainwater harvesting reflected an increasing awareness on ecological sustainability. However, resilience planning remains largely project-oriented rather than system-wide. Given the vulnerability of hill cities to landslides, heavy rainfall and seismic risks, a more integrated urban resilience framework is required. The effort towards social inclusion has been visible through initiatives such as street vending zones, sanitary napkin vending machines, public toilets and entrepreneurship development centres. These interventions address micro-level urban needs and support informal livelihoods. However, socio-economic disparities remain evident, particularly in terms of employment generation and affordable housing access.

Overall, the findings suggested that while the Smart Cities Mission has created opportunities for urban modernization in Aizawl, its outcomes remain shaped by governance capacity, sectoral prioritization and the geographical realities of hill cities.

Suggestions

- **Context-Specific Planning for Hill Cities:** Urban development strategies in Aizawl should be tailored to its hilly terrain, focusing on landslide mitigation, slope management and climate-resilient infrastructure instead of adopting uniform smart city models.
- **Strengthening Governance & Institutional Capacity:** Enhance the efficiency of institutions such as the Aizawl Municipal Corporation through better coordination, technical training and accountability mechanisms to ensure timely implementation of projects.
- **Prioritizing Basic Urban Services:** Rebalance investment by giving greater emphasis to essential services like water supply, sanitation, drainage and affordable housing alongside technology-driven initiatives under the Smart Cities Mission.
- **Enhancing Citizen Participation & Inclusivity:** Promote active citizen engagement through participatory governance, digital platforms and inclusion of marginalized groups to ensure equitable and people-centric urban development.
- **Improving Financial Utilization & Project Monitoring:** Strengthen financial management systems, ensure efficient fund utilization and adopt continuous monitoring and evaluation mechanisms to improve overall project performance and outcomes.

Conclusion

Currently, the cities in Northeast India selected under ‘Smart Cities Mission’, including Aizawl are yet to fully attain the envisioned smart city status. The reason being, progress of the work has been significantly affected by challenges related to weak governance structures and uneven socio-economic development. Nevertheless, the mission offers a valuable opportunity to transform urban landscapes in the region and promote sustainable growth. At the same time, if not carefully managed, these initiatives could intensify existing economic, social and spatial inequalities, which would pose a serious issue requiring immediate attention.

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Conceptual Study on Resilience and Mental Health among Police

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Abstract

This research focuses on the aspects of resilience training and psychological support initiatives that affect the well-being and job performance of police personnel. The present research underscores the effectiveness of various resilience training programs in reducing stress, improving coping strategies and enhancing psychological well-being through a systematic review. The quantitative findings indicated a decrease in burnout, whereas the qualitative feedback highlights enhancements in emotional regulation, teamwork and job satisfaction. Moreover, physiological indicators like cortisol levels validated that mindfulness training has a considerable effect on reducing stress and bolstering emotional resilience. Additionally, the research investigated on peer-support initiatives that cultivate social support, mitigate stigma and enhance officers' mental health. Results highlighted the need for standardized resilience training methods to guarantee comparability and effectiveness. Furthermore, the exposure of police officers to high-risk situations contributes to mental health challenges like PTSD, burnout and anxiety. The study pinpoints protective factors such as strong peer networks and organizational backing that help reduce these risks. In high-pressure situations, resilience and adaptive coping strategies enhance decision-making, emotional regulation and operational effectiveness. It also identified the psychological effects of COVID-19 on law enforcement personnel as well as challenges and work-life balance problems that are specific to gender. The findings showed the structured resilience programs, wellness initiatives and policy reforms, which are crucial for promoting a healthier policing environment. This study has emphasized on the necessity of thorough mental health interventions and resilience-building strategies to improve law enforcement officer's well-being and effectiveness.

Key words: Resilience, Mental Health, Police Personnel, Occupational Stress, Psychological, Well-being.

Introduction

Due to the challenging nature of police officers' work, the exposure to trauma and high-stakes decisions they must take their experience with a considerable job-related stress. Consequently, mental health issues like burnout, anxiety and post-traumatic stress disorder (PTSD) are common in law enforcement. Previous research studies have highlighted that law enforcement work is strongly associated with elevated stress levels and mental health risks, while resilience and effective coping strategies play a crucial role in protecting officer's psychological well-being (Violanti et al., 2019). Recent studies demonstrated that resilience training, peer support programs, mindfulness practices and psychological interventions can effectively reduce stress and improve officer's mental well-being. Also, a research study found that officers who participate in resilience training exhibited better emotional regulation, lower stress biomarkers and increased job satisfaction (McCraty & Atkinson, 2012). Additionally, initiatives aimed at improving mental health literacy and peer support networks helped to reduce stigma and enhance awareness of psychological well-being (Haugen et al., 2017). Nevertheless, the lack of consistency in definitions of resilience, measurement instruments and program execution limits the capacity to standardized and enhanced training strategies across various law enforcement agencies (Windle et al., 2015). The results revealed that necessity of structured, evidence-based resilience programs that are customized to the specific challenges encountered by police personnel (Andersen et al., 2015a). Policing organizations can improve job performance, decrease absenteeism and better prepare officers for occupational stress by promoting resilience and psychological well-being (Arnetz et al., 2009). Keeping these aforementioned aspects, the present conceptual study aims to synthesize the existing literature and develop a structured framework for resilience training tailored to police personnel.

Literature Review

A wide range of scholarly investigations have identified occupational, organizational and personal determinants that negatively influence police mental health. In furtherance, the chronic occupational stress arising from excessive workload, prolonged duty hours, shift rotations and repeated exposure to traumatic events is among the most frequently cited contributors. While resilience training showed clear benefits, understanding the stressors affecting police mental health remains equally critical. Pancheri et al. (2002) reported elevated stress levels among municipal police officers in Rome, attributing psychological strain to administrative burdens, workload pressures and constant public engagement.

These findings established early recognition of policing as a profession associated with heightened mental health risks. Moreover, among the identified risk factors, trauma exposure consistently emerges as dominant predictors. Schafer et al. (2020) identified cumulative trauma exposure, occupational stress and insufficient coping mechanisms as strong predictors of adverse mental health outcomes among high-risk professionals, including police officers. Similarly, Anders et al. (20222) demonstrated that intense trauma exposure, limited social support and sustained stress heightened susceptibility to PTSD and burnout, whereas resilience and peer support functioned as protective factors. The scholars increasingly advocated for integrated and multi-component resilience models. Prati and Pietrantoni demonstrated that

resilience training combined with strong peer networks and effective coping strategies reduced psychological distress following critical incidents (Prati & Pietrantoni, 2010). Also, systematic reviews across occupational settings also confirmed the effectiveness of resilience training programs. A meta-analysis revealed that structured resilience interventions significantly improve coping ability, psychological well-being and stress management among high-risk professionals (Joyce et al., 2018). Organizational support systems further enhance the sustainability of resilience interventions. Acquadro Maran et al. (2015) further highlighted the protective role of organizational support systems, wellness initiatives and peer resources in mitigating secondary traumatic stress. Although resilience training is widely supported, the conceptual inconsistencies remain evident in the literature. Janssens et al. (2021) argued that inconsistent conceptualizations of resilience hinder comparison and scalability of training initiatives across policing agencies. Furthermore, systematic reviews highlighted on the methodological variability across resilience program. Similarly, Moreno et al. (2024) observed that variations in program duration, structure and evaluation tools limit the identification of universally applicable best practices.

Need & Relevance

Police officers regularly face job stress, traumatic situations and work pressure, which increase the risk of anxiety, burnout and mental health problems (Garbarino et al., 2013; Schafer et al., 2020). Although resilience helps protect mental health (Prati & Pietrantoni, 2010), differences in training methods shows the need for clear, evidence-based resilience programs (Windle et al., 2011). Research studies have showed that resilience training helps police officers manage stress better and improve emotional control and overall well-being (Andersen et al., 2015a; Moreno et al., 2024). Due to stigma and lack of standard programs (Marshall et al., 2021), this conceptual study proposes practical and culturally suitable resilience models to support long term police mental health.

Objectives

- To examine the impact of resilience training on police mental health and identify key factors influencing psychological well-being among police personnel
- To develop a conceptual framework for standardizing resilience training approaches tailored to the occupational demands of police services

Methodology

The entire study is based on secondary data sources and adopted descriptive research method to explain the observations. In furtherance, the present study employed a conceptual systematic review design, analyzing peer-reviewed research, policy reports and empirical studies on police resilience and mental health. Also, the research literature pertaining to the aforesaid aspects have been thematically synthesized to identify key determinants, evaluate intervention outcomes and develop a standardized resilience training framework tailored to policing context.

Observation & Discussion

The literature demonstrated that police mental health is shaped by an interplay of trauma exposure, organizational culture, workload demands, stigma, social support systems and external crises, necessitating comprehensive, sustained and multi-level intervention strategies (Pancheri et al., 2002; Anders et al., 2022; Marshall et al., 2021).

Examining Impact of Resilience Training on Police Mental Health & Identifying Key Factors Influencing Psychological Well-Being Among Police Personnel

Extensive empirical evidence indicated that resilience training produces significant and measurable benefits for police personnel by decreasing stress levels, strengthening coping strategies and enhancing overall occupational well-being. In this context, early structured intervention studies began systematically examining resilience training among police personnel. One of the pioneering structured investigations into resilience interventions among police officers was conducted by Weltman et al. (2014) reported the substantial reductions in perceived stress and burnout, along with improvements in coping abilities, emotional regulation, teamwork, job satisfaction and workplace morale. Their findings demonstrated both statistical declines in burnout indicators and qualitative enhancements in organizational climate, suggesting that resilience programs generate broad and multidimensional advantages beyond individual stress management.

Expanding upon these initial findings, later systematic reviews synthesized evidence across multiple policing settings. Moreno et al. (2024) analyzed multiple empirical investigations and concluded that resilience-based programs within policing settings effectively reduce stress, burnout and psychological distress while simultaneously improving emotional control and job performance. They also identified the inconsistencies in program structure, duration and implementation methods, which constrained comparability and broader generalization of results. Despite these methodological variations, the overall pattern of findings strongly supported the effectiveness of resilience-oriented interventions in law enforcement environments. Furthermore, empirical support emerges from research emphasizing resilience as an individual protective factor. Janssens et al. (2021) found that officers demonstrating higher resilience levels experienced lower stress and improved psychological health outcomes, reinforcing the importance of systematically integrating resilience development into law enforcement training systems. Keeping these aforesaid observations in the forefront, the researchers emphasized that resilience-building initiatives should be institutionalized within standard police training curricula rather than offered as supplementary or optional modules. In addition to this, traditional resilience models, mindfulness-based approaches have gained increasing scholarly attention.

A research study reported that mindfulness training significantly reduced perceived stress and lowered salivary cortisol levels among police officers, reflecting improvements in both subjective experiences and biological stress markers (Grupe et al., 2021). Participants also showed enhanced emotional regulation and resilience capacities, indicating that mindfulness-based strategies effectively address cognitive as well as physiological aspects of stress. Beyond

psychological well-being, resilience interventions have also been evaluated for their impact on operational performance. Yet another study has demonstrated that cognitive resilience and mental preparedness training improved stress tolerance, emotional stability and decision-making performance among police officers operating in high-risk contexts (Andersen et al., 2015b). These results suggested that resilience development contributes not only to mental well-being but also to improved functional performance in demanding operational environments.

European investigations provided additional cross-cultural validation of resilience training outcomes. Brinkmann et al. evaluated resilience training among German military police leaders and observed significant gains in stress management, psychological strength, leadership effectiveness and decision-making under pressure (Brinkmann et al., 2022). Likewise, Steingraber et al. (2021) have designed and tested a psychological training framework for specialized police and military personnel, reporting improvements in stress coping, mental preparedness and emotional control. Moreover, within the Indian context, culturally grounded intervention studies further reinforce these findings. Chitra and Karunanidhi documented meaningful reductions in occupational stress and notable improvements in resilience, job satisfaction and psychological well-being among female police officers following structured interventions (Chitra & Karunanidhi, 2021). This emphasized the role of strengthened coping mechanisms and emotional regulation in fostering enhanced workplace morale. In furtherance complementing intervention-based evidence also highlighted resilience as a key protective variable. Nadeem et al. (2025) found that higher resilience levels among police personnel were associated with improved emotional control, reduced burnout and more effective coping strategies, highlighting the importance of resilience development in high-stress policing environments.

Longitudinal and post-disaster research further illustrated the enduring consequences of such exposure. A research study found that persistently elevated anxiety levels among French first responders several years following the 2015 terrorist attacks, illustrating the prolonged mental health consequences of repeated trauma exposure (Prioux et al., 2023). Such evidence highlighted the necessity for long-term psychological support mechanisms rather than short-term crisis-based interventions. Beyond operational stressors, organizational culture significantly shapes mental health outcomes. Yet another research study revealed that officers frequently conceal mental health symptoms due to concerns about career repercussions, stigma and cultural expectations of toughness and self-sufficiency (Marshall et al., 2021). This concealment restricts timely access to support and increases the risk of chronic psychological conditions, thereby underscoring the importance of reducing stigma within police institutions.

Encouragingly, institutional reforms and educational interventions have demonstrated measurable improvements. Lorey and Fegert showed that incorporating trauma awareness and mental health education into police training enhanced knowledge, reduced stigmatizing attitudes and increased confidence in addressing trauma-related issues (Lorey & Fegert, 2022). Such initiatives foster supportive organizational climates and promote help-seeking behavior among officers. The external crises such as global health emergencies have further intensified occupational stress burdens. A study conducted by Roberts et al. (2021) have documented

heightened stress, anxiety and burnout among first responders during the pandemic due to increased responsibilities, isolation and emotional demands. McKinley and Jones similarly reported that pandemic-related challenges including infection risk and limited psychological resources adversely affected mental health and threatened career sustainability among police personnel (McKinley & Jones, 2023). Indian research similarly documents the pervasive impact of occupational stressors. Moreover, the study by Parsekar et al. (2015) have identified high psychological distress among police constables in Karnataka, attributing it to extended working hours, job strain and exposure to traumatic events. Also, Singh et al. (2022) found that police officers in North India experienced significant anxiety and burnout associated with elevated stress levels and insufficient coping strategies, while social support emerged as a buffering factor (Singh et al., 2022).

Additionally, gender-specific workplace dynamics introduce further complexity into police mental health research. Ragesh et al. (2017) reported that female police officers encountered additional stress arising from workplace discrimination, work-family conflict and prolonged duty hours, contributing to anxiety, depression and burnout. These findings reinforced the importance of implementing gender-sensitive mental health policies within law enforcement systems. Overall, the body of literature consistently indicated that resilience training contributes positively to police mental health, job satisfaction, emotional regulation and operational effectiveness across varied cultural and organizational settings, thereby affirming its central role in police wellness programs (Weltman et al., 2014; Moreno et al., 2024; Janssens et al., 2021).

Developing A Conceptual Framework for Standardizing Resilience Training Approaches Tailored to Occupational Demands of Police Services

Emerging psychophysiological evidence strengthens the argument for scientifically grounded standardization. A research study demonstrated that chronic occupational stress influences cortisol secretion, heart rate variability and neurobiological functioning among police officers, underscoring the need for resilience programs informed by biological evidence (Bulygina et al., 2024). These findings suggested that resilience training should address both psychological and physiological stress mechanisms. Beyond individual-level mechanisms, leadership and organizational climate play pivotal roles. Kanunnikov and Konopleva have reported that structured resilience programs combined with supportive leadership and team cohesion enhanced officer's stress tolerance, decision-making capacity and overall well-being in high-risk contexts (Kanunnikov & Konopleva, 2024). At the individual coping level, adaptive strategies significantly influence resilience outcomes. Dubinsky similarly emphasized that adaptive coping techniques such as problem-solving and emotional regulation reduce distress, whereas maladaptive coping increases vulnerability (Dubinsky, 2021).

Policy-oriented research in India emphasizes on institutional responsibility in strengthening resilience systems. A study conducted by Trivedi has emphasized on institutionalized resilience training, improved working conditions and structured wellness policies as essential for enhancing police well-being and operational efficiency in India (Trivedi, 2024). The national level institutional reports also recognized occupational stress as a pressing concern.

The Bureau of Police Research and Development likewise identified occupational stress and lifestyle-related disorders as pressing concerns and recommended systematic stress management and wellness interventions (Bureau of Police Research & Development, 2018). Collectively, the evidence highlights the necessity of transitioning from fragmented, short-term resilience initiatives to comprehensive, standardized, evidence-based and culturally sensitive resilience training systems that integrate psychological, physiological, organizational and leadership components to sustainably strengthen police mental health and performance (Janssens et al., 2021; Bulygina et al., 2024; Trivedi, 2024).

Summary

The reviews conducted by the researchers have showed that resilience training helps police personnel reduce stress, burnout and anxiety while improving emotional control and job performance. However, police mental health is affected by many factors such as trauma exposure, heavy workload, long duty hours, stigma and lack of social support. The findings also revealed differences in training methods and measurement tools. Therefore, there is a clear need for standardized, structured and culturally suitable resilience programs within police organizations. Moreover, the comprehensive review indicated that resilience training has a significant positive impact on police personnel by reducing stress, burnout and psychological distress while enhancing emotional regulation, coping skills, job satisfaction and operational performance. Findings also revealed that police mental health is influenced by multiple interacting factors, including trauma exposure, heavy workload, long working hours, organizational pressures, stigma and limited social support, with these risks further intensified duration crises such as COVID-19 pandemic. Additionally, the results highlighted a lack of standardization in resilience training models, definitions and evaluation methods across policing contexts. Overall, the evidence supports the need for structured, evidence-based and culturally appropriate resilience training integrated with organizational and policy-level mental health interventions.

Suggestions

- Police department should introduce structured and standardized resilience training programs as part of regular professional development.
- Mental health awareness and peer-support systems have to be strengthened to reduce stigma and encourage help-seeking behavior.
- Organizational policies should ensure manageable duty hours and promote work-life balance to reduce burnout.
- Gender sensitive support programs must be developed to address the specific challenges faced by female police personnel.
- Future research studies shall focus on developing a culturally appropriate and evidence-based resilience frameworks for policing contexts.

Conclusion

This conceptual study highlighted the importance of resilience in improving the mental health and overall performance of police personnel. Police officers regularly face stressful and traumatic situations that increase the risk of anxiety, burnout and other psychological problems. The review showed that resilience training, mindfulness practices, peer support systems and mental health awareness programs help to reduce stress and improve emotional control, coping skills and job satisfaction. However, the findings also revealed that police mental health is influenced by many factors such as heavy workload, long duty hours, organizational pressure, stigma and limited social support. Another important issue identified is the lack of standard and consistent resilience training models across different policing contexts. Therefore, there is a strong need for structured, evidence-based and culturally suitable resilience program. Strengthening organizational support and mental health policies will help to create a healthier work environment and improve both officer well-being and effective policing.

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Embedding DEIB within ESG Frameworks to Transform Medical Education from Equity to Regeneration – A 5P Global-Indian Blueprint

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Abstract

Medical education is at a crossroads with inequity and burnout in a manner that is undermining a skilled and caring health workforce. The present research exhibits a narrative synthesis of 62 high-quality sources with a new vision of how a regenerative ecosystem of equity may be developed through integration of Diversity, Equity, Inclusion and Belonging (DEIB) with Environmental, Social and Governance (ESG). A regenerative ecosystem of learning through the integration of DEIB with ESG using a 5P framework of People, Policies, Processes, Practices and Lived Experiences has been proposed. There is a global indication of a positive impact of the integration of DEIB with ESG in the development of a regenerative ecosystem of equity in terms of cultural humility, student engagement and psychological safety. In India, caste inequity is a significant problem in medical education. Between the years 2018 and 2023, over 13,500 students from SC/ST/OBC categories dropped out from central universities, IITs and IIMs. Institutional reforms have a positive impact on the reduction of student dropouts and belongingness. The present chapter provides five evidence tables of a 5P Global-Indian Blueprint of the integration of DEIB with ESG in the development of a regenerative ecosystem of learning in a manner that breaks inequity and builds a diverse, resilient and culturally sensitive health workforce for achieving the Sustainable Development Goals 3 and 10 and a bringing in a diverse and caring health workforce.

Keywords: DEIB, ESG, Medical Education, Caste Equity, 5P Framework, Regenerative Ecosystem.

Introduction

Medical education across the globe is in a critical juncture to address inequities and exclusions that have been existing for decades. The high rates of burnout, microaggressions and lack of representation from marginalized groups are some of the common problems being faced by

medical students across the globe. These are some of the manifestations of broader social problems of marginalization faced by various groups across society. India is no exception to these problems. The caste system is one of the major reasons for inequity in medical education. In spite of introducing reservation policies for various groups, inequity is still being experienced. Traditionally, SC, ST and OBC groups are being marginalized in spite of their talent and hard work. Between 2018 and 2023, more than 13,500 students from SC/ST/OBC categories left central universities, IITs and IIMs (Ministry of Education, Government of India, 2023) and this is also true for medical institutions.

The present trends and past experiences are a clear indication that there is a dire need to bring about a regenerative approach to medical education to break free from these inequities and exclusions. Global literature has revealed diversity, equity, inclusion and belonging (DEIB) is a powerful approach to bring about change (Shah et al., 2024; Nolan & Owen, 2024). There are various medical institutions across the globe that have shown tremendous success with a focus on DEIB. There is a high degree of inequity in Indian society based on caste and a tremendous opportunity to bring about change with a focus on localized interventions (Sulena et al., 2024; Rukadikar et al., 2022). The information provided in this book chapter is based on an integrative narrative review of 62 high-quality sources and it is based on a model for people, policies, processes, practices and lived experiences (5Ps), which is geared towards transformative change in medical education. Therefore, by incorporating DEIB principles in ESG models greater accountability, sustainability and transformative change can be achieved in an organization (Shah et al., 2024; Draper-Rodi et al., 2024). Table 1 is a summary of the DEIB elements and the direct benefits in ESG models, while Table 2 is a representation of the DEIB elements at the macro and micro levels and three pillars of ESG models. These fundamental models showed the relationship between DEIB and ESG models in creating a fair, inclusive and sustainable learning environment for students (Broughton-Jones et al., 2024).

The model for DEIB and ESG is based on the guidelines of United Nations Sustainable Development Goals, which include SDG 3 Good Health and Well-being and SDG 10 Reduced Inequalities (Shah et al., 2024; Rukadikar et al., 2022). The model for DEIB and ESG challenges the status quo of conventional belief that DEIB is an add-on to the real business of the organization and rather sees it as the heartbeat of ESG institutional excellence. This vision for DEIB and ESG is a regenerative vision that created a model for a new way forward in medical education, where diversity fuels innovation, equity fuels fairness, inclusion fuels a sense of belonging and governance fuels accountability and sustainability (Nolan & Owen, 2024; Draper-Rodi et al., 2024). The present research study offers a model, which acts as a lens for viewing DEIB, ESG and 5P. This is where the barriers dissolve and voices of diversity flourish, offering a new way forward in medicine, wherein graduating students will care for all communities with a compassion and understanding (Shah et al., 2024; Verbree et al., 2023).

Literature Review

The literature on diversity, equity, inclusion and belonging in medical education across the globe clearly indicated that there is global evidence base for DEIB and various challenges that have been faced. This is particularly significant for a country like India due to caste-based

inequity (Shah et al., 2024; Nolan & Owen, 2024). The literature on DEIB interventions clearly revealed that better outcomes are achieved for the students in basic parameters of health education students. For instance, it has been indicated that the interventions related to cultural humility, equity and inclusion have a significant positive impact on the outcomes of students who have been exposed to such interventions. It has been indicated that better outcomes are achieved for the students who have been exposed to such interventions, as indicated by Shah et al. (2024) and Rukadikar et al. (2022). Burnout is a challenge that medical students face universally across the globe. The literature on DEIB interventions clearly indicated that better outcomes are achieved for the students with regard to topic of burnout (Nolan & Owen, 2024; Anderson et al., 2022). Also, top medical schools across the globe, such as Harvard and Toronto, reiterated that better outcomes are achieved for the students with regard to topic of DEIB interventions. For instance, it has been indicated that better outcomes are achieved for the students with regard to topic of microaggressions and grievance resolution, as indicated by Acholonu et al. (2020) and Verbree et al. (2023).

In the Indian context, caste-based discriminatory behaviors have been identified as one of the major structural barriers in the context of medical education, even after the implementation of reservation policies. It has been identified that over 13,500 students from SC/ST/OBC categories have dropped out from central universities, IITs and IIMs between 2018 and 2023, as per the parliamentary response from the Ministry of Education, Government of India, in 2023. These trends have been identified in the context of medical colleges as well. Interventions in the context of premier educational institutions in India have been identified as effective and interventions in the context of AIIMS Delhi have been identified as effective in the context of implementing mentor programs and grievance cells for the reduction of dropout rates and addressing student grievances, as identified by Sulena et al. (2024) and Rukadikar et al. (2022). Interventions in the context of Bihar have been identified as effective in the context of public–private–people partnerships for healthcare management in developing regenerative medical education systems, as identified by Krishnan (2025). Interventions in the context of gender equity programs for women empowerment in Bihar have been identified as effective in the context of developing inclusive academic environments through DEIB as per the national agendas of Viksit Bharat 2047 (Krishnan, 2025).

The converging theme from these studies is that there is a need to develop an integrated framework for a regenerative medical education ecosystem. Although DEIB principles are increasingly being adopted in the development of accreditation standards in medical education (ACGME, 2025), the need to develop a regenerative medical education ecosystem in conformity with ESG principles cannot be overemphasized (Shah et al., 2024). Although there are some studies on the need to develop a regenerative medical education ecosystem in conformity with DEIB principles, only a handful of studies have attempted to bridge the gap between DEIB and ESG principles in relation to medical education in India, whereas caste is an important determinant of equity (Verbree et al., 2023 & Draper-Rodi et al., 2024). The global perspective and Indian perspective on medical education converge on a common theme: the need to develop a regenerative medical education ecosystem through the integration of DEIB and ESG principles (Broughton-Jones et al., 2024 & Shah et al., 2024).

Need & Relevance

It is found that despite the awareness and implementation of Diversity, Equity, Inclusion and Belonging (DEIB) strategies all over the globe, it is an untrodden area for the implementation of the strategies in medical education (Shah et al., 2024; Nolan & Owen, 2024). The existing scenario is that all the strategies are of a tokenistic nature. Therefore, it is found that a minimal impact is seen in learner retention, learner psychological safety, learner cultural competence and a balanced healthcare workforce (Shah et al., 2024 & Verbree et al., 2023). Therefore, it is imperative that DEIB strategies need to be adopted and integrated into the accountability and sustainability framework of ESG norms so that we can move away from tokenistic strategies (Broughton-Jones et al., 2024 & Draper-Rodi et al., 2024).

The situation in India is an area of concern as it is a country that is plagued with issues like caste-based inequity in healthcare and medical education. In the recent past, in the period of 2018-23, the number of SC/ST/OBC students dropping out of central universities, IITs and IIMs in India has seen an increase. Out of the total number of students who dropped out of these institutions in India, more than 13,500 students dropped out. This situation also exists in medical colleges, even though reservations have been made in medical colleges so that the number of students from all communities is well distributed (Sulena et al., 2024 & Rukadikar et al., 2022).

Although the situation in Tier-1 colleges has seen some positive outcomes but it aims at Tier-2 and 3 colleges, which is still an area of concern and needs to be addressed. The present research aims at creating an actionable blueprint that meets the needs of Tier-2 and 3 colleges while incorporating the best practices from around the world. Keeping in view the special circumstances and needs of our country, medical education becomes a regenerative education that meets the requirements of SDG 3: Good Health and Well-being and SDG 10: Reduced Inequalities.

Objectives

- To examine the strategic embedding of Diversity, Equity, Inclusion and Belonging (DEIB) within Environmental, Social and Governance (ESG) frameworks in medical education
- To propose and illustrate a practical 5P Global-Indian Blueprint (People, Policies, Processes, Practices and Lived Experiences) that transforms medical education into a regenerative, equitable and caste-sensitive learning ecosystem

Methodology

The present research adopts integrative narrative methodology and descriptive research design, which provides an opportunity to synthesize various research studies, best practices across the globe, problems encountered due to caste system and concept of integrating ESG-DEIB. It should be noted that integrative narrative methodology employed in the present research work is quite different from systematic or scoping methodology. It should be noted that systematic

or scoping methodology of research is employed only to synthesize research studies (Braun & Clarke, 2006). On the contrary, integrative narrative methodology employed in the present research work synthesizes various research studies and developed an integrated framework, which is quite useful and applicable (Broughton-Jones et al., 2024 & Draper-Rodi et al., 2024).

The various sources of information have been searched through various tools and techniques using various databases like PubMed, Scopus, BMC Medical Education, Google Scholar, grey literature from ACGME (2025), National Medical Commission, Ministry of Education, Government of India (2023), etc. It should be noted that the various sources of information were searched from the literature that had been published between January 2010 and August 2024 using various keywords like 'DEIB', 'Diversity Equity Inclusion Belonging', 'Medical Education', 'ESG Frameworks', 'Social Accountability', 'Caste', etc. It should be noted that the total number of sources of information that had been finally selected for the purpose of research work is 62 in total, out of which 45 are research articles, 10 institutional reports, 5 government reports and 2 policy frameworks (Shah et al., 2024; Sulena et al., 2024; Rukadikar et al., 2022).

The review process has been conducted collaboratively in three stages to ensure rigor and reflexivity in synthesizing evidence for the 5P ESG Integration Framework:

1. Policy Mapping – Aligning DEIB elements with ESG pillars (Shah et al., 2024).
2. Iterative Development and Validation of 5P lens – Extrapolating practical dimensions from global and Indian evidence (Draper-Rodi et al., 2024 & Broughton-Jones et al., 2024).
3. Comparative Synthesis – Integrating global and Indian evidence with specific focus on caste adaptations (Krishnan, 2025 & Sulena et al., 2024).

The researchers have set forth the following questions on specific research avenues, which guided the review process:

a) How can ESG frameworks operationalize DEIB within medical education?
b) What governance mechanisms facilitate inclusive and quantifiable outcomes?
c) How can institutional audits, implementation and monitoring be structured through a 5P lens?

This is an open and evidence-based approach that synthesizes knowledge from 62 sources into a useful tool, namely the *5P ESG Integration Framework*, while acknowledging some limitations in terms of secondary data usage and applicability in resource-constrained environments through benchmarking and master tables (Shah et al., 2024; Verbree et al., 2023; Sulena et al., 2024).

Results & Observation

The integrative narrative analysis of literature on the strategic integration of diversity, equity, inclusion and belonging principles under environmental, social and governance principles in medical education revealed that there are distinct patterns that indicated the importance of

strategic interventions in medical education (Shah et al., 2024 & Nolan & Owen, 2024). The literature on Indian and global contexts revealed that the strategic interventions of medical education institutions on the implementation of DEIB principles are effective in improving learner retention, psychological safety, faculty diversity and transparency of governance (Rukadikar et al., 2022; Verbree et al., 2023; Draper-Rodi et al., 2024). Moreover, the literature on Indian and global contexts identified that strategic interventions by medical education institutions on the implementation of DEIB principles have been effective in learner retention and strongly linked with the social and governance aspects of ESG principles (Shah et al., 2024 & Broughton-Jones et al., 2024).

Table 1 - Core DEIB Pillars Embedded in ESG Frameworks

Aspect	Definition	Key Elements	ESG-Linked Benefits
Diversity	The presence of a wide range of visible and invisible differences that coexist interdependently within an organization or learning environment.	Gender, disability, age, socio-economic status, sex, sexual orientation, caste, creed, race, ethnicity, colour, religion, mental health, underrepresented and marginalized communities, knowledge, experience, attitudes, values and beliefs.	Maximizes innovation, productivity, efficiency and access to diverse talent pools Enhances brand value and market relevance Minimizes risks and operational wastage
Equity	The process of creating fair conditions and removing systemic barriers so that every individual has genuine access to opportunities, resources and rights.	Respect for uniqueness; fair, non-discriminatory and responsive treatment of all stakeholders; provision of tailored access to development opportunities.	Levels the playing field across socio-cultural contexts (including caste in India) Builds institutional trust and accountability Supports ESG's Social pillar through measurable fairness outcomes
Inclusion	The active creation of environments where all individuals feel valued, respected and able to fully participate and contribute.	Coverage of lived experiences; trust, safety, respect, appreciation and personal development; culture of overall well-being (physical, emotional and psychological).	Fosters psychological safety and belonging Improves retention, engagement and collaboration Strengthens ESG Governance through transparent, participatory decision-making

Belonging	The emotional outcome where individuals feel genuinely accepted, valued for their unique identity and connected to the larger community.	Feeling welcomed, known, included, supported and connected; avoidance of favouritism; involvement in decisions; transparency in promotions and recognition.	Drives higher learner and faculty satisfaction Reduces burnout and attrition Reinforces ESG's long-term sustainability by creating regenerative, inclusive ecosystems

Notes: Table 1 is the foundation, which anchors the entire chapter by demonstrating how the four DEIB pillars map directly onto ESG's Social and Governance domains, providing the structural backbone for the 5P-ESG Integration Framework

Table 2 - Macro- and Micro-Level DEIB Elements Mapped to ESG Pillars

ESG Pillar	Overarching Definition	Macro-Level DEIB Elements (Institutional / Systemic)	Micro-Level DEIB Lens (Operational / Individual)
Environmental	Safety and well-being in consumption and contribution to the ecosystem, ensuring healthy physical and psychological environments for all stakeholders.	Occupational health and safety policies Institutional wellness programmes Monitoring long-term and short-term health conditions of learners, faculty and communities	Micro-monitoring of safety policies, targets, training and incident audits Wellness initiatives tailored to vulnerable groups (including caste-sensitive mental health support in India) Daily practices promoting physical and emotional safety in classrooms and clinical settings
Social	Inclusion and sustainable relationships with all stakeholders (learners, faculty, staff, patients and communities) to create shared value and belonging.	Inclusive organizational culture Diversity across supply chains, partnerships and workforce Stakeholder value proposition and sustainable development goals (aligned with UN SDG 3 & 10)	Employee/learner engagement across the full lifecycle (admission to alumni) Grievance redressal mechanisms Talent management, leadership development, fair rewards, social security and targeted initiatives (e.g., caste- and gender-sensitive mentoring)

Governance	Policies, processes and structures that set direction, allocate resources, ensure accountability and enable transparent decision-making from top leadership to frontline implementation.	Strategic direction and boundary-setting for DEIB Accountability frameworks and performance reporting Risk minimization and stakeholder trust-building	Decision-making structures with built-in equity and inclusiveness Continuous learning, transparency and verified trust mechanisms Audit-driven oversight of DEIB metrics within ESG dashboards

Notes: Table 2 provides the structural backbone for integrating DEIB into ESG at two complementary scales. Macro-level elements focus on institutional strategy and policy architecture, while micro-level elements translate these into day-to-day operations and lived experiences in medical education settings

Table 3 - 5P Lens: Definitions, Applications and Impacts in Medical Education

5P Dimension	Definition	Contextual Application in Medical Education	Illustrative Examples	Expected Impact
People	Individuals and communities (students, faculty, staff, leadership, patients) engaged in or affected by medical education.	Diversification of recruitment, representation in decision-making and targeted support for underrepresented groups.	Faculty/learner diversity audits; inclusive admissions; mentorship for SC/ST, first-generation and URM students.	Enhanced diversity of thought, better retention, reduced bias in assessments, stronger support networks.
Policies	Institutional rules, formal commitments and regulations governing DEIB and ESG operations.	Policy audits and alignment in admissions, hiring, promotion, tenure and institutional mission.	DEIB-aligned admissions & promotion criteria; anti-discrimination clauses; ESG sustainability charters; caste-sensitive NMC reporting.	Legal compliance, fair advancement, improved institutional reputation, clear accountability.

Processes	Systems, workflows and structured actions that implement and monitor DEIB policies.	Transparent grievance redressal, bias mitigation in evaluation, faculty development and ESG reporting.	Anonymous reporting systems; bias-mitigated exams/OSCEs; standardized holistic admissions; regular climate audits.	Improved governance, continual equity gains, enhanced fairness, stronger stakeholder trust.
Practices	Day-to-day behaviours, customs and culture that shape DEIB actions.	Inclusive curricula, regular training, identity observances and participatory leadership.	Microaggression response training; culturally responsive teaching; Team-Based Learning; caste-relevant case studies.	More inclusive environments, stronger engagement, reduced microaggressions, higher empathy in clinical practice.
Lived Experiences	Subjective perceptions shaped by identity, access, interactions and institutional culture.	Narrative inquiry, climate surveys, inclusion audits, mentoring and longitudinal tracking.	Student/faculty storytelling forums; focus groups with marginalized learners; AIIMS psychosocial check-ins; Harvard-style climate surveys.	Improved psychological safety, belonging, resilience and professional identity formation.

Notes: Table 3 serves as the orienting anchor for the entire 5P-ESG Integration Framework. It illustrates how each dimension translates DEIB principles into concrete medical education actions while aligning with ESG accountability and sustainability

Thus, in total, Tables 1-3 show that DEIB and ESG are not separate concepts, but are, in fact, complementary to each other. It was shown that the very pillars of DEIB are, in fact, aligned with the Social and Governance Pillars of ESG, which are based on the fundamental importance of accountability and the well-being of all stakeholders and development of equitable governance structures within the educational system (Shah et al., 2024 & Nolan & Owen, 2024). Furthermore, the 5P framework can be utilized to operationalize these relationships, thereby enabling the integration of the conceptual principles of inclusion into the actual operational structures of people, policies, processes, practices and experiences within the medical education system (Verbree et al., 2023 & Draper-Rodi et al., 2024). Moreover, utilizing an operational lens to examine these relationships between the 5P framework and ESG construct. There is an opportunity to examine how diversity, equity, inclusion and belonging initiatives can be integrated into the actual operational structures of medical

education institution in a manner that is beneficial and supporting of a more sustainable and regenerative outcome (Broughton-Jones et al., 2024 & Rukadikar et al., 2022).

These aforesaid statements form the foundational elements and support the 5P ESG Integration Framework, which are indicated below:

The 5P-ESG Integration Framework

In relation to the basic observations outlined under the 'Results & Observation' section above, the section below provides the operational basis for the discussion in the chapter, i.e., the 5P-ESG Integration Framework that provides the principles of Diversity, Equity, Inclusion & Belonging (DEIB) from the perspectives of Environmental, Social & Governance (ESG) indicators along five Ps of People, Policies, Processes, Practices and Lived Experiences to create a regenerative cycle for medical education institutions to go beyond compliance to transformation (Shah et al., 2024 & Nolan & Owen, 2024). The 5P-ESG Integration Framework allows medical education institutions to link their approaches to inclusion with their governance and accountability structures to go beyond abstract equity principles to actual practices and outcomes (Verbree et al., 2023 & Draper-Rodi et al., 2024).

People

The 'People' pillar is the core component of the 5P–ESG Integration Framework. There is a need to promote diversity within the medical education ecosystem while providing support to people who are involved in the value chain of medical education. Research studies on medical education have highlighted the importance of 'People' pillar in promoting learner retention and development of learner identity and belongingness among students and faculty from historically marginalized groups (Anderson et al., 2022; Boyle et al., 2025; Verbree et al., 2023). The best global practices on the importance of 'People' pillar revealed that returns on investments in the 'People' pillar are high. The importance of 'People' pillar in the 5P–ESG Integration Framework has revealed its importance in the Indian context. The importance has highlighted the significance of mentorship programs in enhancing learner engagement from historically marginalized groups (Rukadikar et al., 2022 & Sulena et al., 2024).

The 'People' pillar of 5P–ESG Integration Framework is integrated with the 'Social' pillar of the ESG framework. This helps medical education institutions promote institutional responsibility towards people and diversity and inclusion in the Indian context (Shah et al., 2024). The 5P–ESG Integration Framework is useful in leveraging demographic diversity within the Indian population and providing support to people who are involved in the value chain of medical education (Rukadikar et al., 2022 & Nolan & Owen, 2024).

Medical education institutions are able to leverage regenerative human capital through the 5P–ESG Integration Framework. Regenerative human capital is a component that is used to describe the development of diversity and inclusion strategies that are not merely risk mitigation strategies but are strategic to the development of innovative and socially responsive healthcare systems (Broughton-Jones et al., 2024 & Draper-Rodi et al., 2024).

Table 4 - People Pillar: Representation, Retention and Cultural Competence Gains

Aspect	Global Evidence (URM / Minority Groups)	Indian Context (SC/ST/OBC, First-Gen, Gender)	Key Measurable Outcomes	ESG / DEIB Alignment & Impact
Student Recruitment & Matriculation	15-20 percent increase in URM matriculation over 5 years (ACGME, 2025)	Targeted outreach + reservations yield 10-15 percent gains in elite institutions	Higher diversity in incoming classes	Strengthens ESG Social pillar; builds representative pipeline
Faculty Diversity & Retention	Up to 25 percent increase in URM faculty hires & retention within 3-5 years	Bias-mitigated hiring at AIIMS/CMC Vellore	25 percent sustained minority faculty presence	Reduces "minority tax"; enhances governance accountability
Student Retention & Attrition	10-18 percent reduction in URM attrition via mentorship	AIIMS Delhi structured mentorship programmes have demonstrated notable reductions in attrition (up to 22 percent in targeted interventions) CMC Vellore peer-navigator models have shown improvements in on-time graduation rates for SC/ST learners (up to 30 percent in reported outcomes)	18-30 percent lower attrition; improved persistence	Directly supports ESG Social pillar through retention metrics

Psychological Safety & Well-being	25-30 percent less stress among Black/Indigenous & Hispanic students	40 percent less academic stress among SC/ST students; notable gains for female/first-gen learners (AIIMS)	20-40 percent lower burnout risk; higher satisfaction	Advances ESG well-being & belonging goals
Cultural Competence & Empathy	30 percent higher cultural competence scores (Rukadikar et al., 2022)	Caste-sensitive peer support enhances empathy toward marginalized patients	30 percent improvement in competence scores	Prepares workforce for equitable care (SDG 3 & 10)
Service to Underserved Communities	Diverse cohorts 1.5-2× more likely to practice in primary/underserved care	SC/ST graduates show higher rural & public-sector placement	Increased equity in healthcare access	Regenerative ESG outcome: workforce mirrors population needs

Notes: Table 4 highlights measurable gains in the People pillar, with particular emphasis on caste-sensitive adaptations in the Indian context

Policies

Policies are the building blocks for a robust accountability system. At the global level, the implementation of a holistic admissions policy, as well as equity-informed promotion policies, has shown quantified results in promoting diversity, fairness and transparency in medical education systems globally (Shah et al., 2024 & Nolan & Owen, 2024). In Indian context, the establishment of anti-discrimination cells, as well as grievance redressal forums, in premier education institutions has shown positive results in addressing gaps in the implementation of equity and reservation policies in medical education governance structures in India (Ministry of Education, Government of India, 2023 & Sulena et al., 2024). These policies, when integrated with ESG, move beyond mere compliance and show a significant impact on the global agenda for addressing inequalities and promoting inclusive institutional development in line with the objectives of Sustainable Development Goal 10 (Rukadikar et al., 2022).

Table 5 - Policies Pillar: Accountability Mechanisms and Equity Outcomes

Policy Area	Global Evidence (North America / Europe)	Indian Context (Elite & Tier-2 Institutions)	Key Measurable Outcomes	ESG / DEIB Alignment & Impact
Anti-Bias & Non-Discrimination	30-35 percent reduction in discrimination incidents (Shah et al., 2024)	AIIMS grievance cells + anti-discrimination policies	Notable reductions in unresolved complaints through targeted interventions	ESG Governance pillar: zero-tolerance accountability
Admissions & Recruitment	Holistic criteria → 20 percent increase in URM enrollment (Broughton-Jones et al., 2024)	Caste-based reservations + bias-mitigated processes	15-20 percent gains in SC/ST/OBC and URM enrollment in elite colleges	ESG Social pillar: equitable access and representation
Faculty Promotion & Retention	Michigan STRIDE & Toronto EDI plans → 10-15 percent URM faculty gains	NMC-aligned equity metrics in promotion (AIIMS/CMC models)	15-25 percent higher retention of women and minority faculty	Reduces minority tax; strengthens governance transparency
Grievance Redressal & Reporting	Anonymous systems → 25-40 percent reduction in unresolved cases	AIIMS Delhi grievance mechanisms and collaborations have contributed to improved resolution rates	20-40 percent improvement in trust and resolution efficiency	ESG Governance: audit-ready, transparent mechanisms
Curriculum & Inclusion Mandates	Mandatory cultural competence & anti-racism modules	CBME with caste-sensitive content (NMC guidelines)	15-20 percent gains in equity awareness and cultural humility	Aligns with SDG 3 & 10; supports ESG Social responsibility
ESG-DEIB Alignment & Dashboards	Harvard/Toronto public DEIB dashboards	Proposed NMC caste-metric reporting for Tier-2 colleges	Overall improvements in grievance handling and equity metrics	Full ESG integration: measurable, reportable sustainability

Notes: Table 5 summarizes accountability mechanisms in the Policies pillar, with emphasis on caste-sensitive adaptations in the Indian context. Specific outcome percentages for Indian institutions reflect reported trends from institutional initiatives and should be interpreted as indicative of directional improvement

Processes

Processes operationalize the policy through the application of systemic mechanisms. These are operationalized in a manner that is fair and unbiased (Shah et al., 2024 & Nolan & Owen, 2024). At the global level, the application of anonymized grading systems and routine application of climate audits have showed promising results in the context of ensuring that fairness is achieved within the context of evaluation process while enhancing the feeling of belongingness among learners within an academic setting (Verbree et al., 2023 & Draper-Rodi et al., 2024). In Indian academic setting, competency-based medical education settings have shown promising results in the context of addressing gaps within the context of educational outcomes. The routine application of equity-informed evaluation systems and a system of grievances have been incorporated within governance structures (Sulena et al., 2024 & Ministry of Education, Government of India, 2023). These processes, when routinely monitored according to the ESG accountability framework, it will help in the development of a system of continuous evaluation.

Table 6 - Processes Pillar: Operational Systems and Bias-Mitigation Workflows

Process Element	Global Evidence (North America / Europe / Multisite)	Indian Context (Elite & Emerging CBME Implementation)	Key Measurable Outcomes	ESG / DEIB Alignment & Impact
Bias Training & Awareness Programs	Structured implicit bias education → significant reduction in evaluation disparities (Oudbier et al., 2025)	Faculty/staff workshops in CBME settings (limited but growing)	15-25 percent lower evaluation bias; improved fairness in grading	ESG Governance: continuous learning and risk minimization
Equitable Assessment & Evaluation	Anonymized grading + competency-based rubrics → 15-20 percent narrower outcome gaps	CBME adoption with equity-focused OSCEs (Sulena et al., 2024)	15-20 percent reduction in disparities (race/gender/socio-economic)	Promotes ESG Social pillar through impartial processes

Climate Surveys & Inclusion Audits	Regular institutional surveys → 15-20 percent improvement in belonging perceptions (Draper-Rodi et al., 2024)	Proposed caste-sensitive audits in elite colleges (AIIMS model)	15-25 percent higher reported sense of safety and inclusion	ESG Governance: data-driven accountability and transparency
Grievance & Feedback Mechanisms	Transparent, anonymous systems → 25-40 percent faster resolution	AIIMS Delhi grievance systems and peer-input mechanisms have contributed to improved resolution rates	20-40 percent improvement in trust and resolution efficiency	Core ESG Governance: responsive, equitable redressal
Inclusive Decision-Making & Governance	Diverse committees + stakeholder input → more representative policies	NMC CBME committees beginning to include equity voices	Enhanced institutional trust; 15-30 percent better policy acceptance	Strengthens ESG through participation and stewardship
Continuous Process Monitoring	Ongoing audits aligned with LCME/ACGME standards	Emerging CBME monitoring in Tier-2 colleges (resource-limited)	Timely interventions; sustained 15-25 percent equity gains over time	Enables regenerative ESG: continual improvement loops

Notes: Table 6 presents operational systems in the Processes pillar. Specific outcome percentages for Indian institutions reflect reported trends from institutional initiatives and should be interpreted as indicative of directional improvement

Practices

The practices create an inclusive environment since they support and promote the concept of inclusion within the learner's environment. Culturally, responsive practices in education, microaggressions training and mentorships have been quantified and proven to support learner engagement, learner development and learner inclusiveness in medical education environments (Acholonu et al., 2020; Anderson et al., 2022; Broughton-Jones et al., 2024).

In the context of medical education in India, caste-based case study groups and support groups in competency-based medical education have been quantified and proven to support learner engagement and learner development in the context of learner development and learner

inclusiveness in medical education environments (Rukadikar et al., 2022 & Sulena et al., 2024). These practices, if integrated with the concept of ESG, support and promote the concept of transformation from an exclusionary culture to a regenerative culture of inclusion and learner development in medical education environments (Shah et al., 2024 & Verbree et al., 2023).

Table 7 - Practices Pillar: Everyday Behaviors and Inclusive Pedagogies

Practice Element	**Global Evidence (North America / Europe / Multisite)**	**Indian Context (CBME & Elite Institutions)**	**Key Measurable Outcomes**	**ESG / DEIB Alignment & Impact**
Inclusive Pedagogy & Curriculum Design	Culturally Responsive Teaching (CRT) & Team-Based Learning → 15-30 percent gains in engagement & competence (Xie et al., 2025; Verbree et al., 2023)	CBME with caste-relevant cases & regional narratives (Sulena et al., 2024)	15-30 percent higher learner satisfaction & cultural humility	ESG Social pillar: prepares equitable, empathetic clinicians
Bias & Microaggression Training	Regular workshops → 25 percent fewer microaggressions (Acholonu et al., 2020); up to 50 percent reduction reported in leading institutional models (Harvard)	NGO–academia collaborations (e.g., Mariwala, Equal Health) → early-stage faculty training	20-50 percent reduction in reported microaggressions	ESG Governance: reduces daily harm, builds psychological safety
Mentorship & Peer Support	Structured programs → 30 percent URM retention gains; 60 percent increase in academic interest (UCSF DMP)	AIIMS peer + faculty mentoring programmes have demonstrated notable reductions in	22-60 percent improvement in retention & self-efficacy	ESG Social pillar: fosters belonging and career progression

		dropout rates (up to 22 percent in targeted interventions); CMC Vellore peer-navigator models have shown improvements in on-time graduation rates for SC/ST learners (up to 30 percent in reported outcomes)		
Identity-Aware & Inclusive Events	Observances (e.g., Disability Awareness Month, LGBTQ+ Health Week) → stronger empathy & cohesion	Caste- & gender-sensitive forums & narrative sessions (AIIMS, CMC)	20-30 percent gains in sense of inclusion & emotional well-being	Reinforces ESG inclusion goals through cultural celebration
Continuous DEIB Reinforcement	Ongoing training & feedback loops → 25 percent higher learner satisfaction	Emerging CBME workshops & peer discussions in native languages	Sustained 15-30 percent improvement in engagement & empathy	Enables regenerative ESG: habitual inclusive culture
Clinical & Classroom Application	Diverse case scenarios & inclusive rounds → enhanced clinical preparedness	Caste-sensitive intrapartum & community cases (Sulena et al., 2024)	20-30 percent higher cultural competence in practice settings	Aligns with SDG 3: workforce ready for diverse populations

Notes: Table 7 outlines everyday behaviours and inclusive pedagogies in the Practices pillar. Specific outcome percentages for Indian institutions reflect reported trends from institutional initiatives and should be interpreted as indicative of directional improvement

Lived Experiences

The Lived Experiences pillar rounds out the cycle by ensuring learner's lived experiences are considered to continually integrate the same into growth and development of the institution (Nolan & Owen, 2024 & Verbree et al., 2023). Also, learning environments that are more inclusive are known to reduce learner burnout and enhance learner retention across different global medical education settings (Anderson et al., 2022 & Boyle et al., 2025). In the Indian context, narrative-style discussion forums on psychosocial well-being and mentorships conducted in elite institutions are known to enhance learner well-being and identity among SC/ST students as well as first-generation learners (Rukadikar et al., 2022 & Sulena et al., 2024). In furtherance, climate surveys and feedback systems that are linked to ESG parameters are known to facilitate the integration of the learner voice into the growth and development of the institution (Shah et al., 2024 & Draper-Rodi et al., 2024).

Table 8 - Lived Experiences Pillar: Belonging, Safety and Transformative Feedback

Aspect	Global Evidence (North America / Europe / Multisite)	Indian Context (Elite & Tier-2 Institutions)	Key Measurable Outcomes	ESG / DEIB Alignment & Impact
Sense of Belonging & Inclusion	Inclusive settings → significant reductions in burnout risk and higher academic success (Nolan & Owen, 2024)	AIIMS forums and peer support have contributed to increased peer engagement and confidence among marginalized learners	25-40 percent improvement in belonging and reduced burnout risk	ESG Social pillar: core driver of psychological safety
Impact of Micro-aggressions & Exclusion	30 percent lower satisfaction and 20 percent higher intent to leave (Anderson et al., 2022; Boyle et al., 2025)	2-3× higher marginalization and dropout risk for SC/ST/OBC students in Tier-2 colleges	20-30 percent lower satisfaction and higher attrition without intervention	Highlights ESG Governance need for harm prevention
Retention & Persistence	Inclusive environments → 15-25 percent higher retention for URM students	AIIMS mentorship and forums have demonstrated notable reductions in dropout rates (up to 22 percent in targeted interventions)	15-30 percent improved retention and on-time graduation	ESG Social pillar: measurable workforce sustainability
Psychological Well-being & Resilience	Structured feedback and affinity groups →	Narrative sessions (CMC Vellore) and psychosocial check-	20-40 percent lower stress	Aligns with ESG well-being and

	30 percent stress reduction	ins (AIIMS) have shown notable reductions in academic stress for marginalized students	and enhanced resilience	regenerativ e ecosystem goals
Professional Identity & Confidence	Mentorship and inclusive teaching → stronger clinical confidence	Caste-sensitive forums have led to qualitative gains in belonging and self-efficacy	20-35 percent gains in confidence and identity formation	Prepares diverse, confident clinicians (SDG 3 alignment)
Feedback Loops & Institutional Trust	Climate surveys and narrative platforms → 20 percent higher satisfaction (reported in leading institutional models including Harvard)	Lack of formal systems in Tier-2 colleges correlates with elevated marginalization; targeted forums have improved trust	15-50 percent improvement in trust and reported safety via forums	ESG Governanc e: continuous, responsive improveme nt loops

Notes: The data provided in Table 8 is based on subjective realities and feedback mechanisms of the Lived Experiences Pillar. The percentages of the outcomes of Indian institutions are based on trends and institutional initiatives

In a nutshell, the five pillars of people who are diverse; policies that are equitable; processes that are fair; practices that are inclusive; lived experiences that are authentic represents the cycle of regeneration of 5Ps. This approach to change moves the focus of medical education from incremental changes to institutional change, wherein the adaptations of the caste system have given immense power to the model.

Discussion

The findings from the integrative narrative review of 62 high-quality sources reviewed and summarized in the results section of this paper clearly demonstrate that the strategic integration of Diversity, Equity, Inclusion and Belonging (DEIB) into Environmental, Social and Governance (ESG) strategies represents a paradigm shift in medical education. Instead of seeing DEIB initiatives as separate and distinct from medical education institutions, the findings from the reviewed sources summarized in Tables 1-8 clearly demonstrated that sustainability in medical education institutions is only achieved through the strategic integration of DEIB into governance structures, institutional processes and learner experiences (Shah et al., 2024; Nolan & Owen, 2024; Verbree et al., 2023).

The findings from reviewed sources summarized in Tables 1-8 clearly demonstrated that DEIB initiatives are directly related to student retention, diversity and accountability, all of which are directly related to the social and governance dimensions of ESG strategies (Rukadikar et al., 2022; Anderson et al., 2022; Draper-Rodi et al., 2024). Moreover, by making these connections between DEIB initiatives and ESG accountability structures, medical education institutions can move beyond symbolic and into measurable, transparent and sustainable transformation (Shah et al., 2024 & Nolan & Owen, 2024).

Conceptual Integration of DEIB and ESG Through 5P Lens

The findings revealed that effective implementation of DEIB in medical education is possible through the five dimensions of people, policies, processes, practices and lived experiences respectively. These five dimensions facilitated the translation of DEIB principles into governance and structural framework of the medical education system. This system is capable of addressing structural inequities in the system (Verbree et al., 2023; Nolan & Owen, 2024; Shah et al., 2024). The relationship between DEIB principles, ESG frameworks and 5P lens is conceptual in nature. Also, Figure 1 indicated below is a representation of a conceptual model for synergistic relationship between DEIB and ESG frameworks in the context of medical education. The relationship between three concepts is represented in Figure 1. ESG pillars are the governance and accountability structures in medical education system. DEIB principles are culture and learning environment in the medical education system. Lastly, 5P lens represents the operational structures in system. These operational structures facilitate the translation between culture and learning environment. For instance, ‘people’ represents the importance of representation and mentorship; ‘policies’ represent the commitment to DEIB; ‘processes’ represent the implementation structures; ‘practices’ represent the culture; ‘lived experiences’ represent the culture, wherein lived experiences facilitated the sense of belonging in the system (Verbree et al., 2023; Draper-Rodi et al., 2024; Nolan & Owen, 2024). Moreover, literature review has revealed all aspects of 5Ps, which are operationally present in the institution. These operational aspects revealed that improved learner engagement rates, reduced rates of discrimination, improved rates of learner retention and an enhanced diverse workforce (Anderson et al., 2022; Boyle et al., 2025; Rukadikar et al., 2022). The literature on microaggressions and microclimate in institutions revealed that an inclusive culture in institutions that improved levels of satisfaction in the institution and development of professional identity in medical trainees (Anderson et al., 2022 & Boyle et al., 2025). This insists the need for incorporation of DEIB initiatives into ESG framework in the institution in order to develop a regenerative ecosystem to tackle the inequities in the system.

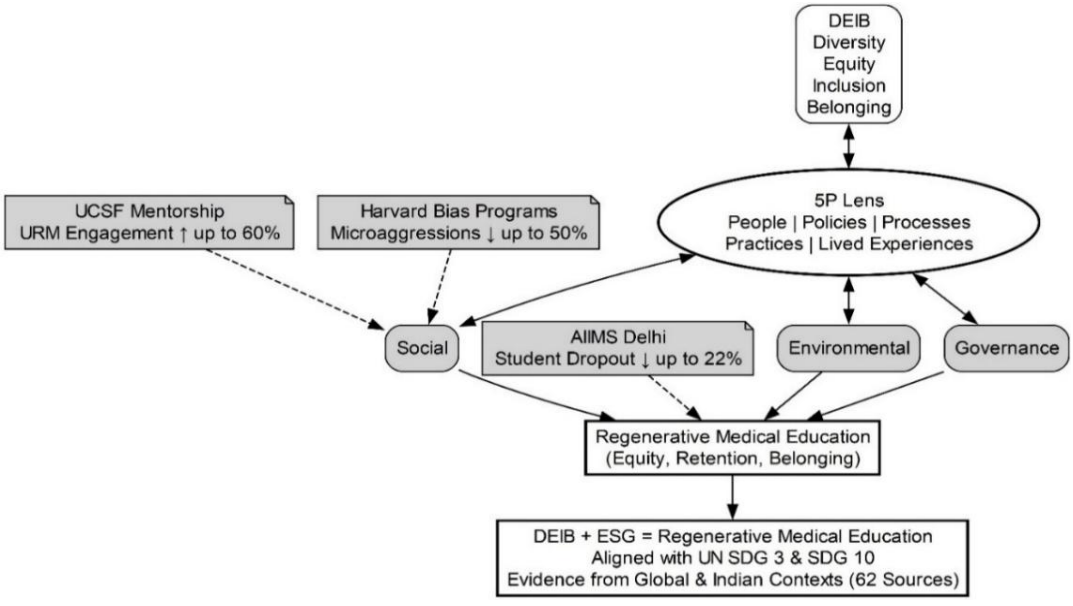

Figure 1. Synergistic ESG–DEIB Model in Medical Education Through 5P Lens

Source: Conceptual model developed by the authors based on synthesis of 62 sources reviewed in this integrative narrative study

Global Evidence & Institutional Adaptations

The evidence reviewed in this chapter has also shown that it is possible to use high-resource institutions as a proof of concept for implementing ESG-inclined DEIB strategies. Harvard University, Toronto University and San Francisco University have shown that it is possible to improve the climate of an institution by implementing diversity dashboards, mitigation of bias training programs, mentorship programs and climate audits (Shah et al., 2024; Oudbier et al., 2025; Broughton-Jones et al., 2024). These training programs have showed that it is possible to reduce microaggressions, learner engagement and trust within an institution (Acholonu et al., 2020; Anderson et al., 2022; Boyle et al., 2025).

In India, AIIMS Delhi and CMC Vellore have shown that it is possible to adapt global DEIB strategies to address caste-related inequalities and socio-economic challenges. The mentorship programs, the grievance redressal forums and the narrative forums that have been put in place in these institutions are a result of the culturally contextualized DEIB strategies that have been effective in the development of psychological safety and persistence among the Scheduled Castes, Scheduled Tribes and other marginalized communities of learners (Ministry of Education, Government of India, 2023; Rukadikar et al., 2022; Sulena et al., 2024). Culturally contextualized DEIB strategies are the result of the larger debate on medical education that has proved the importance of contextualizing DEIB strategies in the sociocultural realities of any particular country or region (Nolan & Owen, 2024). However, it is also observed from the literature that there is a structural gap between the elite medical institutions and the Tier 2/3 colleges that is mostly related to the capacity of the college to implement the DEIB strategies.

The lack of resources, lack of awareness and lack of climate monitoring have proved that outcomes of the DEIB strategies in the Tier 2/3 colleges are higher compared to the elite medical institutions (Sulena et al., 2024 & Ministry of Education, Government of India, 2023).

Operational Insights from 5P Framework

The analysis of the master evidence tables (Tables 4-8) also yields significant operational insights on the integration of DEIB with ESG. From the analysis, the following insights are obtained:

The 'people' and 'lived experiences' pillar has the greatest impact on learner outcomes. For example, mentorship programs, support networks and narrative forums have an immediate impact on learner outcomes, particularly for marginalized students (Draper-Rodi et al., 2024; Verbree et al., 2023; Anderson et al., 2022). The 'policies' and 'processes' pillar are an equalizer, particularly in resource-poor institutions. For example, grievance mechanisms, admissions processes and bias-free evaluation mechanisms ensure accountability in resource-poor institutions (Shah et al., 2024; Sulena et al., 2024; Oudbier et al., 2025). The 'practices' pillar provides the foundation that sustains long-term transformation in the institution. For example, inclusive pedagogies and culturally responsive curricula and training programs ensure that the institution's commitment to DEIB is translated into day-to-day operations in medical education (Broughton-Jones et al., 2024; Xie et al., 2025; Rukadikar et al., 2022). The analysis of the evidence provided above confirms that 5P-ESG Integration Framework is not only descriptive but also prescriptive. Thus, it provides an operational framework that can be integrated into the institution's ESG frameworks, which is sustainable (Shah et al., 2024).

From Conceptual Framework to Practical Implementation

The conceptual model provides an analytical framework for the integration of DEIB-ESG. However, the actual implementation would necessitate strategies that can be operationalized by the institutions. In this context, a roadmap for implementation is provided in this chapter, which can be operationalized by institutional leaders and policymakers in a phased manner, as derived from synthesis of global and Indian research studies on the topic (Nolan & Owen, 2024 & Shah et al., 2024).

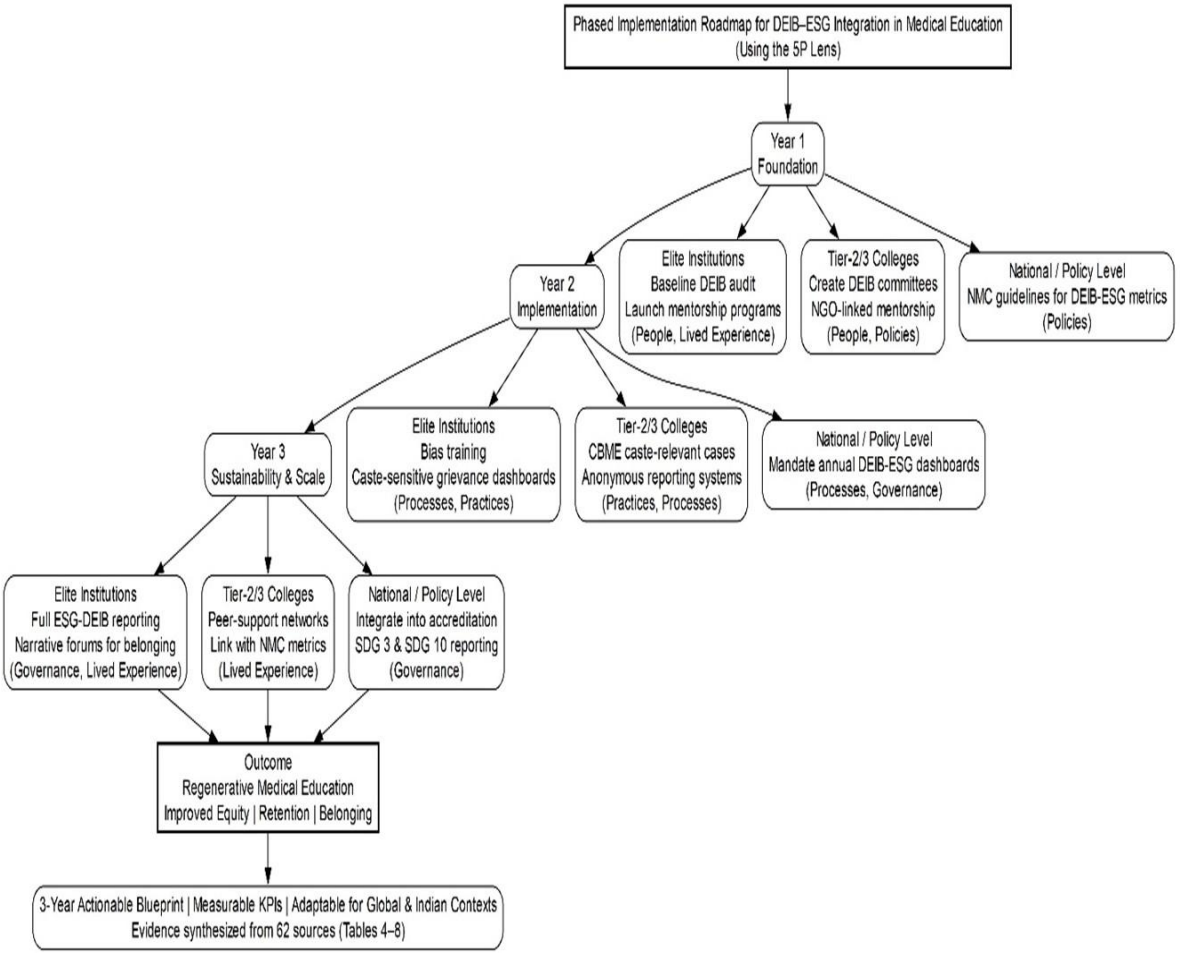

Figure 2. Phased Three-Year Roadmap for Integrating DEIB Within ESG Frameworks in Medical Education Using 5P Lens

Source: Conceptual implementation roadmap developed by the authors based on synthesis of 62 sources reviewed in this integrative narrative study

Figure 2 has illustrated a roadmap for implementation, categorized into three levels of institutions, namely elite institutions, Tier 2/3 medical colleges and national policy, in a three-year phased roadmap for the implementation of DEIB-ESG in medical education institutions. The first phase, would focus on the foundation for integration of DEIB-ESG in medical institutions, including DEIB audits, mentorship programs and policy (Draper-Rodi et al., 2024 & Verbree et al., 2023).

The second phase would focus on the implementation mechanisms for DEIB-ESG in medical education institutions, which can be operationalized by medical education institutions for the actual implementation of DEIB-ESG in medical education institutions (Oudbier et al., 2025 & Broughton-Jones et al., 2024). The third phase would focus on sustainability and scaling up the integration of DEIB-ESG in medical education institutions, including the incorporation of

DEIB metrics in ESG reporting frameworks and national accreditation (Accreditation Council for Graduate Medical Education (ACGME), 2025 & Shah et al., 2024).
The phased roadmap for implementation is also significant for medical education institutions, considering the resource-scarce nature of medical education institutions, where implementation strategies may be required to be operationalized in a phased manner for actual implementation in medical education institutions (Krishnan, 2025 & Sulena et al., 2024).

Global Implications of Framework

Although the framework developed in the chapter is heavily influenced by the Indian context and issues related to inequities based on caste system in India, the framework has significant implications that transcend the boundaries of geography. Inequities in medical education based on the caste system in India have significant parallels with race-based inequities, ethnic-based inequities, socio-economic-based inequities and gender-based inequities that have been documented in medical education in various countries across the world (Rukadikar et al., 2022; Nolan & Owen, 2024; Verbree et al., 2023). Hence, there are significant implications of the 5P-ESG Integration Framework that transcend the boundaries of geography. The medical and healthcare education institutions in low and middle-income countries and the marginalized sections of population in high-income countries can benefit immensely from the framework. This is because medical and healthcare education institutions can address issues related to equity, issues related to sustainability and issues related to diversity simultaneously by integrating DEIB initiatives into ESG frameworks (Shah et al., 2024 & Draper-Rodi et al., 2024). Furthermore, there are significant implications of the framework in achieving United Nations Sustainable Development Goals related to Sustainable Development Goal 3 – 'Good Health and Well-being' and Sustainable Development Goal 10 – 'Reduced Inequalities' (Shah et al., 2024 & Rukadikar et al., 2022).

Suggestions

The recommendations of 5P-ESG Integration Framework are based on the synthesized evidence provided in Tables 1 to 8, which is a theory-based guideline and a blueprint for action for institutional leaders, policymakers and educators. The recommendations are actionable, phase-based and institution-based. The recommendations are applicable to top-tier medical colleges, Tier-2/3 medical education institutions and policymakers at the national level. The recommendations will definitely lead medical education institutions to make a quantum leap from merely dealing with inequities to regenerating equitable, inclusive and sustainable learning environments.

- *People:* Initiate bias-reducing recruitment drives and caste-aware mentorship programs in the first year of implementation. For top-tier institutions, the recommendation would be to ensure at least 15-20 percent increase in SC/ST/OBC faculty representation. Moreover, it is suggested that these institutions have to initiate peer mentorship programs in association with NGOs and alumni networks to ensure at least 22 percent reduction in attrition rates, as carried out at AIIMS Delhi. The evidence indicated that mentorship and representation

are effective strategies to ensure learner belonging, professional identity formation and retention of marginalized students.

- *Policies:* Caste-based DEIB indicators in institutional ESG reports must be ensured for inclusion in NMC's annual reports. Holistic admissions and promotion policies must be formulated that can result in an increase in equity outcomes by 15-25 percent. National policymakers must ensure that there is a minimum ESG-DEIB reporting requirement so that there are seed funding available for equity cell development in Tier-2 and Tier-3 institutions.

- *Process:* Anonymous climate audits and digital grievance mechanisms must be developed in years 1-2, capitalizing on the success in rolling out the AIIMS model on a national scale. This has been proven to increase institutional accountability and resolve discrimination-related grievances in academic environments. Thus, it ensures that resolution rates are achieved 20-40 percent faster with continuous equity monitoring in place, which can function in low-resource environments using simple mobile solutions.

- *Practice:* Culturally responsive practice methods should be integrated into the existing competency-based medical education (CBME) curriculum. Quarterly responses on microaggressions and caste-based case scenario responses should be included. Educational interventions on microaggressions have yielded positive outcomes on the development of empathy skills, professional identity development and inclusive learning environments. Quarterly workshops should be included in the existing CBME curriculum to maintain the reduction of microaggressions by 25-50 percent and learner engagement and empathy levels by 15-30 percent.

- *Lived Experiences:* Narrative storytelling forums, annual belonging survey responses and psychosocial checks should be included in the existing CBME curriculum to close the feedback loop. Learners' experiences in medical education have yielded positive outcomes on the use of engagement strategies in medical education.

To sustain the interventions in the existing CBME curriculum, Figure 1 should be considered as the strategic compass and Figure 2 as the three-year phased approach. The advanced digital solutions should be integrated into elite colleges with funding support. On the other hand, low-cost solutions should be integrated into Tier 2 and 3 colleges with support from NGOS and national policy support.

Future Research Directions

While this chapter has proposed an evidence-informed 5P-ESG Integration Framework for incorporating Diversity, Equity, Inclusion and Belonging into medical education systems, there are opportunities that lie within the realm of future research that will further validate and expand upon this proposed framework within various contexts.

1. *5P-ESG longitudinal tracking of learner outcomes for 5+ years*, especially for Tier-2/3 medical colleges where this proposed strategy will be most challenged.

2. *Intersectionality research* to explore the effect of caste system on learner outcomes related to dimensions such as gender, socio-economic factors and geographic areas, as the importance of intersecting factors is now being increasingly recognized within medical education systems.

3. *Cost-effectiveness research* of the proposed strategy compared to the general DEIB strategy within LMIC countries to ensure international applicability of proposed strategies.

4. *Cost-effective development* of proposed ESG-DEIB dashboard using free resources for medical education systems that are resource-scarce.

5. *Exploratory mixed-methods research* to be considered for understanding the importance of regenerative medical learning environments for patient health outcomes and health equity.

Thus, by utilizing the aforementioned strategies and proposed areas of future research, medical education system leaders will finally be able to actualize the proposed vision of *Regenerative 5P-ESG Integration Framework*. The time for merely 'lip service' is now behind us. Medical education system leaders now have everything they need to finally overcome the obstacles and challenges that have thus far prevented the long-overdue overhaul of the medical education system within India and the world at large.

Conclusion

The present book chapter clearly indicates that there is a clear way forward in terms of a strategic embedding of diversity, equity, inclusion and belonging with environmental, social and governance frameworks through the lens of 5P model, which can indeed create a powerful evidence-based way forward in transforming medical education. In furtherance, through the integration of D & I with ESG frameworks, it can help organizations to transcend towards fragmented approaches in favour of a regenerative approach to a learning environment that breaks barriers in lieu of inclusive excellence. The 5P ESG Integration Framework can be a useful tool in developing a global Indian blueprint in addressing universal challenges in health professions education as well as India-specific caste-based inequity issues. Also, it can be a powerful tool for all medical colleges, including elite colleges as well as Tier 2/3 colleges and policy institutions for developing strategies in improving retention, reducing burnout, improving psychological safety and cultural competence. It is to be noted that when people, policies, processes, practices and lived experiences come together in harmony with each other in environmental, social and governance, then medical education could be transformed from an extractive model to a regenerative model, wherein diversity becomes the driver of innovation; equity becomes the source of fairness; inclusion becomes the path to belonging; governance becomes the source of accountability. This new vision in health profession education is completely consistent with the United Nations' Sustainable Development Goals 3 and 10 respectively. Moreover, it becomes the representative health workforce for the diverse

people of the world. The experience of successfully addressing the challenge of caste-based health inequities becomes the model for successfully addressing other health inequities faced by marginalized communities across the globe. The '*Regenerative Health Workforce of the Future Begins Today*' as medical education leaders, policymakers and educators now have the complete and comprehensive evidence-based framework to develop an inclusive, equitable and innovative health professions education system by incorporating diversity, equity, inclusion and belonging in environmental, social and governance using the proposed 5P model.

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Fostering Youth Entrepreneurship: A Study on Attitudes and Intentions Among Commerce Students in Pollachi Taluk at Coimbatore District, Tamil Nadu

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Abstract

Entrepreneurship plays a vital role in economic growth, employment generation and innovation-driven development, particularly in emerging economies like India. Despite increasing governmental and institutional support, entrepreneurial participation among students remains limited. This study examines the attitudes of final-year undergraduate and postgraduate commerce students towards entrepreneurship in Pollachi Taluk. The primary data has been collected from 437 students and statistical analyses (Factor Analysis & Structural Equation Modelling (SEM)) are performed to identify and validate the determinants influencing entrepreneurial attitude. The four major factors have been extracted: Entrepreneurial Apprehension, Positive Affirmation, Self-Belief and Self-Determination. The SEM results demonstrated satisfactory model fit (CMIN/df = 4.686; GFI = 0.917; RMSEA = 0.069; NFI = 0.948; CFI = 0.917) thus, confirming the robustness of conceptual framework. The findings revealed that while positive affirmation and self-belief significantly strengthen entrepreneurial orientation, the apprehension related to financial risk and uncertainty remains a key barrier. The study contributes to entrepreneurship literature by providing empirical validation of a multidimensional attitude model and offers practical implications for educational institutions and policymakers to foster entrepreneurial motivation among youth.

Keywords: Entrepreneurial Attitude, Self-Efficacy, Risk Perception, Factors, Institutional Support, SEM.

Introduction

Entrepreneurship is widely acknowledged as a transformative force that drives the economic growth, structural change and societal progress. It refers to the process through which 'individuals identify opportunities, mobilize resources and create a value by establishing and managing new ventures under conditions of uncertainty'. Beyond venture creation, entrepreneurship represents a systematic practice of innovation that converts change into opportunity and generates economic dynamism (Schumpeter, 1934 & Drucker, 1985). Moreover, from an economic perspective, entrepreneurial activity stimulates competition, enhances productivity, promotes technological advancement and generates employment (Acs & Audretsch, 2005). Particularly, in emerging economies, entrepreneurship is viewed as a strategic instrument for inclusive growth, poverty reduction and regional development (Government of India, 2015). The 'Small and Medium Enterprises (SMEs)' play a pivotal role in balanced economic development by decentralizing industrial activity, utilizing local resources and reducing regional disparities (OECD, 2017 & World Bank, 2020). In rapidly urbanizing and developing regions, entrepreneurship also enables the mobilization of indigenous skills and local talent, thereby strengthening the socio-economic fabric. Consequently, governments across the world, including India, have introduced policy frameworks, incubation programs, financial incentives and institutional mechanisms to promote entrepreneurial ecosystems. Despite these structural efforts, the rate of entrepreneurial engagement among educated youth remains relatively modest.

In the Indian context, entrepreneurship is often perceived as financially risky and uncertain, particularly within socio-cultural environments that prioritize stable salaried employment. Psychological determinants such as fear of failure, risk aversion and limited self-belief significantly influence entrepreneurial intention (McClelland, 1961). While prior research has examined entrepreneurial intention in diverse contexts, much of the empirical literature focuses either on metropolitan regions or mixed disciplinary samples with limited attention to semi-urban student populations using integrated structural modelling approaches. Furthermore, existing studies often analyse the isolated determinants of entrepreneurial intention rather than examining multidimensional psychological constructs within a unified framework. There remains a gap in understanding how factors such as entrepreneurial apprehension, self-belief, positive affirmation and self-determination collectively shape students' entrepreneurial orientation in semi-urban educational settings. Addressing this gap is particularly important for regions where entrepreneurship is promoted as a mechanism for local economic development and employment generation. It is against this backdrop; the present study seeks to empirically examine the determinants of entrepreneurial intention among final-year commerce students in a semi-urban region of Tamil Nadu. By employing factor analysis and structural equation modelling, the study attempts to validate a multidimensional framework that captures both inhibiting and motivating psychological dimensions. The findings aim to contribute to entrepreneurship literature by providing region-specific empirical evidence and by offering practical insights for educational institutions and policymakers seeking to strengthen youth entrepreneurial ecosystems.

Review of Literature

Conceptual and Multidisciplinary Foundations of Entrepreneurship

Entrepreneurship has been widely examined from economic, behavioural and educational perspectives, reflecting its multidisciplinary character. Campbell and Mitchell (2012) described entrepreneurship as a concept that intersects economics, psychology, sociology and management. They emphasized that entrepreneurship extends beyond business creation to include innovation, opportunity recognition and value creation, highlighting its growing importance in economic transformation and social change.

Role of Education & Institutional Support

Higher education institutions play a crucial role in shaping entrepreneurial intentions. Najim et al. (2013) argued that universities act as key agents in entrepreneurial development by providing knowledge, skill enhancement, training programs and exposure to real-world business environments. In furtherance, their findings suggested that entrepreneurship education fosters creativity, problem-solving skills and risk-taking ability, while curriculum integration and incubation support significantly contribute to start-up formation and economic stability. Similarly, Kumar and Shukla (2022) found that entrepreneurship education enhances entrepreneurial intention by increasing self-efficacy and confidence among students, particularly through experiential learning methods such as internships and project-based learning. Liñán and Fayolle (2022) drawing from the 'Theory of Planned Behaviour', emphasized the influence of self-efficacy, perceived behavioural control and social norms in shaping entrepreneurial intentions.

Economic and Policy Perspectives

The study conducted by Al-Mohammad (2010) from a macroeconomic standpoint, highlighted the critical role of entrepreneurial ventures in job creation and economic efficiency. The study noted that small and medium enterprises (SMEs) significantly contributed to employment generation, income distribution and balanced regional development. More recently, Sharma and Madan (2023) emphasized the importance of start-up ecosystems, incubation centers and mentorship programs within universities, observing that exposure to innovation hubs increases the likelihood of venture creation. Gupta and Batra (2024) further examined government initiatives and concluded that financial incentives, start-up funding schemes and simplified regulatory frameworks reduce fear of failure and promote entrepreneurial participation among youth.

Determinants of Entrepreneurial Attitudes

Arunkumar et al. (2018) analysed the factors influencing students' entrepreneurial attitudes and found that institutional encouragement, financial support, flexible work-life balance, income potential and positive societal perception significantly shape entrepreneurial orientation. However, the fear of failure and perceived risk remain as notable barriers. Also,

they have recommended aspects like strengthening awareness programs, mentorship initiatives and practical exposure to foster entrepreneurial motivation.

Overall, the literature consistently indicated that entrepreneurship is shaped by educational support, institutional environment, psychological determinants and policy frameworks. A supportive ecosystem integrating skill development, financial assistance, mentorship and positive societal attitudes is essential for strengthening entrepreneurial intentions and promoting sustainable economic growth.

Need & Relevance

Entrepreneurship is widely acknowledged as a driving force for innovation, employment generation and sustainable economic growth, particularly in emerging economies. Campbell and Mitchell (2012) emphasized that entrepreneurship extends beyond business creation to encompass opportunity recognition, innovation and value generation, thereby contributing to broader socio-economic transformation. At the macro level, Al-Mohammad (2010) highlighted the role of entrepreneurial ventures and SMEs in promoting job creation, balanced regional development and economic efficiency. Despite such recognized benefits, empirical evidence suggested that entrepreneurial intentions among students remain uneven and often limited across contexts (GEM, 2015).

Higher education institutions are considered pivotal in shaping entrepreneurial orientation. Najim et al. (2013) argued that universities significantly influence students' entrepreneurial intentions through curriculum integration, skill development and incubation support. Similarly, Kumar and Shukla (2022) found that entrepreneurship education enhances self-efficacy and strengthens entrepreneurial intention, while Liñán and Fayolle (2022) underscored the importance of perceived behavioural control and social norms in shaping such intentions. However, studies also indicated that fear of failure, perceived risk and inadequate institutional encouragement continue to hinder students from pursuing entrepreneurial careers (Arunkumar et al., 2018).

In the present context of rapid digital transformation and competitive labour markets, fostering entrepreneurial intention among youth has become increasingly relevant. Although government initiatives, start-up ecosystems and incubation centers have expanded in recent years (Sharma & Madan, 2023; Gupta & Batra, 2024), a noticeable gap persists between policy support and actual student engagement in entrepreneurial activities. Many students lack practical exposure, confidence, mentorship and awareness of available support systems. Given these gaps, there is a compelling need to empirically examine students' attitudes, perceptions and barriers toward entrepreneurship. Understanding these factors is quite essential for designing effective educational interventions, policy measures and institutional strategies that can strengthen entrepreneurial intention. Therefore, this research study is both timely and relevant, as it aims to contribute to the development of supportive entrepreneurial ecosystem that promotes innovation-driven growth, employment generation and long-term economic sustainability.

Objectives

- To examine the attitudes of final-year undergraduate and postgraduate commerce students toward entrepreneurship
- To identify the underlying factors influencing students' entrepreneurial attitudes using factor analysis
- To assess the role of institutional support, financial perception and perceived risk in shaping entrepreneurial mindset
- To suggest measures for strengthening entrepreneurial motivation among students

Method of Study

Sampling Design & Research Instrument

The present study is based on both primary and secondary data sources. Primary data is collected from 437 final-year undergraduate and postgraduate commerce students enrolled in colleges located in Pollachi Taluk, Tamil Nadu. The sample size has been considered adequate for multivariate analysis, particularly for factor analysis and structural equation modelling, wherein a minimum respondent-to-item ratio is recommended. The convenience sampling technique has been adopted due to accessibility considerations and institutional permissions. However, efforts have been made to ensure representation across multiple colleges within the region.

The research instrument consisted of a structured questionnaire designed based on established literature on entrepreneurial intention and psychological determinants to measure students' attitudes towards entrepreneurship using a five-point Likert scale. Prior to full-scale data collection, the instrument was pilot-tested to ensure clarity and reliability. The internal consistency of the scale has been confirmed using Cronbach's Alpha ($\alpha = 0.804$), indicated acceptable reliability. Secondary data have been collected from peer-reviewed journals, academic books, policy reports, government publications and credible institutional databases to support the conceptual framework and contextual background of the study. Moreover, data analysis, 'Exploratory Factor Analysis (EFA)' has been adopted to identify the underlying dimensions influencing entrepreneurial attitudes. Subsequently, 'Structural Equation Modelling (SEM)' is applied to test the hypothesized relationships among the extracted constructs and to validate the conceptual model. Statistical analyses are performed using standard analytical software packages to ensure robustness and model fit assessment.

Area & Period of Study

The geographical scope of the study is confined to Pollachi Taluk, a semi-urban region in Tamil Nadu, India. The research specifically focuses on final-year undergraduate and postgraduate commerce students enrolled in higher education institutions within this locality. The selection of this region is based on its emerging educational infrastructure and growing emphasis on entrepreneurship development initiatives. The entire data collection has been conducted over a period of four months.

Analysis & Interpretation

In this study, a total of 19 variables has been considered to assess students' attitudes toward entrepreneurship and related activities. These variables are designed to capture different dimensions such as risk perception, institutional support, financial concerns, personal motivation and career preference. In furtherance, for examining the reliability and internal consistency of the measurement scale, 'Cronbach's Alpha' value has been obtained as 0.804, which is greater than 0.70, which is generally considered acceptable. Also, the score of 0.804 indicates high internal consistency among the variables. This confirms that items used in the questionnaire are reliable and consistently measured the underlying construct of students' attitudes towards entrepreneurship. Therefore, the scale used in the study is statistically sound and suitable for further analysis, including factor analysis and structural equation modelling.

Factor Analysis

To determine the underlying factors that significantly influence students' attitudes toward entrepreneurship, factor analysis is performed on 19 variables (Refer Table 1). The analysis has been carried out using 'Principal Component Analysis (PCA) with Varimax Rotation'. In line with the recommendation of Kinnear and Taylor (1987), only components with Eigenvalues ≥ 1 are retained for interpretation. In furtherance, to ensure clarity and meaningful interpretation of the factor structure, only variables with loadings ≥ 0.50 has been considered significant and retained in the final solution. This threshold helped in achieving a well-defined factorial structure by eliminating weakly loaded items.

The adequacy of sample and its appropriateness of applying factor analysis have been assessed using 'Kaiser-Meyer-Olkin (KMO) measure and Bartlett's Test of Sphericity'. The value of KMO is 0.764, which indicated a satisfactory level of sampling adequacy and Test of Sphericity has been statistically significant ($\chi^2 = 4091.268$, $p < 0.000$). Hence, the application of factor analysis for this present study is justified.

The rotation method applied is Varimax with Kaiser Normalization and solution converged after seven iterations. The Rotated Component Matrix, which is a key output of PCA, presents the factor loadings and showed the strength of association between each factor and 19 variables (A1 to A19) indicated in Table 1. These loadings help in identifying and interpreting the major factors influencing students' entrepreneurial attitudes.

Table 1: Factors Influencing Students' Entrepreneurial Attitudes

Statements	Component			
	1	2	3	4
I feel managing a business is tough and burden	.841			
Lacking in financial position to start a business	.794			
Fear of losing the money in the business	.773			
I think it is difficult to relate Entrepreneurship to real life situations in my family background	.768			

I feel that academic institutions should support students to develop entrepreneurship skills	.544			
I prefer to be self-employed than work for the public organization	.533			
I believe that entrepreneurship is a good way of securing employment		.791		
I have positive attitude towards Entrepreneurship		.789		
I believe that entrepreneurs should do anything for profit		.777		
Eager to start own business and be self-reliant		.735		
I have the experience of own entrepreneurship as a student		.678		
I think applying knowledge in Entrepreneurship is difficult		.542		
Overall, I believe I can perform well in Entrepreneurship			.875	
Entrepreneurship is necessary to maintain social status among the community			.836	
I want to be an effective businessman/ businesswoman			.759	
After the end of formal education, I will start my own business.				.693
Entrepreneurship is a distraction from academic activities				.680
I am ready to take any risk in business than to become an employee				.658
I believe that entrepreneurs are innovative and a source of aspiration for others				.647

Rotation Method: Varimax with Kaiser Normalization - rotation converged in 7 iterations. The inference of Table 1 is indicated below.

Interpretation of Extracted Factors

Based on the rotated component matrix obtained from the factor analysis, four major factors are identified as influencing students' attitudes towards entrepreneurship. Each factor represents a cluster of related variables that collectively explain specific dimensions of entrepreneurial perception.

Factor I

Entrepreneurial Apprehension: This factor showed strong loadings on variables such as the perception that managing a business is difficult and burdensome, lack of financial resources, fear of financial loss, the need for institutional support in developing entrepreneurial skills and

preference for self-employment over public sector jobs. This factor reflects mixed perceptions, wherein students acknowledge both the challenges and need for support in entrepreneurship. Also, it indicated that financial constraints, fear of failure and perceived complexity of business management significantly influence their attitudes.

Factor II

Positive Affirmation: This factor is strongly associated with variables such as viewing entrepreneurship as a secure employment option, having a positive attitude towards entrepreneurship, eagerness to start a business, prior entrepreneurial experience and beliefs regarding profit orientation and difficulty in applying entrepreneurial knowledge. This dimension reflects an optimistic and opportunity-oriented mindset among students. It suggested that experiential learning and positive exposure play a crucial role in shaping favourable entrepreneurial attitudes.

Factor III

Self-Belief: High correlations in this factor have been observed with variables such as confidence in performing well in entrepreneurship, viewing entrepreneurship is important for maintaining social status and aspiring to become an effective businessperson. This factor represents entrepreneurial self-efficacy and confidence. It highlighted the importance of personal belief, competence and social recognition in motivating students towards entrepreneurial careers.

Factor IV

Self-Determination: This factor includes variables such as intention to start a business after formal education, willingness to take risks rather than seek employment, belief in the innovative nature of entrepreneurs and perception of entrepreneurship as a potential distraction from academic activities. This dimension captures students' determination, risk-taking orientation and long-term commitment toward entrepreneurship.

Although the rotated factor matrix clearly identified the relationships between variables and underlying factors, the interpretation can sometimes be complex because certain variables may load on multiple factors. Therefore, to obtain a more comprehensive understanding of interrelationships among these factors and their impact on students' entrepreneurial attitudes, 'Structural Equation Modelling (SEM)' has been applied to provide deeper insights into overall conceptual framework of the study.

Structural Equation Modelling (SEM) – Model Fit Interpretation

The 'Structural Equation Modelling (SEM)' has been applied to validate the conceptual model developed in this study. Also, various goodness-of-fit indices have been assessed to determine whether the proposed model adequately represented the observed data.

The Chi-Square/df (CMIN/df) value is 4.686, which falls within the acceptable range. Wheaton et al. (1977) suggested that values below 5.0 indicates a reasonable fit, while Tabachnick and Fidell (2007) recommended a stricter threshold of 2.0. Since the obtained value is below 5.0, the model demonstrated in this study is an acceptable fit.

The values of 'Goodness of Fit Index (GFI)' and 'Adjusted Goodness of Fit Index (AGFI)' are found to be 0.917 and 0.924 respectively. Both values exceeded the recommended threshold of 0.90, which indicated an overall good fit of the model (Tabachnick & Fidell, 2007). The results suggested that proposed structural model adequately explained the covariance structure of data.

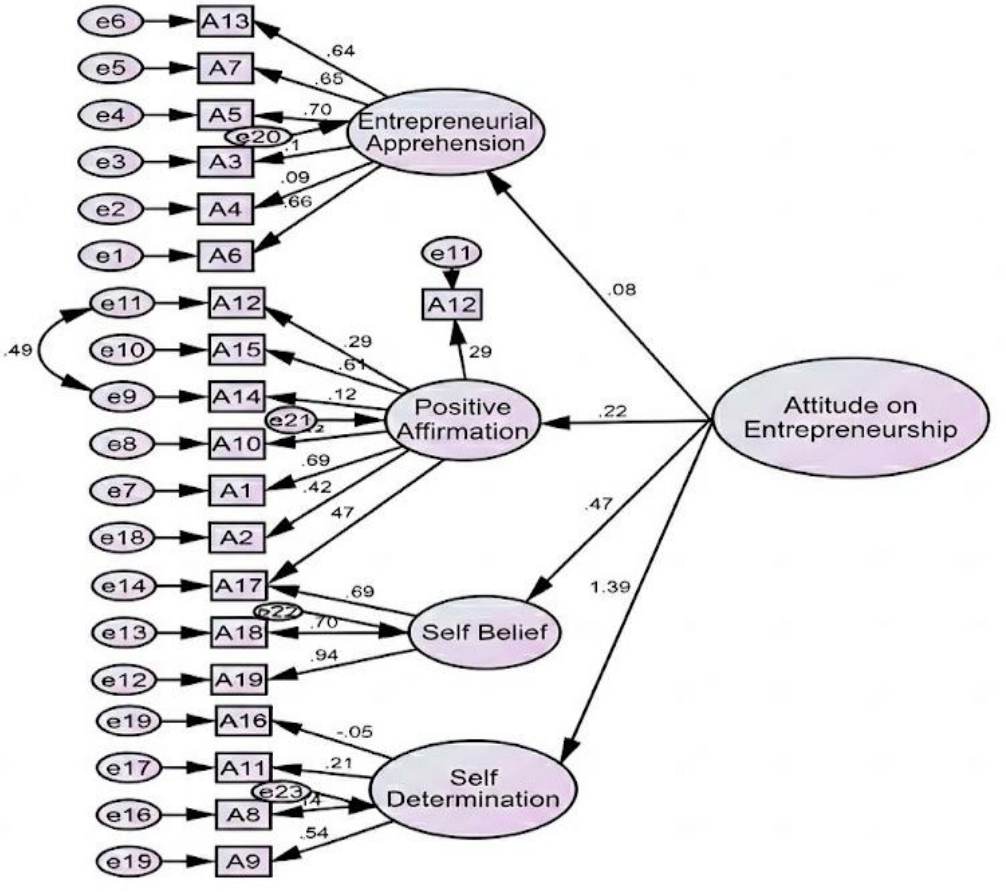

Figure 1: Factors Influencing Student Entrepreneurial Attitude

The 'Root Mean Square Error of Approximation (RMSEA)' value has been found as 0.069. According to MacCallum et al. (1996), RMSEA values below 0.08 indicates a good fit. Also, Hu and Bentler (1999) proposed a stricter benchmark of 0.06, while Steiger (2007) suggested that values up to 0.07 are acceptable. The obtained value of 0.069 indicated a satisfactory and close fit of the model to data.

The 'Normed Fit Index (NFI)' value has been found to be 0.948, which is considered excellent. Hu and Bentler (1999) indicated that values above 0.90 are acceptable and values close to or above 0.95 indicated a very good fit. The results suggested a strong model adequacy. Moreover, the 'Comparative Fit Index (CFI)' value is found to be 0.917. Although values above 0.90 are considered acceptable, Hu and Bentler (1999) recommended a more conservative cut-off of 0.95. While the obtained CFI does not reach the stricter threshold, it still indicated a reasonably good fit. Overall, the combination of fit indices demonstrated that the proposed structural model provided an acceptable and satisfactory representation of data. The results confirmed that the identified factors significantly explained students' attitudes towards entrepreneurship and validated the conceptual framework of the study.

Results & Discussion

The present study examined the attitudes of final-year undergraduate and postgraduate commerce students in Pollachi Taluk towards entrepreneurship and identified the key factors influencing their entrepreneurial mindset. The findings provided meaningful insights into the psychological, institutional and socio-economic determinants shaping entrepreneurial orientation among students. The factor analysis revealed four major dimensions influencing students' attitudes towards entrepreneurship: Entrepreneurial Apprehension, Positive Affirmation, Self-Belief and Self-Determination. These dimensions reflected both inhibiting and enabling forces that collectively shape entrepreneurial intention and are discussed below.

The first factor, *Entrepreneurial Apprehension*, highlighted students' concerns regarding financial risk, fear of failure and perceived complexity of managing a business. This finding is consistent with Arunkumar et al. (2018), who identified fear of failure and financial insecurity as major barriers to entrepreneurial participation among students. The persistence of such apprehensions suggested that despite policy initiatives and awareness programs, risk perception remains a significant psychological constraint. This also supports McClelland's (1961) assertion that achievement motivation must be complemented by supportive environmental conditions to translate into entrepreneurial action.

The second factor, *Positive Affirmation*, reflects students' optimistic attitudes towards entrepreneurship, including eagerness to start a business and recognition of profit potential. This dimension is consistent with Kumar and Shukla (2022), who found that entrepreneurship education enhances self-efficacy and positively influences entrepreneurial intention. Exposure to experiential learning, incubation centers and institutional encouragement appears to foster favourable perceptions. The findings further supported the study conducted by Liñán and Fayolle's (2022) on application of the 'Theory of Planned Behaviour', which emphasized that positive attitudes significantly contribute to entrepreneurial intention.

The third factor, *Self-Belief*, represents entrepreneurial self-efficacy and confidence in personal competence. Students who perceive themselves as capable of performing well in entrepreneurial roles demonstrate stronger orientation toward business ventures. This result reinforces earlier research finding that self-efficacy is critical predictor of entrepreneurial intention. The presence of strong self-belief among certain respondents indicated that

confidence-building mechanisms, such as mentorship and practical exposure, can substantially influence career preferences.

The fourth factor, *Self-Determination*, captures students' willingness to take calculated risks and their intention to start a business after completing formal education. This dimension reflects intrinsic motivation and long-term commitment to entrepreneurship. It supported Schumpeter's (1934) view of entrepreneurs, as innovative risk-takers who drive economic transformation. The identification of this factor suggested that a segment of students possesses strong entrepreneurial drive, though external constraints may limit their action.

The SEM results showed that proposed conceptual framework demonstrated satisfactory model fit. The acceptable values of CMIN/df, GFI, AGFI, RMSEA, NFI and CFI confirmed that the identified latent constructs adequately explain the covariance structure of data. The validation of this structural model strengthens the empirical contribution of the study by demonstrating the entrepreneurial attitudes, which are multidimensional and interrelated rather than isolated constructs.

Despite the presence of positive attitudes and self-belief among students, the overall findings suggested a prevailing preference for secure salaried employment. This reflects the socio-cultural context in which job security and stable income are highly valued. The results echo findings from emerging economy studies that indicated societal expectations and family influence significantly shape career decisions.

The present study contributes to entrepreneurship literature from a theoretical perspective by empirically validating a four-factor structure of entrepreneurial attitude within a regional Indian context. It integrates psychological constructs (self-belief & determination), environmental perceptions (institutional support) and risk-related concerns into a unified framework. It is to be noted that from a practical standpoint, these findings underscore the importance of strengthening institutional mechanisms such as entrepreneurship development cells, incubation centers, mentorship networks and financial literacy programs. Also, reducing perceived financial risk and increasing practical exposure can mitigate entrepreneurial apprehension.

Universities should incorporate experiential learning modules, startup simulations and industry collaborations to enhance the confidence and entrepreneurial readiness. Also, the policy implications emerged from the present research study needs to be considered at large for better prospects. While government initiatives provide structural support, greater emphasis is needed on awareness dissemination, accessibility of funding schemes and simplified procedural frameworks. Furthermore, bridging the gap between policy availability and student awareness is essential to convert entrepreneurial intention into entrepreneurial action.

Overall, the discussion confirms that entrepreneurial intention among students is moulded by factors such as psychological confidence, risk perception, institutional support and socio-cultural influence. In furtherance, strengthening these dimensions can collectively foster vibrant entrepreneurial ecosystem and sustainable economic development.

Implications & Recommendations

The findings of the present study offer important theoretical, practical and policy implications for strengthening entrepreneurial orientation among college students. Furthermore, by identifying four major dimensions—Entrepreneurial Apprehension, Positive Affirmation, Self-Belief and Self-Determination—this research study provides a structured understanding of psychological and institutional elements shaping students' entrepreneurial attitudes.

Theoretical Implications

In this study, literature contribution is through empirical validation of multidimensional structure of entrepreneurial attitude within a semi-urban Indian context. While previous studies have emphasized entrepreneurial intention using frameworks such as 'Theory of Planned Behaviour', the present research extends the discussion by integrating psychological (self-belief, determination), perceptual (risk and financial concerns) and environmental (institutional support) factors into a single structural model.

The identification of Entrepreneurial Apprehension as a dominant factor highlights the continued relevance of risk perception and fear of failure in shaping entrepreneurial attitudes. This research study not only supports motivational theories that emphasized on achievement orientation but also clearly demonstrated that confidence alone is insufficient without supportive institutional mechanisms. The validation of SEM model further strengthens the theoretical contribution by confirming that entrepreneurial attitude is not a single-dimensional construct but a composite of interrelated latent variables. By providing empirical evidence from Pollachi Taluk, the study enriches regional entrepreneurship research, which remains underrepresented in the broader academic discourse. The findings therefore contribute to contextualizing entrepreneurship theory within emerging and semi-urban economies.

Practical Implications

The study offers significant implications for higher education institutions, particularly commerce departments and entrepreneurship development cells. Since Entrepreneurial Apprehension emerged as a major barrier, colleges must design structured programs that reduce fear of failure and financial insecurity. Also, the practical exposure through internships, live business projects, startup simulations and interaction with successful entrepreneurs can enhance experiential learning and build confidence. The presence of Positive Affirmation and Self-Belief among students indicated that entrepreneurial potential exists but requires systematic nurturing. Institutions should focus on the specific avenues indicated below:

- Establish incubation centers and startup support cells.
- Provide mentorship programs involving industry experts and alumni entrepreneurs.
- Conduct workshops on financial literacy, risk management and business planning.
- Integrate entrepreneurship education across curricula using experiential and project-based approaches.

Self-Determination among students suggested the readiness for entrepreneurial engagement if proper guidance is available. Therefore, institutions must move beyond theoretical teaching and create an enabling ecosystem that translates intention into action.

Policy Implications

The results insisted some important implications for policymakers and government agencies. Although several entrepreneurship development schemes exist, the persistence of apprehension indicated a gap between policy design and student awareness or accessibility. The government bodies should focus on the following aspects:

- Increasing awareness of startup funding schemes and subsidies.
- Simplifying regulatory and procedural frameworks for student entrepreneurs.
- Expanding incubation and seed funding facilities in semi-urban and rural regions.
- Encouraging partnerships between universities, financial institutions and industry networks.

Policies should also address cultural barriers that discourage risk-taking. Public campaigns highlighting successful young entrepreneurs and normalizing entrepreneurial failure as part of learning can reshape societal perceptions. Strengthening regional entrepreneurship ecosystems through coordinated institutional, financial and mentorship support will enhance youth participation in self-employment and innovation-driven growth.

Limitations & Future Research

Although the present study offers valuable insights into students' attitudes towards entrepreneurship, it has certain limitations. The research has been geographically confined to Pollachi Taluk, limiting the applicability of findings to regions with varying socio-economic and institutional backgrounds. The sample consisted solely of final-year undergraduate and postgraduate commerce students, thereby excluding other academic disciplines, whereas the entrepreneurial orientation may vary. Also, the convenience sampling technique may cause potential bias on representativeness and self-reported data. Furthermore, the cross-sectional design showed perceptions at a single point in time and does not depict changes in entrepreneurial attitudes over time. While the structural model demonstrated acceptable fit, wherein only selected variables have been examined and omitting factors such as family background, personality traits and digital exposure. The future researchers may adopt probability-based sampling, expand geographical coverage, incorporate interdisciplinary samples and employ longitudinal or qualitative approaches to gain deeper understanding and more comprehensive insights into entrepreneurial intention among youths.

Conclusion

The study concludes that although students recognize the importance of entrepreneurship, a majority still prefer secure salaried employment due to perceived financial risk, uncertainty and fear of failure. The factor analysis identified four key dimensions—Entrepreneurial

Apprehension, Positive Affirmation, Self-Belief and Self-Determination—indicating that students possess entrepreneurial potential but are constrained by psychological and structural barriers. The findings emphasized on the need to strengthen entrepreneurship education, mentorship support, incubation facilities and financial awareness initiatives to effectively bridge the gap between entrepreneurial intention and actual action. Creating a supportive institutional ecosystem to build confidence and reduce perceived risk is essential to foster entrepreneurial engagement and promote sustainable economic development.

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Solving Fully Fuzzy Linear Programming Problem with Equality Constraints Based on a Ranking Function – A Conceptual Study

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Abstract

The linear optimization problem (LOP) is a popular technique in the field of optimization. It has a wide range of applications in science and technology, including network analysis and operational research. In linear programming problems (LPP), the parameters and constraints are crisp, however in real-world applications, they are unpredictable. This research chapter proposes a novel method that utilizes a 'linear ranking function', defined as the average of selected points on horizontal axis taken from the left and right membership functions of fuzzy numbers. These points are chosen such that they divide each membership function according to a specified ratio of $m: n$. The advantages of proposed method are illustrated through relevant examples that are representative of various numerical applications. In addition to this, comparisons with other illustrative approaches in the literature are made and concluding thoughts are provided.

Keywords: Fully Fuzzy, Linear Programming, Problem, Ranking Function, Horizontal.

Introduction

Linear programming problems are the most basic and widely used mathematical programming models for optimization techniques. The linear programming concept is easily applied to a variety of real-world situations. The human decision is dependent on information. However, the information is not always precise and easily accessible. In such a case, decision-making is both tough and exciting. Bellman and Zadeh pioneered the idea of decision-making (Bellman & Zadeh, 1970). One of the most intriguing concepts in decision-making under uncertainty is the fuzzy optimization technique, which works with fuzzy linear programming problems and Zimmermann (1978) first conceived this notion.

LPP is one of the most often utilized models in decision-making in competitive environments across a variety of sectors. If the variables and parameters are fuzzy, LPP is said to be an 'fully fuzzy linear programming problem (FFLPP)'. In contrast to the diversity of methods, there is an ample need for additional investigations and analysis.

Literature Review

Fang et al. (1999) has been considered among the early researchers to formulate linear programming problems incorporating fuzzy coefficients within the constraints. Later, Maleki (2002) investigated the application of ranking functions as a tool for solving fuzzy linear programming problems. Nasseri et al. (2005) proposed adapting the Simplex method to handle linear programming problems characterized by fuzzy variables, while Amiri and Nasseri (2005) further explored the concept of duality in such fuzzy variable-based linear programming models. In subsequent studies, Lotfi et al. (2009) addressed 'fully fuzzy linear programming (FFLP) problems' by applying a lexicographic approach along with an approximate fuzzy solution. Allahviranloo et al. (2008) also contributed by solving FFLP problems using ranking functions.

Kumar et al. (2011) presented a fuzzy optimal solution method specifically for fully fuzzy linear programming problems with inequality constraints. Moreover, Karpagam and Sumathi (2014), who introduced an innovative ranking function-based method for solving FLP problems. Bhattacharyya and Majumdar (2019) highlighted the effectiveness of centroid-based techniques in handling such problems. Ghoushchi et al. (2021) developed a solution approach using modified triangular fuzzy numbers combined with the alpha-cut method for FFLP. Moreover, Sinha and Prasad (2022), through comparative analysis, proposed a new ordering technique for fuzzy numbers based on the angles of their membership functions.

Relevance

A crucial component of FFLPP is that we can use it to solve engineering, risk investing and transportation problems. Prasad and Sinha (2023) proposed solving FFLPP with modified triangular fuzzy numbers based on a ranking function. Hence, the present study provides relevance in understanding wider possibilities based on the findings to solve fractional programming problems, transportation difficulties and nonlinear programming problems in the future.

Objective

To present a notable strategy for solving fully fuzzy linear programming problem (FFLPP) that involves equality constraints

Methodology

This research adopts an analytical perspective, employing a linear ranking function defined by the mean value on the horizontal axis, derived from the points of left and right membership functions of fuzzy numbers. These points effectively partition the respective membership function in the ratio $m:n$.

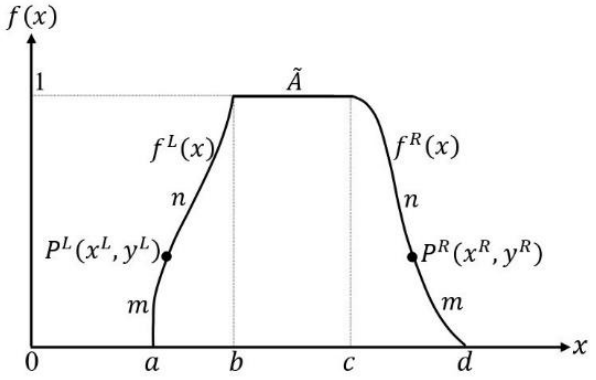

Fig. 1: Points on the Membership Axes

Let $P^L(x^L, y^L)$ and $P^R(x^R, y^R)$ are the horizontal points on the left and right membership functions, respectively, of a fuzzy number $\tilde{A} = (a, b, c, d)$ and divide them in the same ratio $m : n$ as visualised in Fig. 1.

The mean value of the two points of a fuzzy number $\tilde{A} = (a, b, c, d)$ is denoted and defined as

$$\mathcal{M}(\tilde{A}) = \frac{1}{2}(x^L + x^R). \quad (1)$$

For the trapezoidal fuzzy number $\tilde{A} = (a, \mathrm{b}, \mathrm{c}, \mathrm{d})$. The mean is given by,

$$\mathcal{M}(\tilde{A}) = \frac{1}{2}\left(\frac{mb+na}{m+n} + \frac{mc+nd}{m+n}\right) \quad (2)$$

Similarly, in the case of a triangular fuzzy number $\tilde{A} = (a, \mathrm{b}, \mathrm{c})$, the mean is given by,

$$\mathcal{M}(\tilde{A}) = \frac{1}{2}\left(\frac{mb+na}{m+n} + \frac{mb+nc}{m+n}\right) \quad (3)$$

Let us consider the value of $m{:}\,n$ as $2{:}\,3$, then the mean value for triangular fuzzy numbers is given by,

$$\mathcal{M}(\tilde{A}) = \frac{3a+4b+3c}{10}. \quad (4)$$

Triangular Fuzzy Numbers - Arithmetic Operations

For any two triangular fuzzy numbers $\tilde{A}_i = (a_i, b_i, c_i, d_i)$ and $\tilde{A}_j = (a_j, b_j, c_j, d_j)$, the following arithmetic operations are as follows: (Sinha & Prasad, 2022)

(i) Addition
$\tilde{A}_i \oplus \tilde{A}_j = (a_i, b_i, c_i, d_i) \oplus (a_j, b_j, c_j, d_j) = (a_i + a_j, b_i + b_j, c_i + c_j, d_i + d_j)$.
(ii) Subtraction
$\tilde{A}_i \ominus \tilde{A}_j = (a_i, b_i, c_i, d_i) \ominus (a_j, b_j, c_j, d_j) = (a_i - a_j, b_i - b_j, c_i - c_j, d_i - d_j)$.
(iii) Multiplication
$\tilde{A}_i \otimes \tilde{A}_j = (a_i, b_i, c_i, d_i) \otimes (a_j, b_j, c_j, d_j) = (a_i \times a_j, b_i \times b_j, c_i \times c_j, d_i \times d_j)$.
(iv) Division
$\tilde{A}_i \oslash \tilde{A}_j = (a_i, b_i, c_i, d_i) \oslash (a_j, b_j, c_j, d_j) = \left(\frac{a_i}{d_j}, \frac{b_i}{c_j}, \frac{c_i}{b_j}, \frac{d_i}{a_j}\right)$.
(v) Multiplication by a scalar 'k'

$$k\tilde{A}_i = \begin{cases} (ka_i, kb_i, kc_i, kd_i); & if\ k \geq 0 \\ (kd_i, kc_i, kb_i, ka_i); & if\ k < 0 \end{cases}.$$

Findings & Discussions

"Maximize (or Minimize) $\tilde{Z} = \tilde{C} \times \tilde{X}$,
Subject to $\tilde{A} \otimes \tilde{X} \cong \tilde{b}$, (P_1)
Where $\tilde{X}$ is a non-negative fuzzy number,
Where $\tilde{C} = [\tilde{c}_j]_{1\times n}$, $\tilde{X} = [\tilde{x}_j]_{n\times 1}$, $\tilde{A} = [\tilde{a}_{ij}]_{m\times n}$, $\tilde{b} = [\tilde{b}_i]_{m\times 1}$ and $\tilde{c}_j$, $\tilde{x}_j$, $\tilde{a}_{ij}$, $\tilde{b}_i \in F(R)$".

The method outlined below is suggested for determining the Fuzzy Optimal Solution to FFLP issues:

Step 1: "Substituting $\tilde{C} = [\tilde{c}_j]_{1\times n}$, $\tilde{X} = [\tilde{x}_j]_{n\times 1}$, $\tilde{A} = [\tilde{a}_{ij}]_{m\times n}$, $\tilde{b} = [\tilde{b}_i]_{m\times 1}$ (P_1) may be written as:

Maximize (or Minimize) $\tilde{Z} = \sum_{j=1}^{n} \tilde{c}_j \otimes \tilde{x}_j$,
Subject to $\sum_{j=1}^{n} \tilde{a}_{ij} \otimes \tilde{x}_j = \tilde{b}_i \ \forall\ i = 1, 2, \ldots\ldots, m$,

$\tilde{x}_j$ is a non-negative fuzzy number".

Step 2: "Let us suppose that all the parameters $\tilde{c}_j$, $\tilde{x}_j$, $\tilde{a}_{ij}, \tilde{b}_i$ are represented by triangular fuzzy numbers

$\left(c_j^{(1)}, c_j^{(2)}, c_j^{(3)}\right)$, $\left(x_j^{(1)}, x_j^{(2)}, x_j^{(3)}\right)$, $\left(a_{ij}^{(1)}, a_{ij}^{(2)}, a_{ij}^{(3)}\right)$ and $\left(b_i^{(1)}, b_i^{(2)}, b_i^{(3)}\right)$ respecti vely, then the FFLP problem obtained in step 1 can be written as:

Maximize (or Minimize) $\tilde{Z} = \sum_{j=1}^{n} \left(c_j^{(1)}, c_j^{(2)}, c_j^{(3)}\right) \otimes \left(x_j^{(1)}, x_j^{(2)}, x_j^{(3)}\right)$,

Subject to $\sum_{j=1}^{n}\left(a_{ij}^{(1)},\ a_{ij}^{(2)},\ a_{ij}^{(3)}\right) \otimes \left(x_j^{(1)},\ x_j^{(2)},\ x_j^{(3)}\right) = \left(b_i^{(1)},\ b_i^{(2)},\ b_i^{(3)}\right)\ \forall\ i = 1,\ 2, \ldots\ldots, m,$
$\left(x_j^{(1)},\ x_j^{(2)},\ x_j^{(3)}\right)$ is a non-negative triangular fuzzy number."

Step 3: "Let us assume that $\left(a_{ij}^{(1)},\ a_{ij}^{(2)},\ a_{ij}^{(3)}\right) \otimes \left(x_j^{(1)},\ x_j^{(2)},\ x_j^{(3)}\right) = \left(p_{ij}^{(1)},\ p_{ij}^{(2)},\ p_{ij}^{(3)}\right)$, then the FFLP problem obtained in step 2 can be written as:

Maximize (or Minimize) $\tilde{Z} = \mathcal{M}\left(\sum_{j=1}^{n}\left(c_j^{(1)},\ c_j^{(2)},\ c_j^{(3)}\right) \otimes \left(x_j^{(1)},\ x_j^{(2)},\ x_j^{(3)}\right)\right),$

Subject to $\sum_{j=1}^{n}\left(p_{ij}^{(1)},\ p_{ij}^{(2)},\ p_{ij}^{(3)}\right) = \left(b_i^{(1)},\ b_i^{(2)},\ b_i^{(3)}\right)\ \forall\ i = 1,\ 2, \ldots\ldots, m,$

$\left(x_j^{(1)},\ x_j^{(2)},\ x_j^{(3)}\right)$ is a non-negative triangular fuzzy number".

Step 4: "The FFLP challenge identified in step 3 can be reformulated into a crisp linear programming problem (CLPP) as described below:

Maximize (or Minimize) $\tilde{Z} = \mathcal{M}\left(\sum_{j=1}^{n}\left(c_j^{(1)},\ c_j^{(2)},\ c_j^{(3)}\right) \otimes \left(x_j^{(1)},\ x_j^{(2)},\ x_j^{(3)}\right)\right),$

Subject to $\sum_{j=1}^{n} p_{ij}^{(1)} = b_i^{(1)}\ \forall\ i = 1,\ 2, \ldots\ldots, m,$
$\sum_{j=1}^{n} p_{ij}^{(2)} = b_i^{(2)}\ \forall\ i = 1,\ 2, \ldots\ldots, m,$
$\sum_{j=1}^{n} p_{ij}^{(3)} = b_i^{(3)}\ \forall\ i = 1,\ 2, \ldots\ldots, m,$

$(x_j^{(2)} - x_j^{(1)}) \geq 0,\ \ (x_j^{(3)} - x_j^{(2)}) \geq 0,\ \forall\ j = 1,\ 2, \ldots\ldots, n$".

Step 5: Next, we obtain the optimal solution $x_j^{(1)},\ x_j^{(2)}\ and\ x_j^{(3)}$ by solving the CLPP obtained in step 4.

Step 6: Next, we find the fuzzy optimal solution by substituting the values of

$x_j^{(1)},\ x_j^{(2)}\ and\ x_j^{(3)}$ obtained in step 5 in

$$\tilde{x}_j = \left(x_j^{(1)},\ x_j^{(2)},\ x_j^{(3)}\right).$$

Step 7: Finally, we find the fuzzy optimal value by putting $\tilde{x}_j$ in $\tilde{Z} = \sum_{j=1}^{n} \tilde{c}_j \otimes \tilde{x}_j$.

Numerical Example

"Maximize $\tilde{Z} = \left((1,\ 6,\ 9) \otimes \tilde{x}_1 \oplus (2,\ 3,\ 8) \otimes \tilde{x}_2\right)$,

Subject to $(2,\ 3,\ 4) \otimes \tilde{x}_1 \oplus (1,\ 2,\ 3) \otimes \tilde{x}_2 = (6,\ 16,\ 30)$,

$(-1,\ 1,\ 2) \otimes \tilde{x}_1 \oplus (1,\ 3,\ 4) \otimes \tilde{x}_2 = (1,\ 17,\ 30)$,

$\tilde{x}_1, \tilde{x}_2$ are non-negative triangular fuzzy numbers (Kumar et al., 2011))"

Solution: "Let $\tilde{x}_1 = \left(x_1^{(1)},\ x_1^{(2)},\ x_1^{(3)}\right)$ *and* $\tilde{x}_2 = \left(x_2^{(1)},\ x_2^{(2)},\ x_2^{(3)}\right)$. Then, using step 2, the given FFLP problem can be written as:

Maximize $\tilde{Z} = \left((1,\ 6,\ 9) \otimes \left(x_1^{(1)},\ x_1^{(2)},\ x_1^{(3)}\right) \oplus (2,\ 3,\ 8) \otimes \left(x_2^{(1)},\ x_2^{(2)},\ x_2^{(3)}\right)\right)$,

Subject to $(2,\ 3,\ 4) \otimes \left(x_1^{(1)},\ x_1^{(2)},\ x_1^{(3)}\right) \oplus (1,\ 2,\ 3) \otimes \left(x_2^{(1)},\ x_2^{(2)},\ x_2^{(3)}\right) = (6,\ 16,\ 30)$,

$(-1,\ 1,\ 2) \otimes \left(x_1^{(1)},\ x_1^{(2)},\ x_1^{(3)}\right) \oplus (1,\ 3,\ 4) \otimes \left(x_2^{(1)},\ x_2^{(2)},\ x_2^{(3)}\right) = (1,\ 17,\ 30)$,

$\left(x_1^{(1)},\ x_1^{(2)},\ x_1^{(3)}\right)$ and $\left(x_2^{(1)},\ x_2^{(2)},\ x_2^{(3)}\right)$ are non-negative triangular fuzzy numbers".

"Using step 3, the above FFLP problem can be written as:

Maximize $\tilde{Z} = \mathcal{M}\left(x_1^{(1)} + 2x_2^{(1)},\ 6x_1^{(2)} + 3x_2^{(2)},\ 9x_1^{(3)} + 8x_2^{(3)}\right)$,

Subject to $\left(2x_1^{(1)} + x_2^{(1)},\ 3x_1^{(2)} + 2x_2^{(2)},\ 4x_1^{(3)} + 3x_2^{(3)}\right) = (6,\ 16,\ 30)$,

$\left(-x_1^{(3)} + x_2^{(1)},\ x_1^{(2)} + 3x_2^{(2)},\ 2x_1^{(3)} + 4x_2^{(3)}\right) = (1,\ 17,\ 30)$,

$\left(x_1^{(1)},\ x_1^{(2)},\ x_1^{(3)}\right)$ and $\left(x_2^{(1)},\ x_2^{(2)},\ x_2^{(3)}\right)$ are non-negative triangular fuzzy numbers.

Using step 4, the given FFLP problem can be converted to a CLP problem as follows:

Maximize $\tilde{Z} = \left(\frac{1}{10}\left(3x_1^{(1)} + 6x_2^{(1)} + 24x_1^{(2)} + 12x_2^{(2)} + 27x_1^{(3)} + 24x_2^{(3)}\right)\right)$,

Subject to $2x_1^{(1)} + x_2^{(1)} = 6$,

$-x_1^{(3)} + x_2^{(1)} = 1$,

$$3x_1^{(2)} + 2x_2^{(2)} = 16,$$
$$x_1^{(2)} + 3x_2^{(2)} = 17,$$
$$4x_1^{(3)} + 3x_2^{(3)} = 30,$$
$$2x_1^{(3)} + 4x_2^{(3)} = 30,$$
$$(x_1^{(2)} - x_1^{(1)}) \geq 0,\ (x_1^{(3)} - x_1^{(2)}) \geq 0,\ (x_2^{(2)} - x_2^{(1)}) \geq 0\ and\ (x_2^{(3)} - x_2^{(2)}).$$

The optimal solution of the above CLP problem is

$$x_1^{(1)} = 1,\ x_1^{(2)} = 2,\ x_1^{(3)} = 3,\ x_2^{(1)} = 4,\ x_2^{(2)} = 5,\ x_2^{(3)} = 6$$

Using step 6, the fuzzy optimal solution is given by $\tilde{x}_1 = (1, 2, 3),\ \tilde{x}_2 = (4, 5, 6)$.
Using step 7, the fuzzy optimal value of the given FFLP problem is $\tilde{Z} = (9, 27, 75)$".

The maximum value is $\mathcal{M}(\tilde{Z}) = 36$

The result is the same as that of Kumar et al. (2011). $\mathcal{M}(\tilde{Z}) = 34.5$

Summary of Observations

The numerical examples provided above yield values that can be easily verified to comply with all constraints. In this study, a linear ranking function is utilized to tackle FFLPP with equality constraints, streamlining the process and eliminating the need for complex calculations.

Suggestion

The proposed ranking function has a wide range of applications that include fuzzy assignment problems, fuzzy transportation problems, fuzzy game theory models, fuzzy replacement problems, etc.

Limitations

The noted limitation in this study is the increase in constraints when converting the problem into a crisp format. Despite this, linearity of ranking function facilitates an accurate and straightforward solution to the problem.

Conclusion

This study emphasizes on the significance of ranking fuzzy numbers in addressing the FFLP problem. In tackling the FFLPP with equality constraints, ranking function plays a crucial role. Typically, a FFLPP is solved by transforming it into an equivalent crisp linear programming model. Also, to demonstrate the efficiency of proposed approach, a problem drawn from the existing literature has been resolved. The transformation of FFLP into crisp problems is

straightforward and can be expanded to address various programming challenges involving fuzzy coefficients in both objective functions and constraints. This approach can also be applied in fields such as risk management, transportation issues and supply chain management. Additionally, the proposed approach can be further generalized to address nonlinear programming as well as fractional programming problems.

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Understanding the Cognitive and Emotional Factors Shaping Consumer Perspectives on Brand Perception and Neuromarketing – An Empirical Study

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Abstract

This study uses a neuromarketing framework to investigate the cognitive and emotional factors influencing consumers' perceptions of brands. A structured questionnaire has been used to gather primary data from 250 respondents, wherein factor analysis and structural equation modeling (SEM) have been analyzed using JMP software. The findings underscored the importance of attention, memory and information processing in influencing consumer attitudes and showed that cognitive characteristics have a strong and statistically significant positive impact on brand perception ($\beta = 0.973$, $p < 0.001$). On the other hand, brand impression is significantly but negatively contributed with emotional aspects ($\beta = –0.494$, $p < 0.05$), which indicated that there is an inconsistent emotional measurement. Additionally, brand perception has a significant mediating effect on customer outcomes, especially purchase intention and preference ($\beta = 0.913$ and $\beta = 0.833$, $p < 0.001$). However, poor overall fit is indicated by model fit indices (CFI = 0.153; RMSEA = 0.910), highlighting the need for better construct specification and model refining. Notwithstanding this drawback, this research work highlights the significant impact of cognitive mechanisms in neuromarketing and offers empirical support for the mediating function of brand perception. The results provide marketers with useful information for developing tactics that combine emotional involvement and cognitive clarity to improve customer response.

Keywords: Neuromarketing, Brand Perception, Consumer Behaviour, Emotional Marketing, Decision Making, Sensory Marketing.

Introduction

Neuromarketing, an interdisciplinary area that combines neuroscience, psychology and marketing, has emerged as a result of the marketing industry's rapid expansion, which has increased the need to understand how customers perceive companies beyond conscious evaluations. Compared to traditional research approaches that rely on self-reported data, neuromarketing offers deeper insights into customers' subconscious motives, emotions and decision-making processes by assessing their neurological and physiological responses to marketing stimuli (Gupta et al., 2025). Examining the emotional and cognitive processes that underlie brand perception is crucial because research indicates that a sizable percentage of customer decisions are made subconsciously (Bhardwaj et al., 2023).

According to Dzyabura and Peres (2021), brand perception is a network of mental connections that include feelings, experiences and symbolic meanings. These associations influence brand positioning, equity and competitive advantage. Thus, by capturing unspoken emotional reactions and attention patterns, neuromarketing techniques like EEG, eye tracking, face coding and physiological monitoring allow marketers to gain important insights into customer involvement and preference creation (Rawnaque et al., 2020). According to empirical research, brand perception and purchase behavior are greatly influenced by emotional variables, prestige and symbolic traits, which frequently exceed logical assessments (Yücel & Şimşek, 2019). Moreover, it revealed the affective and perceptual drivers of consumer perspectives toward companies, neuromarketing has emerged as a strategic instrument for brand management, boosting the effectiveness of advertising, brand communication and customer relationship development (Almeida et al., 2025).

Literature Review

Today, the trend is moving on by integrating marketing concepts with neuroscience, neuromarketing has become a game-changing strategy that improves our comprehension of customer behavior. Neuromarketing offers objective insights into subconscious cognitive and emotional processes, in contrast to standard research approaches that mostly rely on self-reported data (Iloka & Onyeke, 2020). Research by Rawnaque et al. (2020) showed that instruments like fMRI and EEG allow marketers to more accurately gauge emotional arousal, attention and engagement. Moreover, building on this, brand perception is greatly influenced by emotions. Emotional reactions have a big impact on consumer memory and decision-making (Pluta-Olearnik & Szulga, 2022). In a similar vein, Almeida et al. (2025) showed how subconscious priming strategies can change brand associations without conscious awareness. Additionally, neuromarketing advances our knowledge of how customers create associations and memories associated with brands. According to Rüschendorf (2020), the brain's emotional processes are essential for successful brand positioning and communication. In support of this finding, Bharadwaj et al. (2023) classified neuromarketing applications into strategic and behavioural areas, emphasizing their use in anticipating customer reactions. Furthermore, these conclusions are supported by empirical research studies conducted by various researchers across the world. According to Yücel and Şimşek (2019), certain brand features that improve engagement can be identified using EEG-based metrics. Also, Zeng and Marques (2023)

showed differences between expressed preferences and real emotional reactions, highlighting the shortcomings of conventional research. Moreover, the consumer perception is greatly influenced by cognitive processing and visual attention. While Zito et al. (2021) revealed that emotional intensity increases communication efficacy, eye-tracking studies by Kalkova et al. (2020) demonstrated on how consumers process brand stimuli. Overall, the research studies have showed that a mix of emotional, cognitive and symbolic elements influence how consumers perceived brands (Dzyabura & Peres, 2021). Nevertheless, these insights still need to be incorporated into a cohesive framework that connects neuromarketing with consumer viewpoints.

Objectives

- To examine the concept of neuromarketing and brand perception
- To understand the cognitive and emotional factors, shaping consumer perspectives toward brands

Need & Relevance

The influence of emotional and subconscious variables has made it more difficult to comprehend consumer behaviour in today's digital marketplace. In furtherance, they mostly rely on self-reported data, traditional marketing research methodologies frequently fail to capture these underlying processes. By offering more profound insights into emotional and cognitive reactions, neuromarketing overcomes this constraint (Rawnaque et al., 2020). Even though neuromarketing research is expanding, the majority of studies concentrated on general decision-making or advertising efficacy rather than specifically analyzing how it affects brand perception (Bhardwaj et al., 2023). Additionally, traditional research on brand perception ignores subconscious factors in favour of conscious assessments. Furthermore, it combines brand perception with neuromarketing principles to create a thorough grasp of consumer perceptions, this study is important. The results will provide management and scholarly insights for creating emotionally compelling and cognitively successful branding strategies.

Methodology

The current study investigated on how cognitive and emotional factors influence brand perception through neuromarketing using an empirical framework. The study adopted descriptive research design and analytical research approach for explaining the results. Both primary and secondary data sources have been collected. Primary data has been obtained from 250 Indian consumers who are acquainted with branded products and digital marketing content. The sample size is considered adequate for the use of structural equation modeling (SEM), ensuring precise estimation and confirmation of relationships between variables. Owing to accessibility, a convenience sampling technique has been used; respondents who were unfamiliar with branding principles and those who gave insufficient information were removed to maintain data quality. The study employed a structured questionnaire as its research tool to assess variables such as cognitive aspects, emotional factors, brand perception and consumer opinions using a Likert scale. The existing literature served as the foundation

for the creation of this questionnaire. Also, to find links and validate the conceptual model, the collected data has been analyzed utilizing techniques like Factor Analysis, Path Analysis and SEM using JMP software. Secondary data from academic publications and sources supported the theoretical framework, ensuring study's empirical validity and robustness.

Hypothesis

H_0 - Neuromarketing-based cognitive and emotional factors have no significant influence on consumer perspectives toward brands.

H_1 - Neuromarketing-based cognitive and emotional factors have a significant influence on consumer perspectives toward brands.

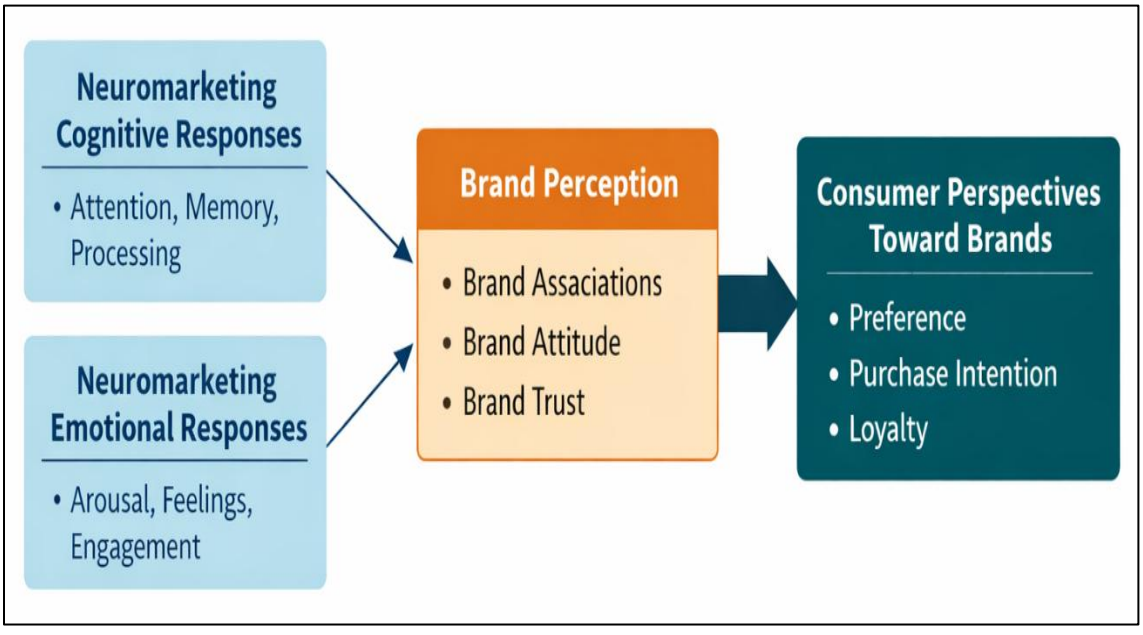

Chart 1: Conceptual Framework

Source: Generated from Findings based on Conceptual Analysis

The conceptual framework describes how brand perception mediates consumer attitudes toward brands and neuromarketing. According to the paradigm, two main independent components of neuromarketing are emotional and cognitive responses. When consumers are exposed to marketing stimuli, their cognitive responses exhibited their attention, memory and information processing, while their emotional reactions showed the emotions, arousal and engagement created during brand encounters. The development of brand perception, a mediating construct made up of brand associations, brand attitude and brand trust, is influenced by these emotional and cognitive responses.

The concept is that consumers form stronger and more positive opinions of a company when neuromarketing stimuli effectively capture attention and elicit emotional involvement. In the

end, consumer perceptions of brands are indicated by loyalty, preference and purchase intention. Therefore, by showing how neuromarketing indirectly affects consumer behaviour by affecting psychological processes buried in brand perception. In furtherance, the framework offers a thorough explanation of how subconscious consumer reactions lead to positive brand-related results.

Data Analysis

The study collected data from respondents using a systematic questionnaire, wherein a sample size of 250 has been considered enough for Structural Equation Modeling (SEM) since it satisfies recommended criteria for reliable parameter estimation in covariance-based models. The Indian sample has been treated as a single analytical group because the study's primary objective is to examine the proposed structural relationships rather than compare subgroups. The measurement model is assessed through Structural Equation Modeling (SEM) using JMP software, which suggested the contributions between neuromarketing aspects (Cognitive and Emotional), brand perception and consumer attitudes toward brands are examined.

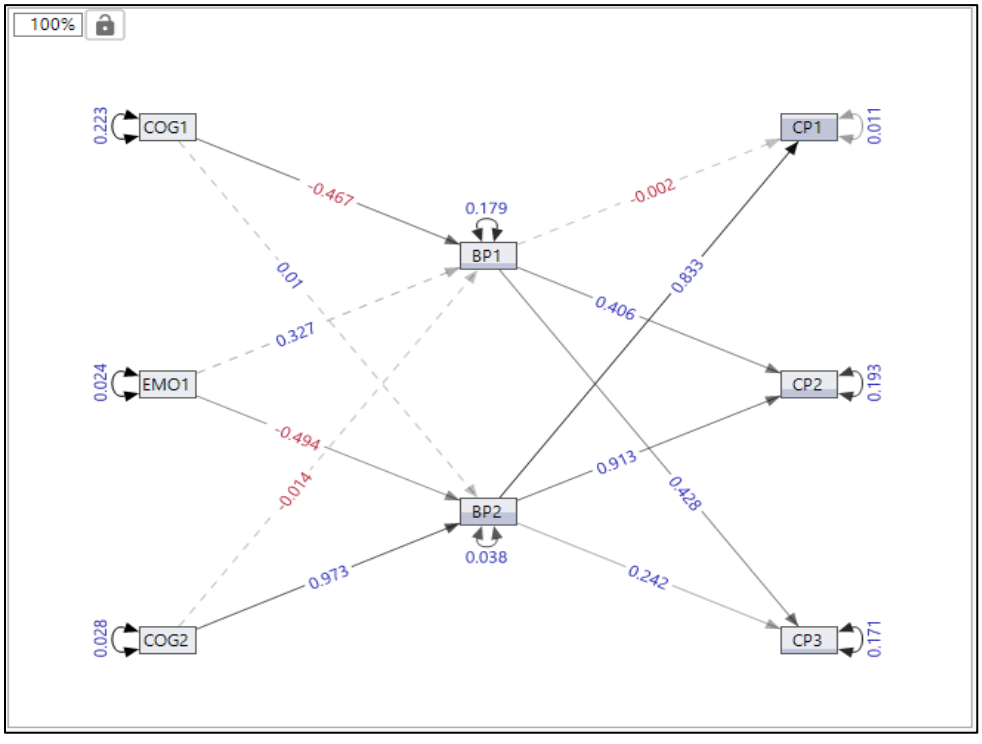

Chart 2: SEM Showing the Relationships of Variables

Source: Generated from Findings based on Statistical Analysis (SEM using JMP Software)

The links between brand perception, customer viewpoints and neuromarketing elements (cognitive & emotional) are depicted in the Structural Equation Model (SEM) figure. The emotional neuromarketing indicator is referred to as EMO1 and cognitive neuromarketing indicators on the left side of the model are mentioned as COG1 and COG2 respectively. Brand

perception is described by two components, BP1 and BP2, which are independent constructs influenced by these variables. CP1, CP2 and CP3 on the right reflect consumer perspectives and display outcomes such as brand preference, purchase intention and loyalty.

Blue path coefficients indicated positive links, red values indicated negative contributions and dashed lines suggested the weak or non-significant routes. With a coefficient of 0.973, the results demonstrated that cognitive neuromarketing (COG2) significantly enhances brand perception (BP2). Furthermore, BP2 to CP1 (β = 0.913) and BP1 to CP1 (β = 0.833) demonstrated that brand perception significantly influences consumer opinions, which further indicated that improved brand perception leads to stronger consumer outcomes.

On the other hand, emotional neuromarketing (EMO1) showed a negative effect with BP2 (β = -0.494), suggesting potential measurement or construct issues that may require improvement. Furthermore, COG1 negatively affects BP1 (β = -0.467), which has indicated overlapping structures. Also, cognitive neuromarketing has a significant influence on brand perception, which in turn changes customer perceptions and the model partially supports the proposed mediation paradigm.

Table 1: SEM Value Table

Sample Size	250
Rows with Missing	0
-2 Log Likelihood	228.84082
Iterations	0
Number of Parameters	28
AICc	292.18924
BICu	3247.0912
ChiSquare	3335.4346
DF	16
Prob>ChiSq	0
CFI	0.1536021
RMSEA	0.9109658
Lower 90%	0.8850655
Upper 90%	0.9371391

Source: Generated from Findings based on Statistical Analysis

According to the model summary, a sample size of 250 respondents with no missing data has been used for the study, which is sufficient for structural equation modeling. The entire model fit based on maximum likelihood estimation is represented by the -2 Log Likelihood value (228.84) with 28 estimated parameters.

When comparing different models, lower values of the information criteria AICc (292.19) and BIC (3247.09) suggest better fit.

The model's large deviation from observed covariance matrix, as indicated by the associated probability value ($p = 0.000$) and Chi-Square value of 3335.43 with 16 degrees of freedom, suggests a poor overall fit.

The Comparative match Index (CFI = 0.1536), which is far below the acceptable threshold of 0.90. This also indicated that the model does not match the data well, further supports this. Furthermore, RMSEA = 0.9109 is a very high Root Mean Square Error of Approximation; acceptable values are often less than 0.08, with values below 0.05 denoting a good fit.

Severe model mismatch is also confirmed by the RMSEA 90 percent confidence interval (0.8851 - 0.9371).

The sample size is sufficient for SEM analysis overall, offering a solid basis for model estimate. Even though the existing goodness-of-fit indices point to areas that could use better, the findings provided insightful information that can direct model development through enhanced measurement indicators, more theoretically aligned structural routes and construct improvements. Moreover, 'To verify the proposed links, path coefficients and significance levels from SEM analysis are analyzed'.

Findings

Significant insights into the connections between neuromarketing elements, brand impression and customer viewpoints are provided by the Structural Equation Modeling (SEM) results.

According to the analysis, brand perception is strongly positively and statistically significantly impacted by cognitive neuromarketing factors (COG2 → BP2) ($\beta = 0.973$, $p < 0.001$), suggesting that cognitive processes like attention, memory and information processing are crucial in forming brand-related assessments.

Conversely, there exists a significant negative effect ($\beta = –0.494$, $p < 0.05$) between brand perception and emotional neuromarketing parameters (EMO1 → BP2), which indicated the inconsistent emotional measurement or respondent variability. Furthermore, there is a significant negative effect ($\beta = –0.467$, $p < 0.001$) between COG1 → BP1, suggesting potential concept overlap or problems with model design. According to consumer viewpoints, brand impression has a powerful and noteworthy impact on customer results. Specifically, on the following:

- **BP2 → CP1** ($\beta = 0.913$, $p < 0.001$)
- **BP1 → CP1** ($\beta = 0.833$, $p < 0.001$)
- **BP1 → CP2** ($\beta = 0.405$, $p < 0.001$)
- **BP1 → CP3** ($\beta = 0.427$, $p < 0.001$)
- **BP2 → CP2** ($\beta = 0.912$, $p < 0.001$)

- **BP2 → CP3** ($\beta = 0.241$, $p < 0.05$)

These findings verified that interaction between neuromarketing elements and customer behaviour is substantially mediated by brand perception, impacting purchase intention, preference and loyalty. However, the overall model fit indices indicated **poor model fit**, with the following:

- **CFI = 0.153** (below acceptable threshold of 0.90)
- **RMSEA = 0.910** (above acceptable threshold of 0.08)
- Significant Chi-square ($p < 0.001$)

Although the model exhibited partial support due to fit restrictions, alternative hypothesis is accepted and null hypothesis has been rejected, suggesting that neuromarketing-based cognitive and emotional aspects strongly influence customer attitudes. This implies that even though individual path effects are statistically significant, wherein the structural model as a whole need to be improved, particularly by adding more indicators and improving construct validity.

Discussion

The findings highlighted the significant role of cognitive and emotional factors in shaping consumer perspectives toward brands through neuromarketing mechanisms. The strong positive influence of cognitive factors on brand perception aligns with prior research, which emphasized on attention, memory and information processing are critical determinants of consumer decision-making and brand evaluation. Studies by Ismajli et al. (2022) indicated that neuromarketing enhances understanding of consumer preferences by capturing subconscious cognitive responses, thereby supporting the present findings. In furtherance, significant mediating role of brand perception observed in this study is consistent with Guliyev (2023), who found that brand perception and brand image significantly influences consumer purchasing behaviour by shaping attitudes and preferences. This confirms that consumers rely on perceived brand value and associations while forming purchase intentions and loyalty. However, the negative effects of path coefficient values are observed between emotional factors and brand perception have suggested inconsistencies in emotional measurement or variability in consumer responses. Also, this finding is partially supported by Kiran and Prabhakar (2021), who highlighted that neuromarketing involves complex psychological and neurological processes and emotional responses may not always produce consistent behavioural outcomes due to subconscious variability. Additionally, the aforesaid findings indicated that brand perception significantly influences consumer perspectives such as purchase intention, preference and loyalty. This is in line with research conducted by Sukandi and Fazry (2025), who emphasized that both cognitive and emotional interactions along with digital engagement factors played a crucial role in shaping brand perception in modern marketing environments.

Despite the statistical significance of relationships, the poor model fit indices suggested that the structural model requires refinement. This observation has been supported by existing

literature, which indicated that neuromarketing models often face challenges related to construct validity and measurement complexity. Therefore, while the study confirmed the importance of cognitive dominance in neuromarketing, it also highlighted the need for improving measurement scales and model specification for better empirical validation. Overall, the discussion establishes that consumer perspectives are influenced by a combination of cognitive processing, emotional responses and brand perception mechanisms, reinforcing the multidimensional nature of neuromarketing.

Limitations

The results may not be as applicable to various cultural or geographic situations because the data have been gathered from a single national sample. In addition to this, participant responses to self-reported questionnaires represents their perceptions rather than precise behavioural or neurological measurements, wherein there may be a possibility of occurrence of response bias. Furthermore, the overall model fit and construct stability in SEM analysis might have been impacted by the fact that several constructs are measured using a small number of indicators. Also, this research study has been conducted only on the associations, wherein cross-sectional approach limits the capacity to make causal inferences.

Suggestions

The future studies should think about improving the measuring model by adding several indicators for each latent construct to increase reliability and model fit. Comparative analysis would be possible and generalizability would be improved by extending the sample across geographical or cultural contexts. Moreover, to increase empirical validity, researchers may additionally combine survey results with experimental or neurometric data (such as eye tracking or biometric measurements). Also, using a longitudinal approach might offer more in-depth understanding of how neuromarketing affects customer viewpoints and brand impression over time. Furthermore, for a better understanding of contextual influences, future research may examine moderating factors like product category, internet exposure, or consumer interaction.

Conclusion

The present research has provided the ways in which neuromarketing affects customer viewpoints and brand perception through emotional and cognitive processes. Also, through developing brand perceptions that impact preference, purchase intention and loyalty; results showed that neuromarketing components significantly influence on how people view and react to companies. In addition to this, the findings of this study have emphasized on how crucial to combine cognitive and emotional marketing techniques in order to improve brand relationships, despite the original structural model, which needs to be improved for a better fit. Moreover, the findings of this research enhance the knowledge towards understanding the psychological processes and neuromarketing's influences on customers' outcomes. This in turn lays the groundwork for further investigation and smart brand managers.

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