ISSN: 0019-4824

The Indian Geographical Journal

Volume 100 2025 No.1 & 2

Centenary Volume

The Indian Geographical Society
Department of Geography
University of Madras
Guindy Campus
Chennai-600 025,India

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Acknowledgement

The Indian Geographical Society is thankful to the I.C.S.S.R., New Delhi for the grant received for 2024-25, towards the publication of The Indian Geographical Journal.

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The Indian Geographical Journal
Volume 100 (1) June - 2025, pp 01-19
ISSN 0019-4824

THE FIRST BRIDGE ON THE RIVER BRAHMAPUTRA IN GUWAHATI (ASSAM): ASSESSMENT OF TRANSPORT NETWORK GROWTH IN ITS NEIGHBOURING AREAS

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Abstract

This study focuses on the temporal change in road connectivity and accessibility after the completion of the Saraighat Bridge in 1963 on the river Brahmaputra. It aims at analysing the evolution of the road network in the neighbouring areas of the bridge from 1951 to 2021 in Guwahati, based on the data collected from various sources, including archival documents, topographical sheets, satellite images, and field observations. Besides an understanding of the spatio-temporal change in the pattern of transport connectivity before and after the construction of the Saraighat Bridge, the study investigates the relationship between the development of the road network and the economic activities in the neighbouring areas, particularly with respect to non-agricultural activities. The study utilises graph theory parameters and the Shimbel Index to assess the network connectivity, geographical accessibility, and road network density. The correlation between the network density and the existence of non-agricultural workers is also examined. After the Bridge, north bank regions gained convenient access to Guwahati city, resulting in a notable impact on the economic landscape of the area and commuters to Guwahati city. The northern neighbouring regions of the city transitioned from a predominantly agrarian economy to a non-farm economy over the decades. The study provides insights on transformative role of Saraighat Bridge in shaping the settlement pattern, land use and economic development of Guwahati.

Keywords: Brahmaputra, Bridge, Road Network, Connectivity and Accessibility, Economy

1. Introduction

Accessibility and mobility are the major components of the development of an area where transport networks play a significant role. In the contemporary social context, the transport network stands as a backbone of development exerting a profound impact on the very fabric of the environment and society. The transport network not only plays a significant role in improving the pattern of connectivity but also contributes towards the transformation of the landscape by providing accessibility to the places around. The development of road networks also improves social and economic condition (Deichmann et al., 2005) through better and easy access to health care, education and employment

opportunity (Patarasuk, 2013; Alstadt et al., 2012). Additionally, road networks play a pivotal role in shaping urban landscapes, serving as a catalyst for urban expansion and facilitating the growth and development of cities.

Construction of bridges on the rivers or water bodies has brought about a revolutionary change in transport connectivity. Humans can easily now overcome the water barrier such as rivers and wetlands between two land masses and accelerate the connectivity. In Korea, for instance, in the context of the country's complex terrain, bridges and tunnels are vital for the transport network, playing a crucial role in connecting regions, making them indispensable for national economic growth (Chang & Choo, 2009).

Various studies have been conducted to examine the factors, processes and patterns of development over time after the construction of bridges and tunnels. Barthelemy (2015) conducted a comprehensive study covering nearly two centuries to investigate the evolution of transport networks in Paris, France, and the findings revealed that the development of road networks is intricately shaped by a combination of gradual, localised expansions and occasional changes occurring over expansive regions. Erath et al. (2009) delved into the transformation of Swiss road and railway networks during 1950 - 2000. Their primary focus lies in assessing the structure, significance, and effectiveness of these networks. Meanwhile, Masucci et al. (2013) put their attention to the structural changes within London's road networks, scrutinising developments from 1786 to 2010. This historical perspective offers valuable insights into the long-term evolution of urban transport systems, particularly in densely populated metropolises like London. In a recent study, Reza et al. (2024) focused on the structural properties of road networks, critical nodes or intersections and examined network efficiency, accessibility, and community structure of the road networks in Porto, Portugal. The study employed a combination of graph theory and complex network science to measure centrality, network structural metrics, and community detection, and validated the complex network science approach as an effective tool to identify structural weaknesses and strengths and to understand the urban road system. Deng et al. (2023) emphasised the mutual relationship between urban growth and road network development and pointed out the limitations of traditional linear models and Euclidean geometry. These kinds of contemporary analyses provide critical insights into the dynamics of modern road networks, offering views on the implications for current transportation planning and policy-making efforts.

In addition, many studies have examined the impact of road networks on economic activities, consistently demonstrating the positive effects of well-maintained road networks on rural non-farm employment opportunities (Qiao et al., 2014). Studies in different parts such as Mexico (De Janvry & Sadoulet, 2001) and Vietnam (Van de walle & Mu, 2007) have found that a significant relationship exists between the expansion of rural road infrastructure and off-farm employment. In a case study in Peru, it was observed that access to the proper road has a positive influence on the returns from off-farm activities (Escobal, 2001). The accessibility provided by road networks has also created positive impacts on healthcare and education. Thus, scientific understanding of the evolution and

changes in road networks/infrastructure over time can provide valuable insights into their development patterns. In the background, this paper aims at analysing the temporal changes in the road network connectivity and accessibility using OpenStreetMap (OSM) data combined with satellite imagery and topographical maps in neighbouring regions of Guwahati city.

This study explores how the construction of the Saraighat Bridge on the Brahmaputra in 1963 has been influencing the development of its nearby areas. The bridge, which is the first road-cum-rail bridge over the Brahmaputra, is a vital link connecting India's northeastern region with the rest of the country. After the construction of the bridge, transport infrastructure developed in the surrounding areas, leading to a surge in population. The municipal area was also expanded, resulting in the establishment of urban facilities during the recent decades. These newly developed urban facilities, along with the growth of industrial setups, have played a significant role in changing the local economy and further growth of the population in the region. The present study is carried out to achieve two main objectives: i) to assess the changes in road network connectivity and accessibility over time to analyse the progress and development of the road network pattern in the region over a period of seven decades (1951-2021), and ii) to examine the relationship between road network development and economic activities, especially the impact of road network density on the proportion of non-agricultural workers in the study area and rise in non-agricultural workers.

2. Study Area

The study area covers both the banks of the Brahmaputra River connected by the Saraighat Bridge directly and indirectly. The south bank area is demarcated by physical features, with Kamakhya and Fatasil-Ambari hills in the east and south-east, and the Deepor Beel, a Ramsar wetland in the south and south-west. The area lies in two districts of Assam, namely Kamrup and Kamrup Metro. The geographical extent of the study area ranges from 26° 7' 46" to 26° 15' 38" North and from 91° 36' 7" to 91° 43' 55" East. The entire study area comprises 24 villages, 3 census towns, and 9 municipal wards, covering 94.16 square kilometres of area on both sides of the Saraighat Bridge. The villages on the north bank primarily belong to Kamrup district, while the entire south bank falls within Kamrup (M) district. The area within the Kamrup (M) district comprises the wards of the Guwahati Municipal Corporation (GMC) and the satellite towns (Dharapur and Amingaon) of Guwahati City. The area around the Saraighat Bridge experiences warm summers and mild winters, with very heavy rainfall during the summer season. Monsoon winds prevail over the region from June to August with the highest rainfall in May, June, and July months.

2.1 Historical Background

With a rich historical background, the area under study serves as a strong foundation for the future development of the Guwahati city. Bhuyan (1947) provides an insightful account of the region's geographical significance and some notable events in his

book *Lachit Barphukan and His Time*. According to him, prior to the British colonial rule, this region held strategic importance for the Ahom kingdom. It bore clear witness to two major conflicts between the Ahoms and the Mughals, namely the Battle of Alaboi in 1669 and the Battle of Saraighat in 1671. The first engagement took place in the north-western plains of the study area, specifically the Dalibari-Dadara area, where a formidable force of 10,000 Ahom soldiers fought valiantly. The Ahoms sought retribution in the subsequent battle, that is the battle of Saraighat in 1671, leveraging the region's advantageous physical landscape to secure victory over the Mughals in a naval confrontation.

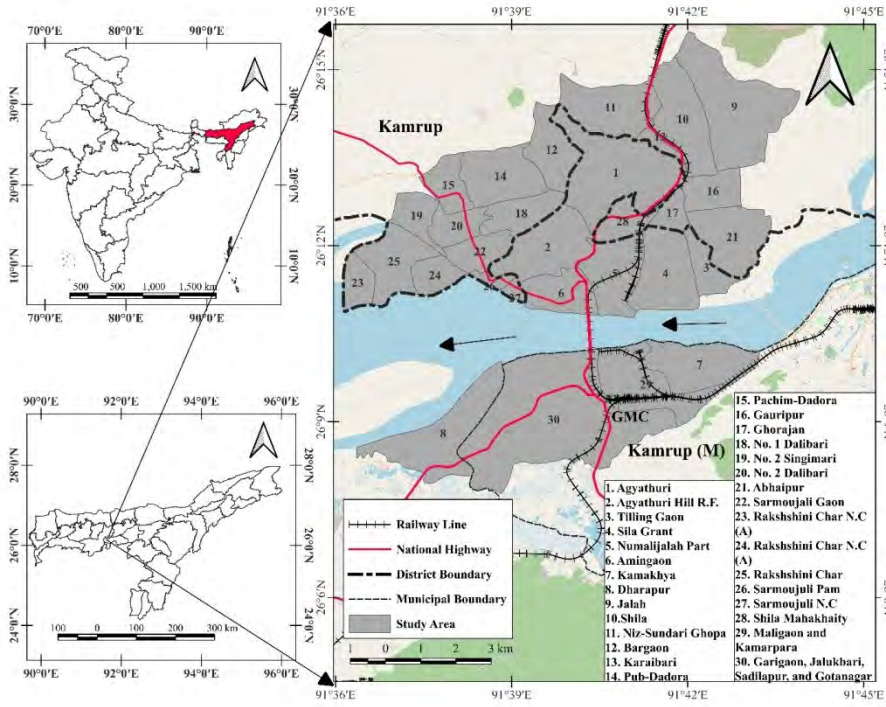


Figure 1: Study Area (Guwahati city and neighbouring areas) in Assam, India

Following the signing of the Treaty of Yandaboo in 1826, the British assumed control over the region, transforming it into an economic hub. Medhi (1978) highlights the region's economic significance as a vital river port, facilitating the progress of the entire north-eastern region. During the British era, the establishment of railways and roadways in this region linked it with the mainland of India. The Pandu-Amingaon port played a crucial role in facilitating the import and export of goods for the entire north-eastern region, with well-integrated railway and road networks converging at the port. With the advent of Independence, the Assam-Bengal Railway was partitioned based on political boundaries, and the Northeast Frontier Railway was established with its headquarters in Maligaon of this region. During 1956-57, the port experienced its pinnacle of import-export activities, facilitating the transportation of 49,600-meter gauge wagons. The completion of the Saraighat Bridge in 1963 played an important role in the development of the neighbouring

areas and the overall progress of the north-eastern region (Medhi, 1978). Notably, during the Sino-Indian war of 1962, this bridge held critical significance as the sole passage over the Brahmaputra River. Today, the bridge serves as an important transportation route for both roadways and railways, intersecting the east-west corridor represented by National Highway (NH) Number 27.

3. Methodology

3.1 Database

To evaluate the road network connectivity and accessibility Open Street Map (OSM) website (https://download.geofabrik.de/asia/india.html) was the main source to obtain data. OSM is widely acknowledged as a dependable and precise source of road network data, especially in urban areas (Liu et al., 2020). Data sets for 1951, 1971, 1991, 2011, and 2021 were generated by applying a combination of OSM data, satellite imageries from Landsat TM (acquired on 10.11.1991 and 30.01.2011), and Sentinel-1C (acquired on 10.01.2021) from the United States Geological Survey (USGS), as well as Google Earth images and topographical maps of the Survey of India (SOI) were used to capture the changes in network connectivity and accessibility over time. Survey of India's (1:50000) and U.S. Army's (1:250000) topographical maps were used for 1971 and 1951 respectively. Primary Census Abstract (PCA) data were collected from the Census of India for 1951, 1971, 1991, and 2011 were used to compare road network data with economic activity.

The OSM road network data were acquired from the OSM website as a vector feature layer, which was transformed into the Universal Transverse Mercator (UTM) zone 46 and World Geodetic System 1984 (WGS 84) projection using the ArcGIS platform. Topographical maps were georeferenced and rectified to a base image (Sentinel-1C, 2021), which was transformed into the same projection. An identical process was carried out for Landsat images. The OSM road network was extracted within the study area boundary, and the extracted layer was used as a base layer for road network preparation for 1951, 1971, 1991, 2011, and 2021. It involved feature editing of the road network using topographical maps, satellite imagery, and Google Earth images in the GIS platform.

3.2 Road network connectivity

Graph theory is now widely used for examining and comparing urban transportation networks (Levin, 2021). Kansky in 1989 also introduced different parameters for measuring road network connectivity based on graph theory (Kansky & Danscoin, 1989). In a road network, nodes (vertices) 'v' are represented by the starting and ending points of streets and road intersections, while road segments represent edges 'e'. The parameters developed by Kansky are widely accepted and have been applied in various studies to explore road network connectivity (Arif & Gupta, 2020). The parameters used in this study to measure connectivity are: Cyclomatic number (C), Alpha Index ($\boldsymbol{\alpha}$), Beta Index ($\boldsymbol{\beta}$), Gamma index ($\boldsymbol{\gamma}$), and Eta index ($\boldsymbol{\eta}$)

3.3 Geographical Accessibility

Shimbel Index (SI) is employed to examine the development of geographical accessibility of the study area. The SI is the most common and widely accepted parameter for assessing geographical accessibility (Moufad et al., 2018). The measurement of the Shimbel Index is done by adding the shortest distance between the junctions and placing it in the accessibility matrix (Moufad et al., 2018). Shimbel Index (Si) can be defined as:

$$SI = \sum_{j=1}^{n} dij$$

In this study, 19 x 19 origin and destination points (figure 2) are taken to calculate the shortest distance between them by using the network analysis tool in ArcGIS and placed the values into the accessibility matrix. From the matrix table, the Shimbel index is determined for each junction, and a geographical accessibility map is prepared by employing IDW (inverse distance weighted) in the ArcGIS platform.

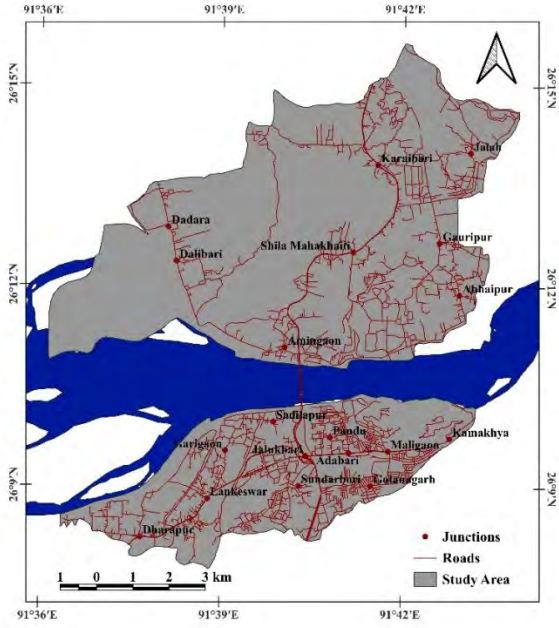


Figure 2: Junctions for calculating geographical accessibility

3.4 Road Network Density

In the context of transportation and urban planning, road network density refers to the amount of road infrastructure in a given area, usually expressed as the length of road per unit area. Road network density can be calculated using various metrics, such as the

total length of roads in a given area (e.g., kilometres of road per square kilometre of land) or the number of road segments (e.g., street blocks or road links) per unit area. In this study, road density is defined as

Network Density = total length of network of the region / total area of the region

3.5 Correlation between network density and non-agricultural worker population

Pearson's correlation coefficient is employed to determine the degree of relation between road network density and non-agricultural population. Pearson's correlation coefficient is widely used in many fields, including geography, social sciences, engineering, and finance, to assess the strength of the relationship between two variables.

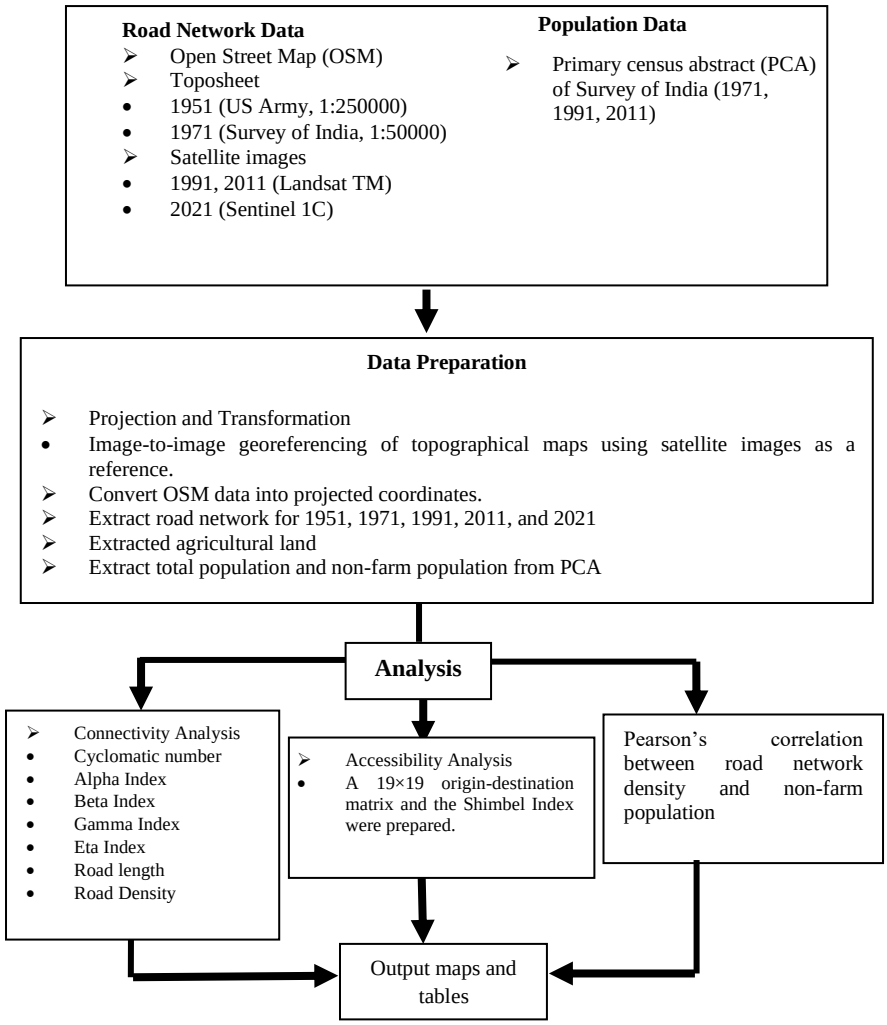


Figure 3: Flow chart of methodology of the study

4. Results and discussion

In 1865, Guwahati was designated as Gauhati Municipal Town. However, the area of the municipal town was restricted to the core area of the present-day Guwahati city. Pandu, Maligaon, and Jalukbari on the south bank along with some settlements on the north bank, were served as villages. These areas were sparsely populated, and most of them had agricultural land, forests, and wetlands. In 1941, the settlements in Pandu were evacuated due to the establishment of a military cantonment during World War II. Under the British administration, Pandu-Amingaon emerged as an important river port and railway station.

Railways were initiated in Assam during the 1880s, mainly to serve the tea-growing areas of Upper Assam. However, 91 per cent of trade at that time was supported by river transport (Medhi, 1978). In 1903, the Kharikatia (Jorhat)–Gauhati town railway link was utilised for the first time to ship tea; however, the shipment to Kolkata was done via river transport from the Pandu port (Dutta, 2002). On April 1, 1909, the eastward extension of the Eastern Bengal Railway connected Pandu via Amingaon with ferry services at Pandu-Amingaon, and on January 1, 1910, a five-mile section was extended from Pandu to Gauhati town, connecting Eastern Bengal Railway with the Assam Bengal Railway (Dutta, 2002; Medhi, 1978). With the extension of the Eastern Bengal Railway to Amingaon and Pandu, the Pandu port became one of the busiest ports in the Brahmaputra Valley, Assam. It is apparent that the region has experienced discernible progress in road network development through these railway projects.

Before independence, particularly in the first couple of decades of the 20th century, there was only one metalled road on the south bank, which connected Kachari Bazar with Maligaon, Pandu Port, Jalukbari, and the Dharapur area. The other parts of the south bank were connected by unmetalled roads. The northern part of the study area had no metalled roads at all. Most of the villages on the north bank, such as Shila, Jalah, No. 1 Dalibari, and Agyathuri, were accessible only by foot tracks or unmetalled roads. After independence, the road network saw some improvements. Foot tracks were replaced by cart tracks. One secondary metalled road connected Majgaon Ghat with other districts on the north bank of the Brahmaputra. Majgaon had a bus station from where public and private buses ran to other districts. However, this secondary metalled road had a loose surface, resulting in low traffic. People from the north bank, who wanted to reach Guwahati, would first travel to Majgaon Ghat and then take a ferry to Guwahati. The Hajo-Amingaon Road, which connected Majgaon Ghat and Amingaon station, remained unmetalled causing difficulties during the monsoon season.

The inauguration of the first rail-cum-road bridge over the Brahmaputra River in 1963 marked the genesis of a vital road and railway connection in the area. Subsequent to the completion of the bridge, the region had witnessed a remarkable surge in the expansion of its road infrastructure (Figure 5). This growth has catalysed the establishment of various industries, industrial parks, healthcare facilities, and esteemed educational institutions like

the Indian Institution of Technology (IIT) and All India Institute of Medical Sciences (AIIMS), National Law University and Juridical Academy, etc., within this vicinity. To evaluate this progress, the road networks for five different periods (1951, 1971, 1991, 2011, and 2021) were examined and compared (Table 1).

4.1 Cyclomatic number

In this study, the average cyclomatic number of the entire area was 22.33 for 1971, which increased to 33.09 in 2021. There is clearly an increasing trend observed in the average value of the cyclomatic number with an annual rate of 0.22. A similar trend is observed in the minimum and maximum values. The highest cyclomatic number was found for Garigaon, Jalukbari, Sadilapur, and Gotanagar region in 1971 and this trend continues till 2021. On the other hand, the lowest cyclomatic number was observed for both Tilling Gaon and Bargaon village in 1971. However, in 2021, connectivity increased for Tilling Gaon village, while Bargaon village still scores the minimum cyclomatic number (Table 1).

Table 1 : Minimum, maximum and average values of different connectivity parameters and percentage of Non-agricultural workers

Parameters or Indices	Minimum					Maximum					Average				
	1951	1971	1991	2011	2021	1951	1971	1991	2011	2021	1951	1971	1991	2011	2021
Cyclomatic Number		2	3	4	2		153	202	216	277		22.333	26.684	28.579	33.091
Alpha Index		0.0467	0.0488	0.0447	0.0447		0.667	0.727	0.727	0.519		0.224	0.227	0.228	0.199
Beta Index		1.0714	1.0857	1.0761	1.0818		1.667	1.875	1.875	1.813		1.274	1.316	1.327	1.308
Gamma Index		0.3704	0.3689	0.3667	0.3652		0.833	0.833	0.833	0.690		0.501	0.497	0.497	0.477
Eta Index (in Km)		0.1001	0.0985	0.0994	0.1012		0.514	0.419	0.419	0.500		0.222	0.199	0.193	0.180
Road Length	0.721	0.6023	0.8398	0.8398	0.8017	22.301	81.798	100.599	105.525	131.664	5.145	12.098	15.76	15.736	17.630
Road Density	0.533	0.1732	0.2416	0.2416	0.5140	3.029	8.874	10.692	11.400	11.826	1.468	2.882	3.549	3.764	4.597
Percentage of Non-agricultural workers		7.5	28.57	63.97			98.94	98.23	98.94			43.43	60.59	84.87	

Source: Calculated from road network topology obtained from toposheets and satellite imageries

4.2 Road network connectivity

Three parameters were employed to analyse the degree of connectivity of the network for all the years. Despite the ongoing development of the road network in the region, no discernible trend was found in the values of these parameters. However, they demonstrate regional variation for each particular year. The average value of the alpha index showed negligible change until 2011, after which it decreased to 0.20 in 2021, indicating a tree pattern or less connected road network in the area around the Saraighat bridge. In contrast, there was a decrease in the maximum value to 0.51 in 2021, while the minimum value also decreased in the same year. The maximum value of the alpha index

was found for Tilling Gaon (north bank) village in 1971. In 1991 and 2011, Shila Mahakhaity on the north bank consistently exhibited the maximum alpha index values. However, despite the South Bank areas having a significantly higher total road length, they lack maximal connectivity, indicating a disconnected or tree-pattern road network topology. Conversely, the north bank areas with maximal connectivity exhibit fewer nodes and edges, indicating a lower number of routes. Conversely, the minimum value of the alpha index was found for Jalah village from 1971 to 2011, while in 1991 and 2021, it was found in the Dharapur region, indicating an elongated tree pattern road network in the area.

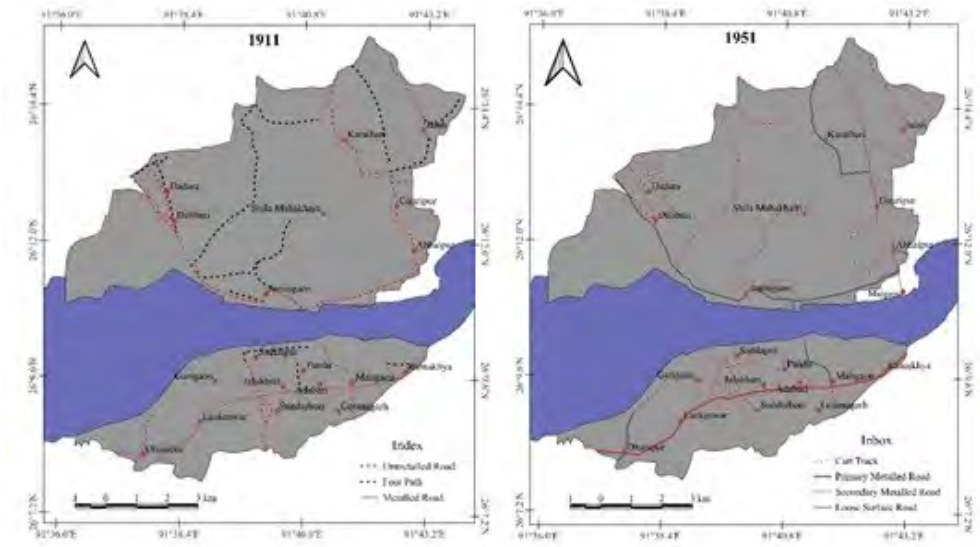


Figure 4: Road Networks of the neighbouring areas of the Saraighat Bridge in 1911 and 1951

In terms of the Beta index, no significant fluctuation in the average and minimum values over time was observed. Nevertheless, a subtle upturn in the maximum value occurred in 1991, remaining unchanged until 2021. Much like the Alpha index, this pattern suggests a shift in the road network of these areas towards a less connected configuration in recent decades. Shila Mahakhaity village consistently demonstrated the highest level of complexity or maximal connectivity from 1971 to 2011, while in 2021 maximum value was obtained for Karaibari. Conversely, Jalah village exhibited the lowest values from 1971 and 2011, while Dharapur area recorded the lowest value in 1991 and 2021. These findings imply the development of elongated and tree-like road networks in these areas, aligning with the results observed in the Alpha index.

The Gamma index, representing the ratio of the number of edges to the maximum possible edges, shows a slight decrease in its average value. So far, the regional variations are concerned, Tiling Gaon exhibited the highest value in 1971, while in the subsequent years, Shila Mahakhity (1991 and 2011) and Karaibari (2021) recorded the maximum value.

This suggests improved connectivity in Shila Mahakhaity and Karaibari, even though it has a lower total road length and network density. In line with the alpha and beta indices, Jalah village consistently displays the minimum value of the gamma index from 1971 and 2011. However, in 1991 and 2021, the Dharapur area took over this position with the lowest recorded gamma index value. These trends indicate a tree-patterned road network in these areas, reinforcing the patterns observed in the alpha and beta indices.

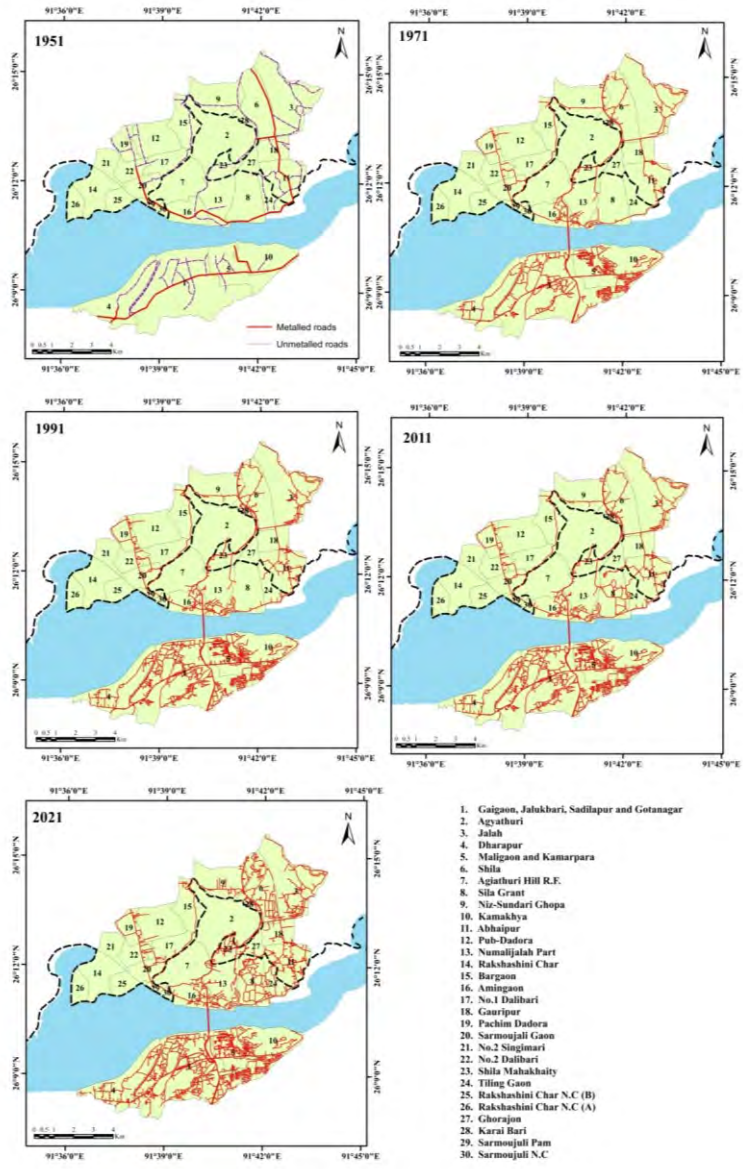


Figure 5: Temporal change of road network in the neighbouring areas of the Saraighat Bridge.

4.3 Eta Index

The Eta index measuring the average length of edges within a network reveals a consistent and noteworthy downward trend in average, minimum, and maximum values from 1971 to 2011. However, with the introduction of new roads, No. 1 Dalibari village exhibited the maximum value. This trend signifies a notable enhancement in road network coverage over the past decades. From 1971 to 2011, the Bargaon area consistently outperformed, maintaining the highest Eta values. This suggests that these areas have historically exhibited lower road network coverage or higher distances between nodes. The Maligaon and Kamarpara areas consistently exhibited superior road network coverage from 1971 to 2021.

4.4 Road Network and Length Density

The road network length and density in the area witnessed an overall growth. Notably, there was a significant rise in the average road length and density observed from 1951 to 1971 and from 2011 to 2021. In 1951, Tiling Gaon had the highest road density. In contrast, between 1971 and 2021, Maligaon and Kamarpara, along with Garigaon, Jalukbari, Sadilapur, and Gotanagar, exhibited the highest road density, with the fastest rate of change at 0.14 and 0.1 km/km^2/year, respectively.

4.5 Geographical accessibility

The Shimbel Index is a method used to assess the geographic accessibility of a region. To analyse accessibility from 1971 to 2021, 19 x 19 origin and destination points or junctions were selected. The results indicate a consistent increase in the overall accessibility over time. Notably, the junction at Jalukbari had the lowest Shimbel Index value, indicating that it is the most accessible location in the area. Conversely, Jalah, Gauripur, and Dadara junctions were identified as the least accessible locations. The accessibility map (Figure 6) illustrates that the areas closer to the bridge have greater accessibility, and this accessibility is progressively improving over time.

4.6 Economic Impact

After the construction of the Saraighat Bridge, residents on the north bank gained convenient access to Guwahati city, resulting in a notable impact on the economic landscape of the area. A remarkable shift was observed as a considerable portion of the population started commuting to Guwahati city, catalysing a transition from a predominantly agrarian economy to a non-farm economy over the decades, which is reflected in the decreasing agricultural land in the area. In 1971, the total agricultural land was 3,422 hectares, which decreased by 81.04% (648.52 hectares) in 2021. In this period, infrastructural developments throughout the region played a pivotal role in driving this economic transformation (Figure 7). Notably, the proportion of non-agricultural workers increased in all the areas except for Tiling Gaon during this period. Moreover, there was a consistent upward trajectory in the average, minimum and maximum percentages of non-

agricultural workers across the years. Throughout the period under consideration, the south bank consistently exhibited the highest proportion of non-agricultural workers. In contrast, the north bank, particularly No.1 Dalibari in 1971 and 1991, and Agyathuri in 2011 recorded the lowest percentage of non-farm workers. Sila Grant and Shila Mahakhaity emerged as special areas experiencing the most significant increase in the proportion of non-farm workers. Conversely, the south bank collectively exhibits the lowest rate of change in the proportion of non-farm workers.

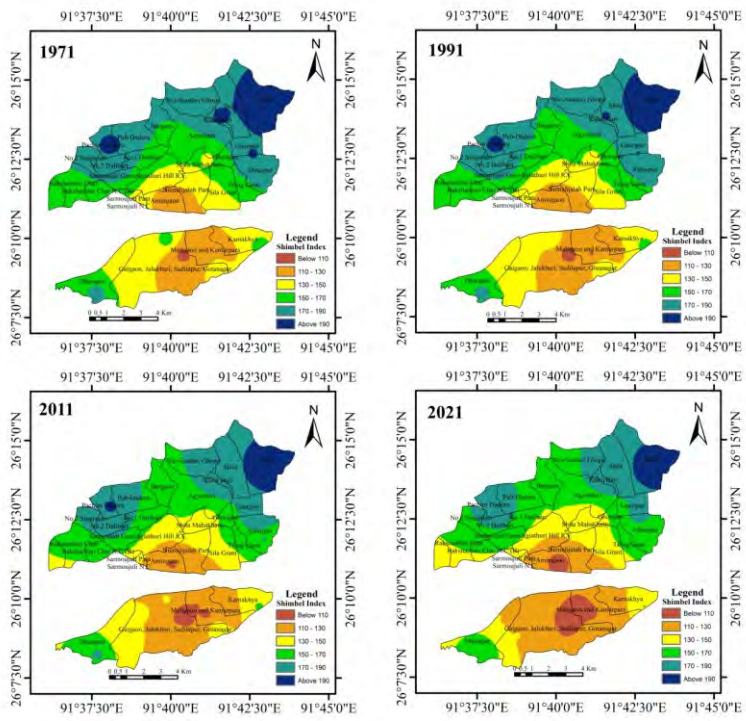


Figure 6: Temporal change of geographical accessibility of the neighbouring areas of the Saraighat Bridge.

In 1974, after the construction of the bridge, the municipal area of the Guwahati city got expanded, leading to the emergence of new urban areas. One such area is Adabari, located on the south bank, which has experienced significant growth during recent decades. Various urban facilities, such as shopping malls, cafés, a city bus station, and showrooms, were developed creating new job opportunities. Meanwhile, due to the rapid population growth and expansion of built-up areas, agricultural land started decreasing (Figure 8). As a result, many individuals previously engaged in agriculture shifted to newly growing non-farm activities. Additionally, several industries have been established on the north bank in recent decades, including the Brahmaputra Industrial Park, Export Promotion Industrial Park, and Trinity Business Park, for example (Figure 7). These developments have remarkably influenced the economic landscape of the north bank

Relation between Road network and growth of non-farm work:

Karl Pearson's correlation coefficient technique was employed to investigate the relation between the road network density and the number of non-agricultural workers during a period of 40 years (1971 – 2011). The results reveal a statistically significant positive relationship between the two variables. Specifically, the correlation coefficient values were $r(16)=0.7$ ($p < 0.01$) in 1971, $r(18)=0.5$ ($p < 0.05$) in 1991, and $r(19)=0.7$ ($p < 0.01$) in 2011. These results indicate that there exists a moderate to strong positive correlation between road network density and non-agricultural workers throughout the periods. In other words, an increase in road network density is likely to be associated with an increase in the number of non-agricultural workers in the area.

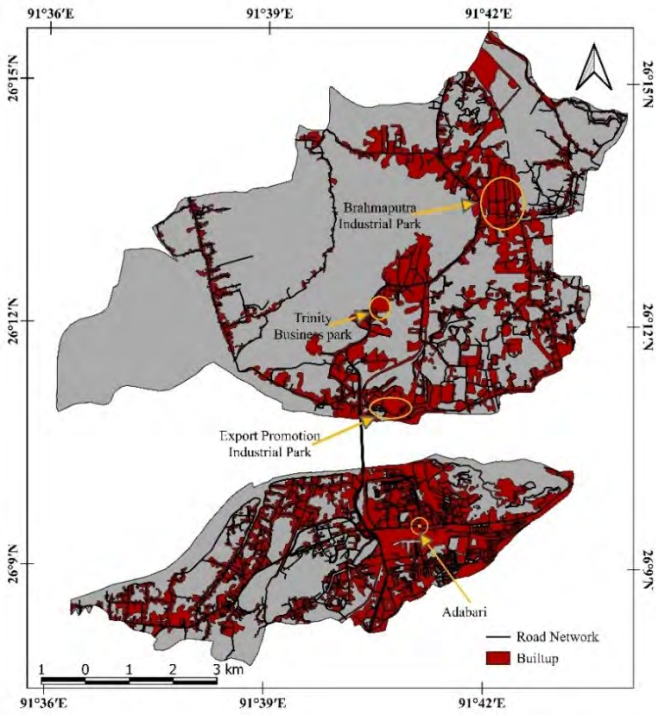


Figure 7: Growing urban area and industrial regions of the surrounding areas of the Saraighat bridge

The temporal changes and regional variations in road network connectivity, accessibility, and their correlation with economic activity are examined for the period 1951 to 2021. In 1951, the road network was fragmented, with only 29.35% of roads being metalled and motorable. However, in 1971, there was a significant surge of 128.72% in the network's mileage, accompanied by the construction of the Brahmaputra's first rail-cum-road bridge, contributing to the development of more complex road networks. This reveals an increasing trend in the complexity of the circuit over time, indicating improved connectivity between areas. While the total mileage of the network increased, the ratios of observed circuits and possible circuits, edge-vertex, and observed edges to the maximum

possible edges remained unchanged or slightly changed. Additionally, the average edge distance exhibited a negative trend. Overall accessibility was found to improve, particularly near the Saraighat Bridge, and there was a shift of the working population towards non-agricultural work, as evident from the increase in the non-agricultural during from 1971 to 2011.

The analysis spans several decades, tracking the evolution of the road network from 1951 to 2021, and reveals significant development in the network's mileage and complexity. This aligns with the first objective of assessing the changes in connectivity and accessibility over time. Additionally, the study establishes a correlation between road network development and economic activities. The increase in the non-agricultural workers from 1971 to 2011 is shown to have a significant positive relationship with road density, indicating the impact of transportation development on shifting employment patterns. This aligns with the second objective of examining the correlation between road network development and economic activity. Surprisingly, despite the overall increase in the total mileage of the road network, the study also found an unexpected result. It is observed that both road length and road density have increased impressively, resulting from the development of new built-up areas, population surge, expansion of the municipal area, and the rural road connectivity program by the government. The Pradhan Mantri Gram Sadak Yojana has played a significant role in this regard. However, it was observed that this increase in mileage did not have a noticeable effect on the alpha, beta, and gamma indices. Despite the expansion of the road network, the index remained relatively stable, suggesting that other factors might be influencing this index.

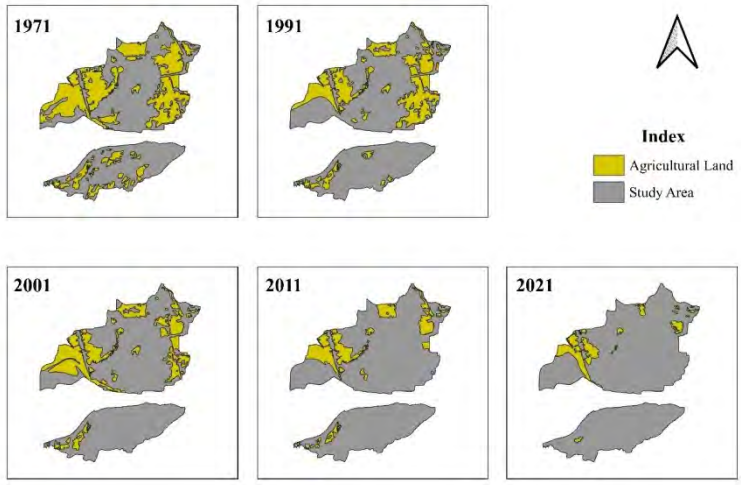


Figure 8: Temporal change in agricultural land in the area around the Saraighat Bridge

There has been a progressive increase in the circuit connectivity or cyclomatic number (C) over time, indicating the introduction of additional alternative routes between

nodes. The expansion of the road network has led to the creation of more alternative routes, which can effectively reduce travel time (Mittal et al., 2017). Furthermore, it influences aspects like the labour market, trade, and commerce (Alstadt et al., 2012). However, when comparing regional disparities in circuit connectivity, the cyclomatic number alone proves inadequate since it solely considers the total number of nodes and edges, disregarding the region's total area. Nevertheless, this index can be employed to compare the temporal growth of circuit connectivity within a specific region. The highest growth in circuit connectivity was observed from 2011 to 2021 across the entire road network. This growth can be attributed to increased urbanization (Pawe and Saikia, 2018) and the establishment of various industries near the Saraighat Bridge. With the expansion of the municipal area in 1974, the population of the study area gradually increased. In 1991, the total population of the area was 86,804, which increased by to 1,67,746 in 2011. Such a rapid growth led to the construction of new built-up areas and roads, which boosted further urban expansion. This type urban expansion puts stress on the agricultural land, wetlands, and other natural features, resulting in an increase in the non-farm population and also environmental degradation. As the road network connectivity expands, the average distance between edges decreases, which can be quantified using the eta index. Calculations for the Eta index from 1971 to 2021 indicate a notable decline in the initial period. This decline can be attributed to the construction of the Saraighat Bridge, which connected the north and south banks of the Brahmaputra River, resulting in a rapid growth rate of the road network. A high eta value suggests a sparsely populated region or a lack of network coverage (Arif and Gupta, 2020). In this study, it was observed that regions on the southern bank have low eta values and higher population density compared to the northern bank (Census 1951, 1971, 1991, and 2011).

Another notable trend observed in the study is the increased accessibility between areas, which consistently improved over time. Areas closer to the Jalukbari junction exhibit the highest accessibility due to the Saraighat Bridge, which serves as the sole link between the regions on both banks. As the distance from the bridge increases, areas become less accessible in between the study area. Circuit connectivity and network density can also impact accessibility. Interestingly, unexpected results were observed in the Alpha, Beta, and Gamma indexes, which also measure road network connectivity. Despite the total road length of the network increases in all periods, these three indices did not show any improvement. They decreased in 2021, indicating that these indices are not indicative of road network development. Moreover, these indices consistently exhibited low connectivity values throughout the periods. This unexpected outcome could be attributed to the extension of the road network into agricultural fields or other land cover areas, which may lead to dead-end roads and an imbalanced ratio of nodes and edges within the network (Patarasuk, 2013).

Connectivity plays a significant role in influencing travel time (Mittal et al., 2017), thereby impacting economic activities (Alstadt et al., 2012). This study establishes a significant positive relationship between road network density and the non-agricultural

population. The construction of the bridge and expansion of the road network has facilitated the establishment of various industries and increased people's access to markets, resulting in the generation of new employment opportunities within the region. The establishment of various institutions, industries and new employment opportunities act as a driving factor for population growth in the area, resulting in an increase in built-up area around the Saraighat bridge (Figure 9). The total population of the area in 1951 was 47,142 which increased by 255.83% (1,67,749) in 2011 (Census of India). Urban sprawl from 1951 to 2021 has also affected the region (Pawe and Saikia, 2018), leading to a shift in people's preferences towards non-agricultural.

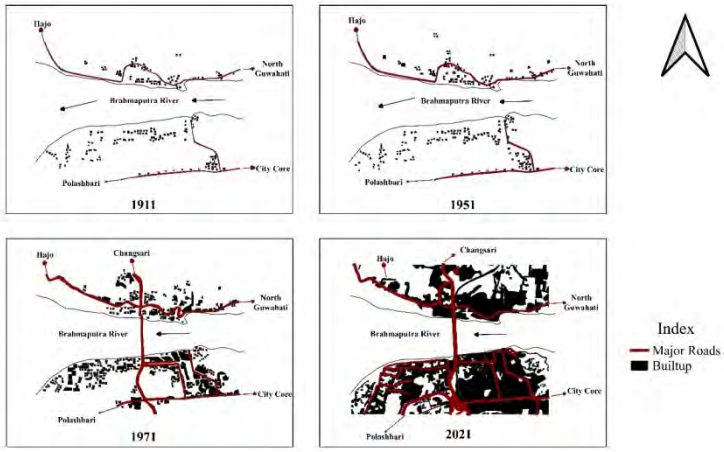


Figure 9: Increasing built-up density in the nearby areas of the Saraighat Bridge

5. Conclusion

This study systematically examines the temporal changes and regional variations in road network connectivity, accessibility, and their correlation with economic activity in the context of a specific region. The study observes a surge in the network's mileage and complexity from 1971 onward, accompanied by the construction of a crucial infrastructure like the Brahmaputra's first rail-cum-road bridge. Despite the increase in the total mileage of the road network, the study observes some stability in alpha, beta, and gamma indices, suggesting influences of other factors on the connectivity pattern. The progressive increase in circuit connectivity over time indicates improved regional connectivity. Moreover, the construction of additional alternative routes between nodes is found to contribute towards reducing travel time and thus influences the labour market, trade, and commerce.

With the increase in connectivity, various changes have been observed in the surrounding areas of the bridge. Due to the increase in population of the region the built-up areas got expanded including encroachment of the agricultural lands. After the construction of the bridge, the urban areas started spreading over the southern bank of the study area. With the development of connectivity, a number of institutions and industrial areas have emerged playing a significant role in the local economy.

It has been observed that the accessibility of this area has improved significantly, especially near the Saraighat Bridge, which serves as a vital link between north and south Guwahati. The analysis reveals a positive relationship between road density and the non-agricultural population, indicating the impact of transportation development on employment pattern and urbanization. The increase in road network density has led to the expansion of the built-up areas creating more pressure on the agricultural lands. On the other hand, urbanization and the establishment of more industries in the region provided various opportunities for non-agricultural employment, resulting in a gradual shift of people from agricultural to non-agricultural activities. The study found that the road infrastructure (Saraighat bridge) has not only improved the regional connectivity but also played a transformative role in shaping the settlement pattern, land use and economic development in Guwahati.

Acknowledgements

The authors would like to express their gratitude to Indian Council of Social Science Research (ICSSR) for supporting the research work.

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The Indian Geographical Journal
Volume 100 (1) June - 2025, pp 20-38
ISSN 0019-4824

PERCEPTION OF HOUSEHOLD SOLID WASTE MANAGEMENT PRACTICES IN THE SOUTH ZONE OF COIMBATORE CORPORATION, TAMIL NADU, INDIA

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Abstract

Solid waste generation depends on population characteristics and can impact local scenery and ecosystems. This study investigates household solid waste management perceptions in Coimbatore's south zone using questionnaire data analysed with SPSS factor analysis. Factor associations and variances were examined, and spatial variations were assessed using Z scores in ArcGIS 9.1 software. As a result, the findings show that the people in this region have a moderate to high standard of living. The analysis of the collected dataset proved that the eight attributes, specifically socio-economic condition, facility in the house, accessibility of dust bin, environmental problem, the standard of living, attitude towards the workers, disposal and collection of solid waste materials, determine solid waste management practices in the south zone of Coimbatore Corporation. The eight identified attributes were combined to determine household solid waste management levels in Coimbatore's south zone, ranging from very low to very high. The resulting Z scores reflected residents' perceptions of solid waste management practices in the study area. In general, most of the wards fall into the low to medium categories, with significant numbers of wards facing challenges in waste management, environmental issues, and accessibility to services like dustbins. These challenges appear to be the most pressing concerns in the study area, and it also seems to reflect that there is a need for targeted improvements in certain wards. Proper solid waste management practices are to be developed in the study area, which is vital to keeping a tidy environment in this study region.

Key Words: Solid Waste, Factor Analysis, Z-score Map, Coimbatore, Public Perception

1. Introduction

Globally, urban areas generate approximately 3.5 million tons of solid waste each day—a figure projected to rise to around 6.1 million tons per day by 2025, according to the World Bank (2019). Solid waste generation is influenced by factors such as socioeconomic status, cultural habits, population structure, and income levels (Emery et al., 2003; Ismail et al., 2018; Bradley et al., 1999; Eagles & Demare, 1999). Economic growth, urbanisation,

and rising living standards in Indian cities have increased both the quantity and complexity of solid waste, potentially impacting local landscapes and ecosystems. Research by Mohamad Noufal et al. (2020) identified several factors influencing solid waste generation rates and composition. Their findings, based on Pearson's coefficient values, indicate a positive correlation between household solid waste generation and variables such as monthly income, household size, and age of the household head. Conversely, a negative correlation exists with the education level of the household head. Roy and Deb (2013) established a positive relationship between the number of occupants in a household and the quantity of solid waste produced. Understanding residents' characteristics and their perspectives on sanitary workers is crucial for effective solid waste management.

Current solid waste management practices are frequently hampered by conventional transport methods, roadside dumping, disposal into water bodies, irregular waste collection programs, inadequate infrastructure, financial constraints, insufficient skilled personnel, and poorly regulated landfills (Mulat et al., 2019; Okeyode & Rufai, 2011; UNESC, 2009). Nkansah et al. (2015) found that household size directly impacts waste generation and positively influences improved solid waste collection services among households. Hoornweg and Bhada-Tata (2012) argued that increases in population, lifestyle changes, and rising income levels are critical contributors to solid waste generation. Additionally, Gu et al. (2015) reported that higher education is negatively associated with increased awareness of environmental issues.

Poor solid waste management exerts considerable adverse effects on public health, local and global environments, and economic stability (Hoornweg & Freire, 2013; Adeleke et al., 2021). Locally, improperly managed waste attracts disease vectors, leading to greater disease burdens among those living or working near such sites (Fadhullah et al., 2022). The diversion of recyclable, reusable, and remanufacturable materials from landfills through effective sorting methods offers significant environmental benefits (Zhang et al., 2019). Poor segregation can, however, result in both environmental and health hazards (Heidari et al., 2018). Unsuitable disposal methods, such as unsorted waste disposal, can lead to groundwater pollution, soil degradation, and other environmental disturbances. Similarly, burning unsorted solid waste contributes to air pollution and poses risks to human health (Matsuda et al., 2018). These negative impacts underscore the importance of sustainable solutions for solid waste management (Agovino & Garofalo, 2018). Human activity remains the primary source of solid waste production (Khalil et al., 2018). Efficient household solid waste management is a key challenge within urban centres, as highlighted by extensive research on generation patterns, socioeconomic dynamics, and environmental impacts. While studies such as Hoornweg and Bhada-Tata (2012), Gu et al. (2015), and Mohamad Noufal et al. (2020) have elucidated important relationships between waste generation and variables including income, education, and population density, several important research gaps persist.

This study examines the socioeconomic conditions, housing types, household waste collection, environmental issues, and residents' views toward sanitary workers in the

south zone of Coimbatore Corporation. Existing studies on household solid waste management largely focus on statistical relationships between socioeconomic factors and solid waste generation, often neglecting spatial dimensions and public perceptions. Limited attention is given to environmental challenges and operational efficiency, such as solid waste collection accessibility. Moreover, research seldom addresses region-specific contexts or provides actionable policy insights. Hence, this study fills these gaps by employing GIS-based spatial analysis, exploring public attitudes, and integrating socio-economic and environmental factors, offering tailored recommendations for the South Zone of Coimbatore Corporation.

Study Area

The South Zone of Coimbatore Corporation extends from 10°54′00″ N to 11°01′30″ N latitude and 76°54′00″E to 77°00′30″ E longitude, encompassing an area of 54.13 sq. km (Figure 1). This region is represented on Toposheet 58A16, 58B13, and 58F1. Comprising 20 wards, it is bordered by the Western Ghats Mountain range to the west and north, and by reserved forests to the north. These geographical features contribute to generally pleasant weather conditions, although the area predominantly experiences a tropical wet and dry climate. The average temperature hovers around 26°C, ranging from 24°C during the monsoon season to 30°C in summer. April is typically the hottest month, with temperatures occasionally exceeding 38°C, whereas January is the coolest, with lows down to 12.2°C.

The Noyyal River traverses this zone, delineating the southern boundary of the Corporation. The city lies within the Noyyal basin and benefits from an extensive tank system supplied by the river and rainwater. Topographically, the surface slope trends from west to east, while altitudes vary between 256 feet and 6,371 feet above mean sea level. As of 2021, the projected population is 537,019, comprising 268,939 males and 268,080 females. The area exhibits an average population density of 9,920 per sq. km, an average sex ratio of 964.35, and a literacy rate of 80.96%. Coimbatore is renowned for its textile industries, engineering firms, machine and machine tool manufacturing, healthcare facilities, and educational institutions. Within this context, the current study examines public perceptions regarding household solid waste management practices in the region.

2. Methodology

The information for the study was collected through a structured questionnaire via a stratified random sampling method—100 households from each of the 20 wards, resulting in a total sample size of 2,000. The survey included socio-economic details, household facilities, and accessibility of disposal infrastructure, environmental problems, and solid waste disposal practices. A total of 69 variables were initially recorded. Given the large number of variables, Principal Component Analysis (PCA) was used for dimensionality reduction in SPSS. Based on factor loadings (≥0.5), eigenvalues (>1), and thematic relevance, 20 key variables were retained and grouped under eight principal components.

Variables with low communalities, cross-loadings, or conceptual redundancy were excluded. A total of 20 out of 69 variables were extracted across eight dimensions to characterise the relationships and variance among all attributes. Furthermore, spatial variations for each factor were analysed by incorporating Z-score values within ArcGIS 9.1 software. The resulting maps facilitate further interpretation and provide insights into the influence of each factor within its respective regions.

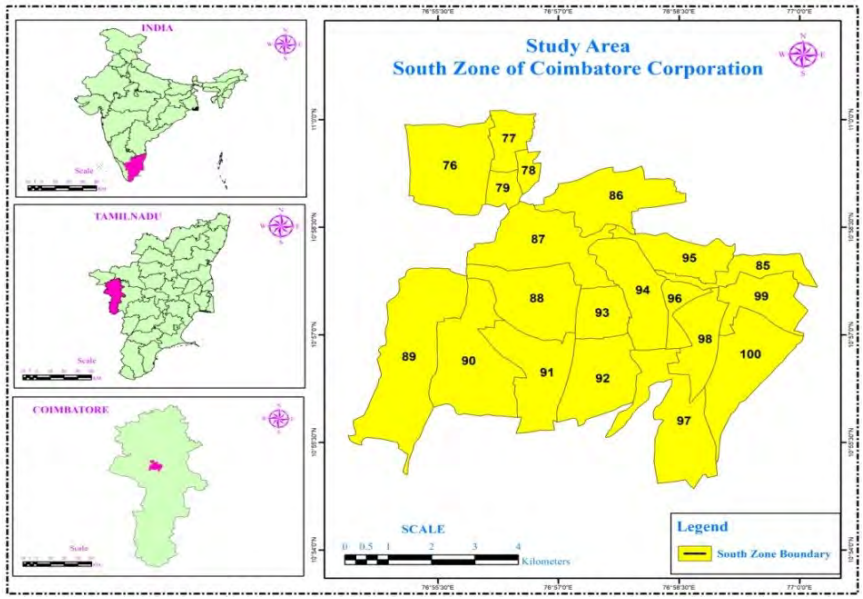


Figure 1. Study Area-South Zone of Coimbatore Corporation

3. Results and Discussion

3.1 Factors Extraction

Factor analysis identified eight key dimensions driving household solid waste generation and management in the South Zone, Coimbatore Corporation. These factors cover infrastructure, socio-economic status, public attitudes, and environmental issues. The Kaiser-Meyer-Olkin (KMO) value was 0.702, indicating a sufficient sample size for analysis. Bartlett's Test of Sphericity was significant ($p = 0.001$), validating the correlation matrix for factor analysis. Eight dimensions were interpreted based on Eigenvalues (>1) and scree plot results. Variables with factor loadings ≥ 0.6 were deemed important, though variable selection varied by factor.

All retained variables had loadings ≥0.64 and communalities ≥0.5, ensuring high statistical and thematic relevance. Factor-wise spatial Z-score maps were created for each component to visualise their influence across wards. These maps reveal spatial disparities in infrastructure, waste collection efficiency, and environmental problems. For instance, households in wards with higher Z-scores for infrastructure (e.g., Ward 89) do not

necessarily face higher environmental risks, indicating the moderating effect of institutional services. Tables in the sections below summarise the number of variables associated with each factor and the respective survey questions.

Table 1. KMO and Bartlett's Test

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.702
Bartlett's Test of Sphericity	Approx. Chi-Square	11856.512
	Df	190
	Sig.	0.001

3.2 Socio-Economic Conditions

Among 2000 respondents who live in the south zone of the Coimbatore corporation 45% and 55 % are male and female respondents, respectively. Their ages were < 20 (6.10%), 21 to 40 (43.30%), 41 to 60 (38.00%) and > 61 (12.80%) years. Religiously, they are Hindu (70.80%), Christian (16.20%), Muslim (12.00%) and others (01.05%). Their educational backgrounds are illiterate (16.20%), elementary (20.10%), high school (19.90%), higher secondary school or diploma (18.40%), bachelor's (22.20%) and master's degree (3.20%). The respondents are engaged in daily labour (22.30%), private jobs (22.70%), government jobs (9.40%), doing their own business (16.70%) and housewives/retired (28.90%). They live as a separate (62.00%) and joint family (38.00%), and their family sizes were <2 (11.30%), 3 to 5 (66.00%) and >6 (22.70%). The respondent's average monthly incomes were ₹<10,000 (17.20%), ₹10,001-20,000 (33.60%), ₹20,001-30,000 (25.60%), ₹30,001-40,000 (14.00%) and ₹>40001(9.60%).

3.3 Factor I: Facility in the House

Factor analysis in this study effectively identified key dimensions of people's attitudes toward sanitary workers in Coimbatore's south zone. Residents evaluated solid waste management workers on tasks such as waste collection, bin clearing, transport, and local challenges. Household waste generation varies by socio-economic status and living standards. The primary factor, ‘facility in the house,’ had an eigenvalue of 3.152 and explained 15.8% of the total variance (Table 2). Although this may seem modest, Principal Component Analysis identifies key patterns, and the results were validated by KMO and Bartlett’s tests, confirming statistical significance.

There are four variables positively loaded on this factor, specifically toilet facility (0.953), bathing room facility (0.946), drainage facility (0.912) and LPG gas cylinder (0.646). These positive scores of the variables undoubtedly proved that the people's standard of living is very high in this region. As a result, it is proven that the people in this region have a chance of producing large quantities of solid waste material, and they are fond of a clean environment. This paves the way for solid waste management workers to maintain a tidy environment in this study area.

Table 2. Factor I: Facility in the House

Variable No.	Variable Name	Factor Loading	Communalities
Ih1	Toilet Facility	0.953	0.915
Ih7	Bathe Room Facility	0.946	0.901
Ih12	Drainage Facility	0.912	0.835
Ih16	LPG Gas Cylinder	0.646	0.630
Eigen value:3.152			**Total Variance:15.759**
Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalisation. Rotation converged in 5 iterations.			

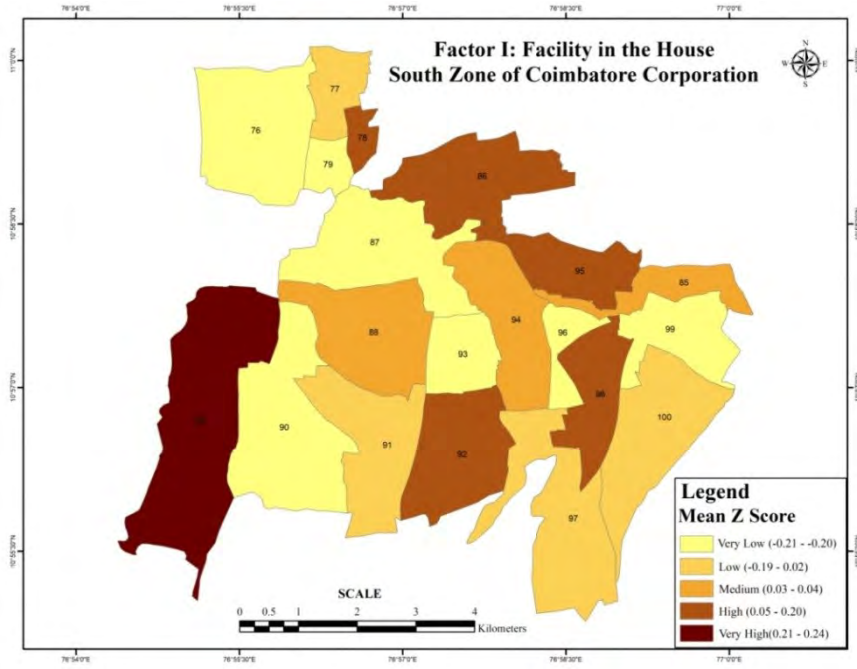


Figure 2. Facility in the House

Figure 2 shows the residents' facility in the south zone of Coimbatore Corporation. Hence, the very meagre negative Z score (-0.21 to -0.20) has registered in seven wards. This unquestionably exhibits that the facilities in their house were meagre among the people residing in these wards. Likewise, the low Z score values (-0.21 to -0.13) were observed in three wards, indicating that the people have fewer facilities in their houses. The medium negative to positive Z score (-0.14 to 0.06) was recorded in four wards of the study region, so the inhabitants in these wards have moderate amenities at their homes. The high positive Z score (0.07 to 0.33) for five regions indicates that the people have high facilities in their houses.

Likewise, a very high positive Z score (0.34 to 0.61) was observed in one ward, which shows the higher level of facilities at their home. Z-scores were computed from 20 selected variables across eight dimensions (possibly socio-economic, housing, sanitation, water, waste management, etc.). Based on PCA analysis, Wards 77, 88, 85, and 100 have high Z-scores, indicating a higher standard of living overall. However, wards 89, 95, and 96 have higher household facilities scores (not aligning with the high Z-score wards). A high standard of living Z-score doesn't necessarily imply high household facilities, because the Z-score is a weighted composite of many variables, and facilities may not dominate or correlate strongly. Also, recent targeted interventions might raise facility scores in wards with otherwise lower socio-economic status.

3.4 Factor II: Environmental Problem

Usually, the solid waste material thrown in the dust bins flies away by the wind or is picked by the birds and animals and is spread on the street and blocks sewage channels, which creates environmental problems (Table 3). Therefore, the factor 'environmental problem' emerged as the second most important factor with an eigenvalue of 1.699 %and a total variance of 8.494 %. There are three variables positively laden with this factor, namely, Does solid waste create environmental problems in your locality? (0.800), Are birds and animals eating and sitting in and around the dust bin? (0.732), Is solid waste material decreasing soil fertility? (0.700). Therefore, this factor unquestionably established that in this study area, people are facing environmental problems with household solid waste materials. Hence, it is confirmed that the corporation's sanitary workers should take necessary action against the above-mentioned problems. In the environmental problem survey, multiple variables were initially considered. However, only the three most significant variables were presented in Table 3, as they had the highest factor loadings and were statistically relevant based on the Principal Component Analysis (PCA) output.

Table 3. Factor II: Environmental Problem

Variable No.	Variable Name	Factor Loading	Communalities
Ep4	Is solid waste creating environmental problems in your locality?	0.800	0.652
Ep1	Are birds and animals eating and sitting in and around the dustbin?	0.732	0.559
Ep8	Is solid waste material decreasing soil fertility?	0.700	0.504
Eigen value:1.699		**Total Variance:8.494**	

These variables, shown in Table 3, were selected because they exhibited strong correlations with the primary environmental challenges in the study area, making them the most representative indicators. While the survey included more variables, only those with significant loading values were displayed to ensure a concise and meaningful representation of the data. Figure 3 demonstrates the mean of environmental problems of

people living in the study area. Accordingly, a very low negative Z score (-0.45 to -0.38) was registered in four wards, and it shows that the people of this region are facing tremendously fewer environmental problems. The low negative Z score (-0.38 to -0.13) has been recorded in three wards, and it indicates that in this region, people have fewer environmental issues.

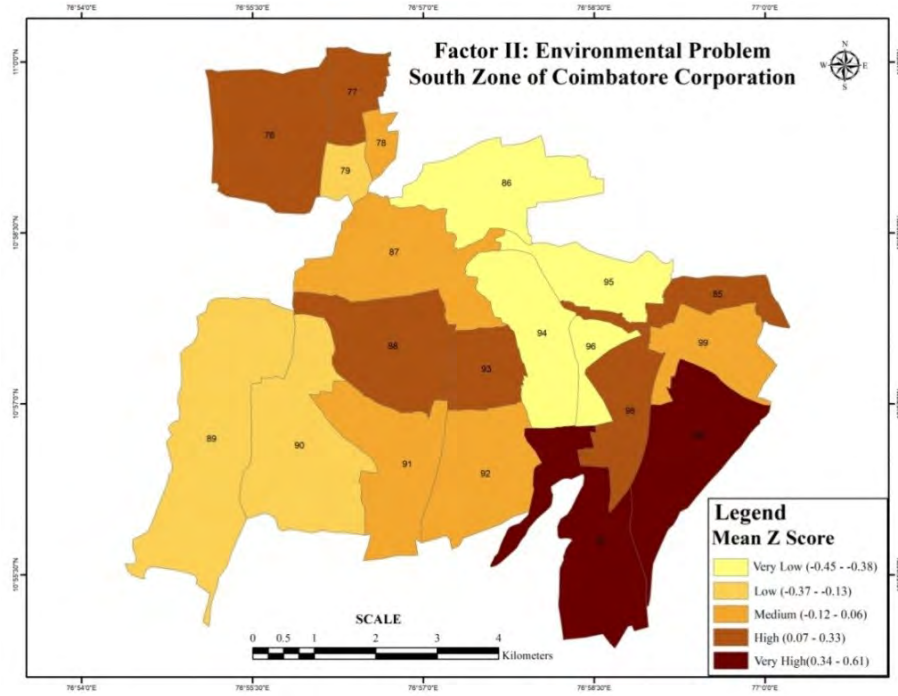


Figure 3. Environmental Problem

However, the medium negative to positive Z score (-0.13 to 0.06) was established in five wards, which shows signs of moderate environmental problems. On the contrary, the high positive Z score (0.06 to 0.33) has been recorded in six wards, and it proved that the greater numbers of people living in these wards are facing high levels of environmental inconvenience. Similarly, the extremely high positive Z score (0.33 to 0.61) has been traced in the two wards, which reveals that the environmental problems are very high in these regions.

3.5 Factor III: Standard of Living

The variables, particularly Air Conditioner (0.770), Micro Oven (0.727) and Washing Machine (0.699), are absolutely loaded on this third factor of Standard of Living, with an eigenvalue of 1.653 % and a total variance of 8.267 % (Table 4).

Table 4. Factor III: Standard of Living

Variable No.	Variable Name	Factor Loading	Communalities
Sl6	Air Condition	0.770	0.635
Sl12	Micro Oven	0.727	0.542
Sl14	Washing Machine	0.699	0.561
Eigen value:1.653		**Total Variance:8.267**	

Figure 4 shows the standard of living of the people in the south zone of Coimbatore Corporation. The extremely low negative Z score (-0.08 To -0.07) observed in three wards, the low negative Z score (-0.08 To -0.05) in the four wards, the medium negative to positive Z score (-0.06 To -0.02) in the six wards, the high positive Z score (0.03 To 0.09) in three wards and the very high positive Z score (0.09 To 0.11) in four wards. Hence, the standard of living conditions of the people differ from very low to very high in this study area.

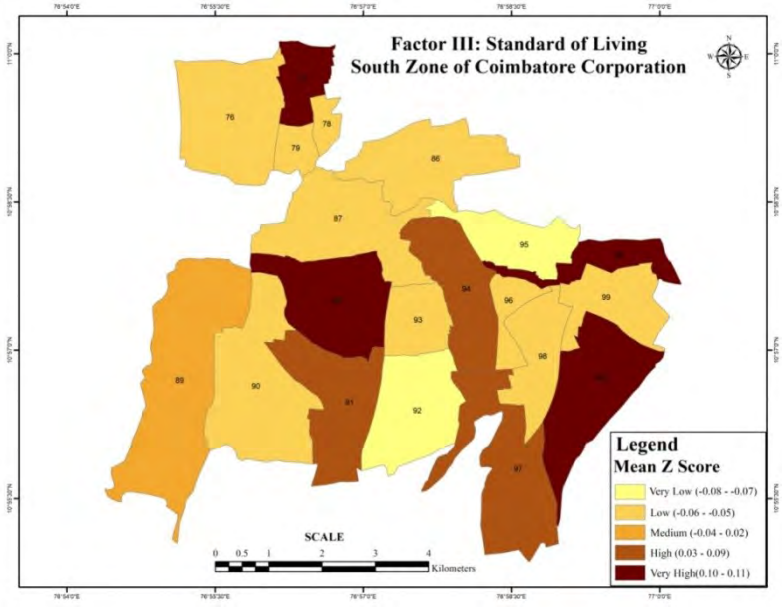


Figure 4. Standard of Living

3.6 Factor IV: Socio-Economic Condition

The amount of solid waste disposal in a household or region chiefly depends on socioeconomic and demographic conditions (Table 5). Accordingly, the fourth important factor, 'Socio-Economic Condition', emerged with an eigenvalue of 1.352 % and a total variance of 6.758 %. The variables, namely family size (0.818) and monthly income (0.804), are confidently loaded on this factor. It was established that the people's socio-economic conditions in this region influence the solid waste management activities of this study area.

Therefore, socioeconomic factors that significantly influenced waste generation are supported by factor loadings.

Table 5. Factor IV: Socio-Economic Condition

Variable No.	Variable Name	Factor Loading	Communalities
Se4	Family Size	0.818	0.675
Se7	Monthly Income	0.804	0.658
Eigen value:1.352		**Total Variance:6.758**	

Socio-economic conditions in the study area differ across wards (Figure 5). Five wards show very low socio-economic status with Z scores from -0.26 to -0.16, while three wards have low status with Z scores between -0.17 and -0.05. Four wards fall in the medium range, with Z scores from -0.06 to 0.05. Z-scores indicate how far data points deviate from the mean; higher positive values suggest above-average socioeconomic status. Six wards have high socioeconomic levels (Z scores 0.06 to 0.16), and two wards have very high status (Z scores 0.17 to 0.31).

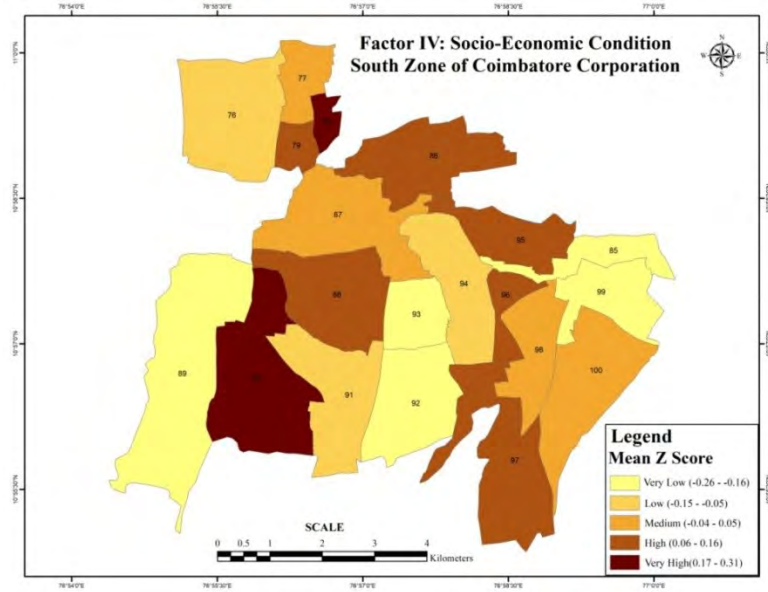


Figure 5. Socio-Economic Condition

3.7 Factor V: Collection of Solid Waste

Clearing the dust bins and collecting solid waste materials from the place of dust bins and households are respectively the most important activities of workers engaged in cleaning activities of this study area (Table 6). For that reason, the variables specifically are: When they are clearing the dust bins? (0.804) and How they collect solid waste from the house? (0.798) are positively encumbered on this fifth factor, 'collection of solid waste'.

Table 6. Factor V: Collection of Solid Waste

Variable No.	Variable Name	Factor Loading	Communalities
Csw4	When are they clearing the dustbins?	0.804	0.657
Csw6	How do they collect solid waste from the house?	0.798	0.649
Eigen value:1.348		**Total Variance:6.742**	

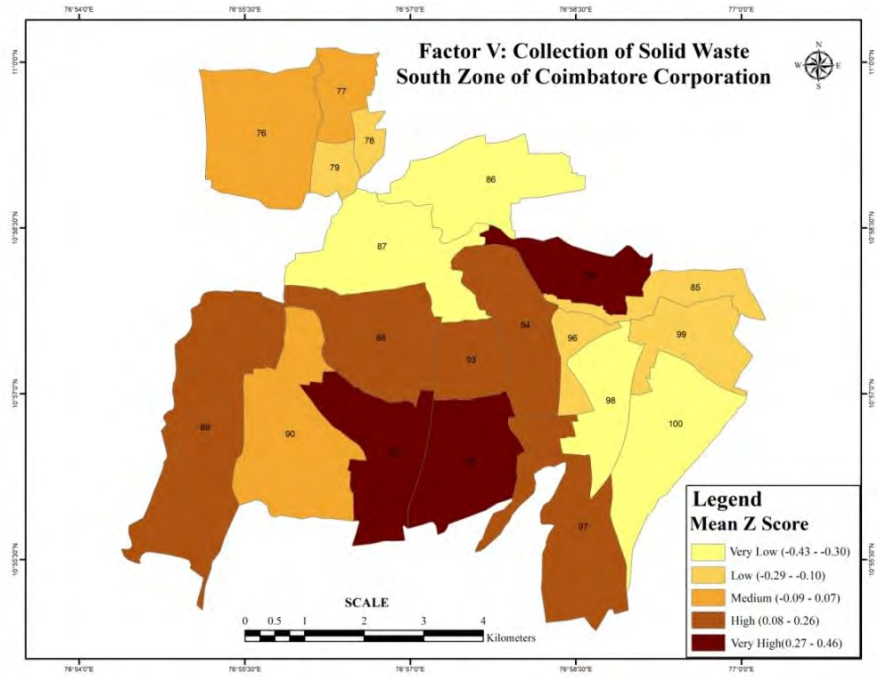


Figure 6: Collection of Solid Waste

This factor comes into view with an eigenvalue of 1.348%and a total variance of 6.742%. Thus, it is demonstrated that the collection and clearance of solid waste from this study area was perfect and on time by the sanitary workers working in this region. The extremely low negative Z score (-0.43 to -0.30) was established in four wards for the collection of solid waste (Figure 6). It reveals that the collection of solid waste is very low in these regions.

Similarly, the low negative Z score (-0.30 to -0.10) has been registered in five wards and shows that the people in this region are producing less amount of solid waste. The medium negative to positive Z score (-0.11 to 0.07) has been recorded in three wards, and it is confirmed that the residents of this region are generating moderate levels of solid waste. The high (0.08 to 0.26) and very high (0.27 to 0.46) positive Z scores come out in five and three wards, respectively, revealing that the collection of solid wastes is high and very high in these regions.

3.8 Factor VI: Accessibility of Dust Bin

Accessibility to the location of dust bins is more important for the disposal of household solid waste materials every day (Table 7). Herein, there are two variables, particularly the distance from the house to the dust bin. (0.784) and dispose of solid waste every day (0.739) are positively loaded on this factor. Accordingly, it is unquestionably confirmed that the dust bin locations are easily accessible to the people, and they dispose of solid waste material in the dust bin every day.

Table 7. Factor VI: Accessibility of Dust Bin

Variable No.	Variable Name	Factor Loading	Communalities
Db3	How much of the distance from the house to the dustbin?	0.784	0.646
Db1	Do you dispose of solid waste every day?	0.739	0.599
Eigen value:1.209		**Total Variance:6.047**	

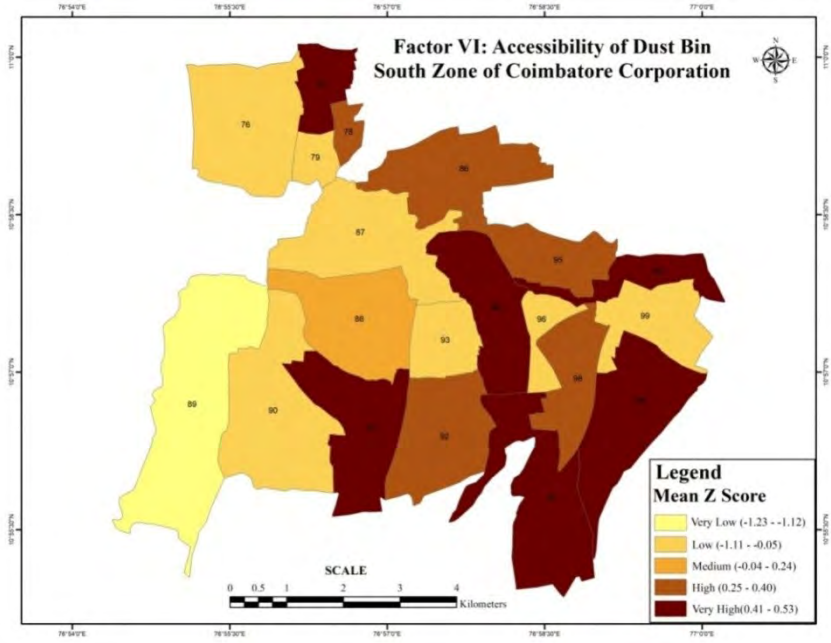


Figure 7. Accessibility of the Dust Bin

The extremely low negative Z score (-1.23 to -1.22) registered (Figure 7) in only one ward for the accessibility of the dust bin reveals that the people living in this ward are unable to access the dust bin. Similarly, the low negative Z score (-1.23to -0.52) has been recorded in the seven wards of this study area, the medium negative to positive Z score (-0.53 to 0.24) witnessed in one ward, the high positive Z score (0.25 to 0.40) established in five wards and, the high positive Z score (0.41 to 0.53) listed in six wards. As a result, the accessibility of dust bins is very low to very high in this study area.

3.9 Factor VII: Attitude towards Workers

The people's attitude towards the sanitary workers is more important for the measurement of the cleaning activity of a region. The variables are as follows: Do you dispose of solid food waste? (0.725) and the opinion of people towards sanitary workers (0.702) positively encumbered this factor. Therefore, it is recognised that the people in the study area are highly satisfied with the workers who are engaged in solid waste disposal activities.

Table 8. Factor VII: Attitude towards the Workers

Variable No.	Variable Name	Factor Loading	Communalities
Aw15	Do you dispose of solid food waste?	0.725	0.583
Aw2	Opinion of People Towards Workers	0.702	0.538
Eigen value:1.164		**Total Variance:5.818**	

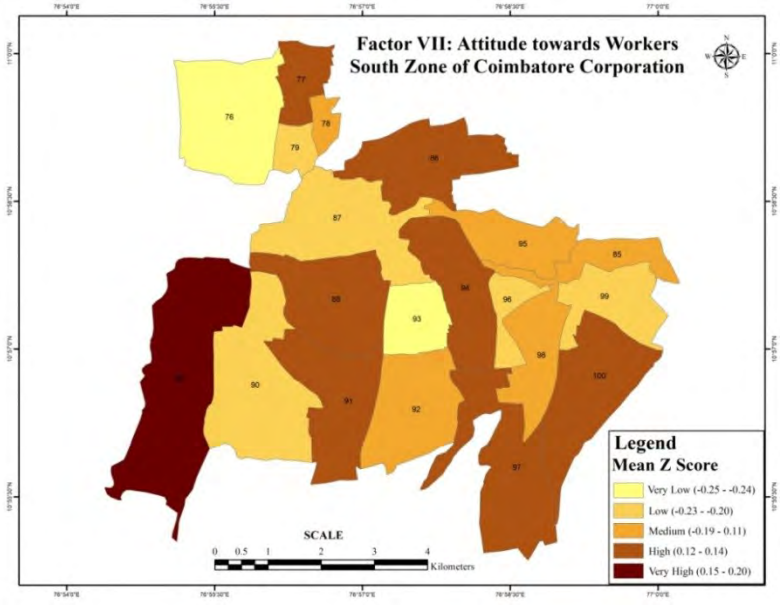


Figure 8. Attitude towards Workers

The extremely low negative Z score (-0.25 to -0.24) was registered in one ward for the variable attitude towards the workers and it shows that the people in this region (Figure 8) have very low thoughts towards the sanitary workers. Similarly, the low negative Z score (-0.25 to -0.20) has been traced in six wards, and it is recognised that the people of this region have a low level of attitude towards the workers. The medium negative to positive Z score (-0.21 to 0.11) was recorded in five wards of this region, so the people living in this region have a moderate mindset towards the workers. The high positive Z score (0.12 to 0.14) has been established in seven wards, and the very high positive Z score (0.14 to

0.20) has been found in one ward, which indicates that this region's people have a higher level of opinion towards the sanitary workers.

3.10 Factor VIII: Disposal of Solid Waste Material

The factor 'Disposal of solid waste material' emerged as an eighth factor with an eigenvalue of 1.161%and a total variance of 5.803% (Table 9). There are two variables, particularly, Do you dispose of solid clothes waste? (0.803) and Do you dispose of solid battery waste? (0.673) are positively loaded on this factor. It is confirmed that the people living in the study also dispose of solid cloth and battery waste.

Table 9. Factor VIII: Disposal of Waste Material

Variable No.	Variable Name	Factor Loading	Communalities
Wm8	Do you dispose of solid clothes waste?	0.803	0.679
Wm10	Do you dispose of solid battery waste?	0.673	0.519
Eigen value:1.161		**Total Variance:5.803**	

The disposal of solid waste materials is very low in five wards in the study region because the mean value was a very small negative Z score (-0.16 to -0.14), which has been observed (Figure 9) in these wards. Likewise, the low negative Z score (-0.15 to -0.11) has been recorded in the five wards of this study area, the medium negative to positive Z score (-0.12 to 0.09) was well recognized in two wards, the high positive Z score (0.09 to 0.22) recorded in the seven wards and, the extremely high positive Z score (0.22 to 0.25) viewed in one ward. Hence, the disposal of solid waste materials differs from very low to very high among the wards in the study region.

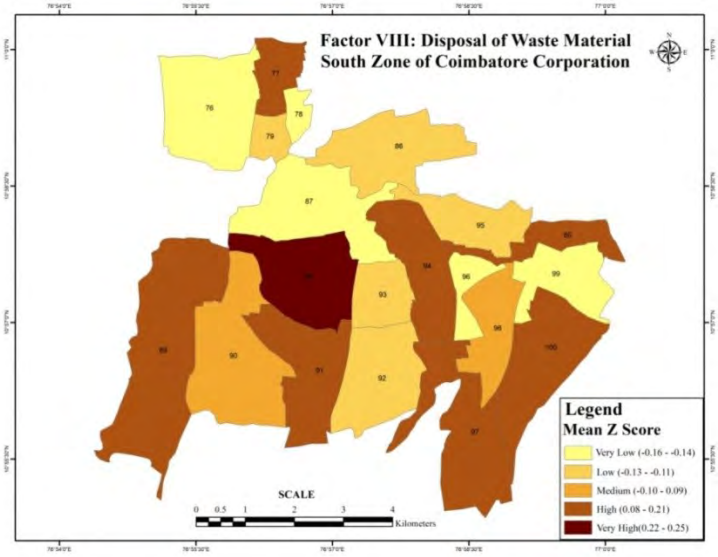


Figure 9. Disposal of Solid Waste Material

3.11 Spatial Analysis of the Factors

Overall, the spatial analysis of residents' factor structure in the south zone of Coimbatore Corporation established that the eight factors, such as facility in the home, environmental problem, standard of living, socio-economic condition, collection of solid waste, accessibility of dust bin, attitude towards workers and disposal of solid waste materials, are shared in overlaps under different categories. The wards are divided into categories based on the level of these factors, ranging from "Very Low" to "Very High", and are presented in Table 10.

Table 10: Spatial Overlaps of Factor Structure

No.	Category	Factors								Total	Percentage
		Factor I Facility in the House	Factor II Environmental Problem	Factor III Standard of Living	Factor IV Socio-Economic Condition	Factor V Collection of Solid Waste	Factor VI Accessibility of Dust Bin	Factor VII Attitude towards Workers	Factor VIII Disposal of Solid Waste Material		
		No. of Wards									
1	Very Low	7	4	3	5	4	1	1	5	30	18.75
2	Low	3	3	4	3	5	7	6	5	36	22.50
3	Medium	4	5	6	4	3	1	5	2	30	18.75
4	High	5	6	3	6	5	5	7	7	44	27.50
5	Very High	1	2	4	2	3	6	1	1	20	12.50
Total		20	20	20	20	20	20	20	20	160	100.00

The overall spatial analysis of factor structure data reflects an analysis of various factors that influence the quality of services or conditions in different wards. Ward 89 records the highest waste generation; its comparatively lower environmental problem index may reflect stronger municipal infrastructure and efficient waste management. Conversely, Wards 100 (Nearby Vellalore Dumping Site) and 97 (Tomato Market), though generating lesser waste, exhibit higher environmental concerns, possibly due to inefficient collection systems, poor public awareness, or institutional neglect. These factors cover a wide range of aspects related to the environment, socio-economic conditions, waste management, and public attitudes.

Facility in the House seems to be relatively evenly spread across the categories. The distribution indicates that, for some wards, housing facilities may be in poor condition, while others show a higher standard of living in terms of available amenities. Environmental problems are most common in the "Low" and "Medium" categories, which suggests that a significant number of wards are facing environmental issues that are moderate or relatively

manageable but still problematic. However, the "Very Low" and "Very High" categories are less populated, indicating that extreme cases are rare.

The spread across categories for the Standard of Living factor shows that while there are some wards with a higher standard of living, many wards still fall into the "Medium" and "Low" categories. This indicates that, generally, many wards experience a standard of living that is neither excellent nor poor but somewhere in between. Likewise, the socio-economic condition of the wards also seems to have a broad distribution. This might indicate that there are disparities in the socio-economic status across different wards, with some experiencing more favourable conditions than others. However, the concentration in the "High" category suggests that a significant portion of wards may be relatively better off.

The collection of solid waste shows a higher concentration in the "Low" and "High" categories, with the "Low" category reflecting wards where waste collection services are lacking, and the "High" category indicating wards where waste collection is more efficient. This could point to inconsistent waste management services across the wards. While the accessibility of Dust bins falls mostly under the "Low" category, suggesting that access to dust bins is a problem for many of the wards. This might point to a lack of infrastructure or insufficient waste disposal facilities in certain areas. On the other hand, the "Very Low" and "Very High" categories are less common, indicating that extreme cases are rare, but the problem still affects a substantial number of areas.

The factor of Attitude towards Workers has a wide distribution, but the number of wards falling under the "High" and "Very High" categories suggests that there may be positive public attitudes towards workers in many areas. Still, a portion of wards does show more neutral or negative attitudes. The data shows a relatively equal spread of wards across the categories for the factor ‘Disposal of Solid Waste Material’. This might suggest that while waste disposal services are generally available, they are not uniformly efficient. Some wards are managing waste disposal effectively, while others are not.

In general, the wards in the area show a range of conditions across various factors, with most wards falling into the "Low" to "Medium" categories. While there are some areas with high standards of living and good services, there are also significant numbers of wards that face challenges in areas such as waste management, environmental issues, and accessibility to services like dustbins. This suggests a need for targeted improvements in certain wards, particularly in waste collection and accessibility, which appear to be the most pressing concerns. There also seems to be room for improvement in addressing socio-economic disparities and the overall standard of living in some areas.

4. Conclusion

The present study has concluded that the people in this region have moderate to high standards of living conditions. The factor analysis of collected primary datasets reveals

that the variables, namely socio-economic condition, facility in the house, accessibility of dust bin, environmental problem, and the standard of living, attitude towards the workers, disposal and collection of solid waste materials, are determining the solid waste management practices. The analysis reveals that certain socio-economic factors—such as household income, education level, occupation type, family size, housing type, access to services, and awareness levels—play a more pronounced role in influencing the quantity and type of waste generated. For example, households with higher income and education levels tend to produce more packaging and electronic waste, whereas lower-income households are more associated with organic and mixed waste due to consumption patterns and limited segregation practices. In addition, the people of this region are suggesting and conveying that they are facing problems in the separation of household solid waste into degradable and non-degradable; recycling of household solid wastes and proper solid waste management practices are playing a vital role in keeping a tidy environment in this study region. To further understand these dynamics, Z-score normalisation was employed to examine the spatial variations of these key socio-economic factors across different neighbourhoods. This helped highlight clusters or areas where specific socio-economic profiles correlate strongly with waste management behaviours—such as lack of source segregation, irregular collection practices, or higher per capita waste generation. Thus, the study emphasises the need for targeted interventions in waste management policy and education programs that are sensitive to the socio-economic contexts of different localities within the South Zone of Coimbatore.

This study fails to address the working conditions of sanitary workers and the involvement of the Corporation in the solid waste management activities in this study area. Therefore, the above-mentioned area will be covered in future research.

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The Indian Geographical Journal
Volume 100 (1) June - 2025, pp 39-54
ISSN 0019-4824

MOTHER AND CHILD HEALTH CARE IN MADURAI DISTRICT: A STRUCTURAL EQUATION MODELLING APPROACH

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Abstract

Maternal and child health are vital components of a nation's overall well-being, especially in developing regions where healthcare access is limited. This study focuses on mother and child healthcare in Madurai District of Tamil Nadu state, where socio-economic pressures have led to challenges in maternal and child health, including concerning practice of female infanticide. Using a structured questionnaire survey, the data were collected from 650 mothers across 13 blocks of the district, with a random sample size of 50 mothers from each block, to evaluate the healthcare conditions and socio-economic factors affecting mothers and children. The variables encompassed socio-economic status, attitudes towards antenatal care, healthcare usage, childcare practices, health issues, and psychological well-being, were used for confirmatory factor analysis in SPSS. Structural Equation Modelling (SEM) and path analysis were attempted in AMOS software to explore relationships between these healthcare factors. Results reveal that infant mortality, and health challenges during pregnancy notably affect maternal and child healthcare in the district. The findings underscore improving healthcare accessibility and addressing socio-economic disparities to foster better health outcomes for mothers and children in Madurai District.

Keywords: Mother and child health, Health care utilisation, Infant mortality, SEM, Madurai district

1. Introduction

A healthy mother delivers a healthy baby, forming the foundation of a nation's future. Mothers and children are regarded as the most vulnerable members of society since they are more susceptible to health problems than other members of society.

Motherhood is the most significant role a woman can play in her life, yet it may also be life-threatening. (Baykemagn et al. 2024). During pregnancy, any woman can develop severe, life-threatening complications that require accessible and affordable medical care (Chaudhuri & Nath, 2019). Reproductive morbidities are the leading cause of women's ill health and death worldwide (Alicandro et al., 2023). It can be noted that younger women are at a higher risk of reproductive problems related to pregnancy, delivery, post-delivery, menstruation, menopause, and family planning than older women. Antenatal care, the care provided to pregnant women to ensure a safe pregnancy and the birth of a healthy baby, is crucial (Tripathy & Mishra, 2023).

In addition to public health factors, the study of location factors is essential for improving the quality of life for individuals and groups (Laatikainen et al., 2018; Saravanabavan et al., 2021, 2023). Spatial location has a significant influence on the risk of disease and various health effects (Balasubramani et al., 2024; Vinothini & Saravanabavan, 2023). There are many techniques involved in the location of health centres and their determinants of health variables. (Vinothini et al. 2024). In this context, the healthcare facilities in rural and urban areas of Madurai district are assessed in this study. The maternal mortality rate (MMR) and infant mortality rate (IMR) of the district was remained at 39.7 per one lakh live births and 9.5 per 1,000 live births, respectively, during 2023-24. The maternal mortality rate in the district is calculated during the period between when a woman conceives and 42 days after delivery, while infant mortality rate is calculated from day one of birth to till 365th day. The MMR and IMR of the district are below the state average. The state average of the same was recorded as 60 per one lakh live births and 13.7 per 1,000 live births (https://www.newindianexpress.com/states/tamilnadu/2024/Aug/22/infant-maternal-mortality-rates-below-state-average-in-madurai). The studies have also shown that integrated care models in rural Madurai significantly improved maternal and child health outcomes through coordinated care effects and community involvement (Saravanabavan et al., 2019). Antenatal care has a favourable impact on pregnancy since it allows for the early detection of risk factors and the early diagnosis of pregnancy difficulties such as premature delivery, as well as appropriate management (Silva et al., 2021). The use of health applications has also improved antenatal and postnatal care in both urban and rural settings of the district, although there are economic and educational disparities in healthcare access (Neethi Mohan et al., 2024). Although there is a system of healthcare in the district, many rural locations of the district are faced with unbearable socio-economic pressures, especially by the practice of female infanticide in certain specified communities. Parents are killing their female infant babies in the district by feeding them poison. An estimated 6,000 babies have been killed in the last decade alone (https://www.indiatoday.in/magazine/cover-story/story/19860615-women-of-kallar-community-in-tamil-nadu-kill-their-female-babies-by-feeding-them-poison-800940-1986-06-14).

Structural Equation Modelling (SEM), using Analysis of Moment Structure (AMOS) techniques, is widely applied to analyse healthcare datasets (Balaji et al., 2024; Saravanabavan et al., 2021a; Thakkar & Thakkar, 2020; Renugadevi& Vadivel, 2017). The

The purpose of SEM is to define a theoretical causal model consisting of a set of predicted covariances between variables and then test whether it is plausible when compared to the observed data (Cheung et al., 2024). In this regard, many research has attempted to study the spatial distribution of morbidity conditions and mortality of women during pregnancy. These models help to identify the risk factors of maternal morbidity and mortality. The present study focuses on examining the general health status of women, child health status, and socio-economic predictors of reproductive morbidities among mothers and children in Madurai District, South India. The research aims to identify key factors that influence maternal and child health outcomes in this district using hypothesis testing through path analysis with Structural Equation Modelling and provide insights into potential interventions to improve health and reduce disparities.

2. Methodology

2.1 Study area and Data sources

Madurai, the oldest historical city in Tamil Nadu, is centrally located in the southern part of Tamil Nadu with an area of 3,710 km² (Fig. 1). According to the 2023 Statistical Handbook, Madurai's population is approximately 3.6 million. The district's urban population accounts for 60.8%, with a population density of 819 persons per square kilometre. The recorded sex ratio stands at 990 females per 1,000 males, slightly lower than Tamil Nadu's state average of 996. The literacy rate in the district is 83.5%, surpassing the state average of 80.1% (Census, 2011). The district has made significant strides in healthcare, notably through the development of neonatal departments, which have helped reduce the Infant Mortality Rate. As of 2018, Madurai's IMR stood at 16.6 per 1,000 live births—0.6 points higher than the state average. However, the district's IMR was reduced to 9.5 per 1,000 live births in 2023-24. The district hosts numerous specialised private hospitals, nursing homes, and polyclinics. Socio-economic factors, particularly for patients visiting Primary Health Centres (PHCs), have a considerable impact on healthcare access and quality. There exists a strong correlation between income, education levels, and health outcomes, leading to significant disparities in healthcare utilisation. This study investigates the accessibility and quality of healthcare facilities in the context of the demographic and socio-economic conditions of PHC patients in Madurai District.

This study utilised both primary and secondary data sources. Primary data were collected via a structured questionnaire survey conducted in the 13 blocks of Madurai District. A uniform random sampling method was employed, selecting 50 mothers from each block, resulting in a total sample size of 650 respondents. The questionnaire captured details on socio-economic status, attitudes towards antenatal care providers, healthcare utilisation, childcare practices, health issues, and psychological conditions of mothers. Secondary data on reproductive health were gathered from the Statistical Cell at the District Health Office, Madurai.

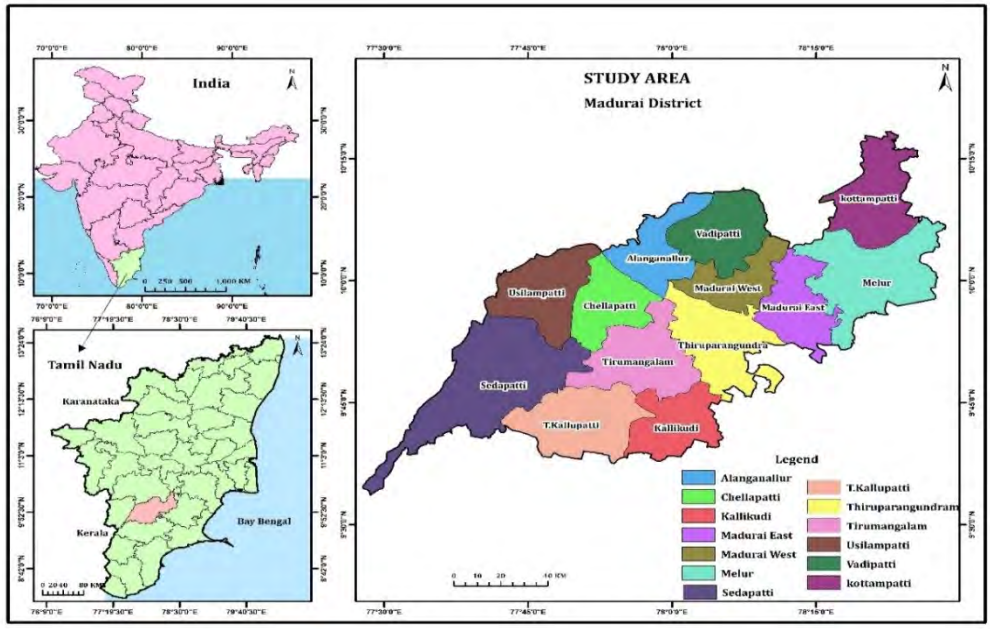


Fig. 1 Location of the study area.
Source: compiled by the authors

2.2 Tools and Techniques

Data were processed using SPSS for confirmatory factor analysis, while AMOS software facilitated factor analysis, discriminant validity tests, and path analysis through SEM. The bootstrap method was applied to examine indirect relationships. Mean factor scores were extracted and spatially represented using ArcGIS software to illustrate regional variations in healthcare determinants. Firstly, Exploratory Factor Analysis (EFA) was employed to identify latent factors contributing to the variation among observed variables. Subsequently, Confirmatory Factor Analysis (CFA) was conducted to validate the hypothesised factor structure, ensuring the data's fit to the proposed measurement model. Factor loadings of 0.6 or higher were set acceptable for dimensionality.

The analysis confirmed that the absolute fit indices were consistent with the sample data, indicating that the proposed path model achieved a satisfactory fit. Principal Component Analysis (PCA) identified nine components with eigenvalues exceeding 1.0. Path analysis, utilising simple and multiple regression models, was employed to assess causal relationships among the variables and identify mediation effects within the model. Pooled CFA ensured the reliability of items related to mother and child care in Madurai district. The results affirmed that the model's fit indices met recommended standards, enabling a comprehensive examination of the associations between various factors affecting mother-child healthcare in the study area.

3. Results and Discussion

3.1 Key dimensions of mother and child health Care

Factor analysis was employed to identify key dimensions of mother and child healthcare in Madurai District. Five principal factors were extracted, collectively explaining 70.20% of the total variance (Table 1). An eigenvalue threshold of 1.0 determined the number of extracted factors, and the block-wise distributions of factors scores are presented in Table 2.

Table 1: Rotated Component Matrices

Name of the Factor	Rotated Component Matrix					
		Component				
		1	2	3	4	5
Experience of Health Problems during the Pre-Natal Period	Experience any problems during the prenatal period	.88				
	Place of treatment for any problems during the prenatal period	.84				
	Treated for any problems during the prenatal period	.84				
	Reason for not visiting any gynaecologist	.70				
	Special care during menstruation	.68				
	Respiratory Disease Asthma	.61				
Health Problems during Pregnancy	Kidney Disease or Urinary Tract Infections		.88			
	Hepatitis liver disease Jaundice		.85			
	Tuberculosis		.84			
	Abnormal Pap smear		.77			
	Feel comfortable with the Sexual and reproductive health services in your area.		-.73			
Child Care	Duration of breastfeeding for your children			.86		
	Weight of the baby during delivery			.85		

	Any abnormalities during birth			.81		
	Type of labour and if complications			.81		
Infant Death	Number of Infant Deaths				.77	
	Educating pregnant women about their health conditions				.67	
	Satisfaction with your health				-.67	
Healthcare Utilization	Receive prenatal care during pregnancy					.90
	Medical check-ups during pregnancy					.88
Eigen Values		**3.80**	**3.58**	**2.95**	**1.87**	**1.82**
Percentage of Variance		**19.03**	**17.91**	**14.75**	**9.36**	**9.11**
Cumulative Percentage		**19.03**	**36.95**	**51.72**	**61.09**	**70.20**
Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalisation. Rotation converged in 6 iterations.						

Table 2: Distribution of Factor Scores of the Structural Equation Model

Sl.No.	Name of the Block	F1	F2	F3	F4	F5
1	Kottampatti	0.37	0.12	0.01	0.083	0.07
2	Melur	-0.39	0.12	0.11	0.327	-0.69
3	Madurai East	-0.66	-0.15	-0.06	0.103	-0.50
4	Thiruparankundram	-0.48	-0.46	0.11	0.092	-0.21
5	Madurai West	0.68	0.17	-0.08	-0.507	0.60
6	Alanganallur	0.47	0.19	-0.10	-0.098	0.73
7	Vadipatti	0.37	0.12	0.01	0.083	0.07
8	Chellampatti	-0.39	0.12	0.11	0.327	-0.69
9	Thirumangalam	-0.66	-0.15	-0.06	0.103	-0.50
10	Kallikudi	-0.48	-0.46	0.11	0.092	-0.21
11	T. Kallupatti	0.68	0.17	-0.08	-0.507	0.60
12	Sedapatti	0.47	0.19	-0.10	-0.098	0.73
13	Usilampatti	0.37	0.12	0.01	0.083	0.07

Factor-I represents the experience of health problems during the prenatal period. Prenatal healthcare is essential for ensuring maternal and child health, as well as safe deliveries. This dimension emerged as the most significant, accounting for 19.03% of the total variance with an eigenvalue of 3.80 (Table 3). Six variables loaded positively on this factor, such as experiencing issues during pregnancy (0.88), treatment during the prenatal period (0.84), and absence of gynaecological consultations (0.70). These results indicate prevalent prenatal health challenges among women in the study area. Spatially, positive factor scores indicating satisfactory prenatal healthcare experiences were observed in T. Kallupatti (0.37), Madurai West (0.68), Sedapatti (0.47), Usilampatti (0.37), Vadipatti (0.37), Alanganallur (0.47), and Kottampatti (0.37). Conversely, negative scores in Chellampatti, Kallikudi, Thiruparankundram, Melur, Thirumangalam, and Madurai East suggest dissatisfaction with prenatal healthcare (Fig. 2).

Table 3: Factor I - Experience of Health Problems during the Pre-Natal Period

Variable Name	Factor Loading	Communalities
Experienced any problems during the prenatal period	0.88	0.83
Experienced any problems at the place of treatment during the prenatal period	0.84	0.77
Treated for any problems during the prenatal period	0.84	0.77
Not visiting a gynaecologist for treatment	0.70	0.59
Take any special care during menstruation	0.68	0.60
Experienced any respiratory disease/Asthma	0.61	0.53
Eigenvalue: 3.80	**Total Variance: 19.03**	

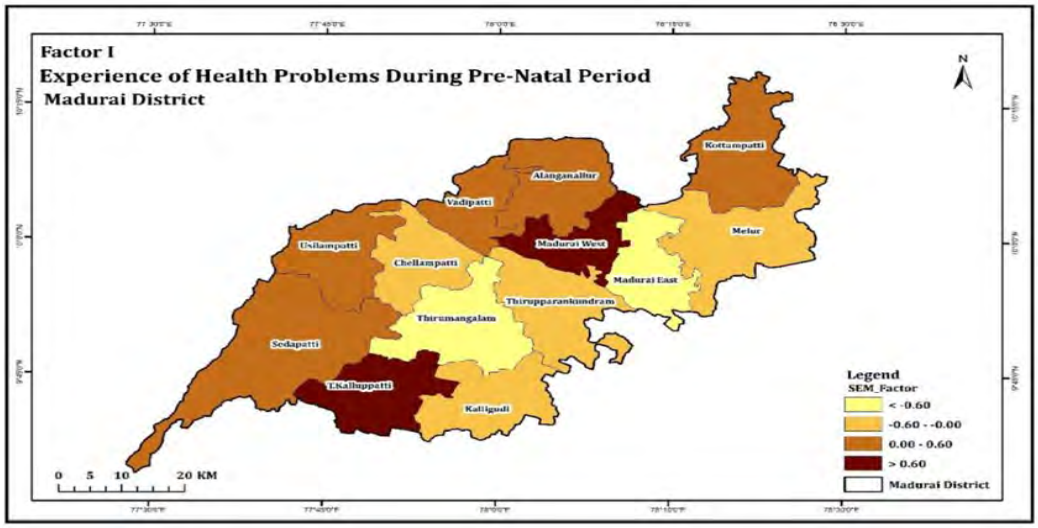


Fig. 2 Factor Score of Health problems during the pre-Natal Period in Madurai district

Factor-II is related to health problems during pregnancy. This dimension accounted for 17.91% of the variance with an eigenvalue of 3.58 (Table 4). Positively loaded variables include kidney diseases or urinary tract infections (0.88), hepatitis or jaundice (0.85), tuberculosis (0.84), and abnormal Pap smear results (0.77). A negative loading was observed for comfort with local sexual and reproductive health services (-0.73), highlighting service dissatisfaction. High positive factor scores were noted in Sedapatti, T. Kallupatti, Alanganallur, Madurai West, Usilampatti, and others, whereas Thirumangalam, Madurai East, Thiruparankundram, and Kallikudi showed lower scores (Fig. 3).

Table 4: Factor II - Health Problem during Pregnancy

Variable Name	Factor Loading	Communalities
Any kidney disease or urinary tract infections	0.88	0.77
Hepatitis liver disease /Jaundice	0.85	0.73
Tuberculosis	0.84	0.71
Abnormal Pap smear	0.77	0.62
Comfortable with sexual and reproductive health services	-0.73	0.55
Eigenvalue: 3.584	**Total Variance: 17.918**	

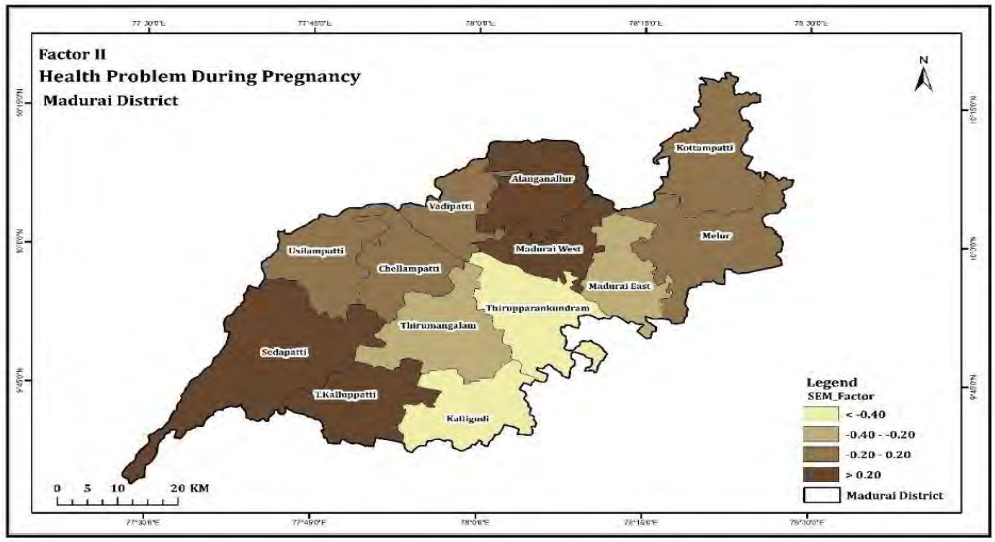


Fig. 3 Factor Score of Health problems during the Pregnancy Period in Madurai district

Childcare, vital for a nation's future, emerged as **Factor III**, with 14.75% variance and an eigenvalue of 2.95 (Table 5). Key variables included breastfeeding duration (0.86), baby weight at birth (0.85), birth abnormalities (0.81), and labour complications (0.81). High scores were concentrated in Chellampatti, Kallikudi, Thiruparankundram, Melur, and others, while low scores appeared in Thirumangalam, Madurai East, Sedapatti, T. Kallupatti, Alanganallur, and Madurai West (Fig. 4).

Table 5 Factor III: Child Care

Variable Name	Factor Loading	Communalitis
Time duration of breastfeeding your children	0.86	0.75
Weight of the baby during delivery	0.85	0.74
Abnormalities during birth	0.81	0.71
Types of labour and its complications	0.81	0.69
Eigenvalue: 2.95	**Total Variance: 14.75**	

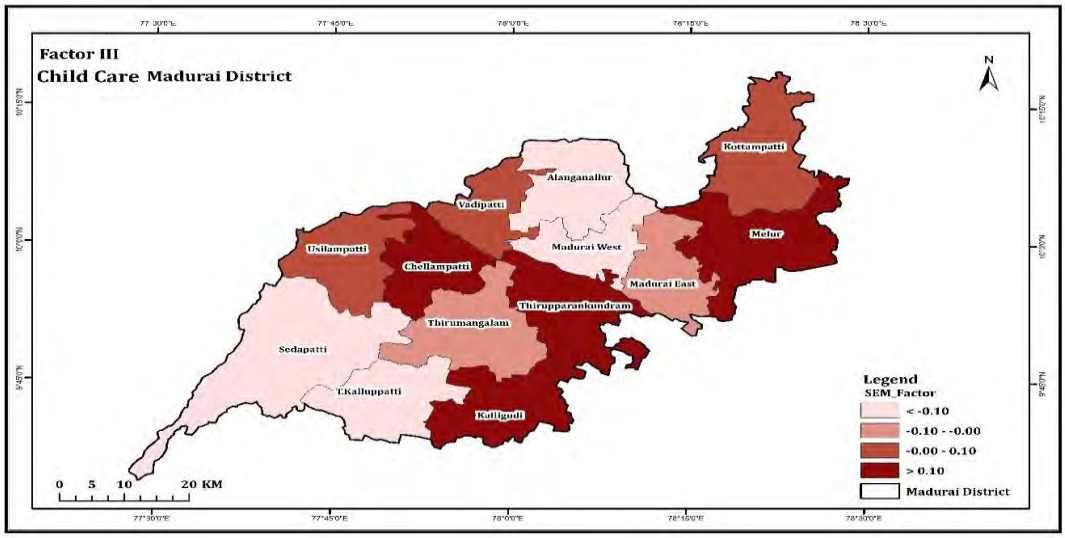


Fig. 4 Factor Score of Child Care in Madurai district

With 9.36% of the variance and an eigenvalue of 1.87 (Table 6), Infant Death ~~is~~ emerged as **Factor IV** includes positive loadings on the number of infant deaths (0.77) and health conditions of educated pregnant women (0.67), alongside a negative loading on satisfaction with personal health (-0.67). High infant death rates were found in Chellampatti, Melur, Usilampatti, and others, whereas Sedapatti, Alanganallur, T. Kallupatti, and Madurai West showed lower rates (Fig. 5).

Table 6: Factor IV - Infant Death

Variable Name	Factor Loading	Communalities
Number of infant deaths	0.77	0.73
Health condition of educated pregnant women	0.67	0.52
Satisfied with health condition	-0.67	0.63
Eigenvalue: 1.87	**Total Variance: 9.36**	

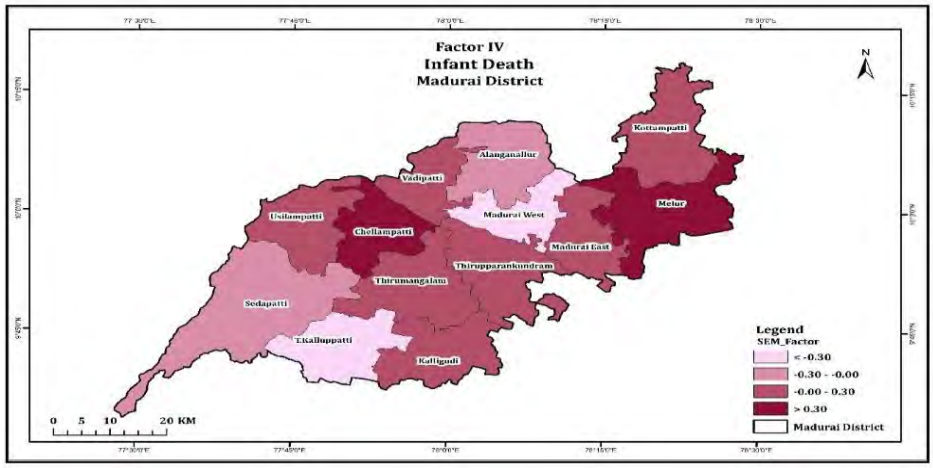


Fig. 5 Factor Score of Infant Death in Madurai District

Factor-V denotes utilisation of health care systems in the district. This last factor represents 9.11% of the variance with an eigenvalue of 1.82 (Table 7), with variables like prenatal care (0.90) and medical check-ups (0.88). High utilisation of health care is noted in Sedapatti, T. Kallupatti, Alanganallur, Madurai West, and others, while Thirumangalam, Kallikudi, Madurai East, Chellampatti, and Melur scored with lower utilization (Fig. 6).

Table 7 Factor V: Utilisation of Health Care

Variable Name	Factor Loading	Communalities
Prenatal care during pregnancy	0.90	0.84
Medical check-ups during pregnancy	0.88	0.87
Eigenvalue: 1.82	**Total Variance: 9.11**	

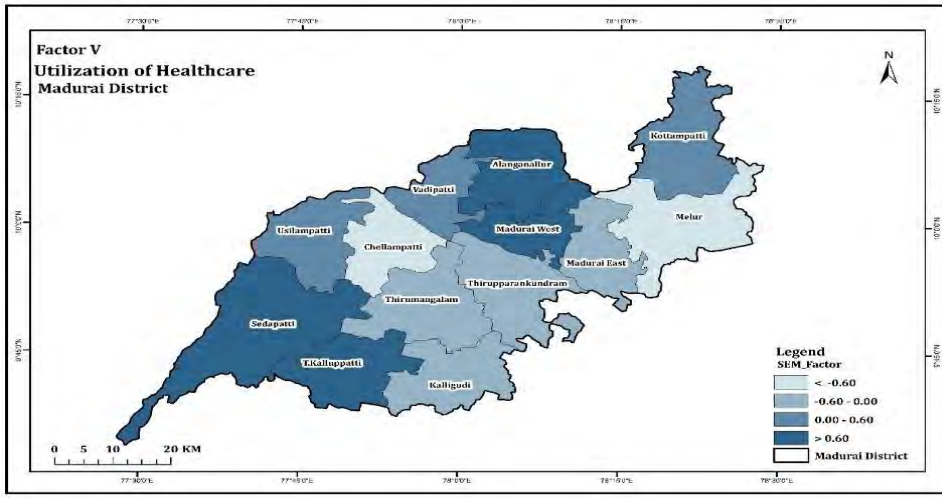


Fig. 6: Factor Score of Utilisation of Health care in Madurai district

3.2 Path Analysis with SEM

Structural Equation Modelling (SEM) using AMOS was used to evaluate the model's fit and confirming discriminant validity (Ahmad et al., 2016). This ensured that exogenous constructs were appropriately distinct. The fitness indexes are presented in Table 8. These metrics are used to determine how effectively the proposed model captures the covariance between all of the model's elements.

Table 8 Fitness Indexes

Name of the Category	Name of Index	Acceptance Level	Obtained Result	Literature
Factor Loading	Standardized Regression Weight	Weight ≥0.6	≥0.6	Hair et al (2020)
Absolute Fit	Chi-Square	P>0.05	0.095	
	Root Mean Square Error of approximation (RMSEA)	<0.08	0.043	Browne and Cudeck, (1992)
	Goodness of Fit Index (GFI)	>0.9	0.996	
Incremental Fit	Adjusted Goodness of Fit Index (AGFI)	>0.9	0.979	
	Comparative Fit Index (CFI)	>0.9	0.956	Bollen (1989)
	Tucker Lewis Index (TLI)	>0.9	0.854	
	Normated Fit Index (NFI)	>0.9	0.927	
Parsimonious Fit	Chi-Square/Degree of Freedom	<5.0	2.119	

3.3 Testing of Hypotheses

The study tested both direct and indirect relationships between the factors. The direct relationships are assessed with the hypotheses of:

H1: Infant death does not significantly impact childcare (p>0.05),

H2: Childcare significantly affects health problems during pregnancy (p=0.008).

H3: Infant death significantly impacts health problems during pregnancy (p=0.001).

H4: Health problems during pregnancy significantly influence prenatal health experiences.

In indirect relationships, the hypotheses are:

H5: Infant death indirectly affects health problems during pregnancy through childcare, but the effect is not significant (p=0.244).

H6: Infant death has a significant indirect effect on prenatal health problems via childcare (p=0.005).

H7: Infant death significantly influences healthcare utilisation indirectly through childcare (p=0.001).

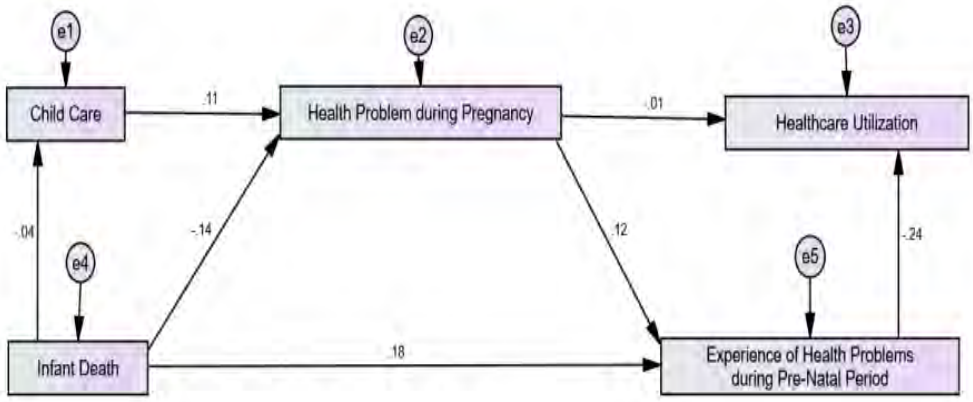


Fig 7: Unstandardised Model of Mediator Construct

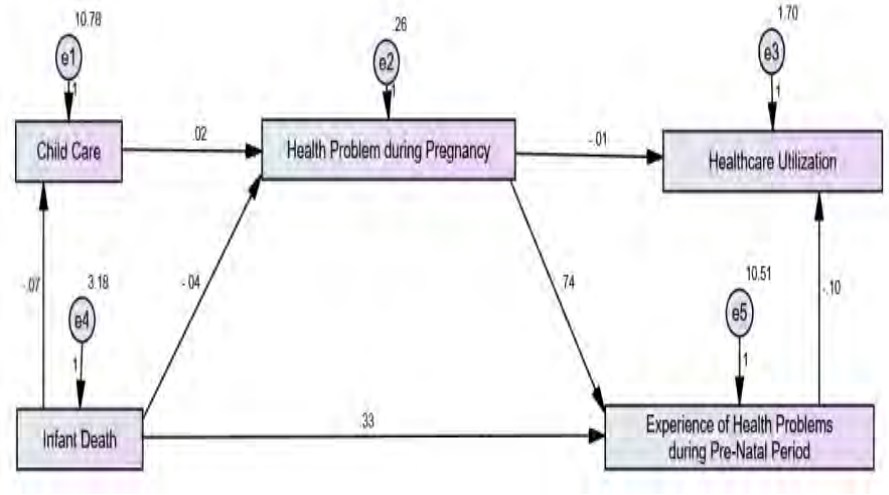


Fig. 8 Standardised Model of Mediator Construct

According to these assumptions, the outcomes such as regression weights, unstandardized and standardized factor model structures for every path, and its significance were extracted. Figs. 7 and 8 depict the SEM pathways, and Table 9 details the effects and confidence intervals.

Table 9: Infant Death and Health Problems during Pregnancy

Relationship			Standardised Indirect Effect			
			Estimates	95% Confidence Interval		Two Tailed Significance (BC)
				Lower Bound	Upper Bound	
Infant Death	Child Care	Health Problems during Pregnancy	0.005	-0.020	0.003	0.244
Infant Death	Child Care	Experience of Health Problems during the Pre-Natal Period	0.010	-0.041	-0.003	0.005**
Infant Death	Child Care	Utilisation of Healthcare	0.012	-0.062	-0.015	0.001**
Child Care	Health Problems during Pregnancy	Experience of Health Problems during the Pre-Natal Period	0.009	0.001	0.035	0.050*
Child Care	Health Problems during Pregnancy	Utilisation of Healthcare	0.005	-0.018	0.002	0.241
Health Problems during Pregnancy	Experience of Health Problems during the Pre-Natal Period	Utilisation of Healthcare	0.010	-0.050	-0.010	0.003**

*** Denotes significant at 1% level* Denotes significant at 5% level*

Direct Relationship of Mother and Child Healthcare: The results indicate that infant death goes up by 1 unit and child care goes down by 0.070 units. The regression weight for infant death in the prediction of child care is not significant, because the p-value is greater than 0.05. Therefore, the assumption (H_1) infant death was not having a significant impact on child care in this study area. However, child care has significant effect on health problems during pregnancy. The child care increase by 1 unit and health problem during pregnancy increases by 0.017 units, with p=0.008 at the 0.001 level (two-tailed). Also, infant death has significant effect on health problems during pregnancy. The infant death variable rises by one unit, but the health problem during pregnancy falls by 0.042. The regression weight for infant death is significant (p=0.001) at the 0.001 level (two-tailed). The health problems during pregnancy have significant effect on experience of health problems during pre-natal period. The variable of health problem during pregnancy ascends by 1 unit and the experience of health problems during the pre-natal period rises by 0.738 units, with the significance at 0.001 level (two-tailed).

Indirect Relationship of Mother and Child Variables: Initially, the experience of health problems during the prenatal period, health problems during pregnancy, child care, infant death, and utilization of healthcare constructs of six (6), five (5), four (4), three (3), and two (2) items respectively. The other items were dropped from the model for having factor loadings of lower than 0.6. The low reliability of the items may cause deviation to the model fit indexes measurement, hence were dropped from the model. Fig 7 and 8 illustrate the unstandardized and standardized estimates of direct and indirect effects of the exogenous construct towards the endogenous construct in the existence of the mediator construct. The six indirect effects are identified through one mediator (Table 9).

Infant death and health problems during pregnancy have significant indirect effects through child care. Table 9 shows how infant death's indirectly effects health problems during pregnancy. As a result, infant death increases by 0.005 for every one-unit increase in health problems during pregnancy in the study area. The construct of infant death has an indirect effect on the experience of health problems during the prenatal period through the mediator child care and its impact is 0.010. As a result, infant death increases by 0.010 for every one unit increase in experience of health problems during the prenatal period. The indirect effect of child care is having significant partial mediation at a 1.0 percent level between the construct of infant death and experience of health problems during the prenatal period(p=0.005). The exogenous path construct infant death has an indirect effect on the utilization of healthcare through the mediator child care and its impact is 0.012. As a result, infant death increases by 0.012 for every one unit increase in utilization of healthcare. The indirect effect of child care is having significant partial mediation at a 1.0 percent level between the construct of infant death and utilization of healthcare (p=0.001).

This present study has proven that the factors specifically experience of health problems during the prenatal period, health problems during pregnancy, child care, infant death and utilization of healthcare influence the mother and childcare in Madurai district. The results revealed that the socio-economic status significantly impacts access to nutrition, healthcare, and the overall utilisation of reproductive health services in the district. The likelihood and statistical association of essential elements estimate the goodness of fit of the structural model and represent an adequate description of mother and child healthcare indicators.

4. Conclusion

SEM and path analysis revealed significant direct and indirect relationships between mother and child health variables in Madurai district. Notably, prenatal care, regular medical check-ups, and effective healthcare utilisation are pivotal in enhancing child care and maternal health outcomes in the district. The findings underscore that both direct and indirect pathways, particularly childcare and infant mortality, play crucial roles in influencing maternal health problems during pregnancy and healthcare utilisation in the district. Policymakers should focus on improving healthcare accessibility and addressing socio-economic disparities to foster better health outcomes for mothers and children in Madurai District.

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The Indian Geographical Journal
Volume 100 (1) June - 2025, pp 55-68
ISSN 0019-4824

SPATIAL PATTERNS OF ECONOMIC MARGINALITY AND THEFT IN MANIPUR CENTRAL VALLEY, NORTH EAST INDIA

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Abstract

The spatial configuration of economic marginality and theft across the Manipur Central Valley reveals a positive correlation (r=0.341), between non-worker populations and theft cases, which underscores how informal employment and economic instability reinforce social vulnerability, where limited access to formal economic opportunities may lead to increased engagement in theft as a coping mechanism within marginalized groups. This research paper aims to analyze the demographic and economic marginality profile and evaluate the spatio-temporal patterns of deviant behaviours (Theft) within the Manipur Central Valley. The theft cases and its patterns in Manipur Central Valley were assessed using FIRs and victim's letters drawn from the law enforcement agency (NCRB), and police station of Manipur. The demographic and economic parameters were extracted from the Census of India, 2011. The study investigated the intercorrelation between theft (X1), population density (X2), Schedule Caste population (X3), Schedule Tribe population (X4), and economic marginality (X5). The study adopts both (mixed) qualitative and quantitative approach to analyze the spatial distribution of theft and its relationship with demographic and economic factors, as well as the impact of crime on victims. The quantitative analyzes include estimate of decadal population growth rate, z-score of economic marginalities and Pearson's correlations. Qualitatively, narrative analysis (FIR reports and victim letter of 2021 incidence) had utilised to gain insights into the social and psychological repercussions of theft. The study reveals that regional disparities are evident in socio-economic indicators, with Imphal East exhibiting the highest incidence of theft (z-score = 1.496), and Imphal West showing a significant concentration of non-working population (z-score = 0.989). The sum of correlations also reveals patterns in how each variable interacts with the others. Economic marginality shows the highest combined influence on the other variables, whereas Scheduled Caste (X2) has the weakest overall association. Theft cases reported (FIR qualitative analysis) across Manipur Central Valley offer rich cultural insights into the changing moral economy, spatial insecurity, and community perceptions of safety and trust. The spatial disparities in theft and economic marginality across the districts underscore the need for targeted crime prevention strategies and economic development programs.

Keywords: Theft, Marginality, Economic Disparities, Demography, Spatial Analysis.

1. Introduction

A fundamental aspect of social geography is the study of social patterns and problems. Crime, a deviant human behaviour, is a universal issue that plagues all societies. It has been regarded a severe vital concern for every society, whether rural or urban, peasant or industrial. Crime is a deviation from the social ideal that can be remedied by group effort (Furfey, 1961). The legal definition of crime is that, it is a behaviour or activity in violation of the legal code (Mishra, 2022). Theft emerges when there is a disconnection between individual aspirations and societal expectations—a state termed as "anomie." Anomie occurs when rapid social change, economic instability, or breakdowns in social institutions weaken the moral fabric of society, leaving individuals feeling disconnected, alienated, and lacking clear guidance on acceptable behaviour (Durkheim, Émile, 1951). The rapid demographic change resulting social conflicts. Population, social composition, and economic marginality are deeply interlinked elements of society. Rapid population growth often intensifies resource scarcity, leading to unequal access to basic amenities like education, healthcare, and housing. Social composition, shaped by factors such as caste and ethnicity, determines how resources and opportunities are distributed. Marginalized groups often face systemic exclusion, which pushes them into economic marginality—characterized by poverty, unemployment, and lack of access to productive resources. Marx emphasized that population growth in capitalist societies often exacerbates class struggles and intensifies economic inequalities (Saito, 2020). The urban planning and resource allocation practices often reflect broader capitalist priorities, resulting in uneven development and spatial injustice (David, 2001). Economic marginality further entrenches social inequalities, creating a cycle of deprivation, urbanization and uneven population distribution exacerbate these disparities and hence turn to deviant for the fulfilment of their goal survival.

Manipur (including Central Valley) has experienced a notable social, cultural and demographic transformation over the past decades; the population of the Manipur has increased significantly, rising from 577,635 in 1951 to 2,855,794 in 2011 (Directorate of Economics & Statistics, 2017; Singh, 2014; Alamá-Sabater et al., 2021). This demographic trend reflects a complex interplay of factors, including natural population growth and migration patterns (Bhattacharyya, 2006; Singh, 2014). The population growth rate of Manipur had been higher than India as a whole since 1901. The state has experienced steady population growth up to 1951, the post-1951 period witnessed a continuous rise in population, which subsequently intensified the problems associated with overpopulation (Bhattacharyya, 2006). This has placed significant strain on resources, including infrastructure, healthcare, and education, which often lag behind the growing demand (Abeysinghe, 1986). The rapid urbanization in the fertile Central Valley, coupled with inadequate infrastructure and social services, has contributed to socio-economic inequalities and heightened social tensions (Singh, 2014; Durkheim, 1951). One of the manifestations of these tensions is the rise in deviant behaviours such as theft. The essential ingredients of theft include a dishonest intention to take the property, the property

must be movable, it must be taken without the owner's consent, and there must be some movement of the property to complete the act (Mishra, 2022)**.**

Economic marginality is a critical factor contributing to social unrest in the Manipur (including central valley); the predominantly agrarian economy, with limited industrial development, restricts formal employment opportunities, resulting in high rates of informal employment and non-worker populations (Bhattacharyya, 2006; Schöneberg et al., 2022). Economic marginalization intensifies social tensions and conflicts, as marginalized communities struggle to access the resources necessary for a stable and prosperous life, leading to higher incidences of deviance in a society and potentially lead to thefts (Callo-Concha et al., 2014; Gatzweiler & Baumüller, 2014; Durkheim, Émile, 1951). In this context, the primary objectives of the study are to: 1) analyze the demographic and economic marginality profile of the Manipur Central Valley, 2) evaluate the spatio-temporal patterns of deviant behaviours, with a specific focus on theft within the region, and investigate the intercorrelation between theft cases (X1) and key socio-economic variables, such as population density (X2), Scheduled Caste population (X3), Scheduled Tribe population (X4), and economic marginality (X5).

2. Study Region

Nestled between latitudes 24°20' N to 25°0' N and longitudes 93°0' E to 94°0' E, the Manipur Central Valley spans approximately 2,067 sq. km and comprises five core districts—Imphal West, Imphal East, Thoubal, Kakching, and Bishnupur. Surrounded by the eastern and western hill ranges, this valley serves as the ecological and cultural heartland of Manipur (Singh, 2014). The valley presents a unique lowland settlement pattern distinct from the highland communities inhabiting the hills of Northeast India. The valley's alluvial soil, indicative of a relatively young geological formation, has historically encouraged sedentary agriculture over shifting cultivation. This environmental stability facilitated the evolution of settled village life and a deeply agrarian ethos. Some geologist interpretations suggest that the valley may have once been a vast water body, larger even than Loktak Lake, whose gradual silting by surrounding hill streams gave rise to fertile plains and the foundation for human settlement. The presence of the saucer-shaped depression towards the southeast—housing the sacred Loktak Lake—adds spiritual and ecological depth to the valleys cultural (Arunkumar, 2011). The Imphal River, originating from Senapati and flowing through Kangpokpi into the valley, is more than a geographic feature; it is a living artery of socio-economic life. Its network of tributaries supports rice cultivation, fishery practices, and ritual-based water usage, anchoring land tenure customs and influencing clustered settlements. Seasonal cycles—summer, monsoon, retreating monsoon, and winter—regulate agricultural rhythms and cultural festivals. March and October are considered climatically pleasant, while December and January are colder months when agricultural labour patterns and even communal interactions slow down.

Land holding and agrarian identity are shaped by the Manipur Land Revenue and Land Reforms Act, 1960, which codifies ownership, personal cultivation rights, and land

ceilings. This legal framework not only governs land access but also intersects with caste, clan, and kinship-based inheritance patterns, influencing socio-political hierarchies within valley communities (Census of India, 2011). Under this law, a single person can hold up to 2.5 acres of land, and a family up to 7.5 acres, which implicitly structures social inequality, resource allocation, and rural power dynamics. Urbanisation in the valley has accelerated post-2001 census. Of the Fifty-one (51) urban centres recorded in 2011, Forty-four (44) lie within the Central Valley, reaffirming its role as a population magnet due to infrastructure concentration and economic opportunity (Bhattacharyya, 2006). This shift reflects a transition in spatial identity—from agrarian society to hybrid urban-rural cultures that negotiate modernity with tradition.

3. Database and Methodology

This research adopts a spatial analysis approach, leveraging GIS and spatial statistical techniques using ArcGIS software, to analyse the dynamics of socio- economic and behaviour in Manipur's Central Valley Imphal East, Imphal West, Thoubal, Kakching, and Bishnupur. Crime data (theft) were collected from the law enforcement agencies (NCRB, 2001, 2011; Manipur Police department, 2017) and geo-coded to identify the spatial clustering of thefts. The demography data have collected from the Census of India (2011). The study adopts both qualitative and quantitative methods to analyze the spatial distribution of theft and its relationship with demographic and economic factors. The qualitative aspect involves narrative analysis of FIR reports and victim letter of 2021 incidence to gain insights into the social and psychological repercussions of theft. On the other hand, the quantitative approach incorporates techniques such as the calculation of decadal variation of population growth, z-score of economic marginalities, theft and intercorrelation analysis of variable from the Pearson's correlation to evaluate population trends and their correlation with the theft patterns. This dual approach ensures a comprehensive understanding of how demographic changes and economic conditions influence crime distribution and its effects on individuals in the Manipur Central Valley.

The calculation of decadal variation of population growth is expressed as:

$$\mathrm{Dg} = \frac{P1 - P2}{P2} \times 100$$

Dg= Decadal Growth rate of the population, P1=Population at End of Decade, P2= population at the start of the Decade. The z-score of marginal workers (non-worker) is expressed as:

$$z = \frac{x - M}{S.D}$$

Where: z =z-score of the Marginal worker, x= incidence of Marginal worker, M= Mean, S. D=Standard deviation. Further, z-score had utilised for the theft analysis. The intercorrelation-matrix analysis was attempted using a Pearson Correlation (r). The formula is given as:

$$r = \frac{\sum XY - \frac{\sum X \sum Y}{N}}{\sqrt{\sum X^2 - \frac{(\sum X)^2}{N}} \sqrt{\sum Y^2 - \frac{(\sum Y)^2}{N}}}$$

The qualitative approach aims to delve deeper into the impact of deviant crimes on individuals within the Manipur Central Valley. The selected FIRs (2021), representing diverse districts, include cases from Imphal East (Porompat Police Station), such as FIR 224 (9) 2021 PRT-PS Under section 379/34 IPC and FIR (226) 2021 PRT-PS Under section 379/34 IPC. As well as Imphal West (Imphal Police Station), which includes FIR 192 (11)2021 IPC Under section 379 and FIR 212 (12) 2021 IPS Under section 379 IPC. Similarly, from Thoubal district (Police station) FIR 29 (3) 2021 TBL-PS Under section 380 IPC and FIR 39 (5)2021 TBL-PS Under section 379 IPC. Kakching (Police Station), FIR (61)2021 KCG-PS Under section 380/34 IPC and FIR 79(08)2021 KCG-PS Under section 380/34 IPC. Lastly, Bishnupur (Police Station), FIR 29(4)2021 BPR-PS Under section 380 IPC and FIR 33 (6) 2021 BPR-PS Under section 380 IPC. These cases were strategically chosen to represent various deviant crimes across the region, enabling a comprehensive analysis of their social and psychological effects on victims.

4. Results

4.1 Demographic and Economic Marginality Profile

The population density of the Manipur Central Valley is given in Table 1. The total area of the Valley is 2,238 square kilometres, with a combined population of 1,633,672, resulting in an overall population density of 730 persons per square kilometre. Imphal West has population density of 928.3 persons per square kilometre, which is the highest density among the districts. The social composition of the Manipur Central Valley is diverse, as seen in the distribution of different social groups across its districts. In Imphal East, the population comprises 15,839 (Scheduled Castes) and 27,657 (Scheduled Tribes). Imphal West shows a similar composition, with 16,530 (Schedule Caste) and 24,161 (Schedule Tribe). Bishnupur has a population that includes 22,113 (Schedule Caste) and 3,287 (Schedule Tribe). Thoubal including Kakching is notable for having the highest Schedule Caste population among the districts, with 40,593 (Schedule Caste) and 1,808 (Schedule Tribe). Imphal East and Imphal West have relatively balanced distributions between Schedule Caste, Schedule Tribe.

The consistent population increase may lead to issues of social integration, especially if infrastructure and social institutions (e.g., schools, healthcare) do not keep pace with the growing population (Durkheim, 1951). The population of the Manipur Central Valley has shown a consistent increase from 1951 to 2021 (Table 2). In 1951, the population was 387,523 (Table 2). By 1961, this had increased to 532,793, resulting in a decadal variation of 145,270 and a growth rate of 37.49%. In the following decades, the growth rates maintained as 35.99% in 1971, 28.23% in 1981, and 27.65% in 1991. From

1991 to 2001, the population grew to 1,411,766, with a decadal growth rate of 19.04%. The 2011 census recorded a population of 1,633,672 with a growth rate of 15.72%. This data highlights a steady increase in population over seven decades with a declining growth rate. The declining growth rates may be attributed to lower birth rates and migration patterns.

Table 1: Population distribution, density and Social Composition in Manipur Central valley, 2011

District	Area in sq. km	Total Population	Population Density	Schedule Caste	Schedule Tribe
Imphal East	670	456113	680.8	15839	27657
Imphal West	558	517992	928.3	16530	24161
Bishnupur	496	237399	478.6	22113	3287
Thoubal (Kakching)	514	422168	821.3	40593	1808
Valley Total	2238	1633672	730	95075	56913

Source: Census of India, 2011; Note Pd= Population Density (persons per square kilometre)

Table 2: Growth trend of Population in Manipur Central Valley (1951-2021)

Year	Population	Decadal Variation	Growth Rate in %
1951	387523	-	-
1961	532793	145270	37.49
1971	724537	191744	35.99
1981	929077	204540	28.23
1991	1185992	256915	27.65
2001	1411766	225774	19.04
2011	1633672	221906	15.72
2021	1877416	243744	14.92

Source: Calculated from the Census of India; Note: 2021 is based on the projected population

According to the Census of India, 2011, a non-worker is an individual who is not currently engaged in paid employment (Directorate of Census Operation, India, 2011). This group encompasses both those who are not participating in the labour force (such as students, homemakers, retirees, and those unable to work) and those who are classified as unemployed, meaning they are actively seeking employment and are available to work but do not currently have a job. The non-worker data for the Manipur Central Valley in 2011 reveals significant regional variations (Table 3). Imphal West has the highest concentration of non-workers, accounting for 33% of the total non-working population, with 304,605 individuals. This is reflecting in its z-score of 0.989, indicating it is almost one standard

deviation above the mean (230,045.25). Bishnupur has the lowest percentage of non-workers at 14%, with 127,462 individuals, and a z-score of (-1.360), highlighting it is significantly below the mean. The total non-working population across these regions is 920,181. The statistics highlight the uneven distribution of informal employment across the Manipur Central Valley, with Imphal West and Imphal East exhibiting higher concentrations of non-workers compared to Bishnupur, which has notably lower levels.

Table 3: Non-worker population and z –score in Manipur Central Valley, 2011

Region	Non-worker	Percentage	Z-Score
Imphal East	261265	28	0.414
Imphal West	304605	33	0.989
Bishnupur	127462	14	-1.360
Thoubal (Kakching)	226849	25	-0.042
Total	920181	100	-
Mean	230045.25	-	-
Standard Deviation	75426.27	-	-

Source: Compile from the Census of India, 2011; Note: The data include informal employment such as illegal activities such as prostitution, drug trafficking, gold smuggler etc.

4.2 Spatial distribution of theft

In 2001, the theft data for the Manipur Central Valley reveals significant variation across different districts (Table 4 and Figure 1). Imphal West reported 39 theft incidents, making up 17 % of the total thefts, whereas Thoubal (Kakching) stands out with 162 theft incidents, a substantial 71% of the total thefts. Theft data of 2011 revealed significant differences in theft rates among its districts. Thoubal recorded 65 incidents, representing 10% of the total thefts, wheras Imphal West experienced 76 theft incidents, making up 11% of the total. Imphal East, on the other hand, had a strikingly high number of thefts at 496 incidents, which constituted 73% of the total thefts. The total number of thefts in the Central Valley was 677 with considerable variation in theft rates.

The relationship between theft cases and population growth over two decades reveals distinct patterns. During this period, a strong positive correlation ($r = 0.8$) was observed between theft cases and population growth, suggesting that higher population growth was associated with increased theft rates. Despite a dramatic rise in overall theft numbers in 2011, the correlation between theft cases and population growth during this period weakened significantly ($r = 0.15$). This analysis indicates that while theft occurrences were strongly linked to population growth in the earlier decade, other factors likely played a more dominant role in influencing theft rates in 2011.

Table 4: Distribution of theft in Manipur Central Valley (2001-2011)

District	2001			2011		
	No. of Theft	Percentage	Z-Score	No. of Theft	Percentage	Z-Score
Bishnupur	9	4	-0.675	40	6	-0.592
Imphal East	18	8	-0.548	65	10	-0.477
Imphal West	39	17	-0.253	76	11	-0.427
Thoubal (Kakching)	162	71	1.476	496	73	1.496
Total Valley	228	100	-	677	100	-
Mean	57	-	-	169.25	-	-
Standard Deviation	71.12	-	-	218.35	-	-

Source: Prepared from NCRB Report, Superintendent of Police, Manipur Central Valley

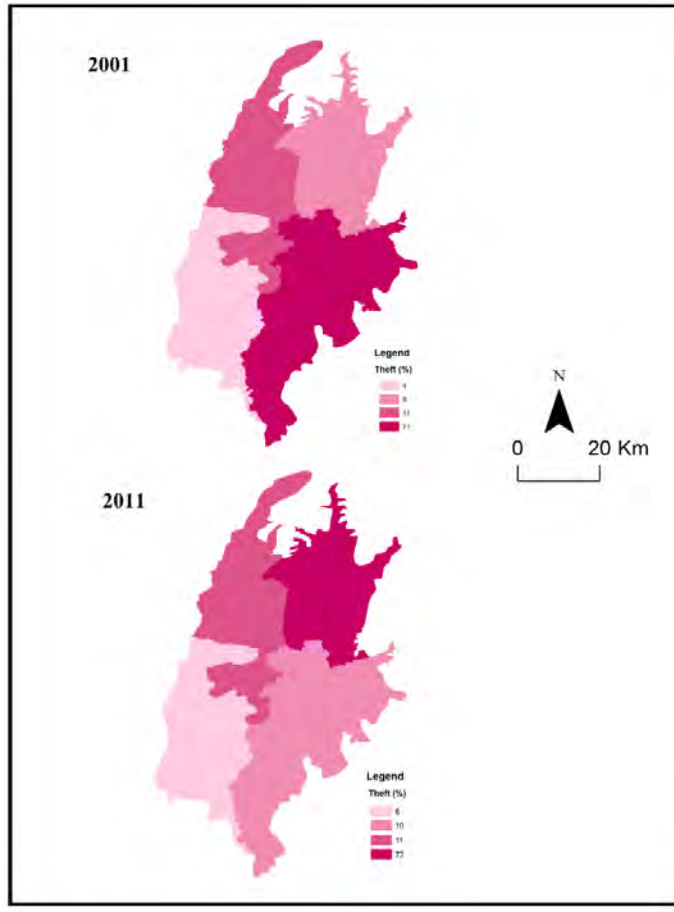


Figure 1: Spatial distribution of theft in Manipur Central Valley. ***Source: NCRB 2001 and 2011***

4.3 Correlation Analysis

The correlation matrix provides valuable insights into the factors influencing theft (X1) in relation to population density (X1), Scheduled Caste population (X2), Scheduled Tribe population (X3), and economic marginality (X4, non-workers). Theft and population density show an insignificant correlation (r= -0.091), suggesting that theft rates are not directly affected by the populated in an area. However, theft has a moderately negative correlation (r= -0.456) with Scheduled Caste populations, indicating that areas with larger Scheduled Caste communities experience fewer thefts.

Table 5: Correlation Matrix of Deviant, demography, social composition and Economic

	X1	X2	X3	X4	X5
X1	1.000	-0.091	-0.456	0.694	0.341
X2	-0.091	1.000	0.135	0.370	0.881
X3	-0.456	0.135	1.000	-0.784	-0.257
X4	0.694	0.370	-0.784	1.000	0.756
X5	0.341	0.881	-0.257	0.756	1.000
Sum	1.487	2.295	-0.362	2.035	2.721

Source: Prepared from NCRB, 2011 report and Census of India, 2011; Note: X1=Theft, X2=population density, X3=Schedule Caste population, X4=Schedule Tribe population, X5=Economic marginality (non-worker population)

In contrast, theft shows a moderately strong positive correlation (r= 0.694) with Scheduled Tribe populations, suggesting that these areas are more prone to theft. Furthermore, a mild positive correlation (r=0.341) exists between theft and economic marginality, meaning that regions with more non-working individuals are slightly more susceptible to theft. Population density also correlates positively with economic marginality (r=0.881) and Scheduled Tribe populations (r=0.370), emphasizing its role in shaping socio-economic contexts in the study region. The sum of correlations also reveals patterns in how each variable interacts with the others. Economic marginality (X4, with r sum=2.721) shows the highest combined influence on the other factors, whereas Scheduled Caste (X2) has the weakest overall association (r sum=-0.362), indicating its more limited interaction within this context. Areas with higher Scheduled Tribe populations and greater economic challenges tend to experience higher theft rates. Interestingly, while population density has little direct correlation with theft, its strong association with economic marginality suggests it indirectly contributes to theft-related factors.

4.4 Social-Geographical Inquiry into Property Crime

The qualitative study overviews the experiences of theft victims across the districts of Manipur. Drawing from reported FIRs, the analysis provides a narrative-rich lens into the socio-economic and psychological dimensions of these incidents. The vibrant yet densely

populated Imphal East has seen a wave of two-wheeler thefts, reflecting a growing concern over property safety. These incidents underscore the collective anxiety surrounding the erosion of safety. The heart of Imphal (Imphal West) is no stranger to theft, with offenders displaying increasing levels of sophistication and boldness. The vehicle thefts in this district not only stripped the owner of an expensive vehicle but also exposed systemic gaps in community safety mechanisms. The suburban district of Thoubal offers a glimpse into crimes that exploit the relative quiet of non-urban spaces. The intrusion into private property marks an unsettling shift in criminal strategies targeting residential spaces. The district of Kakching presents a unique facet of theft incidents, moving beyond personal vehicles to institutional and workplace property. In Bishnupur, thefts often involve breaches of domestic and institutional sanctuaries, leaving victims grappling with both financial and emotional losses.

5. Discussion

The present study observes a spatio-temporal shift in theft concentration across the Manipur Central Valley between 2001 and 2011. In 2001, Thoubal (including Kakching) registered the highest theft incidents. However, by 2011, the hotspot had shifted to Imphal East. This transition marks a dynamic and evolving geography of deviance, suggesting theft is not spatially static but reshaped by underlying socio-economic and environmental changes. This finding aligns with Sivamurthi's (1982) spatial analysis of Madras City, where he noted increasing theft trends in peripheral urban zones such as Adyar, Anna Nagar, Sembium, and Agaram. He attributed this to land-use changes and new environmental opportunities. Conversely, theft rates declined in inner congested areas like Tondiarpet and Seven Wells, where limited economic potential and constrained spaces possibly deterred offenders. A similar logic unfolds in the Manipur context, where theft incidents are more concentrated in peripheral or semi-urban zones like Thoubal and Imphal East, rather than in commercial cores or established central business districts. This reinforces the idea that spatial expansion, infrastructural development, and ecological restructuring—rather than centrality—shape theft patterns. However, a point of divergence arises when examining the relationship between population growth and theft. In 2001, theft incidents in Manipur showed a high positive correlation ($r = 0.8$) with population growth from 1991 to 2001, indicating that urban expansion and demographic pressure might have driven initial crime surges. Yet, by 2011, this correlation dropped significantly to $r = 0.15$, suggesting that population growth alone was no longer a reliable predictor of theft distribution. This decoupling highlights the need to consider other intervening variables such as urban planning, surveillance infrastructure, and socio-spatial reorganization—elements that Sivamurthi tended to subsume under broader land-use transitions rather than demographic dynamics.

The correlation analysis between theft and socio-economic variables in the Manipur Central Valley offers deep insights into the structural roots of deviant behaviour. A strong positive correlation between theft and Scheduled Tribe populations ($r= 0.694$) suggests that areas with higher tribe populations are more prone to theft. This aligns with studies

(Sengupta & Mukherjee, 2018), which argue that socio-economic marginalisation often predisposes communities to crime. In Manipur, not just the Scheduled Tribes but also economically deprived subgroups within the Meitei population, such as the Pangals, reflect this vulnerability. The mild positive correlation between theft and economic marginality (r= 0.341) further reinforces that poverty and lack of employment can push individuals toward property crime. This supports findings from Anser et al.(2020) on income inequality's role in increasing urban theft. However, the negative correlation with Scheduled Caste populations (r = –0.456) indicates lower theft rates in Scheduled Caste dominated areas. This contrasts with studies like Metz & Burdina (2018), suggesting regional variation. In Manipur, Scheduled Caste groups may live in more cohesive, regulated communities, where social integration discourages deviant behaviour—echoing Durkheim's theory on collective solidarity (Durkheim, 1951). Population density, although weakly correlated with theft (r= –0.091), shows a strong association with economic marginality (r=0.881), implying that densely populated areas tend to face deeper socio-economic stress. From a structuralist view, these patterns reflect the contradictions of capitalism. Drawing from Bonger (1916) and Marx (1887), Theft in Manipur—especially the stealing of essential items like two-wheelers—can be seen as a survival strategy amid exploitation. In suburban and rural regions, the erosion of traditional bonds creates vulnerability to crime. Private security in urban centres benefits the elite, while deprived groups face the brunt of criminalization. The theft trends reveal systemic alienation and inequality, not merely moral failure.

Theft cases reported across Manipur's Central Valley offer rich cultural insights into the changing moral economy, spatial insecurity, and community perceptions of safety and trust. Anthropologists have long viewed crime not merely as legal violations, but as embedded acts within cultural, spatial, and relational systems. In urban districts like Imphal East and Imphal West, the stolen two-wheelers (Cases 1–4) are not just objects of economic value. Within the Meitei middle-class household economy, scooters symbolize mobility, dignity, and modernity—especially for the younger working population and families accessing health and education services. According to Mary Douglas (1992), material objects are symbols of order, and their loss signifies the disruption of everyday structure. Jenil's case, where the theft occurred at a healthcare facility, highlights how public institutions fail to safeguard not just life but livelihood — deepening the sense of vulnerability in moral spaces. In cultural terms, the theft is a moral rupture—an act that violates both legal codes and local social norms. In the context of Wangkhei Angaom Leikai (Case-2), the act of stealing under stringent personal precautions points to a fracture in the assumed ethical bond within Leikai-based neighbourhoods, traditionally known for social cohesion and watchfulness. Drawing from the concept of *communitas* (Turner, 1969), such thefts disturb the informal moral orders that bind these kin-based and clan-sensitive communities. Cases 3 and 4 show how urban space is increasingly weaponized by criminal actors. Gyanendro's experience, where a scooter was stolen near an office gate. In Thoubal, Cases 5 and 6 highlight a deeply relational consequence of theft. For Nunghitombi and Shantakumar, thefts involve not just stolen items but disrupted livelihoods and psychological trauma. Anthropologist Veena Das (1995) reminds us that, violence is not

limited to the act itself but continues in the lives of people long after the event is over (Das, 1995). When identity documents and shop-side vehicles are stolen, the victim's social agency and bureaucratic legibility are also erased — pushing them deeper into marginality. In Kakching, the theft of educational and institutional items (Cases 7 and 8) reflects not individual victimhood but a collective vulnerability. From an institutional social view, such acts are attacks on state authority and community development. The stolen desktop from the IED office and the cash-mobile theft from GR Infra base camp serve as *cultural evidence of criminal adaptation* to emerging state-society gaps — especially in liminal development zones. Bishnupur's cases (9–10) reveal cultural trauma stemming from the violation of sacred household boundaries. The act of creating a hole in a wall (Case-10) is culturally significant — not merely an entry point but a ritual desecration of the domestic sacred space. The loss of medical equipment from a health centre (Case-9) shows how crime undermines communal resilience, turning health into a casualty of insecurity.

The cultural tapestry of thefts in Manipur's Central Valley exposes a gradual erosion of communal bonds, the emergence of new criminal ecologies, and the symbolic collapse of safety in public and private domains. Theft here is not merely an economic act but a cultural performance of power and helplessness—where the urban poor, the suburban self-employed, and rural households all confront different shades of victimhood. This qualitative inquiry underscores the need for spatial sacredness, symbolic property value, and social trauma rather than just policing statistics. As crime seeps into the moral architecture of Meitei and multi-ethnic Manipuri society, only a culturally grounded response can restore trust and resilience.

6. Conclusion

The consistent growth in the population of the Manipur Central Valley from 1951 to 2021, accompanied by a declining growth rate, signifies persistent demographic pressure. While the growth rate has diminished, the overall increase continues to strain resources, exacerbating issues related to infrastructure, healthcare, and education. The uneven population density across districts highlights regional disparities, with Imphal West and Imphal East facing higher densities and consequently more significant competition for resources. This strain is potentially link to higher rates of deviant behaviour, such as theft, particularly in high-density areas like Imphal East, which shows a disproportionately high incidence of theft. Across districts, recurring patterns of theft show a preference for two-wheelers and electronic devices as targets, with incidents often occurring during early mornings or nighttime. These patterns reflect not only the opportunistic behaviour of thieves but also highlight the vulnerabilities within personal and institutional spaces. Victim's narratives emphasize the breach of trust and safety, underscoring the broader social and psychological impact of theft. However, amidst the material losses, the community demonstrates resilience and an enduring hope for justice in an evolving social fabric. The correlation between non-worker populations and theft (r=0.341) suggests that economic marginality—evidenced by high non-worker rates and informal employment—may drive individuals toward criminal activities as a coping mechanism. The disparities in theft rates

and economic marginality across the districts underscore the need for targeted crime prevention strategies and economic development programs. Addressing these issues requires a multifaceted approach that integrates social, economic, and infrastructural improvements to manage the impacts of population growth and reduce the propensity for deviant behaviour.

Acknowledgment

I extend my sincere gratitude to the Indian Council of Social Science Research (ICSSR) for their generous support towards this research endeavour. The assistance provided by ICSSR has been instrumental in the successful completion of this project under File No. ICSSR/RFD/2023-24/344.

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The Indian Geographical Journal
Volume 100 (1) June - 2025, pp 69-81
ISSN 0019-4824

CHALLENGES OF SCHEDULED TRIBES TOWARDS EDUCATIONAL ATTAINMENTS IN THE WESTERN GHAT VILLAGES OF QUEPEM SUB-DIVISION IN GOA

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Abstract

Education plays a pivotal role in transforming and empowering a community. Goa, an Indian State, got liberated from Portuguese Colonial Rule in 1961, has achieved a remarkable overall literacy rate of 88.70% (Census of India, 2011). However, the literacy rate among the Scheduled Tribes (ST) was only 71%, significantly lower than the state average. To reveal bottlenecks of educational attainment in the state, primary data collected from 198 households, which contain information about the educational status of 1,018 family members. This data was collected through a structured questionnaire and schedule. Ten villages in the Quepem Sub-Division, located in the Western Ghats region of South Goa district, have been selected. The two villages around Quepem town which is bestowed with easy access to educational infrastructure, and eight villages from remote location in the hilly and forested region have been selected to find out the impact of nearness to infrastructure. Descriptive statistical techniques have been applied to analyse the data using IBM's SPSS software. Among the selected villages, the two very remotely located villages, viz. Corla-Kazugotav and Vavurla are still in the shadow from mainstream developmental activities point of view; the children scale the hills up and down several kilometres every day to attend their school. The lack of access to infrastructure, poverty and inadequate awareness about the value of formal education among the tribal community in these villages has resulted in a slower pace of social development and transformation. It is essential to create awareness about the legal rights and government schemes available for the Scheduled Tribe students towards education and economic empowerment leading to the transformation of the Scheduled Tribe community in the study region in particular and the State of Goa in general.

Keywords: Scheduled Tribe, Educational Status, Challenges, Quepem Sub-Division, Goa.

1. Introduction

It is well recognised and documented that education is the most essential and potential tool for the overall development of all the marginalised and lesser privileged population in a nation. Globally, around 123 million people between the age group of 15 to 24 years lack basic reading and writing skills (Ramachandran & Deepan, 2017). The situation of India is more concerning, where certain sections of society, like the Scheduled Tribe (ST) communities, have faced social and economic deprivations due to their educational marginalisation. The monthly average income of the ST population in India was between Rs. 5000- Rs. 10000 (Jayakumari & Palaniyammal, 2016). The tribals are referred to as the indigenous people exhibiting a sustainable lifestyle, having a unique social, religious and cultural pattern of living. Scheduled Tribe is the constitutional term to refer to the tribal population of India under Article 342 of the Indian Constitution (Vidhyarthi & Rai, 1977). They are also referred to as *Adivasi, Anusuchit Janjati, etc.* The country is home to over 730 Scheduled Tribes that constitute 8.6% of the total population (PIB, 2022). Goa is home to three major Scheduled Tribe communities, namely the Velips, Kunbis and Gawdas, who together constitute just 0.1% of India's total Scheduled Tribe population (Census of India, 2011). The state of Goa has one-tenth (10.8%) of its population as Scheduled Tribes. The major tribal communities have a long history, even before the colonial rulers reached Goa. These tribal communities are the original settlers and are called Mull Goenkars or the first people to arrive in Goa (Kamat, 2014).

There have been significant differentials in educational attainments showing a gap between Scheduled Tribes and other sections of the community. The gap in literacy rate at the national level between the entire population and the Scheduled Tribe population is 14% where the scheduled tribe literacy rate is 59% much lower than the national average (73%). Whereas, in Goa, the literacy rate gap is lower (9.6%) with the Scheduled Tribe literacy rate of 79.1% and 88.7% of the overall literacy rate in the state (Govt. of Goa, 2025). Even though the gap in literacy rate is lower in Goa compared to many other states, it reflects upon various challenges faced by the tribal communities in the State in terms of pursuing education. The Velips, Gawdas and Kunbis have been granted Scheduled Tribe Status in 2003 (Govt. of India, 2003). These communities are isolated in terms of geographical locations but they are living in harmony with the local environment for generations. The Velips are known for their distinct customs and vibrant festivals, often practising traditional agriculture and gathering forest products (Velip, 2016). The Gawda community, primarily residing in the southern parts of Goa, is recognised for agricultural practices and deep knowledge of local ecosystems (Fernandes & Desouza, 2022). The Kunbis are involved in agriculture and maintaining traditional rice cultivation practices, contributing to Goa's agrarian economy and cultural richness (Gawas, 2018). They are predominantly living in the remote forest and hilly areas lacking access to higher educational facilities. The ancestors of the major tribes racially belong to Proto-Australoid group (Gawas, 2015). They settled in the forested areas and had their unique way of life, using the forest and its products for their survival. Later, the forests were cleared and used for cultivating crops and developing plantations. The tribes had their separate institutions of administration (Gaonkari

system), where the village headmen, called the Gaonkar or Budhovant, would resolve the disputes. Even today the institutional practices are still seen in the tribal communities in Goa (Gawas, 2015).

Easy and affordable access to education is a very important tool to eradicate socio-economic inequalities among these communities. However, physical challenges in remote areas have limited their access to the quality education available in the towns. This has hindered the socio-economic development of the ST population, thereby widening the gap between them and the general population. There are notified welfare programs and schemes launched towards tribal welfare and community development in Goa (Govt. of Goa, 2023), but the percolation of these facilities to the needy tribal communities is not effective. The impact and the effective evaluation of the welfare scheme can be done by understanding the ground situation of the tribal communities living in far-flung areas.

There are some visible gaps and there are scopes for research especially in issues pertaining to the educational access for the ST population and attainments by them. There have been very limited available studies on the educational challenges faced by the tribal communities in the study area especially from a spatio-temporal perspective. The available literature has mostly dealt with the cultural, historical, socio-economic aspects and presently available constitutional safeguards.

Hence, this study has focused on the educational access and the challenges faced by the tribal people of the villages located in the Western Ghat region of Quepem Sub-Division in South Goa. The study has relied on grassroots information collected from the selected 10 villages. It has set two objectives: to analyse the educational status of the ST community and, secondly, to identify the hardships faced by the students from these Western Ghat villages. The current study has established its novelty by providing measurable and feasible solutions to overcome the difficulties of distance-decay aspects of educational attainment faced by the ST population living in remote areas.

2. Database and Methodology

The study has been conducted based on primary as well as secondary data. The primary data has been obtained through a structured questionnaire and a schedule obtained through personal interviews of 198 households from the 10 selected Western Ghat villages of Quepem Sub-Division in South Goa. Out of the ten villages, two villages, being located near the Sub-Divisional headquarters of Quepem town: Adnem and Ambaulim, have been selected due to their easy access to educational infrastructure. The other eight villages, namely, Barcem, Cazur, Corla, Gokuldem, Mangal, Morpirla, Padi and Quiskonda have been selected due to their farthest, remote and hilly locations in the Sub-Division (Fig. 1).

A structured questionnaire cum schedule was designed to collect information about the educational background of 1,018 members from 198 households across the study area. A stratified random sampling technique wasused in collecting the primary data. The

secondary data has been compiled from the Census of India 2011 tables, newspaper articles, reports published by Govt. organisations and research papers. The data collected has been classified and tabulated, then analysed using descriptive statistics and cross-tabulation of the data using IBM's SPSS Statistics version 20 and Microsoft Excel.ArcGIS 10.8 software has been used to prepare the base map of the study area. The study has two hypotheses based on the prevailing situations reported in the literature: there is a gender gap in educational attainments among the ST population in the study area, where males have higher literacy than females. Educational qualifications of the ST population in the study area are limited to the SSC/HSSC level due to the non-availability of Higher Educational Institutions (HEI) in the vicinity. They have been tested using the Independent Samples Test for the first hypothesis and the second test has been based on the statistical figures obtained from the study.

3. Study Area

The selected villages (Fig. 1) are part of the Quepem Sub-Division, a western Ghats region with a very high number (25,290) and proportion (16.94%) of Scheduled Tribe population in Goa. This administrative division has a total population of 81,193 of which 31.15% are STs (Census of India, 2011). The Sub-Division has 11 Panchayats and two Municipalities. The selected villages in their respective panchayat areas are mostly inhabited by the ST population. There are little urban influence and migration from other communities in these eight remote villages. Two villages near the urban centres, viz. Ambaulim and Adnem have settlements belonging to different communities. The other selected eight villages have a high concentration of 80 to 100% ST population (Table 1). The literacy rate for males is 87.50% and for females is 78.35%. The total literacy rate of Quepem Sub-Division is 82.93% (Census of India, 2011). Most of the selected villages, especially those situated in the hilly and forested areas, lacked even basic facilities like tar road connectivity and public transport.

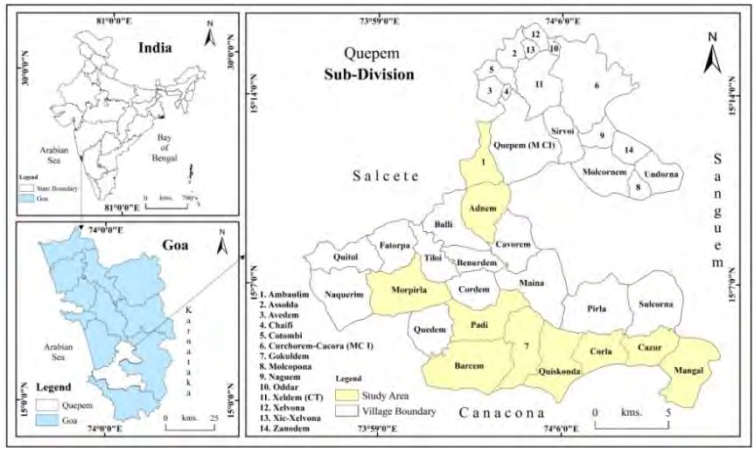


Figure 1: Location Map of the Selected Villages in Quepem Sub-Division of Goa, 2024

Source: Survey of India toposheet

The Government of Goa has taken some initiatives towards providing free education at the elementary and school level in the respective villages, considering access to elementary educational institutions is a fundamental right of the children. However, to access higher education, the children have to travel several kilometres. This is why a large group of students stay in less accessible areas, often discontinuing or stopping their further education due to the distance and public transport issues, including limited frequency.

Table 1: Scheduled Tribe Population in Selected Villages of Quepem Sub-Division, 2011.

Sr No	Names of the Villages	ST Population	Total Population	Percentage of ST Population
1	Adnem	790	1657	47.67
2	Ambaulim	2579	2987	86.34
3	Barcem	2443	2685	90.98
4	Cazur	505	510	99.01
5	Corla- Kazugotav	170	209	81.33
6	Gokuldem	526	579	90.84
7	Mangal	259	296	87.5
8	Morpirla	2752	2857	96.32
9	Padi	195	268	72.76
10	Quiskonda	490	491	99.79

Source:Directorate of Tribal Welfare, Goa's, 2011.

4. Results and Discussions

4.1 Accessibility to High Schools

The state government has provided elementary educational institutions in the form of Anganwadis and Primary schools in all the villages of the Sub-division. However, the distance travelled by the student within the villages varied according to the location of their houses in the wards (Table 2). For instance, Corla village didn't even have an Anganwadi, indicating a deficiency in the lowest order of social amenities. The students of some of the villages with large geographical areas like Cazur, Morpirla and Quisconda travelled between 1 and 3 km to reach elementary educational institutions, i.e. Primary Schools.

Only Adnem and Ambaulim villages had a high school within 1 to 3 km. The school-going children from the rest of the villages had to travel beyond 3 km to get access to high schools and higher secondary schools (Table 3). The students of the villages situated in hilly and remote places like Corla-Kazugotav and Vavurla had to travel beyond 10 to 20 km to reach a high school. Additional challenges were faced by the majority of the school-going children from some parts of these villages since they did not have even road connectivity nor had access to public transport near their settlements. Though there are claims about full accessibility to road amenities to most of the inhabited villages in Goa, it was disturbing to

find that even today, the school-going children of these settlements had to walk a minimum of 1 km to board a bus coming to their nearest accessible settlements.

Table 2: Elementary institutional accessibility in Quepem Sub-Division, 2023-24.

Villages	Anganwadi		Primary		
	Within the settlement	1 to 3 km	Within the settlement	Within 1 km	1 to 3 km
Adnem	✓	-	-	✓	-
Ambaulim	✓	-	-	✓	-
Barcem	✓	-	-	✓	-
Cazur	-	✓	-	-	✓
Corla- Kazugotav	-	-	✓	-	-
Gokuldem	✓	-	-	-	-
Mangal	✓	-	-	-	✓
Morpirla	✓	-	-	-	✓
Padi	✓	-	✓	-	-
Quiskonda	-	✓	-	✓	-
Vavurla	✓	-	✓	-	-

Source: Compiled by the researcher from field survey information, 2023-24.

Table 3: Accessibility to High School and Higher Secondary Schools in Quepem Sub-Division, 2023-24.

Villages	High School			Higher Secondary Schools	
	1 to 3 km	3 to 5 km	Above 5 km	3 to 5 km	Above 5 km
Adnem	✓	-	-	✓	-
Ambaulim	✓	-	-	✓	-
Barcem	-	-	✓	-	✓
Cazur	-	-	✓	-	✓
Corla- Kazugotav	-	-	✓	-	✓
Gokuldem	-	✓	-	-	✓
Mangal	-	-	✓	-	✓
Morpirla	-	✓	-	-	✓
Padi	-	✓	-	-	✓
Quiskonda	-	✓	-	-	✓
Vavurla	-	-	✓	-	✓

Source: Compiled by the researcher from field survey information, 2023-24.

It has been found that distance was a major reason for the students to stop or discontinue their education after SSC or HSSC. The villagers were facing severe hardships in pursuing education in professional colleges and post-graduate institutions, as they had to either travel more than 60 km. every day, or find accommodation in hostels or stay as paying guests around these institutions. The students found these options quite costly and unaffordable for many of them. In addition, most of the adult-aged students were helping their families in agriculture in their respective villages, deterring them from staying in other than their respective homes. Though the tribal welfare department has the post metric scholarships and other incentives, still the number of students opting for higher education was low due to these unavoidable challenges faced as mentioned here.

The educational attainment of 1,018 household members is depicted in Table 4. One tenth (10.7%) of the people were illiterate, with a higher number of females in all the villages. About one-tenth (9.3%) of people were literate, but they didn't receive any formal education, affecting both genders, especially those in the 40 and above age group. A quarter of the population had completed their studies only till SSC or HSSC (25.4%) due to the limitation of transport facilities, long distance of travelling and family pressure to share the financial and occupational responsibilities. Resultantly, they tried to somehow complete their Secondary or Higher Secondary School education and attempted to find small earning avenues to support their personal and family livelihood.

The study found that 65.84% of the surveyed ST population from 8 villages located in the remote and forested areas had attained educational qualifications till SSC/HSSC. Only 14.41% had pursued higher education and professional degrees. About 12.05% of the population was found to be illiterate and 7.70% were literate without any formal education. The sub-division has only one higher educational institution located in the approachable town of Quepem. The distance decay factor played a very important role in the selection of higher educational institutions for higher studies. This has supported the hypothesis stating that the educational qualifications of the ST population in the study area were limited to the SSC/HSSC level due to the non-availability of HEI in the vicinity.

4.2 Gender Gap in Educational Attainments

Gender disparity was reflected at all the levels of educational attainments, where the female educational status remained lower due to the cultural taboos towards female education, safety concerns, commuting-related constraints and shouldering family responsibilities from early ages. However, among the present young generation, this gap has been bridged with the increase in female education at higher education levels. A high proportion of literate and educated females were found within the respective villages of Adnem (52%), Ambaulim (52%), Mangal (54.8%) and Quisconda (51%). A very low percentage of males and females completed their graduation and post-graduation or other professional degrees. However, among them, the number of females was higher than that of males. The potential college-going male youths often assisted in their family occupation to get rid of the high labour cost and non-availability of reliable agricultural labour during the

needs. This has led to lower educational achievement for the male youths.In this context, a statistical test was performed to test gender gap in educational attainments among the ST population in the study area.

Table 4. Educational Attainment of ST population in Villages of Quepem Sub Division, 2023-2024

		Educational Qualifications									
Villages	Gender	Illiterate	Literate but no formal education	I to V std	VI to IX std	SSC/ HSSC	UG	Graduation /PG	Professional (PhD, Engineer, LLB, MBA)	Technical (Diploma/IT)	Total
Adnem	M	6.5%		2.2%	21.7%	17.4%	-	-	-	-	47.8%
	F	4.3%	8.7%	4.3%	15.2%	19.6%	-	-	-	-	52.2%
	T	10.9%	8.7%	6.5%	37.0%	37.0%	-	-	-	-	100.0%
Ambaulim	M	1.2%	6.6%	10.2%	11.4%	13.8%	1.2%	1.2%	1.2%	-	47.3%
	F	4.2%	8.4%	6.6%	13.8%	13.8%	-	4.8%	1.2%	-	52.7%
	T	5.4%	15.0%	16.8%	25.1%	27.5%	1.2%	6.0%	2.4%	.6%	100.0%
Barcem	M	3.3%	2.5%	5.8%	11.6%	14.9%	1.7%	8.3%	3.3%	.8%	52.1%
	F	3.3%	4.1%	9.9%	6.6%	14.0%	4.1%	4.1%	.8%	.8%	47.9%
	T	6.6%	6.6%	15.7%	18.2%	28.9%	5.8%	12.4%	4.1%	1.7%	100.0%
Cajur	M	4.3%	3.2%	12.8%	13.8%	18.1%	-	2.1%	1.1%	1.1%	56.4%
	F	7.4%	4.3%	9.6%	11.7%	5.3%	-	3.2%	2.1%		43.6%
	T	11.7%	7.4%	22.3%	25.5%	23.4%	-	5.3%	3.2%	1.1%	100.0%
Corta	M	5.6%	9.3%	7.4%	5.6%	13.0%	-	11.1%		1.9%	53.7%
	F	7.4%	1.9%	14.8%	7.4%	9.3%	-	3.7%	1.9%		46.3%
	T	13.0%	11.1%	22.2%	13.0%	22.2%	-	14.8%	1.9%	1.9%	100.0%
Gocoldem	M	-	10.3%	9.0%	9.0%	10.3%	1.3%	6.4%	-	3.8%	50.0%
	F	3.8%	6.4%	10.3%	14.1%	9.0%		6.4%	-		50.0%
	T	3.8%	16.7%	19.2%	23.1%	19.2%	1.3%	12.8%	-	3.8%	100.0%
Mangal	M	4.8%	-	11.9%	16.7%	4.8%		7.1%	-	-	45.2%
	F	19.0%	-	9.5%	11.9%	7.1%		2.4%	4.8%	-	54.8%
	T	23.8%	-	21.4%	28.6%	11.9%		9.5%	4.8%	-	100.0%
Morpila	M	4.2%	2.8%	11.6%	10.6%	15.7%	.5%	3.7%	1.4%	1.9%	52.3%
	F	8.8%	4.2%	7.4%	6.0%	13.9%	2.3%	4.6%	.5%	-	47.7%
	T	13.0%	6.9%	19.0%	16.7%	29.6%	2.8%	8.3%	1.9%	1.9%	100.0%
Padi	M	6.4%	6.4%	4.3%	21.3%	19.1%	-	4.3%	-	2.1%	63.8%
	F	12.8%	2.1%	4.3%	10.6%	4.3%	-	2.1%	-		36.2%
	T	19.1%	8.5%	8.5%	31.9%	23.4%	-	6.4%	-	2.1%	100.0%
Quiliconda	M	6.5%	3.9%	9.8%	11.1%	12.4%	0.7	3.9%	-	0.7%	49.0%
	F	5.9%	4.6%	17.0%	10.5%	8.5%	0.7	2.6%	0.7%	0.7%	51.0%
	T	12.4%	8.5%	26.8%	21.6%	20.2%	1.4	6.5%	0.7%	1.4%	100.0%
Total	M	3.9%	4.4%	9.3%	12.1%	14.2%	.7%	4.3%	1.0%	1.3%	51.3%
	F	6.8%	4.9%	9.6%	10.1%	11.2%	1.1%	3.8%	1.0%	.2%	48.7%
	T	**10.7%**	**9.3%**	**19.0%**	**22.2%**	**25.4%**	**1.8%**	**8.2%**	**2.0%**	**1.5%**	**100.0%**

**M= Male F= Female T= Total*

Source: Compiled by the researcher from field survey information, 2023-24.

An independent samples t-test has recorded a statistically significant difference in educational attainment between males (Mean = 4.15, Standard Deviation = 1.79) and females (Mean 3.82, Standard Deviation = 1.79), t (1014) = 2.98, with p value < .003 (Table 5). The 0.33-point difference in means with a 95% confidence interval (0.11, 0.55) indicates that males have achieved significantly higher levels of education than females in the study area. The hypothesis is accepted as there is a gender gap in educational attainments among the ST population in the study area, where males have higher educational attainments than females.

Table 5. Gender wise Group Statistics and Independent Samples Test

	Gender	N	Mean	Std. Deviation	Std. Error Mean
Educational Qualifications	Male	518	4.1544	1.79385	.07882
	Female	500	3.8200	1.78941	.08003

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Educational Qualifications	Equal variances assumed	.994	.319	2.977	1016	.003	.33444	.11233	.11402	.55486
	Equal variances not assumed			2.978	1014.899	.003	.33444	.11232	.11403	.55485

4.3 Financial Schemes for Educational Upliftment

The Government of India and the State Government have placed numerous schemes and programmes to provide financial assistance to students belonging to the ST community. Some of the schemes are mentioned as follows. Central Government-sponsored schemes for the ST students include the pre-matric and post-matric scholarships, national fellowships to pursue M. Phil. and Ph.D. courses, scholarships for graduate and post-graduatelevels and national scholarships for overseas studies. In addition, the Government of Goa offers several schemes for the ST students, such as pre-matric scholarships, Vidya Laxmi scholarships for girls, scholarships for home nursing courses, and aid to voluntary organisations for running hostels for ST students. Further, Gagan Bharari Shiksha Yojana, a merit-based award and recognition of high performance in the board exams of SSC and HSSC in Goa, are provided to the students. Financial assistance is also available for pre-primary schools in remote areas, as well as the Prashikshan Yatra Scheme (study tours) for school students. Short-term professional training courses for the members of the ST community are also organised in different institutions of the State.

Some visible development in the inclination to educational attainment has been observed in the selected villages. Slowly, the transformation in education has been seen in the tribal community through the beneficiaries of different tribal welfare schemes. The

published data by the Ministry of Tribal Welfare, Govt. of Goa, has stated that 4,944 (86%) of ST students across the state have availed pre-matric (IX and X class students) and post-matric central sponsored scholarships and 9122 (95%) ST students have benefited from different State Schemes (Govt. of Goa, 2024). The students who have discontinued their education have faced numerous challenges in availing these schemes, either due to their lack of awareness about the available schemes or a lack of institutional support from the Government through their schools and higher secondary schools. The awareness was found to be very limited about most of the schemes. There was high awareness about the pre-matric and post matric scholarships since the school and college administration took a lot of interest and motivated the students to avail of these schemes. The Citizen Charter published by the Directorate of Tribal Welfare, Goa noted that a very small percentage of students availed the schemes for professional courses like Home Nursing and other short-term professional training courses across the state. It also showed that there were no beneficiaries from the study area for the period of 2020-2024.

4.4 Major Problems for Educational Attainment

The findings from the study revealed some inherent challenges deterring educational attainment of the studied villages, which are discussed below.

4.4.1 Physical and Infrastructural Challenges

The tribal population residing in forested villages such as Vavurla and Corla-Kazugotav continues to face significant physical and infrastructural challenges. Many houses lack basic amenities, including toilet facilities. The community experiences frequent power cuts, poor road connectivity, unreliable internet access and limited public transport. Educational institutions are located at considerable distances from these villages, creating barriers to regular school attendance and reducing motivation among students. Consequently, most students pursue education only up to Secondary School Certificate (SSC) or Higher Secondary School Certificate (HSSC), with very few progressing to higher education, which in turn constrains their employment opportunities. These findings align with previous studies that highlight how geographical isolation, inadequate infrastructure and socio-economic marginalisation hinder educational outcomes among tribal communities across India. For instance, Patra, Dutta and Bharti (2025) note that infrastructural deficits in tribal regions undermine the goals of the National Education Policy. While Kavitha and Vanita (2021) emphasise that poor road and transit facilities discourage school attendance. Similarly, Maharana (2025) underscores that despite constitutional guarantees, tribal children remain disadvantaged due to structural barriers, necessitating integrated interventions in sanitation, electricity, transport and digital connectivity alongside culturally sensitive educational reforms.

4.4.2 Economic and Family Constraints

The majority of the Scheduled Tribe families in the studied villages remain dependent on seasonal agriculture as their primary source of income, which contributes to

a fragile financial base. Most of the school or college-going children were first-generation learners, and therefore, they often lack consistent moral encouragement and financial support from their families. In many cases, households expect children to contribute to the family income through early participation in agricultural work or related occupations, which reduces the time and interest available for education. This situation closely reflects findings from previous studies across India, which highlight how economic hardship, lack of parental motivation and early work participation act as major barriers to tribal education. For example, Minz, Kujur and Pujari (2024) observed that low economic status and involvement in domestic or agricultural work hinder educational attainment among tribal adolescents in Odisha. Mahata and Singh (2025) emphasised that socio-economic inequalities and cultural marginalisation continue to deprive tribal girls of equitable access to education. Similarly, Sahu et al. (2025) noted that despite government interventions, dropout rates among tribal children remain disproportionately high due to insufficient parental involvement and economic constraints. Together, these studies confirm that the challenges faced in Goa are part of a broader national pattern, underscoring the need for targeted financial assistance, parental awareness programs and livelihood diversification to strengthen educational participation among tribal communities.

4.4.3 Social and cultural barriers

There has also been lack of awareness regarding the value of formal education amongst the older generation among the people living in the isolated parts. The social customs and socially detrimental practices also restrained the children, especially the girl child, from pursuing higher education by travelling to other parts away from home. To pursue higher education, the children had to travel several kilometres, which made it time-consuming and tiring for the students to coordinate with the household work and their studies. This has broadly affected female education as most of them were from an agrarian background. All these challenges have forced the girls into early marriage or to seek jobs in nearby urban centres as per their qualifications. These challenges had limited their aspirations of achieving higher education,as observed in the villages of Vaurla and Corla. These findings resonate with the research on tribal education in India. The study by Das and Bhoi highlights that cultural traditions and gendered expectations often restrict tribal girls from continuing education beyond secondary school (Das & Bhoi, 2025). The studies confirm that the social and cultural barriers observed in Goa are part of a wider national pattern, underscoring the need for interventions that combine awareness-building, gender-sensitive educational policies and improved access to higher education facilities.

4.4.4 Emerging Behavioural Trends

Recent observations in the study villages indicate that the younger generation is increasingly influenced by the high-risk alcohol consumption pattern, overuse of social media and online gaming, which has diverted their mainstream educational focus. A concerning trend observed among some adolescent ST students is their engagement in easy money-making activities such as matka (daily result-oriented gambling) and other

digital and mobile-based gambling practices, even if only occasionally. The lure of quick financial gains from these activities has influenced a segment of the younger generation. If left unaddressed, such a pattern could lead to significant adverse consequences for both individuals and the wider community. These findings are consistent with broader research on tribal and rural youth in India. Shivdasani, writing for the American India Foundation, highlighted the complexities of alcoholism in tribal communities, noting its deep social and economic impact (Shivdasani, 2025). Jadav studied the effects of social media on tribal students in South India, finding that excessive usage often undermines educational focus and contributes to cultural shifts (Jadav, 2022).

5. Conclusion

The selected villages in Quepem Sub-Division of Goa have a large proportion of tribal population, facing major challenges in educational achievements, despite various welfare schemes aimed at helping children access proper education. The illiteracy rate among the old generation ST population of the selected villages is quite high. There is a need for public investment in setting up educational institutions at nearby sites of the tribal community.There is also an urgency to provide the remotely located villages with reliable public transport facilities with a required frequency and special care for the education of the intending female students. Awareness about the importance of formal education, especially amongst the parents, is required to help them motivate their children to get educated and empowered.

The transformation of the local communities is possible only through educational upliftment and empowerment. People's participation is necessary for a reform in the implementation of the policies and schemes of the government regarding the regional planning of these micro units. The district and sub-divisional administration should ensure the provision of basic amenities to these remote villages of the State to effectively check out-migration of the ST population from their homelands. The educated youth of the ST community of these villages need to motivate the younger generations and act as guides to provide proper directions for the school-going children. The state and central governments should ensure that educational attainment with required qualification and only merit are the necessary considerations in the employment in government and private recruitments. This will be the moral booster for good education to transform the ST community. Private parties and corporate houses enthusiastic to start educational institutes should be allowed to establish their institutions in the tribal dominated regions, if they admit and provide free education to the students from the hinterland to demonstrate the value of education to society.

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The Indian Geographical Journal
Volume 100 (1) June - 2025, pp 82-100
ISSN 0019-4824

GROUNDWATER STRESS UNDER THE GREEN REVOLUTION: EVIDENCE FROM THE WESTERN HARYANA PLAINS, INDIA

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Abstract

Groundwater depletion in northwestern India has intensified under the bequest of the Green Revolution, particularly in semi-arid agrarian regions such as the Western Haryana Plains (WHP). The present study provides a comprehensive block-level assessment of groundwater recharge, extraction, and development stages across 31 administrative blocks over four decades (1974-2018) using the GWREC-97 methodology integrated with GIS analysis. Groundwater recharge was estimated from rainfall, canal seepage, and irrigation return flow, while domestic and irrigation withdrawals were quantified to determine net annual availability and development status. Results indicate that total annual recharge (1,84,564 ha-m) is insufficient to sustainably balance the high groundwater draft (1,52,395 ha-m), of which over 90% is attributed to irrigation. The rapid expansion of rice–wheat cropping systems and the proliferation of electric tubewells have significantly accelerated extraction rates. Spatial patterns reveal acute groundwater stress in northern and northeastern blocks, with eleven blocks categorised as over-exploited and several exceeding cent percent extraction of groundwater. The persistent recharge-draft imbalance highlights an unsustainable trajectory of groundwater use. The study underscores the urgent need for crop diversification, regulation of tubewell expansion, and improved irrigation efficiency to ensure long-term hydrological sustainability and regional water security in the WHP.

Keywords: Groundwater Stress, Green Revolution, Western Haryana Plains, Geospatial Techniques

1. Introduction

Globally, groundwater depletion is emerging as a critical sustainability challenge. According to NASA's Gravity Recovery and Climate Experiment (GRACE), 13 of the Earth's 37 largest aquifers examined between 2003 and 2013 experienced little to no recharge, leading to severe depletion. The aquifer system in northwestern India is among them (Chen et al., 2016). Between 2000 and 2015, global groundwater extraction contributed to 11% increase in irrigated cropland and 92.4% rise in agricultural value-added, from USD 1.64

trillion to USD 3.17 trillion (World Bank, 2024).In India, groundwater supports approximately 62% of irrigation, 85% of rural, and 50% of urban water supply (CGWB, 2022).Since the onset of the Green Revolution in the 1960s, groundwater gradually became the primary irrigation source, with the net groundwater-irrigated area increasing from 6 million hectares (Mha) in 1950 to 45 Mhaby 2010.Of India's 82 million farm households, 26 million own tubewells, and nearly one million new tubewells are added annually (Beero and Narayanamoorthy, 2014). The extensive overdraft of groundwater for food-grain cultivation is now triggering serious ecological consequences.The introduction of modern drilling and electric pumping technologies, combined with subsidised or free electricity and weak groundwater governance, has further accelerated groundwater exploitation (Foster et al., 2021). India now faces a groundwater crisis, particularly in semiarid regions where water tables are declining by 2–3 meters annually. Of the country's 7089 groundwater assessment units, 1226 are classified as critical or overexploited, indicating extraction beyond recharge limits (CGWB, 2022; Sahu and Pradhan, 2024). One key driver of groundwater decline is the cultivation of water-intensive crops such as rice and sugarcane in unsuitable regions (Mizan et al., 2022).The Haryana Plains, a semi-arid to arid region, are among India's most agriculturally developed regions but face severe groundwater stress due to extensive tubewell irrigation (Singh and Sharma, 2010). Since the Green Revolution, the adoption of high-yield, water-intensive crops like wheat and paddy has sharply increased water demand—from 34.96 BCM in 2021 to projected 45 BCM by 2045 (CGWB, 2022). The region lacks perennial rivers, and rainfall remains the primary source of recharge. Approximately two-thirds of the area is underlain by brackish groundwater, compounded by a rising water table and inadequate natural drainage. The Western Haryana Plains (WHP), consisting of sandy-alluvial tracts and Aravalli outliers, receive an average annual rainfall of about 360 mm (Sharma, 2020). Several studies have applied the GWREC-97 (Groundwater Resources Estimation Committee, CGWB) methodology to evaluate groundwater resources at regional scales. For example, Singh and Sharma (2010) used this approach to assess groundwater in the Rewari district of Haryana. The method estimates dynamic groundwater resources, annual extraction, and utilisation rates based on parameters such as rainfall infiltration, irrigation return flow, and canal seepage (Malik and Rajeshwari, 2015; Sharma, 2020). However, most previous research has focused on district-level analyses over short time frames, while block-level assessments spanning longer periods remain limited across the Western Haryana Plains. Therefore, the primary objective of this study is to evaluate the stages of groundwater extraction in the WHP between 1974 and 2018 and to map their spatial distribution across districts using GIS techniques.

2. Study area

The study area, Western Haryana Plains (WHP), spans over four districts, Sirsa, Fatehabad, Hisar, and Bhiwani, and covers an area of around 15,646 square kilometres and lies between latitudes 28° 22° to 29° 59° North and longitudes 74° 27° to 76° 28° East (Kumar& Rao, 2021) (Fig. 1). Administratively, WHP is divided into four districts with 31 blocks, 381 inhabitants per square kilometre, and a population of over 5.6 million (Table 1).

Based on occupational structure, it is evident that agriculture continues to be a main source of income in the region, employing more than 60% of the total workforce. The area has a semi-arid and tropical steppe type climate, experiencing hot summers and cold winters. The south-west monsoon contributes around 80% of the total annual rainfall and temperatures ranging from 5 ˚C to 43 ˚C with an average temperature of 26.5 ˚C. Aeolian sediments, loess, and sand dunes are found across the plains, which are formed possibly by wind erosion. Aeolian sediments, such as sands and sand dunes, have the potential to create excellent reservoirs; however, in most cases, they are located above the groundwater level in the region (CGWB 2021). The WHP is covered with coarse loam, sandy loam, loamy sand and sandy soils. The research area is mostly irrigated through canal networks fed by the Yamuna, Ghaggar, and Sutlej rivers. Except for the water that flows down the slopes of the Aravali mountains seasonally.

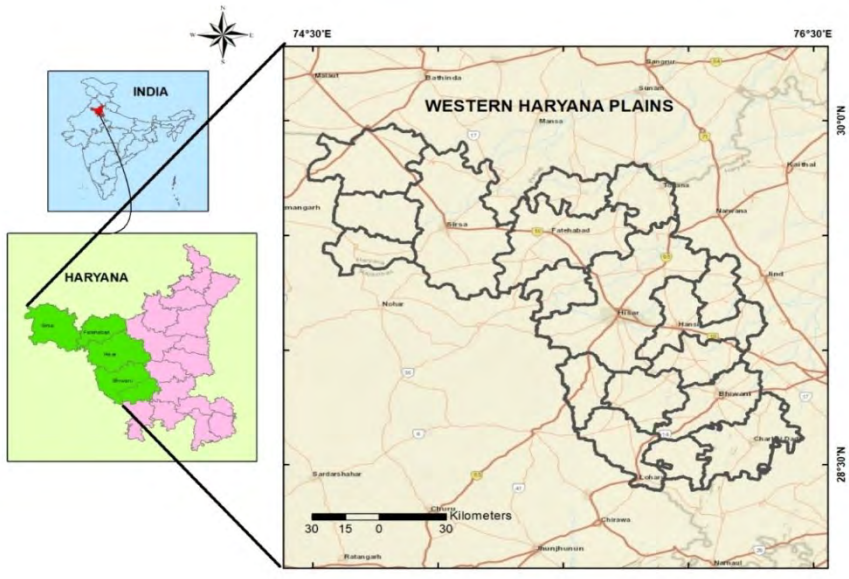


Figure 1: Location map of the study area – the Western Haryana Plains.

3. Materials and Methods

In the present study, the Groundwater Resource Estimation Committee (GWREC-97) methodology was adopted to estimate the groundwater development and its stages of utilisation. The necessary parameters taken into consideration were rainfall, canal seepage and return flow from irrigation as groundwater availability parameters; population and tubewell irrigation as groundwater draft parameters; and depth of groundwater table in the calculation of groundwater development stages (Singh and Sharma, 2010).

Monthly rainfall data were obtained from the India Meteorological Department (IMD), tubewell data from District Statistical Offices, water levels from Groundwater Cells,

canal data from Irrigation Departments, crop data from the Directorate of Agriculture, topographical maps from the Survey of India, satellite images from the Earth Explorer website, and demographic data from the District Statistical Handbooks (Census of India), Haryana. An administrative block was taken as an assessment unit for both kharif and rabi seasons in the study. The dataset used for the present analysis is given in Table 2.

Table 1. Names of blocks in different districts of Western Haryana Plains.

Name of district	Name of block	No. of blocks	No. of villages	Total Population	Population density (Person/ sq. km)
Bhiwani	Badhra, Bawani Khera, Bhiwani, Dadri-I, Dadri-II, Loharu, Kairu, Siwani, Tosham	09	436	1634445	342
Hisar	Adampur, Agroha, Barwala, Hansi-I, Hansi-II, Hisar-I, Hisar-II, Narnaund, Uklana	09	257	1743931	438
Fatehabad	Bhattu Kalan, Bhuna, Fatehabad, Jakhal, Ratia, Tohana	06	226	942011	373
Sirsa	Baragudha, Dabwali, Ellenabad, Nathusari Chopta, Odhan, Rania, Sirsa	07	322	1295189	371

(Source: Director of Land Records, Panchkula, Haryana, 2018 & Census of India)

Table 2. Details of data sets and thematic layers used in the present study.

Dataset	Source of data	Time period	Utilization
Monthly rainfall	India Meteorological Department, New Delhi, and Groundwater Cell, Panchkula, Haryana	1974-2018	Estimation of groundwater recharge
Groundwater level	Groundwater Cell, Panchkula, Haryana	1974-2018	Estimation of groundwater draft
Number of tubewells	District Statistical Office (Bhiwani, Hisar, Fatehabad, Sirsa of Haryana).	1974-2018	Estimation of groundwater draft for irrigation use
Diesel and electricity-operated tubewells	Groundwater Cell and Directorate of Agriculture, Panchkula		
Water discharge and running days of canals	Department of Irrigation (Districts: Bhiwani, Hisar, Fatehabad, Sirsa of Haryana)	1974-2018	Estimation of recharge from canal seepage
Irrigated area under different crops (Block-wise)	Directorate of Agriculture, Panchkula, Haryana.	1974-2018	Estimation of recharge as return flow from irrigated fields
Topographical sheets	Survey of India, Regional Office, Chandigarh, Haryana	1974	For preparing the base map and calculating the total length of canals
Satellite images	Landsat 7 ETM+&IRS P6 LISS IV	2017-2018	
Demographic information	Districts Statistical Handbooks (Census of India), Statistical Abstracts of Haryana	1971-2011	Estimation of groundwater for domestic use

3.1 Estimation of Recharge from Rainfall (R_{rf})

To estimate the recharge from rainfall, we used the average monthly rainfall data for each block. Water level fluctuation (WLF) and rainfall infiltration factor (RIF) methods were used to estimate the groundwater recharge from rainfall. WLF determines the change in storage (S) by multiplying water level fluctuations between pre- and post-monsoon seasons with the area of the aquifer and specific yield using the following equation:

$$S = h \times S_y \times A \quad \text{.....(1)}$$

Where h is the rise in water level in meters, S_y is the specific yield (0.16 for unconsolidated formation), and A is the area of the aquifer in hectares (ha).

The groundwater recharge from rainfall (R_{rf}) by WLF is calculated as:

$$R_{rf}(WLF) = S + (DG - R_c - R_{sw} - R_{gw}) \quad \text{.....(2)}$$

Where, S = Change in storage (ha-m), DG = Gross groundwater draft for all uses (ha-m), R_c = Recharge from canal seepage (ha-m),R_{sw} = Recharge from surface water irrigation (ha-m), andR_{gw} = Recharge from groundwater irrigation (ha-m).

The groundwater recharge from rainfall (R_{rf}) by RIF is calculated as:

$$R_{rf}\ (RIF) = f \times A \times R_k \quad \text{.....(3)}$$

Where, f = Rainfall infiltration factor (0.22 for unconsolidated formations), A = Area of the aquifer (ha), R_k= Average annual rainfall (mm) during kharif season

The percentage difference (PD) is calculated as (CGWB 1997, Chatterjee et al. 2009):

$$PD = \frac{\text{Rrf (Normal WLF)} - \text{Rrf (Normal RIF)}}{\text{Rrf (Normal RIF)}} \times 100 \quad \text{.....(4)}$$

The calculated values of groundwater recharge from rainfall are taken if

PD is within ± 20%, and then Rrf (Normal) is taken as the value estimated from the WLF method.

PD is < -20%, then Rrf (Normal) is taken as 0.8 times the value estimated from the RIF method.

PD is > +20%, then Rrf (Normal) is taken as 1.2 times the value estimated from the RIF method.

3.2 Estimation of Recharge from Irrigation Return Flow (R_{irf})

The recharge from irrigation return flow from fields (R_{irf}) was calculated individually for both the paddy and non-paddy crops. The return flow from irrigated fields was estimated

by multiplying the volume of water used for irrigation in paddy and non-paddy crops in a block by the return flow factor of that block. The sum of the return flow from paddy and non-paddy crops is measured as the groundwater recharge as return flow from irrigated fields. Mean return flow factor values at the block level have been taken into consideration as per GWREC-97. The volume of groundwater utilised for irrigation in a block is the sum of the canal and groundwater applied in a particular season. For surface water irrigation, season-wise water released in each canal has been collected from the district subdivisions of the Irrigation Department. The block-wise estimation of canal water availability was done by calculating the length of canals passing through the respective blocks and proportionally distributing the water released in that canal in a particular season. 60% of the total water released in a canal is considered water applied for irrigation (GWREC 97). The requirement of water for rice crops in each block was calculated by multiplying the total depth of irrigation required for paddy as 63.5 cm by the total area of that block under paddy cultivation (Hassan et al. 2015).

3.3 Estimation of Recharge from Canal Seepage(R_{cs})

The study area is served by many canal networks namely Sub Sunder Branch (SSB), Bhiwani Sub Branch (BSB), Siwani, Deosar Feeder and Loharu Feeder (Bhiwani), Fatehabad Branch of Bhakra canal, Barwala Branch, Balsamandh and Pabra Sub-Branch of Barwala Link and Sirsa branch from Bhakra Main Line, Hisar Major Distributary and Deosar Feeder of Western Yamuna Canal System through Hansi Branch (Hisar), Bhakra Main Canal, Fatehabad Distributary (Fatehabad) and Bhakra Main Branch, Sukhchain Distributary, Northern Ghaggar Canal and Fatehabad Distributary (Sirsa). Groundwater recharge through canal seepage (Rcs) depends on factors such as the canal's size, cross-section, flow depth, soil characteristics of the canal bed, site location, and the level of adjoining drains. Canals may be either lined (cemented) or unlined (natural) (Chattrejeeet al. 2009).

Recharge through canal seepage (R_{cs}) was calculated using the following equation:

$$R_{cs} = W_a \times S_f \times NCR_d \quad (5)$$

Where, W_a = Wetted area in million square meters of each canal, S_f = Seepage factor (4 ha-m/day/million square meters) of wetted area, NCR_d = Number of canal running days.

The statistics on wetted area were collected from the Irrigation and Water Resource Department, Panchkula, Haryana. The predominant soil types in the study area are sandy, loamy, and sandy loam. Therefore, for lined canals, the seepage factor is 4 ha-m/day/mi. sq. m of the wetted surface and the number of days the water is released in a canal during the kharif and rabi seasons was considered in the analysis (Kumar and Kumar 2021, CGWB 2011).

3.4 Net Annual Groundwater Availability (NAgwa)

The net annual groundwater availability (NA_{gwa}) is the sum of the recharge from all sources after deducting the allocated natural discharges from the gross annual replenishable groundwater resource.

To calculate NA_{gwa}, the following equation is used:

$$NA_{gwa} = AR_{gwr} – N_d \quad (6)$$

Where, AR_{gwr}= Annual replenishable groundwater resource (ha-m),which is the sum of R_{rf}, R_{irf} and R_{cs} during both kharif and rabi seasons, and N_d = Natural discharge (ha-m) is kept 5% of the gross annual groundwater recharge if the WLF method is used, while it is taken as 10% if the RIF method is employed to compute rainfall recharge.

3.5 Estimation of Groundwater Draft for Domestic Use(GDdu)

Block-wise domestic water demand (GD_{du}) was assessed by considering the growth rate of the population of their respective district based on the available Census data from 1971 to 2011. To get the average annual population data for estimating the domestic draft during the study period from 1974 to 2018, the average values of the particular census year were taken into consideration. Water demand for domestic uses is considered to be 100 litres per capita per day (CGWB 2004). Total domestic draft was estimated by multiplying the total population of each block in a particular year by the per capita demand. The average of the volume of groundwater drafted from the years 1974 to 2018 was considered as the average domestic draft. Out of the annual domestic draft, 40% was considered as kharif draft and 60% as rabi draft (Kumar and Srinivas, 2012;Ray et al., 2017).

3.6 Estimation of Groundwater Draft for Irrigation Use (GDiu)

The groundwater draft for irrigation (GD_{iu}) was estimated by multiplying the unit tubewell draft by the number of tubewells in each block (CGWB 1997, Singh and Sharma 2010). The mean of the groundwater draft by tubewells for irrigation for a period of 44 years was considered as the mean annual irrigation draft of groundwater for each block in the study area. Out of this annual draft, 25% was taken as kharif draft and 75% as rabi draft (Sitender and Rajeswari, 2012).

3.7 Stages of Groundwater Development (SGd)

The stage of groundwater development (SG_d) was calculated as the percentage of gross groundwater draft to the net groundwater available in each block:

$$SG_d\ (\%) = \frac{GD}{NA_{gwa}} \times 100 \quad (7)$$

Where, SG_d = Stage of groundwater development (%); GD= Groundwater draft for all uses (ha-m); NA_{gwa} =Net annual groundwater availability (ha-m).

3.8 Categorisation of Assessment Units

Finally, the assessment units were categorised on the basis of stage of groundwater development and long-term trend of pre- and post-monsoon water levels (GWREC 1997). The long-term groundwater level fluctuations were computed for the period from 1974 to 2018. The depth of water level for pre-monsoon is recorded in the month of June, and for post-monsoon in the month of October. The significant rate of water level decline was taken as more than 20 cm per year (CGWB 2007, Malik and Rajeswari 2015). Assessment units are categorised into four categories, namely safe, semi-critical, critical and over-exploited.

4. Results and Discussion

4.1. Groundwater Recharge from Rainfall(R_{rf})

Rainfall is the major source of groundwater recharge in the study area. The average annual rainfall trend in the Western Haryana Plains shows that an erratic behaviour with intermittent rise and fall. The highest and the lowest average annual rainfall in the study area recorded were 509 mm (1976) and 167 mm (2002), respectively (Fig. 2).

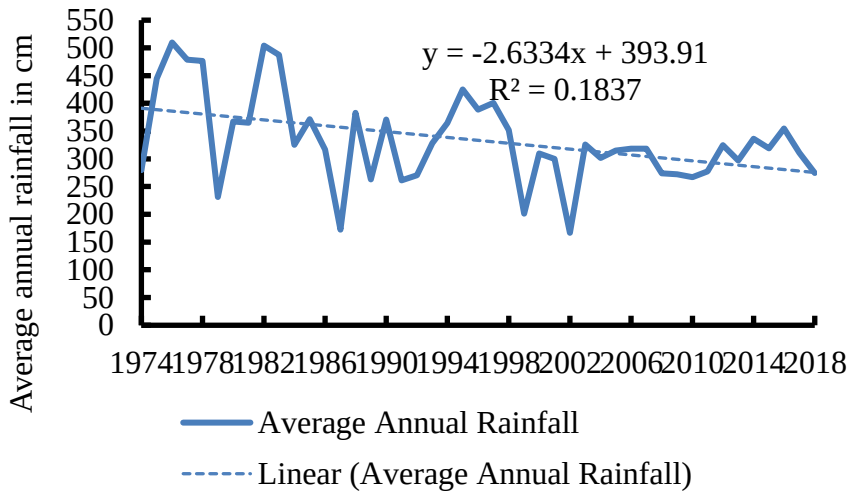


Figure 2: Trend in average annual rainfall over Western Haryana Plains (1974-2018).

During 1974-2018, it was only in seven instances, i.e. 1975, 1976, 1978, 1982, 1983, 1995 and 1997, when the average rainfall crossed the 400 mm mark. WHP recorded a declining trend with an average of 227 mm.Among the 31 blocks in the study area, 14 received above-average rainfall, with the Badhra block recording the highest (426 mm), and the lowest rainfall was observed in the Baragudhablock (113 mm). The data shows block-

wise groundwater recharge during the rabi and kharif seasons across the districts of Bhiwani, Hissar, Fatehabad, and Sirsa (Table 3).Rabi recharge ranges from a minimum of 115 ha-m to a maximum of 888 ha-m, while kharif recharge varies widely between 642 ha-m and 6,275 ha-m. Consequently, total annual recharge spans from 805 ha-m to 7,163 ha-m. Most locations record totals between 1,500 and 4,500 ha-m, indicating moderate recharge conditions (Fig. 3). Higher totals are associated with strong monsoon infiltration, whereas lower values reflect limited recharge potential and possible groundwater stress.Blocks with higher recharge generally correspond to regions with greater precipitation and more-permeable, unconsolidated alluvial formations, thereby enhancing infiltration capacity (CGWB, 2005).

4.2 Groundwater Recharge from Irrigation Return Flow(R_{irf})

In the study area, the irrigation is practised by both surface and groundwater sources. The canal water is generally released for irrigation in almost all the blocks of the study region. The irrigation return flow is the portion of excess irrigation water that drains beyond crop evapotranspiration and eventually recharges the aquifer. It varies widely, from nearly 0% in drip irrigation systems to about 50% in standing-water paddy cultivation (Rushton et al., 2020). The classification of irrigated land into rice and non-rice crops is necessary in order to accurately compute the return flow from both types of crops. The category of non-rice encompasses the irrigated area of all crops except for rice, while the rice category solely comprises the irrigated area of the rice crop in the kharif. The region shows substantial cultivation of water-intensive crops, particularly rice in the kharif season and wheat during rabi. The non-rice crops hold a predominant position in the kharif season across various blocks, namely Badhra, Kairu, Loharu, Tosham, and Siwani. The R_{irf} values vary widely from a minimum of 805 ha-m to a maximum of 5,021 ha-m, indicating strong spatial differences in irrigation practices and soil permeability. Most locations record recharge between 1,000 and 2,500 ha-m, suggesting moderate return flow contribution (Fig. 3). Lower values likely correspond to efficient irrigation methods, while higher values indicate intensive irrigation and greater percolation losses. The pattern might be explained by the fact that rice is grown on larger areas and has higher percolation rates than other crops. Because wheat needs more water input during the rabi season, there is also a direct correlation between the area under wheat and irrigation return flow. While blocks dominated by other crops have relatively lower return flow, blocks with large irrigated wheat lands show higher return flow.

4.3. Groundwater Recharge from Canal Seepage

The seepage process originating from canals is a crucial factor in the restoration of groundwater storage within an aquifer. It was found in the study area that the length of the canal irrigation system is highest in Hissar district,with the longest in Sirsa (279 km). The length of canals is shortest in Fatehabad and Bhiwani districts. Canal seepage occurs when water conveyed through unlined or partially lined canals infiltrates surrounding soils and percolates downward to recharge groundwater. The recorded values ranged between 346

ha-m and 1364 ha-m, indicating considerable spatial variability in seepage losses and recharge potential (Table 4). Higher values over 550 ha-m indicate significant percolation, which is typically linked to unlined canals and prolonged flow duration, whereas lower values throughout the research area probably represent lined canals, decreased discharge, and impermeable soils. The analysis of spatial distribution reveals that Fatehabad block exhibits the highest wetted area while Kairu block exhibits the lowest wetted area. During the kharif 14301 ha-m seepage was estimated, while 11520 ha-m was observed during the rabi season by canal seepage in the Western Haryana Plains from 1974 to 2018. During the kharif season, an abundance of water is made available in the river as a result of rainfall from the southwest monsoon. This water is subsequently released into canals.

Table 3. Rainfall recharge during the rabi and kharif seasons in WHP.

District	Block	Average rainfall in the Rabi (m)	Average rainfall in the kharif (m)	Aquifer area (ha)	Total recharge (rabi)	Total recharge (kharif)	Total recharge (ha-m)
Bhiwani	Badhra	0.058	0.426	52275	668	3919	4587
	Bawani Khera	0.030	0.321	38529	255	2176	2431
	Bhiwani	0.053	0.269	76026	888	6275	7163
	Dadri -1	0.061	0.262	42066	560	2458	3018
	Dadri -2	0.055	0.371	41347	498	2702	3200
	Kairu	0.021	0.193	33346	154	1131	1285
	Loharu	0.047	0.306	67882	697	3651	4348
	Siwani	0.038	0.229	52594	433	2119	2552
	Tosham	0.028	0.179	59014	362	2784	3146
Hissar	Adampur	0.020	0.178	32189	140	1009	1149
	Agroha	0.024	0.239	32978	172	1387	1559
	Barwala	0.038	0.279	50251	418	3701	4119
	Hansi1	0.038	0.218	61021	515	2330	2845
	Hansi 2	0.037	0.234	29938	243	1233	1476
	Hisar 1	0.059	0.216	55144	717	2582	3299
	Hisar 2	0.050	0.257	72703	803	3276	4079
	Narnaund	0.040	0.188	40970	359	1500	1859
	Uklana	0.023	0.174	22971	115	703	818
Fatehabad	Ratia	0.048	0.186	53244	567	1745	2312
	Jakhal	0.048	0.236	15477	163	642	805
	Bhattukalan	0.053	0.268	36353	423	1714	2137
	Fatehabad	0.052	0.130	68710	786	1567	2353
	Tohana	0.059	0.203	34569	445	1782	2227
	Bhuna	0.052	0.213	39493	449	1478	1927
Sirsa	Baraguda	0.024	0.113	53803	281	1067	1348
	Dabwali	0.031	0.173	82653	571	4450	5021
	Ellenabad	0.045	0.124	54696	541	1197	1738
	Nathusari Chopta	0.034	0.217	73431	551	2805	3356
	Odhan	0.022	0.178	48752	233	1778	2011
	Rania	0.021	0.135	57447	263	1359	1622
	Sirsa	0.044	0.313	56185	544	3093	3637

By lining the unlined canals and maintaining and repairing the ones that are already lined, direct recharge through canal seepage can be minimized (Maanjhu and Anandha 2012). The elevated number of canal operating days during the kharif season, in comparison to the rabi season, leads to a greater amount of recharge during this period.

4.4. Total Groundwater Recharge and Net Annual Groundwater Availability

The annual groundwater recharge in the study area was estimated at 1,84,564 ha-m, comprising 79,081 ha-m from rainfall, 25,821 ha-m from canal seepage, and 79,664 ha-

m from irrigation return flow. Recharge varied spatially, with the lowest value recorded in Bhiwani (2416 ha-m) and the highest in Sirsa (8,941 ha-m). Low recharge zones indicate limited aquifer replenishment, likely resulting from reduced rainfall infiltration, limited irrigation coverage, decreased canal seepage, and lower irrigation return flow. In contrast, moderate to high recharge areas reflect a balanced contribution from rainfall and irrigation sources.

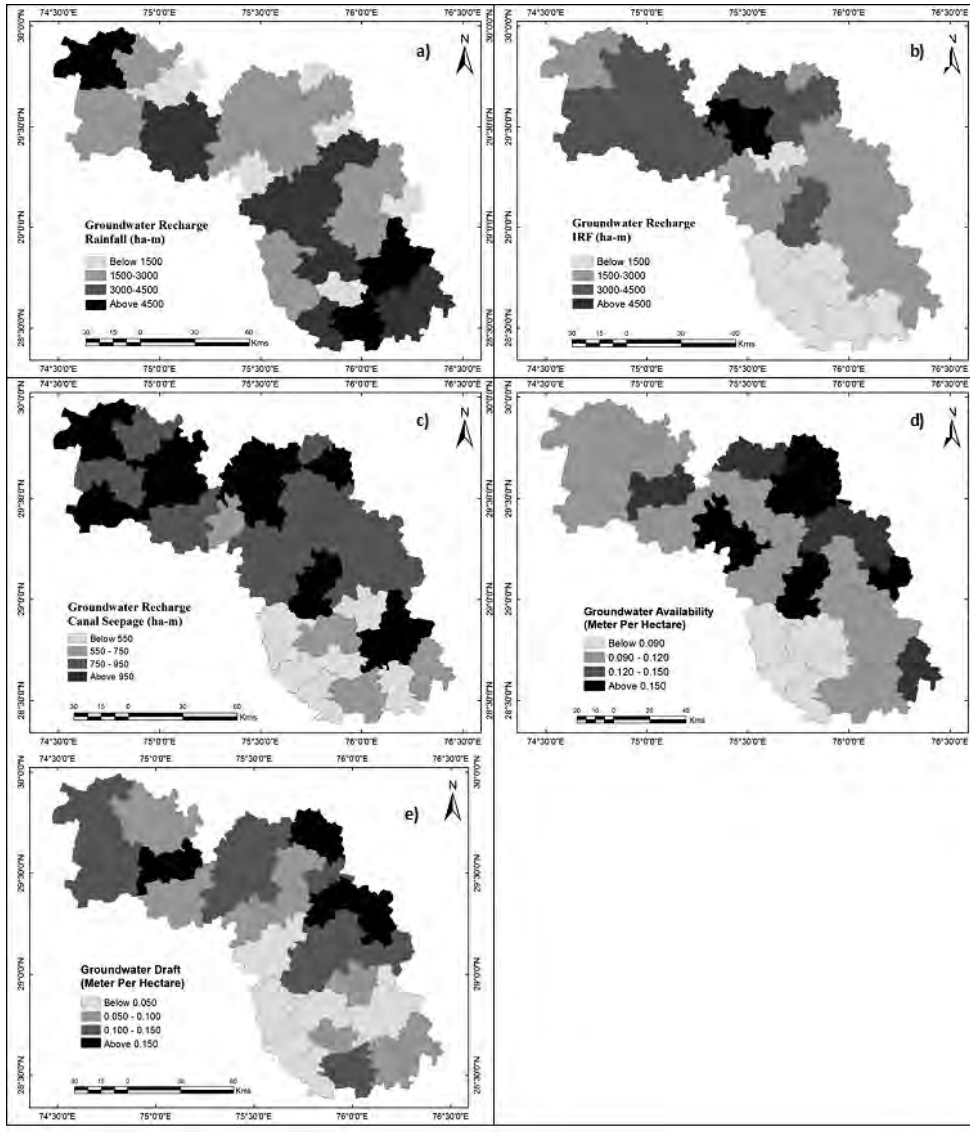


Figure 3. Spatial distribution of groundwater recharge a) from rainfall b) from irrigation return flow, c) from canal seepage and d) groundwater availability and e) groundwater draft in Western Haryana Plains (1974-2018).

Table 4. Groundwater recharge from all sources during the kharif and rabi seasons.

District	Block	Rainfall (ha-m)	Canal seepage (ha-m)	Irrigation returns flow (ha-m)	Total recharge (ha-m)
Bhiwani	Badhra	4587	573	637	5797
	Bawani Khera	2432	493	1733	4658
	Bhiwani	4487	1035	3318	8840
	Dadri -1	2500	585	2666	5751
	Dadri -2	3201	373	971	4545
	Kairu	1286	346	785	2416
	Loharu	4348	543	518	5409
	Siwani	2552	363	741	3656
	Tosham	3146	646	911	4703
Hissar	Adampur	1148	842	1790	3781
	Agroha	1560	816	1340	3716
	Barwala	4123	942	2118	7183
	Hansi1	2854	937	2314	6105
	Hansi 2	1476	845	1979	4299
	Hisar 1	2814	1147	3689	7650
	Hisar 2	4086	920	2379	7385
	Narnaund	1717	790	2597	5104
	Uklana	818	808	2684	4310
Fatehabad	Ratia	2312	1183	3596	7090
	Jakhal	805	928	2034	3766
	Bhattukalan	2136	708	3172	6016
	Fatehabad	2353	1364	4715	8431
	Tohana	1680	1091	3784	6556
	Bhuna	1927	804	3958	6689
Sirsa	Baraguda	1348	970	3906	6224
	Dabwali	5021	1109	2811	8941
	Ellenabad	1738	1151	3861	6749
	Nathusari Chopta	3356	798	3737	7892
	Odhan	2011	751	3283	6045
	Rania	1622	949	4226	6797
	Sirsa	3637	1011	3411	8060

Enhanced recharge in certain blocks can be attributed to higher precipitation and improved canal infrastructure, particularly from the Western Yamuna, Ghaggar, and Bhakra canal systems.Additionally, the cultivation of water-intensive crops such as rice (kharif) and wheat (rabi) contributes significantly to recharge through irrigation return flow, which accounts for over fifty per cent of total recharge during the rabi season.The spatial distribution map depicts that the per-hectare groundwater availability is found to be higher in the northern and northeastern blocks of the study area (Fig. 3).The net annual groundwater availability recorded was 1,83,120 ha-m in the study area. The areas with a well-established canal network and larger irrigated area, particularly with water-intensive crops such as rice during the kharif and wheat during the rabi, exhibit higher net groundwater availability during both seasons. The primary means of replenishing

groundwater in these blocks is through rainfall, and as a result of reduced rainfall in the rabi season, groundwater availability is also found to be low.

4.5. Groundwater Draft for Domestic and Irrigation Use

Groundwater use for domestic purposes includes drinking water supply, household consumption through private hand-pumps and bore-wells, as well as public and municipal water supply systems. The total groundwater draft in a given block is primarily a function of per capita water demand and population size (CGWB, 2004). Population growth, urbanisation, and rising living standards have significantly increased domestic water demand in semi-arid regions like the Western Haryana Plains (WHP), where groundwater remains the dominant source of supply due to the limited availability of surface water resources (Sahu and Pradhan, 2024).Within the study area, the blocks of Bhiwani and Dadri I in Bhiwani district, Sirsa and Ellenabad in Sirsa district, Hansi I and Hisar I in Hisar district, and Fatehabad and Bhattu Kalan in Fatehabad district exhibit the highest population densities and consequently the greatest domestic groundwater extraction. The Hisar district recorded the highest groundwater withdrawal for domestic use. More than 60% of the total mean groundwater extraction for domestic purposes across the Western Haryana Plains was found to be in the Hisar and Bhiwani regions due to high populations and better canal-based water supply coverage (Table 5). A clear positive correlation was observed between population density and groundwater draft, aligning with the strong linkage between demographic growth and domestic groundwater stress in northern India (Kumar and Singh, 2018; Kaur and Ravindranath, 2020). The elevated domestic groundwater withdrawal in Bhiwani and Hisar can be attributed to factors such as increasing population pressure, construction activities, and higher per capita water consumption (Tiwari et al., 2019). While other parts have relatively limited extraction may be due to smaller populations, lower urbanisation, and the limited extent of irrigated areas. Additionally, deeper groundwater tables and higher costs associated with tubewell installation and maintenance likely contribute to reduced domestic groundwater abstraction in these areas (Kaur and Ravindranath, 2020).In total, the study area contains 70,686 electric-powered and 55,122 diesel-powered tubewells. The mean unit draft for diesel-operated tubewells is 0.6 ha-m yr^{-1}**,** compared to 1.1 ha-m yr^{-1} for electric-operated ones. A notable shift from diesel to electric pumps has occurred, largely due to subsidised electricity, higher discharge efficiency, and operational cost advantages (Sahu & Pradhan, 2024).Agriculture accounts for nearly 90% of the total groundwater draft during the *kharif* season and 92% during the rabi season, with domestic use contributing 8–10%. Spatially, Sirsa and Fatehabad exhibit thehighest annual irrigation draft. The intensity of groundwater extraction depends not only on the number and capacity of tubewells but also on cropping patterns and groundwater depth. The dominance of rice–wheat cultivation in Sirsa and Fatehabad drives high irrigation demand (Chatterjee et al., 2021), whereas deeper water tables and lower yields in Siwani**,** Kairu**,** and Tosham limit groundwater use (Sharma, 2020). These findings reflect broader regional trends of unsustainable groundwater dependence in northwestern India, intensified by energy subsidies, limited recharge, and intensive double-cropping systems (CGWB, 2022).

Table 5. Stages of groundwater development in Western Haryana Plains during 1974-2018.

District	Block	Net Groundwater Availability (ha-m)	Draft (ha-m)	Gap (ha-m)	Stage (%)	Category
Bhiwani	Badhra	5440	7061	-1621	130	Over exploited
	Bawani Khera	4460	3522	938	79	Semi critical
	Bhiwani	7926	3305	4621	42	Safe
	Dadri -1	6017	3850	2167	64	Semi critical
	Dadri -2	4256	2577	1679	61	Safe
	Kairu	2301	2807	-506	122	Over exploited
	Loharu	5261	3255	2006	62	Semi Critical
	Siwani	3432	1075	2357	31	Safe
	Tosham	4414	1607	2807	36	Safe
Hissar	Adampur	5262	2935	2327	56	Safe
	Agroha	3943	2304	1639	58	Safe
	Barwala	7290	2910	4380	40	Safe
	Hansi1	6700	6907	-207	103	Over-exploited
	Hansi 2	4791	3433	1358	72	Semi-critical
	Hisar 1	8890	6350	2540	71	Semi critical
	Hisar 2	7181	3437	3744	48	Safe
	Narnaund	5817	7198	-1381	124	Over-exploited
	Uklana	5086	2934	2152	58	Safe
Fatehabad	Ratia	6608	7894	-1286	119	Over exploited
	Jakhal	3510	3889	-379	111	Over exploited
	Bhattukalan	5598	3722	1876	66	Semi critical
	Fatehabad	7862	9797	-1935	125	Over exploited
	Tohana	6661	6289	372	94	Critical
	Bhuna	6245	3569	2676	57	Safe
Sirsa	Baraguda	5791	3684	2107	64	Semi Critical
	Dabwali	8597	9009	-412	105	Over-exploited
	Ellenabad	6421	7980	-1559	124	Over exploited
	Nathusari Chopta	7345	4973	2372	68	Safe
	Odhan	5672	4344	1328	77	Semi-critical
	Rania	6484	8455	-1971	130	Over exploited
	Sirsa	7859	11323	-3464	144	Over exploited

4.6. Stages of Groundwater Development in WHP

Analysing the balance between recharge and extraction provides insight into the sustainability of groundwater use. When extraction exceeds recharge, a decline in water levels is expected, whereas a surplus indicates potential for further groundwater development (Foster et al., 2021). Blocks exhibiting negative recharge–draft gaps indicate a deficit in groundwater availability, while positive values signify a surplus or stable condition (Table 5). The results reveal that 11 out of 31 blocks show negative values, indicating overextraction and unsustainable groundwater conditions. Notably, the Bhiwani block (Hisar district) recorded the highest groundwater recharge (7,926 ha-m) during

1974–2018, followed by Barwala (7,290 ha-m) and Hisar-II (7,181 ha-m). In contrast, Sirsa and Rania (Sirsa district) exhibited significant annual deficits of −3,529 ha-m and −1,971 ha-m, respectively, with Sirsa showing the most severe depletion (>3,000 ha-m deficit).Other critically affected blocks include Rania, Fatehabad, Badhra, Ellenabad, Narnaund, and Ratia, each exhibiting annual deficits exceeding 1,000 ha-m. Meanwhile, Kairu, Dabwali, Jakhal, and Hansi-I show moderate deficits (<1,000 ha-m). Conversely, Hisar-I, Bhiwani, and Baraguda recorded surplus availability (>3,000 ha-m), suggesting relatively stable hydrogeological conditions, while Tohana, Bawani Khera, and Odhan displayed marginal surpluses. The observed groundwater deficit patterns align closely with agricultural intensification trends in the region. High withdrawals in Sirsa, Fatehabad, and Rania correspond with intensive rice–wheat cropping systems, driven by Green Revolution technologies, subsidised power, and minimal regulation (Rodell et al., 2018). In contrast, blocks with coarser soils, deeper aquifers, or lower irrigation coverage show relatively stable conditions (Chatterjee et al., 2021). These findings reinforce that unsustainable irrigation practices remain the dominant factor shaping groundwater stress across the WHP, consistent with national-scale depletion patterns in northwestern India (CGWB, 2021; Sahu & Pradhan, 2024).

4.7. Spatio-Temporal Trends in Stages of Groundwater Development (1974-2018)

Based on the results of groundwater availability and groundwater draft across the study area, the stages of groundwater development were categorised(Fig. 4).In 1974, only two blocks in Bhiwani district were classified as semi-critical and over-exploited. However, by 1988, 12 blocks were categorized as semi-critical and three as critical**,** indicating an accelerating decline in groundwater levels linked to rapid tubewell proliferation and expansion of water-intensive crops such as rice and wheat (Foster et al., 2021).By 1998, the adverse effects of over-extraction were spatially evident across the WHP, particularly in Sirsa, Fatehabad, and Bhiwani districts, where five blocks were identified as over-exploited and three as critical.

The condition further deteriorated by 2008, when 15 blocks were classified as over-exploited and three as critical**,** reflecting persistent overdependence on groundwater for irrigation and limited surface water availability (Rodell et al., 2018; CGWB, 2022). By 2018, all blocks in Sirsa district**,** along with four in Fatehabad, two in Hisar, and three in Bhiwani, were declared over-exploited. The number of over-exploited blocks has increased consistently every decade**,** revealing an unsustainable trajectory of groundwater use.The north-eastern WHP exhibits the highest groundwater stress, while central and southern blocks, such as Badhra, Kairu, Narnaund, and Hansi, still show moderate availability. Groundwater assessment indicates a net availability of 1,83,120 ha-m, with 1,52,395 ha-m extracted annually, primarily for irrigation, resulting in a deficit of 30,725 ha-m between recharge and draft (Table 5). Eleven blocks-Badhra (130%), Kairu (122%), Hansi-I (104%), Narnaund (124%), Ratia (117%), Jakhal (111%), Fatehabad (122%), Dabwali (103%), Ellenabad (125%), Rania (130%), and Sirsa (145%)-have surpassed 100% development, classifying them as over-exploited (CGWB, 2022; Sahu and

Pradhan, 2024). Overall, only 12 of 31 blocks remain within the safe zone, confirming that the WHP is in a critical stage of groundwater development (Fig. 4). The lack of perennial rivers, limited canal infrastructure, and dominance of groundwater-based irrigation exacerbate depletion, posing serious implications for both agricultural sustainability and domestic water security (Singh and Singh 2020; Chatterjee et al., 2021).

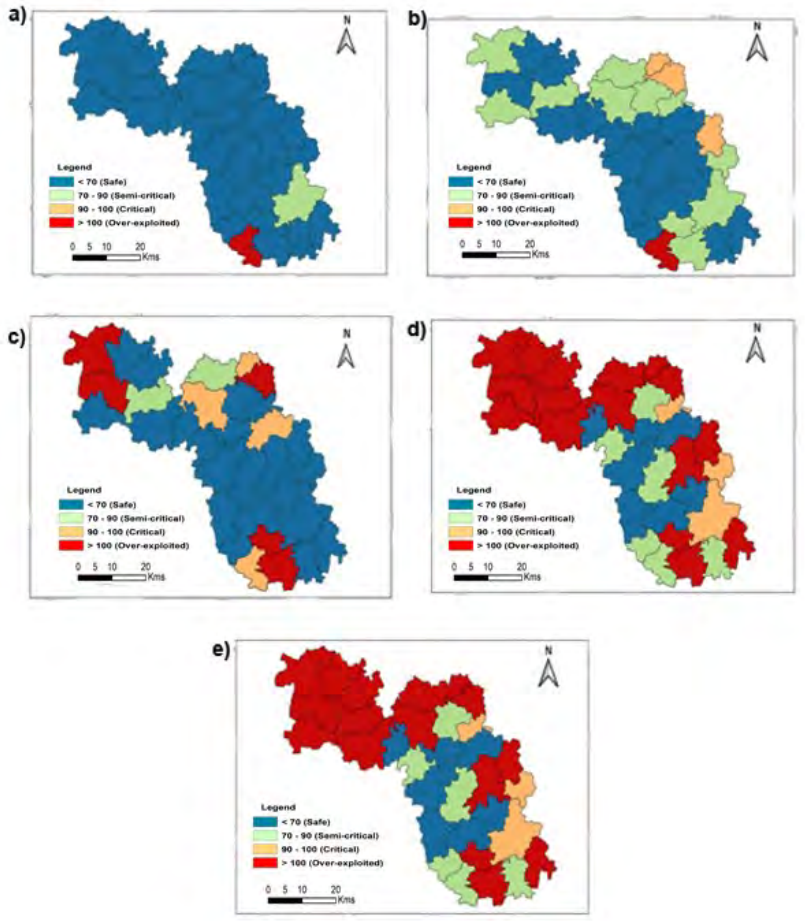


Figure 4: Stages of groundwater development in Western Haryana Plains, a) 1974, b) 1988,c) 1998, d) 2008 and e) 2018.

5. Conclusions

Irrigation planning in agriculture-dominated plains requires the comprehensive evaluation of multiple hydrological components, including groundwater availability, recharge, and extraction. A long-term evaluation (1974–2018) was conducted to assess the groundwater status across various blocks of the Western Haryana Plains (WHP) in northern India. A major shift toward rice–wheat cropping systems was observed, with the area under rice cultivation increasing dramatically from less than 1% of total cropped land in 1974 to

21% in 2018. This transition has significantly increased groundwater dependency, as rainfall in this semi-arid region averages only 227 mm annually, serving as the principal source of recharge. The estimated groundwater recharge was 1,84,564 ha-m, of which rainfall contributes 79,081 ha-m**,** canal seepage 25,821 and irrigation return flow accounts for 79,664 ha-m. Groundwater draft, including domestic and irrigation purposes, was recorded 1,52,395 ha-m from the net availability of groundwater, i.e. 1,83,120 ha-m. Irrigation withdrawals were considerably higher, mainly extracted through tubewells. Continuous over-extraction has led to a steady decline in groundwater levels, as annual withdrawals consistently exceed natural replenishment. Among the 31 blocks analysed, 20 were classified as critical to over-exploited**,** with the highest annual groundwater withdrawals recorded in the northern and eastern WHP, particularly in the Sirsa block (11,323 ha-m), followed by Fatehabad, Rania, Ellenabad, Ratia, and Narnaund**.** Increased reliance on tubewell irrigation has also driven land-use changes, converting sandy and wastelands into intensively cultivated farmland. Significant expansion of irrigated areas and conversion of sandy or wastelands into productive farmland were observed, primarily driven by the increased reliance on tubewell irrigation. This highlights the urgent need for regulatory measures to control the installation and electrification of tubewells, particularly in over-exploited blocks. Further, promoting horticulture and drip irrigation technologies could reduce water demand and enhance efficiency. At this stage, government interventions are needed to classify critical and over-exploited blocks as dark zones and impose restrictions on water-intensive crops such as rice and wheat, ensuring sustainable groundwater management in the Western Haryana Plains.

Acknowledgement

The authors extend their gratitude to the Directorates of Land Records, Groundwater Cell, Irrigation and Agriculture, Panchkula, Haryana, for providing the data.

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The Indian Geographical Journal
Volume 100 (1) June - 2025, pp 101-109
ISSN 0019-4824

Archives - 1

Founder of The Indian Geographical Society

Prof. N. Subrahmanyam, M.A., L.T., F.R.G.S.,

(14.01.1885 - 29.01.1943)

I. Birth and Formative Years

The late N. Subrahmanyam was born in the town of Polur, (Polur Taluk, North Arcot District), his mother's maternal uncle's place on 14th January 1885. He came of Appayya Dikshita family which has produced in these four centuries a long line of celebrated Sanskrit scholars.

His father Arunachala Dikshitar (d. 1918) was an Additional Translator to the High Court, Madras, for thirty years. His services were engaged where high accuracy was required as in Privy Council Cases, thanks to his mastery of Tamil, Telugu, Sanskrit and Law English.

Mrs. Balakucham, his mother, died when he was scarcely five years old; but her mother, Mrs. Lakshmi, a sweet flower of ancient Hindu womanhood, lived long enough to shed upon him her benignant influence.

Many a trait of his, observed in later life - his successful leadership of excursion parties and his drive, his wander-lust and impulse to travel far and wide to geographise his knowledge and concretise his Geography with tours all over India, Great Britain and the Continent, at his own cost - all these were derived from his maternal grandfather, C. Sivarama Aiyar (d. 1905), a man of strong will and decision of character, great drive and physical endurance, who did the pilgrimage from near Arcot to Benares on foot twice and would lead pilgrims of undisciplined relations without a mishap on the way in the eighties and nineties of last century when railway communications and means of transport were still primitive and circuitous.

Apropos, it may be mentioned that N. Subrahmanyam planned to write an Historical Geography of South India and for that purpose gathered materials and made tours to most places to trace on the ground the several routes and the scenes of battle and realise the geographical factors behind. But he sacrificed his own research opportunities, precarious as they were, in order to create full and substantial research opportunities for others at large.

From those grand-parents, five generations have come up, many of whom have made their mark in public life and service; by this widening circle of relations he was received with esteem; and he kept up affectionate contacts with them.

When it came to choice of profession, he chose Education under the shining example of his maternal uncle (and my father) C. Chandrasekhara Sastri, B. A., a profound Sanskrit and English Scholar; who dedicated himself to Education and who, in his brief years (d. 1887, 32 years old) - 'one crowded hour of glorious life' -under the patronage of the Maharajahs, Vizaya Rama Gajapathi Ras and Ananda Gajapathi Ras raised the High school at Vizia-nagaram to a Graduate College and became its first Principal and also the first Indian Principal of any College in South India up to that time.

No sketch of the late N. Subrahmanyam's character can omit the personality of his virtual Guru who moulded it and who was far and away the greatest factor in his mental and moral make-up. He was the late C. Chandrasekhara Iyer (d. 1915) of Royapuram, Madras; son to the erudite C. Krishnaswami Iyer, (d. 1883) cousin to that illustrious namesake Sastri, just mentioned, cousin to Sir C.V.Kumaraswami Sastri (d 1934) and grandson to the celebrated C. Ranganatha Sastri (d 1881) who was the first to receive education of the modern type. He was thus suckled in a great tradition of scholars and gentlemen. Prof. K. B. Ramanathan once described them as the Tondiarpet and Royapuram Circles with high cultural traditions making a happy blend of the East and the West; and of the Old and the New. He had a brilliant intellect, keen wit and playful humour; was simple as a child and sincere; was easily the master of two literatures, Sanskrit and English; and abreast of modern thought. He set us, boys, at ease in his company, encouraged us to be free in mind, to assess values; to speak with open heart; served us with the cream of Literature and Scientific Thought and with a store of instructive anecdotes. To talk with him was liberal education and to be with him was to be, as it were, in a true residential university. From him N. Subrahmanyam derived his social ease, catholicity, resilient and open mind and his capacity to meet situations and mix in societies.

He learnt Rapid Reading and Fluency in English, of his cousin H. H. The Puri Sankaracharya, and had his schooling up to V Form in Muthialpet High School, Madras. He passed his Matriculation and F. A. (corresponding to the modern Inter.) examinations in first class and graduated from Pachaiappa's College, Madras (taking a high second class) with History and Economics. His undergraduate studies included the Elements of Physics, Chemistry, Physiology, Elementary and Advanced Mathematics of Inter. Standard. This grounding helped him vastly in his self study of Modern Geography. He carried all the Sanskrit prizes and scholarships and got, the English Essay Prize open to all the classes of the College.

Some teachers left a deep impression upon him. The erudite Prof. Ramanathan infected him with zeal for Co-operation and the Teachers' Guild. There was the shrewd and sagacious Professor K. Ramanujachari who commanded respect and compelled the attention of every single member of the class, whatever the subject he taught. He was master of clear exposition and incisive analysis. Better teacher there was none to be

mindful of the weak and put them into the fold. His methods of teaching were not lost upon N. Subrahmanyam or other fellow-pupils who like him took to Education - C. S. Srinivasachari, T. K. Duraiswamy Iyer, A.Venkatraman etc. He was stirred by the boundless enthusiasm of Prof. Drew lecturing on Tennyson or Greek History, which in his day he emulated and followed. The greatest influence at College however flowed from Mr. Yates, the Principal, who taught his pupils not to cram but to think, to look beyond the Lecture Room and Examination Hall to Cultural Aspects. In his frequent 'At Homes' to which we were invitees he made us feel at ease and taught us to admire Art and Music and gave us glimpses of English life. The friendship struck up then grew with years and has been sundered now only, with the death of the pupil.

II. Government Service

Immediately after graduation, Mr. Yates appointed N. Subrahrnanyam, teacher in the High School, had him undergo training at Teachers College, Rajahmundry, and drafted him into Subordinate Educational Service, when he himself became an Inspector of Schools. He took his M. A. Degree in History some fifteen years after, while he was teacher, to qualify for College lecturership.

A man entering Government service at the lower rungs of the official ladder gets the chance, if he is diligent, of disciplining himself for all drudgery; and has the opportunity, if he has a waking eye, of looking abroad and gaining experience in many posts and at many places. The Government has created a certain number of posts and selects a certain personnel to fill them, who are expected to fit themselves into several of them; and the exigencies of service require a man to be rolled from one to another, irrespective of other considerations. That is in the order of things here. But a rolling lecturer can at least gather much knowledge and N.Subrahmanyam turned them all to advantage. He was ever a thorough and indefatigable worker and he was all the better, for serving at Rajahmundry; Mangalore; Villupuram; Madrasa-I-Azam; Presidency College and Saidapet. He had to lecture on History of several countries and on different periods of History; on Theory and Practice and History of Education; and on Geography both in substance and methods of teaching. As early as 1906, he learnt through Mr. Yates of the leaven of Modern Geography fermenting then in Britain; even while he was only History lecturer, his interest in Geography was keen; he cultivated it albeit under adverse conditions; got the modern outlook from the start and became geographer of first rank by dint of self-study. Off and on he was acting Lecturer in Geography and was appointed to the Chair at Saidapet permanently in 1926, which he filled with distinction till he retired from Government service in 1940.

III. Geographical Association

By this time a very potent influence began to exert its full force upon him and shape him for his life-work of Modem Geography, inspiring him with high standards and ideals, helping him break through his shyness and diffidence, and setting him on the ways and means. It came from another fellow-disciple of the late C. C. Iyer of Royapuram, the versatile Mr. M. Subramaniam, B.A., B.L., (his mother's cousin) a man of deep and wide

scholarship and of varied experience in affairs and organizations and modem movements here. Their talents were complementary, both idealists, the one a hard original thinker, the other a splendid Organizer and a notable man of action.

Both were now in Madras. Long before, he had persuaded N.Subrahmanyam when he was still hesitant (1916) to choose Modern Geography for his province in preference to History in which he was long a Lecturer, or Sanskrit in which he was a College Prizeman. The former now awakened the latter to the importance of Modern Geography in Modern life and Modern Education; pointed out how it lay a virgin field here in South India where the labourers were few, where to labour was worth a man's ambition, and how a geographical movement generated here would travel far afield and shed its beneficent influence everywhere. Their combination was very fruitful and happy in results. Together they evolved the idea of a Geographical Association on a working plan which found ready support and response among a few kindred minds like Miss J. M. Gerrard (1926). The story of the Madras Geographical Association (now the Indian Geographical Society) has been told by Mr. M. Subramaniam, one of the founders, in his Presidential Address at Rishi Valley (Journal of Madras Geographical Association, Vol. XVI. P. 220; Para. 7 to 24).

Regarding N. Subrahmanyam's camel-load of burdens and activities, one may quote from it: "By his devoted work, by his obstinate refusal to be side-tracked under personal bickerings, by his perseverant energy and persistence in season and out of season, by his indefatigable lecturing tours, besides the normal duties of his office (the chair at Saidapet College) the Secretary, Mr. N.Subrahmanyam, has kept the objects (of the Association) steadily in view and has been fortunate in his colleagues who have accorded him their hearty co-operation."

And he had the satisfaction also of carrying out a cherished object of his-to erect a platform where can meet ladies and gentlemen, European and Indian, irrespective of caste, creed, colour, race, or sex, whoever, in short, takes an interest in Geography.

His work for Modern Geography was, indeed, astonishing in its value and variety, in its volume and range. Not only the normal duties of a Secretary but the organising, maintaining, or running, and providing for the last detail, in all the spheres of that activity-Provincial Geographical Conferences, Summer Schools with intensive courses done in short time, Refresher courses for teachers repeated at different centres, memorials and interviews, for pressing Geography on the highly-placed, finding persons to lecture and arranging for meetings, taking out excursion parties under his ever-watchful leadership, preparing syllabuses and regulations for discussion; besides writing elementary text-books and making geographical tours on his own account. And his zest for work never flagged, nor his zeal.

The success has been great. This other extract from the same may be read with interest:-

Ideals and achievements: -We may now compare the work done by the Association with the objects it set itself at the outset. They are (a) to promote and diffuse geographical knowledge; (b) to secure for Geography its proper place in Schools; Colleges and Universities; (c) to help to improve the methods of teaching Geography; (d) to work for a School of Geography being started; (e) to promote studies about South India from various standpoints.

The Madras Geographical Association can look back with legitimate pride on the work it has accomplished. Sixteen years; and every year crowded with activities and crowned with success!

"It found Modem Geography nowhere in South India (or India for that matter) and has relied it here to its rightful place. It has successfully educated the educators and educated the people at large, It has been endeavouring to make the public cultivate "a geographical mind" as Mr. Sabhesan put it and to "geographise education" as Dr. Cousins suggested. Most gratifying of all; the work done by the Association has been hailed as unique in India and first-rate on its merits by veteran British Geographers. By its exertions it has earned for Madras the fame of being 'the cradle of Modern Geography in India' (Dr. S. P. Chatterji of Calcutta University). And its example is spreading.

IV. The Dedicated Life

Upon the founding of the Association, he consecrated his life to Modern Geography. Even in his last mortal hours while in agonising struggles with death, his thoughts lay with the Indian Geographical Society and for its future. His eager earnest emotional nature found its mission of life and it transfigured him into a Zealot and Enthusiast. He lived, moved and had his being in Geography. He thrust the importance of Geography upon all and sundry, who-ever he came across, unmindful of derision, ridicule or boredom. He lost no opportunity of spreading geography whenever and wherever an occasion was found or made. Accepting invitations, he would travel at his own cost near and far and seize the occasion of any meetings) school or college societies, Teachers' Guild, Primary or Secondary School Teachers' gatherings, Indian Science Congress, All-India Educational Conference. It may be as stop-gap or a specially arranged course; he would accept it all. No call too high, none too low, none for which he would not make time. Geography Subrahmanyam was a sobriquet that clung to him and he received with smiles the epithet of 'Enemy of Geography' conferred by some candid friends of his. It gave him pleasure that his name was associated with geography even in such arresting manner.

A prophet is not honoured in his own country; and it is a tribute to his earnest and hard work that even in Madras also he succeeded in carrying with him a good part of Madras opinion. It took years of spade-work to build up a reputation there second to none and it was too firmly set for his detractors to injure it, so long as he was alive.

Outside the dust and heat of Madras, his work and worth were seen in true light and correct perspective. His influence extended in ever-widening circles; from Travancore to Kashmir, he spread the gospel of Modern Geography with missionary Zeal and found his reward in the quickened life that followed in the places he visited which stand out in bold relief against the life where his influence did not reach. At Lahore, for example, he made a strong plea for the establishment of a Punjab Geographical Society; he was delighted beyond measure when two years later he received a letter from its Secretary that it was his exhortation and the reconciliation he effected there, between rivals that led to the formation of that society with a record of work already (1941) to its credit. In Indore, only three weeks before his death (January, 1943), he capti-vated the men of light and leading and shaped their attitude to Modern Geography, interesting them in the Indian Geographical Society.

Above all his other services, there stands his inauguration of the Modern Geographical Movement in India and his advancement of it by and through his dedicated life as leader, path-finder and road-builder. To have inspired and led a great educative and educational movement, which is also a part of the creative evolution at work in India, is his enduring fame and entitles him to rank with the great educationists of India of our times.

Recognition came slowly but surely. At the Silver Jubilee Session of the Indian Science Congress (Calcutta, 1938) Dr. H. J. Fleure F.R.S., the doyen of British Geographers, in proposing his name for Presidentship of the Geography Section at the next session at Lahore (1939) declared that his work was meritorious and, that he had done everything a man could do for Geography in India. Similar tributes of recognition came from other eminent British Geographers such as Professors Fawcett, Ogilvie and Dudley Stamp. Recognition coming from such quarters, from men whose names are so well-known in the world of Geography, gave him the proudest moments of his life.

His Lahore Address (1939) on the Geographical Personality of India also met with appreciation at their hands. Prof. Fawcett, among others, wrote that he read over again that "brilliant" address, which seemed rather like notes of Human Geography and desired its expansion.

V. Last Years

After retirement with pension from Government service on completing 55 years of age (Jan. 1940), his hands were as full of work as ever. He gave to Geography all the hours thus released from official duties.

He had now a more crowded programme of work for the Association than ever before and gave himself no rest. Nor could he spare time for the books be had been contemplating to write and for which he had taken copious notes for long years - Historical Geography of South India, Tour in Europe, Teaching of Geo-graphy, etc. He laid them all aside - absorbed in the greater task of creating full opportunities for the men to come.

In 1941 the old Madras Geographical Journal was renamed the Indian Geographical Journal. From now on, his ambition was to re-create the Madras Geographical Association into an India wide body and to it he gave his time and thoughts. He had the strong support of men like Mr. Rowland Bowen of N.W.F. Province who gave the first stimulus, and from Lahore to Dharwar he received encouraging approval. He was able to carry his colleagues with him and he got transformed the old Association into the Indian Geographical Society with a constitution like that of the Royal Geographical Society of London. He intended it to be much more than a change of name. He travelled at his own cost to Kashmir, Baroda, Bombay and Indore and persuaded several to interest themselves in the Society. The last three years (1940-42) were devoted to this work. It is pathetic reading to note this in a letter addressed to him (dated 7-3-43 and received here on 2-4-43) which Mr. Yates wrote, "I can't tell you how delighted I was to hear from you again with your family news and news of your dream fulfilled - an All India Geographical Society".

It was the last scene of all when in the midst of these labours and activities, on his return from Indore and Trivandrum, the curtain dropped on him with tragical suddenness (Jan. 29, 1943). Dr. Heron said how deeply he felt the loss of a man who was a Geographer every inch of him, who learnt Geography and taught Geography, and in short, was Geography itself. Other feeling tributes are still coming in, from far and wide showing the appreciation as well as the extent of his service to Geography.

VI. General and Personal Traits

Idealist as he was, he would look to the practical side of things. He was always at his best in the many committees and other bodies such as those of the University, Teachers' Guild, Co-operative Societies, etc. He came to them after full preparation, knowing every inch of the ground. Keen on the promotion of business he would reconcile the diametrically opposed, bridge yawning gulfs and seek the via media. He kept an open mind and was ready to change the position he took up, when convinced by the discussion. He stood on no false prestige (all prestige is false, he said with his Guru C. C. Iyer).

As lecturer, he was genial, whether at school or college or elsewhere. He was a good speaker, speaking with steady eloquence, holding the attention of every member of the audience in the manner of his teacher Prof. Ramanujachariar; and would also step beyond the syllabus to inspire them with the great things of the subject. Crammers, too, found it a pleasure to listen to him and follow with the head, as aptly described by one of his pupils.

With his colleagues, he mixed on terms of mutual respect and with his students he was very popular. Long after they passed from under his authority having left school and college, they used to keep up with him and seek counsel on personal matters as well. He helped them with wise and helpful advice - not only students but colleagues, friends and others. He was eager to do his bit and help forward the deserving.

As excursion-leader, he was all eyes and ears, arranging and planning everything in advance, and selecting and explaining the things to observe, with a view to their geographical importance. He would keep careful watch over the flock, rallying them with his whistle, keeping to the time-table and bringing them back home in safety. He was the poor man's friend, cutting costs to the bone. It was a personal triumph to him to have led with great success a geographical party of about thirty persons over a thousand miles doing geography in Mysore for ten days at a cost per head of about Rs. 35 only, all inclusive.

Though after 1926, he lived for an idea, so to say, and was Geography-mad, as it were, his enthusiasm (unlike Prof. Drew's) was tempered with saving common-sense and a shrewd understanding of the situation. The Royapuram training had inured him to humour even at his own expense.

A remarkable feature of him was his excellent business habits and financial integrity. These were his characteristics even as a boy and they stood him in good stead when in later life; he had much miscellany of work to get through. He lived through life an upright man.

He was a voracious reader and industrious, and ready with tongue and pen. His intellect was served by a strong memory for words and places and things. He could easily pick up old familiar faces after long years of separation. He would gladly learn and gladly teach, take immense pains to master a new situ-ation. For example, he used to conform to the exacting conditions of Mr. M. Subramaniam and take lessons, all the first three years of the Association, until he knew the ropes perfectly at last. He was ever handsome in his acknowledgements, as when at last year's Annual Meeting of the Association he introduced Mr.M.Subramaniam as the brains, himself the hand, in those early years. He gave everyone his due and that generously.

He was simple in life and manners, was plain living, without sides; unostentatious and unpretentious. Genial in company, he was social and sociable, and kindly. He wore his heart on his sleeve, though daws might peek at it. He would share his thoughts and feelings, his hopes and fears with all, making no secret of them. And his emotional nature was sensitive to carping criticism and back-biting. He felt keenly the injustice of aspersions and insinuations, took offence and was prone to sally out and fight, keeping himself, however, ever ready to forget and forgive.

A College-friend, Mr. P.C. Chetty, B.A., dropping in by chance, found him busy at his desk and wrote: 'My friend, whose enthusiasm is of an infectious quality, is the founder of a Geographical Association, the first of its kind in India. Though he has passed the age of superannuation at which men unlearn such subjects, my friend is never tired of increasing his stock of knowledge which has now assumed colossal proportions. He is certainly a credit to his alma mater' (Free-lance Writer, April-July 1942 p. 13).

A normal day before his retirement from his Chair at Saidapet (say October 1938) would find him rise at 3 a.m., take brisk walks in his garden and settle down to work at 4 a.m. First, the college work; next, reading up new books to keep abreast of Geography and Literature. Typing and proofs for the Press, Maps, Correspondence. 9 to 10 a.m. Breakfast and to the College. 10 a.m. to 4 p.m. at College: usual lectures on Geography-teaching and special ones on Rousseau and Pestalozzi; and attending to administrative matters. Home again by 5 p.m. and 5 to 9 p.m. carrying on with work left unfinished in the morning. 9 to 9-30 p.m. dinner, and so to bed by 9-45 p.m. On Saturdays and Sundays and holidays he overtook arrears whether left over or due to going on tours. An hour's nap after the morning meal was the only luxury he indulged in after retirement (Jan. 1940). This full time-table was diversified by visitors who were welcome at any time without previous appointment, by social functions and by meetings which he seldom missed; by going out and arranging for lectures. The calls of house-keeping would come in now and then; and very often the ruffled children would demand his attention as they cut in with disputes to compose. His amusements were the morning walks; tours and travels; social functions; and motoring for business. He cultivated a taste for music late in life; and he would have it on the radio as an undertone while he was busy at work. All his leisure he gave to work and his work gave him pleasure. The more his work, the greater his pleasure. It used to be a wonder to us how he could manage time for so much out-turn. He got the best out of time by his using it carefully and doing things once-for-all; helped by his business habits, he found time for all things.

He was a warm friend, a good companion and mixer. The picture his last years' students carry of him is of the loving father lecturing with his last child seated by his side. In person, he was of middle height and medium build; fair of complexion; with a big round head and full speaking eyes, the eager face easily expressive of his mind, now lit up by joys and hopes, now darkened by griefs and fears.

He married twice. The first wife was Mrs. Rukmini (daughter to C. Srinivasa Iyer, C. C. Iyer's brother); she was genial and cheery, endowed with robust common-sense. She relieved him of house-keeping, took lessons herself and helped him with typing notes for his lectures. When she died (1924) without surviving issue, he married again; his second wife was Mrs. Annapurni (daughter to M. Swaminathan now in war service in Sudan), who excelled in house-keeping. She died in 1937, leaving two boys and two girls, all of tender years.

It has been a melancholy thing to think of him as dead; I almost feel his warm genial presence even as I write. He was my cousin, my father's sister's son. We have known each other for the last 54 years. We grew for years together and have shared griefs and joys together and he would look up to me for comfort and sympathy, opinion and understanding until death has closed his beaming eyes at last. Such was N. Subrahmanyam as I knew and I pay with tears the tribute to his memory.

The Indian Geographical Journal
Volume 100 (2) December - 2025, pp 110-120
ISSN 0019-4824

ROLE OF CHLOROPHYLL-A AND SEA SURFACE TEMPERATURE ON FISH PRODUCTION: A STUDY FROM EXCLUSIVE ECONOMIC ZONE OF SOUTHEAST COAST OF INDIA

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Abstract:

This study examines how SST and chlorophyll-a influence fish production along the Tamil Nadu Coast from 2017 to 2021. The results show annual SST ranges between 27.08°C and 30.75°C (highest April-June, lowest December-February) and chlorophyll-a concentration varies between 0.16 and 0.8mg/m³ (maximum July-September, minimum March-May). A significant positive correlation is identified between chlorophyll-a and fish catch, while SST shows a significant negative correlation with fish catch. The study concludes that SST and chlorophyll-a, play a crucial role in regulating fish production. Continuing increases in SST driven by global warming may reduce primary productivity and threaten India's blue economy by limiting food availability for fish populations.

Keywords: Sea Surface Temperature, Chlorophyll-a, Exclusive Economic Zone, Fish catch, Giovanni.

1. INTRODUCTION

Our environmental conditions play a major role in the existence of life on Earth. Similarly, in a marine environment, the growth and development of the fish populations depend on nutrient availability and favourable physicochemical conditions. Changes in environmental condition scan influence fish production, which is reflected in India's blue economy. However, fishing in India is a major sector within the economy, and it contributes 1% of its total GDP, and Tamil Nadu ranks 4th place in total fish production of the nation(Ngasotter et al., 2020). Tamil Nadu is a leading exporter of marine products in India. The fishing activity in the exclusive economic zone is referred to as coastal fisheries (Juda, 1991). Currently, approximately 40% of the world's population lives within 100 kilometres of the coast. Coastal fisheries are very important and provide food, nutrients, and livelihood to the coastal population.Fish production in India increased from **16.24 million metric tonnes in 2021–2022** to **17.35 million metric tonnes in 2022–2023**, reflecting a **growth rate of 6.8%**. Marine exports from India are projected to rise from **1,149,341 metric tonnes**,

valued at **₹43,717.26 crore** in **2020–2021**, to **1,735,286 metric tonnes**, valued at **₹63,969.14 crore** in **2022–2023**, representing a **51% increase in quantity** and a **36% increase in value** (Najmudeen, 2023). According to MPEDA, during the **financial year 2023–24**, India exported an **all-time high of 1,781,602 metric tonnes of seafood**, worth **US $7.38 billion** (₹60,523.89 crore). According to Anagha (2022), shifts in fish catch rates pose significant challenges to both the coastal population and the Indian economy.Therefore, monitoring the coastal environmental status is essential for sustainable development. The coastal fishery sector in India faces several challenges, including overfishing, habitat destruction, and the impact of climate change(Anagha, 2022). To understand coastal fisheries, we need environmental data about coastal waters. In the marine environment, the growth and development of fish populationsmainly dependon nutrient availability and favourable physicochemical conditions(Vivekanandan, 2011). Oceans continuously interact with the atmosphere, and sea surface temperature (SST) can also have profound effects on the global climate. Increases in SST have led to an increase in the amount of atmospheric water vapour over the oceans(Nemani et al., 2001). This water vapour feeds weather systems that produce precipitation, increasing the risk of heavy rain and snow. Although many major river systems bring in large quantities of nutrients, narrow shelves, persistent cloud cover, and low light penetration are responsible for low productivity (Prasanna Kumar et al., 2002;Vinayachandran, 2009).

The information about spatial and temporal variation in biological and physical properties of coastal water provides a more comprehensive understanding of the productivity status of coastal waters. The primary production of the marine environment mainly depends on SST and physicochemical parameters(Satpathy et al., 2011). By monitoring the above-mentionedparameters, we can gain insights into fish production ina particular region.Specifically, SST and chlorophyll-a (Picado et al., 2014;Ningsih et al., 2021; Rahman et al., 2019;Sarangi, 2019) significantly influence fish production. Remote sensing serves as a reliable tool to obtain information about these parameters (Prados et al., 2010), enabling more effective analysis of spatial and temporal distribution that can be measured from space (Das et al., 2012). It is the only way to monitor changesin marine ecosystems, which exhibit high-resolution physical and biological variability on a daily, weekly, monthly, and seasonal basis.SST and chlorophyll-a indicate close coupling(Nurdin et al., 2013). The variability of chlorophyll-a is related to the seasonal monsoon due to changes in water conditions, such as SST. Chlorophyll-a pigment concentration serves as a convenient index of phytoplankton biomass, and SST is a crucial factor influencing phytoplankton growth.In the Bay of Bengal, Chlorophyll concentration was low(8 mg/m^3) during April, May, and June, whereas July, August, September, and October report higher concentrations (12 mg/m^3) (Sarangi, 2019). During winter months, chlorophyll concentration increases with a decrease in SST, whereas in summer months, it decreases with an increase in SST. Consequently, the declining trend in chlorophyll-a concentration due to warmer SST and high Sea Surface Humidity(SSH) significantly impacts the ocean's primary productivity and may lead to diminishing the marine resources(Annapurna & Krishna, 2021).

In the Bay of Bengal(BoB), winter SST varies from 25.7℃in the north to 28.7℃ in thesouth, while summer SST ranges from 28℃in the east to 28.6℃ in the west. The objectives of this study are to investigate the relationship between SST and chlorophyll-a concentration from 2017 to 2021, determine the preferred range of SST and chlorophyll-a for-fish production, and map the potential fishing grounds in the Exclusive Economic Zone (EEZ) of Tamil Nadu.

2. STUDY AREA:

The exclusive economic zone (EEZ) of Tamil Nadu is located between Chennai (13°04’57"N, 80°16’15"E) and Kanyakumari (8°04’40"N, 77°32’28"E). It encompasses a 1,076 km long coastline with an EEZ of 1.9 lakh sq. km in the Bay of Bengal.Figure 1 represents a potential fishing zone and Exclusive Economic Zone (EEZ) zone identified by Nammalwar et al. (2013).Coastal **Tamil Nadu**is influenced by key ecological zones such as the **Bay of Bengal upwelling zones, the Gulf of Mannar Biosphere Reserve, and the Palk Bay ecosystem**. The coastal region of Tamil Nadu is unique, and it has several estuaries, biosphere reserves, mangrove forests, and small islands, which act as spawning and nestling grounds for a variety of fish species. It is equipped with 6 major and 3 medium fishing harbours, alongside 36 fish landing centres and 254 fish landing points. This extensive infrastructure collectively harvests over 85 metric tons of fish annually (Berrick et al., 2008).Fish catches were significantly higher in Kancheepuram, Tiruvallur, and Chennai compared to the southern part. Regarding the climate, the study area differs from other parts of India due to the southeast coast receiving 70% of its rainfall during the northeast monsoon. Both the southwest and northwest monsoons influence the southern part of the study area. Reasonable freshwater discharge with nutrients, which enhances the productivity of the study area. Surface water temperatures ranged from a maximum of 32.0°C in summer to a minimum of 27.5°C during the monsoon season. Monsoon dominates the regional climate, resulting in an average annual precipitation of 96 cm.The seasonal variation in chlorophyll distribution in the surface water of the study area showed a maximum during the summer and pre-monsoon seasons, while it was minimum during the monsoon season. Chlorophyll concentration and primary productivity remained high during the summer months.

3. METHODS

In this study, satellite-derived SST and chlorophyll-a data was collected by using Giovanni portal from 2017 to 2021. Monthly average SST data were obtained from the MODIS-Aqua Level 3 product (11 μm daytime band) at a 4 km spatial resolution. Additionally, the area-averaged chlorophyll-a data was collected from a time series of monthly 4km (MODIS-Aqua MODIS-L3m-CHL) in milligrams per cubic meter($mg/m^{3)}$from2017 to 2021(Prados et al., 2010). Available fish catch data from the Fisheries Resources Assessment Division of the Central Marine Fisheries Research Institute (CMFRI), Kochi, were tabulated along with SST, chlorophyll-a, and correlations

were established.To assess the linear association of SST, chlorophyll-a, and fish catch, we have performed the Spearman rank correlation test, which estimates the strength and direction of the correlation. For statistical analyses, we used SigmaPlot version 14.0 to plot the pairwise correlation between the variables.

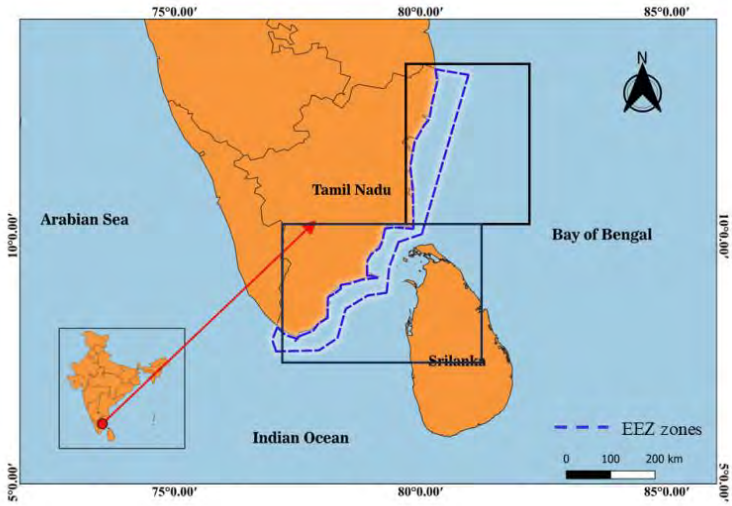


Fig 1: Study area map showing the Exclusive Economic Zone (EEZ) and a black colour rectangle box denoting a potential fishing zone of southeast India.

4. RESULTS AND DISCUSSION

4.1 SST, Chlorophyll-a and Fish Production

The results show that annual SST ranges between 27.08°C and 30.75°C, with relatively higher temperatures (29.3°C–31.08°C) recorded during April, May, and June of each yearand lower temperatures (26°C–27.56°C) recorded during December, January, and February (Fig.2). Moderate SST was recorded between June, July, and August.In contrast, chlorophyll-a concentration varied between 0.16 and 0.8 mg/m^3. The annual maximum chlorophyll-a concentration occurred during July, August, and September (0.4–0.8 mg/ m^3), and minimum values were observed in March, April, and May (Fig.2).

This analysis reveals an annual relationship between fish catche sand chlorophyll-a. Figure3 indicates that 2019 had the highest fish production in the last five years. The main varieties of fish catches in this study include Lesser sardines, Oil sardines, Silverbellies, Cephalopods, Tunnies, Scads, Indian mackerel, Penaeid prawns, and *Odonus niger*. Figure 4 highlights the dominant fish production over the last five years,with Lesser sardine being highly abundant from 2017–2022, followed by Silverbellies. In 2019, *Odonus niger* was prevalent and found only during that year.*Odonus niger*likely inhabits reef channels or long slopes that have strong water currents,which prevent them from being swept away by rocks and crevices.In 2017, Tamil Nadu's land yielded 6,55,000 metrictons,

representing a 7% decline. Despite a 36% drop in oil sardine landings, Lesser sardines regained their previous prominence, accountingfor more than 100,000 metric tons (Fig.3). The peak fishing season faced disruptions from three cyclones and heavy rains that struck the region in 2021. During July to September, there was a higher landing percentage due to less moisture advection and reduced convective activity in the southwest Bay of Bengal region during the pre-monsoon season, which may have contributed to below-normal rainfall over Tamil Nadu.The weather remains consistently pleasant during this time, with minimum rainfall.

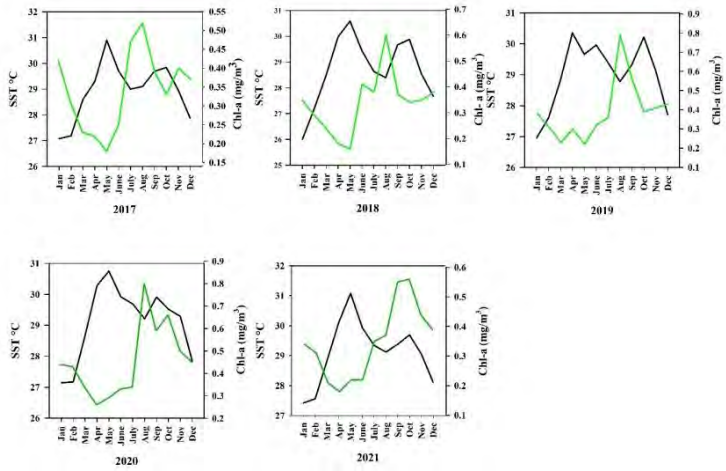


Fig 2: Variation between the monthly mean Chlorophyll-a and SST during 2017 -2021. The black line demonstrates the SST, and the green line demonstrates the Chlorophyll-a.

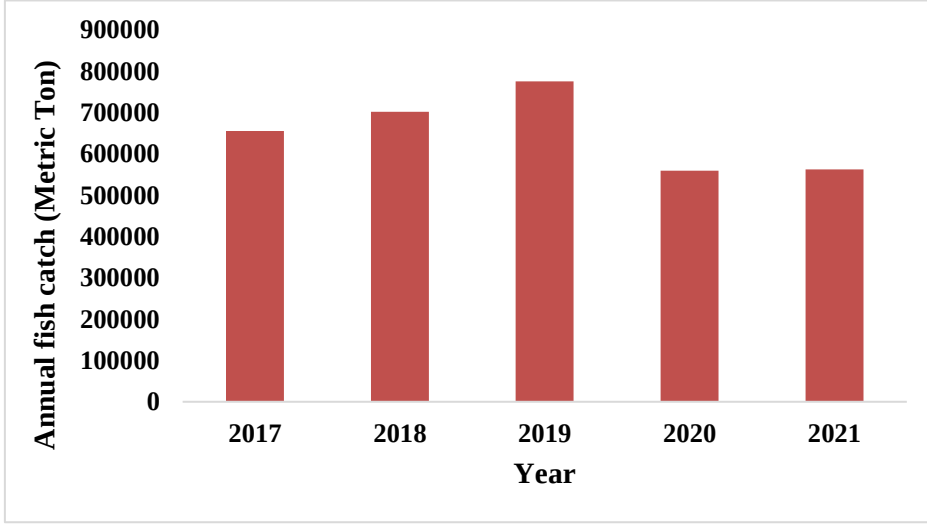


Fig 3: Shows the annual fish catch data for southeast India during 2017-2021.

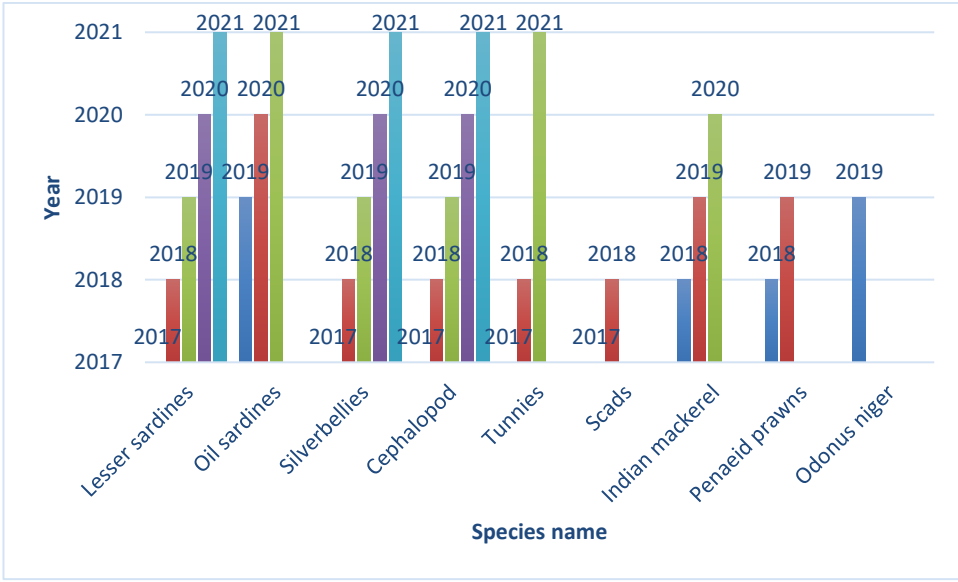


Fig 4: Shows the top five dominant varieties of fish caught in southeast India for the past five years (2017-2021).

The variation of SST and chlorophyll-a in the study area has significant implications for fishery management and conservation. Seasonal changes in these parameters can help identify potential fishing zones and monitor the health of the marine ecosystem. The monthly distribution of SST and chlorophyll-a produced for the study area reveals clear spatial patterns. The results show that SST increased from March to May, influencing both fish catch and chlorophyll-a concentration. The rise in mean SST is a key indicator of ocean warming, affecting fish reproduction, growth, and migration (Shoba et al., 2014). During 2017–2021, chlorophyll-a increased during July–September (Fig. 2). Tomczak and Godfrey (1994) reported that upwelling occurs in this region from January to July and downwelling from August to December. Low SST and high chlorophyll-a levels could be associated with southwest Bay of Bengal upwelling (Mishra et al., 2006; Sahu et al., 2016). Maximum chlorophyll-a concentrations occur at the onset of the Northeastern Monsoon (NEM). Sarangi (2019) also noted high chlorophyll biomass in the Gulf of Mannar and Palk Bay, and predicted consistently high fish catch in the southern Bay of Bengal. Changes in wind direction, speed, and ocean circulation further influence surface water temperature by mixing deeper, nutrient-rich waters (Vivekanandan, 2011).

4.2 Correlation between Chlorophyll-a and SST

The relationship between SSTand chlorophyll-a was attempted in this study.Figure 2 illustrates the variation between the monthly mean chlorophyll-a and SST during 2017–2021. The correlation of SST and chlorophyll-a reveals the coefficient of determination (R^2) and correlation coefficient from 2017 to 2021 (Fig.5). The negative correlation coefficient for all years indicates a negative linear trend between SST and chlorophyll-a. This negative

relationship occurs because higher SST generally enhances water column stratification, which reduces vertical mixing and limits the upward transport of nutrients from deeper layers into the euphotic zone. However, none of these correlations are statistically significant at the 0.05 level, as the p-values are all greater than 0.05 (Table 1). Consequently, we cannot reject the null hypothesis that there is no significant correlation between SST and chlorophyll-a in the study area.

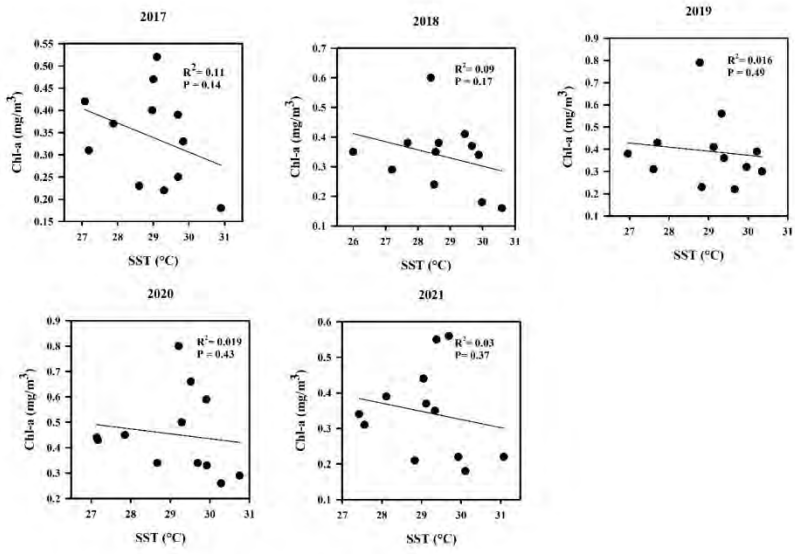


Fig 5: Relationship between SST and Chlorophyll-a during 2017 -2021.

Table 1: R-square, correlation coefficient and p-value for the linear regression model between SST and Chlorophyll-a for each year.

Year	R-Square (R^2)	Correlation Coefficient	P-Value
2017	0.11	-0.33	0.14
2018	0.09	-0.30	0.17
2019	0.01	-0.10	0.49
2020	0.01	-0.12	0.43
2021	0.03	-0.17	0.37

Our results indicate that SST and chlorophyll-a concentrations were negatively correlated (Fig. 5), consistent with previous regional studies (Rahman et al., 2019; Hidayat et al., 2023). Various researchers have examined the inter-annual and seasonal relationship between chlorophyll-a and SST (Ningsih et al., 2021; Rahman et al., 2019; Castillo et al., 1996). This inverse relationship is likely driven by the upwelling in the Southwest Bay of Bengal and the intrusion of nutrient-rich water (Mishra et al., 2006; Sahu et al., 2016). Seasonal monsoon currents (SMA and NMC) and nitrate availability also influence chlorophyll-a distribution (Sarangi, 2019). During the summer monsoon (June–September), the West India Coastal Current (WICC) flows southwesterly along the west

coast and eastward along the east coast, further affecting SST and nutrient dynamics (Shenoi et al., 1999).

4.2 Correlation betweenChlorophyll-a, SST, and Fish catch:

The variations of SST, chlorophyll-a, and fish catch in the study area are presented in Figure 6. The result showed a significant negative correlation between SST and fish catch (R^2 = 0.37; p<0.0501) as well as a significant positive correlation between chlorophyll-a and fish catch (R^2 = 0.97; p<0.05). The preferred range of SST for fish production was found to be 30.01± 0.21℃, while the preferred range of chlorophyll-a was found to be 0.31 ± 0.10 mg/m^3(Fig. 6).Fish catch data shows that annual fish production was higher during July, August, and September, suggesting that an increase in chlorophyll-a concentration leads to an increase in the fish catch. The annual fish production and chlorophyll-a were positively correlated; whenever chlorophyll-a increased, fish production also increased. This finding supports the hypothesis that a higher chlorophyll-a concentration indicates higher primary productivity and food availability for fish in the study area.

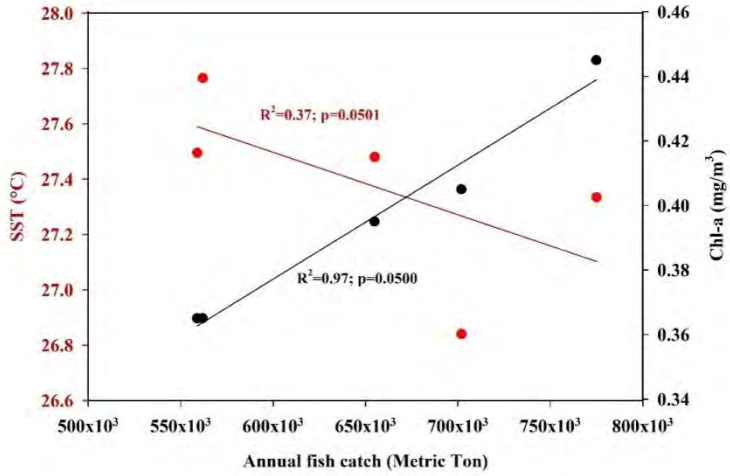


Fig. 6: Red colour shows the variation between the annual SST and fish catch. And black colour shows Chlorophyll-a and fish catch during 2017 -2021. The X-axis shows the annual fish catch, the Y-axis on the right side shows the chlorophyll-a, and the left side shows the SST.

Several studies recommend analysing the relationship between SST, chlorophyll-a, and fish catch, and demonstrates that chlorophyll-a significantly influences marine capture fisheries production, with fish populations thriving within optimal monsoon-driven temperature and productivity ranges(Ningsih et al., 2021; Nurdin et al., 2013; Sachoemar et al., 2012; Suwannathatsa & Wongwises, 2013; Kämpf & Chapman, 2016).We observed a significant positive correlation between chlorophyll-a and fish catch (R^2 = 0.97; p < 0.05) (Fig. 6), consistent with previous findings on optimal environmental conditions for Indian

waters. Sachoemar et al. (2012) noted that fish productivity is strongly influenced by seasonal changes in chlorophyll-a, with higher productivity corresponding to higher chlorophyll values. Ningsih et al. (2021) similarly reported higher fish production in areas with elevated chlorophyll-a concentrations. However, fish production was consistently low during April–June throughout the study period. This aligns with the observation that chlorophyll-a peaks from July–September, coinciding with increased fish landings (Fig. 6). Other studies have highlighted seasonal variability in species distribution driven by temperature and salinity (Castillo et al., 1996). The reduction in fish catch in 2020 compared to 2019 is likely due to COVID-19 restrictions rather than environmental limitations.

5. CONCLUSION:

This study highlights the seasonal variability of SST, chlorophyll-a, and fish catch along the Tamil Nadu EEZ from 2017 to 2021. SST peaked during April–June, while chlorophyll-a reached its maximum during July–September. Fish landings, dominated by Lesser sardines, Silverbellies, and other pelagic species, were highest in 2019.A consistently negative but non-significant relationship was found between SST and chlorophyll-a. However, fish catch showed a significant negative correlation with SST and a strong positive correlation with chlorophyll-a, indicating that primary productivity strongly influences fish abundance. The preferred environmental ranges for optimal fish production were ~30°C SST and ~0.31 mg/m^3 chlorophyll-a. Overall, the results demonstrate that monsoon-driven changes in temperature and chlorophyll-a productivity play a central role in determining fish availability in the region. Continued monitoring of these oceanographic variables is essential for improving fisheries management under changing climatic conditions.

Acknowledgements:

All authors acknowledge RUSA 2.0, CMRG, and the Department of Marine Science, Bharathidasan University. Analyses and visualisations used in this paper were produced with the Giovanni online data system, developed and maintained by the NASA GES DISC. We are also thankful to CMFRI for providing fisheries data.

Conflict of interest:

The authors declare no competing interests.

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The Indian Geographical Journal
Volume 100 (2) December - 2025, pp 121-139
ISSN 0019-4824

EMPLOYMENT PATTERNS, LIVING CONDITIONS AND SOCIAL INTERACTIONS OF WOMEN MIGRANT WORKERS IN SALCETE TALUK OF GOA

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Abstract

This study examines the employment patterns, composition, and characteristics of women migrant workers and their challenges prevalent in the Salcete Taluk of South Goa District in the State of Goa, India. It has focused on their accommodation, income levels, and social interactions and the study utilises a mixed-method combining quantitative and qualitative data. A structured questionnaire cum schedule-based survey was administered to 380 women migrant workers in Salcete Taluk for deriving data on the variables related to employment conditions, income, accommodation and social treatment. Correlation and K-means clustering analyses were performed using statistical tools in IBM SPSS Statistics 20 and MS Excel 2019. The results reveal key relationships between working hours, income, accommodation quality, and job stability, and providing insights into employment condition's influence on living standards and social dynamics. The findings revealed that most of the women are employed in low-wage but high-demand sectors working as domestic help, unskilled or semi-skilled manufacturing workers, housemaids and helpers, making up nearly 66% of the studied workforce. A significant portion (86.5%) works in temporary or casual jobs, leading to income instability and job insecurity. Despite earning about Rs. 6,000 per month, issues like high rent, poor housing quality and lack of job stability persist. Social relations are generally respectful, but excessive working hours correlate with poorer treatment. To improve their living and working conditions, the study recommends welfare policies, insurance coverage, ESI health services, better wages, job security, subsidised housing and a positive societal outlook towards migrant workers in line with the idealistic national labour welfare framework. Implementing these measures would enhance their overall well-being to raise self-respect for the migrant female workforce in the state.

Keywords: Migrant Workers, Wages, Job Security, Social Interactions, Welfare Policies.

Introduction

Goa, a state of India is the smallest but economically prosperous state with the highest per capita income (Census of India, 2011) and offers plenty of economic

opportunities to those seeking work (Moraes, 2014). People from other states have been migrating to Goa for various job purposes since Liberation (Das et al., 2012; Radderatti et al., 2023). Migration data from Census 2011 reveals that Goa has a high inflow of population from various states with the largest numbers coming from the neighbouring states of Karnataka and Maharashtra (Fernandes et al., 2011). It has the highest proportion of migrants from other states as a percentage to total population, there by the density of population in the state increased from 364 to 394 during the decade 2001 to 2011 (Devi, 2019).

Labour migration is a significant phenomenon in India, driven by various socio-economic factors including unemployment, poverty and the pursuit of better economic opportunities and getting rid of social conflicts (Unni, 2000; Adger, 2011; Rao, 2020). In India, migration mostly takes place due to poverty, unemployment, natural calamities and underdevelopment at the origin place (Nancy, 2017; Goel et al., 2018). Between 1991 and 2001, Maharashtra, Gujarat, Punjab, Delhi and Haryana attracted a large number of interstates migrants in India. In recent years, the numerous changes in policies on education, market and trade in India have impacted the pattern of migration. It has progressively created a gap between the agriculture and non-agriculture sectors, between rural and urban areas, employment and labour turnover (Singh et al., 2022). Women migrant labourers, in particular, represent a crucial yet often overlooked segment (Neetha, 2004; Rao, 2020). In urban areas, they contribute substantially to sectors like domestic work, retail and low-wage employment (Lingam, 1998; Ponnusamy et al., 2015; Mehta, 2020), yet their experiences are frequently marked by vulnerability and precarious living conditions (Augustine et al., 2016). This paper aims to shed light on the characteristics of the inter-state migrant women, their employment patterns, living conditions, and their social interactions with the locals and employers. We chose Salcete Taluk of Goa, since this regions faces unique challenges that mirrors broader trends of migration and labour dynamics in India.

The present study considers the women workers who have arrived from other states or union territories other than Goa, for all practical purposes. The women workers reach Goa either by way of marriage, as other family members, or as acquaintances of existing migrant male or female workers working in Goa for a while. However, a significant number of workers, both males and females, come to Goa through the labour contractors taking supply contracts from local firms and entrepreneurs. The women workers who have a different place of origin other than Goa are regarded as the target group in this study, irrespective of their urban or rural background. Here in Goa, they are spread in most of the economically productive rural and urban areas through acquaintances or rehabilitated by the labour contractors immediately after arriving in Goa (Mawii et al., 2020; Sawant, 2021).

The study focuses on three key aspects of the lives of women migrant workers in the study area. It examines the composition, patterns and characteristics of these workers with particular attention to their working conditions. Additionally, the study assesses their

housing and overall living conditions, highlighting the challenges they encounter in terms of accommodation and related issues. The study also explores the treatment these workers receive from locals, colleagues and employers, analysing how social interactions and workplace dynamics affect their well-being and job satisfaction. These areas of focus provide a comprehensive understanding of the experiences of women migrant workers in the region.

Study Area

Salcete Taluk, a sub-district in South Goa District of Goa (Figure 1), located in the southern part of the State, spans approximately between latitudes 15.10°N and 15.30°N and longitudes 73.90°E and 74.10°E. It is bordered by the Arabian Sea to the west and by the Mormugao and Quepem taluks to the north and east, respectively. Covering an area of around 650 sq. km, Salcete is one of the most populous and economically active regions of Goa, with Margao as its administrative and commercial hub (Government of Goa, 2021-22). The region's population is diverse, consisting of local Goans and a significant proportion of migrant workers, particularly women, who contribute to sectors like domestic work, agriculture and manufacturing. The total population of the taluk is estimated at around 3,00,000 (Census of India, 2011), with a substantial portion of the population living in rural areas (approximately 60%), while urbanisation is concentrated in Margao and nearby towns. The sub-district's economy is driven by tourism, agriculture and small-scale industries (GIDC, 2024). Salcete Taluk was chosen for this study because it is one of the most economically developed taluks in Goa, having a high concentration of migrant workers, especially women. The taluk has a wide range of employment opportunities in tourism, hospitality, industries, construction and service sectors, giving a scope for the migrant female labour to earn their livelihood. This made Salcete an area for studying women's participation in different types of work. In addition, Salcete has experienced continuous in-migration over the years, resulting in both short-term and long-term settlement of migrant families in visible clusters. Therefore, the taluk provided a suitable and representative setting to examine the employment and living conditions of migrant women workers in Goa.

Methodology

The study has adopted a mixed-method approach integrating both quantitative and qualitative data to carry out an analysis of the working women migrant labourers in Salcete Taluk (sub-district). The quantitative aspect involves the administration of a structured questionnaire cum schedule-based survey designed to capture a broad spectrum of data pertinent to the conditions of women migrant labourers. The target sample comprises 380 women currently residing and working in various rural and urban areas of the Taluk. The questionnaire incorporates both closed-ended and open-ended questions as well as Likert-scale items (Tanujaya et al., 2023). Tabular and graphical representations were utilised to organise and interpret the data effectively.

The collected data collected was classified and tabulated on MS Excel 2019, and analysis was carried out using IBM SPSS Statistics 20. Cross-tabulations are employed to examine the relationships between different variables, enabling a deeper understanding of the interrelationship of various factors (Ahmad et al., 2021). Correlation analysis is conducted to explore the strength and direction of relationships between key variables, with a correlation matrix developed to visualise these associations. Pearson correlation analysis was computed to explore the associations between different variables related to employment and living conditions.

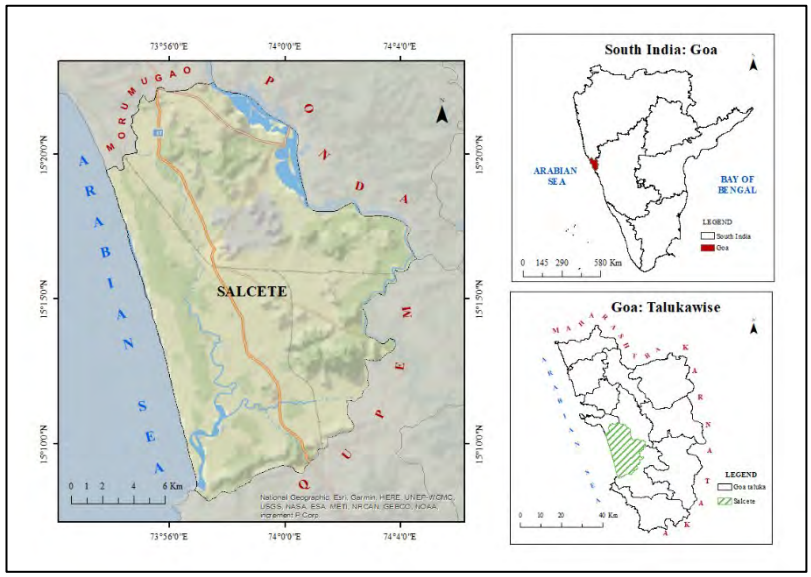


Figure 1: Location Map of the Study Area

The analysis aimed to identify significant correlations among selected variables such as working hours, income, nature and duration of employment, type of accommodation, and treatment received from locals, colleagues, and employers. The correlation coefficients and significance levels were computed for each pair of variables to determine the strength and direction of linear relationships. For instance, strong positive correlations were observed between working hours and income ($r = 0.315$, $p < 0.001$), whereas significant negative correlations were observed between the length of employment and accommodation quality ($r = -0.395$, $p = 0.009$). The outcomes offer understandings into how different aspects of employment and living conditions are interrelated, highlighting areas where variables are strongly associated or show minimal relationships (Chee, 2015).

The correlation values were computed at 0.01 or 0.05 significant levels, which means that there is less than a 1% or 5% probability that this correlation happened randomly, indicating a strong relationship between the variables. The analysis was conducted using a two-tailed test, which examines the possibility of correlations in both positive and negative directions.

K-Means clustering was utilised using IBM SPSS Statistics 20 to segment individuals based on key variables linked to their employment and living conditions (Siregar et al., 2024). The dataset, which included variables such as occupation, nature of employment, duration of employment, working hours, income, type of accommodation, duration of stay, and treatment received from locals, colleagues and employers, was first normalised to ensure consistency across all measures. The optimal number of clusters was determined based on the output, and the K-Means algorithm was executed to partition the data into three distinct clusters. It revealed three distinct clusters among labourers based on their occupational attributes and experiences.

Results and Discussions

This study examines the working conditions and job roles of the migrant women workers, the housing and overall living conditions and behaviours of the employers, colleagues and local population. Examining these dimensions, it provides a comprehensive view for the well-being and integration of these workers.

Places of Origin

The study reveals a significant concentration of neighbouring state origins as depicted in Figure 2, with Karnataka accounting for a dominant 69.7% of the total, making it the primary source. This suggests that Karnataka is the predominant region of origin due to the nearness of location along with another originating State, which is also a neighbouring one. Maharashtra follows with 10.0%, while Uttar Pradesh and Bihar contribute 7.6% and 5.0%, respectively. The remaining states, namely Gujarat, Odisha and others, contribute relatively small percentages ranging from 0.3% to 1.3%. This distribution indicates that the mainstream of the migrants primarily comes from the contiguous states of Karnataka and Maharashtra, with only an inconsequential share from other states.

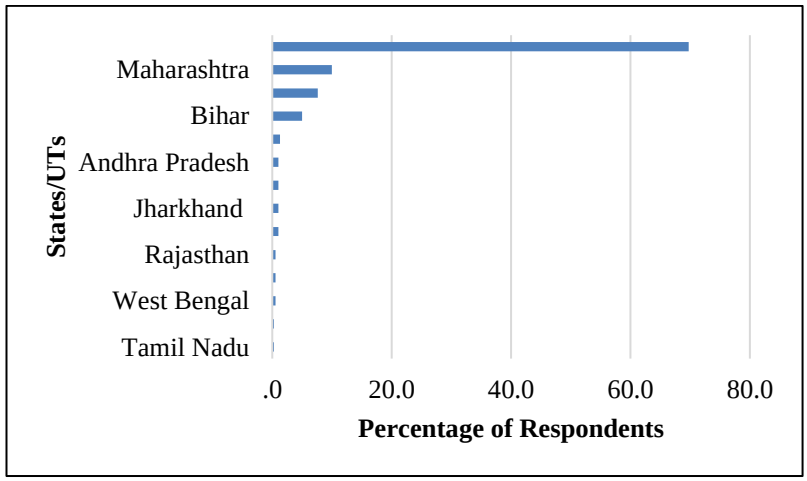


Figure 2a: States/UTs of origin of women migrant workers in Salcete taluk

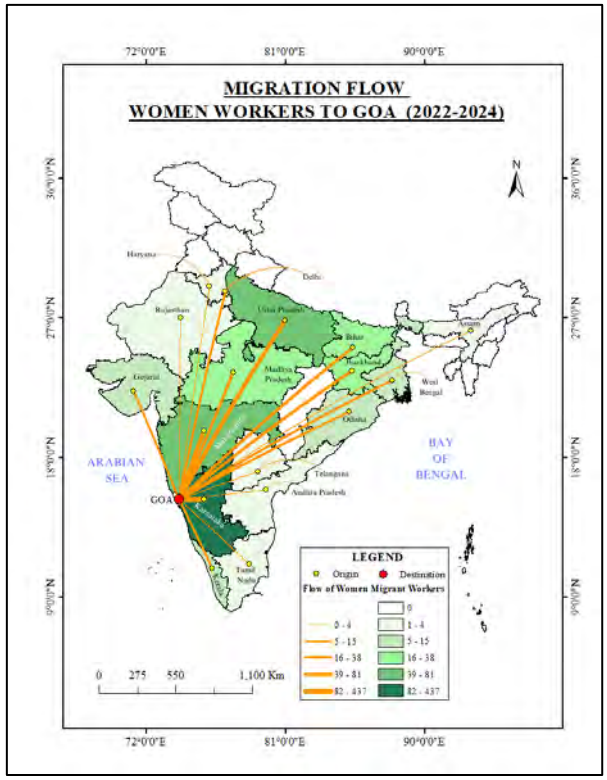


Figure 2b: Map showing the flow cum volume of women migrant workers from other states / UTs of India to Goa

Occupational Environment and Job Characteristics

The occupational distribution (Table 1) reveals a pronounced dominance of housemaids who constitute 47.4% of the workforce, followed by helpers at 18.2%, indicating a substantial portion of individuals involved in support job roles. Occupations such as vendors (11.1%) and tailors (8.7%) also represent notable segments, though they are less prevalent. Factory workers, labourers and saleswomen each make up fewer than 5% of the total, suggesting these roles are less common in this dataset. The minimal presence of sweepers (0.5%) and garbage collectors (0.8%) highlights their marginal representation, notwithstanding the fact that the workers in these professions identify themselves as native or resident population, as they have been doing these jobs for more than 10 years. Overall, the data reveal a skewed occupational structure with a heavy emphasis on low-wage and service-oriented positions.

The study shows a predominance of casual employment comprising 57.6% of the workforce. This indicates a significant reliance on informal or short-term job arrangements. Temporary positions account for 28.9%, highlighting a notable segment of the workforce engaged in non-permanent roles. Daily wage employment, at 11.6%, while permanent

positions represent a mere 1.8% of the total, signifying a minimal presence of job security and long-term employment within the population.

Table 1: Distribution of the WMW into Selected Variables related to Working Conditions

Variables	Class	Frequency	Percentage (%)
Current Occupation	Housemaid	180	47.4
	Helper	69	18.2
	Vendor	42	11.1
	Factory Worker	13	3.4
	Labourer	16	4.2
	Saleswoman	8	2.1
	Sweeper	2	.5
	Housekeeping	14	3.7
	Tailor	33	8.7
	Garbage Collector	3	.8
Nature of Employment	Casual	219	57.6
	Daily Wages	44	11.6
	Temporary	110	28.9
	Permanent	7	1.8
Duration of Current Employment	<2 years	48	12.6
	2-4 years	92	24.2
	4-6 years	77	20.3
	6-8 years	56	14.7
	>8 years	107	28.2
Working Hours	<= 2 hours	4	1.1
	3 to 5 hours	176	46.3
	6 to 8 hours	133	35.0
	8 to 10 hours	63	16.6
	> 10 hours	4	1.1
Monthly Income (in Rs.)	Below 3000	23	6.1
	3000-6000	182	47.9
	Above 6000	175	46.1
		N=380	

In this study, duration of current employment refers to the total number of years the migrant women worker has been engaged in paid work in the present occupation or sector. A considerable portion of 28.2% of individuals have been in their present jobs for over 8 years, reflecting a significant portion of long-term employees. In contrast, 24.2% have remained hired for 2 to 4 years, and 20.3% for 4 to 6 years, suggesting a notable presence of mid-term employment. A smaller percentage, 14.7%, have been in their positions for 6 to 8 years, while 12.6% have been employed for less than 2 years. This distribution highlights a relatively balanced workforce with a considerable segment of long-term employees alongside a noteworthy proportion in mid-term roles, indicating a mix of stability and turnover within the workforce.

The study displays a diverse distribution of work patterns among the workforce. The majority, 46.3%, work between 3 to 5 hours per day, closely followed by those working 6 to 8 hours a day (35.0%). A smaller group (16.6%) works between 8 to 10 hours. Both those working less than or equal to 2 hours and those exceeding 10 hours each constitute 1.1%, highlighting rare instances of very short or exceptionally long working hours. This distribution highlights a prevalence of part-time and normal working hours, with relatively few individuals working extreme hours.

The study reveals a relatively balanced spread across different income brackets. A significant portion of the workforce (47.9%) earns between Rs. 3,000 and Rs. 6,000 per month. Another similar segment (46.1%) earns above Rs. 6,000, suggesting a considerable proportion of higher-income earners. In contrast, only 6.1% of individuals fall into the lowest income bracket of below Rs. 3,000. This distribution suggests a generally higher income level among the majority of the workforce, with a notable concentration in the mid to upper income ranges and relatively few individuals in the lower income bracket.

Quality of Housing and Living Conditions

Table 2 shows the housing and living conditions of WMW. The duration of stay throws light on a prominent trend towards long-term tenure among the workforce. A notable 34.7% of individuals are working for over 20 years, reflecting a substantial proportion of highly experienced employees. Those employed for 5 to 10 years constitute 25.3%, indicating a significant segment of mid-career professionals. The 10 to 15 years bracket includes 16.1%, while 13.2% have been in their positions for 15 to 20 years. The smallest segment, at 10.8%, has been working for less than 5 years. This distribution suggests a workforce with a strong presence of long-term tenure, coupled with a considerable proportion of mid-term employees, indicating a mix of stability and seasoned experience within the labour force.

Table 2 shows the housing and living conditions of women migrant workers (WMW). The duration of stay highlights a clear trend towards long-term residence among the respondents. In this study, duration of stay refers to the length of time (in years) a woman migrant worker has been residing in her current place of residence in Goa, irrespective of changes in workplace or occupation.

A significant 34.7% of women have been living in the current location for over 20 years, indicating a high level of residential stability. Those who have stayed for 5 to 10 years constitute 25.3%, representing a significant group of medium-term residents. The 10 to 15 years category accounts for 16.1%, while 13.2% of the respondents have lived in the area for 15 to 20 years. The smallest proportion, 10.8%, consists of women who have resided in the location for less than five years. Overall, this distribution suggests a predominantly settled migrant population, with a strong presence of long-term residents alongside a smaller group of recent migrants.

The study highlights a dominant trend towards renting among the workforce, with 78.2% residing in rented accommodations. This contrasts sharply with the 19.5% who own their homes, indicating a relatively lower proportion of homeownership. Only 2.4% of individuals have accommodation provided by their employer, suggesting that employer-provided housing is a minor benefit in this context. This distribution underscores a significant reliance on rental housing, with homeownership being less common and employer-provided accommodations playing a minimal role.

A substantial majority (54.9%) pay between Rs. 3,000 and Rs. 6,000 per month in rent, indicating that this is the most common rent range among the workforce. Additionally, 39.4% of individuals spend below Rs. 3,000 on rent, reflecting a notable portion of the population in lower rent brackets. Only 5.7% pay above Rs. 6,000, suggesting that higher rental costs are less prevalent. This spread suggests that most individuals experience moderate rental expenses, with a significant portion in the lower range and a smaller segment facing higher costs.

Table 2: Distribution of the WMW into Selected Variables related to Living Conditions

Variables	Class	Frequency	Percent (%)
Duration of Stay	Less than 5 years	41	10.8
	5 to 10 years	96	25.3
	10 to 15 years	61	16.1
	15 to 20 years	50	13.2
	More than 20 years	132	34.7
Type of Accommodation	Own	74	19.5
	Rented	297	78.2
	Provided by Employer	9	2.4
Rent Paid	Below 3000	117	39.4
	3000-6000	163	54.9
	Above 6000	17	5.7
Nature of House	Coconut roof	8	1.1
	Asbestos roof/steel or tinned roof	300	78.9
	Flat	72	18.9
No. of Rooms	1 to 2	257	67.6
	2 to 4	113	29.7
	More than 4	10	2.6
Overall condition of the house	Miserable	2	.5
	Dilapidated	8	2.1
	Bad	32	8.4
	Satisfactory	151	39.7
	Good	187	49.2
		N=380	

The nature of housing roofs reveals a predominant use of asbestos, steel, or tinned roofs, which cover 78.9% of homes, indicating a widespread preference for these materials due to their durability and cost-effectiveness. Flat roofs are the next most common, with

18.9% of homes featuring this design, suggesting a preference for modern, often urban housing styles. Only 1.1% of homes have coconut roofs, reflecting their rarity and likely use in more traditional or rural settings. This distribution highlights a strong preference for more contemporary roofing materials, with a minor presence of traditional options.

The majority of households, 67.6%, have 1 to 2 rooms, reflecting a trend towards smaller living spaces. A significant portion, 29.7%, occupies homes with 2 to 4 rooms, suggesting a moderately larger but still relatively compact living arrangement. Only 2.6% of households have more than 4 rooms, indicating that larger residences are quite rare. This distribution underscores a predominance of smaller living spaces, with a small proportion of households enjoying larger accommodations.

With reference to the overall condition of houses, the majority of homes are in relatively good condition, with 49.2% rated as "Good" and 39.7% as "Satisfactory." This indicates that a significant portion of the housing stock is in decent to favourable condition. A smaller segment, 8.4%, is classified as "Bad," suggesting that a moderate number of homes are in less favourable states. Very few homes are rated as "Dilapidated" (2.1%) or "Miserable" (0.5%), reflecting that extreme conditions are quite rare. This dispersal proposes that while most housing is in fair to good condition, there is a small but notable proportion of substandard housing that may require attention.

Social Interactions of Women Migrant Workers (WMW)

An extensive portion of the workforce experiences professional and respectful treatment from their employers, as shown in Table 3. Specifically, 37.1% report being treated very professionally, while 32.9% believe they are treated with love and care, suggesting a generally positive work environment characterised by both professionalism and personal concern. A significant 27.6% of women feel they are treated with dignity and respect, emphasising a predominantly respectful atmosphere. However, a small minority of 1.6% report having no employer and 0.8% feel they are treated with suspicion as a stealer or cheat, highlighting a minimal occurrence of negative treatment.

In relation to treatment by colleagues, a significant majority of 59.5% stated that they are treated as equals, reflecting a positive and equitable work environment among peers. However, 40.5% do not have colleagues, suggesting that they work in isolation, especially those working as housemaids, vendors and hawkers. As far as incentives provided by employers are concerned, a vast majority of women (87.4%) revealed that they receive no incentives, indicating a prevalent lack of additional financial or non-financial rewards in their work environment. A modest 10.0% receive gifts during festivals, suggesting that some employers offer occasional, culturally significant incentives. Only a small fraction receives transport allowance (1.6%), advance salary and loans (0.8%) or Bonuses (0.3%), highlighting that these forms of financial support are rare. This distribution underscores a dominant trend of minimal incentive offerings, with only a small portion of employees benefiting from limited rewards.

The most common expectation of the migrant women labourers from their employers is a hike in pay, with 29.7% expressing this desire. A significant number, 15.4%, hope for better working conditions. Other expectations include making the job permanent, maintaining good behaviour, providing bonuses, avoiding pay deductions and ensuring timely payment. A substantial portion, 46%, reported having no specific expectations. This pattern indicates that while many respondents have specific expectations, a notable proportion have no additional demands from their employers.

Table 3: Distribution of the WMW into Selected Variables related to Social Interactions

Variables	Class/ Category	Frequency	Percentage (%)
Treatment by Employer	No employer	6	1.6
	With dignity and respect	105	27.6
	Very professional without affection	141	37.1
	With love and care	125	32.9
	With suspicion as a stealer or cheat	3	.8
Treatment by Colleagues	As equals	226	59.5
	No Colleague	154	40.5
Incentives by Employer	None	332	87.4
	Gifts during festivals	38	10.0
	Transport allowance	6	1.6
	Advance salary & loans	3	.8
	Bonuses	1	.3
Expectations from Employer	Hike in Pay	105	27.6
	Make job permanent	20	5.3
	Provide toilet facilities	255	67.1
Treatment by Locals	Bad	2	.5
	Satisfactory	82	21.6
	Good	231	60.8
	Very good	65	17.1
Treatment in the Locality	With dignity and respect	105	27.6
	With love and care	176	46.3
	No respect and neglect	2	.5
	No interference	97	25.5
		N=380	

The study specifies that the majority of individuals experience positive interactions with the locals, with 60.8% rating the treatment as good and 17.1% as very good. This proposes that an important portion of people have favourable experiences with locals. Additionally, 21.6% find the treatment satisfactory, demonstrating that their exchanges are acceptable but not outstanding. Only 0.5% report experiencing bad treatment, reflecting that negative interactions are quite rare. Overall, the statistics disclose that most individuals

perceive their treatment by locals in a positive light, with only a small fraction encountering negative experiences.

The majority of these women specified that they receive positive treatment within the locality in which they reside, wherein 46.3% reported being treated with love and care, and 27.6% feel they are treated with dignity and respect. Additionally, 25.5% experience no interference, suggesting a degree of neutrality or acceptance. Only 0.5% of respondents feel they receive no respect and are neglected, indicating that such undesirable experiences are rare.

Major Problems faced by WMW

Figure 3 outlines the major problems faced by the 380 respondents. The most prevalent issue is a lack of own housing, reported by 29.2% respondents. Another significant concern is the financial problems, affecting 25.5% respondents. A smaller number of respondents face issues related to the absence of the government Social Security documents, unstable job and income, improper living conditions and family issues. Notably, a vast majority of respondents (35.8%) report having no major problems. This data highlights that financial problems and lack of home ownership are the most significant challenges for the majority of respondents, while fewer report issues related to job stability, living conditions, or family matters.

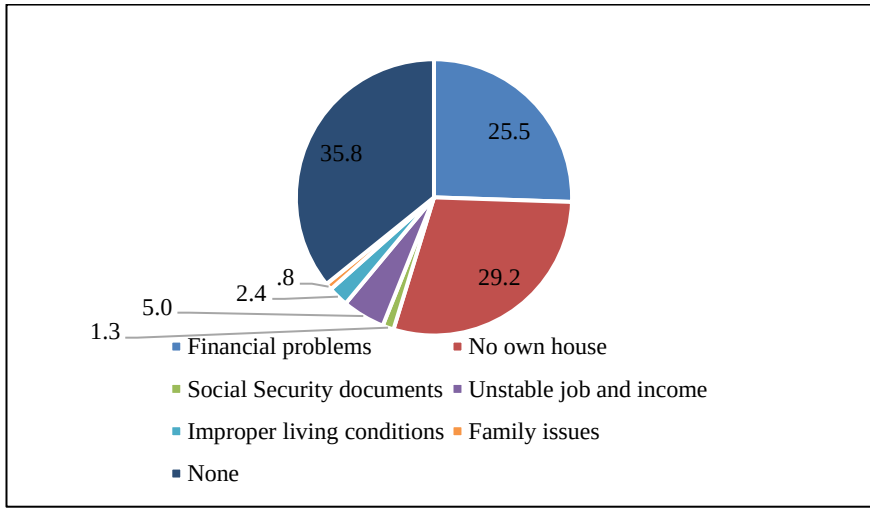


Figure 3: Major Problems Faced by Women Migrant Workers in Salcete Taluk

The study has attempted to study the interrelationship among the selected variables to find the extent of the relationship and draw plausible inferences about the migrant women's socio-economic status. The crosstabulation between two variables from the collected information was carried out, and inferences were drawn for broad findings (Figure 4) and discussed as follows.

Duration of stay and accommodation types reflect a shift in housing patterns. For those staying less than 5 years, 75.6% live in rented accommodations, 19.5% in employer-provided housing and 4.9% own their homes. As the stay extends to 5-10 years, rental accommodation remains dominant at 89.6%, while homeownership increases slightly to 10.4%. By 10-15 years, homeownership rises to 13.1% and rental accommodation decreases to 86.9%. After 15-20 years, ownership increases to 22% and rental accommodation drops to 76%. For those staying over 20 years, homeownership peaks at 32.6%, showing a gradual shift toward owning homes over time.

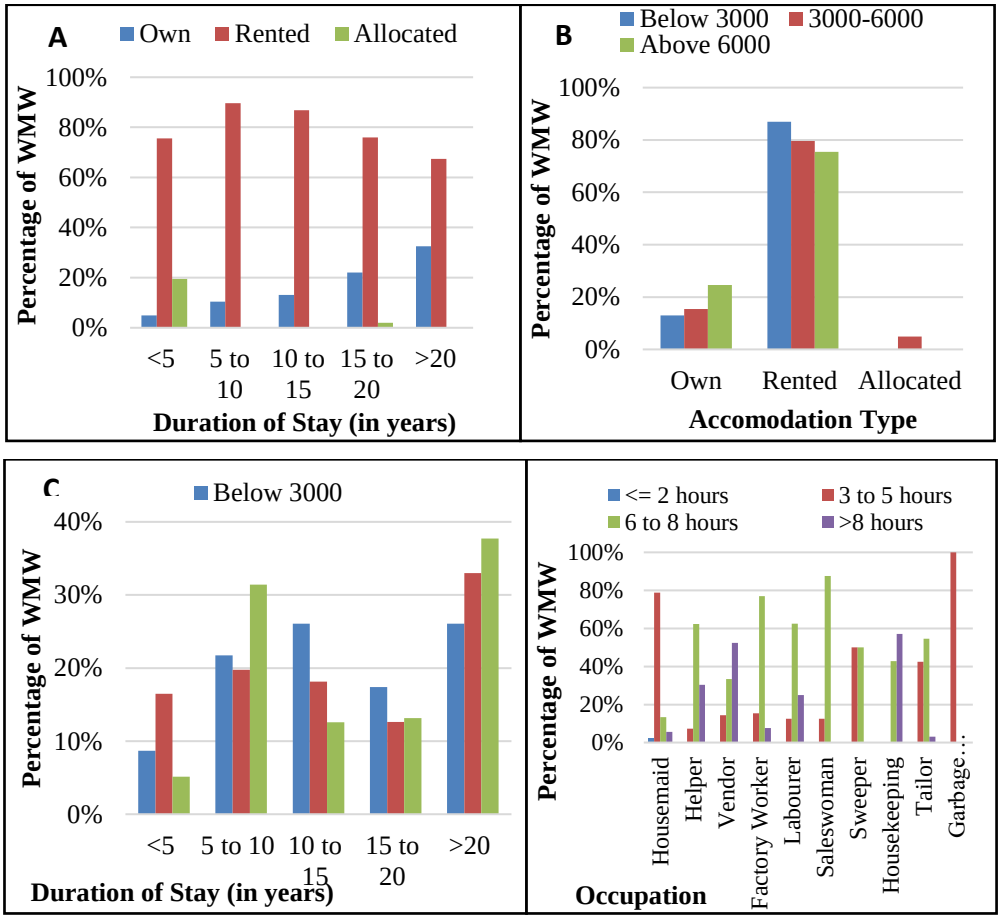


Figure 4: A- Accommodation Type and Stay Duration, B- Income and Accommodation Type C- Income and Stay Duration, D- Occupation and Working Hours

Income levels and accommodation types among women migrant workers reveal distinct patterns in housing preferences across different income levels. Women with incomes below Rs. 3000, the majority (87%) are in rented accommodations, while a small portion of 13% are in accommodation provided by their employer, and none own their

homes. This indicates a heavy reliance on rental housing among lower-income groups. In the Rs. 3000-6000 income bracket, 79% are renters, while 5% live in employer-provided housing, and 15% own their homes, suggesting a moderate shift towards ownership as income increases but still a predominant trend towards renting. For those earning above Rs. 6000, home ownership becomes more prevalent, with 24.6% owning their homes and 75.4% renting.

Income levels and duration of stay among women migrant workers reveal patterns in housing stability. Most women earning below Rs. 3000 have shorter tenures: 8.7% stay less than 1 year, 21.7% for 1-2 years, and 26.1% for 2-3 years, indicating lower-income workers experience less residential stability. In contrast, women earning between Rs. 3000 and Rs. 6000 show more stability, with 33.0% staying 4-5 years. Those earning above Rs. 6000 tend to have even longer tenures, with 37.7% staying 4-5 years, suggesting higher income correlates with greater housing stability and longer residence periods. Occupation and Hours at work among female migrant workers reveal distinct patterns in employment. Housemaids predominantly work shorter hours, with 78.9% working 3 to 5 hours, 13.3% working 6 to 8 hours and 5.6% exceeding 8 hours. Helpers work for extended hours, with 62.3% working 6 to 8 hours and 30.4% over 8 hours. Vendors have the longest work hours, with 52.4% working more than 8 hours. Factory workers and labourers mostly work 6 to 8 hours, while saleswomen, sweepers, and garbage collectors work fewer hours. Tailors and housekeeping staff also show a tendency for moderate to long working hours.

A correlation matrix is created to depict all the relationships existing among the variables (Table 4). The matrix table displays Pearson's correlation coefficients between pairs of variables. Pearson's correlation coefficient (r) measures the strength and direction of the linear relationship between two variables, ranging from -1 to 1.

The matrix offers insights into the associations between various factors affecting labour conditions and experiences. Nature of Work illustrates strong positive correlations with Hours of Work (r = 0.47) and Income (r = 0.35), indicating that more secure and higher-paying jobs tend to involve longer working hours. Conversely, it has a negative correlation with Major Problems (r = -0.12), suggesting that a more stable nature of employment is associated with fewer major problems.

Table 4: Correlation Matrix of selected variables

Variables	Nature of Work	Hours of Work	Income	Period of Work	Type of Housing	Rent Paid	Period of stay	Treatment by Locals	Treatment in Locality	Treatment by Colleagues	Treatment by Employer	Major Problems
Nature of Work	1	.47**	.34**	-.11	-.00	-.06	-.10	-.00	.25**	-.11*	-.07	-.12*
Hours of Work	.47**	1	.43**	-.20	.06	.06	.00	.04	.15**	-.10*	-.11*	-.14**
Income	.35**	.43**	1	-.12	-.14*	.14*	.06	.01	.09	-.17**	-.04	-.08
Period of Work	-.12	-.20	-.12	1	-.29*	.14	.36**	.14	-.07	-.04	-.11	.13
Period of stay	-.20	.00	.06	.36**	-.31**	.24**	1	.50**	-.34**	-.28**	.08	.22**
Treatment by Locals	-.00	.04	.01	.14	-.11*	.23**	.46**	1	-.44**	-.25**	.00	.17**
Treatment in Locality	.25**	.15**	.09	-.07	.15**	-.16**	-.33**	-.44**	1	.35**	.05	-.20**
Treatment by Colleagues	-.11*	-.10*	-.17**	-.04	-.01	-.03	-.28**	-.25**	.35**	1	.12*	-.12*

The following correlations were eliminated from the matrix table due to very weak 'r'

Type of Housing	-.00	.06	-.14**	-.29*	1	-.13*	-.31**	-.11*	.15**	-.00	-.24**	-.24**
Rent Paid	-.06	.06	.14*	.14	-.13*	1	.24**	.23**	-.16**	-.03	.00	.15*
Treatment by Employer	-.07	-.11*	-.04	-.16	-.24**	.00	.08	.00	.05	.19*	1	.03
Major Problems	-.12*	-.14**	-.08	.13	-.24**	.15*	.22**	.17**	-.20**	-.12*	.03	1

Note: * indicates 95% significant and ** indicates 99% significant

Hours of Work correlates positively with Income (r = 0.43), implying that longer working hours are associated with higher income levels. It also shows a poor negative correlation with Period (r = -0.20), indicating that longer working hours are associated with shorter periods of employment or tenure. Hours of Work are weakly correlated with Major Problems (r = -0.14), suggesting that increased working hours relate to a moderate rise in the number of issues faced.

Period of Stay shows a slight positive correlation with Type of Housing (r = 0.36) and Locals (r = 0.50), implying that a longer stay is associated with better accommodation and interactions with locals. It has a feeble negative correlation with Major Problems (r = -0.22), indicating that longer periods of stay are associated with fewer major problems.

Type of Housing correlates positively with Period of Stay (r = 0.36) and negatively weak with Major Problems (r = -0.24), suggesting that better accommodation is linked to longer stays and fewer problems.

Overall, the matrix indicates that secure, well-paying jobs are linked to longer working hours, better accommodation, and longer periods of stay, while those facing more significant major problems tend to have less secure employment and poorer living conditions.

Categorisation of WMW based on Cluster Analysis of Selected Variables

To understand the diversity among migrant women workers, K-means cluster analysis was used to group migrant women workers based on shared characteristics. K-means cluster analysis was carried out in SPSS to identify distinct groups of migrant women workers based on selected socio-economic and work-related variables. The variables used for clustering were age, marital status, education, occupation, monthly income, distance to workplace, working hours, duration of employment, type of accommodation and overall conditions of the house. These variables were originally collected in categorical ranges and were subsequently coded into numerical values (e.g., 1, 2, 3…) to represent ordered categories. All variables were coded in the same numerical direction, where higher values indicated higher levels of the characteristic. The K-means algorithm was then applied to group respondents with similar characteristics. The number of clusters was determined based on meaningful interpretation and clarity of the resulting group profiles. Cluster centres and group memberships were examined to describe the socio-economic patterns observed among the migrant women workers. Table 5 provides the outcome of cluster analysis of different variables related to women migrant workers.

Cluster 1 comprised migrant women with a primary level of education, who were mainly engaged in sales and retail activities such as vending, hawking and sales work within local neighbourhoods. These women had 5 to 8 years of work experience, worked less than 5 hours per day and travelled short distances of about 2 to 5 kilometres, mostly on foot. This indicated the localised nature of their work and limited access to transport. Their monthly income was above Rs. 6000, and they had lived in their present location for 10 to 15 years. Migration in this cluster was primarily driven by the search for better wages, indicating economic motivation. Their housing conditions were satisfactory, and employment was largely undertaken to support family needs. Overall, this cluster represented women who, despite limited resources, had achieved a degree of occupational and residential stability.

Table 5: K-Means Clusters of Selected Variables

Variable	Clusters		
	1	**2**	**3**
Age	35-54	35-54	35-54
Marital Status	Married	Married	Married
Education	Primary	Secondary	Primary
Occupation	Sales and Retail	Domestic and Cleaning	Domestic and Cleaning
Duration of Employment	5 to 8 years	0 to 4 years	5 to 8 years
Working hours	<5 hours	<5 hours	<5 hours
Distance covered for work	2 to 5 kms	2 to 5 kms	2 to 5 kms
Income	More than Rs 6000	Less than Rs. 6000	More than Rs 6000
Commute to work	On Foot	By Bus	By Bus
Accommodation Type	Rented	Rented	Rented
Overall condition of the house	Satisfactory	Satisfactory	Good
Period of Stay	10-15 years	5-10 years	>20 years
Reason for Migration	Better wages	Marriage	Marriage
Expenditure	Rs 3000-6000	Rs 3000-6000	Rs 3000-6000
Reason for working	To support the family	To support the family	To become self-sufficient

Cluster 2 consisted of women with low levels of education, predominantly engaged in domestic and cleaning work such as housemaids, helpers, housekeeping staff and garbage collectors. Most had limited work experience of a few months to 4 years, indicating recent entry into the labour market. Although their working hours and travel distances were similar to those of other clusters, they mainly relied on public buses for commuting, suggesting limited familiarity with local routes. Their monthly income was below Rs. 6000, suggesting economic vulnerability. Migration among these women was largely associated

with marriage rather than employment, indicating a socially driven movement. Their duration of stay ranged from 5 to 10 years, pointing to relatively recent settlement. This cluster thus represented a transitional group facing greater risks of job insecurity, exploitation and limited upward mobility.

Cluster 3 included women with primary education who were also engaged in domestic and cleaning work, but differed significantly from Cluster 2 in terms of stability and motivation. These women had 5 to 8 years of work experience and earned more than Rs. 6000 per month. They commonly travelled by bus, suggesting longer commuting distances or a preference for more efficient transport. Unlike Cluster 1, where work was driven by family responsibilities, women in this cluster cited self-sufficiency as their main motivation, indicating greater personal authority. Their residence of above 20 years in the current location and "good" housing conditions indicated long-term settlement and improved living standards. This cluster therefore, represented a relatively empowered group showing signs of upward mobility, economic independence and secure livelihoods.

Overall, the cluster analysis revealed three distinct groups of migrant women workers reflecting varying levels of stability, motivation and socio-economic conditions. Cluster 1 showed moderate stability driven by family responsibility, Cluster 2 highlighted vulnerability and transition linked to socially driven migration, while Cluster 3 reflected greater empowerment, independence and long-term settlement within the informal labour market.

Conclusion

The findings provide a detailed understanding of the work environment, job characteristics and living conditions of women migrant workers in Salcete Taluk of Goa, highlighting broad patterns and differentials. There is a need to improve the situation by implementing the labour- oriented policies that promote housing stability for the poor, fair wages and income security, providing legal protections, etc., which will significantly eliminate major challenges faced by these women. Additionally, offering support services, insurance coverage and health services like ESI can safeguard their rights and improve their quality of life. Focused interventions towards welfare policies, job security and positive societal attitudes are critical for creating a more equitable environment for women migrant workers. By addressing both general and specific factors, these measures will foster greater social and economic stability, benefiting this vulnerable segment of the workforce. Addressing these issues requires targeted interventions that consider both the systemic and individual factors. The implementation of these suggestions is expected to benefit this vulnerable section of migrant female workers. Moreover, they need to be treated with compassion in line with the idealistic national labour welfare framework. Implementation of such measures would positively enhance the overall well-being to raise self-respect for the migrant female workforce in the State of Goa, which might be replicated in other parts of India.

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The Indian Geographical Journal
Volume 100 (2) December - 2025, pp 140-159
ISSN 0019-4824

GEOGRAPHICAL INVESTIGATION OF CRIME CONCENTRATION AND DISPERSION: MAPPING HOTSPOTS OF PROPERTY OFFENCES IN SAIFABAD CIRCLE OF HYDERABAD

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Abstract:

The field of crime studies has witnessed significant advancements in recent years, embracing a comprehensive and interdisciplinary approach. However, notable gaps remain in the investigation of property related criminal offences within their spatial context in India. This study investigates the complex relationship between geographic factors and the nature, type, and intensity of property related offences within the administrative jurisdiction of the Hyderabad Police Commissionerate, using crime data collected from 2016 to 2018. The study aims to generate insights into the relative significance and influence of the area's morphology and socio-cultural-governance structures on property crime incidence. To facilitate spatial understanding, crime analysis tools, including hotspot analysis and gradient analysis, were employed. The thematic layers obtained from the Telangana State Remote Sensing Applications Centre (TSRSAC) were utilised for spatial analysis. The results of the study shedding light on the spatio-temporal dimensions of property related crime in the study area. The crime patterns were found to be closely linked to land use and socio-economic conditions, with dense mixed-use and informal areas exhibiting higher incidences of robbery and theft. Vulnerability was observed to rise in zones characterised by informal employment and gentrification. Weekday crime rate peaks corresponded to commuting activity, while monthly spikes aligned with salary disbursement and festival cycles. Predictive analysis revealed elevated crime intensity in March, July, and October, as well as on Tuesdays during the first and last weeks of each month in certain sectors. Peripheral and transit corridors remained persistent hotspots for crimes, possibly due to transient populations and limited surveillance. The findings contribute to a deeper understanding of the dynamics underlying property related criminal offences in the study area and serve as an empirical resource for future advancements in spatial crime studies.

Key Words: Crime and Space – Hotspots – Land Use - Impactors- Challenges

1. Introduction:

The growing concern over urban crime has spurred a substantial body of literature

emphasizing spatial analysis, data-driven policing, and socio-economic correlations to enhance public safety strategies. However, there appears to be a lack of evolved research models and methods in the sphere of spatiality of crime in urban areas. Oliveira (2021) critiques the traditional per capita rankings of crime, arguing that such measures are inadequate when comparing cities of differing scales. The study reveals that crime does not necessarily increase linearly with population, highlighting the need for more uncommon approaches that incorporate scaling laws to better understand crime patterns. Similarly, Sharma et al. (2016) explore spatial crime mapping and hotspot analysis in Ajmer City, demonstrating how geospatial techniques can support local law enforcement in identifying high-risk zones and optimising surveillance strategies. Their findings stress the utility of mapping historical crime data to predict future incidents and inform resource deployment based on proximity and intensity of crime occurrences. Complementing these insights, Cheng and Chen (2021) provide a comprehensive examination of urban crime in the context of urban informatics. They trace the evolution of crime prevention from traditional criminology to modern data-driven policing, emphasising the effectiveness of analytical tools and big data technologies in urban security management. The authors advocate for a shift toward evidence-based strategies that align with the complexities of modern cities. Supporting this direction, Gupta (2020) investigates the relationship between urbanisation and crime in Delhi, establishing a strong correlation between crime incidence and factors like population growth, mobility, and vehicle density. The study integrates GIS and GPS technologies, and the results reveal that areas with high population density and public neglect are especially vulnerable to crime. He also identifies public perceptions of safety, showing that while police presence can enhance the feeling of security, there is considerable dissatisfaction with the response time and accessibility of law enforcement.

Collectively, these studies underscore the multidimensional nature of urban crime and the value of integrating spatial data, technology, and community feedback in crafting effective crime prevention and control measures. Crime Prevention Through Environmental Design (CPTED) has emerged as a promising framework for mitigating crime. Cozens and Love (2015) highlight the importance of environmental interventions, such as improved street lighting and the strategic placement of surveillance cameras, in deterring criminal behaviour. Crowe (2000) emphasizes that urban spaces should be designed with safety in mind, ensuring that public areas are well-lit, visible, and actively monitored by both authorities and the community. This design philosophy aligns with Weisburd and Bernasco's (2018) findings that well-planned environments reduce opportunities for crime, particularly in residential areas with limited surveillance.

In these backdrops, the objective of the study is set as to analyse the spatio-temporal dynamics of property offence-related crime in the Saifabad Circle of Hyderabad. It conducts a temporal assessment of offences from 2016 to 2018 and examines spatial variations to identify dominant sectors and key crime zones. The research further explores crime patterns across different time frames, like diurnal, date-wise, and month-wise, to capture behavioural and situational trends. Sector-wise hotspot mapping is undertaken to visualise crime concentration, followed by the determination of preference scores to rank

vulnerability levels within the study area. The study also intends to examine the potential for predictive analysis in strategic urban crime management.

2. Study Area:

The study area of Saifabad Circle falls within the Hyderabad Police Commissionerate. The total extent of the study area is approximately 3.21 sq.km. bordering Panjagutta, Nampalli, Abid road, Narayanguda, Chikkadpally, and Ramgopalpet police station limits. The study area is bounded on the north by Hussain Sagar Lake, known for its parks and recreational zones. The western side is predominantly occupied by middle-income residential neighbourhoods, while the southern part features government institutions, hostels, and stadiums. To the east lies the Birla Mandir, set amidst undulating terrain and surrounded by a mix of residential and commercial buildings. The study area does not align with the existing mandal divisions used in the district's census structure. Therefore, the demographic data sourced from the mandal census had to be adjusted to correspond to the mapped area in this case study.

The study area is dynamic due to its central location within the central business district (CBD) of Metropolitan Hyderabad (Fig. 1). It is characterised by a unique blend of residential and commercial establishments, as well as serving as the administrative headquarters for the states of Andhra Pradesh and Telangana during the study period. Specifically, one sector of the study area encompasses significant administrative and cultural centres, including various central and state government offices. Another sector has been known for accommodating short-term commuters, such as those staying in hotels and lodges, who visit the state capital for political, administrative, and business purposes.



Fig. 1: Location Map of the Study Area.

While the movement of people in this locality has undergone significant changes, particularly with a reduction in commuters following the shift of Andhra Pradesh's capital city

from Hyderabad to Amaravathi in 2018—this study does not delve into the dynamics of people's movement and its impact on local businesses. The focus of this study is primarily on understanding the spatial aspects of property crime and the societal implications of offences. Relevant references from related studies are used to test or support the arguments and structure the study, ensuring consistency in the incidence of crime analysis.

Saifabad jurisdiction is classified into seven sectors by analysing its demographic characteristics and land use patterns. Based on this assessment, a broad and interpretive typology of land use was developed, as summarised in Table 1. The classification incorporates key parameters such as the dominant land use type, sector designation, demographic and socio-economic attributes, and notable spatial or functional features.

Table 1: Sector-wise Summary Table with Socio-Economic Profiles:

Sector	Dominant Land Use	Title	Demographic & Socio-Economic Profile	Key Features
1	Urban Core with Dense Mixed Housing and Administrative Concentration	Central Business Districts (CBDs)-Residential with roadside commercial and slum clusters	Predominantly middle- and lower-income groups; high population density; informal and semi-formal employment	Slums (Chintal Basti), major state roads, religious sites, GHMC & State Stats Office
2	Transitional Residential Zone with Emerging Commercial Pressure	Informal Settlements / Slum Clusters - Residential with increasing commercial use	Mixed-class residents; signs of gentrification; student and working-class populations	Govt. Degree College, HMWSSB, demarcation issues; triangular configuration
3	Mixed-Use Entertainment and Residential Hub with Demographic Variability	Entertainment and Leisure Districts - Mixed residential and entertainment	Socio-economically diverse; the West is more densely populated with middle/lower classes; the eastern institutional zone	NTR Garden, IMAX, Secretariat, Post Office
4	Service-Oriented Transit Corridor with Moderate Density	Transit Hubs - Residential and service-oriented	Predominantly working class; renters and service workers; moderate housing density	Lakdikapool railway station, hotels, educational institutions, and the Khairatabad metro proximity
5	High-Activity Mixed Zone with Cultural and Governmental Anchors	Religious and cultural Hubs - Mixed-use: residential, service, entertainment	High population density; mix of slum dwellers, govt. employees, and service workers	Birla Temple, Birla Science Museum, Nizam Club, Income Tax Office
6	Low-Density Institutional and Recreational Axis	Industrial/Institutional Zones - Entertainment, govt. and residential mix	Sparse southern population; north has govt. employees, professionals, and recreational users	LB Stadium, Public Garden, Assembly, DGP Office, RBI, AG Office
7	Peripheral Government-Commercial Fringe with Pockets of Informality	Govt. Offices with Slum Clusters - Mixed-use: Govt., residential, commercial	Mixed socio-economic class; informal workers in slum areas; govt. staff and business class in commercial zones	Govt. offices, eastern commercial strip, southwest slum clusters and open spaces

3. Database and Methodology:

The property offence-related crime data used in this study were collected from the Telangana State Remote Sensing Applications Centre (TSRSAC) website. The study focuses on ten types of offences, including Ordinary Theft, Attention Diverting, Robbery and Snatching, Automobile Theft, Dacoity, Extortion, Housebreak in Day, Housebreak in Night, and Pseudo Police. Detailed information, such as the incidence location (address with latitude and longitude) and occurrence date, was considered for the spatio-temporal analysis.

Land use type data, including residential, commercial, entertainment, government administrative areas, density of built-up areas, and different types of roads, were obtained from the ArcGIS Pro base map layer and from the field data collected in 2018.

The collected data were analysed based on date, weekday, month, and subdivision, integrating spatial and non-spatial data. GIS techniques were employed, utilising ArcGIS Pro software for overlay and geo-querying, as well as statistical methods such as standard deviation. Furthermore, spatial analysis models such as the urban crime heat-intensity map and crime prediction models were employed, leveraging tools such as Kernel Density Estimation (KDE) to calculate the intensity of crime at each location (point of crime) based on proximity and frequency, through weighted allocation using a Gaussian kernel function.

3.1 Kernel Density and Gradient Change

Kernel Density and density change tools were utilised for crime analysis, identifying dense clusters of different crime types in the study area (Nakaya and Yano 2010). Density change analysis was conducted to detect temporal changes in crime patterns (Hu et al. 2018). The KDE algorithm calculates the intensity of crime at each location based on the proximity and frequency of nearby crime points, using a specified search radius (bandwidth).

The Kernel Density Estimation (KDE) formula is as follows:

Crime Heat Intensity (I) at location x:

$$I(x) = k \sum_{i=1}^{n} \frac{1}{h^2} \left(\frac{d(x, x_i)}{h} \right)$$

Where, x: Location where intensity is estimated; x_i: Location of crime event I; d (x, x_i): Distance between x and crime event x_i; h: Bandwidth (search radius or smoothening parameter); K: Kernel function (usually Gaussian or quadratic)

A Gaussian kernel function was employed to assign greater weight to crimes closer to the location of interest. The resulting output is a continuous raster surface, with areas of

higher density represented by warmer colours on the heat map. This method effectively highlights crime-prone zones, assisting in hotspot detection and spatial trend analysis.

3.2 Standard Deviation and Frequency Analysis

The study employed standard deviation analysis to assess the variability in crime frequency across different sectors from 2016 to 2018. Standard deviation measures the dispersion of data points from the mean, used to evaluate how consistently or inconsistently crimes were distributed spatially within each crime category. This statistical approach enabled the identification of sectors that significantly deviated from the average crime incidence, offering critical insights into the temporal and spatial fluctuations in criminal activity (Leitner 2013; Santos 2016). The standard deviations of crime data were used to identify below average Sectors (< Mean), above average Sectors (+ 1σ), high concentration Sectors (+ 2 σ), and very high concentration Sectors (+ 3 σ).

3.3 Hotspot Analysis

The optimised hotspot tool in ArcGIS Pro was employed to identify significant clusters of hot and cold spots, indicating overall positive and negative confidence in crime occurrences. The hotspot analysis presents a comprehensive examination of the spatial characteristics of offences, identification of crime hotspots, and crime gradients (Chainey 2008).

3.4 Predictive Analysis and Spatial Correlation Techniques

Predictive analysis in this study was conducted using trend extrapolation and spatial correlation techniques to forecast potential crime hotspots based on historical crime data from 2016 to 2018. By applying linear regression and GIS-based mapping, the method identifies patterns and projects future crime-prone sectors with reasonable accuracy (Hu et al. 2018).

Formula (Z-Score Normalisation for Crime Prediction):

$$z_{ij} = \frac{C_{ij} - u_j}{\sigma_j}$$

Where, z_{ij}: Standardised crime score (Z-score) for sector I during time period j (month, day of week, or date range); C_{ij}: Actual or predicted number of crimes in sector i during time j; u_j: Mean number of crimes across all the sectors for the time period j; σ_j: Standard deviation of crimes across all sectors for time period j.

3.5 Crime Heat Intensity Map of Kernel Density Estimation (KDE)

The Crime Heat Intensity Map was generated using Kernel Density Estimation (KDE), a spatial analysis method that calculates the density of crime incidents over a

defined area by applying a smoothening function around each data point. This method highlights high-risk zones (hotspots) by converting discrete crime occurrences into a continuous surface, enabling visualisation of spatial crime concentration across sectors (Martin and Ralphs 2014).

4. Results and Discussion:

4.1 Crime Incidence and Dispersion

The investigation of property crime through spatial and temporal analysis is crucial in understanding the underlying factors contributing to crime within urban areas. The study area is situated in the heart of Hyderabad, provides an ideal case study due to its diverse socio-economic landscape and dense population. As Brantingham and Brantingham (1995) highlight, urban spaces, particularly those characterised by high foot traffic or poorly lit areas, often serve as "crime generators" and "crime attractors." This concept aligns with Cohen and Felson's (1979) Routine Activity Theory, which suggests that crime is the result of a convergence between motivated offenders, suitable targets, and the lack of capable guardians.

A consolidated 3-year data of the property offences for 2016, 2017, and 2018 that occurred in the Saifabad area has been mapped and presented in Fig. 2, 3, 4 and 5.

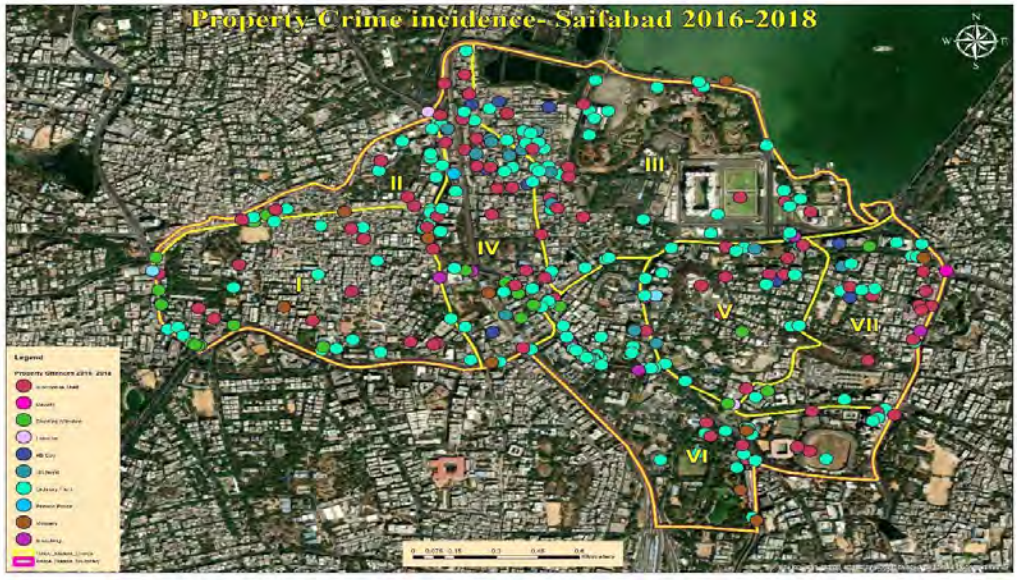


Fig. 2: Property Crime Incidence Study Area 2016-2018

In India, research into the spatial dynamics of crime has grown in importance, with studies from cities like Chennai and Delhi beginning to leverage GIS and spatial data. Gandhirajan's (2002) pioneering work in Chennai laid the groundwork for understanding

how territoriality within criminal gangs could influence crime patterns. While such research has yet to be fully integrated into law enforcement strategies in many Indian cities, there is growing recognition of the value of spatial analysis in understanding property crimes. In the study area, for instance, a combination of commercial activity, infrastructure, and socio-economic vulnerability creates conditions conducive to theft and robbery. These findings align with global research, which suggests that crime is often a product of a city's-built environment, as well as the socio-economic status of its residents.

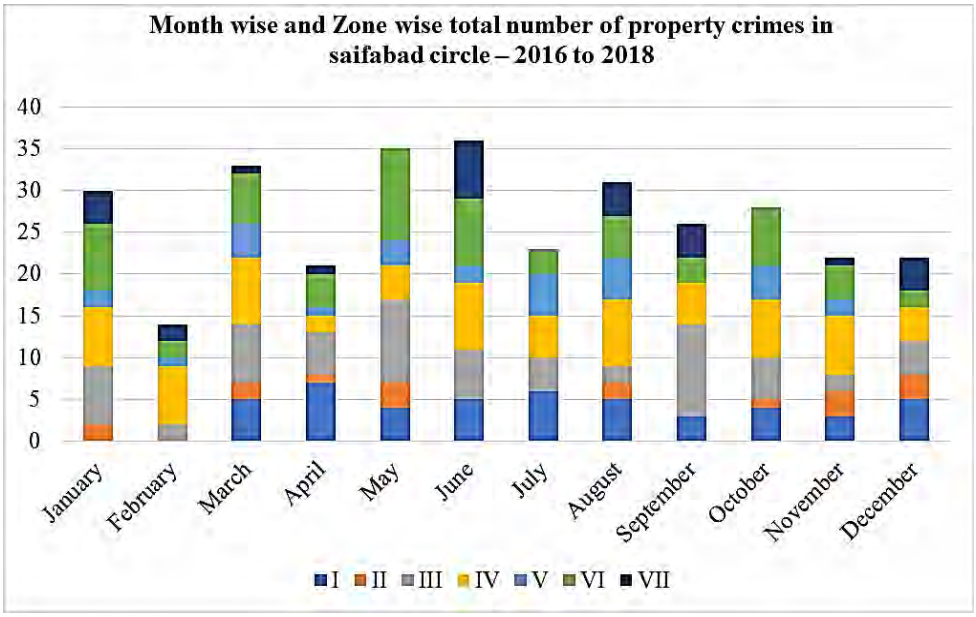


Fig. 3: Month-wise and zone-wise total number of property crimes in Study Area 2016-2018

From the Fig. 3, it can be observed that of the three years' aggregate, the highest number of offences was 36, representing the 11.21 % of the total offences that occurred in the month of June alone in all the years 2016, 2017 and 2018. The second highest occurrences were 35 instances (10.90 %) in May, followed by 33 offences (10.28 %) in March. The months of February and April recorded the lowest offences of 14 (4.36 %) and 21 (6.54 %) respectively.

In all three years (2016, 2017 and 2018), (fig.04) the highest number of offences committed was 72 (22.43%), in Sector IV alone. The second largest number were committed in Sector II - 65 instances (20.25 %) in Sector III, the third highest number of crimes were 63 (19.63%) in Sector VI, and the least number of offences were 17 (5.30 %) in Sector II, the second lowest number of offences were 28 (8.72 %) in Sector V, of the total crimes in the study area.

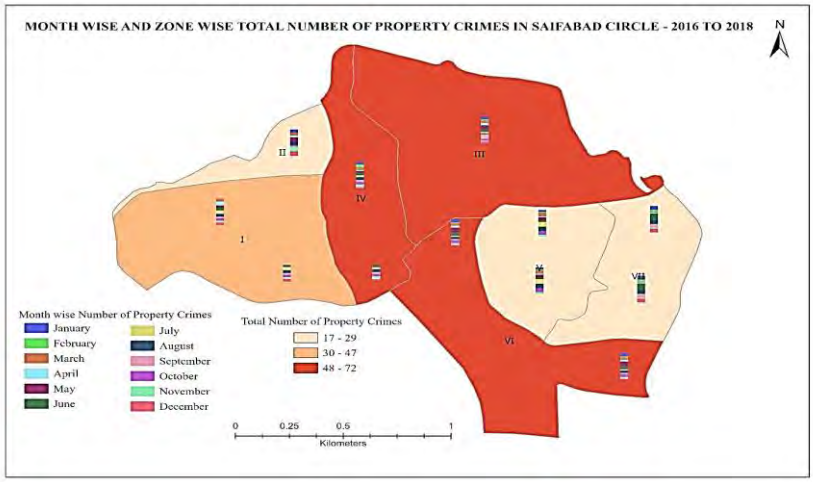


Fig. 4: Month-wise and zone-wise total number of property crimes in Study Area 2016-2018

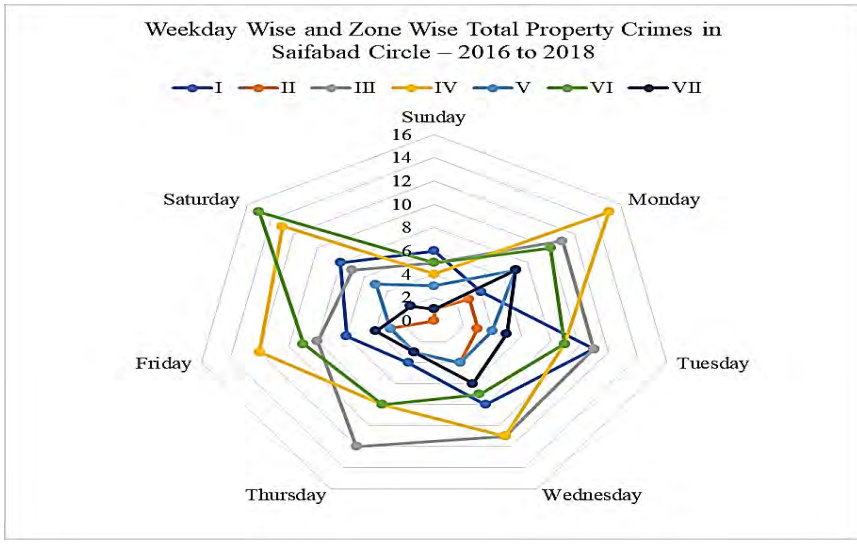


Fig. 5: Weekday Wise and Zone Wise Total Property Crimes in Study Area 2016-2018

An analysis of crime incidence in relation to weekdays was undertaken to examine both the frequency and temporal distribution of offences. The results, as illustrated in the above Fig. 5, highlight variations in crime intensity across different days of the week, offering insights into the temporal patterns and potential routine activity influences on criminal behaviour.

In the three years 2016, 2017 and 2018, the highest number of offences, 57 (17.76 %) of the total crimes, were committed on Mondays. The second highest number of offences was 52 (16.20 %) of the total crimes were committed on Tuesdays, the third

highest instances of 51 (15.89 %) of the total crimes were committed on Wednesdays, and the least number of crimes was 25 (7.79 %) of the total crimes, committed on Sundays. The second least number of crimes was 41 (12.77 %) committed on Wednesdays and Thursdays.

4.2 Hotspot Analysis

The Crime Hotspot Map was generated using Kernel Density Estimation, highlights high-risk zones (hotspots) by converting discrete crime occurrences into a continuous surface, enabling visualisation of spatial crime concentration across sectors.

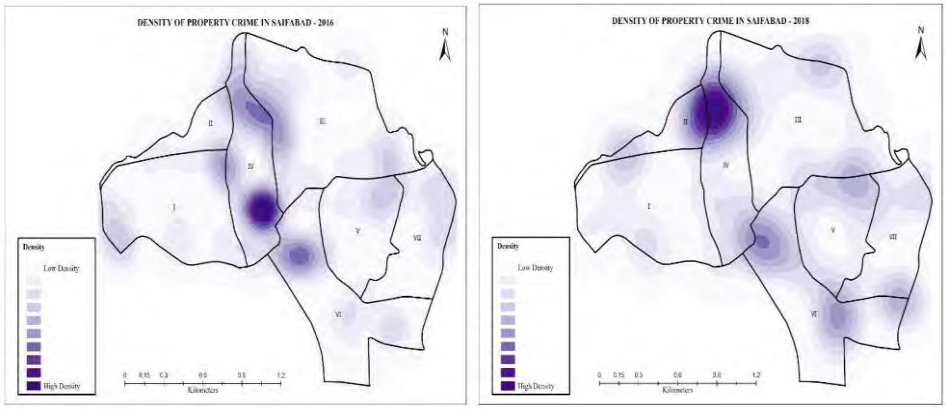


Fig. 6: Density of Property Crime in Study Area – 2016 & 2018

Between 2016 and 2018, the spatial distribution of property crimes (Fig. 6) in the Saifabad police station jurisdiction revealed consistent high-density zones in Sectors IV and VI, particularly along their southern and eastern sides. In contrast, Sectors V and VII consistently displayed low crime densities across all three years, while Sectors I and II generally remained low-density areas, except for localised increases in 2018. Overall, crime hotspots remained concentrated in specific peripheral and sectoral zones, with limited spread into central or traditionally low-density areas.

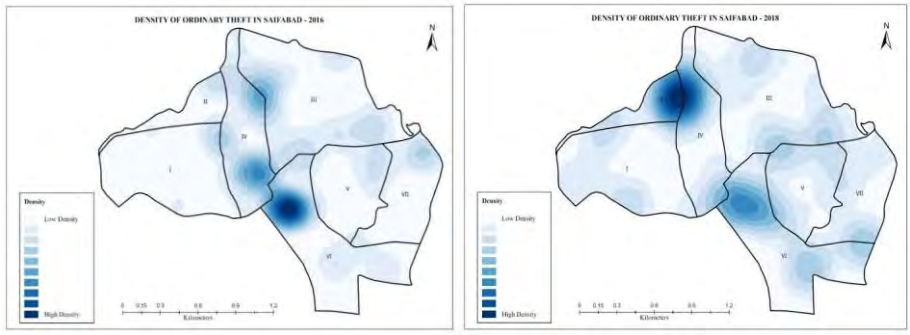


Fig. 7: Density of Ordinary Theft in Study Area – 2016 & 2018

In 2016, ordinary theft (Fig. 7) accounted for 42.67% of all property-related crimes, with higher concentrations observed in Sectors IV and VI. In 2017, the share of ordinary theft rose to 64.04% and by 2018, Sector II emerged as a new hotspot, with its northern, eastern, and southern parts showing high crime intensity. Sector IV maintained its high-density status, particularly along the west–east stretch. Despite fluctuations in total crime share, the spatial concentration of ordinary theft remained centred in key sectors like IV and VI, with new emerging pockets in Sector II.

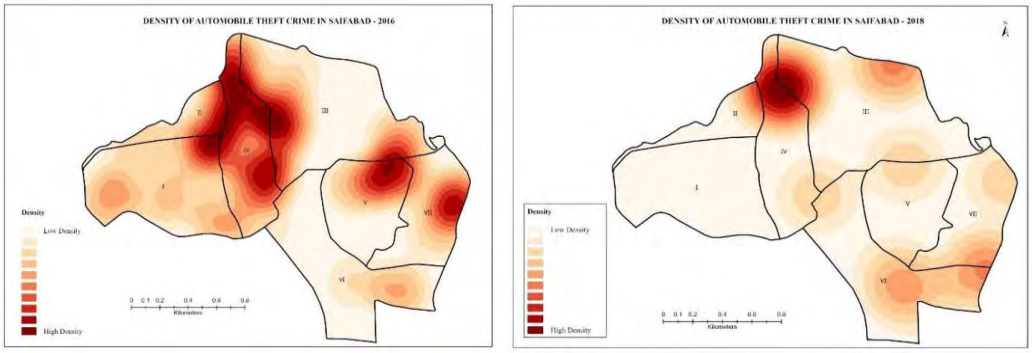


Fig. 8: Density of Automobile Theft Crime in Study Area – 2016 & 2018

In 2016, automobile theft (Fig.08) accounted for a significant 34% of total property crimes, with high-density areas concentrated in Sectors II, III, IV, V, and VII. This crime pattern indicates widespread vulnerability across multiple sectors, particularly those with high traffic or vehicle presence. By 2017 and 2018, the proportion of automobile theft declined to 23.6% and 15.85%, respectively, though Sectors II, III, and IV remained hotspots. Overall, the trend shows a gradual decline in automobile theft, but with clear spatial recurrence in selected sectors requiring targeted interventions.

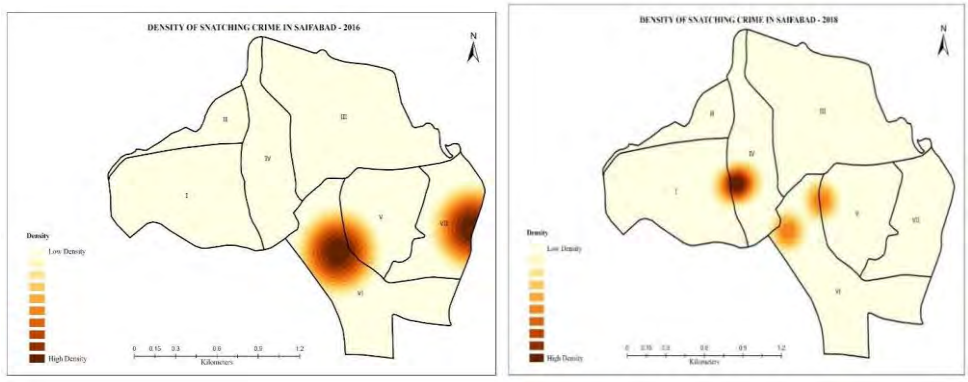


Fig. 9: Density of Snatching Crime in Study Area – 2016 & 2018

In 2016, snatching crimes (Fig. 9), such as theft of chains, mobiles, and purses, accounted for 1.33% of total property offences in the Study Area. These incidents were

primarily concentrated in Sectors VI and VII. By 2018, the proportion of snatching crimes increased significantly to 4.88%. The spatial pattern shifted to Sectors I and IV, emerged as the new high-crime zones. The shift indicates a redistribution of snatching crime across the jurisdiction, likely influenced by changing public movement patterns and surveillance measures.

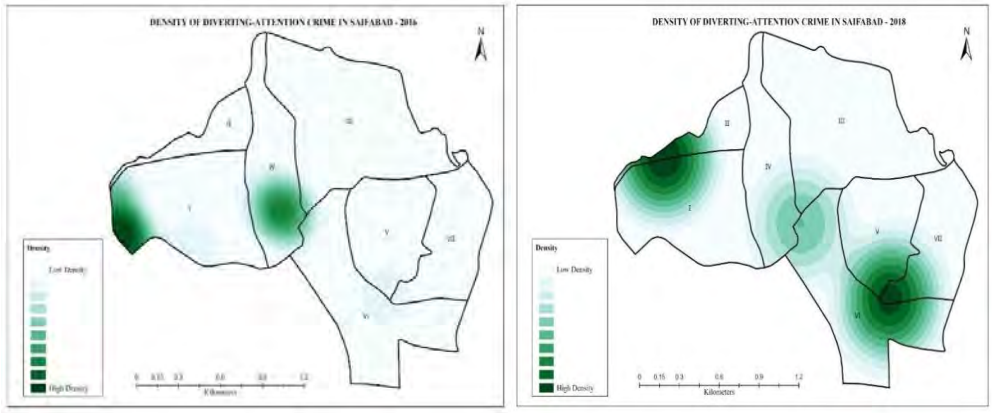


Fig. 10: Density of Diverting-Attention Crime in Study Area – 2016 & 2018

In 2016, attention-diverting crimes (Fig. 10), typically involving theft through distraction, accounted for 10% of total property offences. High-density areas were concentrated primarily in Sectors I and IV. By 2017 and 2018, the proportion of these crimes declined to 4.49%, though the spatial pattern became more dispersed. Sector I remained a recurring hotspot, particularly in its southwest and northwest areas. In 2018, attention-diverting crimes shifted to Sectors V, VI, and VII.

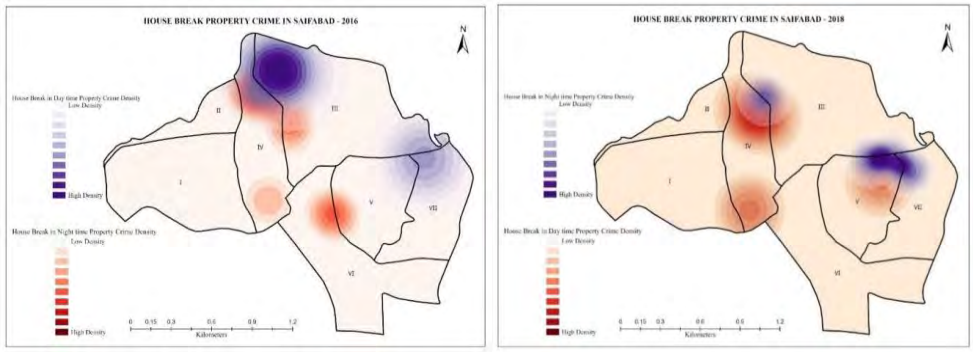


Fig. 11: House Break Property Crime in Study Area – 2016 & 2018

Between 2016 and 2018, the distribution of house break-in offences became more dispersed across the study area (Fig. 11), despite fluctuations in their overall share. In 2016, such crimes accounted for 8% of total offences, concentrated mainly in Sectors III, IV, VI, and VII. Night-time incidents prevailed in the northern parts, whereas day-time

crimes occurred more often in the southern sectors. Sector IV exhibited dense clusters along its eastern and western edges, while Sector I consistently recorded low activity. In 2018, house break-ins rose sharply to 9.76%, with hotspots shifting to Sectors III, IV, V, and VII. Activity was concentrated in the eastern and northern parts of Sector IV and the western and southeastern areas of Sector III

Day-time and night-time offences were equally distributed at 4.88% each, with both displaying similar spatial patterns. Sectors I, II, and VI continued to show low crime densities, reinforcing their position as relatively safer zones over the three years. Overall, the spatial analysis suggests a recurring concentration of house break crimes in specific pockets, particularly in Sectors III and IV.

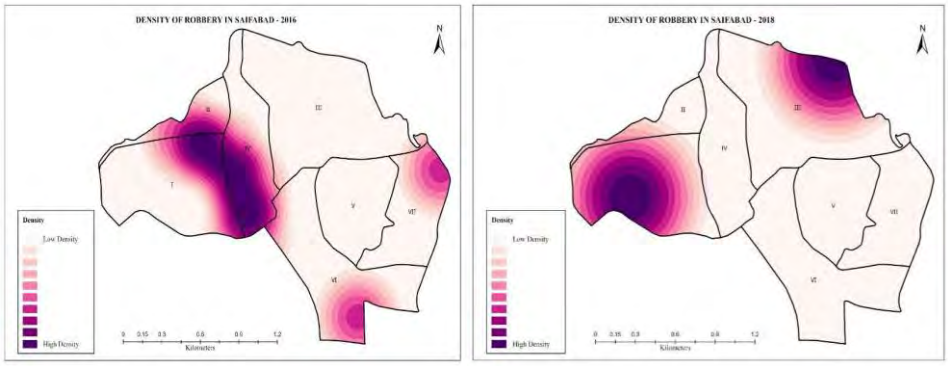


Fig. 12: Density of Robbery in Study Area – 2016 & 2018

In 2016, robbery (Fig. 12) constituted 4% of total property offences in the study area, with higher crime densities concentrated in Sectors I, II, and IV. By 2017 and 2018, the incidence of robbery declined slightly to 2.25% and 2.44%, respectively. In 2017, Sector VI was the only area with high-density robbery activity, particularly in its northeast side, while all other sectors showed low levels. However, in 2018, robbery hotspots shifted to Sectors I and III, with Sector I's southern part and Sector III's north-eastern side recording the highest densities. Despite the overall drop in robbery cases, localised surges in different sectors point to dynamic spatial variations over time.

4.3 Crime Frequency Variations through Standard Deviation:

In this study, Standard deviation was applied to evaluate the spatial variation in crime frequency across different sectors in the study area from 2016 to 2018, across various crime categories. This method enables the identification of sectors that significantly deviate from the average, thereby revealing spatial concentrations and fluctuations in crime incidence.

Fig. 13 represents the distribution of sectors across these categories, highlighting both the frequency and percentage of crime occurrences over the study period. The graph compares the number of high-frequency and low-frequency sectors for each crime type.

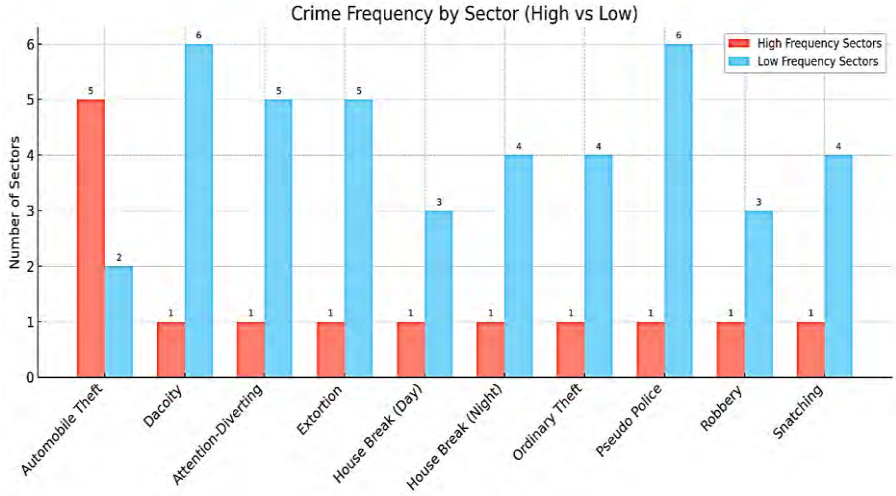


Fig. 13: Crime Frequency by Sector (High vs Low)

The spatial analysis of crime frequency revealed significant variation across sectors in the study area between 2016 and 2018. Automobile theft emerged as the most spatially dispersed crime, with five sectors exceeding the high-frequency threshold (Mean + 1σ), highlighting its widespread nature and suggesting the need for broader urban surveillance measures. In contrast, crimes such as Dacoity, Extortion, Attention-Diverting Thefts, and House Break-ins (Day and Night) showed highly localised patterns, with only one sector each registering high frequency. This points to the existence of discrete high-risk pockets requiring targeted interventions rather than city-wide policing strategies. Additionally, a notable number of sectors recorded frequencies below the mean for less prevalent crimes such as Dacoity and Pseudo Police offences, indicating rare but spatially concentrated criminal activities.

While Ordinary Theft and Robbery are relatively more common, their spatial distribution was uneven, with only one sector falling under the high-concentration category and four under the low-frequency bracket. These findings underscore the value of using standard deviation-based classifications and spatial statistics to detect both persistent and emerging crime hotspots.

4.4 Predictive Analysis

Predictive policing technologies have gained traction worldwide, with agencies in cities like Los Angeles and London using statistical models to forecast crime patterns and allocate resources effectively. While such models hold promise, scholars like Lum and Isaac (2016) caution that these systems may inadvertently perpetuate bias, particularly in areas with historically disproportionate policing. Similarly, Williams et al. (2017) explore the potential of big data and social media in crime detection. These new tools provide real-time insights but require careful consideration to avoid reinforcing existing socio-economic disparities.

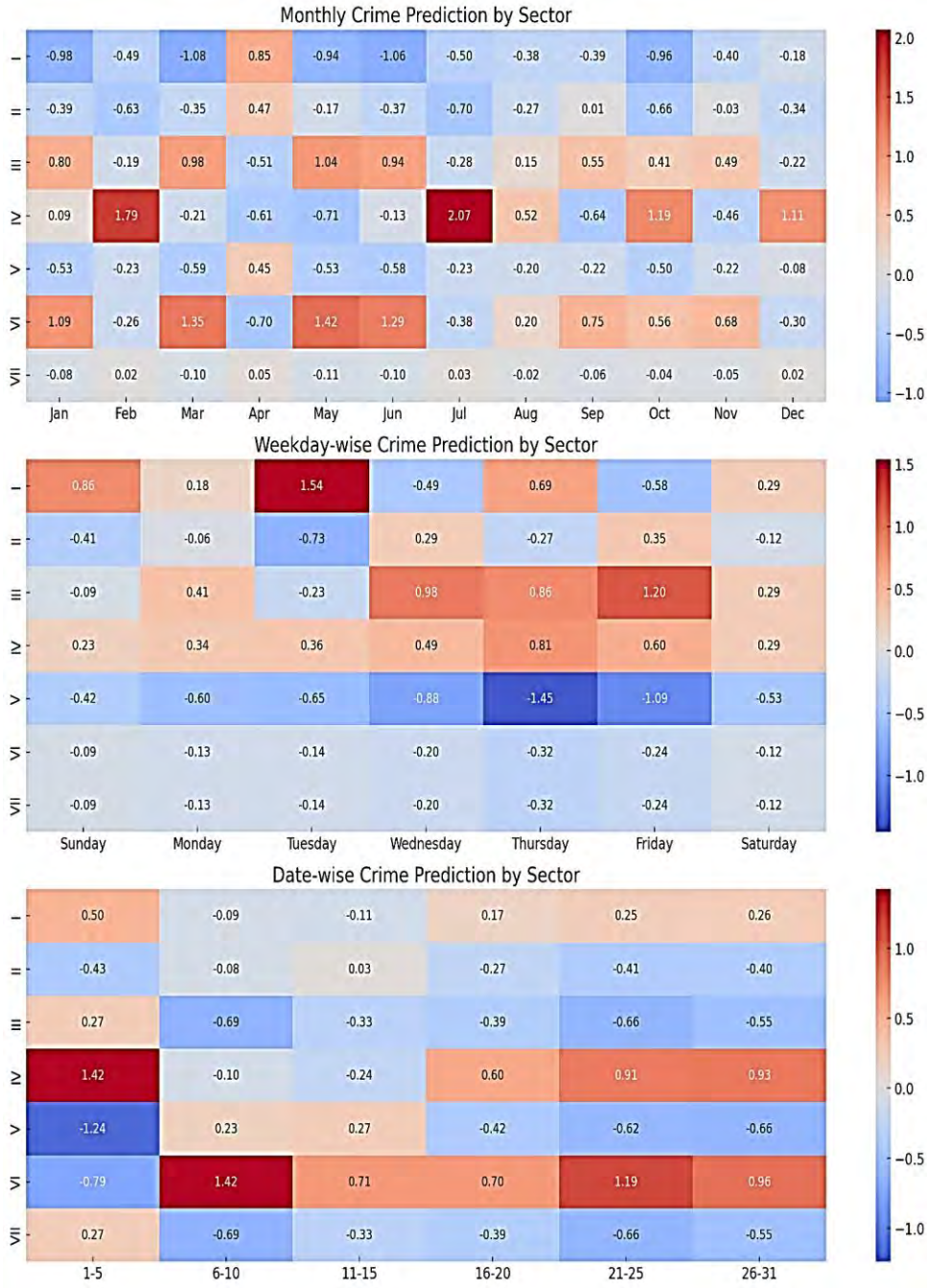


Fig.14: Monthly, Weekday-wise and Date-wise Crime Prediction by Sector

Based on the predictive heatmaps for monthly, weekday-wise, and date-wise crime predictions across the seven sectors of the Study Area, notable temporal and spatial patterns emerged (Fig. 14). Sector IV consistently demonstrates elevated predicted crime

intensity, particularly in March, July, and October, as well as on Tuesdays and during the first and last weeks of each month. This indicates a potential correlation between public activity cycles and crime incidence, likely tied to administrative movements and crowd flows within Sector IV's transit and institutional zones. Sector VI also shows high monthly crime projections in May, June, and September, with peaks during mid-to-late month periods (21st–31st), possibly reflecting patterns of financial activity, footfall around institutional complexes, or salary-related street crimes.

Conversely, Sectors II, III, and VII show consistently lower predictive scores across most timeframes, suggesting relatively subdued crime risks. Notably, Sector III sees slight increases during summer months (April–July) and on Wednesdays and Thursdays, aligning with its mixed-use entertainment profile, which might see more crowd interaction midweek. Meanwhile, Sector I, the dense urban core, reveals intermittent but notable spikes in April and October and during weekends, pointing to leisure-linked vulnerabilities. These insights underscore the importance of targeted policing strategies, with higher alertness during temporal hotspots (late months, mid-week) and sector-specific interventions that factor in both land use and socio-economic dynamics.

4.5 Crime Intensity Heat Map

To analyse the spatial distribution of crimes, a Crime Heat Intensity Map was generated using Kernel Density Estimation (KDE). Each crime incident was treated as a point feature, and KDE was applied to estimate the density of crime events across space.

The crime intensity heat map (Fig.15) provides a visual representation of sector-wise distribution and severity of different property and theft-related crimes. By categorising crime occurrences into three statistical thresholds, Above Average (1σ), High Concentration (2σ), and Very High Concentration (3σ), the map reveals distinct spatial patterns of crime clustering within urban sectors.

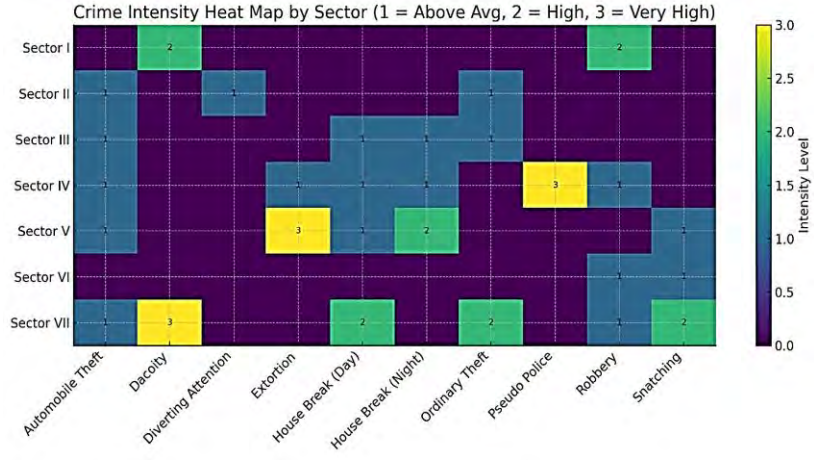


Fig.15: Crime Intensity Heat Map by sector

The areas with high foot traffic, such as markets, transport corridors, and commercial-residential zones like Sectors I, IV, V, and VII, recorded more thefts, snatchings, and property-related crimes. On the other hand, sectors with stable land use, such as Sector VI with more institutional presence, experienced fewer but more targeted crimes like nighttime house break-ins. The overall risk parameters for the study area in the context of time stamp and locational influence are projected below in Table 2, while highlighting sectoral differences.

Table 2: Property Crime in Study Area for the period 2016 – 2018 and Risk Patterns

Dimension	High-Risk Sectors	Low-Risk Sectors	Notable Temporal Peaks
Monthly Trends	Sector IV (Feb, Jul, Oct, Nov) Sector II, VI, III, V	Sectors I, II, V (most months)	Festivals, Salary Cycles
Weekday Patterns	Sector IV (All days) Sector I (Wed–Sat)	Sectors V, VI, (majority of blocks)	Start & End of Month
Date-wise Trends	Sectors IV & VI (1–5 & 21–31)	Sectors II, III, V, VII (majority blocks)	Relatively Stable

Sector IV is recorded consistently high-risk across time scales, needs sustained attention. Sector VI is recorded with crime peaks linked to economic cycles such as festivals, salary cycles of employees, indicating the relevance of the flow of cash/money and density of population. Sectors I and III is recorded high-risk during mid-week (Wed–Sat), requires additional enforcement. These sectors are identified as high-risk sectors due to increased incidence of crime, denoting the necessity of deploying resources during the mid-week in addition to temporal peaks and seasons. Sectors V, VI, and VII are generally stable but should be monitored for emerging shifts. These sectors are classified as low-risk sectors with possible shift due to dynamism in the spatial trends over time.

5. Spatial Interplay between Sectors and Crime Incidence

The crime intensity heat map, when examined in conjunction with the socio-economic and land-use characteristics of the study area's sectors, reveals significant spatial disparities in crime occurrence. These disparities underscore the role of urban morphology, socio-economic stratification, and functional land use in shaping crime patterns. The following discussion presents a sector-wise interpretation of crime intensity in relation to local demographic and socio-spatial dynamics.

Sector I, categorised as a Central Business District (CBD) with dense residential and administrative functions, demonstrates high intensity in Robbery and Snatching. The co-existence of lower- and middle-income populations, slum settlements such as Chintal Basti, and significant footfall due to government offices and religious institutions, creates a

conducive environment for crimes of opportunity. High pedestrian movement and limited surveillance in crowded and informal spaces may facilitate such criminal activities.

Sector II, characterised as a transitional residential zone with growing commercial activity, records moderate levels of Extortion and Ordinary Theft. The ongoing gentrification and demographic transformation may contribute to socio-spatial tensions and limited neighbourhood cohesion. The coexistence of students, working-class populations, and informal settlers in this triangularly configured zone presents challenges in consistent monitoring and law enforcement coverage.

Sector III, representing a mixed-use entertainment and residential district, exhibits moderate crime intensity in House Break (Night) and Ordinary Theft. The sector's socio-economic diversity and functional heterogeneity, ranging from institutional areas to lower-income housing, may lead to uneven levels of vulnerability and security. Areas with high visitor turnover, such as NTR Gardens and IMAX, likely contribute to transient crimes that are difficult to predict and control.

Sector IV, defined as a service-oriented transit corridor, shows high intensity in Pseudo Police offences and Robbery. The presence of major transport nodes (e.g., Lakdikapool railway station) and hotels, along with a predominantly working-class and rental demographic, increases exposure to crimes that target transient populations. The fluidity of movement and anonymity in such environments are often exploited by offenders.

Sector V, a high-activity mixed-use zone with religious and cultural significance, registers very high levels of Diverting Attention crimes and moderate intensities of House Break (Night) and Ordinary Theft. The convergence of large public gatherings at sites such as Birla Temple and Birla Science Museum, coupled with residential informality and administrative offices, generates conditions for distraction-based thefts and break-ins.

Sector VI, comprising low-density institutional and recreational zones, indicates elevated levels of House Break (Night) and moderate intensity in Snatching and Robbery. Despite the presence of high-security institutions (e.g., Assembly, DGP Office, RBI), the spatial dispersion and low residential density, particularly in the southern areas may limit natural surveillance, thereby increasing susceptibility to property crimes.

Sector VII, situated on the peripheral fringe with a blend of government offices and slum clusters, reveals very high intensities in Automobile Theft and Diverting Attention, with moderate levels of Snatching and House Break (Night). The juxtaposition of informal settlements and commercial strips in this sector appears to create crime-prone interfaces. The fragmented socio-economic fabric, combined with open spaces and lower levels of formal policing, may further exacerbate vulnerability to theft-related offences.

The variations in time of occurrence, place of occurrence, day of occurrence and even month in the incidence of different criminal offences are not coincidental. There is a definite relation with the kind and width of roads, literacy-education-occupation-income of

perpetrators, location of the PS and CCTV cameras, areas and time of police patrolling, etc. The superimposition of these factors on incidence can yield significant results for policy and better administration.

6. Conclusion:

The study identified hotspots and examines how crime intensity varies from one sector to another. Over the three years, notable improvements were observed in reducing certain crimes, mainly attributed to data-driven policing, better surveillance systems, improved patrol coordination, and community involvement. The analysis suggests that understanding crime through the lens of spatial patterns combined with urban planning and social awareness can help design better prevention strategies. Rather than treating crimes as isolated events, the spatial approach sees them as also the outcomes of everyday activities and urban design. A well-informed and sector-specific strategy, based on real patterns, can help cities become safer and more inclusive. As Indian cities continue to grow, these methods can offer practical tools for future urban crime prevention.

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The Indian Geographical Journal
Volume 100 (2) Dec - 2025, pp 160-176
ISSN 0019-4824

ASSESSMENT OF TERRAIN STABILITY ZONES IN THE BIRAHI GANGA RIVER BASIN, GARHWAL HIMALAYA, UTTARAKHAND, USING AHP AND GIS

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Abstract

The Himalayan region is globally recognised for its complex geology, highly dissected terrain, steep slopes, and intense monsoonal rainfall, making it one of the most landslide-prone and geomorphologically dynamic regions in the world. Landslides, slope failures, and flash floods are frequent in this region and severely affect human settlements, transportation infrastructure and natural ecosystems. Therefore, assessing terrain stability is crucial for sustainable habitation and development planning. The present study evaluates terrain stability zones in the Birahi Ganga River Basin using the Analytical Hierarchy Process (AHP) integrated with Geographic Information System (GIS) techniques. Spatial variability in terrain stability is evident across the basin. Eight key parameters—landslide zones, slope, tectonic units, normalised difference snow index (NDSI), dissection index, relative relief, absolute relief and normalised difference vegetation index (NDVI)—were analysed to generate a composite terrain stability map. Based on weighted overlay analysis, the basin was classified into five stability zones: stable, moderately stable, moderately vulnerable, vulnerable and highly vulnerable. The stable terrain covers 11.8% of the basin and is mainly concentrated in the north-western, central, and south-central parts, whereas highly vulnerable terrain accounts for 12% and is predominantly found in the eastern, north-eastern and south-western sections. Moderately stable and moderately vulnerable zones occupy 22% and 27.8% of the basin, respectively. Overall, the results indicate a gradual decrease in terrain vulnerability from the eastern to the western part of the basin. The study identifies suitable stable zones for human habitation and settlement expansion, demonstrating the effectiveness of the AHP–GIS approach for terrain stability assessment in mountainous regions.

Keywords: Birahi Ganga, Terrain Stability zones, Analytical Hierarchy Process (AHP), Geographical Information System (GIS).

1. Introduction

Mountainous regions are characterised by steep slopes, high relief, complex geological structures, and dynamic geomorphic processes which influence terrain instability and various types of geomorphic hazards such as landslides, slope failures, and flash

floods. The Himalayan regions are geologically young, tectonically active, and subjected to intense monsoonal rainfall experience frequent mass-wasting phenomena that significantly affect human settlements and socioeconomic infrastructure. According to the Geological Survey of India (GSI), nearly 12.6% of the total land area in the country is prone to landslides and Uttarakhand is one of the most affected states. The accelerated population growth demanded the use of areas which were not previously used for agricultural, settlement, urban expansion and other purposes, thereby exposing these areas to landslide problems after rainy seasons (Woldearegay, 2013). Both the natural factors such as lithological variation, tectonic activity, slope morphology, and hydrological conditions, along with anthropogenic pressures like deforestation, road construction, and unplanned settlement expansion trigger the terrain instability in the region. Therefore, assessing terrain stability is significant for sustainable land-use planning, disaster mitigation and environmental management in the study area. Terrain stability zones indicate the areas of slope stability with respect to unstable, potentially unstable and stable terrain within a particular landscape outline the zones of slope failure (Forest Practices Code of British Columbia 1999). Different types of terrain units were used (Guzzetti et al., 1999) and each terrain unit is assigned a series of attributes relevant to stability, including elevation, slope relative relief, dissection index, etc.

Though terrain stability assessment plays a significant role in regional development, there remains a significant research gap in evaluating terrain stability zones at the sub-basin level in the Garhwal Himalaya. In the Himalayan region, a number of research works have focused on landslide susceptibility mapping and hazard zonation; among them, a very few have used integrated multiple geomorphic parameters to assess terrain stability zones, particularly using a multi-criteria decision-making approach such as the Analytical Hierarchy Process (AHP) with the combination of Geographical Information System (Saha et al., 2002; Saha et al., 2005; Chauhan et al., 2010; Kundu et al. 2013; Dinesh Pathak, 2016; Khanduri, S., 2018; Nandy, S., 2021)

At present, different types of interdisciplinary decision-making approaches are used to determine the terrain stability zone. Analytical Hierarchy Process (AHP) is one of the prominent GIS based spatial decision support system, first introduced by Saaty in 1980. Nandy (2021) stated that “AHP is an approach using different types of multi-criterion, which focuses on the relative priorities assigned to each criterion to achieve a defined objective.” AHP is widely used to identify environmentally suitable zones, tourism potential areas, landslide susceptibility zones, agricultural suitability areas, land suitability areas, etc.

The present study analyses the geological, geomorphological and environmental parameters which influence terrain stability in the Birahi Ganga river basin. The primary objective of this study is to prepare a terrain stability map using selected parameters and the AHP–GIS techniques, to delineate and classify the basin into different stability zones and to identify potential areas suitable for sustainable human settlement and development planning.

2. Study area:

The present work is carried out in the Birahi Ganga river basin, located in the Joshimath and Dasholi blocks of Chamoli district of Garhwal division of Uttarakhand. The study area lies between 30º 19´10˝ N to 30º 26´9˝ N and 79º 23´18˝ E to 79º 42´24˝ E. The Birahi Ganga originates from the Nandaghungti glacier of the Nandadevi range at an altitude of about 5600 m and flows east to west direction and meets with the river Alaknanda as a left bank tributary at Jaisal village (30º 24´58˝ N& 79º 23´12˝ E). (Fig.1) The total geographical area of the basin is about 277.27 km² (Patra et al., 2018). Geologically, the study area is characterised by the Pandukeshwar Formation, Munsiyari Formation, Berinag Formation, Tejam Formation and Baijnath Crystalline. (Geological Map of Himalaya, scale 1:1000000, Western sector, Published by Geological Survey of India). In the study area, the presence of Vaikrita Thrust, Munsiyari Thrust, Baijnath Klippe, some minor Thrust and Anticlinal Axis signifies the instability of the area (Valdiya, 1976 & Sharma et al. 2017).

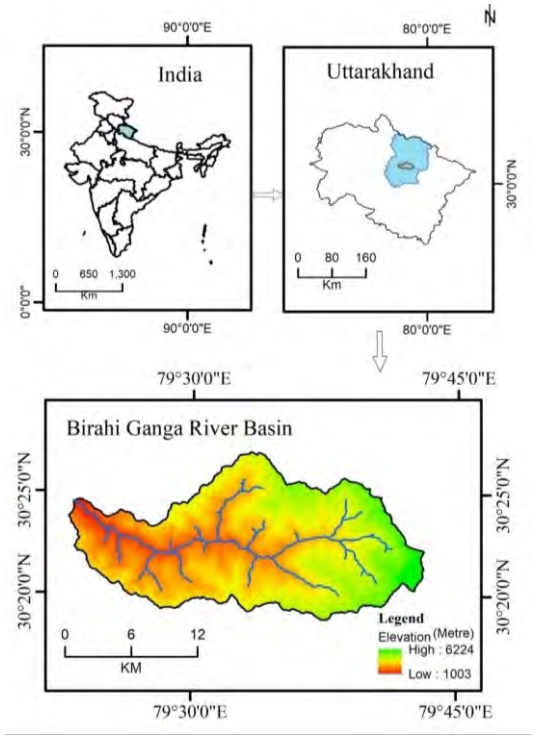


Figure 1: Location map of the study area, Birahi Ganga river basin

The study area is characterised by highly dissected hills and valleys, Altiplanation terraces, valley glaciers, Aretes, Hummocks, Piedmont Alluvial Plain, Piedmont Slope, Ridges, Tellus or Scree, etc. (Survey of India Toposheet 1:50000 and Geomorphological map, Geological Survey of India, Government of India, Kolkata, India). The mean monthly

temperature of the study area varies from 9.39º C in January to 24.53º C in May and the mean monthly rainfall varies from 0.5 mm in October to 454.60 mm in August. (www.imd.gov.in, accessed on 14/04/2019) The Birahi Ganga river basin is fed by Pui Gadhera, Kaliyaghat Gadhera, Shyam Gad, Rogila Gad, Dhadali Gad (right bank tributaries), and Gudiyar Gadhera, Bhori Gadhera, Ghat Gad, Begar Nala (left bank tributaries). The general elevation of the Birahi Ganga river basin varies from 1,000 m (at Jaisal village) to 5,600 m (at Nandaghungti) (Patra et al., 2018).

3. Database:

The main objective of this work is to identify the terrain stability zones in the Birahi Ganga river basin. Firstly, primary data were collected through GPS field surveys, along with interviews and questionnaires administered to experts in relevant disciplines to identify and prioritise the factors essential for demarcating terrain stability zones in the Birahi Ganga river basin. The secondary datasets, like satellite imagery, GIS datasets, articles, and previous records, were collected and are listed in the Table1.

Table 1: Characteristics of the used datasets

Data	Scale/resolution	Date of acquisition	Source	Remarks
Topographical maps	1:50000	-	Survey of India (SOI)	Two Sheets-53N/7 & 53N/11 of the year 1967 7 1985.
ALOS PALSAR DEM	Spatial resolution: 12.5 m	18/11/2018	www.asf.alaska.edu	Radiometrically Terrain Corrected (RTC) data.
Landsat 8-OLI	Spatial resolution: 30 m	17/12/2021	United States Geological Survey (USGS)	-
Landslide data	1: 20,00,000	15/03/2022	National Disaster Management Authority (NDMA), Uttarakhand	
Geology & Tectonic	1:333000	-	Works of Valdiya (1976&1979) & Sharma et al (2017).	-

The selected parameters and their thematic layers were prepared with the help of Microsoft Excel v. 2016 and ArcGIS 10.5 software. Slope, relative relief, absolute relief, and dissection index map have been prepared from ALOS PALSAR DEM by using spatial analysis tools in the ArcGIS environment. The landslide-prone zonation map of the study area has been prepared on the basis of the data provided by the National Disaster Management Authority (NDMA), Uttarakhand. Normalised Difference Vegetation Index (NDVI) maps were prepared from Landsat 8 OLI data with the help of the raster calculator in a GIS environment. Normalised Difference Snow Index (NDSI) was calculated from the Landsat-8 OLI data in ArcGIS 10.5 software.

4. Methodology:

To identify the stable terrain, the first step is the selection of suitable parameters. In this study, eight different parameters such as, landslide prone area, slope, tectonic unit, snow affected area, dissection index, relative relief, absolute relief and normalised difference vegetation index (NDVI) were used. Adequacy of parameters and easy

generation of parameters from related sources for ascertaining the variety of the terrain stable zones are two main causes for selecting these parameters (Nandy,2021).

The final terrain stability map has been prepared through the AHP method in ArcGIS 10.5 software by calculation of the weight of each criterion and sub-criterion (Figure 2).

4.1. Landslide-prone areas

Landslide-prone zones play an important role in marking unstable and vulnerable areas. The landslide-prone zonation map of the study area has been prepared on the basis of the data provided by the National Disaster Management Authority (NDMA), Uttarakhand. At first, the main map was converted into WGS-84 datum and UTM projection, then digitised the map in ArcGIS 10.5 software to trace out three landslide prone zones-moderate to low, high and severe to very high with in the Birahi Ganga valley (Figure 3) and ranked them according to the terrain stability.

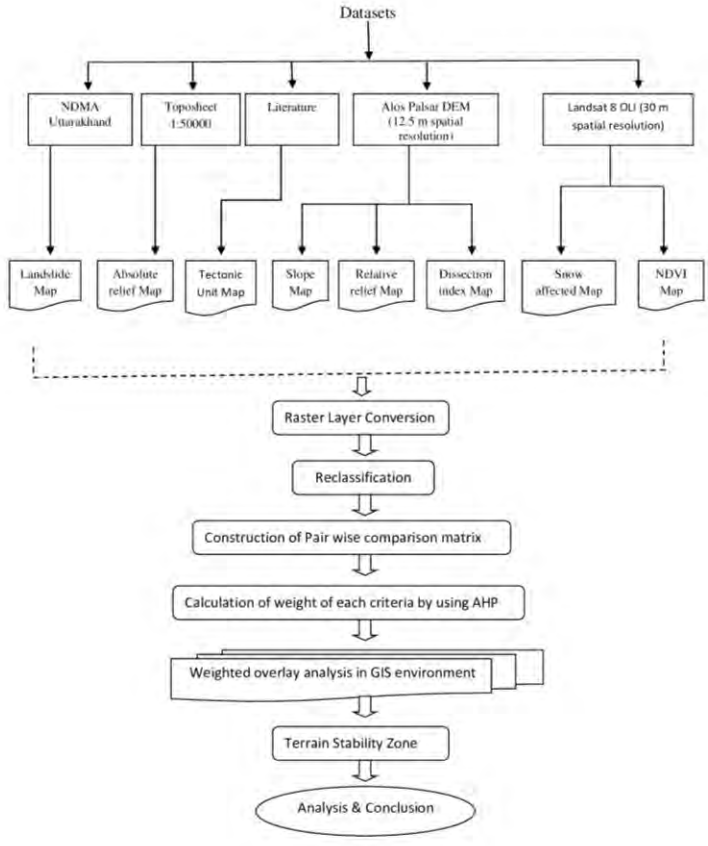


Figure 2: Flow chart of the terrain stability mapping for the study area

4.2. Slope

To determine the stability of a region, slope is a very important landform element (Saha et al., 2005) because the angle of slope show tendency of the slope materials to slide under the force of gravity, nullifying the shearing strength of the component materials in situ. There is a positive relation between slope and erosion (Bhattacharya, 2018). The larger number of landslides occurs in the case of the steeper slope angle of the slope (Youssef et al.,2021).“The stability of the slope against failure can be defined by the relationship between shear forces and the resistance to shear (safety factor), where the driving force of mass movement increases with increasing slope angle” (Guillard and Zezere, 2012). It is an important parameter to determine the terrain stability zones in the study area. It is the first procurement of elevation, with each pixel denoting the angle of slope at a particular location (Saha et al. 2005). Slope gradient directly controls the run-off and indirectly the presence of the soil moisture, which are influenced to the landslide occurrence. In the Himalayan terrain, due to the lack of vegetation or scantily vegetated of, the south-facing slopes are generally more susceptible to slope failure as compared to north-facing slopes (Sinha et al,1975). The slope map of the study area was prepared from ALOS PALSAR DEM (12.5) by using the spatial analysis tool in ArcGIS 10.5 software. The slope angle of the study area ranged from 0º to 82º, which were categorised into five classes at an equal interval of 10º (Fig. 3).

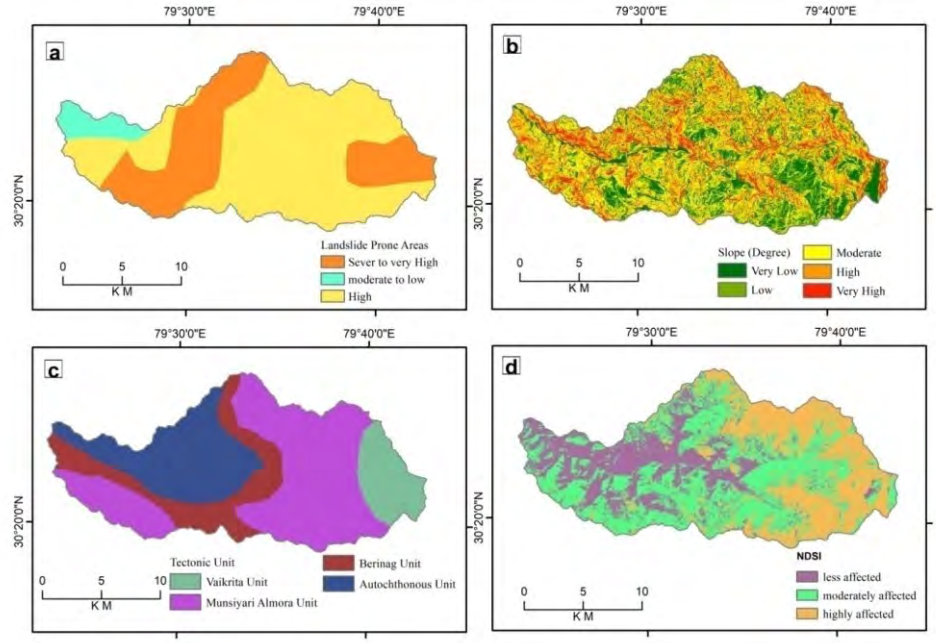


Figure 3: Reclassified parameters: a) Landslide-prone areas, b) Slope, c) Tectonic Unit and d) Snow-affected area

4.3. Tectonic Unit

Terrain stability greatly depends on the bedrock geology of an area, on which geomorphic processes design the landscape (Bhattacharya, 2018). The structural lines and geological formations affect the occurrence of landslides as well as the terrain stability (Bhattacharya 2018). In the study area, four tectonic units have been identified, these are Autochthonous unit, Berinag unit, Munsiyari-Almora unit and Vaikrita unit. Among them Autochthonous unit is comparatively stable, occupying about 26.71% of the total area; on the other hand Vaikrita unit is comparatively highly vulnerable due to the presence of the Vaikrita thrust, and occupied 11.43% of the total area. The tectonic map of the Birahi Ganga river basin had been prepared on the basis of the work of Valdiya (1976). At first, the main map is georeferenced and converted into the WGS 84 datum and UTM projection, and then four tectonic units were digitised (Figure 3).

4.4. Snow-affected area

Snow covers or glaciers, increase instability and vulnerability through physical weathering, erosion, and avalanches. To identify the snow-covered area in the Birahi Ganga river basin, the Normalised Difference Snow Index (NDSI) was calculated from the Landsat-8 OLI data in ArcGIS 10.5 software. Hall et al. (2011) defined Normalised-Difference Snow Index (NDSI) as the normalized difference of two bands (one in the visible and one in the near-infrared or short-wave infrared) and primarily used to map snow cover. The major advantages of NDSI are its elasticity to atmospheric effects and influences caused by viewing geometry (Sibandjeet al., 2014). The NDSI formula is Green-SWIR/Green+SWIR

A greater value (>0.00) of NDSI indicates the presence of snow, whereas a low NDSI value (≤0.0) indicates a snow-free land surface (Riggs et al.,2016). On the basis of the NDSI value, the study area was divided into three zones: less affected, moderately affected, and highly affected. (Fig. 3)

4.5. Dissection Index (DI)

DI plays a very important role in knowing the terrain configuration resulting from the prevalent processes such as the mass movement and fluvial dynamics and also the structural instability exhibited in the form of faulting, tilting, thrusting, and folding (Bhattacharya, 2018). Dissection index is determined for understanding the magnitude of dissection of terrain, morphometry, and physiographic attributes (Singh, 2000). The dissection index helps to identify the stable and unstable terrain. The high value of the Dissection index indicates high relief energy and a high propensity for slope failure when associated with geologically weak and deformed rock strata, and hence the dissection index is closely associated with the stability of the terrain of a region. The dissection index map of the study area was prepared from ALOS PALSAR DEM (of 12.5 m spatial resolution) in ArcGIS 10.5 software by using cartographic and spatial analysis tools. The

value of the dissection index in the study area ranged from 0.0345 to 0.489 and which has been further classified into five classes at 0.1 interval. (Fig. 4)

4.6. Relative relief

The difference between the highest altitude and the lowest altitude in a unit area is called relative relief. There is a close relationship between relative relief and slope and it is more revealing about the localised variation of the magnitude of landform and thus very much beneficial in understanding the potential energy of the landform associated with erosional drainage systems and instability of the slopes (Bhattacharya, 2018). In general, high relative relief indicates steep slope, high erosion probability and landslide potentiality, on the other hand, low relative relief indicates gentle slope and comparatively stable zone (Bhattacharya, 2018). Due to this, relative relief shall be an effective parameter for determing terrain stability zones. The relative relief map of the study area has been prepared from ALOS PALSAR DEM in ArcGIS 10.5 software by using cartographic and spatial analysis tools. The value of relative relief in the study area ranges from 194.61 m to 1231.94 m, which has been classified in five zones at a 200 m interval. (Fig. 4)

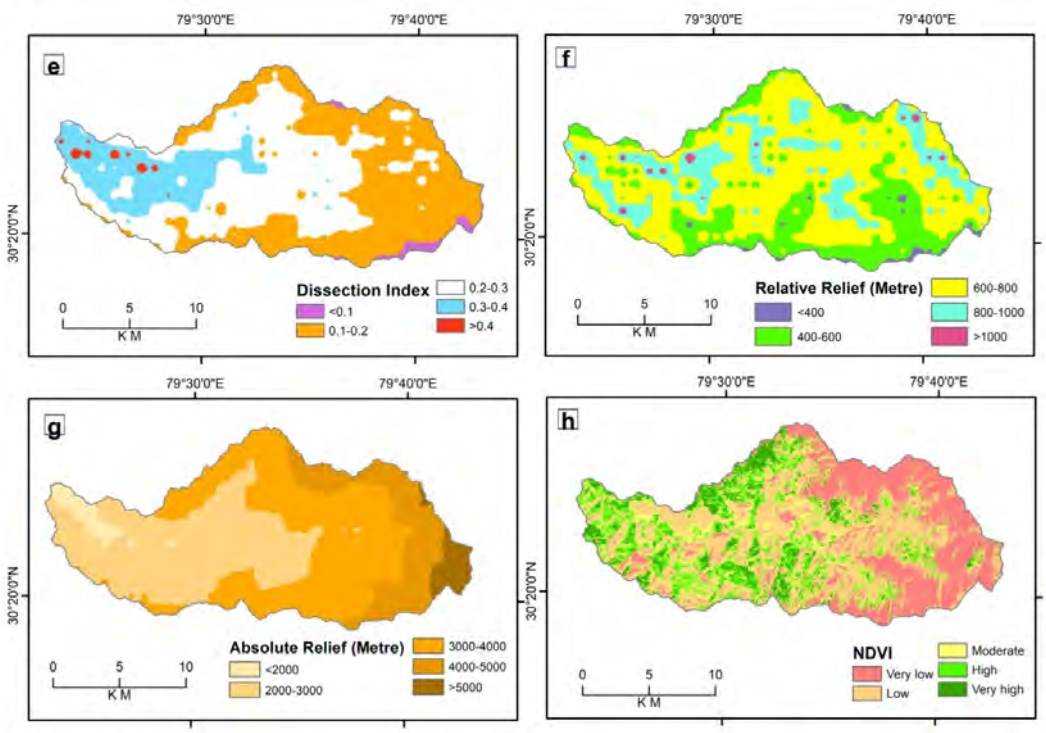


Figure 4: Reclassified parameters: e) Dissection Index, f) Relative relief, g) Absolute relief and h) NDVI

4.7. Absolute relief

Elevation plays a vital role in the terrain sensibility since the higher the elevation higher the relief energy, which responds to the impact of gravity (Bhattacharya, 2018). Generally, altitudinal zones play an important role in the determination of terrain stable zones. Different geological, geomorphological, and meteorological factors such as lithological units, weathering, wind action and precipitation determined the altitude of a region. Altitude is a topographic factor that influences slope instability. It has been mostly used in almost all landslide susceptibility analyses. It was found that increasing elevation decreases the balance of the terrain, similar to the theory of Archdeacon Pratt in the concept of isostasy, the rocks of more elevated objects are made by low-density material and vice versa, which in turn easily destroys the stability of the terrain (Nandy, 2021). The absolute relief map of the study area has been prepared based on some major contour lines by using the digitised method in a GIS environment from SOI Toposheet 1:50,000. The altitude of the basin varies from 1000 m (Jaisal village) to 5600 m (Nandaghungti). The absolute relief of the study area has been classified into five zones at 1000 m intervals. (Fig. 4)

4.8. Normalised Difference Vegetation Index (NDVI)

The Normalised Difference Vegetation Index (NDVI) helps to analyse the vegetation cover of the study area. In the twenty-first century, many researchers used NDVI for vegetation-related monitoring in numerous studies. The vegetation cover plays a vital role in immobilising huge amounts of water through absorption and raising the shear resistance and soil cohesion of the lithological mass (Sidle and Ochiai, 2006). The Normalised Difference Vegetation Index (NDVI) calculation was performed from Landsat 8 OLI imagery of NASA in ArcGIS 10.5 m software based on the following formula-

NDVI = NIR-RED/NIR+RED

Near Infrared (NIR) indicate the wavelength (0.85-0.88) from band 5 and Red indicates the wavelength (0.64-0.67) from band 4 of Landsat 8 OLI satellite imagery. Low NDVI value (<0.18) indicates barren land, built-up area, water body, whereas high NDVI value (>0.18) indicates shrub to dense vegetation. For vegetation, the threshold range is between 0 and 1, with 1 corresponding to very healthy vegetation and 0 reflecting dry and withered plants (Patra et al. 2022). The entire basin is divided into five zones on the basis of NDVI value, these are Very high NDVI value (covers 9.36% area), High NDVI value (covers 17.01%), Moderate NDVI value (covers 10.43%), Low NDVI value (coves 37.41%) and very low NDVI value (covers 25.79% area) (Fig. 4).

4.9. Calculation of Weight for each criterion

To solve any kind of decision-making problem through the AHP model, prioritisation of the criteria by ‘pair-wise comparison’ of all the selected layers is taken into consideration”

(Nandi, 2021). “An excellent and well-known weight evaluation method is the analytical hierarchy process (AHP) proposed by Saaty (1977), which—with regard to the development of weights—has already been called one of the most promising techniques” (Eastman et al.,1998). “To be able to develop criteria weights, the AHP calculates the eigenvalues and the eigenvectors of a square preference matrix which contains the quantified preference information of all possible pairwise criteria constellations” (Marinoni, 2004). “The AHP, as a multi-objective multi-criteria decision making approach, uses a pairwise criteria comparison to arrive at a scale of preferences among sets of alternatives” (Saaty and Vargas, 1991). Here, every parameter is compared to the others by imposing a relative value between 1 and 9. In the present study, Saaty’s fundamental scale for the degree of importance has been used.

Table 2: The fundamental scale for the degree of importance

Intensity of Importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favour one activity over another
5	Essential or Strong importance	Experience and judgment strongly favour one activity over another
7	Very strong or demonstrated importance	An activity is favoured very strongly over another; its dominance is demonstrated in practice
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values between the two adjacent judgments	When compromise is needed

In the ‘pair-wise comparison matrix’, each criterion is related to another criterion in the hierarchical order between 1 and 9 (where the criteria of row become important over column) and between 1/2 and 1/9 (where the criteria of column become important over row). Using the pair-wise, the analytical hierarchy process calculates comparative weights for individual criterion layers (Yalew, et al.2016).

Acceptability of the matrix table has been checked through the Consistency Ratio (CR). The value of the CR is measured through the following formula –

$$CR = CI/RI$$

Where, CI is the Consistency Index and RI is the Random Index of hierarchical order of the matrix. The formula of the CI is

$$CI = (\lambda max - n) / (n - 1)$$

Where λmax is the principal or highest eigenvalue of the matrix and n indicates the order of the matrix. For a significant result, the value of CR must be less than 0.10 (Saaty, 1977). Weights or priorities are decided by normalising the pairwise comparison matrix (Akinci, *et al.*2013, p. 6)

Table 3: Pairwise comparison matrix of 12 stability prospecting factors for the AHP process

Criteria/parameters	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
Landslide zones [1]	1	2	3	4	5	7	8	9
Slope [2]	1/2	1	2	4	4	6	7	8
Tectonic Unit [3]	1/3	1/2	1	3	4	5	6	7
Snow-affected area [4]	1/4	1/4	1/3	1	2	4	5	7
Dissection Index [5]	1/5	1/4	1/4	1/2	1	2	4	5
Relative Relief [6]	1/7	1/6	1/5	1/4	1/2	1	2	3
Absolute Relief [7]	1/8	1/7	1/6	1/5	1/4	1/2	1	2
NDVI [8]	1/9	1/8	1/7	1/7	1/5	1/3	1/2	1

Max. Eigenvalue (λmax) = 8.437; n = 8
Consistency Index (CI) = (8.437–8)/(8–1) = 0.0624
Random Index (RI) = 1.404
Consistency ratio (CR) = (0.0624/1.404) = 0.044; Consistency check = 4%

Table 4: Saaty's Random Index for different values of n

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0.00	0.00	0.525	0.882	1.115	1252	1.341	1.404	1.452	1.484	1.513	1.535	1.555	1.570	1.583

Table 5: Normalised value of cumulative weight (Cw) for each parameter

Criteria/parameters	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	Normalised Weight
Landslide zones [1]	0.38	0.45	0.42	0.31	0.29	0.27	0.24	0.21	0.317
Slope [2]	0.18	0.23	0.28	0.31	0.24	0.23	0.21	0.19	0.233
Tectonic Unit [3]	0.12	0.11	0.14	0.23	0.24	0.19	0.18	0.17	0.172
Snow-affected area [4]	0.09	0.06	0.05	0.08	0.12	0.15	0.15	0.17	0.108
Dissection Index [5]	0.08	0.06	0.04	0.04	0.06	0.08	0.12	0.12	0.076
Relative Relief [6]	0.05	0.04	0.03	0.02	0.03	0.04	0.06	0.07	0.045
Absolute Relief [7]	0.05	0.03	0.02	0.01	0.01	0.02	0.03	0.05	0.028
NDVI [8]	0.04	0.02	0.01	0.01	0.01	0.01	0.01	0.02	0.016

The normalised weight of every thematic layer has been derived by calculating the eigenvector. According to Table 5, landslide zones, which occupies 31.7% weightage is the most important parameter to identify stability. Similarly, Slope (23.5%), Tectonic unit (17.5%), Snow affected area (10.8%), Dissection Index (7.6%), Absolute Relief (2.8%) and NDVI (1.6%) respectively, occupy their weightage and position regarding the influence of terrain stability. The normalised value of each sub-criterion of every parameter has been calculated through rank normalisation. Determination of the rank score of every sub-criterion based on a 'Likert scale' where rank is assigned within 5 responses in numerical value to measure the characteristics of stability of sub-criteria under investigation. Here, the highest rank represents greater terrain stability and vice versa. At last rank normalisation value is multiplied by the parameter weight to get the normalised value of each sub-criterion. After getting the normalised value of each sub-criterion, add the values in the attribute table and prepared terrain stability map by using the weighted overlay tool in ArcGIS 10.5.

Table 6: Normalised value of each sub-criterion of different parameters

Criteria/parameters	Sub-criteria	Parameter weight	Rank	Rank normalization	Normalised value	Area in km2	Area in %
Landslide zones	Moderate to low	0.317	1	0.1667	0.053	14.55	5.25
	High		2	0.3333	0.1056	167.18	60.30
	Severe to very high		3	0.5000	0.1585	95.54	34.45
Slope	<20°	0.235	1	0.0667	0.0156	45.19	16.30
	20° - 30°		2	0.1333	0.0313	70.80	25.53
	30° - 40°		3	0.2000	0.0474	70.69	25.50
	40° - 50°		4	0.2667	0.0626	59.09	21.31
	>50°		5	0.3333	0.0783	31.50	11.36
Tectonic Unit	Autochthonous Unit	0.175	1	0.1000	0.0175	74.07	26.71
	Berinag Unit		2	0.2000	0.0350	52.14	18.80
	Munsiari Almora Unit		3	0.3000	0.0525	119.38	43.06
	Vaikrita Unit		4	0.4000	0.0700	31.68	11.43
Snow-affected area	Less affected	0.108	1	0.1667	0.0180	81.13	29.26
	Moderately affected		2	0.3333	0.0359	110.38	39.81
	Highly affected		3	0.5000	0.0541	85.76	30.93
Dissection Index	<0.1	0.076	1	0.0667	0.005	4.42	1.59
	0.1 – 0.2		2	0.1333	0.010	117.51	42.38
	0.2 – 0.3		3	0.2000	0.015	105.82	38.16
	0.3 – 0.4		4	0.2667	0.020	47.44	17.12
	>0.4		5	0.3333	0.025	2.08	0.75
Relative Relief	<400	0.045	1	0.0667	0.003	3.45	1.24
	400 – 600		2	0.1333	0.005	70.56	25.45
	600 – 800		3	0.2000	0.009	142.17	51.27
	800 – 1000		4	0.2667	0.012	58.91	21.25
	>1000		5	0.3333	0.014	2.18	0.79
Absolute Relief	<2000	0.028	1	0.0667	0.0018	9.33	3.36
	2000 - 3000		2	0.1333	0.0037	110.41	39.82
	3000 - 4000		3	0.2000	0.0056	100.12	36.11
	4000 - 5000		4	0.2667	0.0074	46.95	16.93
	>5000		5	0.3333	0.0093	10.46	3.77
NDVI	Very Low	0.016	1	0.0667	0.0010	25.95	9.36
	Low		2	0.1333	0.0021	47.16	17.01
	Moderate		3	0.2000	0.0032	28.93	10.43
	High		4	0.2667	0.0042	93.72	33.80
	Very High		5	0.3333	0.0053	81.51	29.40

5. Results and Discussion

5.1. Terrain stability map

The predicted terrain stability map of the study area has been prepared with the help of eight parameters, i.e. landslide-prone area, slope, tectonic unit, snow-affected area, dissection index, relative relief, absolute relief, and Normalised Difference Vegetation Index. Among the parameters, Landslide prone area is considered the foremost and the terrain stability is directly regulated by this parameter (Escape et al, 2015). The landslide-prone zonation map is classified into three vulnerability zones: i) moderate to low, ii) high and iii) severe to very high. Among them high landslide-prone area covers the maximum area (60.30%), followed by the middle, the middle-east and one patch in the western side of the basin. Severe to very high landslide-prone area (unstable terrain) is observed in the extreme eastern (upper part of the basin) and the middle-western portion of the study area. Landslide, slope failure, rock creep, and soil erosion are directly related to slope. The total area of the basin is classified into five slope categories, these are: i) Very low (<20º), ii) Low (20º -30º), iii) Moderate (30º -40º), iv) High (40º -50º), and v) Very High (>50º). These slope zones are unevenly distributed in the different parts of the basin. Among them, 20º to 30º, and 30º to 40º slope zones occupied 51.03% of the study area. Very low (<20º) and very high slope zone (>50º) covers 16.30% & 11.36% respectively. In the study area, four major tectonic units are identified: i) Vaikrita Unit, ii) Munsiyari Almora Unit, iii) Berinag Unit and iv) Autochthonous Unit. The Munsiyari-Almora Unit is observed in the middle-east and south-western part has spread over 43.6%, followed by Autochthonous Unit, Berinag Unit and Vaikrita Unit covers 26.71%, 18.80% and 11.43%, respectively. Snow directly controls weathering phenomena, and the study area is classified into less affected, moderately affected, and highly affected snow cover zones. The highly affected snow cover area occupied 30.93% of the study area, noted in the eastern part of the basin and the less affected snow cover area cover 29.26% of the study area and was observed in the western part of the basin.

The roughness of terrain is clearly identified by the dissection index. On the basis of the dissection index value, the total area is divided into five zones: i) <0.1, ii) 0.1-0.2, iii) 0.2-0.3, iv) 0.3-0.4, and v) >0.4. The lowest category observed in the southern, northern, north-eastern and eastern parts of the basin occupied 43.97% of the study area and the high category observed in the middle and western parts of the basin occupied 17.87% of the study area. Direct relation with slope encourages relative relief to be an effective parameter for estimating terrain stability (Bhattacharya, 2018). The relative relief of the Birahi Ganga river basin has been classified into five groups: i) <400 m, ii) 400-600 m, iii) 600-800 m, iv) 800-1000 m and v) >100 m. Very low (<400 m) to low (400-550 m) relative relief classes occupied 74.01 km² (26.69%), whereas moderate (600 800 m) to high (800 1000 m) relative relief classes occupied 218.71 km² (78.87%) and were unevenly distributed in the basin.

The proportionate relationship between altitude and stability acquires an assured situation in the examination of terrain stability analysis (Pack et al, 2001). Based on altitude, the study area was divided into five classes: i) <2000 m (3.36%), ii) 2000-3000 m (39.82%), iii) 3000-4000 m (36.11%), iv) 4000-5000 m (16.93%) and v) >5000 m (3.77%). The elevation of the study area increases from west to east and instability also increases proportionally. There is a positive relationship between vegetation cover and terrain stability. On the basis of NDVI, the study area was classified into five zones: i) Very low (9.36%), ii) Low (17.01%), iii) Moderate (10.43%), iv) High (33.80%) and v) very high (29.40%). High to very high NDVI zones are mainly observed in the western, northern, southern and south-western parts of the study area and low to very low NDVI zones are observed in the middle, north-eastern, eastern and south-eastern portions of the study area.

5.2. Assessment of Terrain stability zones

The terrain stability map of the study area has been prepared on the basis of the weight of the different thematic layers and their classes in a GIS environment. The final map of the terrain stability has been classified into five zones using the quintile classification method. The study area is classified into five terrain stability zones: stable, moderately stable, moderately vulnerable, vulnerable, and highly vulnerable. The stable terrain zone observed in the middle and north of the north western part of the basin occupied 32.84 km². The highly vulnerable zone identified in the middle to eastern part and the south western to western part of the basin occupied 33.51 km².

Table 7: Area of different terrain stability zones

Terrain stability zones	Area (in km²)	Area (in %)
Very stable	32.84	11.84
Stable	61.18	22.07
Moderate stable	77.03	27.78
Unstable	72.71	26.22
Severely unstable	33.51	12.09

Table 7 shows that the area under the very stable zone occupied 11.84% of the total area and is noted mainly in the north-western, western, middle, and middle-southern portions of the basin. The village, namely Birahi, Garigaon, Sainj, Gauna, Pagnamalla, Irani, Jhinji, GengKharak, BodnaKharak, MerumKharak, etc., fall under this zone. The stable zone covers 22.07 % of the study area and is observed in the south-eastern, southern, and mid-western portions of the study area. The stable zone was found around the Soti, Thala, Tuna, Durmi, Semkharak, Taraktal, Madura, Nijmulaetc villages. Among the five zones, these two zones are suitable for human habitation. The moderately stable zone covers 27.78% of the study area, and is mainly observed in the south-western, northern, north-eastern, and south-western portions of the study area (Fig 5).

Due to the presence of steep slopes, lofty mountains, snow cover, rocky outcrops, and glaciers in the south-western, eastern, north-eastern, and south-eastern portions of the study area make unstable to severely unstable.

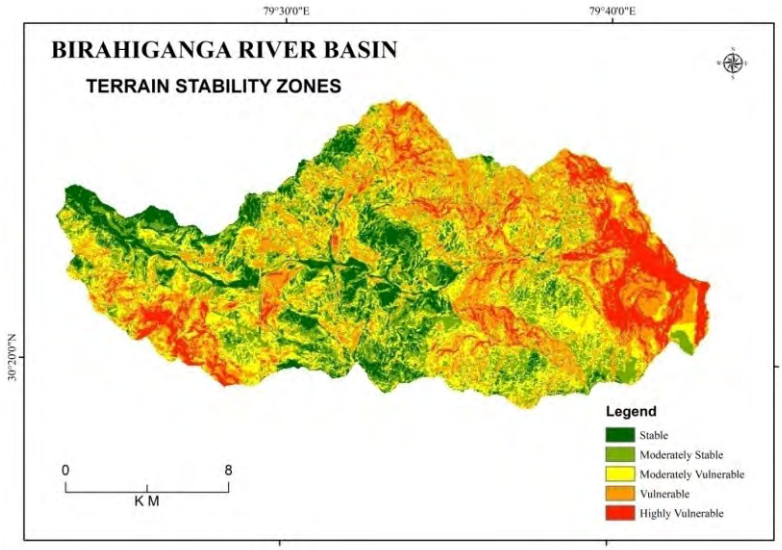


Figure 5: Terrain stability zones of the Birahi Ganga river basin

6. Conclusion

The present work elucidates the integration of Analytical Hierarchy Process (AHP) and Geographical Information System (GIS) techniques for assessing terrain stability zones in the Birahi Ganga river basin of the Garhwal Himalaya. Based on the eight key variables of geological, geomorphological, and environmental conditions, the terrain stability map of the study area was prepared and classified into distinct stability zones: stable, moderately stable, moderately vulnerable, vulnerable and highly vulnerable. The study found that stable (11.84%) and moderately stable (22.07%) zones are primarily distributed in the north-western, middle, and southern portions of the study area. These areas are relatively less affected by tectonic activity, slope instability and snow cover, making them suitable for settlement and associated anthropogenic activities like farming, marketplaces, places of worship, transport, and communication networks. On the other hand, the eastern, north-eastern, and south-western portions of the basin are characterised as highly vulnerable (12.09%) zones due to high relative relief, steep slopes and increased landslide susceptibility. A gradual decrease in terrain vulnerability from the eastern to the western part of the basin has been observed, reflecting the influence of topographic gradient and lithological variation. The study highlights that slope, landslide susceptibility and tectonic structures are the most influential factors controlling terrain stability in the Himalayan environment.

The integration of AHP and GIS helps to evaluate terrain stability and identify suitable zones for infrastructure development and disaster risk reduction. The results of the present study help engineers, policy makers, and regional planning authorities to implement sustainable land-use strategies and minimise geomorphic hazards in the Birahi Ganga river basin and other similar Himalayan terrains.

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The Indian Geographical Journal
Volume 100 (2) Dec - 2025, pp 177-199
ISSN 0019-4824

RIVERBANK EROSION AND ASSESSMENT OF ECONOMIC LIVES OF ENVIRONMENTAL REFUGEES: A CASE STUDY OF GANGETIC RIVERINE TRACT IN MALDA DISTRICT OF WEST BENGAL, INDIA

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Abstract

The Ganges River exhibits dynamic channel shifting, characterised by relentless bank erosion, particularly along its Left Bank (LB), in the Malda district of West Bengal, over the past few decades. This has led to large-scale land loss, the displacement of riverine communities, and the socio-economic challenges they face. The present study focuses on the Left Bank shifting of the Ganges in the district and investigates the economic impacts on internally displaced persons (IDPs), referred to as Environmental Refugees. The research uses a mixed-method approach, blending quantitative and qualitative methods. Primary data are collected using the Household Survey Method, which involves administering a questionnaire, along with Key Informant Interviews and Focus Group Discussions. Satellite images are analysed to estimate the extent of shifting of the LB of the Ganges and the resulting human displacement. Descriptive statistics, Karl Pearson's correlation coefficient, scatter diagrams, and cartographic techniques have been applied to identify how Ganges Left Bank erosion and the resulting shifting are intricately linked to the economic conditions of the displaced population, rendering them economically marginalised and vulnerable to natural disasters. The findings of the research reveal that the continuous eastward shifting of the Ganges has swallowed thousands of acres of highly fertile and productive land, hundreds of inhabited villages, and has compelled the displacement of lakhs of people in the study area. The loss of highly productive agricultural land, jobs, and business establishments has made the lives of IDPs uncertain and their livelihoods highly vulnerable. The study highlights that recurrent riverbank erosion exacerbates socio-economic vulnerability in the riverine tract of Malda district. IDPs are facing multi-dimensional socio-economic challenges that lead to deprivation, destitution, delicacy, and entrenched poverty. Urgent development and deployment of sustainable rehabilitation initiatives and riverbank erosion control strategies are needed to mitigate further human displacement and socio-economic marginalisation.

Keywords: Riverbank, Vulnerability, Environmental Refugees, Resettlement, Migration

1. Introduction

Considering the gravity of displacement due to natural hazards at the global level, the United Nations High Commission for Refugees (2010) provided the definition and conceptual framework of 'Refugee', but did not mention the term 'Environmental or Ecological Refugee' as such. Though the term 'Environmental Refugee' (ER) was first used by Lester Brown of the World Watch Institute in the 1970s, Hinnawi first provided a formal definition of the term 'Environmental Refugee' (Morrissey, 2009). El-Hinnawi (1985) first defined the term Environmental as “those people who have been forced to leave their traditional habitat, temporarily or permanently, because of a marked environmental disruption (natural and/or triggered by people) that jeopardised their existence and/or seriously affected the quality of their life”. ‘Environmental disruption’ in this definition means any physical, chemical and/or biological changes in the ecosystem (or the resource base) that render it, temporarily or permanently, unsuitable to support human life”. The natural, socio-economic, and cultural environmental degradation are a serious issues for the ERs in the affected areas. The quality of life of the refugees gets affected, and they also affect the life of the native dwellers of the concerned receiving areas (El-Hinnawi, 1985).

According to Myers (1997), most of the ERs belong to environmentally hostile regions for human habitation. The ERs have become a global problem in recent years. Many environmental factors and natural disasters in the form of soil erosion, drought, deforestation, desertification, water shortages, climate change, floods, cyclones, storms, and surges may cause the homelessness of many people and resultant ER. It was estimated by Myers (1997, 2001) that worldwide there would be around 50 million ERs in 2010, and he further estimated that there would be approximately 200 million ERs by 2050. Natural, anthropogenic, and human-induced disasters produced a huge number of ERs at the global level. The phenomena of ERs may involve temporary or permanent displacement of people from their own habitats (Bates, 2002). The environmental disaster-induced human displacement is a growing global phenomenon. Environmentally induced hazards such as cyclones, hurricanes, tornadoes, and floods made the land inhospitable for human habitation, and people are very often forced to leave their own habitats (Peters, 2011). As stated by the Global Report on Internal Displacement, published by the Internal Displacement Monitoring Centre (2023), at the end of 2022, there were 71.1 million internally displaced persons (IDPs) at the global level due to conflicts and disasters. The Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report (AR6, 2022) confirms that climate-induced fluvial hazards, including riverbank erosion, are one of the leading drivers of internal displacement in South Asian countries, where India and Bangladesh are identified as critical hotspots. The average rate of climate-induced migration and displacement is more than 20 million people each year globally (IPCC et al., 2022). Thousands of people become victims because of riverbank erosion, and the riverine people lose their fertile agricultural land and habitats. Ultimately, they become landless as well as homeless. Thousands of people have been displaced in the Brahmaputra-Jamuna floodplain of Bangladesh due to riverbank erosion (Zaman, 1991). Natural and man-made environmental disruptions may cause the displacement of people throughout the world.

Hence, there may be a number of reasons behind the occurrence of ERs. Paul (2005) mentioned that North-Central Bangladesh was extremely affected by the Tornado of 2004 which took a heavy toll of lives and destroyed businesses, standing crops, livestock etc., but simultaneously he tried to show that all disasters do not create ERs if the authorities provide appropriate aid on an emergency basis and take proper steps to mitigate the problems of disaster affected areas. As projected by the Groundswell Report, Part II, on internal climate migration, the number of climate-induced migrants in the world could reach 216.1 million by 2050, with 40.5 million primarily in the riverine tracts and deltaic regions in South Asia (Clement et al., 2021). Riverbank erosion has become a serious natural hazard, particularly for those who reside close to riverbanks, which are vulnerable to erosion nearly every year. It has been seen that a large number of people are displaced due to riverbank erosion throughout India and face different types of socio-economic problems (Das et al., 2014). From the pertinent existing literature, it is observed that millions of people have been displaced and become ERs throughout the world due to various man-made and natural hazards, including riverbank erosion. In the last few decades, the Malda district of West Bengal has witnessed the problems of ERs due to the massive LBE of the Ganges. The riverbank erosion-induced ERs are facing severe socio-economic problems and are becoming vulnerable to further environmental disasters. Thakur et al. (2012) studied the bank erosion hazards of the Ganges upstream of the Farakka Barrage up to the Rajmahal Hill, i.e., the riverine tract of the Ganges of Malda district and traced the socio-economic effects of it. Thus, it is observed that several researchers have attempted to study the severity of bank erosion of the Ganges and the resultant effects, but no one has raised the issues of ERs, which are exclusively produced by the LBE of the Ganges in Malda District. Most of the studies regarding the bank erosion in the study area are date back. But this erosion has again revived since 2018, and it has become severe in some areas in the study area. Thus, the main objective of this paper is to highlight the shifting of the LB of the Ganges and the resultant socio-economic hardships of the displaced people in the study area.

Earlier researchers (Thakur et al., 2012; Rudra, 2009) have mostly described the geomorphic dynamics and the extent of LBE of the Ganges upstream of the Farakka Barrage, but these works are largely dated back and focus more on physical processes rather than on the specific economic challenges and other human dimensions of the repeated displacement.

Moreover, the study area has faced large-scale displacement due to renewed LBE and the accelerated eastward shifting of the Ganges, which is not officially documented. Existing studies seldom address the economic trajectories of IDP-households, how displaced people rebuild lives and livelihoods, and cope with repeated relocation. Hence, this study fills a critical gap by focusing on the economic challenges of these displaced people living in one of the most erosion-prone districts of India.

This study is conceptualised on the basic premise that riverbank erosion is a dynamic geomorphological process that triggers multiple socio-economic vulnerabilities

among stable riverine populations. In the riverine tract of the Ganges in Malda district, repeatedly severe left bank erosion (LBE) occurs due to a host of hydro-geomorphologic factors such as high monsoonal discharge, heavy deposition of sediment, channel shifting, and human interventions (notably construction of Farakka Barrage), resulting in eastward migration of the Ganges.

The outcomes of this physical process are the direct loss of productive assets, including fertile agricultural land, orchards, infrastructure, business establishments, common property resources, and, above all, homesteads. Riverbank erosion-induced loss of movable and immovable properties leads to forced displacement, often internal displacement, multiple times. Affected communities are compelled to resettle mostly on fragile lands such as char lands, retired embankments, PWD lands and roadsides, or other insecure places, without legal land tenure. The internally displaced persons (IDPs) become ERs who suddenly lose their livelihoods, economic viability, and social security, and become environmentally vulnerable within their own homeland. These IDPs experience rising unemployment, declining income, and increasing dependence towards informal, insecure, and precarious migration-driven occupations. Most of the workforce is bound to migrate to distant, unknown, and insecure places. These migrant workers are low-paid, and sometimes even unpaid. This substantial transformation of occupational type and structures increases exposure to physical exploitation, socio-economic marginalisation, and health risks.

The prolonged economic crisis produces multi-dimensional socio-economic fragilities, such as poverty, indebtedness, food insecurity, malnutrition, poor housing and infrastructures, limited access to health and educational facilities, and reduced adaptability. Thus, this framework conceptualises riverbank erosion as a very pivotal and continuous process, in which river dynamics interact with administrative failures and socio-economic fragility to reshape the livelihoods of ERs. The framework also demonstrates that without effective and successful erosion control measures, an inclusive policy of rehabilitation, and effective livelihood restoration, the displaced people remain trapped in a vicious cycle of economic insecurity and environmental risk **(Figure 1).**

The objectives of this study to examine the impacts of the continuous LBE of the Ganges on the socio-economic and livelihood of IDP households, referred to as Environmental Refugees (ERs). Identify and address the existing research gap on the severe LBE of the Ganges in Malda district and try to understand why and how this erosion makes the riverine people long–term economically vulnerable communities despite decades of the government's interventions.

2. Study Area

Malda district, the connecting district between North Bengal and South Bengal of India, has been selected as the study area for the present study. With a geographical area of 3733 km^2 (1,441.6 sq. miles) and a population of 3988845, the district ranked 12th

position in terms of area and 11th position in terms of population size in the state (Census of India, 2011). Because of physiographic diversity, the district has three distinctive physiographic divisions, i.e. *Tal*, *Barind* and *Diara*. The northern portion of the district, bounded by the Mahananda and Kalindri River, is known as the *Tal* region, while the eastern part of the district, i.e., the eastern margin of the Mahananda River, is called the *Barind* region. This is basically the upland zone of the district. The south-western part, transitional zone between the marshy *Tal* tract and the *Barind* upland, is known as *Diara*, which is made of highly fertile alluvial soil formed by the Ganges and its tributaries and distributaries. Of the three regions, Diara is bestowed with highly fertile alluvial soil.

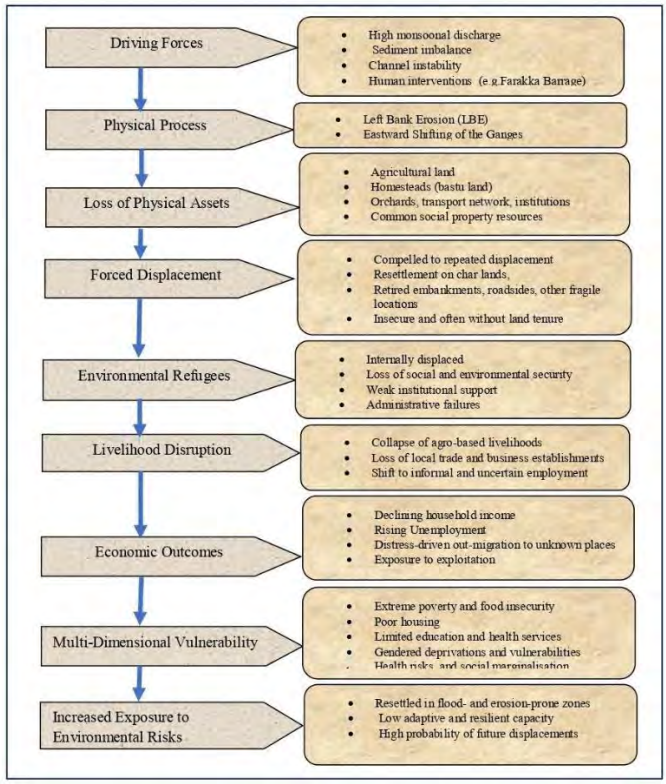


Figure 1: Conceptual Framework of Riverbank Erosion-Induced Impacts on the Economic Lives of the Environmental Refugees

This region is agriculturally prosperous, and most of the working people are engaged in agricultural activities. Opportunities for prosperous agricultural activities and other livelihood opportunities make this region thickly populated. But unfortunately, this region is facing a severe recurring environmental disaster in the form of severe floods and riverbank erosion, which is caused mainly by the river Ganges. This erosion of the Ganges poses a serious problem to the riverine people in the district, mainly Manikchak and Kaliachak-II C.D. Block, and hence these two Blocks have been selected as the study area **(Figure 2)**. A large population has been displaced, and many of them have become

refugees in their own homeland due to this disaster. In fact, both the authors of this paper are native people of this disaster-affected area and have even gone through the sufferings with these refugees. Hence, as co-inhabitants and co-sufferers, this particular aspect of research has been considered to bring the attention of all policymakers to mitigate the sufferings of these refugees.

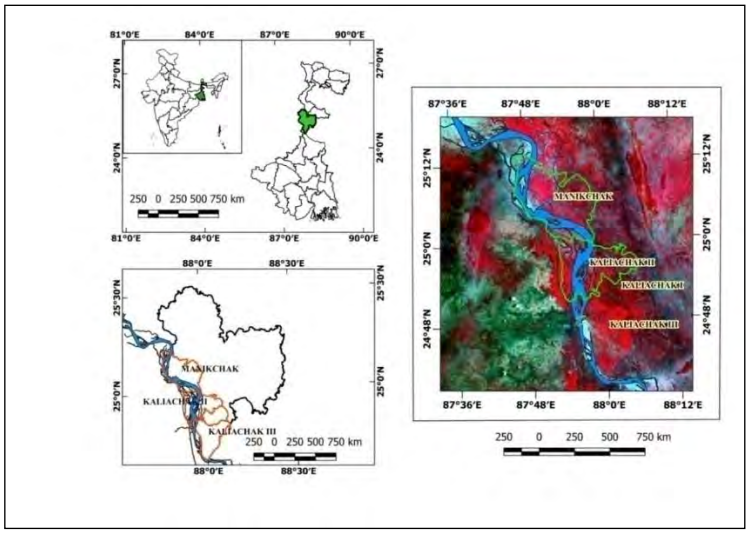


Figure 2: Study area location in Malda district, West Bengal, India.

3. Materials and Methods

3.1 Database

The study is empirical in nature, which is based on both primary and secondary sources of data. The primary data have been collected through field surveys using structured and pre-tested survey questionnaires, KII and FGDs. The secondary data have been obtained from different published and unpublished sources such as the District Census Handbook, District Human Development Report, national and international reputed journals, project reports, and PhD theses, etc. The satellite images have been used for assessing the shifting courses of the Ganges from 1973 to 2023 **(Table 1).** The Mouza (revenue villages) maps and Google Earth images have been analysed for a better understanding of the present location of the riverine tract of the Ganges in the study area.

3.2 Sampling Techniques, Sample Size and Data Collection Procedures

As such, Manikchak, English Bazar, Kaliachak-I, Kaliachak-II and Kaliachak-III C.D. blocks comprise riverine tracts of the Ganges in Malda district. Through analysing satellite images, it becomes evident that Manikchak and Kaliachak-II are the most flood-induced riverbank erosion-affected areas by the Ganges. Hence, samples for the present study are drawn from these two severely affected blocks by riverine erosion and shifting of the river

course of the Ganges. In this study, 'ERs' are defined as people who have been displaced (at least once during 1973-2023) and resettled along the LB and *charlands* of the Ganges as a consequence of having lost their homes and agricultural lands due to riverbank erosion. Stratified random sampling (SRS) technique has been adopted for carrying out this research work. For the Household Survey (HHS), Internally Displaced Household (IDH) is divided into three groups based on the distance between the present LB of the Ganges and resettled households, which are as follows:

Group I: Households resettled within 500 metres of the riverbank,

Group II: Households resettled between 500 metres and 1 km from the riverbank, and

Group III: Households resettled more than 1 km from the riverbank.

Table 1. Particulars of the satellite images used

Date	Satellite and Sensor	Spatial Resolution (m)	Source
1973	Landsat-MSS	57	USGS
1977	Landsat-MSS	57	USGS
1980	Landsat-MSS	57	USGS
1987	Landsat-TM	30	USGS
1992	Landsat-TM	30	USGS
2000	Landsat-TM	30	USGS
2015	Landsat-OLI/TIRS	30	USGS
2023	Landsat-OLI/TIRS	30	USGS

A well-structured survey schedule comprising both closed and open-ended questions has been used for carrying out door-to-door household survey for the collection of first-hand information from the sampled households. Before finalisation of the survey schedule, a pilot survey was conducted in the study area to remove unwanted errors. Taking an equal number of samples from each selected C.D. block (50 from each block), as many as 100 households were surveyed in the month of October-November 2022 and 2023 (post-monsoon situation). The heads of the households were interviewed, of which 70 % male and 30% female, aged 45 years and above, formed the respondents**.** Only those households were selected as sample households which were displaced at least once during 1973 to 2023 due to the LBE of the Ganges and at present do not have legal ownership of their residential land. Out of 100 surveyed households, 50 % were from Group I, 25 % from both Group II and Group III each, but all were IDH. Besides the HH Survey, Observation method, FGD, and KII methods have been applied to gather quantitative and qualitative information to perceive the ground reality of the riverine people of the study area.

Although more than 80,000 households have been displaced due to the erosion in the study area, a total of 100 IDP households have been selected for detailed socio-economic investigation. The drawn sample size is considered sufficient and statistically reliable for several reasons.

First, the decision to select 100 displaced households as the sample size for the present study was guided by methodological considerations. The sample has been drawn by applying a stratified random sampling only from the erosion-induced IDP households belonging to diverse economic and social groups, ranging from small to large farmers, landless labourers, small traders, government employees, fishermen, migrant labourers, etc., from multiple pockets of the affected regions to ensure the representativeness of the sample households. For the determination of sample size, Cochran's (1977) sampling techniques have been followed.

$$n_0 = \frac{Z^2.\mathrm{p.q}}{e^2}$$ (Applicable for the unknown or large population size)

where,

n_0 denotes the initial sample size, z denotes the z-score (based on the level of confidence), p denotes the estimated proportion of the population with attributes, q=1-p is the proportion without the attribute, while e denotes the desired margin of error

Here, the exact displaced population is unknown

z=1.96 at 95% level of confidence

p=0.5 → q=0.5 (used in case of unknown population)

e= .10 (selected precision level)

Substitute the values in the formula, i.e.

$z^2 = 1.96^2 = 3.8416$,

p × q = 0.5 × 0.5 = 0.25

Multiply, 3.8416 × 0.25=0.9604

Divide by $e^2 = .10^2 = 0.01$

n_0= (0.9604/0.01) =96.04 (sample size selected 100 as a round figure)

Second, the IDP households have been selected through stratified random sampling (SRS) from two of the most severely affected C.D. blocks, i.e. Manikchak and Kaliachak-II in the district, to ensure spatial diversity and true representation across six villages from three displacement-distance categories from the riverbank. This stratification allowed balanced representation of the displaced households with varying magnitudes of exposure to erosion-induced economic distress and resettlement stress.

Third, some practical constraints, such as fragmented settlements, limited accessibility to the erosion-affected villages and destruction of roads by erosion, made larger sample surveys practically very difficult. The 100-IDP sampled household, therefore,

strikes a good balance between feasibility and analytical reliability, which enables the use of descriptive statistics and correlation analysis to validate the patterns observed in the field.

Finally, the existing studies (Biswas & Anwaruzzaman, 2019 & Kaiser, 2023) focused on the riverbank erosion-induced displacement in Malda district and adjacent regions have relied on household samples ranging from 80 to 100 to draw the pattern of demographic and socio-economic consequences.

The sample respondents were brought to a common place to have a 'Focus Group Discussion' to get in-depth information on different aspects of the impacts of LBE and the resultant eastward shifting of the Ganges on the lives and livelihoods of the dwellers having various occupations in the region. Key Informants (KI) such as social activists, leaders of the *Bastuhara Committee*, *Ganga Bhangan Protirodh Action Nagorik Committee*, teachers, professors, village representatives, and other learned and well-informed people residing there are interviewed deeply to get the actual sense of loss of properties, educational institutes, medical infrastructures, business and industrial setup, and to assess the magnitude of impacts on the ecological refugees. Being native inhabitants of the LB of the Ganges, the authors are helpless witnesses to this flood-induced massive erosion almost every year and the resultant loss of properties, distressed lives, and livelihoods of the riverine people. Despite this, the authors have physically investigated erosion-affected areas multiple times to know the present location and entire course of the Ganges in the district and the whole situation of the dislocated people who are still fighting with this natural disaster for their survival.

The collected data from both primary and secondary sources have been arranged systematically, and selected descriptive statistics, Karl Pearson's Correlation Coefficient method, as well as some pertinent cartograms such as Scatter Diagram, Pie-graph, Bar Graphs, tables, and charts have been drawn using MS Excel and MS Word. QGIS and SPSS software have also been used for better quantitative, cartographic, and diagrammatic representations.

4. Results and Discussions

4.1 Shifting of the Left Bank of the Ganges in the Study Area during 1973-2023

Riverbank erosion and resultant shifting of its course is a very common fluvial geomorphologic phenomenon that shapes the riverine landscape and channel morphology of the concerned river. This section mainly focuses on the extent of bank erosion and channel shifting of the Ganges in the study area during the period 1973-2023.

According to the Key Informants of the study area, the bank line between Manikchak Ghat and upstream of Farakka Barrage was subjected to severe bank erosion from 1973 to 2020, but the rate of erosion and resultant eastward shifting in the Diara region was not uniform. During 1994-1998, Manikchak Ghat to Gopalpur, Gopalpur to Panchanandapur, and Panchanandapur to Laskarpur faced a rapid phase of bank failure.

Dharampur, Gopalpur, and Panchanandapur again underwent a rapid phase of bank failure intermittently during the period between 2002 and 2005. Up to 1990, a total of 35 inhabited villages were engulfed by the Ganges, while 18 villages were lost during 1990-2005 (Thakur et al., 2012).

Table 2. Left bank erosion (LBE) of the Ganges in Malda District

Year	Total length affected (km)	Maximum width of erosion (m)	Approx. loss of land (Hectares)
1931 to1978	-	-	14,335
1979	5	200	60
1980	7	150	105
1981	11	400	260
1982	5	150	65
1983	5	200	90
1984	7	100	70
1985	6	150	90
1986	6	200	105
1987	8	300	240
1988	7	100	70
1989	10	150	150
1990	8	200	160
1991	11	150	170
1992	9	150	130
1993	7	200	145
1994	7	1250	160
1995	8	200	145
1996	15	250	310
1997	6	100	60
1998	10	900	330

Source: Compiled by the authors based on “Erosion problems of the river Ganga in the districts of Malda and Murshidabad in West Bengal,” by P. K. Parua, 1999, *Bi-monthly Technical Journal of American Society of Civil Engineers - Indian Section, 13*(2), as cited in *A report on the impact of the Farakka Barrage on the human fabric* (p. 26), by M. Banerjee, 1999, South Asia Network on Dams, Rivers and People.

Table 2 vividly illustrates the continuous intensification of LBE of the Ganges in Malda District, revealing a pattern of episodic devastating riverbank failure and lateral shifting of the Ganges over time. The staggering loss of 14,335 hectares of land loss confirms the prolonged severity of the problem, while subsequent years indicate an intensifying variability of lateral expansion and volumetric land erosion. The mid-1990s were a critical phase of lateral shifting, and 1996 and 1998 emerged as peak disaster years with huge land losses of 310 hectares and 330 hectares, respectively. The extreme surge of

lateral erosion of 1,250 metres in 1994 indicates episodic channel aggression and large-scale riverbank retreat. Overall, the data depict that the Ganges is one of the highly dynamic and destructive river systems in India, particularly in Malda, where recurrent bank collapses have not only modified the physical landscape but also intensified the vulnerability of human settlements and agrarian livelihoods over the successive decades.

During the field survey in the months of October-November 2022 and 2023, the researchers observed that the Ganges has continued severe bank erosion at Uttar Hukumat Tola of Gopalpur Mouza (revenue village) in the form of block slide and block slumping, etc. Due to the eastward shifting of the course, the Ganges engulfed thousands of acres of fertile land in the *Diara* region and took a mighty bend in its course between Manikchak Ghat and Panchanandapur **(Figure 3).**

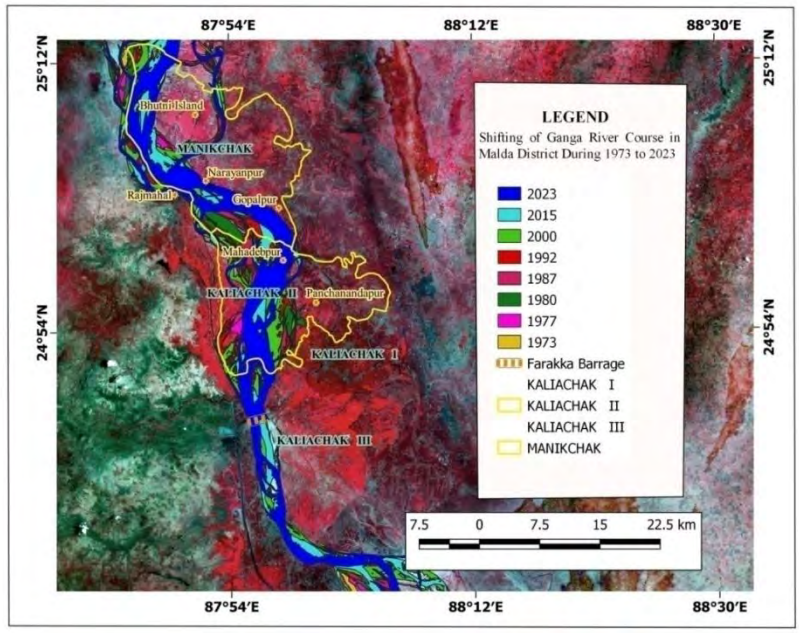


Figure 3: Visual representation of shifting of the Ganges course from 1973 to 2023 with some vulnerable sites in the study area.

Malda district is not the only region which is suffering from the problems of riverbank erosion; the adjoining regions like Bangladesh and Assam are also suffering from severe bank erosion of the Jamuna, Padma and Brahmaputra rivers. The left bank of the Jamuna has eroded a total of 1038 km^2 in Bangladesh during 1973-2019 and shifted its channel towards the east. The junction of the Jamuna River with the Padma is also very dynamic and has witnessed huge lateral migration towards the southeast (Rahman, 2022). Assam is also facing a serious challenge due to the riverbank erosion, as more than 4.27 lakh hectares of land have been eroded by the river Brahmaputra and its tributaries for the

last six decades, which is 7.40 % of the total geographical area of the state. The state is losing nearly 8000 hectares of land each year. **Table 3** discloses year-wise data on the area eroded, number of affected villages and families and the loss of properties because of riverbank erosion in Assam (Govt. of Assam, 2014). Due to bank erosion of the Brahmaputra, thousands of families have been displaced, become landless, and crores of properties were lost in Assam, particularly in Dhubri, Kamrup, Barpeta and Goalpara districts (Dekaraja &Mahanta, 2021).

Table 3. Year-wise area eroded and affected population in Assam

Year	Area Eroded in Hectare	Number of Villages Affected	Number of families affected	Value of property (including land loss) Rs in Lakh
2001	5348	227	7395	377.72
2002	6803	625	17985	2748.34
2003	12589.6	424	18202	9885.83
2004	20724	1245	62258	8337.97
2005	1984.27	274	10531	1534
2006	821.83	44	2832	106.93
2014	12579.13	N.A.	77805	N.A.

Source: Water Resource Department, Govt. of Assam, 2014

4.2 Economic Lives and Livelihoods, and Vulnerabilities of the ERs

Since the inception of the construction of the Farakka Barrage during the late 1960s, the severity of the LBE of the Ganges has increased as it has disturbed the natural dynamics of the river. The easterly flight of the Ganges engulfed as many as 64 inhabited and uninhabited Mouzas (revenue villages) covering about 267 km^2 of the geographical area of Malda district (Rudra, 2009). The riverine dwellers of the LB of the Ganges are losing their productive agricultural lands and *Bastu* (homestead) lands, including household properties and assets, every year since 1973. The actual data regarding land loss is not properly documented, neither by the Land Revenue Department nor by the Irrigation and Waterways Department (I & W) of the Government of West Bengal (GoWB). Kedar Nath Mondal (2015), an activist and leader of the (president) *Ganga Bhangan Pratirodh Action Nagorik Committee,* informed that the Ganges has laterally shifted almost 8-9 km towards east and washed away more than 22 Mouzas (revenue villages), tens of thousands of hectares of productive agricultural lands, Mango Orchards, and displaced around 80 thousand households. As stated by Banerjee (1999), as many as 4.5 lakh people became homeless due to LBE, and 22 Mouzas of Manikchak, Kaliachak-I and Kaliachak-II C.D. blocks have been washed into the river. After losing their permanent home, productive agricultural lands, occupational setups, business establishments, etc, these vulnerable people became refugees in their homeland. As per the District Human Development Report, Govt. of West Bengal (GoWB, 2007), 5343.59 Hectares (ha) and 10163.77

hectares of productive croplands of Manikchak and Kaliachak-I and II blocks, respectively, have been eroded during 1973-2006.

As per the field survey findings, 33 per cent of households lost less than 5 bighas of land, 25 per cent lost 5-10 bighas, 19 per cent lost 10-20 bighas, 14 per cent lost 20-25 bighas, whereas 9 per cent lost more than 25 bighas of agricultural land during 1990-2023 **(Figure 4).**

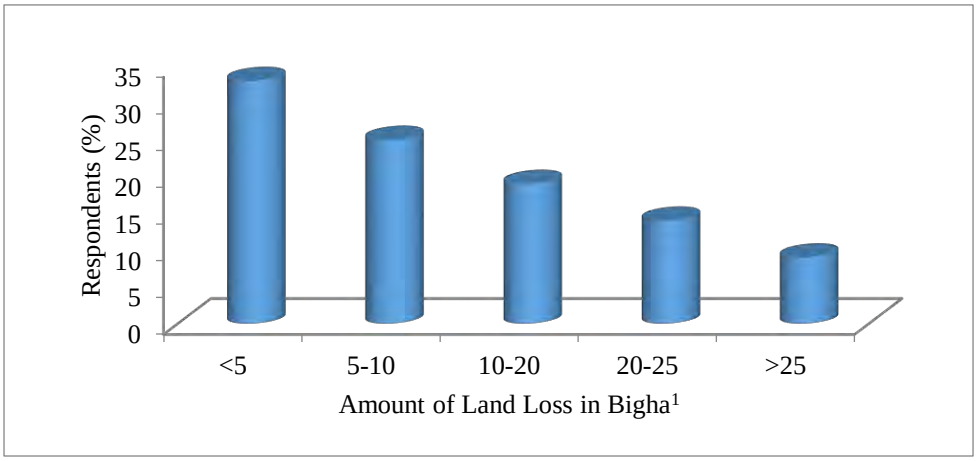


Figure 4: Amount of Land Loss of the Surveyed Households

Field Survey, October-November 2022 and 2023

Note: Bigha[1] is an Indian unit of land measurement (1 Bigha =0.25 hectare)

After losing their land and other assets, they are facing a severe economic crisis because they have lost their other economic setup, such as the silk industry and business establishments, etc. As a result, they are in a state of utter financial uncertainty. Most of the displaced people became destitute as they have lost almost all immovable properties, material resources and assets and are suffering from extreme forms of poverty. After loss of financial and employment setup, they are exposed to massive unemployment, and consequently become rudderless and economically unstable. As a result, most of them are suffering from extreme financial crises. The majority of the workforce have become daily wage earners. **Table 4** shows mean monthly per capita income of the displaced households is Rs. 2354.76, while both the median and modal income are Rs. 2000.00, which is very low when compared to the monthly per capita Gross National Income (GNI) of the country (Rs. 17748.42) as per the financial year 2023-24 (Government of India, 2025).

As they have lost their occupational establishments, many of them have changed their usual and familiar work and are bound to adopt some uncommon jobs as their profession. **Figure 5** shows that before becoming ERs, the people of the study area were mainly dependent on agriculture, in which about 60 per cent of households were

economically dependent on cultivation in the form of crop cultivation, mango, mulberry and other fruit cultivation.

Table 4. Descriptive statistics of per capita monthly income of the households

	N	Minimum	Maximum	Mean	Median	Mode	Std. Deviation	Range
Per Capita Monthly Income of Households (Rs.)	100	1000.00	6333.33	2354.76	2000.00	2000.00	961.21	5333.33
Valid N (list-wise)	100							

Source: Field Survey, October-November 2022 and 2023

Basically, the landless people managed their livelihood as daily wage earners by engaging themselves in different types of informal jobs, while 6 per cent of households had business as their main source of income.

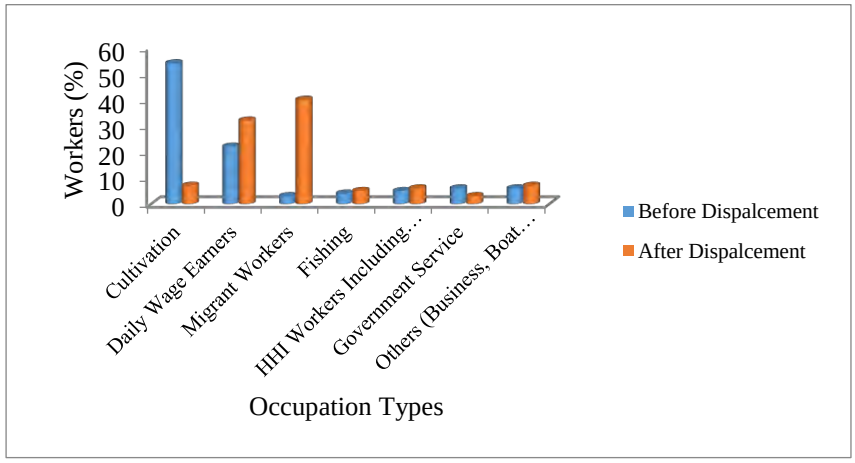


Figure 5: Main Occupation of the Surveyed Households, *HHI denotes Household Industry

Source: Field Survey, October-November 2022 and 2023

A majority of the young male workforce became migrant labour. They are used to going to even far-flung states such as Jammu and Kashmir, Assam, Meghalaya, Mizoram, Gujarat, Delhi, Maharashtra, Kerala, Karnataka, Tamil Nadu, Andhra Pradesh, Telangana, etc., in search of jobs. These workplaces are completely unknown to the migrant workers; they face unpredictable problems due to their unfamiliarity with the new environment. Such out migrant workers are unskilled in nature; hence, they engage themselves as rickshaw

pullers and porters in the market, labourers engage in earthwork, sand mining, construction workers, labourers also engage in construction and cleaning of sewer lines, construction of bridges, power transmission and mobile tower construction labourers, and fruit sellers, etc.

The bank erosion of the Ganges helps the district to gain the identity as 'the Supply Source of Cheap Labour' of the country. The duration and availability of jobs for these out-migrant labourers are highly uncertain. In some cases, they become marginal workers as they get jobs for less than six months a year. The respondents informed that these migrant labourers are facing several difficulties and problems at their workplace, such as extreme shortage of liveable space; consuming unsafe drinking water, malnutrition, unfamiliar language and culture, unhealthy living conditions, and lack of medical facilities, as they are compelled to stay together in an unsafe small tent or room at their workplace. As a result, they lead extremely sub-human lives. Many migrant labourers died due to fatal accidents such as building collapse, falling from towers and buildings, various uncommon and infectious diseases, etc. From the FGD, it was found that 9 migrant labourers who are ERs of the Manikchak C. D. block of the riverine tract of the Ganges were killed due to a multi-storied building collapse at Byculla region of Mumbai on the 31st August 2017. In fact, the Byculla region of Mumbai has become a big colony of the migrant labourers, the displaced people of Malda district. In many cases, they come back to their home carrying difficult-to-treat diseases. Besides these, sexually transmitted diseases are also common among them. On the other hand, their spouses and siblings also lead a sub-standard type of life in their fragile residences because of the absence of guardians. Very often, they have been cheated by the *Thikadar* (labour contractors), private companies, occupants, *Dofadar* (labour gang leader), *Munshi* (Labour supervisor), etc., and they are harassed by local people at their workplace, suspecting them of being Bangladeshis as the majority of them are Muslims, and they speak Bengali. Despite these severe problems, they are compelled to work as migrant labourers throughout the country in search of a livelihood to support their families. **Figure 6** depicts the types of occupation of migrant workers. The majority of the migrant workers (51 per cent) are engaged in electric and mobile tower construction (E.M.T.C.), whereas in building and bridge construction, the share is 20 per cent and 9 per cent, respectively. Thus, the migrant workers primarily become construction workers.

Table 5 exhibits the minimum and maximum average monthly income of the migrant workers at the tune of Rs. 6000 and Rs. 20000, respectively, whereas the average monthly income is Rs. 9780. This small amount is highly insufficient to meet the basic needs of their families.

Table 5. Descriptive statistics of monthly income of the migrant workers

	N	Minimum	Maximum	Mean	Std. Deviation
Average Monthly Income of Migrant Workers (Rs.)	100	6000	20000	9780.00	2736.140
Valid N (list-wise)	100				

Source: Field Survey, October-November 2022 and 2023

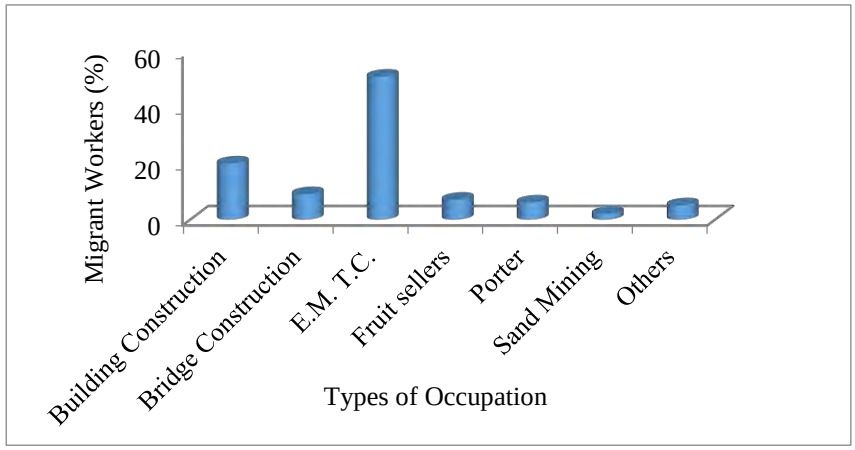


Figure 6: Types of Occupation of Migrant Workers

Source: Field Survey, October-November 2022 and 2023

The scatter diagram **(Figure 7)** discloses the negative linear relation between the 'size of the households' and 'monthly per capita income' (Rs.) of the displaced people. It shows a moderate negative correlation between the variables, which is statistically significant at the 0.01 significance level (2-tailed). It comprehensively indicates that the bigger the household size, the lower the monthly per capita income. As these riparian people are poverty-stricken due to riverbank failure and the recurrence of floods for decades, large families are considered by them an asset. They usually think that more hands mean more income, as most of them believe in hand-to-mouth living, and these misconceptions put them in a vicious cycle.

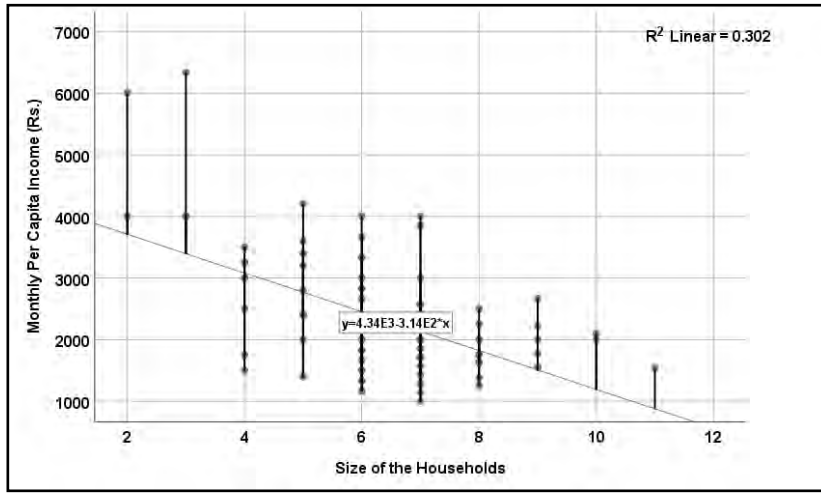


Figure 7: Graphical Representation of the Linear Correlation between the Household Size and Monthly Per Capita Income (Rs.)

Source: Field Survey, October-November 2022 and 2023

The ERs become destitute by losing productive agricultural land, jobs, business establishments, and even their permanent shelter, and they are forced to adapt to new jobs for survival, new places for residence, etc.

Table 6. Distribution of economic indicators adopted by environmental refugees (% of sample)

Daily Per Capita Income of the Household (Rs)	Less than 100	100-200	Above 200
% of Respondents	21	66	13
Income Satisfaction	Satisfied	Dissatisfied	Highly Dissatisfied
% of Respondents	13	39	48
Job Satisfaction	Satisfied	Dissatisfied	Highly Dissatisfied
% of Respondents	26	42	32
Employment opportunity	Very Low	Low	Moderate
% of Respondents	64	22	14
Loan Opportunities	Very Low	Low	Moderate
% of Respondents	55	33	12
Living Conditions	Satisfied	Dissatisfied	Highly Dissatisfied
% of Respondents	7	29	64

Source: Field survey during October – November 2022 and 2023

Table 6 illustrates the economic struggles and their level of satisfaction, in which 87 per cent of respondents reported low income, 87 per cent of them expressed either dissatisfied or highly dissatisfied with their present livelihood and income, while 74 per cent expressed either dissatisfaction or highly dissatisfied with their present jobs. They also reported that they have limited employment and institutional credit facilities, and are highly dissatisfied with their present living conditions.

5. Policy Recommendations and Implications

5.1 Summary of Findings

This study depicts how the LBE of the Ganges in Malda district has transformed a once agriculturally prosperous region into an area marked by widespread displacement and economic distress. Continuous eastward shifting of the Ganges has engulfed thousands of acres of highly productive farmlands, hundreds of inhabited villages, uprooting more than 80000 households and compelling them to relocate multiple times. The IDP people have lost their homesteads, firms and livelihood bases and become Environmental Refugees within their own homeland.

The economic consequences are extremely critical as it has destroyed agricultural livelihoods and diminished employment opportunities. They are facing absolute poverty and are trapped in vicious cycles. After losing their movable and immovable properties and assets, a large section of the working force became migrant manual labourers working in

unknown and distant places under precarious conditions. They are living in remotely located and isolated places, which are highly vulnerable to natural disasters like floods, cyclones, bank erosion, etc. and leading substandard lives with uncertain livelihoods.

5.2 Reasons for Failure of Previous Interventions

The persistence of severe LBE in Malda despite decades of the state's interventions demonstrates that the previous measures have largely failed to mitigate the problem due to certain reasons-

As per the insights of FGDs and KIIs, multiple government departments and agencies, such as the Department of Land Reforms, Irrigation & Waterways, and Disaster Management authorities, have worked independently, often without proper coordination, which has resulted in overlapping and conflicting mandates, bureaucratic delays and inconsistent implementation.

Most of the interventions, such as the construction of kaccha (earthen) embankments, sporadic boulder dumping, bamboo piling, sandbags, etc., were temporary and implemented only during severe erosion, which was washed by the strong current of the Ganges. A combination of central-state, inter-state and intra-state political turmoil, administrative neglect, delayed allocation or discontinuation of funds has also led to an uncoordinated and inconsistent response to the crisis that has destroyed lives and livelihoods and displaced thousands of households. Previous policies didn't focus on the complete socio-economic rehabilitation of the internally displaced households. Most of the displaced households relocated to the fragile, retired embankments and unsafe flood-prone zones without stable lives and livelihoods, education and healthcare facilities.

Moreover, affected local people, the primary stakeholders, in planning and decision-making is a critical factor in the failure of previous states' interventions of mitigation measures. This top-down approach often neglects the vital indigenous knowledge that has led to local community mistrust and mismatched solutions.

5.3 Realistic and Inclusive Policy Recommendations

The policy measures are recommended to address LBE of the Ganges and its impacts on the lives and livelihoods of the IDPs. The LB of the Ganges between Rajmal and the Farakka Barrage is the oscillation zone, which experiences severe bank erosion almost every year during the monsoon and post-monsoon seasons. To address this problem, the government may take preventive measures, such as bank protection and cleaning of alluvial deposits through regular dredging, mainly from the upstream of the Farakka Barrage, to maintain the river’s navigability and discharge of excess water during the rainy season, which is the need of the hour. Though dredging is widely recommended, it’s not a completely risk-free and long-term solution. If these are not scientifically planned and designed or properly executed and maintained, they can alter river dynamics significantly, accelerate sedimentation, and intensify downstream flood and erosion events.

Moreover, the regular dredging may not be budget-friendly as its cost is very high, approximately Rs 1.2 crore per km as seen from the Inland Waterways Authority of India (IWAI) for the works stretching Sultanganj–Mahendrapur and Mahendrapur–Barh in Bihar (Dredge Wire, 2024).

Alternatively, riparian forestations, vegetative bio-engineering, and flood plains restoration are effective measures for the stabilisation of riverbanks naturally and improving ecological health resilience. But Bioengineering works too are quite expensive, and it may cost roughly Rs. 2.2 crore (including coir + geotextile blanket + vetiver grass plantation) per km of river bank as found in the case of Vishwamitra Project, Gujarat (The Times of India, 2025). 'Soft Bank Protection' - Soft bio-engineered bank protection and revegetation costs may cost even ₹4 – 8 crore/km (World Bank, 2021).

A complete rehabilitation package must be implemented for the IDP households, including proper distribution of *Khasland* (vested lands) of the river bed through the administration, basic health infrastructure and services, distribution of subsidised foods through fair price shops (PDS), etc. Financial incentives and easy access to banking and other institutional credit can be very supportive of micro-scale entrepreneurship, as most IDPs are facing an economic crisis and need support to boost their livelihoods. Malda district, specifically the erosion affected region, is well-known for Mango cultivation. Vegetables (Tomato, Cabbage, Cauliflower), Sugarcane and Maize are also widely cultivated in the fertile riverine tract of the Ganges, but the cultivators are not getting the desired benefits due to mismanagement of these agricultural products. The state and the central government should establish agro-based industries, such as the food processing industry at Manikchak and Kaliachak-II C.D. blocks, to generate employment, particularly for the IDPs, which can arrest the migration of these ecosystem people. As the road connectivity and transportation system have been almost destroyed due to this erosion, and the displaced communities become isolated, the road must be rebuilt, and means of transportation such as buses, autos, etc., must be provided to restore the transportation system of the affected area. The restored and reconnected transportation can play a vital role in reviving the economy of this region.

Additionally, a few more steps may be taken to solve some problems of the erosion victims in the region. Immediate initiation of a joint survey by the Bengal and Jharkhand administrations, moderated and supervised by the central representative, to solve the problem of border dispute between West Bengal and Jharkhand is needed. To fix the boundary between the states permanently, it may be defined in terms of coordinates (latitude and longitude). Geospatial technology components such as GPS and satellite imagery may be employed in surveying and demarcating the boundary. The boundary as depicted in the Toposheet No. 72 P/13 (1:63360), published in 1924 by the Survey of India (British-India Government), may be considered as the basis of settling the border dispute. The Government of West Bengal must consider re-establishing the previously abolished Gram Panchayats of K. B. Jhaubona and Paranpur, as Hamidpur Gram Panchayat has already been re-established. Building a road running from Farakka to Barharwa to Piarpur,

or the Farakka-Taltala-Piarpur road are essential for the fast movement of vehicles to access services from mainland Bengal. The road may be built jointly by the Jharkhand and Bengal governments, as the road will be useful to the residents of both states. Similarly, the Government of West Bengal should initiate to supply electricity and may arrive at an agreement with the Jharkhand Government to supply electricity in the erosion-affected char area through Jharkhand. Establishing a police outpost at Piarpur will be very effective to rebuild the dismantled law and order condition, and also to root out the menace of antisocial activities. Jal Police with proper equipment is essential to achieve the goal of re-establishing the rule of law. It is necessary to convert the already existing (Hindi medium) schools into Bengali medium immediately, through recruitment of teachers by the Bengal Govt. in consultation with the Jharkhand government, which is the need of the hour to arrest dropouts substantially (Anwaruzzaman & Khatoon, 2012).The NGOs and district administration should make arrangements for counseling the IDPs to come out of social isolation, loss of identity and mental trauma resulting from repeated displacement. Besides this counseling, the government should provide vocational training such as basic computer courses, tailoring, boutique works, etc., which enables the youths to get various types of blue and white-collar jobs in their own state.

There are limitations of this study as it was carried out solely in the severely affected two C.D. blocks of Malda district. The data were collected through sampled HHS, FGD and KII, which cannot encompass all the dimensions of the bank erosion-induced problems. Hence, the findings may not always be generalised, and all policy measures cannot be recommended to other erosion-prone areas of the states or the country. Temporal and spatial variation in erosion intensity and resultant displacement, land and economic loss at the micro-level, gender issues, and educational crisis could not be fully assessed due to unrecorded and a lack of official data. This study recommends that there is a huge scope for further comparative analysis in multiple erosion-prone areas of West Bengal, India and neighbouring countries, focusing on the displacement of households and socio-economic challenges, the differential impact of erosion on women, children and elderly people, to provide a more comprehensive socio-economic model of riverbank erosion-induced displacement dynamics.

Acknowledgements: The authors would like to express their deep sense of sincere gratitude to the Environmental Refugees who have shared their socio-economic problems and pains which are associated with their daily life and livelihoods. The authors are also grateful to the Key Informants who have provided in-depth, relevant information on the study area.

Funding: No funding was received for this research from any source.

Declaration: The authors declare that we have no known conflict of interest and no financial assistance in any form is received for this work. The authors also declare that there is no personal or political communication that could have materialised to influence the work reported in this paper.

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The Indian Geographical Journal
Volume 100 (2) Dec - 2025, pp 200-213
ISSN 0019-4824

SOCIO-ECONOMIC DETERMINANTS OF EMPOWERMENT LEVEL OF THE FEMALE DOMESTIC WORKERS OF THE MUNICIPAL AREAS OF THE COOCH BEHAR DISTRICT, WEST BENGAL: A CROSS-SECTIONAL STUDY

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Abstract

Domestic work is one of the most common jobs for rural women in Cooch Behar, yet little is known about how much control these women have over their own lives. This cross-sectional study looks at the socio-economic factors linked to empowerment among 317 female domestic workers who travel from rural areas to work in the district's six municipalities. We interviewed them between February 2019 and January 2020. Socio-economic status was scored using the Revised Udai Pareek scale and empowerment was measured through 14 questions covering mobility, political participation, use of income, and decision-making, and combined into a single score using the TOPSIS method. We analysed the data with chi-square tests and logistic regression. About 80 percent of the surveyed domestic workers belongs to the lower socio-economic class. Many of the study participants had limited empowerment on savings (67%), visiting a bank/an ATM (39%) and spending for essentials such as their children's education (54%) or medicines (59%). Yet most (>80%) could decide what to buy for the household, whether to change employers, and how to spend their own earnings. The analysis based on TOPSIS score suggests that 39 percent surveyed individuals were under 'low empowerment level'. No significant association was observed between marital status and empowerment level. Part-time work and longer experience also raised the odds. Better legal protection, working conditions, and access to financial services could help these women gain more control over their lives.

Keywords: Domestic Workers; Decision Making; Empowerment; Freedom; TOPSIS

Introduction

Domestic workers account for a significant portion of the labour force in the informal sector of Indian society (Kuriakose and Iyer, 2016). A domestic worker, also known as domestic help, performs several household chores such as cleaning utensils, washing

clothes, cooking, and, to some extent, babysitting in exchange for wages or sometimes in kind, depending on the requirements of the employer (ILO, 2018). To alleviate their economic burden, they continue to work tirelessly for prolonged hours in multiple households in return for comparatively meagre wages (Kuriakose and Iyer, 2016; ILO, 2018). Their income does not justify their workload (>8 hours daily), hampers their living standard, and compels them to seek other benefits. Even in their occupation, the domestic workers are not entitled to receive sick leave or paid leave, pension schemes, etc (Bhattacharjee and Goswami, 2020). Hence, the deprived workers always remain at the very bottom level of socio-economic status. However, it is surprising to know that the domestic workers, in both their domestic and occupational spheres, experience far more disastrous situations than economic burden. The list includes not only their extreme physical exertion, poor health, and malnutrition (Kundu, 2008) but also exploitation in the labour market (Majid, 2000), maltreatment from their employers (Neetha, 2008), and discrimination in the workplace. In the absence of appropriate legal and regulatory provisions, all these facts indicate that the domestic workers are in an underprivileged situation, and this call for a deeper understanding of their level of autonomy in both the domestic and occupational spheres and what factors influence them.

The present study takes the opportunity to explore both the aspects, *viz.,* socio-economic status, and level of autonomy of the domestic workers working in the municipal areas of Cooch Behar district. Cooch Behar district is not only located in the northern part of West Bengal but also shares international borders with Bangladesh and Bhutan, as well as state borders with Assam and other districts of West Bengal (Hoque and Kalita, 2021). The economy of the Cooch Behar district is generally governed by agriculture, which is driven by the cultivation of rice, jute, and tobacco, supported by rivers such as the Teesta and Jaldhaka (Meitei, 2021). Despite its fertile land, the district faces recurrent floods that disrupt agriculture, along with poor infrastructure and limited industrialisation. These challenges have led to significant male out- migration to urban centres. These limitations lead the Cooch Behar district to high-poverty regions, with poverty levels exceeding the West Bengal average (Kamal, 2009). An even lower literacy rate among rural females has often been encountered in the district. This combination of poverty, low literacy, and environmental vulnerability underscores the rural crisis in the study area. In this scenario, most of the female workers from rural areas came for household chores in the different municipal areas of the Cooch Behar district (Mahalanabis, 2012). The objectives of the present study are to investigate their socio-economic status and to understand their level of empowerment in various lifestyle aspects, as well as to identify the factors behind the level of their empowerment.

Methodology

Study design

The present cross-sectional study was conducted in six urban municipal areas of the Cooch Behar district over a period of one year, from February 2019 to January 2020,

except during the Monsoon (May-July). The sample constituted only the adult female domestic workers who worked at the households of these urban municipal areas but lived in the adjacent rural parts of the district. The female domestic workers are unable to attend work during the monsoon season due to heavy rainfall. The continuous downpour has created difficult travel conditions, making it unsafe and inconvenient for them to reach their workplace. The survey was conducted by the lead author, who visited the domestic workers either at their homes or at a separate location. Data were collected through a semi-structured interview using standard schedules (in vernacular language, Bengali).

Sampling strategy

Multi-stage sampling was performed to select the study participants. In the first stage, around two-thirds of municipal wards in each municipality were randomly selected. At this stage, a total of 52 wards with 4346 households (Cooch Behar = 14 wards; Dinhata = 10 wards; Mathabhanga = 07 wards; Mekhliganj = 06 wards; Haldibari = 07 wards; Tufanganj = 08 wards) were included in the study. In the next stage of the sampling, around one-tenth of the households (HH) in each ward were randomly selected. Later, a door-to-door survey was done in every household to identify potential study participants (Inclusion criteria: Rural domestic workers working in these urban HHs). Among those, nearly 30 percent of HHs (n=1303) were inaccessible at the time of the survey, 38 percent of HHs (n=1651) had no domestic workers, and 22 percent of HHs (n=956) had domestic workers coming from the nearby urban pockets. At this stage, only 405 HHs were identified where rural female domestic workers were engaged. The interviewer directly approached the domestic workers and informed them about the purpose of the visit. Finally, 317 female domestic workers volunteered to participate in the study. The response rate was high (78.2 percent). To our advantage, most of the households had female domestic workers, working for very low wages. They did not receive any additional support or benefits from the government. As a result, most of the female domestic workers willingly provided information to the researcher according to her requirements, hoping to receive some facilities or benefits from the government in the future. However, informed consent was obtained from the participants before enlisting them for the research and the interview.

Data Collection

Socio-demographic data

Data on the socio-demographic profile were obtained using a pre-designed questionnaire by the lead author. Data such as current age (in years), religion, caste, type of family and household they live in, family size, marital status, experience of domestic work, duration of daily work, and monthly income were collected (See Tables 1 & 3).

Socio-economic status (SES) of the female domestic workers was measured by the 'Revised Udai-Pareekh SES scale', designed exclusively for the rural population of India (Wani, 2019). The scale used nine items, viz., caste, occupation, education, land acquisition, social participation, house type, farm power, material possession, and family

size, to assess the SES. Each item in the list had respective categories and scores assigned to it. For example, the 'Caste' variable had six categories. Those are scheduled caste (Score=1), lower caste (Score=2), artisan caste (Score=3), agriculture caste (Score=4), prestige caste (Score=5), and dominant caste (Score=6). Later, all the scores from the nine items were summed up to the final SES score. Finally, the scores were grouped into SES classes (*See* Table 2), following the revised *Udai-Pareekh* scale (Wani, 2019).

Table 1. List of variables used in the study and respective categories

Variables	**Categories**
Age group	[1] >50 years and above [2] 31-50 years [3] ≤30 years
Marital status	[1] Married [2] Divorced or Separated [3] Widowed
Family type	[1] Joint [2] Nuclear
Religion	[1] Hindu [2] Muslim
Experience of domestic work (in years)	Continuous data
Duration of work (in hours/day)	
Monthly income level	[1] Up to ₹ 3000 ($42) [2] ₹ 3000-4000 ($42-55) [3] More than ₹ 4000 ($55)

Empowerment level

Empowerment was measured by the level of freedom in four lifestyle aspects using a pre-designed schedule, which contained 14 items with a 5-point Likert Scale response. The items in the schedule were prepared in vernacular language (in Bengali) for a pilot survey. A pilot survey was conducted on a total of 40 female domestic workers for the reliability and applicability of the questionnaire. The schedule revealed a good internal consistency (Cronbach's $\alpha = 0.738$). The items in the questionnaire were the level of freedom of mobility in terms of visiting a bank and ATM, health care centre, and a relative's house, the level of freedom to political participation in terms of participating in rally, campaigning for political parties and volunteering as a cadre, the level of freedom to utilise

money in terms of savings, child's education, buying household essential, buying medicines and spending on occasion/festivals, and the level of freedom to decide terms of product purchase, changing employer, and spending income on self. All the items had five responses: 'Never', 'Rarely', 'Moderately', 'Often', and 'Always' (*See* Table 4).

Table 2. Items and categories of Revised Udai-Pareekh SES Scale

Revised Udai-Pareekh SES Scale		
Item	Categories (Score)	SES Scale
Caste	Scheduled caste (1); Lower caste (2); Artisan caste (3); Agriculture caste (4); Prestige caste (5); Dominant caste (6)	Upper Class (>43) Upper-middleclass (33-42) Middle (24-32) Lower middle (13-23) Lower (≤13)
Occupation	None (0); Labourer (1); Caste occupation (2); Business (3); Independent service (4); Cultivation (5); Service (6)	
Education	Illiterate (0); Can read only (1); Read and write (2); Primary (3); Middle (4); Highschool (5); Graduate (6); Above (7)	
Land	No land (0); <one acre (1); 1-5 acre (2); 5-10acre (3); 10-15 acre (4); 15-20 acre (5); ≥20 acre (6)	
Social participation	None (0); In one organisation (1); In multiple organisations (2); Officeholder (3); Wide public leader (4)	
House	No house (0); Hut (1); Kutcha House (2); Mixed house (3); Pucca house (4); Mansion (5)	
Number of draught animals	None (1); 1-2 animals (2); 3-4 animals (4); 5-6 animals (6)	
Material possession	None/Animal-carried cart (0); Cycle (1); Radio (2); Chairs (3); Mobile phone (4); Television (5); Refrigerator (6)	
Family member	Up to 5 (2); >5(1)	

The level of overall empowerment was calculated through the TOPSIS (technique for order preference by similarity to an ideal solution) method using the 14 items of level of empowerment together (Opricovic and Tzeng, 2004). The method primarily assumes that every attribute increases or decreases in a monotonic function. Hence, the order of alternatives is generated through comparing the Euclidean distances. The basic principle of the TOPSIS method is that two hypothetical values based on the 14 items are created, known as the 'ideal solution' and 'negative solution'. Now, for each participant, a corresponding value (C^*) is generated, which falls between the ideal and negative solutions. Hence, the closer a C^* value is to the ideal solution (farther from the negative solution), the higher the empowerment level. The steps of the TOPSIS method are documented in detail elsewhere (Raju et al., 2020). In the present study, the median value (0.50) obtained from the C^* was used as the cut-off of empowerment level for the convenience of statistical analysis (See Table 5).

Analysis

Analysis was performed using SPSS version 21 (Babinec et al, 2017). Descriptive statistics of the study sample were measured by (a) mean and standard deviation (SD) for continuous variables, and (b) percentage distribution for categorical variables. Association between empowerment level and socio-demographic variables was measured by (c) Chi-square test (with p-value <0.10).

To identify the predictors of empowerment level, (d) the stepwise logistic regression was done. The dependent variable 'Empowerment level' had two categories - viz., Low (C^*<0.50), which was the experiment category, and High (C^*≥0.50), which was considered the reference category. The backward method was preferred to prevent the 'over-fitting' of the model and identify only significant contributors in the model. Coefficients (β) of predictor variables, their statistical significance (Wald), and the odds ratio (e^B) with a 95 percent confidence interval were measured. Assessment of overall model goodness-of-fit was done by the -2 log-likelihood statistics and Nagelkerke pseudo-R Square.

Table 3. Socio-demographic profile of the female domestic workers in the study (n=317)

Socio-demographic profile		
Variables		n (%)
Age groups	>50 years and above	56 (17.7)
	31-50 years	143 (45.1)
	≤30 years	118 (37.2)
Marital status	Married	168 (53.0)
	Divorced or Separated	62 (19.6)
	Widowed	87 (27.4)
Family type	Joint	106 (33.4)
	Nuclear	211 (66.6)
Religion	Hindu	255 (80.4)
	Muslim	62 (19.6)
Monthly income level	Up to ₹ 3000 ($42)	182 (57.4)
	₹ 3000-400 ($42-55)	93 (29.3)
	More than ₹ 4000 ($55)	42 (13.2)
SES	Lower middle class	63 (19.9)
	Lower class	254 (80.1)
Experience of work	14.28 years (SD=0.56)	
Duration of work	9.23 hours/per day (SD=0.10)	

Results and Discussion

The present section provides the analysis and description of the results of the present study based on the objectives. Table 3 shows the socio-demographic profile of the

317 female domestic workers presently studied. The majority of them belonged to the age group of 31-50 years (45.1 percent), were married (53.0 percent), belonged to a nuclear family (66.6 percent), and were Hindus (80.4 percent). A total of 254 participants (80.1 percent) belonged to the lower socio-economic class, while the rest of the participants (19.9 percent) belonged to the lower-middle socio-economic class. It was found that the mean duration of working experience of domestic work among the study participants was 14.28 years (SD=0.56), and the mean duration of daily working hours among them was 9.23 hours/day (SD=0.10).

Table 4. Female domestic workers' level of empowerment of freedom pertaining to several lifestyle aspects (n=317)

Level of empowerment in lifestyle aspects					
Variables	Never	Rarely	Moderately	Often	Always
	n (%)				
Freedom of mobility in terms of					
visiting a bank and an ATM	124 (39.1)	67 (21.1)	14 (4.4)	94 (29.7)	18 (5.7)
visiting a health care centre	84 (26.5)	116 (36.6)	22 (6.9)	72 (22.7)	23 (7.3)
visiting a relative's house	65 (20.5)	84 (26.5)	32 (10.1)	88 (27.8)	48 (15.1)
Freedom to participate					
in political rallies	133 (42.0)	1 (0.3)	57 (18.0)	28 (8.8)	98 (30.9)
in campaigns for political parties	148 (46.7)	4 (1.3)	69 (21.8)	30 (9.5)	66 (20.8)
in volunteering as cadres	118 (37.2)	4 (1.3)	67 (21.1)	34 (10.7)	94 (29.7)
Freedom to utilize income					
on future savings	212 (66.9)	37 (11.7)	62 (19.6)	3 (0.9)	3 (0.9)
on child's education	172 (54.3)	40 (12.6)	86 (27.1)	11 (3.5)	8 (2.5)
on household essentials	151 (47.6)	41 (12.9)	92 (29.0)	20 (6.3)	13 (4.1)
on medicine	186 (58.7)	48 (15.1)	73 (23.0)	3 (0.9)	7 (2.2)
on occasions/festivals	214 (67.5)	22 (6.9)	68 (21.5)	9 (2.8)	4 (1.3)
Free do make decisions on					
Household product purchase	1 (0.3)	0 (0.0)	1 (0.3)	35 (11.0)	280 (88.3)
Work-related issues	17 (5.4)	2 (0.6)	3 (0.9)	34 (10.7)	261 (82.3)
Spending money for self	8 (2.5)	4 (1.3)	1 (0.3)	29 (9.1)	275 (86.8)

Table 4 demonstrates the female domestic workers' level of empowerment in terms of pertaining to several lifestyle aspects. Around 39 percent of the study participants had no freedom of mobility to visit a bank and ATM alone. Out of all the study participants, approximately 27 percent had no freedom to visit a health care centre alone, and around 37 percent rarely had freedom to do so. Only 20.5 percent of the study participants never had the freedom to visit any relative's house alone.

The table further revealed that 42 percent of the study participants had no freedom to participate in any political rally. Moreover, around 46 percent had no freedom to participate in any campaign that was focused on promoting any political leader. A total of 118 participants (37.2 percent) had no freedom to volunteer as cadres. When asked if they had any freedom to utilise their earnings for some life aspects, 212 study participants (66.9 percent) reported that they had absolutely no freedom to save their earnings for the future. Around 54 percent of the participants reported that they had no freedom to spend it on their child's education. Moreover, 47.6 percent of them never had any freedom to utilise it for buying household essentials. It was revealed that either to buy medicines or spend on occasions/festivals, the majority of the study participants had absolutely no freedom.

However, on the contrary, most of the participants reported that they had complete freedom to decide about what products would be purchased for household needs (88.3 percent). Around 82 percent of the study participants reported that they could totally decide either to quit their work from any household or to work more. The majority of the participants had complete freedom to spend their earnings on themselves (86.8 percent).

Table 5 shows the classification of the level of empowerment among the domestic workers based on the TOPSIS score. Individuals with the TOPSIS score <0.50 were considered to have a 'Low empowerment level'. The sample size in this category was 122 (38.5 percent). Individuals with the TOPSIS score ≥0.50 were considered to have a 'High empowerment level'. The sample size in this category was 195 (61.5 percent).

Table 5. Level of empowerment based on the TOPSIS score

Variable	Score	Level of empowerment	Sample size
TOPSIS Score	<0.50	Low	122 (38.5%)
	>0.50	High	195 (61.5%)

Table 6 shows the distribution of the study participants based on their level of empowerment. In the younger group (≤30 years), around 60 percent had low empowerment. However, in the subsequent group, almost 72 percent of the participants had a low empowerment level (31-50 years). More than 85 percent of the participants in the older age group (>50 years) had low empowerment. Significant association was observed between age group and empowerment level ($\chi 2$ = 12.913). In the present study, approximately 65 percent of the married participants had low empowerment. Comparatively, among the divorced or separated and widowed participants, 74.2 and 73.6 percent had low empowerment, respectively. But no significant association was observed between marital status and empowerment level ($\chi 2$ = 2.599).

Table 6. Empowerment level of the female domestic workers by socio-demographic profile (n=317)

Variables		Level of empowerment		
		n (%)		Chi-square test for association
		Low	High	
Age group	>50 years and above	48 (85.7)	8 (14.3)	χ^2=12.913* *df*=2 (*p*<0.01)
	31-50 years	102 (71.3)	41 (28.7)	
	≤30 years	70 (59.3)	48 (40.7)	
Marital status	Married	110 (65.5)	58 (34.5)	χ^2=2.599 *df*=2 (*p*=0.273)
	Divorced and Separated	46 (74.2)	16 (25.8)	
	Widowed	64 (73.6)	23 (26.4)	
Family type	Joint	74 (69.8)	32 (30.2)	χ^2=0.013 *df*=1 (*p*= 0.509)
	Nuclear	146 (69.2)	65 (30.8)	
Religion	Hindu	174 (68.2)	81 (31.8)	χ^2=0.834 *df*=1 (*p*= 0.361)
	Muslim	46 (74.2)	16 (25.8)	
Monthly income level	Up to ₹3000 ($42)	136 (74.7)	46 (25.3)	χ^2=8.486* *df*=2 (*p*<0.014)
	₹3000-4000 ($42-55)	62 (66.7)	31 (33.3)	
	More than ₹4000 ($55)	22 (52.4)	20 (47.6)	
SES	Lower middle class	39 (61.9)	24 (38.1)	χ^2=2.080 *df*=1 (*p*= 0.149)
	Lower class	181 (71.3)	73 (28.7)	

*Significant at 0.05 level

Around 69 percent of the study participants who were either from a nuclear family or a joint family had low empowerment. The majority of the participants among the Hindus (68.2 percent) had low empowerment. Among the Muslim participants, the percentage was comparatively high (74.2 percent). However, the empowerment level was not significantly associated with family (χ2 = 0.013) and religion (χ2 = 0.834). In the present study, around

53 percent of the 'highest income level group' participants had low empowerment, followed by 66.7 percent of the participants in the 'middle income level group'. The participants of the 'lowest income group' reported around 75 percent of cases with low empowerment. The study observed a significant association between monthly income level and empowerment level ($\chi 2$ = 8.486). Around 62 and 71 percent of the participants from the lower middle class and lower class had low empowerment levels. No significant association was found between SES and empowerment level ($\chi 2$ = 2.080).

Table 7 showed the significant predictors of the level of employment of female domestic workers (dependent variable). The statistical model was a good fit (-2 log likelihood=50.913) and correctly predicted 87.2 percent of the dependent variable. The study findings indicated that female domestic workers who come from a nuclear family had a significantly higher chance of having a low empowerment level than the domestic workers coming from a joint family (OR=2.820, p<0.01). Domestic workers having higher levels of income had an increased chance of having a low empowerment level. The possibility of a part-time domestic worker having a low empowerment level increased 13-fold compared to full-time domestic workers. However, in the present study, the more experienced a female domestic worker was, the more she had the chance to have a low empowerment level (OR=2.071, p<0.01).

Table 7. Binary logistic regression showing the factors behind low empowerment level

Stepwise logistic regression (Forward LR)$^{\lambda}$					
Variables		B	Wald	e^B	95% CI
Family type	Joint	Reference category			
	Nuclear	1.037	1.574**	2.820	1.558-14.240
Monthly income level	Up to ₹ 3000 (Up to $42)	Reference category			
	₹ 3000-4000 ($42-55)	0.809	1.321**	2.247	1.047-4.819
	More than ₹ 4000 ($55)	0.344	0.692	1.411	0.627-3.177
Work type	Full timer	Reference category			
	Part timer	2.592	4.344**	13.358	1.167-152.885
Experience of domestic work (in years)		0.728	5.610**	2.071	1.134-3.784
-2 log likelihood					50.913
Nagelkerke R^2					0.765
Overall correct classification percentage					87.2%

Abbreviation: β = Coefficient value; e^B= Odds ratio.
Note: **Significant at 0.01 level; $^{\lambda}$Only significant predictors are presented.

The present study explored the domestic workers' empowerment level in terms of mobility freedom pertaining to some selected lifestyle aspects. The overall findings

highlighted that the majority had low empowerment related to mobility freedom. In our study, some of them reported that they had to take another family member (preferably male) to visit any place, such as a bank, ATM, or a health care centre. (Acharya et al., 2012) found in their study that women had limited mobility in their social circle, regardless of their socio-economic status. This finding strongly corroborates previous literature (Choudhry et al., 2019), which found that domestic employees have poor mobility-related empowerment. The possible reason for prevalent restricted mobility among the domestic workers may be poor education and job opportunities (Parmar, 2022), patriarchal control in the family and household or existing socio-cultural norms in the society (Uteng, 2012).

In India, women's participation in political issues and their freedom of expression in political matters have always been comparatively low. Our attempt was to know whether domestic workers, being able to earn through their work, have any freedom to participate in political issues. In the current study, the majority of workers had little involvement in local political issues and did not have the liberty to attend political activities or rallies. Moreover, a notable number of cases in our study revealed that the domestic workers had engaged neither in volunteering as cadres nor in campaigning for any specific political party. As Moghadam (2010) also suggested, the political empowerment in terms of either participating in political rallies or joining politics is influenced by the notions of masculinity and femininity in different spheres of society, like in family, labour market, and the polity, which explains that rural women had a very limited personal autonomy and a lack of knowledge or understanding of politics (Moghadam, 2010).

The domestic Ghatak and Sarkar (2022) workers were further asked whether they utilised their money for future savings, on children's education, to buy household essentials or medicine, or to spend it on occasions/festivals. Surprisingly, they had low empowerment for utilising money and no freedom to spend their money on household necessities, the education of children, the purchase of medicine, or even on occasions. This finding is strongly supported by another previous literature and the study of Bhattacharjee and Goswami (2020), who observed that female domestic workers have less authority over the household economy. The work of Agrawal (2023) explains that the decision-making tendencies related to utilising the money among the domestic workers often depend on the decisions of the husband or the elderly in the family.

Domestic workers' decision-making authority on household product purchase, occupational matters, and spending income on themselves was further explored. It was also found that women have low decision-making authority in household and other lifestyle matters, which was not the case for domestic workers in the present study. On the contrary, the majority of the participants reported that they had complete liberty to determine where and when to work, whether to continue working or leave, and how much money to earn. Moreover, they had complete freedom to spend their earnings for themselves and also the freedom to make household purchases. Interestingly, this finding contradicts the few earlier works that pointed out major factors such as low authority in the household, weak bargaining power, and overdependence on the spouse as some of the reasons behind low

freedom of deciding for household purchase (Bhattacharya and Goswami, 2020; Goel Chakravarty, 2023).

Overall, the findings strongly suggest that the domestic workers' understudy had a very low level of empowerment. Because domestic employees had access to and control over their earnings even after meeting family demands, their income level had a substantial influence on their empowerment. Age and marital status also had a great impact. The findings of the study are in line with previous studies by Gaye and Jha (2011). In the present study, most of the younger domestic workers (under 30 years) had a high empowerment level compared to the older age groups. It is probably due to the level of education among the younger workers, while most of the older workers either had no formal education or had a very low level of education (Bhattacharya and Goswami, 2020). The study further suggests that the majority of the workers, who were in wedlock, were more empowered. It was most likely due to the level of support they received from their husbands to continue their job or to decide on some household matters, like product purchase. Basak and Gupta (2018) emphasise that sustainable development requires ensuring women's autonomy in both domestic and social spheres. Although India's Ministry of Labour and Employment has proposed a National Domestic Workers Policy, it has not yet been enacted (Beri, 2020). The case study highlights the urgent need for empowerment initiatives to strengthen workers' rights and decision-making power.

Conclusion

A comprehensive policy for domestic workers empowerment must function across three dimensions: structural protection (laws, fair wages, social security), economic empowerment (income control, financial inclusion), and social–gender empowerment (decision-making, dignity, bargaining power). Findings from Cooch Behar highlight the urgent need for legal protection, improved working conditions, and empowerment initiatives to reduce wage inequality and strengthen domestic workers' rights and decision-making power.

Acknowledgments

The authors are indebted to the respondents for their wholehearted contribution to the survey. The pivotal roles of respective authorities of the Department of Geography, Cooch Behar Panchanan Barma University (CBPBU) in providing logistic support are appreciated as well. Sincere thanks go to the respected editor of the journal and the respected reviewers for their valuable feedback and support.

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Volume 100 (2) December - 2025, pp 214-215
ISSN 0019-4824

News and Notes

IGS TALENT TEST 2026

The Indian Geographical Society is organising the State-wide 16th Talent Test for Young Geographer – 2026 for the final year UG and PG students of Geography Departments in Tamil Nadu on 07th January, 2025 (Tuesday) through online mode. The Executive Committee of the Society, through the Coordinator, is organising this event with the support of Head of the Colleges/Institutes/Geography Departments.

It is requested the Head of the Geography Departments to share the registration link https://forms.gle/ubHEntH3VEeN8YsK9 to students for registering themselves for participating in the Talent Test. Further, the HODs are requested to send softcopy of the list of final year UG and PG students with their Names and Registration Numbers to the Coordinator for verification and also to provide e-Certificate to the eligible participants.

Name of the Departments in Universities and Colleges of Tamil Nadu which are likely to participate the 16th IGS Talent Test (for final year UG and PG students)	
1.	Department of Geography, University of Madras, Chepauk, Chennai – 600 025
2.	Department of Geography, Madurai Kamaraj University, Madurai - 625 021.
3.	Department of Geography, Bharathidasan University, Tiruchirappalli - 620 024.
4.	Department of Geography, Central University of Tamil Nadu, Thiruvarur-610 005
5.	Department of Environmental Remote Sensing and Cartography, Madurai Kamaraj University, Madurai - 625 021
6.	Department of Geography, Presidency College (Autonomous), Chennai-600 005.
7.	Department of Geography, Queen Mary's College (Autonomous), Chennai-600 004.
8.	Department of Geography, Bharathi Women's College (Autonomous), 85, Prakasam Salai, Chennai - 600 108.
9.	Department of Geography, Tourism and Travel Management, Madras Christian College (Autonomous), Tambaram, Chennai - 600 059.
10.	Department of Geography, Government Arts College (Autonomous), Salem – 636 007.

11.	Department of Geography, Arignar Anna Government Arts College, Namakkal – 637 002.
12.	Department of Geography, Sri Vijay Vidyalaya College of Arts and Science, Nallampalli, Dharmapuri – 636 807.
13.	Department of Geography, PSA College of Arts and Science for Women, Sollaikottai, Naickanahalli, Dharmapuri – 636 704.
14.	Department of Geography, Government Arts College (Autonomous), Coimbatore - 641 018.
15.	Department of Geography, Nirmala College for Women (Autonomous), Coimbatore – 641 018.
16.	Department of Geography, Bharathiar University Arts & Science College, Amaikulam, Puliam Parai (P.O.), Gudalur - 643 212.
17.	Department of Geography, Government Arts College (Autonomous), Karur – 639 005.
18.	Department of Geography, Periyar E.V.R. College (Autonomous), Tiruchirappalli – 620 023.
19.	Department of Geography, Government Arts College, Thiruverumbur, Tiruchirappalli – 620 022.
20.	Department of Geography, Kundavai Nachiar Government Arts College for Women (Autonomous), Thanjavur -613 007.
21.	Department of Geography, A.V.V.M Sri Pushpam College (Autonomous), Poondi, Thanjavur - 613 503.
22.	Department of Geography, Government Arts College for Women (Autonomous), Kumbakonam - 612 002.
23.	Department of Geography, Sri Meenakshi Government Arts College for Women (Autonomous), Madurai – 624 002.
24.	Department of Geography, MVM Government Arts College for Women, Dindigul - 624 008.
25.	Department of Geography, Government Arts College for Women, Nilakottai, Dindigul - 624 208.
26.	Department of Geography, Government Arts and Science College for Women, Orathanadu, Thanjavur - 614 625.
27.	Department of Geography, Vellalar College For Women (Autonomous), Thindal, Erode - 638 012

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The Indian Geographical Journal
Volume 100 (1&2) 2025
ISSN 0019-4824

Statement about ownership and other particulars about
THE INDIAN GEOGRAPHICAL JOURNAL
Department of Geography, University of Madras, Chennai - 600 025

Form IV

1. Place of Publication	University of Madras, Chennai
2. Periodicity of its Publication	Bi-annual
3. Printer's Name Nationality Address	A. Paghyaselvam Indian J.J. Printers, 4/726, P.S.K., Nager Hussain Colony Pallapatti - P.O., Sivakasi - 626 189
4. Publisher's Name Address	The Indian Geographical Society Department of Geography University of Madras, Guindy Campus Chennai - 600 025
5. Editor's Name Nationality Address	Dr. K. Kumaraswamy Indian Department of Geography Bharathidasan University Tiruchirappalli - 620 024
6. Names and Address of Individuals who own the journal and society	The Indian Geographical Society Department of Geography University of Madras Guindy Campus Chennai - 600 025

I, K. Kumaraswamy, hereby declare that the particulars given above are true to the best of my knowledge and belief.

Dr. K. Kumaraswamy
Editor, The Indian Geographical Journal