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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.

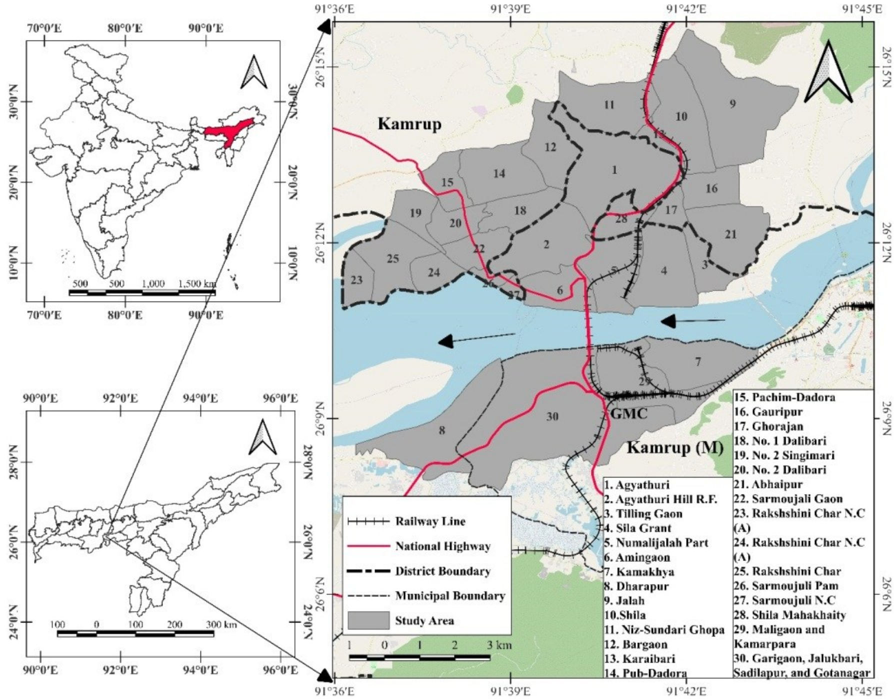

Figure 1: Study Area (Guwahati city and neighbouring areas) in Assam, India

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 (α), Beta Index (β), Gamma index (γ), and Eta index (η)

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.

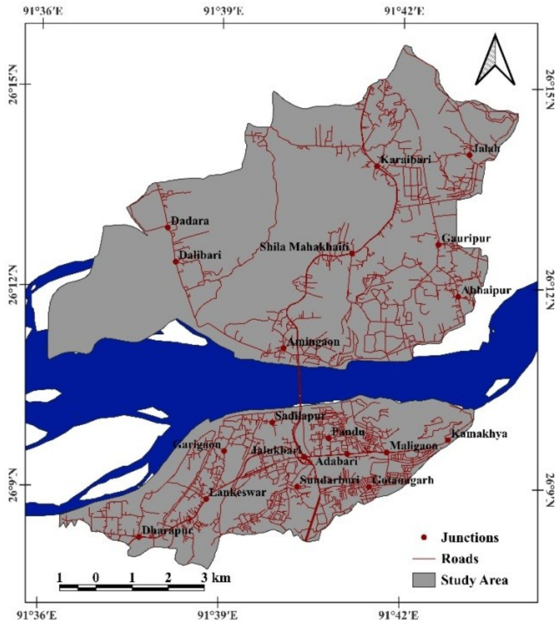

Figure 2: Junctions for calculating geographical accessibility

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.

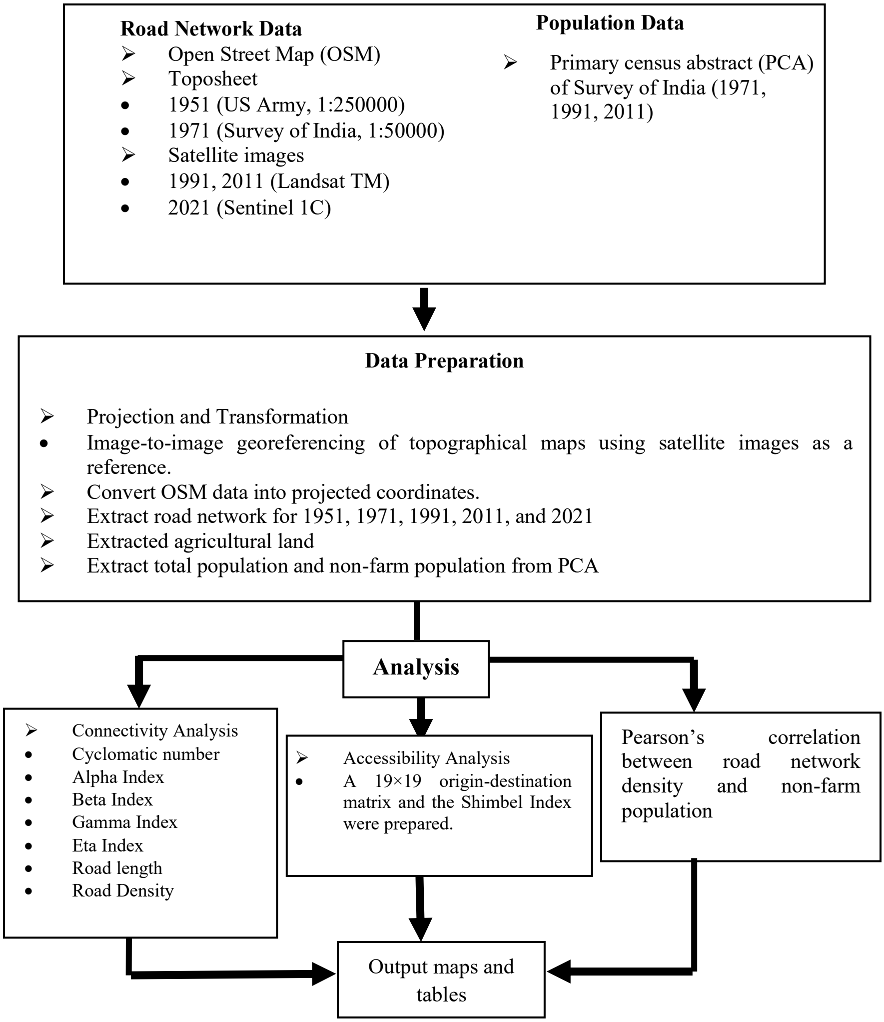

Figure 3: Flow chart of methodology of the study

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.

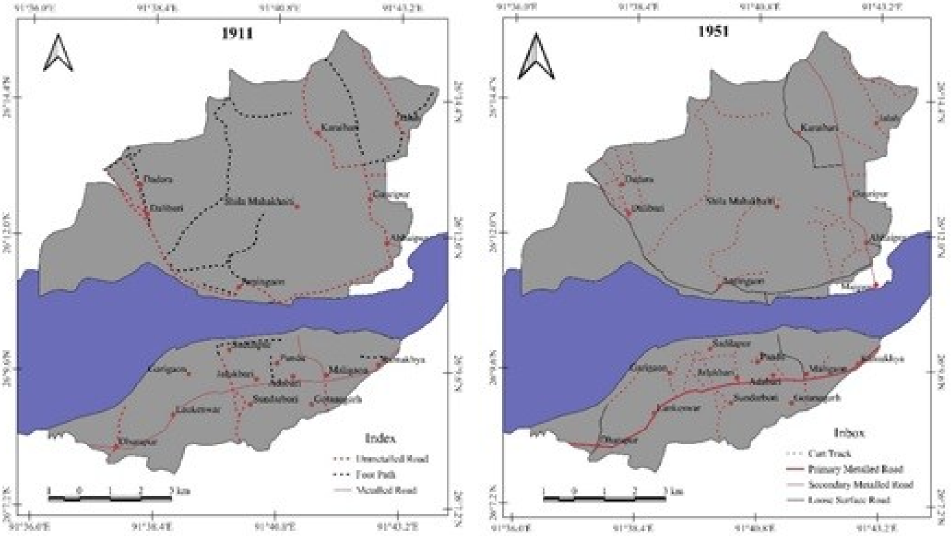

Figure 4: Road Networks of the neighbouring areas of the Saraighat Bridge in 1911 and 1951

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.

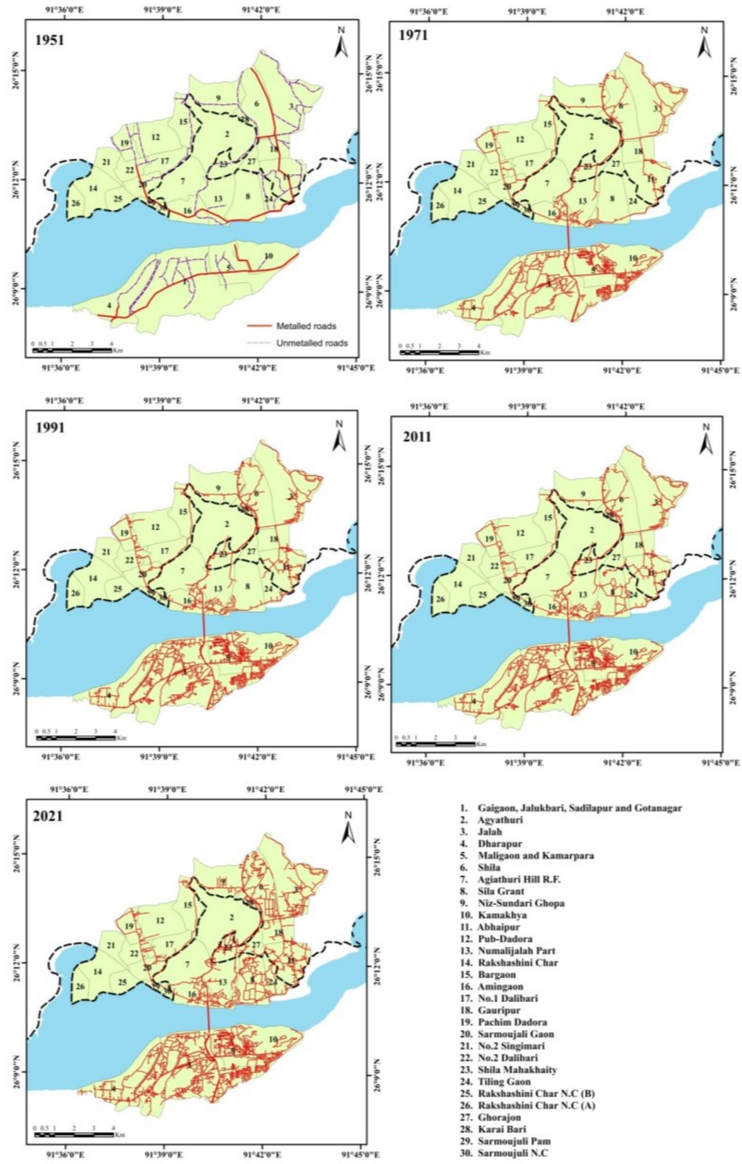

Figure 5: Temporal change of road network in the neighbouring areas of the Saraighat Bridge.

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.

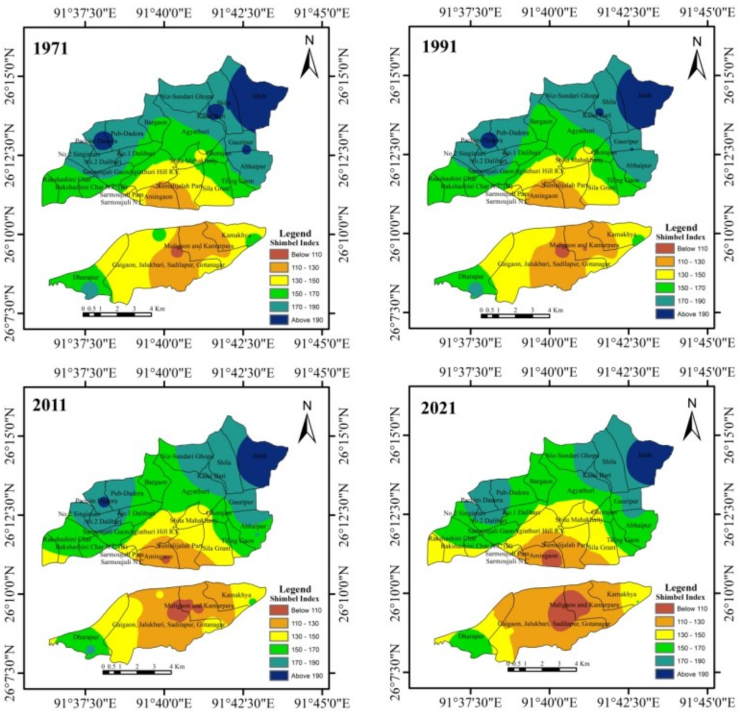

Figure 6: Temporal change of geographical accessibility of the neighbouring areas of the Saraighat Bridge.

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.

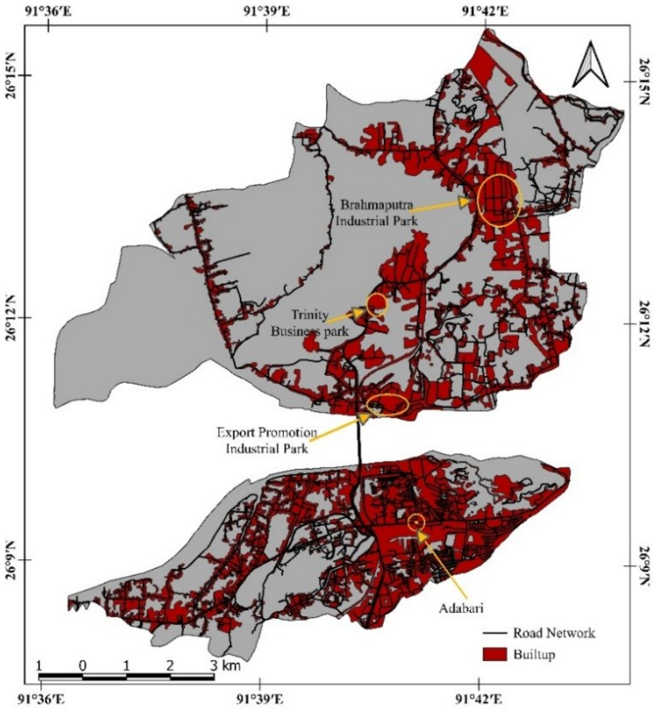

Figure 7: Growing urban area and industrial regions of the surrounding areas of the Saraighat bridge

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.

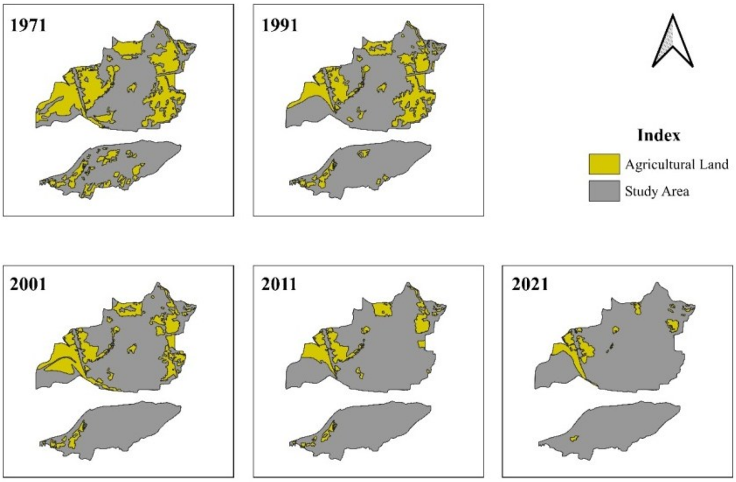

Figure 8: Temporal change in agricultural land in the area around the Saraighat Bridge

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.

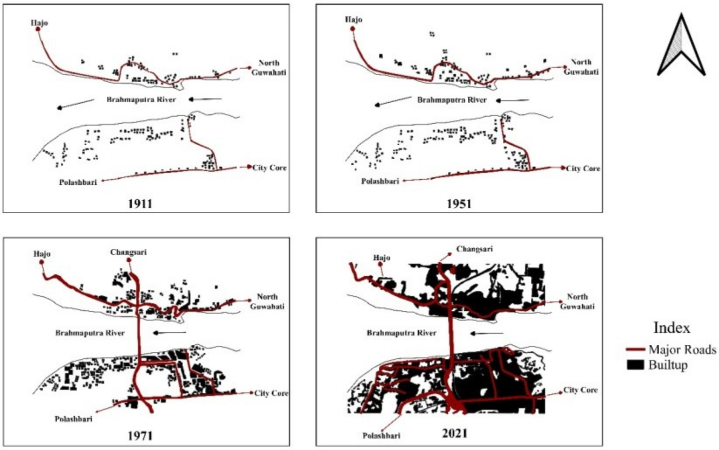

Figure 9: Increasing built-up density in the nearby areas of the Saraighat Bridge

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.

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