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PREFACE

It is our great honor to present the proceedings of the 7th International Conference on Advances in Civil Engineering (ICACE-2024), organized by the Department of Civil Engineering, Chittagong University of Engineering & Technology (CUET), held on 12-14 December 2024. The primary objective of this esteemed conference is to gather leading academic experts, researchers, and professionals from diverse disciplines of civil engineering worldwide to exchange novel ideas, share knowledge, and explore cutting-edge technological advancements in the field. The Editorial Board of ICACE-2024 believes that this conference provides not only an excellent platform for exchanging and disseminating scientific and technical knowledge among participants from various countries but also serves as a crucial bridge between academia and industry.

This proceeding includes the accepted papers of ICACE-2024, encompassing various branches of civil engineering. It predominantly features practical and innovative contributions addressing contemporary challenges in civil engineering, with a particular focus on their applications in developing countries. Topics covered include construction and building materials, eco-friendly ground improvement techniques, waste disposal and management strategies, the durability of concrete structures, aspects of foundation engineering, transport planning, water resource management, and sustainable development in emerging economies.

The conference has achieved notable success. From over 1193 initially submitted abstracts, 645 abstracts were selected for full paper submission. Subsequently, 617 full papers were received, which underwent the review process. Finally, 447 papers were selected for inclusion in this proceeding. Additionally, a subsequent double-blind review of these papers will result in the selection of approximately 50 papers for publication in a prestigious Springer book series after the conference.

In conclusion, we extend our heartfelt gratitude to the dedicated members of various committees whose tireless efforts ensured the success of this event. The ongoing success of the ICACE conference series inspires us as we look forward to ICACE-2026.

Editorial Board

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ASSESSING ROAD CONNECTIVITY IN RAJSHAHI CITY CORPORATION THROUGH GRAPH THEORY-BASED GIS ANALYSIS

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Abstract

Road connectivity plays a vital role in shaping a city's mobility and accessibility; thus, it significantly contributes to modern urban planning techniques. Transportation network connectivity is a measure of the number of links that are present. A general correlation exists between increased connectivity and greater mobility and accessibility of the road network. Modern developments in GIS (geographic information systems) have contributed to modern transportation planning concerning adequate connectivity to ensure mobility within a city framework. Using graph theory, this paper aims to determine the road network's connectivity in 30 Rajshahi City Corporation (RCC) wards. ArcGIS Network Analyst tool is utilized to calculate connectivity indices. Moreover, the factors to consider are the alpha index, beta index, gamma index, eta index, grid tree pattern, completeness, ETA, Network Density, and Intersection Density. Comparative statistics were conducted on these parameters to identify and compare the 30 wards of RCC. This indicates that Ward 23 has the highest network and intersection densities but is the lowest in Ward 1. Again, ward 14 has the lowest Alpha, Beta, and Gamma index values, indicating the roads are more complex (beta>1), but the roads have fewer cycles or loops (alpha<1), and the roads do not have all road connections possible (gamma<1). The analysis offers a comprehensive statistical overview of the current state of roads within RCC wards, facilitating a comparative examination. This comparative insight can assist policymakers, transportation planners, and engineers identify deficiencies and formulate targeted improvements.

Keywords

Graph Theory; Connectivity; GIS; Index; Mobility; Network Parameters

1. Introduction

Urban areas worldwide are experiencing high population concentration, leading to increased demand for transportation and residential accommodation [1]. Only progressive countries have evaluated road networks of the urban areas, so they have great potential for development and application. The transportation network facilitates the communication and supply chain, contributing to economic and social development, particularly in developing countries, where road transport is the primary mode of transportation [2]. The road transportation networks can be represented as topological maps or graphs, with connectivity denoting the extent of connections between nodes [3]. An immediate correlation exists between increased mobility and access to the road network. An extensive network has many small links, lots of intersections, and few dead ends, which allow for continuous and direct paths to different locations [4]. Advancements in geographic information systems (GIS) have played a significant role in contemporary transportation planning by ensuring sufficient connectivity for efficient mobility inside urban areas. Various connectivity indices which assess the road transportation network's connection pattern such as, the Alpha, Beta, Gamma, and Eta Index [4]. In addition, the connectedness and coverage of the study region's transport network system can be described and assessed using additional non-graph theoretic metrics like the Grid Tree Pattern (GTP) index, Network Density, Intersection Density etc. [1]. Numerous studies have concentrated on extracting the fundamental connectivity indices essential for delineating a specific network character. But the spatial pattern of the network and the comprehension of its structural attribute have received very little attention in studies[4]. Similarly, certain studies on the traffic situation of RCC determined a critical situation in major intersection points and calculated a LOS-F for most of the routes but these studies failed to address the reasons behind this critical situation and an overall overview of the road conditions of RCC [5, 6]. Therefore, this study's goal is to ascertain how connected each of Rajshahi City Corporation's (RCC) 30 wards road network and coverage of these networks in these wards. This study also identifies the road condition of RCC wards according to these network indices and determine the wards falling into critical state. ArcGIS Network Analyst Tool is used by the authors to compute connectivity indices. Alpha index, beta index, gamma index, eta index, grid tree pattern, completeness, ETA, Network Density, and Intersection Density are the parameters to take into account. This comprehensive analysis on the 30 ward's Roads of RCC will be advantageous to the policy makers, transportation engineers and planners in prioritizing the infrastructural development in underdeveloped regions hence, improving the current road condition of RCC wards.

2. Methodology

2.1 Study Area

Bangladesh's divisional region, Rajshahi City Corporation (RCC) (**Figure *1***), is located at latitudes 24°21' and 24°25' north and longitudes 88°32' and 88°40' east. It is situated in the northwest part of Bangladesh and on the northern side of the Padma River. RCC has 30 wards with an area of 93.47 km^2. This area's main characteristics are extreme temperature, drought, and reduced rainfall. The total paved road in Rajshahi City is 186.64 km, where 2% of the roads are in a failure condition [7]. Although the area has no significant development, it is a divisional city [8]. The city is expanding towards the northeast with a major road called 'Noahata Road' [8].

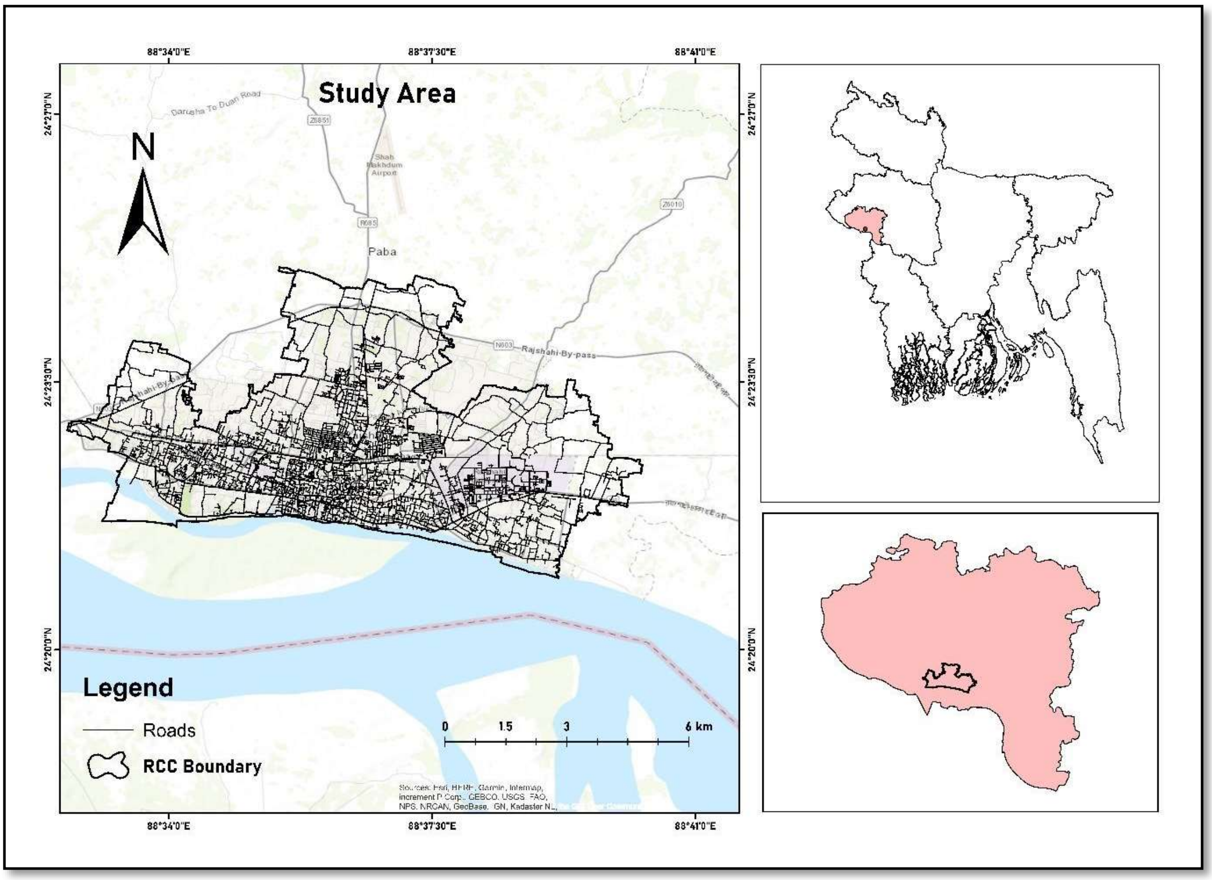


Figure 1: Study Area (Rajshahi City Corporation)

2.2 Network Parameters

An illustrated depiction of a network's interconnectedness is called a graph. In a directed graph G=(N, A), where each element is an ordered pair of different nodes, a set of arcs or edges is represented by the letter A and N represents a set of vertices or nodes. A road network can be modeled using a directed graph, where the road segments that offer connection are represented by edges (e) and junctions or street intersections are represented by vertices (v) [9]. Using these edges and vertices authors utilized several network parameters which helped to determine the connectivity as well coverage of the road network of the wards of RCC. **Table *1*** provides a detailed breakdown of some of this network's parameters:

Table 1: Network Connectivity and Coverage Indices

Index	Description	Equation	References
Alpha	The alpha index calculates the proportion of basic circuits to the highest number that can be included in a network. It specifies a 0–1 value. 0 indicates a simple tree like network where 1 or closer to 1 determines an unsegregated network.	$\alpha = \frac{e - v + 1}{2v - 5}$	[10]
Beta	The number of linkages to nodes is compared to determine the beta index (β), which measures the connectivity of a network.	$\beta = \frac{e}{v}$	[10]
Gamma	The gamma index (γ) measures connectedness by comparing observed and hypothetical links. Gamma ranges from 0 to 1, where value 1 or closer to 1 indicates a highly connected network, which is highly uncommon in practice.	$\gamma = \frac{e}{3(v - 2)}$	[11]
ETA	The eta index (η) represents the average link length. As the average link length decreases, adding nodes decreases the eta index.	$\eta = \frac{L}{e}$	[9]
Grid Tree Pattern	Grid tree pattern (GTP) measures network pattern, ranging from 0 to 1, 0 or closer to 0 determines tree pattern and 1 or closer to 1 depicts grid pattern.	$\text{GTP} = \frac{e - v + 1}{(\sqrt{v} - 1)^2}$	[12]
Completeness	The usefulness of network connectivity is measured by the notion of completeness. It is measurable in percentage terms. When every node in a network has a direct connection to every other node, the network is said to be 100% complete.	$\rho = \frac{e}{v^2 - v}$	[13]
Network Density	Network density is determined by Kilometres of links (L) per square kilometre of surface (A) which also shows the territorial occupation of a transport network. The greater the value, the more a network and economy are established	$\text{ND} = \frac{L}{\Lambda}$	[13]
Intersection Density	The number of intersections per square kilometre for each zone is known as the intersection density. Indicators of network coverage include the total length, network density, and intersection density.	$\text{ID} = \frac{e}{\Lambda}$	[12]

e = Edges

v = Nodes/Vertices

L = Total Network Length

A = Area of the zone

2.3 Data Sources and Method

The Rajshahi Development Authority (RDA) provided the road network data and ward-by-ward shapefile for Rajshahi City Corporation (RCC).

Each ward's road network was extracted using the ArcGIS overlay tools. To ascertain the length of individual road segments, the road network was projected onto the Bangladesh Transverse Mercator (BTM) coordinate system. The network was made completely free of topological flaws. Next, in order to use Network Analyst tools, the road network's shapefile was first transformed into a network data set. Before and after converting the road network into a network data, data was ensured to be topologically accurate. Source features are the basis for network data sets, which hold the connection of the source features. These characteristics included turns and fundamental elements like lines and points.

The aforementioned indices were calculated by counting the nodes and edges in the network data set. To compute connectivity indices, the ArcGIS Network Analyst Tools were utilized and number of nodes and edges for each ward's dedicated road network were extracted and represented into CSV format. The network density, intersection density, completeness, GTP, alpha, beta, gamma, and eta indices were among these parameters which had been calculated by the authors using the equation provided in **Table *1***. Then a correlation analysis and Regression among these indices were performed to understand if these indices were allowed to determine connectivity and could strongly drive network connectivity validating their selection for connectivity analysis. if some indices were redundant or if they convey unique information about the network's connectivity. Then, to portray a comprehensive scenario of the connectivity indices among the wards of RCC, spider diagrams were utilized based on the established data whereas, for coverage indices authors generated thematic maps by joining and relating CSV file with ArcGIS software. To get an overall scenario, authors had constituted a descriptive statistic regarding these indices. These indices offer a thorough picture of the coverage and connectivity of the local road network.

3. Results and Discussions

3.1 Connectivity Indices

According to **Figure *2***, GTP has a correlation coefficient of 0.99 with the Alpha index, 0.97 with the Beta index, and 0.99 with the Gamma index. A higher correlation coefficient can also be observed among the Alpha, Beta, and Gamma index. Alpha and beta indexes have a correlation coefficient 0.98; consequently, the Alpha and Gamma indexes have 0.99, and the Gamma and Beta indexes have 0.98 for a 0.05 significance level. This higher degree of correlation among Alpha, Beta, Gamma, and GTP indicates that each of the indexes can be observed as an indicator of network connectivity [9].

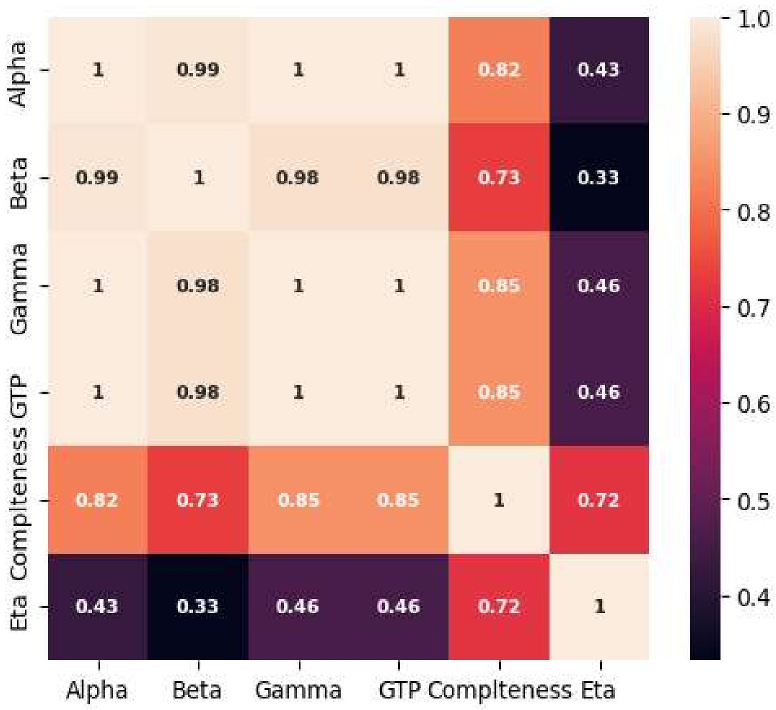


Figure 2: Correlation Matrix

Based on the result of the correlation matrix, a regression model has been built below:

$$\textbf{GTP} = 0.344+3.543*\text{Alpha}-0.561*\text{Beta}+0.535*\text{Gamma and } R^2=0.99$$

With an R^2 of 0.99, the regression model confirms that Alpha, Beta, and Gamma indices collectively explain almost all the variability in GTP. This finding reinforces the interpretation that these indices strongly drive network connectivity and validates their selection for connectivity analysis.
The RCC wards' network pattern is shown by the descriptive statistics of the network connection indices in **Table *2***. The mean values of Alpha (0.17), Gamma (0.46), and GTP (0.48) indicate that most of the roads here follow a spinal or tree pattern. That means the hierarchical structure of the roads often creates bottlenecks at the major intersections during peak hours and creates significant delays [14, 15]. The spinal pattern also increases the travel distance. Travelers must rely on indirect routes, increasing the destination path and wasting time[16]. A lower percentage of completeness index ranges from 1.24 to 14.1 with a mean value of 5.44, confirming that the roads have fewer direct connections between nodes, meaning the network is incomplete.

Table 2: Descriptive Statistics of Network Connectivity Indices

Connectivity Indices	Minimum	Maximum	Mean	Std. deviation
Alpha Index	0.03	0.48	0.17	0.12
Beta index	1.02	1.72	1.25	0.19
Gamma index	0.36	0.67	0.46	0.08
Eta index	0.00	0.05	0.02	0.01
Grid tree pattern	0.07	1.47	0.48	0.38
Completeness	1.24	14.1	5.44	0.03

Figure *3* shows that Ward 14 has the lowest Alpha, Beta, Gamma, and GTP values among all the wards. It indicates that the roads are more complex in nature (Beta>1), but the roads have fewer cycles or loops (Alpha<1), and the roads do not have all road connections possible (Gamma<1). Also, the GTP value closer to 0 specifies that the roads of Ward 14 follow a spinal or tree pattern. Furthermore, **Figure *3*** also depicts wards 2,10, and 30 have peak Alpha, Beta, Gamma, and GTP values, which means these wards' roads are complete in nature. There are better road connections in comparison to other wards.

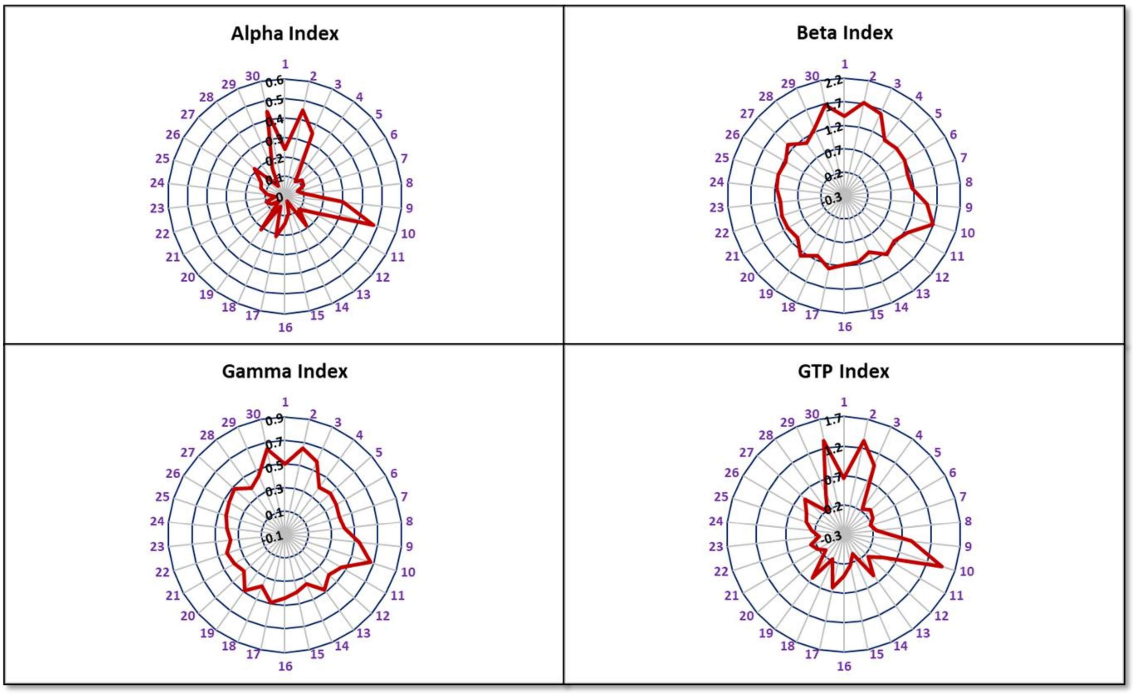


Figure 3: Ward-wise Connectivity Indices Comparison

However, most wards have an Alpha index value between 0.1-0.2 suggesting most of the wards have fewer loops, suggesting limited connectivity and potentially less resilience in the road network, a Beta index value of 0.7-1.2 indicating a complex road network in most of the wards which increases travel time, a Gamma index value of 0.3-0.5 portraying limited connectivity compared to the potential maximum, suggesting opportunities for road network expansion and lastly, a GTP index value of 0.2-0.7 which depicts that limited accessibility or an inefficient road network structure which potentially hindering movement within the ward.

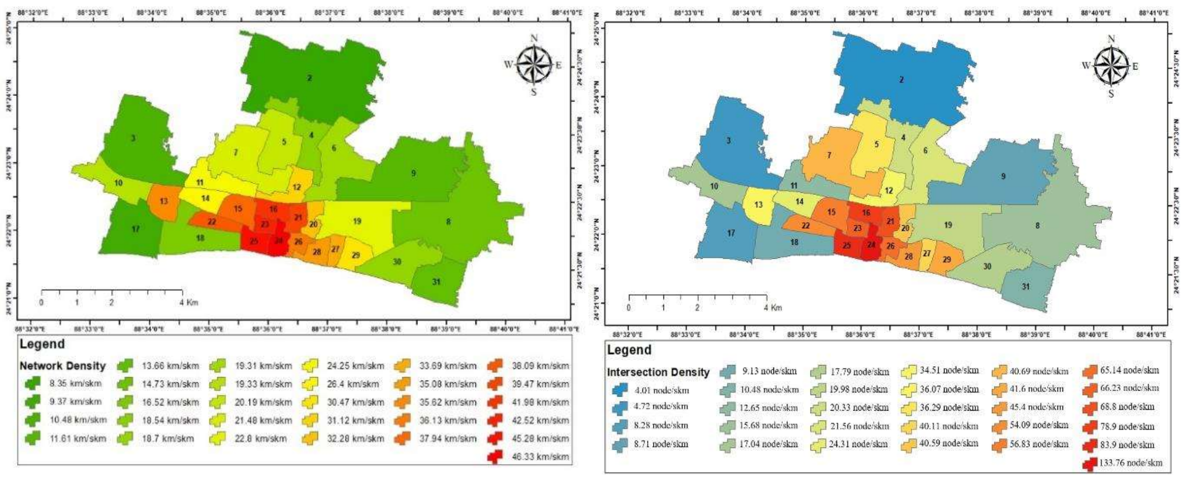
3.2 Coverage Indices

Table *3* indicates the descriptive statistics of the coverage indices, where it can be observed that the network density ranges from 8.5 to 46.33 links/sq km with a mean value of 26.72 links/sq km, which depicts an unstable network with lower road intersections or sparse intersections and the total road network in the area is lower, leading to fewer route choice for the pedestrians and travelers. Fewer roads often lead to severe traffic congestion in peak periods, also confirmed in the connectivity indices [16]. A lower mean of Intersection Density (37.25 intersections/sq km) also confirms the claim by the authors.

Table 3: Descriptive Statistics of Network Coverage Indices

Coverage Indices	Minimum	Maximum	Mean	Std. deviation
Network density	8.35	46.33	26.72	11.54
Intersection density	4.01	133.75	37.25	29.25

The network density map in **Figure *4* (a)** shows the intensity of road network development, where 23, 24, and 25 wards show a comparatively strong intensity of road network development. According to the Intersection density map in **Figure *4* (b)**, 23, 24, and 25 number wards also have higher intersections/sq km. Higher network density leads to a higher intersection density as increasing the roads in an area typically increases the number of intersections, which leads to more accessibility and interconnection [17, 18]. Similarly, Ward 1 has a lower network density and intersection density, a critical condition in Ward 1.



(a) **(b)**

Figure 4: (a) Network Density Map (b) Intersection Density Map

The connectivity indices derived from the analysis, including the Alpha, Beta, Gamma, and Grid Tree Pattern (GTP) indices, offer critical insights into the structure and performance of Rajshahi City Corporation's (RCC) road network. The strong correlations among these indices suggest that each index can serve as an indicator of network completeness and connectivity. Specifically, low Alpha, Beta, and Gamma values highlight that much of RCC's road network follows a spinal or tree pattern [9], with fewer direct links and limited looped routes, which contributes to increased travel distances and potential bottlenecks at intersections [19]. With main intersections serving as hubs, high traffic volumes often converge at these points, leading to congestion and bottlenecks, particularly during peak hours [20]. A study on traffic flow analysis in a major intersection of RCC, shows a similar output where the authors have determined the traffic flow for both normal hours and peak hours and found LOS-F in the intersection for almost all the routes exist which indicates the worst operating conditions in RCC where traffic flow is severely congested, almost at gridlock [6]. Similarly, the coverage indices, including network density and intersection density, measure the extent and accessibility of the RCC road network. An average network density of 26.72 links/sq km reveals a generally sparse road network, which limits route options and can cause severe congestion during peak hours [21]. The low intersection density further indicates fewer route choices, contributing to delays and overcrowding in specific wards.

For city planners, these findings indicate specific areas where connectivity is low and suggest a need for strategic road improvements to address these weak points. Increasing redundant paths and loops to provide alternative routes, enhancing road density with additional connector roads, and adding missing links to create a more complete network, such as Ward 14, would reduce travel time by providing more direct routes, while in areas with higher Alpha and Gamma values (e.g., Wards 2, 10, and 30), current road networks are relatively complete, requiring only maintenance or minor expansions. By targeting areas with the lowest indices for infrastructure investment, RCC can enhance accessibility, reduce congestion and support smoother traffic flow as well they can ensure proper and specific transportation planning which can be cost benefit and effective. Understanding these coverage patterns also helps these authorities in prioritizing areas for road network expansion. Increasing the density of roads and intersections, particularly in wards with sparse connectivity like Ward 1, would provide more routing options, alleviate traffic congestion, and promote more equitable access throughout the city. By focusing on areas with the lowest coverage values, RCC can make targeted improvements, creating a more efficient, accessible, and resilient road network that supports both urban growth and the needs of its residents.

The limitation of this study underlies into identifying the specific and dynamic view of the weak points of the critical roads of identified wards of RCC as this study only portrays the static view of the road network's which is useful for only road project scoping or policy planning. Similarly, the study assumes that RCC authorities have the capacity and willingness to implement the recommended infrastructure improvements. However, budget constraints, political priorities, or shifts in policy focus may limit the feasibility of these recommendations.

4. Conclusion

Roads play a vital element in making a country economically wealthy. Improving the road network means improving connectivity and enhancing accessibility. This study evaluated the road network of 30 different wards of RCC using road connectivity indices and coverage indices. The authors identified that according to the major road connectivity indices, the roads of Wards 2,10, 22, 23, 24, 25, and 30 are in good shape. However, most of the wards' roads have critical situations, especially Ward 14. This suggests an immediate road infrastructural development as a quick response to Ward 14. Again, according to the coverage indices, wards 22, 23,24, and 25 have the highest network and intersection densities. This also confirms a higher road connectivity and developed infrastructure in those wards. The study also gives a clear concept of the pattern recognition of the roads; it suggests that the roads mostly follow a spinal or tree pattern based on the connectivity indices. However, the major limitation of this study is that this graph theory-based analysis on road networks did not consider the varying importance and influence of weightage on different types of roads. Since, this study only inspected the road connectivity and coverage but overlooked the accessibility analysis, future researchers can visualize the current scenario of the RCC roads according to the accessibility indices (Shimbel Index, Detour Index or others). Future researchers can also identify the dynamic factors such as seasonal variations, daily traffic flow fluctuations, or temporary roadblocks in the critical routes to identify more comprehensive overview. This can limit the study's applicability to real-time traffic management and planning. RCC is suffering from improper road development and transportation planning projects for so long such as flyovers in Rajshahi, face criticism for being unnecessary or underutilized, suggesting that feasibility studies or demand assessments. Similarly, Rajshahi is facing challenges with a road expansion project that remained incomplete after eight years due to improper project cost estimation. Thus, Findings of this study offers a structured framework for prioritizing future road development projects, ensuring that resources are allocated to areas with the most critical connectivity needs. This study can benefit the municipal authorities, departments related to roads and transportation, transportation engineers and planners, and policymakers by improving road conditions in underdeveloped areas and increasing the travel speed of the road, with a positive impact on the nation's economy.

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