Mapping Urban Connectivity: A Study of Hyderabad's Road Network Using ArcGIS

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Abstract. The present study discusses the urban road network connectivity of Hyderabad City. Urban road networks are vital for the effective movement of both people and goods throughout urban areas. They improve economic activity and link different city regions, acting as the fundamental support for urban infrastructure. Therefore, this study has focused on the analysis of urban road network by ArcGIS. ArcGIS is a powerful tool that significantly impacts our opinions and actions on city streets. It performs a good job of enhancing the whole procedure. With the help of the ArcGIS tool, the analysis is carried forward. For the evaluation of urban road network various connectivity indices are adopted such as beta index, betty index, correlation index, etc. The main objective of this study is to define the level of connectivity in different locations and also to categorize and rank the locations based on the level of connectivity.

Keywords: Urban Road Network, ArcGIS, Connectivity, Connectivity Indices.

1 Introduction

Urban road networks play a crucial role in shaping the functionality and livability of cities by enabling the efficient movement of people and goods. They serve as the backbone of urban infrastructure, supporting economic activities, enhancing connectivity between different regions, and facilitating access to essential services. Analyzing the connectivity of these road networks is fundamental for urban planners and transportation managers who seek to optimize city traffic flow, reduce congestion, and improve overall urban mobility [1].
Connectivity assessment of road networks involves evaluating how well different parts of a city are linked, which has a direct impact on accessibility, travel time, and economic efficiency [2]. Various indices, such as the alpha, beta, gamma, eta, betty, and correlation indices, have been developed to quantify and analyze the connectivity of urban road networks. These indices provide valuable insights into the structural efficiency and spatial organization of road networks, allowing city planners to identify

B. S. Babu et al. (eds.), *Proceedings of International Conference on Advanced Materials, Manufacturing and Sustainable Development (ICAMMSD-2024)*, Advances in Engineering Research 257,
https://doi.org/10.2991/978-94-6463-662-8_85

areas that need improvement and to design more integrated and efficient transportation systems [3].

In recent years, Geographic Information System (GIS) tools such as ArcGIS have become increasingly popular for urban road network analysis due to their advanced spatial analysis capabilities. ArcGIS provides a robust platform for visualizing, analyzing, and interpreting spatial data, making it an essential tool for evaluating road connectivity and planning urban infrastructure [4]. Through spatial analysis, ArcGIS helps planners understand the intricate relationships between road segments, land use patterns, and urban growth, enabling more informed decision-making in the development of sustainable urban transport systems [5].

Previous studies have demonstrated the effectiveness of GIS in assessing road network connectivity in various urban contexts. For instance, Abdlabass and Al-Jameel evaluated the road network of Al-Kufa City using GIS, highlighting the importance of road connectivity in enhancing urban mobility and spatial organization. Their analysis identified critical areas requiring infrastructure improvements, demonstrating how GIS-based evaluations can guide targeted interventions in urban planning [6]. Similarly, Ahmed, Ali, and Saleh developed a novel GIS-based method for assessing road connectivity in Fayoum City, providing a framework for identifying connectivity gaps and prioritizing road network enhancements [7].

In Hyderabad City, an expanding metropolitan area with growing transportation demands, assessing road network connectivity is vital for ensuring efficient urban mobility. This study aims to analyze the urban road network of Hyderabad using ArcGIS, employing various connectivity indices to evaluate and rank different city locations based on their connectivity levels. By dividing the study area into grids, this research provides a detailed, localized analysis that can inform targeted improvements in road infrastructure. The findings will contribute to enhancing urban connectivity, optimizing land use, and supporting sustainable transportation planning in Hyderabad.

The primary aim of this study is to evaluate and quantify the connectivity of the urban road network in Hyderabad City, focusing on understanding its efficiency and accessibility. This research is structured around three key objectives. First, it aims to quantify road network connectivity on a grid-wise basis using ArcGIS, which allows for a detailed spatial analysis of the road network by dividing the study area into manageable grids. This approach facilitates an in-depth assessment of connectivity variations across different parts of the city. Second, the study seeks to define the level of connectivity in various locations within Hyderabad. This evaluation provides insights into how well different regions are connected, highlighting critical gaps that may affect urban mobility and access. Lastly, the study aims to categorize and rank these locations based on their connectivity levels, creating a framework that prioritizes regions requiring infrastructural improvements. By achieving these objectives, the study provides a comprehensive understanding of the spatial distribution of road network connectivity in Hyderabad, guiding urban planners and policymakers in making data-driven decisions to enhance urban mobility and infrastructure planning.

2 Literature Review

The evaluation of urban road network connectivity has become increasingly important in urban planning and transportation management due to the rapid growth of cities and the consequent need for efficient and sustainable mobility systems. Connectivity analysis helps planners understand the structural layout of road networks, identify deficiencies, and propose improvements to optimize transportation infrastructure [8]. The advent of Geographic Information Systems (GIS) has revolutionized the assessment of urban road networks by providing advanced spatial analysis capabilities. GIS tools such as ArcGIS, QGIS, and Network Analyst allow for the integration of various data sources to analyze connectivity, accessibility, and spatial relationships within urban road networks [9]. Several studies have utilized GIS to evaluate the road connectivity of cities worldwide, highlighting its effectiveness in visualizing and analyzing complex network data.

For example, [6] evaluated the road network of Al-Kufa City using GIS, demonstrating how GIS can be used to assess connectivity and identify critical areas that require infrastructure upgrades. Similarly, [10] examined the spatial patterns of Al-Najaf's Road networks, utilizing GIS to highlight connectivity gaps and recommend targeted interventions for improving urban mobility. Ahmed et al. introduced a novel GIS-based methodology for evaluating road connectivity in Fayoum City, which has been particularly influential in identifying and prioritizing infrastructure investments. Their study showcased the role of GIS in enhancing the precision of road network evaluations by enabling detailed spatial analyses that traditional methods could not easily achieve [7]. K. Sai Sahitya and C.S.R.K. Prasad have made significant contributions to the field by analyzing urban road network connectivity using GIS and various connectivity indices. In their research, they focused on assessing the road network of Hyderabad City, employing indices like beta, and betty to measure connectivity and identify the strengths and weaknesses of the existing network. Their study provided valuable insights into the variations in connectivity levels across different regions of the city, emphasizing the importance of targeted improvements in under-connected areas to enhance overall urban mobility [11]. Various connectivity indices have been developed to quantify the effectiveness of road networks. Common indices include the beta index, and the more recently developed betty and correlation indices, each providing unique insights into the connectivity and efficiency of urban road layouts [2].

The study examined the connections between key structural factors of city road systems, focusing on Hyderabad, India. The research used ArcGIS 10.1 software to analyze a digital map of roads from the Hyderabad Urban Development Authority. The study aimed to determine the inter-relationship of the road network structural parameters such as connectivity, accessibility, spatial pattern, and network density. The findings highlighted the importance of understanding these links for better city transport planning and improving urban movement [12]. The road network in Hyderabad, India is assessed for accessibility. The city is classified as having "Moderate Accessibility" by the researchers, who advise employing GIS to provide more precise accessibility assessments. In order to cut down on commute times and carbon emissions, the study recommends dispersing important locations throughout the city and highlights the significance of GIS for sustainable urban development [11].

A study by Zhang et al. evaluated the connectivity of Beijing’s Road network using the gamma and eta indices, revealing significant variations in connectivity across different urban zones. The researchers found that areas with higher connectivity indices generally experienced better traffic flow and reduced congestion, emphasizing the value of these metrics in transportation planning [13]. Sai Sahitya and Prasad utilized a combination of connectivity indices in their evaluation of Hyderabad's road network, demonstrating how these indices can be used to rank different locations based on their connectivity levels. Their findings showed that certain areas of Hyderabad exhibited low connectivity, which could hinder economic activity and accessibility, suggesting that strategic enhancements could significantly improve the overall network performance [11]. The impact of road network connectivity on urban mobility has been a focal point of numerous studies, demonstrating that well-connected road networks contribute to reduced travel times, enhanced accessibility, and overall improvements in urban quality of life [1]. The integration of connectivity analysis into urban planning processes allows for the creation of more resilient and adaptable cities. Kim et al. conducted a study on the road network of Seoul, using GIS-based connectivity indices to assess how network structure influences daily commuting patterns. Their findings indicated that higher connectivity levels are strongly correlated with reduced travel distances and times, highlighting the critical role of road network design in shaping urban mobility outcomes [14].

Despite the advances in GIS and connectivity indices, several challenges remain in the comprehensive analysis of urban road networks. Data quality, model accuracy, and the dynamic nature of urban growth present significant obstacles [15]. Inaccurate or outdated data can lead to flawed analyses, while the rapidly changing urban landscapes necessitate continuous updates and adjustments to road network models.

Wang and Liu highlighted the limitations of traditional connectivity indices when applied to complex urban environments, suggesting the need for more sophisticated models that account for real-time traffic conditions and multimodal transport networks. Their study emphasized integrating new data sources, such as GPS and IoT sensors, to enhance the accuracy and relevance of connectivity evaluations [16]. Recent research trends point toward integrating machine learning and artificial intelligence with GIS-based connectivity analysis to predict and optimize urban road networks [17]. Predictive models are being developed to forecast connectivity changes under different urban development scenarios, providing valuable tools for proactive planning and decision-making. Gao et al. proposed a machine-learning framework for assessing road network connectivity in megacities, utilizing historical traffic data and spatial analysis to predict areas of potential congestion. Their approach demonstrated the potential of combining GIS with advanced analytics to provide more dynamic and responsive urban planning solutions [18].

The literature highlights the importance of evaluating urban road network connectivity using GIS tools and connectivity indices, providing valuable insights for urban planners and policymakers. While significant progress has been made, ongoing challenges such as data limitations and the need for more dynamic modeling approaches continue to drive innovation in this field. Future research should focus on integrating advanced technologies with traditional connectivity analysis to develop more robust and adaptive urban transportation systems.

3 Methodology

The methodology adopted for this study involves a comprehensive analysis of the urban road network connectivity of Hyderabad City using Geographic Information Systems (GIS), specifically ArcGIS. The process begins with data acquisition, where the digitized road network of Hyderabad was sourced from the Hyderabad Metropolitan Development Authority (HMDA). The road network was then spatially analyzed by dividing the entire study area into grids to assess connectivity at a micro-level. Various connectivity indices, such as the beta index, betty index, and correlation index were employed to quantify the road network's efficiency and structural robustness. Each grid was evaluated based on these indices to determine the level of connectivity in different locations. The results were then used to define and compare connectivity levels across the city, identifying areas with optimal and suboptimal connectivity. Further, these locations were categorized and ranked based on their connectivity scores, providing a hierarchical framework for identifying critical regions that require infrastructure upgrades. Statistical and spatial analysis techniques were applied to validate the results, ensuring the accuracy and reliability of the connectivity evaluation. This methodology provides a systematic approach to understanding road network performance, facilitating data-driven decision-making for urban planners and policymakers aiming to enhance the city's transport infrastructure. The methodology adopted in the study is shown in the form of a flow chart in Figure 1.

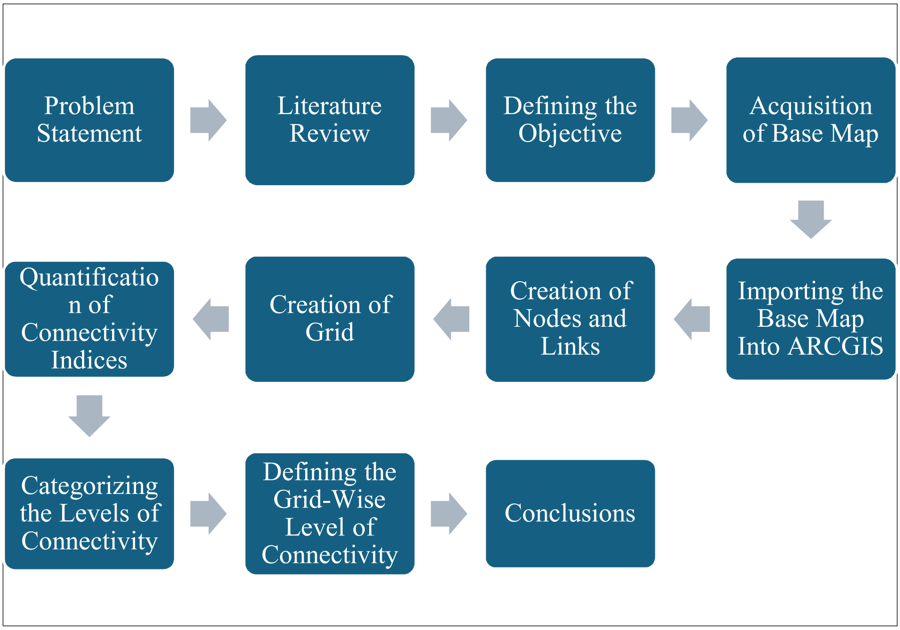

Fig. 1. Flow chart of the methodology used in the study.

3.1 Study Area

The study area of this research is Hyderabad City, the capital of Telangana, India, known for its rapid urbanization and expanding road network. Hyderabad's road network is characterized by a complex mix of primary, secondary, and tertiary roads, including arterial roads, sub-arterial roads, collector streets, and local streets that form the backbone of the city's transport infrastructure. The city's road network is critical for facilitating the movement of people and goods, supporting economic activities, and linking various regions within the urban landscape. The road network includes major corridors such as the Outer Ring Road (ORR), Inner Ring Road, National Highways, and a network of radial and gridiron patterns that serve the metropolitan region. The digitized road network data for this study was obtained from the Hyderabad Metropolitan Development Authority (HMDA), which provides an accurate and detailed representation of the city's transportation infrastructure. This network data reflects the intricate road patterns, varying road densities, and connectivity levels across different parts of the city, which are vital for assessing the overall efficiency and accessibility of the urban road system. Hyderabad's road network faces challenges such as congestion, uneven connectivity, and infrastructural gaps, making it an ideal case for connectivity analysis to identify areas needing strategic improvements to enhance urban mobility and planning.

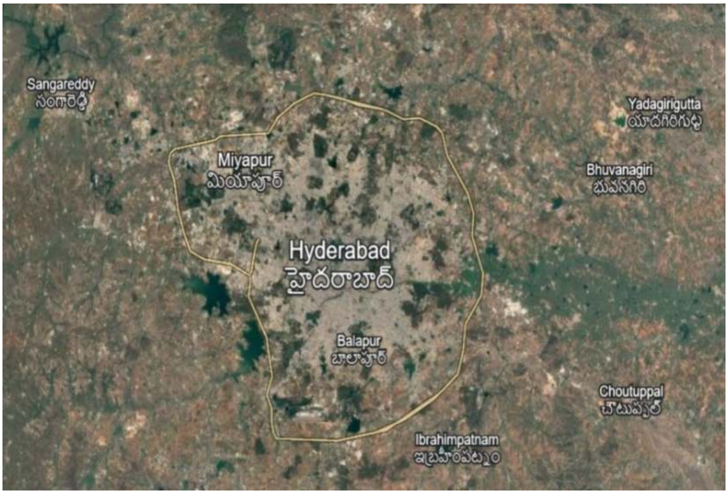

Fig. 2. Map showing the location of the Study Area.

3.2 Connectivity Analysis

Analyzing the connectivity of urban road networks is crucial for assessing the effectiveness and resilience of transportation infrastructure. This analysis focuses on understanding how well different urban areas are linked through their road systems and how easily transportation can be navigated between these areas. Effective

connectivity enhances traffic flow and reduces congestion, enabling urban planners to make informed decisions for improving transportation networks.
Connectivity refers to the ease of travel from one location to another within a network. A well-connected road network is characterized by numerous short links, frequent intersections, and minimal dead ends, which collectively ensure direct and efficient routes to destinations. To evaluate connectivity, the road network is often simplified into a topological diagram, which allows for easier analysis of its structural properties.

Various indices are used to measure and analyze connectivity, including:

a. Beta Index: Quantifies the network's connectivity based on the number of links and nodes, indicating how well-connected the network is.

b. Betty Index: Assesses connectivity by analyzing the network's structure and the presence of alternative routes.

c. Correlation Index: Analyzes the relationship between connectivity and other factors such as

By employing these indices, the study aims to provide a detailed understanding of Hyderabad City's Road network connectivity, enabling targeted improvements and strategic planning for enhancing urban mobility.

The equations adopted in the study is shown in the form of a table in Table 1.

Table 1. Connectivity Indices.

S. No	Index name	Equation	Range	Level of Connectivity
1	Beta Index	$\beta = e/v$	0-1	Higher the value higher the connectivity
2	Betty Index	$\mu = e-v+1$	1& more	0- no spreading, 1& more-Huge spreading
3	Correlation Index	$e/(1/2(n^2-n))$	0-1	Low value - low connection

3.3 ArcGIS

ArcGIS is an advanced geographic information system (GIS) software that plays a crucial role in urban design and planning. It enables users to create, manage, analyze, and share geographic data and maps with high precision. By providing robust toolsfor spatial analysis and data visualization, ArcGIS enhances decision-making processes and facilitates the development of effective strategies for managing urban infrastructure and resources. Its impact on urban planning is particularly significant, as it allows for a detailed examination of spatial relationships, connectivity, and infrastructure performance, thereby supporting more informed and strategic planning efforts. The platform of ArcGIS software is shown in figure 3.

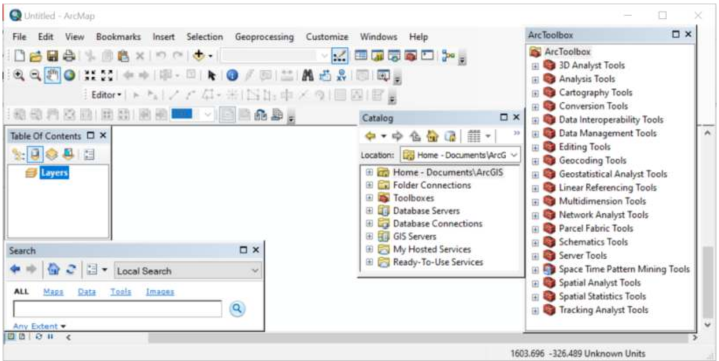

Fig. 3. ArcGIS Software interface.

4 Data Acquisition

The digitized road network map of Hyderabad was imported into ArcGIS for detailed analysis shown in figure 4.From the digitized road network map in ArcGIS, the nodes were formed on the links, which is shown in figure 5.Following the import, a grid overlay was created on the base map using the Fishnet tool available in the data management suite which is shown in figure 6. This process involved dividing the entire map into a series of uniform grids to facilitate a localized examination of the road network. Once the grid structure was established, the road network was clipped according to each grid using a geoprocessing tool shown in figure 7. This clipping process enabled the extraction of road network segments within each grid, allowing for a precise count of links and nodes. With the data on links and nodes, the characteristics of the road network within each grid were assessed. These characteristics, in turn, were used to evaluate the connectivity of the road network across the city. This systematic approach allows for a detailed analysis of connectivity at a granular level, providing valuable insights into the efficiency and structure of Hyderabad's urban road network.

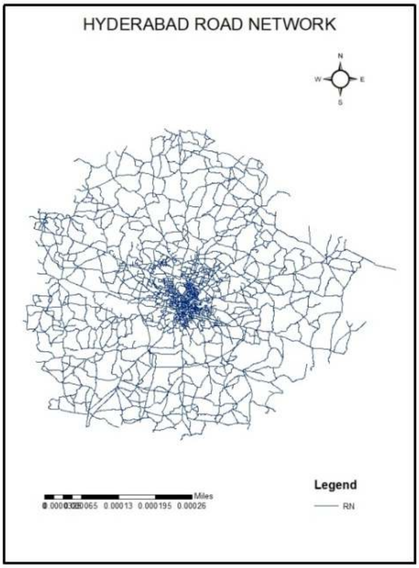

Fig. 4. Hyderabad Road Network Layout.

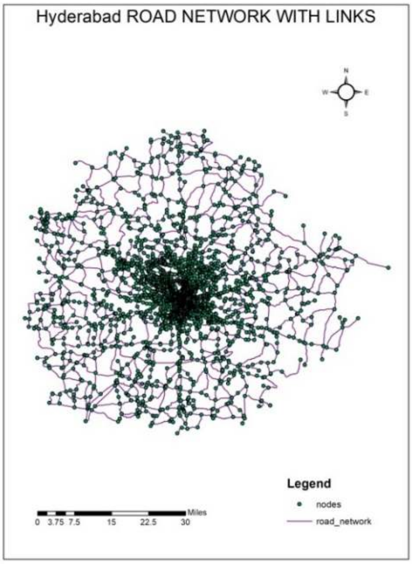

Fig. 5. Hyderabad Road Network Layout with Links and Nodes.

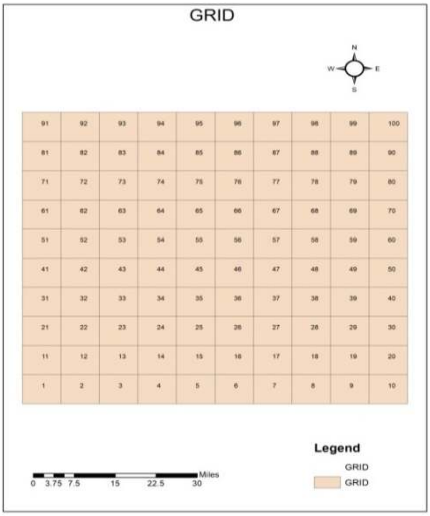

Fig. 6. Creation of grids using ArcGIS .

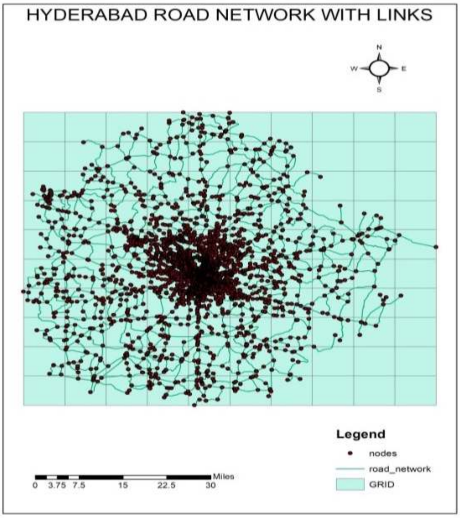

Fig. 7 . Overlayof Hyderabad Road Network in to Grid Layout.

5 Categorization of Connectivity Indices

This study categorizes connectivity indicators to systematically evaluate the metropolitan road network in Hyderabad City by classifying different grid regions according to their performance in indices like the Beta Index, Betty Index, and Correlation Index. These indices are classified into five tiers: Very Poor, Poor, Moderate, Good, and Very Good, offering a distinct representation of each region's connection and functionality. The "Very Poor" and "Poor" grids display insufficient connectivity, low road density, and limited alternate routes, resulting in congestion and inefficiencies, whereas the "Good" and "Very Good" grids indicate strong connectivity, higher road density, and effective traffic flow. This classification enables a focused strategy for pinpointing regions necessitating infrastructural enhancements and improving traffic allocation, so providing a holistic view of the city's connection framework.

6 Quantification of Connectivity Indices

The results of this study provide a comprehensive analysis of the urban road network connectivity in Hyderabad City, utilizing various connectivity indices calculated through ArcGIS. The analysis reveals significant insights into the structure and functionality of the road network, highlighting areas of high connectivity as well as regions that may require infrastructural improvements. This section presents the findings based on the calculated indices, graphical representations, and spatial analyses, which collectively illustrate the connectivity landscape of Hyderabad.

6.1 Beta Index

Table 2. Level of connectivity: Beta index.

Level of connectivity	Grid No.
Very Poor	1,8,9,10,19,20,30,50,70,79,80,81,88,89,90,91,92,98,99,100
Poor	4,6,18,28,34,35,40,44,46,54,55,60,63,64,69,71,78,81,93,96
Moderate	5,11,13,14,16,17,21,23, 24,25,26,27,29,31,32,33,36,37,38,41,42,43,45,47,48,51,53,56,57, 58,62,65,66,67,73,75, 76,77,87,95
Good	2,3,12,15,22,39,52,59,61,72,74,83,84,86,94,97
Very Good	7,49,68,85

The beta index (β) assesses the connectivity of a road network by measuring the ratio of roads to intersections. From table 2 and figure 8, Findings indicate that areas rated as Very Poor (e.g., grids 1,8,9,10,19,20) have limited road choices, leading to congestion and longer travel times. Poor to Moderate categories also show insufficient ratios, resulting in bottlenecks during peak hours. In contrast, Good to Very Good areas (e.g., grids 7,49,68,85) exhibit high connectivity, facilitating better traffic flow and supporting economic activity. Analysis suggests that regions with low beta index values often have a hierarchical road structure, which can create congestion on major routes; improvements could include adding more intersections or parallel routes to enhance traffic distribution.

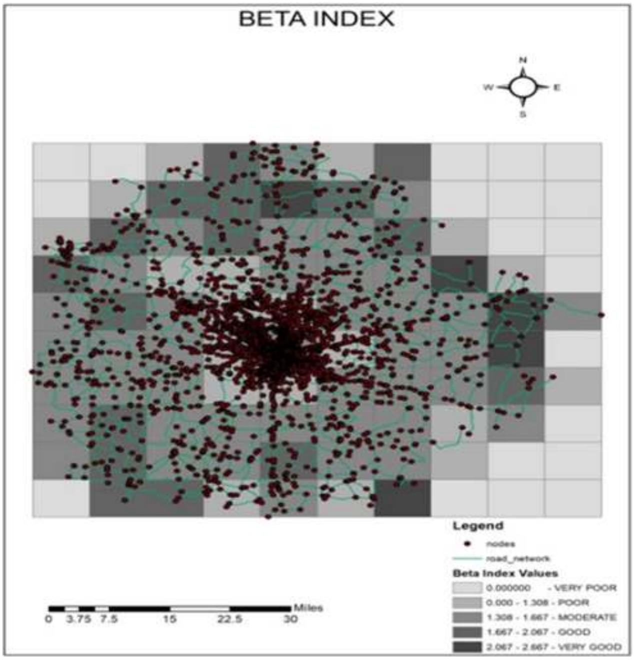

Fig. 8. Beta Index Connectivity Variation.

6.2 Betty Index

Table 3. Level of connectivity: Betty index.

Level of connectivity	Grid No.
Very Poor	1,6,8,9,10,11,18,19,20,21,28,29,30,39,40,50,60,68,70,78, 79,80,81,82,88,89,90,91,92, 93,96,97,98,99,100
Poor	2,3,4,7,16,17,23,27,31,38,41,43,48,49,51,58,62,63,67,71, 73,75,83,84,87,94,
Moderate	5,12,13,14,15,22,24,25,26,32,33,34,37,42,46,47,52,53,56, 57,59,61,64,65,66,72,74,76, 77,85,86,95
Good	35,36,44,54,55
Very Good	45

The Betty Index (μ) evaluates the availability of alternative routes within a transportation network, reflecting its redundancy and robustness. From table 3 and figure 9, Findings indicate that areas rated as "Very Poor" (e.g., grid numbers 1,6,8,9,10,11,18,19) lack sufficient alternative routes, making them vulnerable to traffic jams and disruptions. Those rated "Poor to Moderate" (e.g., grid numbers

2,3,4,7,16,17,23,27) have some alternatives, but they are inadequate for preventing congestion during peak times. In contrast, grids classified as "Good to Very Good" (e.g., grid numbers 45, 36) offer multiple route options, enhancing flexibility during traffic issues and emergencies. The analysis suggests that poor and very poor grids often follow a radial or tree-like structure, which limits route options. Developing more parallel or secondary roads could improve network redundancy, leading to smoother traffic flow and better management of peak-hour congestion.

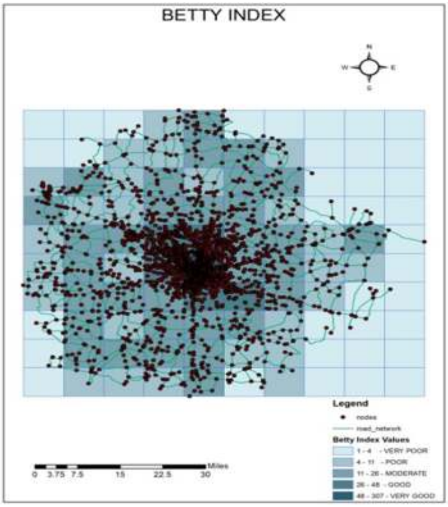

Fig. 9. Betty Index Connectivity Variation.

6.3 Correlation Index

Table 4. Level of connectivity: Correlation index.

Level of connectivity	Grid no.
Very Poor	1,8,9,10,18,19,20,30,33,34,35,36,40,44,45,46,47,50,53,54,55,56,57,64,65,70,78,79,80,81,88,89,90,91,92,97,98,99,100
Poor	4,5,6,12,13,14,15,16,17,22,23,24,25,26,31,32,37,41,42,43,48,52,58,61,62,63,66,67,71,72,73,74,75,76,77,86,95
Moderate	2,11,21,27,28,29,38,51,59,69,82,83,84,85,87,93,94,96
Good	3,7,39,49,60
Very Good	68

The Correlation Index assesses the relationship between road network connectivity and urban factors like traffic flow and land use, indicating the efficiency of the road network in serving area needs. From table 4 and figure10, the Findings categorize areas into three groups: "Very Poor" (e.g., grids 1,8,9,10,18) exhibit inadequate road connectivity for traffic demands; "Poor to Moderate" (e.g., grids 4,5,6,12,13,14) show some alignment but need improvements; while "Good to Very Good" (e.g., grids 68, 37,39) demonstrate strong correlations, leading to efficient infrastructure use. The analysis suggests that poor correlation may result from either underutilized or overcrowded roads, and improving road alignment with land use and traffic patterns can enhance overall efficiency.

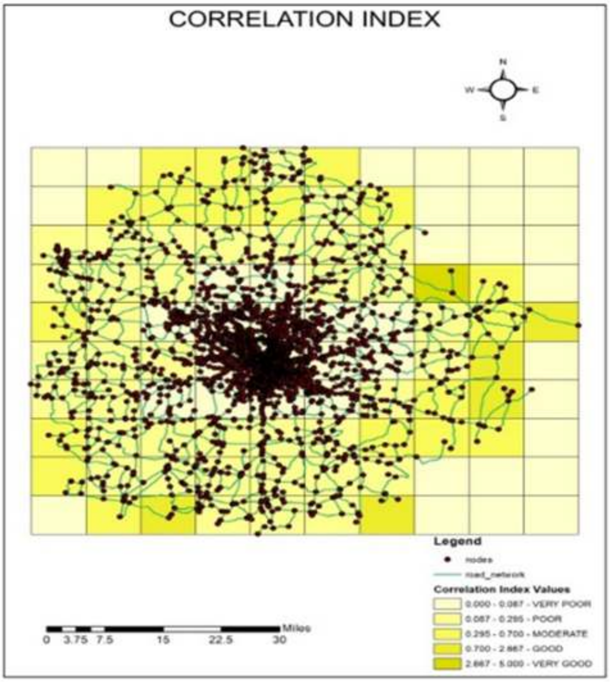

Fig. 10. Correlation Index Connectivity Variation.

7 Conclusions

The examination of Hyderabad's urban road network uncovers notable inequalities in connection, efficiency, and infrastructure density among various regions. Grids designated as "Very Poor" in indices such as Beta, and Betty demonstrate low road density, insufficient intersections, and a lack of alternate routes, resulting in significant congestion, extended travel durations, and diminished accessibility. These regions have a hierarchical road system that directs traffic onto primary routes, resulting in congestion, particularly during peak periods. Conversely, grids classified as "Good" or "Very Good" exhibit superior connectivity, numerous route alternatives, and effective traffic circulation. This suggests that augmenting road density, establishing parallel routes, and improving intersection connectivity may alleviate congestion and enhance accessibility in underdeveloped areas.

The Correlation Index underscores the necessity of aligning road networks with traffic demand and land use patterns. Inadequately connected regions experience traffic inefficiencies and hinder socio-economic development since deficient road infrastructure obstructs access to services and employment centers. In contrast, grids with well-established networks demonstrate fluid movement and increased local trip ratios, enhancing economic activity. Enhancing road infrastructure, especially in poorly connected regions, and aligning road layouts with urban expansion would be essential for optimizing traffic management, alleviating congestion, and increasing overall mobility in Hyderabad. Efforts in sustainable planning that concentrate on these elements can markedly enhance the city's transportation efficiency and quality of life.

This study has certain drawbacks, including dependence on connectivity indices that may not adequately reflect real-time traffic patterns, fluctuations in road usage, or new transportation technology. The research is confined to the current road network, excluding future urban development and the effects of alternate transportation modes like as metro lines and bike-sharing programs. Future research should integrate dynamic traffic data, multimodal transportation alternatives, and predictive modeling to provide a more thorough understanding of the city's changing mobility requirements. Furthermore, suggestions encompass the expansion of road networks in inadequately connected regions, the enhancement of redundancy via alternative routes, and the incorporation of intelligent transportation technologies to improve traffic management and alleviate congestion. Emphasizing sustainable and inclusive urban development would be essential for tackling the enduring transportation difficulties in Hyderabad.

Acknowledgments. I thank HMDA (Hyderabad Metropolitan Development Authority)for extending their cooperation and kind support for the data collection of the Hyderabad RoadNetwork.

Disclosure of Interests: The authors disclose that there are no potential conflicts of interest in publishing the paper.

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