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Evaluation Of Urban Road Network Connectivity Mapping Using Nano Satellite Images: A Model Study

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Indian road network in major cities are highly configurated to reach the demand of transportation, the current road network is insufficient to reach the nation's expanding transportation needs. Utilizing the existing road network more effectively is required in this situation. To make the most use of the existing roads, studying and investigating present network scenario using the road network study criteria such as structure, connections between roads and their accessibility. The objective of this paper is to study Guntur City's road network's connectivity which located in Andhra Pradesh state of India. The indices alpha, beta, gamma, eta, cyclomatic number, and total (aggregate) transportation score are used to quantify the degree of connectedness; different sites within Guntur City were considered.In order to ascertain if the connectivity of networks may account for a significant amount of the differences in the spatial-pattern of the road-network structure, an attempt to analysisGuntur city. According to analysis, the research area's connectivity and coverage have a direct impact on the fractality of the transport network. Compared with different connectivity indices, network density may be a more accurate indicator of the road network's fractality. This indicates that the spatial structure within the research area and the degree of road structuralenhancement are significantly correlated.Theresults of this study may serve as a reference for the city's road network planning authority as they assess the degree of connection at every place and develop more effective planning strategies to raise the city's overall connectedness. Urban transportation planning can make better decisions by utilizing Geographic Information Systems (GIS). Additionally, the current study attempted to demonstrate the effectiveness of GIS in analysing the transport network structure's connectivity-based performance in the research area.

Keywords: Nano satellite Images, GIS, Road Connectivity, Analysis and Planning.

INTRODUCTION

The road transport network is fundamentally structured to connectpeople and local produced products to markets and people gathering places. Consequently, it supports the development of urban systems. A well-functioning road network is crucial in sustaining and enhancing the quality of life mostly at urban areas while promoting sustainable development(Litman, 2005). Given the substantial developmental costs associated with the road transport network, effective utilization is imperative, achievable only through adequate connectivity and accessibility. Therefore, significant attention must be directed towards the design and configuration of the road transportation in urban areas. The evaluation of road networks has seen limited theoretical research, and there is also a scarcity of relevant project cases. Within the urban framework, the transportation system plays a critical role in a location's economic development. The way a transport structure functions is a good indicator of how well an engineer adheres to that location. A well-functioning transportation system is essential to the ongoing development of a region. These days, specialized integrated systems like Geographic Information Systems (GIS) are available to improve the functionality and caliber of the transportation infrastructure.Any road network must have these four fundamental components: hierarchy, morphology, accessibility, and connectedness. A well-connected street system makes it easier to go to your intended locations. An ordered, hierarchical road system facilitates varying vehicle volumes, speeds, and types of transportation (Litman, 2005).To assess the degree of organization and interconnectivity of the street structure, there is a need of indicator which indicates the connectivity. The nodes and links make the easy way to study the structure ratio (Ewing, 1996). An acceptable level of road interconnection is indicated by higher connectivity indicator values (Litman, 2005). For many firms, the network connectivity indices will serve as a foundation for accessibility and efficiency of the road network, which is useful when making mobility planning decisions (Handy, et al., 2002)Finding the best solutions for identifying emergency utilities in Varanasi can be aided by network analysis (Kumar and Kumar, 2016. Arc GIS software was used to quantify transport network indicators, and the results showed that there were few road links in Kerala's Karsagod taluk (Vinod, et al., 2003). Using south west Delhi as an example, the use of the Arc GIS network analysis tool is described as being available for solving numerous network issues related to transit structural performance (Arora and Pandey, 2011). Using several connection indices, transport structural performance based on connectivity is calculated, and the results show that Aurangabad has adequate network infrastructure (Nagne, et al., 2013). The Arc GIS network analysis tool was utilized by the city of Dehradun to find answers to numerous issues with the transportation system (Nijagunappa, et al., 2007). Kansky (1963) presented three key metrics, namely Alpha, Beta, and Gamma, to measure connectedness. These metrics make it simple to understand how well the transportation structure performs in relation to road connectivity. Trans-Amadi, Port Harcourt, Nigeria's road-network system was evaluated using the Beta index, road density, connectivity, road kinds, and condition (Obafemi, et al., 2011). With the use of indices which work on network graph-based study, the inter-relation of inter connection and changes in land cover was examined for the Thai province of Lop Buri(Patarasuk, 2012), The effectiveness of the transport network framework regarding its connectivitywas examined with help of structural measurements for Cooch city in Behar(Sarkar, 2013). In order to help the rural road planners, decisionmakers, researchers, and other various level administration people, an attempt was made to establish a GIS-database with urban roads. The database was created using the network's structural analysis, which included shortest path analysis, Average Pavement Condition Index (APCI) values for each road edges, and connectivity analysis (Manyazewal, et al., 2014)A network consists of a framework of links that are interconnected through nodes. Since 1960, numerous indicators based on networks have been created to analyse the transport network, which can be categorized into connectivity, cyclic properties, and efficiency measures. Garrison, 1960 was introduced graph-theory metrics to measurethe spatial configuration of road structure (network) and to examine their correlation with local economic traits. In the past, the attention given to understanding network structure has predominantly belonged to geographers, who perceive the spatial qualities of the road network as a significant factor for regional development. (Rodrigue, et al., 2006). Recently, it was been observed a significant surge in interest in comprehending the topological links of the roads with other transport networks which link various points in the geographical space.(Gastner, et al., 2006). The potential use of network metrics while proposing is explored by Xie, 2005, specifically diversity, connectivity patterns, and continuances, for measuring the road structure. These proposed metrics were subsequently utilized while tracking the road network characteristics evolution for long time (Xie, et al., 2007). In summary, a variety of spatial metrics offer quantitative insights for the analysis of urban transportnetworks.

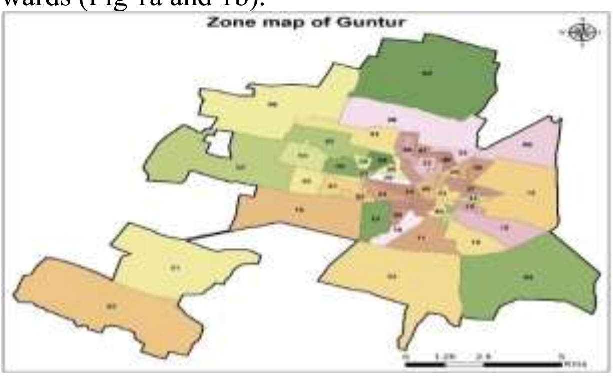
OBJECTIVES

The primary focus of this research is to assess how effective the road system is in Guntur municipality, with regards to its structural connectivity. The specific goals include:

1) To understand the patterns of road network in city andcompute multiple network-connectivity metrics within a one-kilometre radius for each location.
2) To use the Aggregate Transportation Score to assess each location's degree of road network connectivity.
3) To designate areas with networks that are poorly, somewhat, and highly connected.

STUDY AREA AND DATA USED

Guntur city area is selected to this study which is located in Guntur district, Andhra Pradesh. The study area covers Guntur city with an area of 128sq km It is situated 60 km to the west of the Bay of Bengal, along the Eastern Coast of India.The city ranks as the third largest in the state regarding population, area, and economy. It serves as one of the major trades'centres for agricultural products, featuring Asia's largest dried chilli market, along with the national headquarters of the Tobacco Board located within the city. Additionally, Guntur is recognized as a significant medical and educational centre in the state.The Guntur Municipal Corporation (GMC) functions as the city's administrative authority. The city is organized into 54 municipal wards (Fig 1a and 1b).



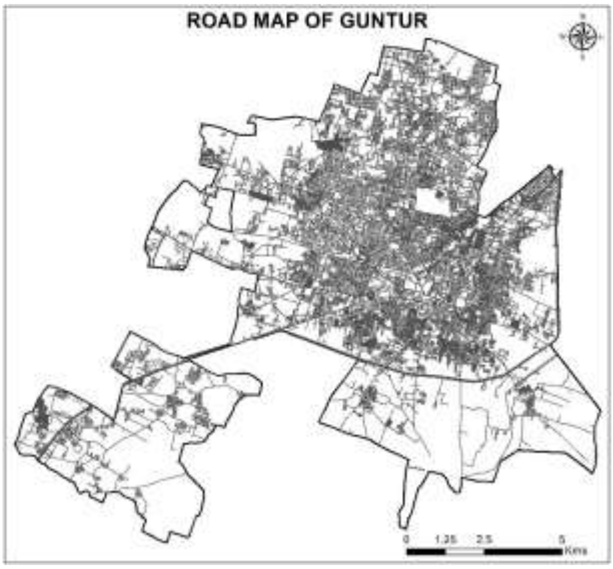


Fig. 1a. Guntur city Zone map

Fig. 1b. Guntur city road digitised map

In the study area randomly 10 locations are selected in the Guntur city in different directions. Guntur City is the district headquarters, Guntur Mandal is well connected by rail and road transport. The road vector file of study areawasdownloaded from the Open Street Map and updated the roads use of Google maps in QGIS. The locations selected for this study are Balaji Nagar, CPI Colony, Gandhi Nagar, Gorantla, Gujjanagundla, Nagarampalem, Naidupet, Nallapadu, Nehru Nagar and RTO/RTA Guntur. Buffer zones of a kilometer radius were drawn for each location. The selected buffer zones at locations for study the connectivity analysis are shown in Figure2.

The number of vertex (nodes) and edges (links)for each location within the 1-kilometer buffer was calculated using network analysis tool in Arc GIS 10.5Figures 3(a) and 3(b) shows the vertex and edges which falls within the buffer zone locations of Gujjanagundlaand Nallapadau. Similarly, the vertex and edges of other selected locations were calculated using GIS software (Arc GIS 10.5). The city roads network connectivity is analysed using the metrics for each selected locations such as vertices count, edges count, α index, β index, edges and vertices ratio, ¥ index, cyclomatic number, and Total Transport Index (Sahitya, et al., 2020).The equations of these indices which are used in this study are shown in the Table 1.

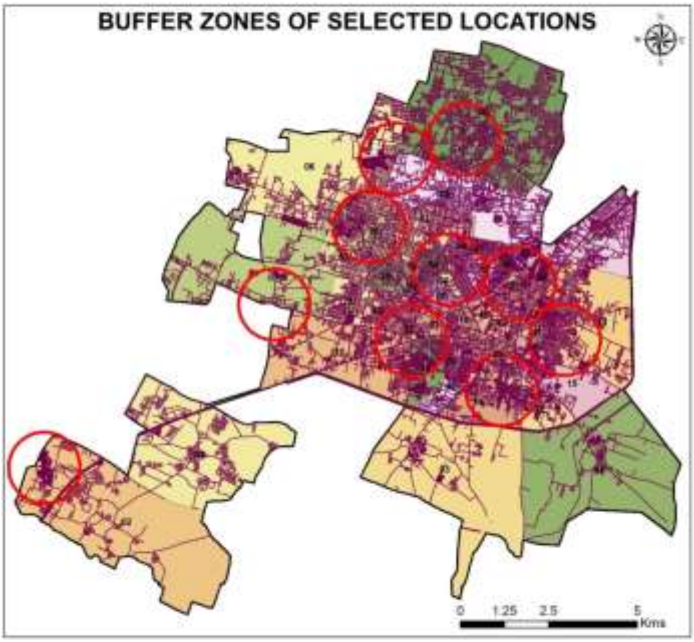


Fig. 2 Buffer zones of locations for connectivity analysis

METHODOLOGY

Methodology for evaluating urban road network connectivity using geoinformatics, with a focus on Guntur, Andhra Pradesh (AP). This methodology involves utilizing GIS tools to assess and quantify the road network connectivity of the urban involves following steps. Import road map into GIS software and identify the location to study the connectivity. The corporation boundary imposed on the road network, extracted the network structure zone wise.

Characteristic of road network

The road structure exhibits both topological and geometric difference in its network structure. Numerous indices have been proposed in previous studies that are applicable for assessing the properties of road networks. These metrics are further utilized whileproposing plansfor transportation practices. The specific quantifying methods employed in this paper are elaborated to study the network connectivity.Connectivity quantifying methods assess the strength of links among road vertices. These connected pertains show the directions of travel between various destinations. A network which is connected well shows connected features with numerous short links, a high number of intersections, and few dead-ends, thereby offering uninterrupted and straight way to destinations. There are many types of connectivity indices have been employed over time. The various indices employed to evaluate the connectivity patterns of road transport networks include the α, β, ¥ andŋIndex (Arora and Pandey, 2011).The applied connectivity measures for this study are be found in Table 1.

Table. 1- Different connectivity indices with equations

S. No	Index	Equation & Notation	Description	Defines Connectivity
1	α index (alpha)	α=(e-V+1)/2v-5	e = number of edges / links v= number of nodes / vertices	Explains about circuitry of the network. Higher value indicates more connectivity.
2	β index (beta)	β = e/v	e = number of edges / links v= number of nodes / vertices	Explains the complexity of the network. A higher value indicates more connectivity.
3	¥ index (gamma)	¥ = e/3(v-2)	e = number of edges / links v= number of nodes / vertices	Explains about the completeness of the network. Higher value indicates more connectivity.
4	η index (eta)	η = L/e	L= summation of all the edges e = number of edges/ links	Explains the utility of the given network. A higher value indicates more connectivity.
5	µ number (cyclomatic Number - CN)	µ = e-v+1	e = number of edges/ links v= number of nodes/ vertices	Explains about the closeness of graphs in the network. Higher value indicates more connectivity.
6	Total Transport Index (TTI)	TTI = β+α+¥+µ	α = alpha index β = beta index ¥ = gamma index µ = Cyclomatic number	Higher value indicates more connectivity and efficiency.

Source: Sahitya, K.s. and Prasad, C.S.R.K., 2020. Methodology for city level urban road network connectivity analysis using geographical information system (GIS). *Stavebni Obzor-Civil Engineering Journal*, 29(1).

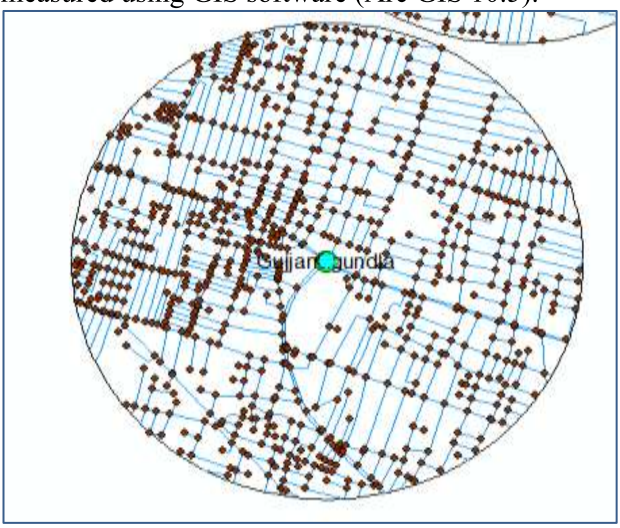
Quantifying Coverage illustrate the density characteristics of network elements, including intersections and road-links. These measures are instrumental in assessing coverage and enhancement of roads. A high value indicates a more developed road-network. Network-Density and Intersection-Density reflect the coverage of the road network within a specific area. The density of the road network in each region is quantified by the total length of roads per square kilometre of land area. A greater road density indicates a larger number of roads and, likely, an enhanced connectivity of the road network. It is probable that road density and junction density are significantly and positively correlated. (Frankhauser, 2008).

Road Network Density = Total Road Length in zone (km) / Area of Zone (sq.km)

Intersection (Junction) density is Number intersection nodes per a square kilometre area is known as junction density. The high value indicates the more junctions which means higher network connectivity.

Intersection Density = Number of Junction / A (sq.km)

To study the network connectivity in junction centers,10 location centre points in the study area are selected to study the accessibility of the road network. Create the buffer zone radius of 1 Km to determine the accessibility level at each location depends on TTI and compute the indices. Prepare the layers for link and nodes to calculate the road network connectivity. This methodology helps to comprehensively evaluate urban road network connectivity, providing insights into how well different areas are connected, and offering actionable recommendations to improve urban mobility and accessibility in Guntur, AP. The nodes and links count for Gujjanagundlaand Nallapadau within a 1-kilometer buffer, calculated using Arc GIS 10.5 network analysis tool are shown in Figures 3(a) and 3(b). In the same way, the vertex (are known as nodes) and edges (are known as links) of all other sites were determined and measured using GIS software (Arc GIS 10.5).



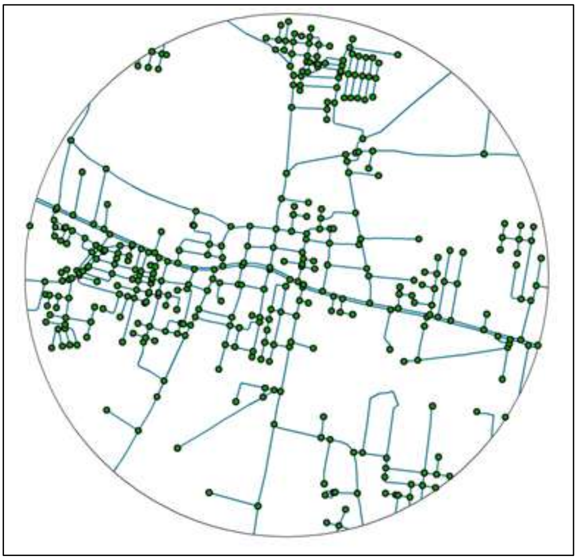


Fig. 3(a) Vertices and edges of Gujjanagundla

Fig. 3(b) Vertices and edges of Nallapadau

RESULTS AND DISCUSSIONS

At first the Guntur city ward (zone) map, overlaid with road network map and extracted the zone wise node and edges count to perform the connectivity study with in each zone. This data was used to study the coverage and spatial pattern of the study area zone wise. The overall the connectivity indices asα index (Alpha), β Index,¥ index, andŋ index- (Eta) are calculated using the number of edges and vertices within each zone. ArcGIS network tools are used to generate the nodes and edges and the zonal information was collected and performs the indices calculation using excel. The descriptive statistics of the connectivity indices for overall study area is mentioned below in table 2.

Table. 2- Descriptive Statistics of network-connectivity index

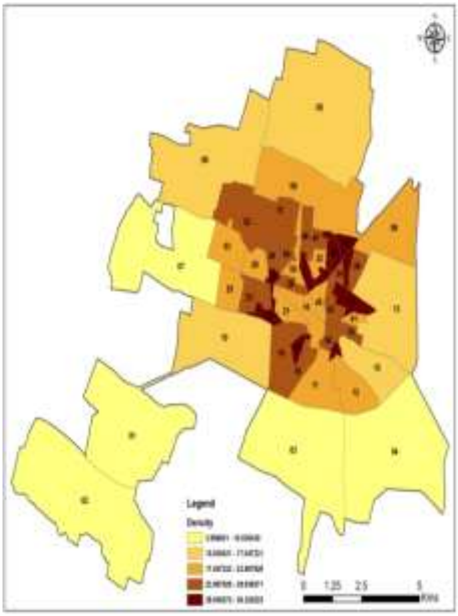
Sno	Index	Min	Max	Mean	Std Dev
1	α	0.0939	0.8556	0.4254	0.1726
2	β	1.185	2.6563	1.8224	0.3268
3	¥	0.3965	0.9043	0.6183	0.1154
4	ŋ	0.044657	0.1150	0.0642	0.0151
5	CN	25	1021.0000	193.9630	180.4725
6	TTI	28.149	1023.1933	196.8290	180.2603

The α index value is between 0.09 to 0.85, where the average for study area is 0.4. It expresses the maximum possible number of cycles in road network which lay between 0.1 to 1. The study area showsan average alpha value which indicates moderate connectivity of road network. The β value is lay between 0 to 3 where, in this study the it is in between 1.185 to 2.65. This indicate the connectivity is moderate is well distributed. The Gamma index value is a ratio between edges and links of network. Where the value 1 is perfect connectivity, where it is an unusual and extremely found. In this study area is showing the value between 0.3 to 0.9 which indicate the connectivity is in between moderately to high. Eta values are very low, this show more edges in network. The average CN number good enough in study area which show high closeness and more connected roads. The TTI score is relay between 28 – 1023, where average 193. This value indicates the moderate to high road connectivity. Network Development and coverage is obtained by calculating the road length, area of zone and node count. The attribute table of road and ward(zone) are used in this calculation. The zone wise road length with in respective zone is used in network density, and the node count with zonal area is used to calculate the intersection density. The descriptive statistics of these index are mentioned in below table 3.

Table. 3- Descriptive Statistics of network coverage indices

	Network Density	**Intersection Density**
Minimum	3.999	28.322
Maximum	36.320	426.076
Mean	23.711	245.376
Standard Deviation	7.774	93.311

The average road network density of study area is 23.7/ square kilometre. It is over all satisfactory, where in the central area is shown more road network where the sub urban area is less network. To identify the density there is need to study individual zones to identify the need of transportation development. The intersection density values vary in between 28 to 426. Where the centre part was more junction points and sub urban area show less-connecting points. The Road Density for zones was presented as thematic maps shown below Fig 4(a), and zone wise Intersection map was in Fig.4 (b)demonstrate how the variable changes throughout the geographical region



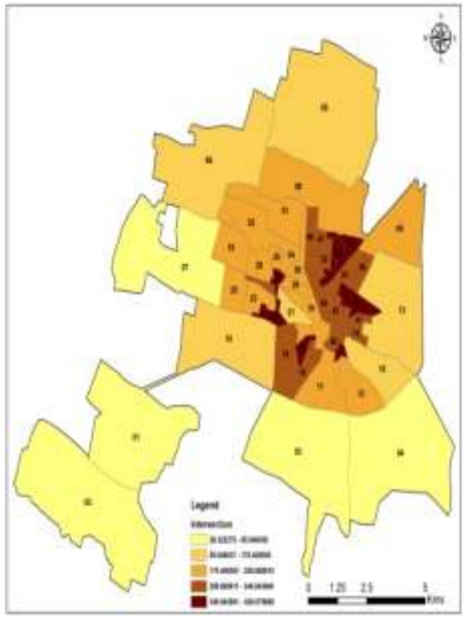


Fig. 4(a) Variation of Road network densityFig.b) Variation of Intersection density

Road-network Spatial Patternwas studied for the selected locations in the study area and calculated indices.Connectivity indices such as α, β, ¥, ŋ, CN and TTI were calculated for 10 locations within the 1 km radius buffer zone and the results are presented in Table 4.

Tab. 4- Statistics of network-connectivity indices

S.No	Location	Vertices	Edges	αIndex	βIndex	¥ Index	ŋIndex	CN	TTI
1	Balaji Nagar	875	1681	0.46	1.92	0.64	0.24	807	810.03
2	CPI Colony	266	477	0.40	1.79	0.60	0.22	212	214.80
3	Gandhi Nagar	908	1703	0.44	1.88	0.63	0.23	796	798.94
4	Gorantla	805	1406	0.38	1.75	0.58	0.21	602	604.71
5	Gujjanagundla	847	1605	0.45	1.89	0.63	0.24	759	761.98
6	Nagarampalem	947	1807	0.46	1.91	0.64	0.24	861	864.00
7	Naidupet	850	1650	0.47	1.94	0.65	0.24	801	804.06
8	Nallapadu	381	657	0.37	1.72	0.58	0.21	277	279.67

9	Nehru Nagar	1099	2156	0.48	1.96	0.66	0.46	1058	1061.10
10	RTO/RTA Guntur	783	1684	0.58	2.15	0.72	0.27	902	905.45

The α Indexindicates the proportion of the most desirable chains in the network, the α index values ranges between 0 - 1, where 0 indicates low connectivity and 1 indicates greaternetwork-connection. The αindex value for the ten locations ranges from 0.37 to 0.98. The average α index value of 0.5 indicates a Medium level of circuitry in the road-network of the location. β index values most of the timelays between 0 to 1, with 0 indicating lownetwork-connectivity and 1 indicating highnetwork-connectivity. β index values greater than 1 indicate more complex network connectivity. All locations have β index values shown higher than 1, which indicates the complicated aspect of the city's road-network. YUING (1996) suggests that the value of the 1.8 beta index (the average beta index) is a suitable goal for plan.Since gamma index is generally represented as a connection rate, the average Gama index, which is 0.63, indicates that connectivity is up to 63%. The higher the Cyclomatic number (CN) and Total transportationIndex (TTI) values show the high network-connectivity and high efficiency of connectivity.

TOTAL (AGGREGATE)TRANSPORTATION INDEX(TTI) OF SELECTED LOCATIONS

The Total (Aggregate) Transportation Index (TTI) was utilized to evaluate the connectivity of a region or location.TTI is capable of interpreting the overall connectivity of the region. The TTI is calculated by adding of α Index (Alpha), β Index (Beta), ¥index, and μ number (Cyclomatic-CN). Therefore, TTI can interpret from global connections to regions or places. The higher the TTI indicate the great degree of connectivity and efficiency of transportation of that particular region of location, Thiswork attempted to classify and evaluate the 10 sites identified for network connectivity assessment based on the received TTI values Road networks in various places are classified into minimum-connected networks, moderately connected networks, and maximum-connected networks. The connection level according to the TTI value is classified in Table 5.

Table 5 Level of network-connectivity based on overall TTI

S. No	TTI Value	Connectivity Level
1	0-250	Less-connected network
2	250-350	Moderately
3	>350	Well-connected network

The sitesidentified for network connectivity assessment classifiedusingTTI values, and presented in Table 5.

Table -6 –Classification of network-connectivity of various places

S. No.	Location	TTI	Level of connectivity
1	Balaji Nagar	810.03	Well-connected network
2	CPI Colony	214.80	Less - connected network
3	Gandhi Nagar	798.94	Well-connected network
4	Gorantla	604.71	Well-connected network
5	Gujjanagundla	761.98	Well-connected network
6	Nagarampalem	864.00	Well-connected network
7	Naidupet	804.06	Well-connected network
8	Nallapadu	279.67	Moderately connected network
9	Nehru Nagar	1061.10	Well-connected network
10	RTO/RTA Guntur	905.45	Well-connected network

The results presented in Table 6 show the location CPI Colony is less connected network, Nallapadu are moderately connected network. Remaining locations Balaji Nagar, Gandhi Nagar, Gorantla, Gujjanagundla, Nagarampalem, Naidupet, Nehru Nagar and RTO/RTA Guntur have shown a well-connected network. The urban transportation planners may concentrate more on the less connected network and moderately connected sitesto improve the road-network of the Guntur mandal and maintain the well-connected network areas as per the demand which improves the network-connectivity of the city.

CONCLUSION

The road network connectivity of Guntur city is evaluated and analysed using the structural parameters, connectivity is one of the key parameters in these studies. The partial analysis of the network study is shown in this study which play a key role in identification of transportation problem in Guntur city using the Geographical Information System (GIS). This study is mainly focused on the evolution of structural road network connectivity.The CN number above 193 for the study area which indicate more interconnected road network, the TTI which is calculated from various connectivity indices shown the value 193, this figure suggests that the study area exhibits a high level of connectivity and efficiency. The average density of the road-network system in Guntur city is 23.711km/sq.km, which is deemed satisfactory. And also the intersection density value of 245 reflects a very high figure, which is also considered satisfactory network connectivity.The high values of indices show the best connectivity in central zone of Guntur city. This attempt is analyze the connectivity of selected locations, with 1 kilometer buffer radius at each location in the Guntur corporation area. The graph-theory based network indices with help of vertices and edges are used in to evaluate the network indices which describe the road network-connectivity. The Total Transportation Index was calculated for the different location buffer zones and evaluates the road network connectivity. The three grade of connectivity was classified based on the TTI score and categorized as less, moderate and well-connected network. This study is purely based on the structural road-network evolution, this work is useful to improve the performance of the road-network in connectivity by the planners. It gives an idea of the connectivity situation in every zone different locations of the city. The enhancing the road network has to be done in the less and moderately-connected network, where well-connected network should be maintained as per the traffic demand. The forthure studies may include the population density and usage of the vehicles in each location which gives a good result to identify the accessibility of the location. The GIS integrated with road-network, spatial connectivity and accessibility studies may give a better result in decision making. These types of studies are very useful to the decision makers and planners to take the necessary steps to take need steps to improve the road network connectivity.

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