
METHOLOGY FOR CITY LEVEL URBAN ROAD NETWORK CONNECTIVITY ANALYSIS USING GEOGRAPHICAL INFORAMTION SYSTEMS (GIS)

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ABSTRACT

In most of the urban cities in India, the existing road network structure is unable to meet the increasing travel demand. In this context, there is a need to utilize the existing road network in a more efficient manner. To effectively utilize the existing road network, the structural parameters like connectivity, accessibility, hierarchy and morphology should be analyzed and evaluated. This study aimed to analyze and evaluate the road network structure of Hyderabad city, Telangana state, India in terms of its connectivity. Different places in Hyderabad city were considered to quantify the connectivity measures such as alpha index, beta index, gamma index, eta index, Cyclomatic number and Aggregate transportation score. Five kilometers radius buffers were drawn from the center of each location to compute the connectivity measures. The results of the study may act as a guide to the transportation planning authorities to understand the level of connectivity at each location in the city and implement better planning practices to improve the level of connectivity in the city. Geographical Information Systems (GIS) is a platform used for better decision making in urban transportation planning. The present study also tried to prove the efficiency of GIS in analyzing the connectivity based performance of the transport network structure in the study area.

KEYWORDS

Connectivity, Road network, GIS, Planning

INTRODUCTION

In the urban framework, the transportation structure is very important and helpful in the economic development of a place. The performance of a transport structure represents the quality of engineer's adherence to that place. A well organized and well-connected transport network is very substantial for continuous progress of an area. To enhance the performance and quality of the transport structure, now-a-days, specifically integrated system like Geographical Information System (GIS) is being availed.

The essential ingredients for any road network are connectivity, accessibility, hierarchy and morphology. The ease of travel to desired destinations is facilitated in a well-connected street structure. Different modes of transport, different speeds and volumes of vehicles are facilitated in a well-organized hierarchical road structure [1].

A connectivity indicator is definitely needed to evaluate how well the street structure is organized and interconnected. This can be easily quantified by the ratio of vertices to the edges in a structure [2]. The higher values of connectivity indicators represent a satisfactory interconnectedness of roads [1]. The connectivity indicators will act as a performance and efficiency base for many organizations which are helpful in the decision making process of transportation planning [3].

Network analysis is helpful for identifying ideal ways for accommodating emergency utilities in Varnasi [4]. Transport network indices were quantified using Arc GIS software which resulted a low level of interconnections between roads in Karsagod taluk, Kerala [5]. The application of network analyst tool of Arc GIS is explained as avail for finding solutions to many network problems relevant to transport structural performance with an example of south west Delhi [6]. Transport structural performance based on connectivity is done using some connectivity indices which proved that Aurangabad has satisfactory network facilities [7]. For Dehradun city, network analyst tool of Arc GIS was used to identify solutions to many problems in transport structure [8]. There are three important indicators measuring connectivity like Alpha, Beta and Gamma proposed by Kansky 1963. With the help of these indicators, the transport structure performance based on connectivity of roads can be explained easily [9]. The road network system of Trans-Amadi, Port Harcourt in Nigeria was assessed in terms of Beta index, road density, level of connectivity, the condition of road and road types [10]. The relationship between interconnectedness and land cover changes was investigated for Lop Buri province; Thailand using graph theory based network indices [11]. The performance of the transport network structure in terms of its connectivity was analyzed using structural measures in Cooch Behar District; West Bengal, India [12]. An attempt to develop GIS based rural road database was done so that planners, decision makers, researchers and other different level authorities in the rural road sector will be benefited from the final output. The database was developed based on the structural analysis of the network in terms of connectivity, average Pavement Condition Index values of the link, shortest path analysis [13].

AIM AND OBJECTIVES OF THE STUDY

This study is aimed to analyze the efficiency of the road network structure in Hyderabad city, capital of Telangana state, India in terms of its connectivity, while the specific objectives are:

- To compute different connectivity indices for each location at five kilometer radius.
- To evaluate the level of road network connectivity for each location based on Aggregate Transportation Score.
- To establish locations with the less connected, moderately connected and well-connected network.

METHODOLOGICAL FRAMEWORK

The flow chart in Figure 1 presents the methodology used in the study to achieve the above mentioned objectives:

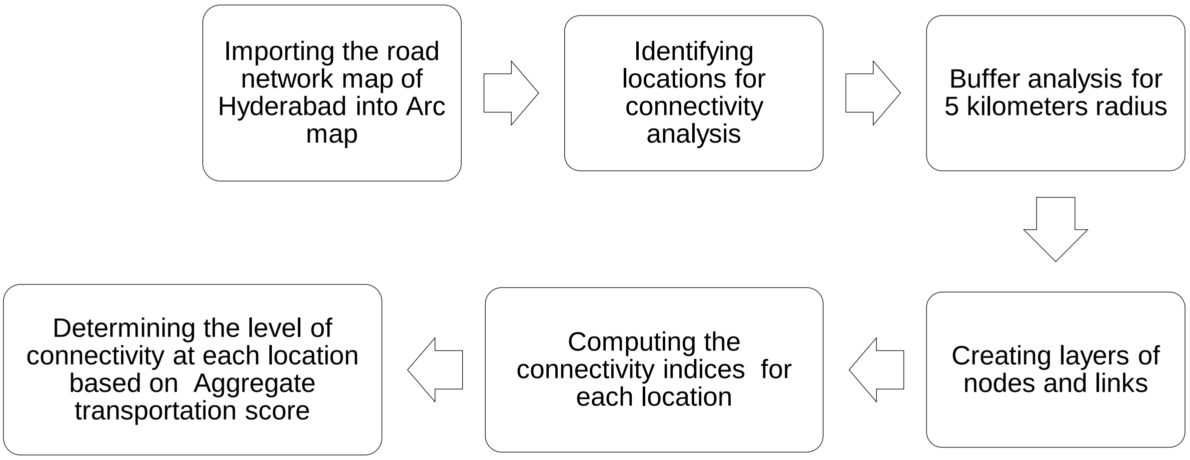

Fig. 1- Flow chart showing the methodology of the study

SITE SELECTION AND DATA PREPARATION

The digitized road network map of Hyderabad city was taken from the HUDA office and further analysis was done using it. The study area for this research is thirty locations of Hyderabad city; India selected randomly covering the entire city in all directions. The locations selected for this study are Abids (AB), Kukatpally (KP), Mehadipatnam (MP), Dilshuknagar(DN), Secundrabad (SC), Panjagutta (PG), Jeedimetla (JM), Sikenderguda (SG), Nadergul (NG), Kothapet (KT), Ameerpet (AT), Banjara Hills (BH), Gandhi nagar (GN), LB Nagar (LN), Malkajgiri (MJ), Hitech city (HC), Bhuvanagiri (BG), Ghatkesar (GS), Bhanur (BR), Moinabad (MB), Rama Chandra puram (RCP), Shivampet (SP), Sangareddy (SR), Wargal (WL), Domarapochampally (DPP), Sitharampuram (SM), Kothur (KR), GolkondaKhurd (GK), Thummaloor (TR) and Ibhrahimpatnam (IBM). Buffers were drawn for each location at a radius of five kilometers. The locations selected for connectivity analysis are shown in Figure2.

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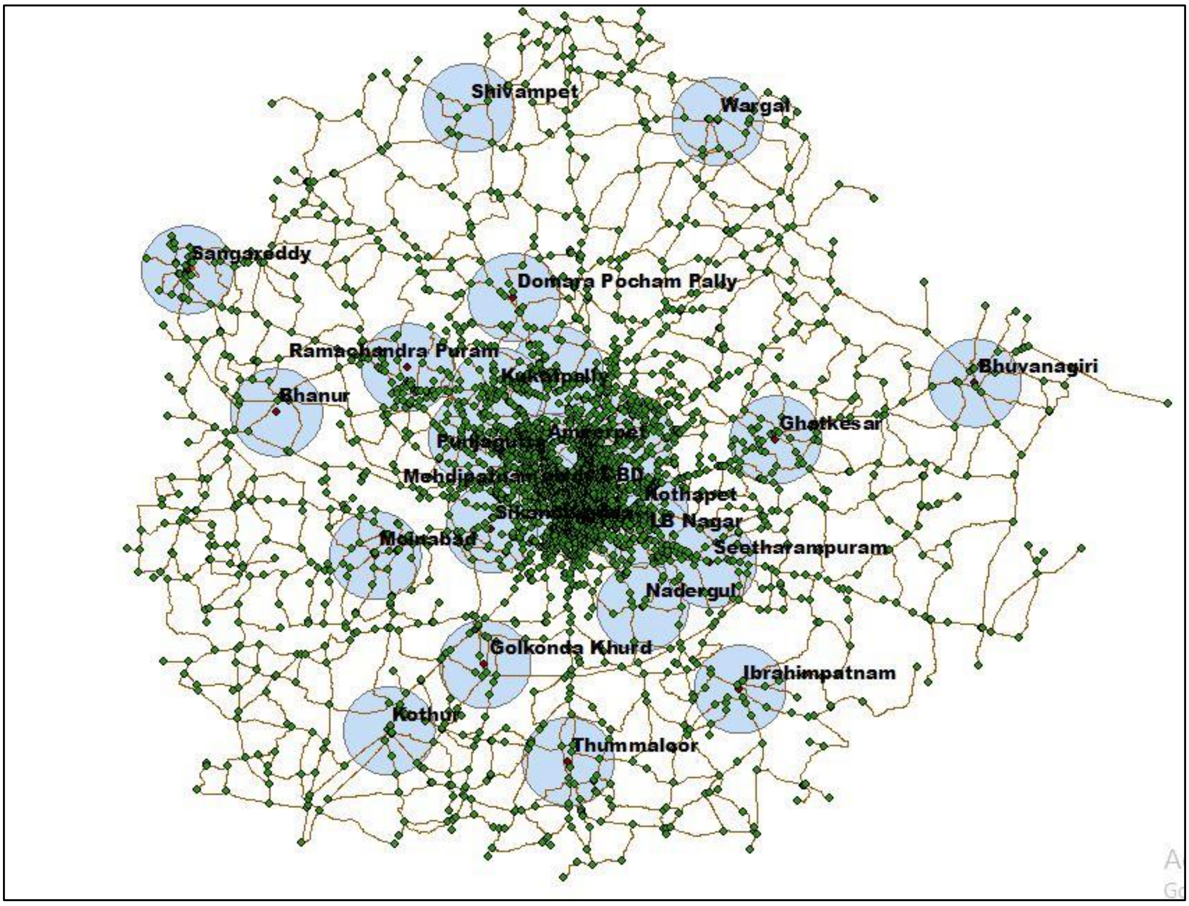
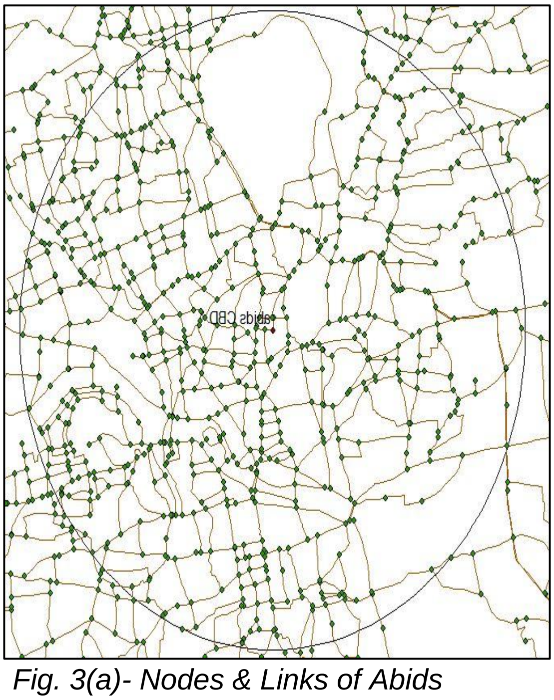


Fig. 2 - Map showing the locations along with buffers for connectivity analysis



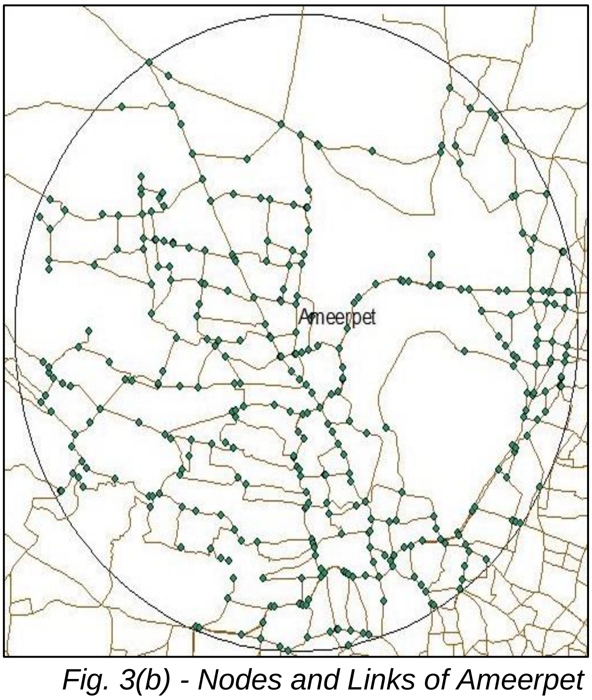


Fig. 3(a)- Nodes & Links of Abids *Fig. 3(b) - Nodes and Links of Ameerpet*

The number of nodes and links for each location at five kilometers buffers were computed using Arc GIS 10.1 software. The nodes and links along with the 5 kilometer radius buffer for the locations Abids and Ameerpet are shown in Figures 3(a) and 3(b). Similarly, nodes and links of all the remaining locations were identified and computed using Arc GIS 10.1 software. The road network connectivity in the city is analyzed using measures of connectivity like the total number of nodes, the total number of links, alpha index, beta index (Link – Node ratio), gamma index, eta index, Cyclomatic number, Aggregate transportation score. The measures of connectivity applied in this study are described in Table 1.

Tab. 1- Description of different connectivity measures

S.NO	Name of the index	Notation & equation	Description	Relation with connectivity
1	Alpha index	$\alpha=(e-v+1)/2v-5$	e = number of edges/ links v= number of nodes/ vertices	Explains about circuitry of the network. Higher value indicates more connectivity.
2	Beta index	$\beta=e/v$	e = number of edges/ links v= number of nodes/ vertices	Explains the complexity of the network. A higher value indicates more connectivity.
3	Gamma 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	Eta index	$\eta=L/e$	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	Cyclomatic number	$\mu = e-v+1$	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	Aggregate Transportation score	$ATS=\beta+\alpha+\gamma+\mu$	α = alpha index β = beta index γ = gamma index μ = Cyclomatic number	Higher value indicates more connectivity and efficiency.

RESULTS AND DISCUSSIONS

The measures of connectivity like alpha index, beta index, gamma index, eta index, Cyclomatic number (CN) and Aggregate Transportation Score (ATS) are computed for thirty locations at 5 kilometers buffer radius and the results are presented in Table 2.

Tab. 2- Descriptive Statistics of connectivity measures

Location	Nodes	Links	Alpha index	Beta index	Gamma index	Eta index	CN	ATS
Abids	687	1238	0.40	1.80	0.60	0.51	552	554.81
Kukatpally	117	222	0.46	1.90	0.64	0.95	106	109.00
Mehadipatnam	432	781	0.41	1.81	0.61	0.59	350	352.82
Dilshuknagar	467	829	0.39	1.78	0.59	0.59	363	365.76
Secundrabad	395	719	0.41	1.82	0.61	0.59	325	327.84
Panjagutta	447	783	0.38	1.75	0.59	0.58	337	339.72
Jeedimetla	92	173	0.46	1.88	0.64	0.98	82	84.98
Sikenderguda	86	165	0.48	1.92	0.65	0.94	80	83.05
Nadergul	32	50	0.32	1.56	0.56	1.58	19	21.44
Kothapet	286	507	0.39	1.77	0.60	0.67	222	224.76
Ameerpet	349	614	0.38	1.76	0.59	0.62	266	268.73
Banjara Hills	411	723	0.38	1.76	0.59	0.60	313	315.73
Gandhinagar	645	1147	0.39	1.78	0.59	0.50	503	505.76
LB Nagar	200	360	0.41	1.80	0.61	0.62	161	163.81
Malkajgiri	266	491	0.43	1.85	0.62	0.72	226	228.89
Hitech city	130	239	0.43	1.84	0.62	1.25	110	112.89
Bhuvanagiri	83	92	0.06	1.11	0.38	2.68	10	11.55
Ghatkesar	39	92	0.74	2.36	0.83	1.43	54	57.93
Bhanur	43	50	0.10	1.16	0.41	1.92	8	9.67
Moinabad	62	79	0.15	1.27	0.44	1.64	18	19.86
RamachandraPuram	56	112	0.53	2.00	0.69	1.20	57	60.22
Shivampet	35	39	0.08	1.11	0.39	1.95	5	6.59
Sangareddy	78	93	0.11	1.19	0.41	2.77	16	17.71
Wargal	68	117	0.38	1.72	0.59	1.84	50	52.69
DomaraPocham Pally	58	117	0.54	2.02	0.70	0.66	60	63.25
Sitharampuram	50	110	0.64	2.20	0.76	1.18	61	64.61
Kothur	44	58	0.18	1.32	0.46	2.60	15	16.96
GolkondaKhurd	45	60	0.19	1.33	0.47	1.76	16	17.99
Thummaloor	37	50	0.20	1.35	0.48	2.38	14	16.03
Ibhrahimpatnam	38	55	0.25	1.45	0.51	1.51	18	20.21
Mean values	192.6	338.83	0.36	1.68	0.57	1.26	147.23	149.84

Alpha index gives the percentage of maximum desirable circuits in the network and its value ranges from 0 to 1. Zero indicates minimum connectivity and one indicates maximum connectivity. The alpha index value for thirty locations ranges from 0.08 to 0.74. The mean value of alpha index which is 0.36 indicates a very low level of circuitry in the city network.

Beta index value also ranges from 0 to 1. Zero indicates minimum connectivity and one indicates maximum connectivity. Beta index value greater than 1 indicates a greater complexity of the network connectivity. The value of beta index in all the locations is greater than 1; this shows the complex nature of the road network in the city. Ewing (1996) suggests that the beta index value of 1.68 (mean value of beta index) is a good target for planning purposes.

Gamma index is normally expressed as a percentage of connectivity, so the mean value of gamma index which is 0.57 indicates that the network in the study area is 57% connected.

Higher Cyclomatic number and higher aggregate transportation score values result in higher degree of connectivity and efficiency.

Evaluation of locations based on the Aggregate Transportation Score (ATS)

Aggregate Transportation Score (ATS) is the addition of alpha index, beta index, gamma index and Cyclomatic number. So, ATS can be able to interpret the overall connectivity of a region or location. Higher aggregate transportation score value results in higher degree of connectivity and efficiency. Based on the ATS values obtained, this study tried to categorize and evaluate the thirty locations selected for connectivity analysis. The road network in different locations is categorized as less connected network, moderately connected network and well-connected network. The level of connectivity according to the ATS values is categorized in Table 3.

Tab. 3 - Level of connectivity based on Aggregate transportation score

Aggregate Transportation Score value	Level of connectivity
0-100	Less connected network
100-200	Moderately connected network
>200	Well-connected network

The locations selected for road network connectivity analysis are evaluated based on their ATS values and level of connectivity in each location is presented in Table 4.

Tab. 4 - Evaluation of different locations based on ATS

S.NO	Location	Notation	ATS value	Level of connectivity
1	Abids	AB	554.81	Well-connected network
2	Kukatpally	KP	109.00	Moderately connected network
3	Mehadipatnam	MP	352.82	Well-connected network
4	Dilshuknagar	DN	365.76	Well-connected network
5	Secundrabad	SC	327.84	Well-connected network
6	Panjagutta	PG	339.72	Well-connected network
7	Jeedimetla	JM	84.98	Less connected network
8	Sikenderguda	SG	83.05	Less connected network
9	Nadergul	NG	21.44	Less connected network
10	Kothapet	KT	224.76	Well-connected network
11	Ameerpet	AT	268.73	Well-connected network
12	Banjara Hills	BH	315.73	Well-connected network
13	Gandhinagar	GN	505.76	Well-connected network
14	LB Nagar	LN	163.81	Moderately connected network
15	Malkajgiri	MJ	228.89	Well-connected network
16	Hitech city	HC	112.89	Moderately connected network
17	Bhuvanagiri	BG	11.55	Less connected network
18	Ghatkesar	GS	57.93	Less connected network
19	Bhanur	BR	9.67	Less connected network
20	Moinabad	MB	19.86	Less connected network
21	RamachandraPuram	RCP	60.22	Less connected network
22	Shivampet	SP	6.59	Less connected network
23	Sangareddy	SR	17.71	Less connected network
24	Wargal	WL	52.69	Less connected network
25	DomaraPocham Pally	DPP	63.25	Less connected network
26	Sitharampuram	SM	64.61	Less connected network
27	Kothur	KR	16.96	Less connected network
28	GolkondaKhurd	GK	17.99	Less connected network
29	Thummaloor	TR	16.03	Less connected network
30	Ibhrahimpatnam	IBM	20.21	Less connected network

Based on the results presented in Table 4, the locations Jeedimetla, Nadergul, Sikenderguda, Bhuvanagiri, Ghatkesar, Bhanur, Moinabad, Ramachandrapuram, Shivampet, Sangareddy, Wargal, Domarapochampally, Sitharampuram, Kothur, Golkunda khurd, Thummaloor, Ibhrahimpatnam have a less connected network. The transportation planning authorities may concentrate more on these locations to improve the connectivity of these places which increases the overall connectivity of the Hyderabad city.

CONCLUSION

Connectivity is one of the most important structural parameters to be analyzed and evaluated for an urban road network. This study shows some conclusions based on a partial analysis of the transportation problem in Hyderabad and shows a possibility of using GIS. This study majorly focused on evaluating the structural connectivity of the road network. This study attempted to analyze the connectivity at a micro scale using buffers of 5 kilometers radius at each location. This is helpful in understanding the network connectivity in each location of the city. This study described the road network connectivity with the avail of graph theory based network indices with respect to nodes and links. The study also tried to propose a methodology for the evaluation of different locations in terms of road network connectivity based on the Aggregate Transportation Score. The level of connectivity for each location is categorized as less connected, moderately connected and well-connected network. The study revealed that many locations of Hyderabad city have a less connected network. Therefore, the performance of the road network in terms of its connectivity should be improved by the transportation planning authorities. The results of the study are also useful for the urban transportation planners to understand the situation of connectivity at different locations in the city. The enhancement or improvement of road network has to be done for the locations where there is less-connected and moderately-connected network. There is a need to implement better transportation planning practices in Hyderabad city to increase the connectivity of the road network which increases the accessibility and reduces the travel time. But connectivity is certainly not just about a simple network of streets and intersections. So, the future studies may also include assessing the width of the streets, the number of people living in the locality, etc., to look into accessibility as a wider problem. The integration of GIS with urban road network connectivity analysis gave better results and is helpful in better decision making. This kind of study may be done for all the urban cities so that the planners or decision makers may estimate the level of connectivity and take necessary steps.

REFERENCES

[1] Litman, T ,2005. Roadway connectivity: Creating more connected roadway and pathway networks. Retrieved October 25, 2005.

[2] Ewing R. ,1996. Best Development Practices: Doing the right thing and making money at the same time, Planners Press.

[3] Handy, S, Paterson, R. &Butler, K., 2002. Can't get there from here: Planning for street connectivity. Prepared for the Planning Advisory Service of the APA.

[4] Kumar, P., & Kumar, D., 2016. Network analysis using GIS techniques: A case study of Chandigarh city, International Journal of Science and Research, Volume 5 Issue 2, February 2016.

[5] Vinod, R. V., Sukumar, B., & Sukumar, A., 2003. Transport Network Analysis of Kasaragod Taluk, Kerala Using GIS, Indian Cartographer

[6] Arora, A. & Pandey, M. K, 2011. Transportation network model and network analysis of road networks, 12th Esri India User Conference 2011.

[7] Nagne, A. D., Vibhute, A. D., & Gawali, B. W., 2013. Spatial Analysis of Transportation Network for Town Planning of Aurangabad City by using Geographic Information System, International Journal of Scientific & Engineering Research, Volume 4, Issue 7.

[8] Nijagunappa, R., Shekhar, S., Gurugnanam, B., Raju, P.L.N. and De, P.,2007. Road Network Analysis of Dehradun City Using High Resolution Satellite Data and GIS, Journal of the Indian Society Of Remote Sensing, Vol. 35, No. 3.

[9] Kansky, K., 1963. Structure of Transportation Networks: Relationships between Network Geometry and Regional Characteristics, Ph. D. thesis, University of Chicago, Research Paper No. 84.

[10] Obafemi, A.A., Eludoyin, O.S., Opara, D.R., 2011. Road network assessment in Trans-Amadi, Port Harcourt in Nigeria using GIS, International Journal of Traffic and Transportation Engineering, 1(4): 257-264.
[11] Patarasuk, R., 2012. Road Network Connectivity and Land-Cover Dynamics in Lop Buri Province, Thailand. Journal of Transport Geography 28, 111–123
[12] Sarkar, D., 2013. Structural Analysis of Existing Road Networks of Cooch Behar District, West Bengal, India: A Transport Geographical Appraisal, Ethiopian Journal of Environmental Studies and Management Vol. 6 No.1
[13] Manyazewal A.L, M.Anil &Prasad CSRK, 2014. Advanced Information System for Planning and maintenance of rural roads using GIS, ISPRS TC VIII International Symposium on Operational Remote Sensing Applications: Opportunities, Progress and Challenges, Hyderabad, India.