SPATIAL MAPPING OF TRAVEL INFORMATION AND ASSESSMENT OF ROAD CONNECTIVITY

K. Ashritha [a], Paresh Chandra Deka [b]

[a] Department of Civil Engineering, Indian Institute of Technology Bombay, Mumbai 400076, India – ashrithasaroja@gmail.com
[b] Department of Water Resources and Ocean Engineering, National Institute of Technology Karnataka, Surathkal, India - dekanitk@gmail.com

KEYWORDS: Road Network, Connectivity, Indices, Least Cost, Mode of travel, and Inaccessible Area.

ABSTRACT

Roads play a crucial role in the urban spatial structure. A place's development and growth depend on the road network connectivity and accessibility being the socio-economic and transportation carrier. It involves the mobility of people and goods from one place to another. The choice of mode of travel depends on the living standards, connectivity, and vicinity to the work area. The study uses satellite data to analyze road network connectivity using the connectivity indices of Mangalore City Corporation, a port city in India. The connectivity indices alpha, beta, gamma, and eta showed the Area's good connectivity with proper roads and interconnectivity. Using Dijkstra's algorithm, the least cost path is identified on which the spatial mapping of the travel information is made. The travel information raster served the commuter in knowing the time, distance, and cost of modes from all possible origins to each city center. Specifically, it serves as the base map for bus routes, their cost, and travel time for significant city bus stations. The cost of travel, Duration, and distance information is mapped for two-wheeler and four-wheeler commuters. The study used the Modis Land Use Land Cover Data to identify inaccessible road network areas.

1. INTRODUCTION

1.1. Background

A network is a linear feature system with the appropriate attribute for the flow of objects. It consists of interconnected elements, such as lines and connecting points. Examples of networks include highways connecting to cities, streets inter-connected at street intersections, civic water supply networks, and sewer connections. The major application of network analysis is found in transportation planning. The urban road network plays a key role in the urban spatial structure. It is the main city's social-economy activities and transportation carrier. The Transportation System is a critical component of the urban infrastructure growth of any region. Barney et al. (2006) mentioned that over the last 20 years, many urban areas have experienced dramatic growth due to rapid population growth. Rapid technological and political change has transformed the world's economy by demanding a proper well-connected road network. Sreelekha et al. (2016) stated that the road network is one of the keys to the regional development of a region. Road network expansion can only be attained when proper connectivity and orientation exist. But the road network in many urban areas develops in an organic growth pattern. Hence, great emphasis must be given to the layout and design of the urban road transport network so that the present connectivity scenario in every region can be known and the current network connectivity loopholes can be dealt with for future growth and smooth mobility of people and goods.

This study is carried out to know the existing road conditions in terms of connectivity and accessibility so that at the regional level, the information regarding the road conditions is known so that it becomes helpful for network planners in future implications like upgradation and widening. The study also provides a travel base map that gives the travel time, distance, and travel mode costs before they start their journey so that the commuters choose the best way for their travel. There also arises a need for quantifying the inaccessible areas within the study limit, so in the present study, the areas of inaccessibility are found, and the reason behind network disconnectivity is analyzed by knowing the Land Use Land Cover of the study area.

1.2. Literature Summary

Studies have been carried out on existing road networks to check their performance using remote sensing data and on the G.I.S. platform, making it easy for urban planners and decision-makers to work and resulting in the efficiency check of a city's road network. The existing road network connectivity and condition assessment is the elementary analysis before predicting or modeling any future scenarios. Ajay et al. (2013), Vikas et al. (2015), Sreelekha et al. (2016), and Igbokwe et al. (2016) did the spatial analysis of transportation networks by performing the density calculation and network indices like Alpha, Beta, Gamma and Eta which are the prime indicators of growth within the network. To understand the city's existing road network in terms of connectivity and characterize the spatial structure of the road network in terms of fractal dimension. The road network was evaluated based on connectivity coverage and spatial variability, and the analysis was performed through regression, scatter plots, and correlation. The indicators taken for measuring the spatial structure of road networks is applied to identify their effect on the performance of the road transport system.

Geographic Information Systems (G.I.S.) and Remote Sensing are potent tools for monitoring urban facilities like power and energy services, water supply, sewage treatment, drainage systems, road availability, and waste management Wesołowska et al. (2016). Remote sensing data acquired from airborne space platforms and engineering surveys have offered the planner a complete picture of the Land and helped identify the location and quantity of activity from the Moments/Trip polygon method and the allocation technique from years. The cost modeling technique has been used to determine the optimum route for the user, system, non-user, government, and region point of view. Various satellite data products like MODIS., ASTER DEM, Landsat, and Google Earth, and very high-resolution data like I.K.O.N.O.S. and QUICK BIRD help carry out the study Claudia et al.(2014). Many G.I.S. platforms like ERDAS IMAGINE, ArcView, Arc Map, Qgis, ENVI., and Google Earth make the study efficient. G.I.S. and Remote Sensing were applied to investigate traffic congestion patterns in the city and determine the management techniques suitable for their reduction. Apart from connectivity analysis, some studies have attempted to solve the vehicle routing problem by generating final route directions for every vehicle and calculating the best travel time with the help of O.D. Cost matrix. The results show the determination of the closest facilities within the study area. This information will enable commuters and motorists to decide rationally which route to take during peak hour travel, i.e., to find out the shortest or best route, the Closest Facility to the incident place etc. The Origin-Destination matrix represents the traffic flows between various points of the network. Assigning an O.D. matrix to a transportation network means that the demand for traffic between every pair of zones is allocated to available routes connecting the zonal pairs Abrahamsson et al. (1998). The Origin-Destination (O.D.) matrix is vital in transportation analysis. The O.D. cost matrix finds and measures the least-cost paths along the network from multiple origins to multiple destinations. The number of destinations to find and the maximum distance to reach can be specified in the O.D. cost matrix analysis configuration. An O.D. cost matrix is a table that contains the network impedance from each origin to each destination. Additionally, it ranks the destinations that each origin connects to in ascending order based on the minimum network impedance required to travel from that origin to each destination (E.S.R.I.).

2. STUDY AREA AND DATA

2.1. Study Area

Mangalore City Corporation (MCC) is developing fast in all directions, including education, industry, and commerce. Mangalore is located at 12º52'N latitude and 74º49'E longitude (Figure 1). The city is situated at the confluence of the Nethravathi and Gurupura rivers. It is bound in the east by the Western Ghats and in the west by the Arabian Sea. Three National Highways viz., NH-17 linking Panvel and Kanyakumari, NH-48 connecting Mangalore and Bangalore, NH-13 linking Mangalore and Sholapur pass through the city. A domestic Airport is located at Bajpe, which is 15 km from the city, connecting it to Mumbai and Bangalore. Mangalore is linked by rail to all major cities of India and has all-weather harbors. MCC consists of sixty wards which are named from 1 to 60. These wards are further grouped into four Zones consisting of fifteen wards each.

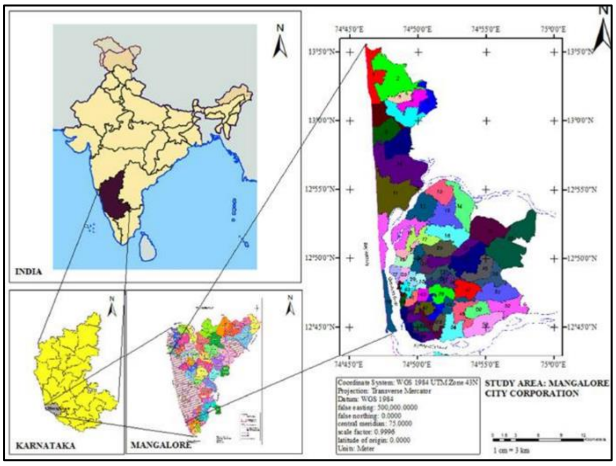

Figure 1. MMC Location Map

2.2. Data

Table 1 gives the complete details of the datasets necessary to carry out the work. The data collection included primary data from google earth, G.P.S. survey, and secondary data from various government agencies.

Sl.no	Data Type	Source	Purpose
1	MODIS	USGS Earth data	L.U.L.C. Map
2	Ward Map	Mangalore City Corporation	Zone Map
3	World Imageries, Street Maps	ArcGIS	Road Network Digitization
4	Road Data	WEBRIS(MAPS), Karnataka P.W.D.	Network Upgradation
5	Google Earth	-	Network Digitization
6	G.P.S. data	Field Survey	O-D Points
7	Ward-wise Population	MCC	Population Density

Table 1. Data and Software Information

3. METHODOLOGY

The work involves four major steps. Step 1 involves road network extraction, and database creation includes database creation. Step 2 performs the network connectivity analysis, and finally, step 3 prepares the travel information map and assesses the road network inaccessible areas.

3.1. Road feature extraction and database generation

The first step is to extract the study region. The interested Feature has two types of features. The first is the polygon feature, and the second is the line feature. The ward map collected from

Mangalore City Corporation was useful in extracting polygon features: study area boundary and zone boundaries of the study area. The line feature contains the road network of MCC; the road network is digitized using world imageries and street maps. The digitized road network was updated using the present road data obtained from W.E.B.R.I.S. of Karnataka P.W.D. and Google Earth imageries. The whole network is divided into four zones for connectivity analysis (Figures 2 & 3).

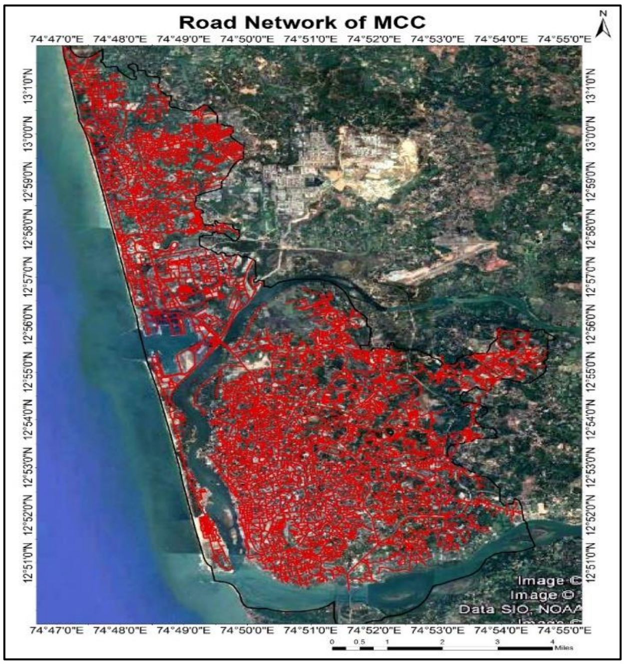

Figure 2. N.M.M.C. Road Network

Later for the travel information map preparation, the extracted road network is generalized into national highways, state highways, major district roads, and other district roads; in other words, into trunk roads, primary roads, secondary roads, and tertiary roads (Figure 4). Geodatabase is a part of the Geographical Information System, which helps to store and manipulate geographical data. Geodatabase combines two words, 'Geo' and 'Database.' The file geodatabase is created to which the road network and boundary datasets is added. Feature datasets, like all Feature classes, have the same coordinate system. Also, it is possible to create Topology for each Feature class.

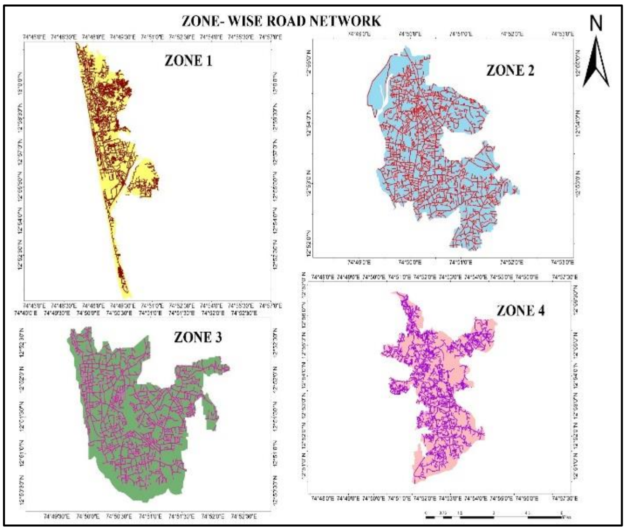

Figure 3. Zone-wise Road Network

Topology is a collection of rules enabling the geodatabase to more accurately model geometric relationships. It is the arrangement for how point, line, and polygon features share geometry. Topology provides a mechanism to check the integrity of data, so it helps to validate and maintain better Features. The road network of each Zone is topologically corrected using the topology tools and the applicable topology rules. The generalized and topologically corrected network consists of attributes, name of a road, and type of road, Length of road, operating speed, Duration, and traveling cost by car, motorbike, and bus. The speed fixed is as per the Pavement design code, which gives the operating speed information for various types of roads, Duration in minutes is calculated as the distance by speed, and traveling cost by car is given as the average mileage of the car is 18kmpl with a diesel cost of 65.67 rupees, a motorbike is considered as 60kmpl with a petrol cost of 75.15 rupees. Finally, the bus rates data per Km of local buses are taken from Mangalore City Corporation.

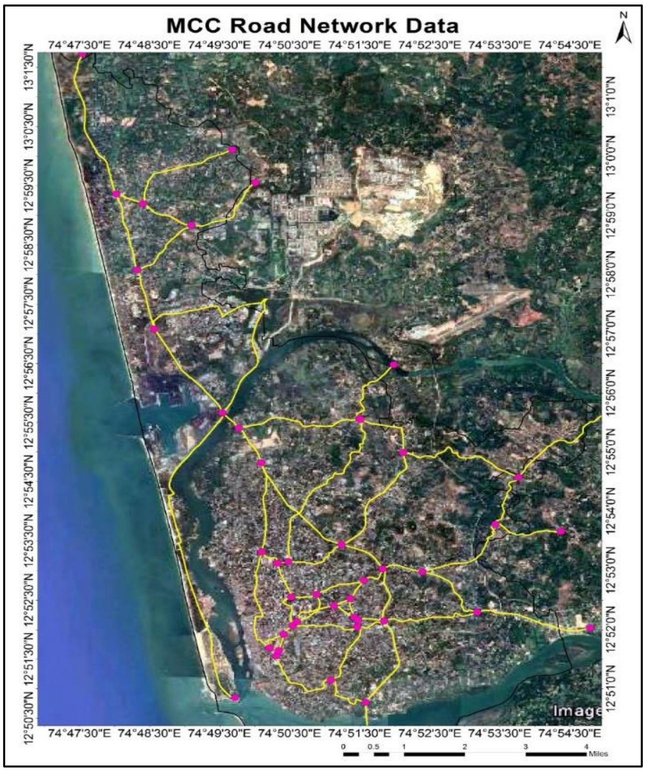

Figure 4. N.M.M.C. Generalized Road Network

3.2. Road Network Connectivity Analysis

A network is a system of interconnected elements such as lines (Edge) and connecting junctions (Vertex or points) representing every possible route from one Junction to another. From a feature class, a network dataset is created. On a Network Dataset, choose the feature dataset for analysis. The network dataset will be built as per the database necessity and all the attributes accumulated to build it. Once the Network Dataset has been created, it will provide the Total number of Lines and the Total number of Junction (Nodes) information required for connectivity analysis. The efficiency of the road network is tested by analyzing the connectivity and accessibility of the present road network of MCC, for which the complete road network was digitized, including the village roads and the connectivity indices were related to population and road density, which is calculated by collecting the data of people from the 2011 senses data of MCC. The Road/Network density is used to measure the Network Development. This index value shows the condition of the MCC Transport network. The most fundamental properties of a Transportation network are Network Indices, like Alpha Index, Beta Index, Gamma Index, etc. There are many Indices, and every Index has its equation for different purposes. Extraction of the connectivity index requires a road network (line) and junctions (nodes). These indices help identify the growth within the network structure and the change detection system. Equations (1) to (6) are listed below Ajay et al. (2013).

$$ND = \frac{l}{A} \tag{1}$$

$$PD = \frac{P}{A} \tag{2}$$

$$\alpha = \frac{(e - v) + 1}{(2 * v) - 5} \tag{3}$$

$$\beta = \frac{e}{v} \tag{4}$$

$$\Upsilon = \frac{e}{3(v - 2)} \tag{5}$$

$$\eta = \frac{L(G)}{e} \tag{6}$$

Where l = total length of a network, A = Total Area of Network, p = total population of Area, ND = Road Density, PD= Population Density e = No. of edges (Line), v = No. of Vertex (Node) and L (G) = Summations of all edges in the network. Eq (1) Alpha Index (α) is a ratio of circuits to the number of maximum possible circuits in the network. Its value ranges from 0.0 to 1.0. If the value is 0, it indicates no circuits; if the value is 100 percent, it indicates a complete, interconnected network. Eq (2) Beta Index (β) is the ratio of the number of edges to the number of nodes. It is more useful for simple networks where no circuits are involved. If the value is 0.0, there are just nodes without any arc. Its value ranges from 0.0 to 1.0 and greater where networks are well connected. Eq (3) The Gamma Index (ϒ) is a Ratio of the actual number of edges to the Maximum possible number of edges in the network. Its value ranges from 0.0 – which indicates no connection between nodes, to 1.0 – the maximum number of connections directly linked to all nodes. Eq (4), the Eta Index (η) is used to Measure the average edge length in the network. And it is used as a measure of speed in traffic network. If a new link is added, it will decrease in the eta index as the average per link declines.

3.3. Travel Information and Network Inaccessibility

The origin-destination cost matrix is conventionally used to know the shortest possible route to reach from one location to another, whereas in the present study origin-destination cost matrix is used to generate a raster for MCC which gives the minimum distance, time, and cost of travel via bus, four-wheeler, and two-wheeler from all the possible locations to defined destinations. The study involves the collection of point locations of important Localities as destinations. The localities were Attavar, Bejai, Bolar, Bondel, Derebail, Hampankatta, Bunder, Kadri, Kankanady, Kodaikal, Kodaibail, Kottara, Krishnapura, Surathkal, Kulai, Kulashekara, Kuloor, Lalbagh, Mary Hill, Konchady, Morgans Gate, Mukka, Nanthoor, Pandeshwar, Pilikula, Thiruvail, Urwa, Vamanjoor, Padil, Kavoor, Srinivasnagar, and Baikampady. The point data was collected using Trimble G.P.S. In order to create origin points a constant raster of pixel value zero and of 500m resolution with road network extent is created. All the localities are considered destinations. After the origins and destinations are ready the O.D. cost matrix calculations are performed. In the O.D. cost matrix output consists of time, distance, cost of travel via bus, car, and motorbike between the defined destinations, and all the possible origins. Then, using the Djkstraw,s algorithm, the minimum Duration, distance, and cost of travel via bus, car, and motorbike from all the possible origins to defined destinations along the network is calculated for MCC road network. Finally, the map containing all the travel information is prepared for the study area (Figure 5).

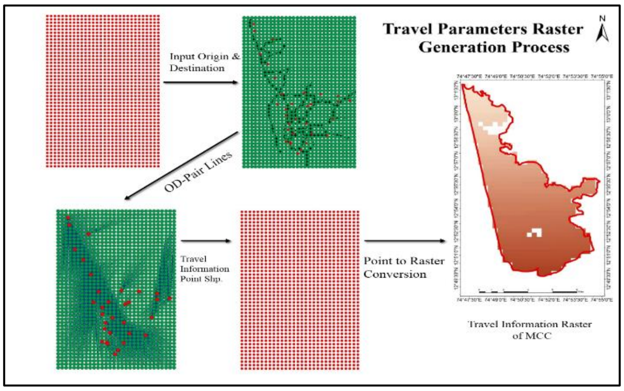

Figure 5. Travel Information Map Preparation Process

The generated information raster exhibits some pixels that do not show any information about the travel, so an attempt has been made to analyze the reason for the failure to provide travel information. The Land use land cover map prepared using M.O.D.I.S. data with 500 m resolution from U.S.G.S. Earth data is overlaid on the generated raster to check the inaccessibility. Then the pixels of the raster, which show zero value, are extracted separately, indicating the inaccessible areas and the reason for it can be interpreted and known with the help of L.U.L.C. and Google Earth. Figure 6 shows the pictorial representation of the method adopted.

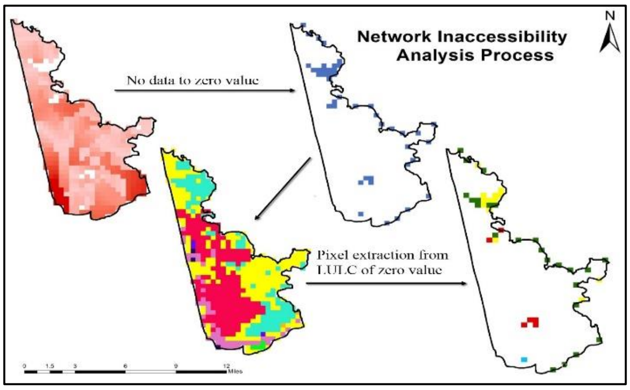

Figure 6. Inaccessible Area Identification Process

4. RESULTS AND DISCUSSION

Mangalore City Corporation has four Zones: Zone '1', Zone '2', Zone '3', and Zone '4'. The population density and road density of all Zones are presented in Figure 7, and the connectivity indices are tabulated in Table 2 for each Zone. Results indicate that Mangalore City Corporation overall has good connectivity with proper roads and interconnectivity between them; the varying gamma values from 35% to 38% zonally tell that only 36% of the road links are deviating from the ideal condition of connectivity, i.e., direct links hence showing that remaining percentage of links have good interconnectivity. Regarding the Beta index, all the zones have greater than 1, indicating more than one good connectivity between roads. Zone '1' has the largest Area but comparatively lesser population resulting in the least population density. The road density of this Zone is also very low, only 8.40 Km/Km^2. Hence, zone 1 has more land area available for undergoing horizontal growth. Zone 1 has less Alpha Index value of 0.03 which is the second lowest value in the remaining Zones; this tells us that there are very few alternative routes to reach from one end to another end in this Zone; it is supported by an eta value which is 0.15 which is the average length of road between two nodes, and it is a highest among all Zone. Considering all the transport network analysis parameters for urban planning and development, this Zone is better than any other zone. The road density of this Zone is 12.07, and the population density is 6635. This is a well-planned area with good alpha and Eta indices, and this Zone includes all the government and development bodies situated.

Zone	e	v	α	β	ϒ	η
1	2764	2631	0.02	1.05	0.35	0.15
2	1980	1799	0.05	1.10	0.36	0.10
3	1174	1045	0.06	1.12	0.37	0.11
4	2561	2353	0.04	1.08	0.36	0.12

Table 2. Connectivity Indices of Road Network

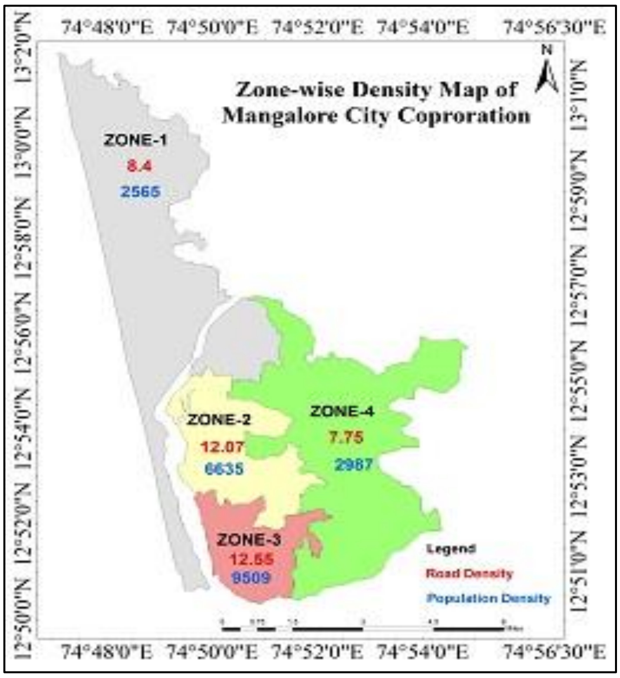

Figure 7. Density Map

Zone 3 is the smallest in Area, with only 10.98 sq. km area compared to the other four zones. As Census 2011 data, this Zone has a population, i.e. 1,04,480. So, the population density is 9509, the highest population density in MCC. Hence this Zone is on the verge of attaining horizontal development. Zone 3 has a low Eta Index value of only 0.12, which indicates the average length of the road, which means the roads are well internally connected, providing an alternate route option to the motorists. In this Zone, most of the Area is commercial Area, and the alpha value of 0.06 tells they are internally connected well. Zone 4 is the second largest in the MCC, with an area of 40.69Km2 with the second lowest population density of 2987. The road density of this Zone is the least, i.e., 7.75 Km/Km2. This is because; an International Airport occupies the major Area of this Zone. This Zone's average road length is the second highest among all Zones, i.e., eta value of 0.123. The alpha value of this Zone is comparatively good, showing better internal connectivity after zone 2 and 3. This Zone has a future scope for undergoing well-planned horizontal development.

FIRST_NAME	Duration	Bus	2_Wheeler	4_Wheeler	Distance
Location 153 - Bejai	0.37	0.32	0.61	1.78	487.66
Location 154 - Bejai	0.53	0.47	0.89	2.59	710.36
Location 155 - Bejai	0.7	0.62	1.17	3.41	935.37
Location 156 - Bejai	1.18	1.05	1.97	5.74	1574.53
Location 157 - Krishnapura	0.65	0.95	0.54	1.58	432.35
Location 158 - Krishnapura	0.51	0.76	0.43	1.25	343.29
Location 159 - Krishnapura	0.8	1.17	0.67	1.95	533.99
Location 183 - Bejai	0.7	0.62	1.17	3.42	937.49
Location 184 - Bejai	0.86	0.77	1.44	4.21	1153.67
Location 185 - Bejai	1.18	1.05	1.97	5.74	1574.53
Location 186 - Krishnapura	1.61	2.36	1.34	3.91	1072.87
Location 187 - Krishnapura	0.91	1.33	0.76	2.21	606.36
Location 188 - Krishnapura	0.33	0.48	0.27	0.8	219.52
Location 189 - Krishnapura	0.59	0.87	0.49	1.44	395.14
Location 190 - Krishnapura	1.27	1.86	1.06	3.09	847.6
Location 213 - Bejai	1	0.89	1.68	4.88	1339
Location 214 - Bejai	1.21	1.08	2.03	5.9	1618.73
Location 215 - Bejai	1.31	1.16	2.18	6.35	1742.44
Location 216 - Krishnapura	1.64	2.41	1.37	3.99	1095.34
Location 217 - Krishnapura	1.22	1.79	1.02	2.96	811.61
Location 218 - Krishnapura	0.48	0.7	0.4	1.17	319.99
Location 219 - Krishnapura	0.25	0.36	0.21	0.6	163.92
Location 220 - Krishnapura	0.97	1.42	0.81	2.36	646.57
Location 243 - Bejai	1.29	1.14	2.15	6.27	1718.38
Location 244 - Bejai	1.21	1.07	2.02	5.87	1610.63
Location 245 - Bejai	1.13	1	1.88	5.48	1502.04
Location 246 - Krishnapura	2.06	3.02	1.72	5.01	1373.99
Location 247 - Krishnapura	1.41	2.07	1.18	3.43	939.36

Figure 8. Travel Information Map

Following the methodology process shown in Figure 8, a raster is obtained whose each pixel details Duration, distance, bus mode cost, two-wheeler mode cost, and four-wheeler mode cost to reach the specified destination from the origins. Its resolution is kept at 500 meters, meaning an area of 500*500 m has the same travel details, and the tolerance limit for considering the destination is 11 km^2. The obtained raster can be used as a base map for creating an application with a search engine that gives the commuters the complete route and location.

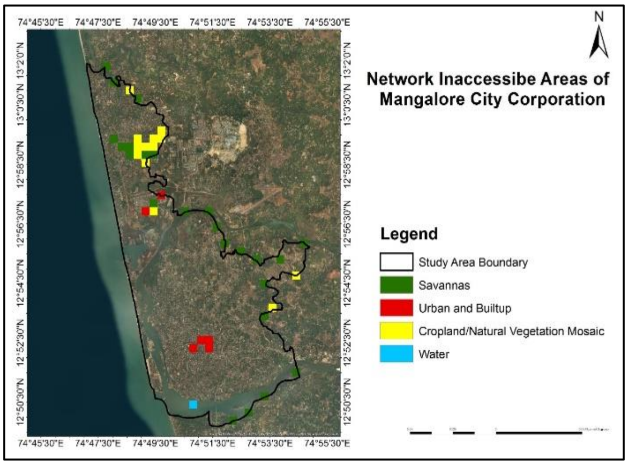

Figure 9. Inaccessible Areas

Figure 9 shows the areas of MCC which are inaccessible to road network, the map revealed that the Area which is inaccessible in zone 4 is having urban settlement which means that Area should be provided a proper connectivity as it a built-up area. The areas in zone 1 are the ones which have maximum inaccessibility due to the presence of croplands or other vegetation, some areas such as Baikampady industrial area is also experiencing inaccessibility to roads. Finally zone 4 is facing inaccessibility in major areas due to the presence of Savannas. Hence the inaccessibility due to built-up areas and crop lands should be investigated and the suiting measures should be taken.

5. CONCLUSION

Mangalore City Corporation is growing in all directions, leading to drastic changes in the road network system, hence demanding changes in the present network condition. So, the present study explains the spatial pattern and connectivity of the road network through connectivity indices, which shows that Mangalore, zone-wise, shows wide variation in pattern, thus making Zone 3 denser than Zone 1 despite having a smaller area than Zone 1. The Origin-Destination study on the MCC road network will help the commuter know the time, distance, and cost of modes from all possible origins to defined destinations through a travel information map, which in turn helps them choose the best possible and cost-effective route to reach their destination. The generated travel information raster can be used as a base map for creating an application specifying the bus routes, costs, availability of travel mode, and its time for the MCC region. The travel information raster presents the areas in the study area that do not contain any of the travel information; on extracting these areas, it was known that these were inaccessible areas within the road network extent. These areas were converted into Land Use Land Cover areas by which it could know the type of L.U.L.C. present in that network.

Further, the work can be focused on a Travel information map prepared from all possible origins to all possible destinations than specified destinations, and the raster of lesser resolution can be prepared for better application. The O.D. can be studied for all types of roads and the operating speeds of each type of road. From the generated inaccessibility map, the type of L.U.L.C. can be known, and analyzing the reason for inaccessibility can be based on land cover type.

References

Ajay D. Nagne, Amol D. Vibhute, BhartiW.Gawali, Suresh and C. Mehrotra. 2013. Spatial Analysis of Transportation Network for Town Planning of Aurangabad City by Using Geographic Information System. *International Journal of Scientific Engineering Research*. 4(7).

Ajay D. Nagne, Dr. Bharti, and W.Gawali. 2013. Transportation Network Analysis By Using Remote Sensing And G.I.S.- A Review. *International Journal of Engineering Research and Applications.* 3(3).

Barney Cohen. (2006).Urbanization in developing countries: Current trends, future projections, and key challenges for sustainability. *Technology in Society*. 28(63).

Claudia Kuenzer, Marco Ottinger, Martin Wegmann, Huadong Guo, Changlin Wang, Jianzhong Zhang, Stefan Dech & Martin Wikelski. 2014. Earth observation satellite sensors for biodiversity monitoring: potentials and bottlenecks. *International Journal of Remote Sensing.* 35(18).

Igbokwe J.I, Nnah S.I, Ejikeme J.O, and Igbokwe E.C. 2016. Mapping And Analysis Of the Transportation Network Of Port Harcourt, Rivers State Using Geographic Information System (G.I.S.) And Remote Sensing. *International Journal of Innovative Environmental Studies Research.* 4(2).

Sreelekha. M.G, Krishnamurthy.K., and Anjaneyulu. M.V.L.R. 2016. Interaction between Road Network Connectivity and Spatial Pattern. *International Conference on Emerging Trends in Engineering, Science and Technology*. 24.

Torgil Abrahamsson. (1998). Estimation of Origin-Destination Matrices. Using Traffic Counts – A Literature Survey International Institute for Applied Systems Analysis.

Vikas Sihag, Vinod Kumar, Hisar, Mohit, Savitpal, and Dr. Ashok Beniwal. 2015. Transport Network Analysis of Rohtak City through Geospatial Technology. *International Journal Of Innovative Research Development.* 4(11).

Wesołowska Judyta, 2016. Urban infrastructure facilities as an essential public investment for sustainable cities – indispensable but unwelcome objects of social conflicts. Case study of Warsaw, Poland. *Transportation Research Procedia.*