Evaluating the connectivity level of the Addis Ababa city road network (Addis Kitema) using GIS

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ABSTRACT

Urban road networks are essential elements of social and economic development processes. With the increasing demand for transportation, many countries are studying and evaluating the effectiveness of urban road networks. Therefore, network assessments are needed to guide the development of urban transport systems and infrastructure. This study aims to evaluate the connectivity level of road network segments in the Addis Kitema suburb of Addis Ababa, Ethiopia, by applying several connectivity metrics such as beta, alpha, gamma, degree of connectivity, node density, and link density. This study uses an evaluation technique that applies metrics to the entire network, calculating metrics for each region using ArcGIS 10. 3. Based on these indicators, most of the city's road network is well-connected, yet outskirts could be better connected. Hence, efforts to develop or create new roads should also be made available in the outskirts. The study also investigated accessibility, road intersections, Sidewalks, Bike lanes, and parking.

1. Introduction

Transportation geography is the study of the relationship between transportation and location. A transportation system comprises five main elements: network, mode, travel, transportation, and cost. All these elements have a clear spatial basis. Communication has been one of the critical issues occupying the minds of transportation geographers. We are studying interconnecting sectors of the network, that is, interconnecting parts of space. Communication is gaining importance due to its relevance to other aspects and issues of transport systems and its potential for development and sustainability. This is evidenced by numerous studies linking communication to such issues. Although there are various ways to measure it, such as the relationship between connectivity and public transport, Ellis et al [1]. and the relationship between the level of connectivity and transport sustainability through its impact on walking and cycling, Hadas [2]. The level of connectivity is geographical information system technology, which is currently being used to reduce distance, time, and cost [3].

Although there are many studies on road network analysis, few studies focus on the communication level. In geographic research. A network is a linear system that allows the movement of population, material, energy, and money between different points in space. Studying transportation networks helps measure the efficiency and effectiveness of transportation systems. This is done by delving into the relationship between the energy, materials used, and the results obtained over some time [4].

2. Material and Method

2. 1. Definition of Connectivity

The term 'network' is defined in standard dictionaries as "a network structure of intersecting lines and spaces." Still, from a geographer's point of view, it is defined as a series of interconnected lines and spaces in a system. 'Network connectivity' refers to the density of connections in rail and road networks, as well as the directness of the connections. A well-connected network has many short links, intersections, and dead ends that are minimized. Increased transport connections reduce travel distances, increase route choice, and allow direct travel between destinations, reflecting the principle of complete roads. Connections can be implemented internally (roads within the territory) and externally (connections to highways and other areas). ["TDM" online encyclopedia, www. vtpi.org].

2. 2. Connectivity Indices Calculation by GIS Tools

Recently, several studies, that enable more accurate, detailed, and easier calculation and evaluation of connectivity metrics using geographic information system applications, have emerged. Before introducing network analysis tools in ArcGIS 9.1, Tresidder developed several methods to investigate and calculate the connectivity index.

2. 3. Network Connectivity Analysis

To analyze the road network connectivity in the city, it is necessary to follow some steps, as shown in Fig. 1.
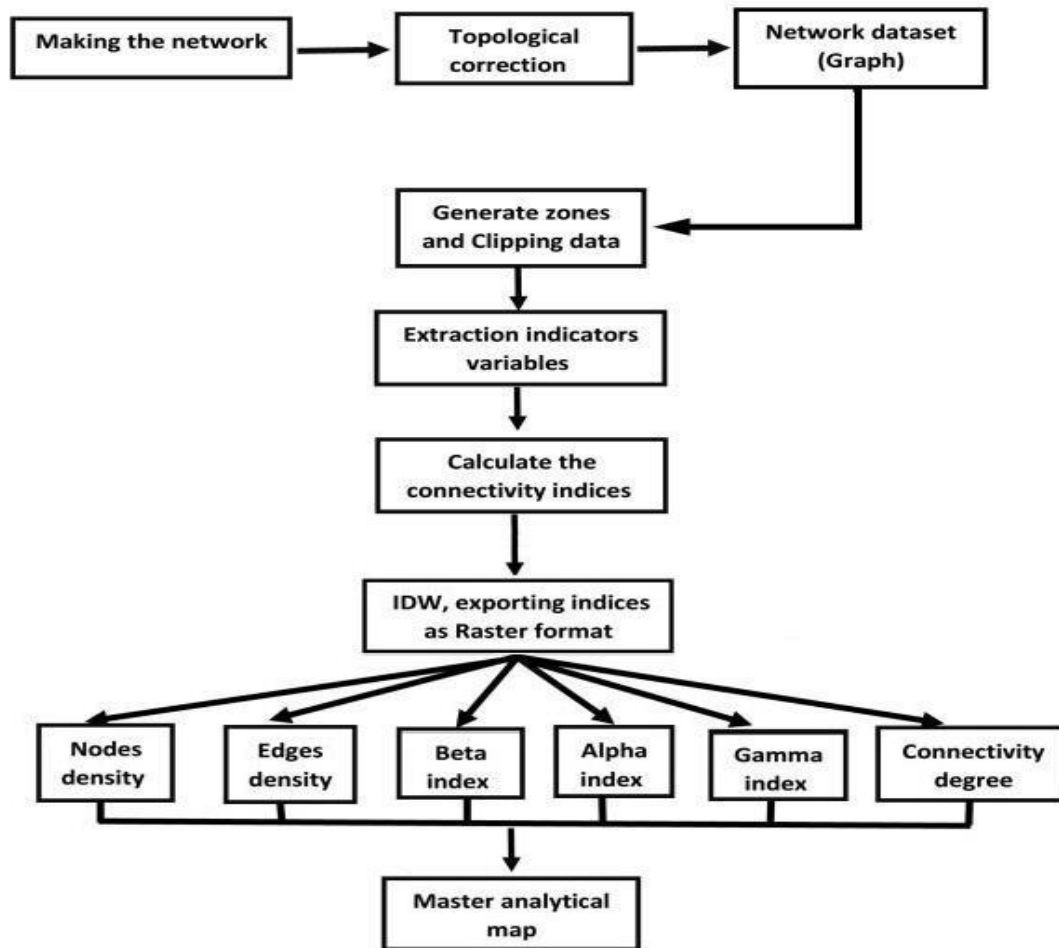

Fig. 1. Connectivity Evaluation Methodology [8].

2. 4. Needed Data

In the evaluation of network connectivity in Addis Ababa, researchers needed the following data:
A)   Road network shapefile (polyline)
B)   Road network diagram (graph)
C)   Analytical area network (polygon shapefile)
D)   Attributed data, such as the number of nodes, links, road length, and area.

2. 5. Data Preparation/ Provision and Extraction

First, the city's road network is digitized, Edited, and exported via Open Street Map [https://www.OpenStreetMap.org/] in ArcGIS 10.3 and use the topology tools in arc catalog 10. 2. 1 to perform topology corrections. It is essential to check the connections of the intersection links. The next step is to create a network dataset in Arc catalog 10.3 and convert the road shapefile to a network dataset. This step is important because it transforms the road into a 'graph' consisting of nodes and edges. Next, researchers needed to get all the edges and nodes of the mesh. This was done using the split line at points tool on the arc toolbar. To extract more detailed connectivity indicators of the city's road network, the city was divided into sections of equal area (0. 25 km2) along the city boundaries, resulting in unfinished sections. Fishnet tool in the Arc toolbox is used to partition it into networks and extract the number of nodes in each region.

3. Results and discussion

3. 1. Quantitative Analysis of Road Network in Addi Kitema

Quantitative analysis of road networks is essential for understanding the network's effectiveness and components; refining the network concept is the first step in this process. Many studies have shown two perspectives on the definition of 'network.' The first is a topological perspective. A network is defined as an intertwined fence resulting from the intersection of lines and connections that pass through a set of nodes. The second is geographical, where a network is defined as "a group of geographical locations interconnected within a given system by a group of roads." As a result of the quantitative analysis of urban street networks, it is essential to answer some fundamental questions: How interconnected is the street network? Which areas/nodes within the city have high accessibility? Where are the most central areas/nodes of the city? The degree of central business district and network connectivity. Is there a relationship between urban centrality and accessibility? Does the road network provide easy and quick transportation? Does it serve equal users across the city? To what extent? Can it provide sustainability?

3. 2. Network Connectivity

This indicator allows one to quickly and generally determine the effectiveness and extent of communication between network nodes. This metric is critical when planning transport networks. The more interconnected the network is, the more options are available for street planning and development. Therefore, according to Fitzpatrick et al. [5], this indicator is an excellent tool in the development process. There are two ways to measure connectivity. The first uses a topological network; The second uses a geographic network. Each has a measurement indicator. To perform the first type of analysis, The road network must be transformed from a geographic network to a topological network (a simplified graph). According to graph theory, Barke. [6] Fig. 2. Network connection to it and the average density of links in the city 14. 3 km2, See fig. 2, and table 1.
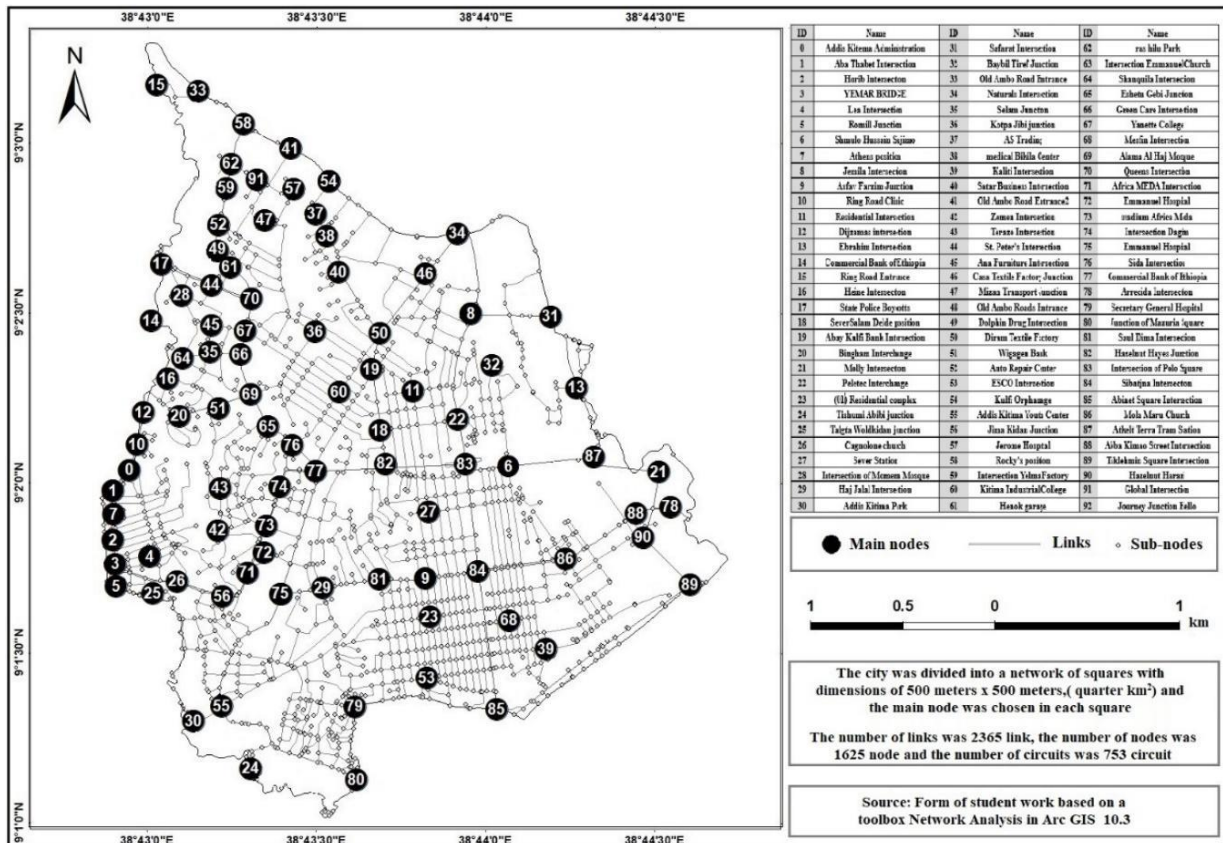

ID	Name	ID	Name	ID	Name
0	Addis Kitema Administration	31	Sefarat Intersection	62	ras hilu Park
1	Aba Thabet Intersection	32	Baybil Tirwl Junction	63	Intersection EmmxmuelChurch
2	Harib Intersection	33	Old Ambo Road Entrance	64	Skanquila Intersection
3	YEMAR BRIDGE	34	Naturals Intersection	65	Esheta Gobi Junction
4	Lta Intersection	35	Salam Junction	66	Green Care Intersection
5	Romili Junction	36	Kotpa Jibi junction	67	Yanette College
6	Shmulo Hussin Sajimo	37	A5 Trading	68	Maslin Intersection
7	Athens position	38	medical Bibila Center	69	Alama Al Haj Mosque
8	Jemila Intersection	39	Kaliti Intersection	70	Queens Intersection
9	Asfer Farxim Junction	40	Satar Business Intersection	71	Africa MEDA Intersection
10	Ring Road Clinic	41	Old Ambo Road Entrance2	72	Emmanuel Hospital
11	Residential Intersection	42	Zoma Intersection	73	sradium Abics Mda
12	Dijsmaz intersection	43	Terazo Intersection	74	Intersection Dagim
13	Ebrahim Intersection	44	St. Peter's Intersection	75	Emmanuel Hospial
14	Commercial Bank of Ethiopia	45	Ana Furniture Intersection	76	Sida Intersection
15	Ring Road Entrance	46	Casa Textile Factory Junction	77	Commercial Bank of Ithiopia
16	Heine Intersection	47	Mizaz Transport junction	78	Arresida Intersection
17	State Police Boycotts	48	Old Ambo Roads Intrance	79	Secretary General Hospital
18	SeverSalam Deide position	49	Dolphin Drug Intersection	80	Junction of Mazuria square
19	Abay Kalfi Bank Intersection	50	Dirmn Textile Factory	81	Smil Dima Intersection
20	Bingham Interchange	51	Wigagan Bank	82	Haselnat Hayes Juartion
21	Molly Intersection	52	Auto Repair Center	83	Intersection of Polo Square
22	Polotee Interchange	53	ESCO Intersection	84	Sibatjna Intersecton
23	(li) Residential complex	54	Kulif Orphanage	85	Abiast Square Interaction
24	Tshumi Abibi Junction	55	Addis Kitima Youts Center	86	Mola Maru Church
25	Taljeta Woldhidan Junction	56	Jima Kidaz Junction	87	Athelt Terra Tram Sation
26	Cagnelona church	57	Jerome Hospital	88	Aiba Klimo Street Intersection
27	Sever Station	58	Rocky's position	89	Tiklehmic Square Intersection
28	Intersection of Momem Mosque	59	Intersection Yolma Factory	90	Hazelnut Hurst
29	Haj Jalal Intersection	60	Kitima IndustrialCollege	91	Global Intersection
30	Addin Kitima Park	61	Hosak garasp	92	Journey Junction fallo

● Main nodes   — Links   ○ Sub-nodes

The city was divided into a network of squares with dimensions of 500 meters x 500 meters,(quarter km²) and the main node was chosen in each square

The number of links was 2365 link, the number of nodes was 1625 node and the number of circuits was 753 circuit

Source: Form of student work based on a toolbox Network Analysis in Arc GIS 10.3

Fig. 2. Geographical and Topological Structure of the Street Network in Addis Kitema in 2022 [8].

The different flows computed traditionally provide a single value that allows for the determination of the connectivity state of the network: interconnected, moderately interconnected, or weakly interconnected. They can have networks that are less interconnected than other regions. As urban centers may be more connected than suburbs or emerging urban areas, this research uses new methods based on information systems. This approach aims to divide the city into groups of equal areas and perform operations in each area. Values for each field that indicate the state of network relationships.

This metric measures the density of the distribution of linear bond lengths over area. The longer the road length compared to the area, the greater the number of connections and the more connected the network is. It is calculated by dividing the total length of each lane connection by its area, and it shows that the connection density is higher in the center and the east in areas with urban districts and street networks. The lowest value of this indicator is among the regions of the city, which indicates weak network connectivity in the area. The average connectivity density in the town is 14. 3 km2 (see Fig. 2 and Table 1).

3. 3. Node Density

Node density describes the shape of the distribution of nodes within a region, and there is a direct relationship between the distribution density of nodes within a region and the degree of network connectivity. Node density is calculated by dividing the number of nodes by the area and total. The overall node density of the city reached 219 nodes/km2 (see Fig. 2 and Table 1), which is a high density that indicates the strength of network connectivity, which can be seen from the distribution of node density within the city. In cities, connection and node density are similar, as a lack of significant thoroughfares characterizes areas with network patterns, intersecting roads have weak network conditions, and network patterns characterized by many intersections have high network connectivity. It represents areas with extensive land use or older areas, marginal areas of urbanization or end-of-street areas, and some internal areas that rely primarily on parallel streets and are only connected to streets if they are relatively narrow. The length of the residential area increases without intersecting long distances, as in most areas south of Addis Kitema.

3. 4. Beta Index

This metric measures the connectivity level of a road network and represents the relationship between the number of connections and the number of nodes. The value of this metric varies depending on the type of network. A simple network has a beta index less than (1), or an interconnected network has one chain with a beta index equal to (1). The index value of the most interconnected, complex network exceeds (1). The beta index of the urban leading street network reaches (1), indicating good connectivity. Some studies have shown that a network beta index value of 1. 4 means that the network has reached the minimum level of connectivity required for a community that supports walking, Sigurd [7]. Therefore, the network connectivity according to the beta index remains relative. It is suitable for funds for non-mobile purposes and provides excellent stability. This metric shows that the entire network has good connectivity across the city, especially for walking. However, this is not logical, as shown below.

3. 5. Gamma Index

This indicator measures network connectivity by considering the relationship between actual connections and the number of possible connections to the network. Values for this indicator range from (0–1) to zero which indicates weak connectivity. Higher values indicate poor connectivity. The higher this number is, the stronger the connection of each node to all other nodes in the network will be. Immediately after this indicator, one will see a means of measuring the progress and development of the network over time. The city's gamma index value reaches 0. 33, which means that the nodes are well-connected; however, the direct connections between nodes are weak, often resulting in long travel times within the network. From a spatial point of view, it is clear that cities can be divided into two categories. One loosely coupled category generally represents the periphery, and the other moderately coupled category represents the urban center. See Fig. 2 and Table 1.

Table 1: Interconnection Indicators for the Street Network in Addis Kitema in 2022

Interconnected nodes	Total thread	Average thread index	Thread Point Index	Alpha Index	Gamma Index	Beta Index	Contract density	Knots/km2	Link density	km/km2	index
0,82	1,42	0,40	0,25	0,17	0,33	1		219		14,3	value

Source: Researchers; based on ArcGIS10.3 using options: Field Calculator, Summarize, Calculate Geometry.

3. 6. Alpha Index

This metric measures the degree of connectivity between networks based on the number of physical circuits in the network compared to the maximum number of circuits that the network can contain. A higher indicator value indicates greater interconnectivity, and the more complex the network, the higher the indicator's value. The alpha value for a tree network is (0), and the alpha value for a fully connected network is (1). The significance of this indicator for Addis Kitema is 0. 17. This means that more connections are needed to form more closed circuits than the network connects. Nodes are directly placed to facilitate fast movement between nodes. Cities are spatially divided into three categories, all of which are weakly connected according to this index. Still, the weakness increases towards the city's outskirts. (See Fig. 2 and Table 1)

3. 7. Connectivity Degree

This index is calculated similarly to the gamma index and has a value range of (0 to 1). Higher values indicate better correlation. When this index is applied to cities, the average value is 0. 25, indicating that connectivity at the network level is weak. However, the situation has changed with the emergence of areas extending from the center to the north and from the center to the urban area. (See Fig. 2, Table 1)

Since different indicators give different values, a city's road network is interconnected in terms of beta index, relatively moderately connected in terms of gamma index, and weak in terms of alpha and degree of connectivity. Therefore, one can use indexes (TCL) to overcome this problem, you can combine the thread measurement indicator with this indicator calculated by the following equation:

$$TCI = \left(\frac{\beta + \gamma + \alpha + cd}{4}\right) * \sqrt{\frac{nd}{ed}}$$

Where (β) is the beta index value for each range, (γ) is the gamma index value, (α) is the alpha index value, (cd) is the bonding degree index value, (nd) is the contract density value, (ed) is the link density value [8].

Using this metric, we obtained the average values of the four metrics (beta, alpha, gamma, and connectivity). In Fig. 2, the value of this metric for the entire network is 0. 4, which indicates that by using the average connectivity of the network and using this average to mathematically relate to the density of connections and nodes in the network, we were able to arrive at a general "tci" flow. It has become clear that the average interconnectivity score is approximately 1. 4, which indicates good connectivity of the city's road network.

The area around Habti Gorge Street, centered on Uganda Street and stretching from Pasteur Street in the north to Abhinit in the south, ranks among the city's busiest intersections, with thread values ranging from 2. 18 to 2. 40. The same goes for the areas around Al Hafar Street and Old Michael. Areas

surrounding the textile mill district in the city's eastern part and areas adjacent to major thoroughfares were areas with good transport links and an overall thread rating of at least 1. 85. Since grid planning relies on numerous intersection points, grid areas score high on this metric. They are represented by an ancient area of the old center and a modern peripheral area, as opposed to a randomized street grid area. The background of urban development is characterized by a grid, whose streets are an incomplete network.

3. 8. Connected Node Ratio (CNR)

This indicator measures the network's connectivity, showing the number of closed-end nodes (cul-de-sac) and their relationship to other connected nodes. The value range for this indicator is (0 to 1). The closer the numbers are, the more accurate they are. This indicates that there are no closed-ended roads and increases the interconnectivity between network parts, Litman [9]. This network index is 0. 82, indicating fewer cul-de-sacs and boulevards with closed ends. This means that the connectivity between network nodes is increasing, as most connections connect to three or more nodes.

4. Nodes Centrality

The centralization index is one of the most critical indicators for the spatial analysis of transport networks. It can be used to classify network nodes to different degrees, depending on the degree of centrality of each node within the overall network. It is measured by creating a matrix and calculating the number of connections required to communicate from one node to all nodes on the network. The fewer connections, the higher the degree of centralization. The degree of centralization can be investigated by examining it at the level of the city node and then applying it to each sub-city separately.

4. 1. Centralization of urban nodes

The number of city nodes in Addis Ababa is ten. Table 2 shows that the Kulfi Kelanyo sub-city represents the first central node, and only 14 connections are required to reach the remaining nodes. City sub-KIRKOS took second place among the network nodes, followed by his three nodes (Arada, Gulele, and Yeka) in the third place; Bole, and Nevis Silk in fourth place; Addis Kitema in fifth place; Ledita in sixth place; Akaki Kariti came last.

Table 2: Degree of Centralization of Urban Nodes in Addis Ababa City. Source: Researchers; based on Fig. 2; distances measured by ArcGis 10. 3.

FROM/TO	AKAKI KALITI	ADDIS KITEMA	ARADA	POLLY	JOLILI	KIRKOS	COLVE KIRANIO	LIDITA	NEVIS SILK LATO	YIKA	TOTAL	LEVEL
Akaki kaliti	0	1	2	3	4	3	3	4	4	3	27	7
Addis kitema	1	0	1	2	3	1	2	3	3	2	18	5
Arada	2	1	0	1	2	2	1	2	2	3	16	3
Polly	3	2	1	0	1	1	2	3	2	2	17	4
Jolili	4	3	2	1	0	2	1	2	1	1	16	3
Kirkos	2	1	2	1	1	0	2	3	2	1	15	2
Colve kiranio	3	2	1	2	1	2	0	1	1	1	14	1
Lidita	4	3	2	3	2	3	1	0	1	2	21	6
Nevis silk lato	4	3	2	2	1	2	1	1	0	1	17	4
Yika	3	2	3	2	1	1	1	2	1	0	16	3

5. Accessibility

This means ease of access to and from various destinations, allowing a person to participate in desired activities. David et al. [10]. The concept of accessibility is considered one of the most important aspects of transportation, especially urban transportation problems, and its measurements include how easy it is, and how easily one can reach it [11].

The distance between nodes can describe reachability. Calculating this variable displays the path length between nodes in the matrix, and nodes are placed according to their accessibility based on which nodes are connected to other nodes. It connects network nodes at the shortest length and provides the most accessible access between nodes, Kamal [12]. This is the best method because it assigns rank to each node.

Table 3: Accessibility Between Urban Nodes in Addis Ababa according to the Distances between Nodes

FROM/TO	AKAKI KALITI	ADDIS KITEMA	ARADA	POLLY	JOLILI	KIRKOS	COLVE KIRANIO	LIDITA	NEVIS SILK LATO	YIKA	TOTAL	LEVEL
Akaki kaliti	0	19. 3	2. 8	13. 7	5. 3	5. 1	4. 1	3. 3	10. 7	7. 5	71. 8	4
Addis kitema	19. 3	0	19. 7	15. 4	23. 0	9. 0	18. 8	16. 2	11. 9	23. 8	163. 1	10
Arada	2. 8	19. 7	0	9. 3	3. 6	5. 3	6. 4	4. 6	10. 1	7. 5	69. 3	3
Polly	13. 7	15. 4	9. 3	0	12. 6	4. 1	12. 3	9. 2	11. 7	6. 7	95. 0	8
Jolili	5. 3	23. 0	3. 6	12. 6	0	8. 1	7. 9	7. 4	12. 8	9. 8	90. 5	7
Kirkos	5. 1	15. 0	5. 3	4. 1	8. 1	0	6. 7	3. 5	6. 7	6. 8	61. 3	1
Colve kiranio	4. 1	18. 8	6. 4	12. 3	7. 9	6. 7	0	2. 3	6. 8	12. 5	77. 8	5
Lidita	3. 3	16. 2	4. 6	9. 2	7. 4	3. 5	2. 4	0	5. 4	9. 4	61. 4	2
Nevis silk lato	10. 7	11. 9	10. 1	11. 7	12. 8	6. 7	6. 8	5. 4	0	12. 9	89. 0	6
Yika	7. 5	23. 8	7. 5	6. 7	9. 8	6. 8	12. 5	9. 4	12. 9	0	96. 9	9

Source: Researchers; based on Addis Ababa Landsat Satellite Visual, Distances measured by ArcGis 10. 3.

According to Table 3, KIRKOS has the shortest travel distance to other city nodes among the city nodes. Redita node ranks 1st, making the city nodes in the second place. Arada came 3rd. Addis and Kitema came 4th. Kulfe Kiranyo, Niwas Silk Lato, Gulere, Buri, Yeka, and Akaki Kariti came 5th, 6th, 7th, 8th, 9th and 10th respectively.
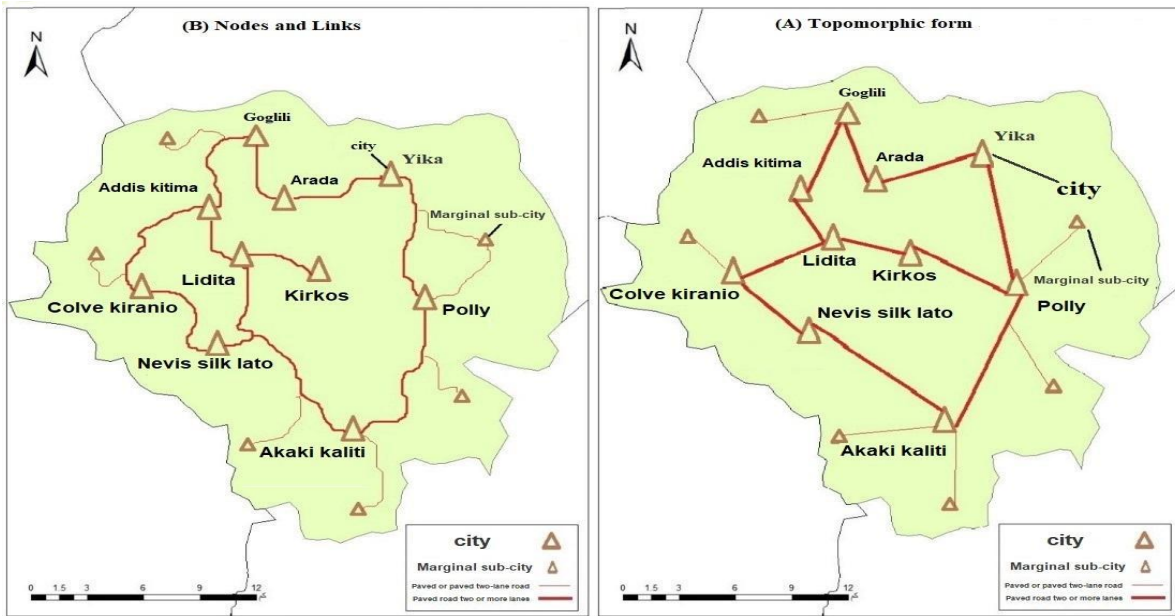
Fig. 3. Accessibility Between Urban Nodes in Addis Ababa according to the Distances between Nodes
Source: Researchers; based on ArcGis 10.3

6. Street Intersections

An intersection is created when two or more roads connect or intersect. It is an area where traffic flows merge, diverge, or intersect, leading to collisions in the direction of travel and increasing danger. When a pedestrian passes through an intersection, Tresidder [13]. intersections can be divided into several types, including triangular intersections with two T-shaped or Y-shaped intersections, four-way intersections, multiple intersections, and circular (Square) intersections [14] (Fig. 4). Intersections vary according to degree and can be procedurally classified into three types. (See Fig. 4)
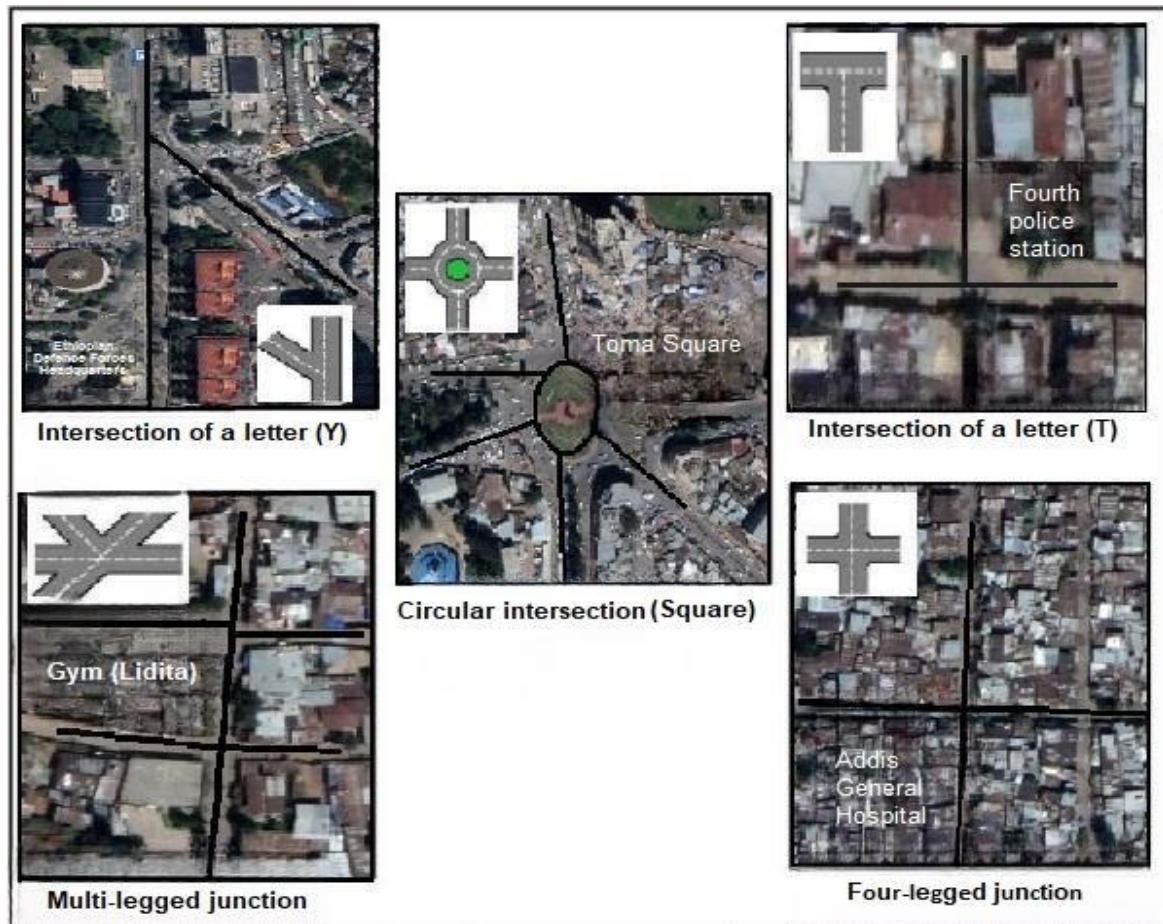
Fig. 4. Classification of Intersections according to their Shape in Addis Ababa in 2022 Source: Researchers; based on Google Earth Pro, Ministry of Housing, Utilities and Urban Communities, Housing, and Building Research Center (1998): Egyptian Code for Urban and Cellular Road Works, (3) Part III, First Edition, Cairo, P. 101.

6. 1. First Class Intersections

Major roads intersect, resulting in high-speed and intense traffic intersections. This requires automatic regulation and control of traffic from these intersections. Significant intersections are often shaped like roundabouts which increases the possibility of traffic accidents.

Fig. 5. Collision of vehicles at some intersections in Addis Ababa city. Source: Debela Deme (2016): Traffic Accident Causes and Countermeasures of Addis Ababa-Adama Expressway, Addis Ababa University, Addis Ababa Institute of Technology, P. 14-23.

6. 2. Second Class Intersections

This type is formed when local streets intersect, or a side street intersects with a local one. Therefore, one or both sides of the intersection are slow and often non-motorized. This intersection does not need a traffic control or regulation system, and the possibility of collisions or accidents between the two movements is reduced.

6. 3. Third Degree Intersections

Therefore, 27 major type 1 intersections in the city require automatic cross-traffic control. There are only eight intersections where automatic cross-traffic control is possible, five intersections where manual control is possible, and two intersections where automatic cross-traffic control is possible. There are 58 sub-intersections. In this case, the city's first-and-second-class intersections pose a significant danger to its transportation system, as only four are available, leading to collisions and accidents at these intersections. A vehicle collision accident is caused by traffic congestion during the evening rush hour, as shown in Images 1, 2, and 3.

This type occurs at the intersection of a road and an alley, two alleys, or a street and a local road, with light to moderate traffic on one or both sides of the intersection and increased traffic. It can be done manually or automatically. However, if these intersections are not controlled, they often risk accidents. This type is formed when local roads intersect or when local roads intersect with side streets. Therefore, traffic monitoring or control at this intersection is optional, as one or both sides are often slow and non-motorized.

7. Shoulders And Pedestrian Pathways

Walking is the primary mode of transportation in urban areas. We all begin or end our journeys by walking. Until recently, walking played an essential role in the growth of cities, until the advent of automated transportation. However, walking is still a necessary mode of transportation. Cities in developing countries have economic, health, and environmental benefits. Walking needs to be supported and encouraged for urban travel, Khair. [14] Nevertheless, pedestrians need to be provided with a safe walking environment, and this is being done through some methods: pedestrian and motor vehicle traffic organized by traffic lights or spatial separation using sidewalks, tunnels, and bridges, or by designating certain roads for pedestrians such as pedestrian plazas [13].

Sidewalks are known as one of the necessary infrastructures for pedestrian traffic. Roads are essential for vehicles; they are also important for pedestrians. The width of the sidewalk changes depending on the amount of pedestrian traffic, which changes the area required for pedestrians to cross the road. The walkway must be oval-shaped, with a width of 64 cm and a length of 60 cm. The width of the sidewalk must be at least 25 meters on urban main roads, 1. 5 meters on urban secondary roads, and 120 cm wide when two people walk in opposite directions [13]. Pedestrian Sidewalks in Addis Ababa are only sold on some main streets. The most essential and most considerable streets are Jomo Kenyatta and Army Square. Menelik Square and some other streets have intermittent or limited access.

8. Bicycle paths

Bicycle path design relies on livability and safety; this service must be available on roads where bicycle traffic exceeds 500 bicycles per day and a bicycle clearance width of 1. 1 meter is required.

The number of deaths and injuries from road accidents in Ethiopia is increasing every year, with cities accounting for more than one-third of the deaths and two-thirds of the seriously injured. Pedestrians cause the majority of fatal traffic accidents in cities, and in the capital Addis Ababa, pedestrians account for nearly 90% of traffic fatalities [15].

Safe road-scaling safe street designs in Ethiopia project was implemented with support from the United Nations Road Safety Fund and collaboration with the Institute for Transport and Development Policy (ITDP), the Ethiopian Ministry of Transport, the Addis Ababa Transport Authority. It aims to strengthen the Ethiopian government's capacity at local and national levels to develop and implement policies that respond to the needs of pedestrians and cyclists.

Non-motorized transport strategies and five-year implementation plans have been adopted in 69 cities and towns with agreed street design guidelines. These plans are now directing investment to safer walking and cycling facilities.

Addis Ababa launched the city's non-motorized transport strategy in April 2019, which has contributed to the construction of approximately 2. 8 kilometers of bicycle lanes, with more than 25 kilometers currently under construction. The 10-year transport sector development plan envisages building 3,000 kilometers of non-motorized transport infrastructure across the country, with a budget allocated for improving non-motorized transport infrastructure from 2022.

Fig. 6. Bicycle Paths in Addis Ababa, 2022 Source: United Nations Human Settlements Program website: (UN-Habitat), https://unhabitat. org.

9. Waiting and Parking Areas

There are two types of parking spaces. One is off-street parking, which refers to a public or private garage, and the other is curbside parking, which allows you to park your vehicle on both sides of the road. Its size varies depending on the type. Parking may be parallel to, perpendicular to, or at an angle to the sidewalk, Kamal [13]. The first type is represented by several garages for government agencies or public sector enterprises; the second type (located entirely randomly on the roadside) in Addis Ababa must be planned and directed. Very few places on the city's roads support parking, and there is no indication of the type of parking or even whether a limited number of signs and ground markings slopes it.

10. Conclusions and Recommendations

Research is finding ways to integrate a set of commonly accepted metrics into a single metric that provides an accurate picture of network connectivity. The above indicators are related to different spatial patterns of roads and indicate that structured roads have better connectivity than random roads. The concept of levels of communication faces many obstacles to its practical application, particularly the lack of generally accepted quantitative measurements, and the need for more meaningful comparative research, Kumar et al [16]. The performance measurement method used in this study is simpler, easier to use, and more accurate than the method used in the study Litman [9].

These results can be used to support the city's transportation system by encouraging cycling in high-traffic areas. You can improve the walkability of these areas by increasing the proportion of pedestrians and cyclists. The general proportion of traffic and mobility within the city can be modified, and environmental benefits can also be obtained. This study goes further than the study of Kumar et al. [16]. The latter concludes that road network density better predicts road network connectivity.

In this study, we have integrated all metrics, including link and node density. Most of the city's road network is well-connected, but areas on the city's outskirts need to be better connected. Therefore, efforts to develop or create new roads must also be made accessible on the city's periphery. Social and economic development processes depend on flexible transportation systems. In this way, connecting road networks can improve the

flexibility and reliability of the transportation system by providing alternative routes for passengers. This redistributes traffic across the road network, reducing congestion, travel times, and costs. Surly, this will help improve public transport and increase demand for it.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this study.

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