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Evaluating Roads Network Connectivity for Two Municipalities in Baghdad-Iraq

Hala Jafar Mahdi[1,*], Maythm AL-Bakri[2], Afrah L. Ubaidy[3]

[1,2] Department of Surveying Engineering, College of Engineering, University of Baghdad, Baghdad, Iraq

[3] Ministry of Science and Technology, Baghdad, Iraq

hala.mahdi1512m@coeng.uobaghdad.edu.iq[1], m.albakri@coeng.uobaghdad.edu.iq[2], adelafrah@yahoo.com[3]

ABSTRACT

The road network serves as a hub for opportunities in production and consumption, resource extraction, and social cohabitation. In turn, this promotes a higher standard of living and the expansion of cities. This research explores the road network's spatial connectedness and its effects on travel and urban form in the Al-Kadhimiya and Al-Adhamiya municipalities. Satellite images and paper maps have been employed to extract information on the existing road network, including their kinds, conditions, density, and lengths. The spatial structure of the road network was then generated using the ArcGIS software environment. The road pattern connectivity was evaluated using graph theory indices. The study demands the abstraction and examination of the topological structure by choosing a few factors associated with the connection of the roads. These involved the cyclomatic number, Eta coefficient, Aggregate Transform Score (ATS), Beta, gamma, and Alpha indices. According to the findings, the Al-Adhamiya roads network is more developed, better linked, and has a higher overall connectivity value than the Al-Kadhimiya network. The two study areas, however, have minimal circuitry and high complexity. Due to the modifications and expansion of land use that the municipalities have seen, the research suggests that the transportation network should be developed to reach greater interconnectedness, particularly in locations outside the city center.

Keywords: Topological characteristic, Connectivity, Graph theory, ArcGIS.

*Corresponding author

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تقييم اتصالية شبكة الطرق في بلديتين تابعتين لمحافظة بغداد–العراق

هالة جعفر مهدي[1]*، ميثم البكري[2]، افراح لؤي العبيدي[3]

[1,2] قسم هندسة المساحة، كلية الهندسة، جامعة بغداد

[3] وزارة العلوم والتكنلوجيا

الخلاصة

تعمل شبكة الطرق كمركز للفرص في الإنتاج والاستهلاك ,استخراج الموارد ,والتعايش الاجتماعي. وهذا بدوره يرفع من معايير مستوى المعيشة وتوسع نطاق المدن بصوره عامه. ان هذا البحث يتحرى الترابط المكاني لشبكة الطرق وتأثيراتها على التنقل والشكل الحضري في بلديتي الكاظمية والأعظمية. تم استخدام صور الأقمار الصناعية والخرائط الورقية لاستخراج المعلومات حول شبكة الطرق الحالية ، بما في ذلك أنواعها وظروفها وكثافتها وأطوالها. تم بعد ذلك إنشاء الهيكل المكاني لشبكة الطرق. باستخدام بيئة برنامج ArcGISتم تقييم ربط أنماط الطرق باستخدام مؤشرات نظرية الرسم البياني. تتطلب الدراسة تجريد البنية الطوبولوجية وفحصها من خلال اختيار بعض العوامل المرتبطة بربط الطرق. تشمل هذه المعاملات معامل إيتا ، مؤشرات بيتا، وغاما ، وألفا وغيرها. ووفقًا للنتائج ، فإن شبكة طرق الأعظمية أكثر تطوراً وترتبطًا بشكل أفضل ولديها قيمة اتصال عامة أعلى من شبكة الكاظمية. ومع ذلك ، فإن منطقتي الدراسة لديهما دوائر منخفضة الكفاءة وعالية التعقيد. نظرًا للتعديلات والتوسع في استخدام الأراضي الذي شهدته البلديات ، يقترح البحث أنه يجب تطوير شبكة النقل للوصول إلى درجة أكبر من الترابط ، لا سيما في المواقع خارج مركز المدينة.

الكلمات الرئيسية: الخصائص الطوبولوجية ,الاتصالية, النظرية البيانية ,برنامج نظم المعلومات الجغرافية.

1. INTRODUCTION

According to the UN, the population of urban areas in less developed nations is expected to increase from 2.7 billion in 2011 to 5.1 billion per person in 2050. Additional residential and industrial buildings will be required due to the growing urban population, the construction of even more (as well as improved) roads, and the supply of general services, such as effective transportation systems **(Atta and Curtis, 2015)**. Due to their vital significance in determining the spatial configuration of urban forms in the city center and the countryside, roads are a basic element of the urban setting and a part of the public services provided by cities **(Al-Saaidy and Alobaydi, 2021).**

Transport is a subject of worldwide interest and relevance since it is a key component of national and international industrial systems that are continuously transforming the world. The significance of transportation grows with the complexity of economies and civilizations. The need for transportation is also determined by the utility of human travel or the demand for transported commodities; each trip is distinct in terms of space and time **(Hashidu and Muhammed, 2018)**. The well-planned road system in urban communities serves as the conduit for all activities and operations. It contributes to the circulation of automobiles and people between and among areas and neighborhoods and solves the traffic problem **(Abid, 2018)**.

A lack of integration between existing urban regions, systems, or expansion has led to several complications in urban centers. Due to ineffective infrastructure design and

coordination, transportation, a component of the urban system tasked with bridging the gap between the producing and consuming sectors and providing a platform for spatial interaction, remains in disarray. Cities in developing countries are attempting to keep up with the fast population growth that threatens to exceed infrastructural capacity and impede economic sustainability. Among the worst problems brought on by this increase are parking lot shortages, air pollution, and congested roads **(Olorunfemi, 2021)**.
The purpose of the inquiry dictates which network analysis strategy to utilize, as there are various analysis methodologies for the transmission network, each with its method. The most beneficial transport network approach is connectivity analysis. It has several indications, each of which carries a unique significance **(Gankhuyag et al., 2021)**. A geographic information system (GIS) will thus be useful for maintaining a cohesive database of streets in a systematic and effective method. GIS has become crucial since it enables researchers to select the optimum path by eliminating places that do not meet the criteria **(Khazael and Al-Bakri, 2021)**. A computerized database management system, Geographic Information System (GIS), collects, maintains, retrieves, interprets, and represents geographical data. Georeferenced geospatial and characteristic data are the two main types of material found in a GIS. As attribute data contains qualitative information that may be generated for recording and analysis, georeferenced spatial data describes objects with location and connection in two- or three-dimensional space **(Wattan and Al-Bakri, 2019)**.
Several earlier studies were relevant to network connectivity. For example, **(Ibrahim, 2007)** handled the quantitative analysis of paved streets in the Sohag governorate of the Arab Republic of Egypt. The goal was to spotlight the internal constructions of the governorate's road axes and clarify the relationship between contracting sites and transportation patterns. In addition, the researcher determined the characteristics of the road network structure and its spatial diversity. The results showed that the road network is in poor condition, and direct contact between its nodes has yet to be realized. The Erbil Governorate's paved road network system to evaluate the degree of interconnection and dependency between urban agglomerations **(Khazal, 2009)**. There are metropolitan regions with high levels of connectedness, such as the Shaqlawa cluster, and peripheral settlements with low levels of connectivity, as in the Hajj Omran cluster. The study also discovered that the Shaqlawa settlement was the governorate's core node in the road network, making it an excellent administrative headquarters. Due to the governorate's complex geography, the county's road network has a high turn value.
(Al Douri, 2010) investigated the length, density, and effectiveness of the transportation routes in Al-Dur, Salahaldeen Governorate / Iraq, by conducting a geographical investigation of the road network. The study found that the Al-Dur district's road network has a low density compared to other districts. The district's road network paths are influenced by natural and human factors, including the district's position, surface texture, and aquatic ecosystems, as well as the distribution of its population and its agricultural and commercial activity. Joeng and his colleagues examined a network city typology by connecting a variety of transportation contexts to small and medium-sized cities in Korea's socio-economically deprived Dongnam area **(Jeong et al., 2016)**. They demonstrated that several tiny socio-economically underdeveloped communities in poor mobility settings were not included in forming urban networks. Therefore, functional connectivity to the big cities and the growth of passenger and commerce-based links are of utmost importance for small communities seeking to achieve sustainability through networking.
This study aimed to identify the general situation and spatial variation for road network development and determine the effectiveness of the road network structure. This may

provide an idea about the existing road network in the region. It also presented some recommendations to decision-makers to enhance the network.

2. THE STUDY AREA

Al-Kadhimiya and Al-Adhamiya municipalities were selected as the research's two locations in this investigation. As two of them are the oldest and most significant municipalities in the capital city of Baghdad, they are also popular locations for religious tourism. Both are situated, respectively, on Baghdad's Al-Karkh and Al-Rusafa sides. Baghdad is the capital of Iraq and the administrative center with a high population density compared to the other governorates. It is located between (33° 10′ - 33° 30′ N) and (44 °11′ - 44° 36′ E).

2.1 Al-Kadhimiya Municipality

It is one of the largest cities of Baghdad's older municipalities. According to Fig. 1, it is situated between (44° 15′- 44° 23′ E) and (33° 20′- 33° 29′ N). According to statistics from the Ministry of Planning Central Statistical Organization Directorate of Population and Manpower Statistics / Iraq, the region has a 56.551 km^2 area and 44,8849 people as of 2019. It is one of the most prominent religious locations, hosting the two shrines of the Imams (Musa Al-Kadhim and Muhammad Al-Jawad, peace be upon them), as well as various service, educational, and commercial facilities, making it a popular tourist and unique destination.

2.2 Al-Adhamiya Municipality

It is one of the first municipalities to be founded in Baghdad. It is located on the Al-Rusafa bank of the Tigris River, between (44° 19′ and 44° 25′ E) and (33° 21′ and 33° 26′ N), as indicated in **Fig. 1**. The region has a 27.26641km^2 area. As of the year 2019, 304,980 people are living there, according to statistics from the Ministry of Planning Central Statistical Organization Directorate of Population and Manpower Statistics/Iraq. Al-Adhamiya municipality is considered unique in terms of residential and commercial development, as well as a prospective destination for expatriates owing to the existence of Imam Abu Hanifa al-Numan's shrine, and it is also regarded as a transit place for tourists to Imam Musa bin Jaafar's shrine (peace be upon him).

3. THE METHODOLOGY

In this study, the regions' roads were digitized using 1:100,000 land use maps and 1:250,000 Baghdad's map provided by Baghdad municipality. The Quick Bird satellite imagery, which has a 60 cm precision, was also utilized to digitize and update the road networks. The 1984 World Geodetic System (WGS) and zone 38 of the Universal Transverse Mercator (UTM) were adopted to georeference the maps using ArcGIS 10.5 software. Roads and boundaries were digitized as polygons and polylines in ArcGIS 10.5. The length of each road was computed, along with the boundary's area. All relevant road characteristics, including road names, were provided. Then, nodes and arcs were produced in the research region to create a network dataset. The nodes and arcs were meticulously counted to calculate various indices. The connection indices were calculated utilizing Microsoft Excel 2010 for identification purposes. The logical steps of the methodology are presented in **Fig. 2**

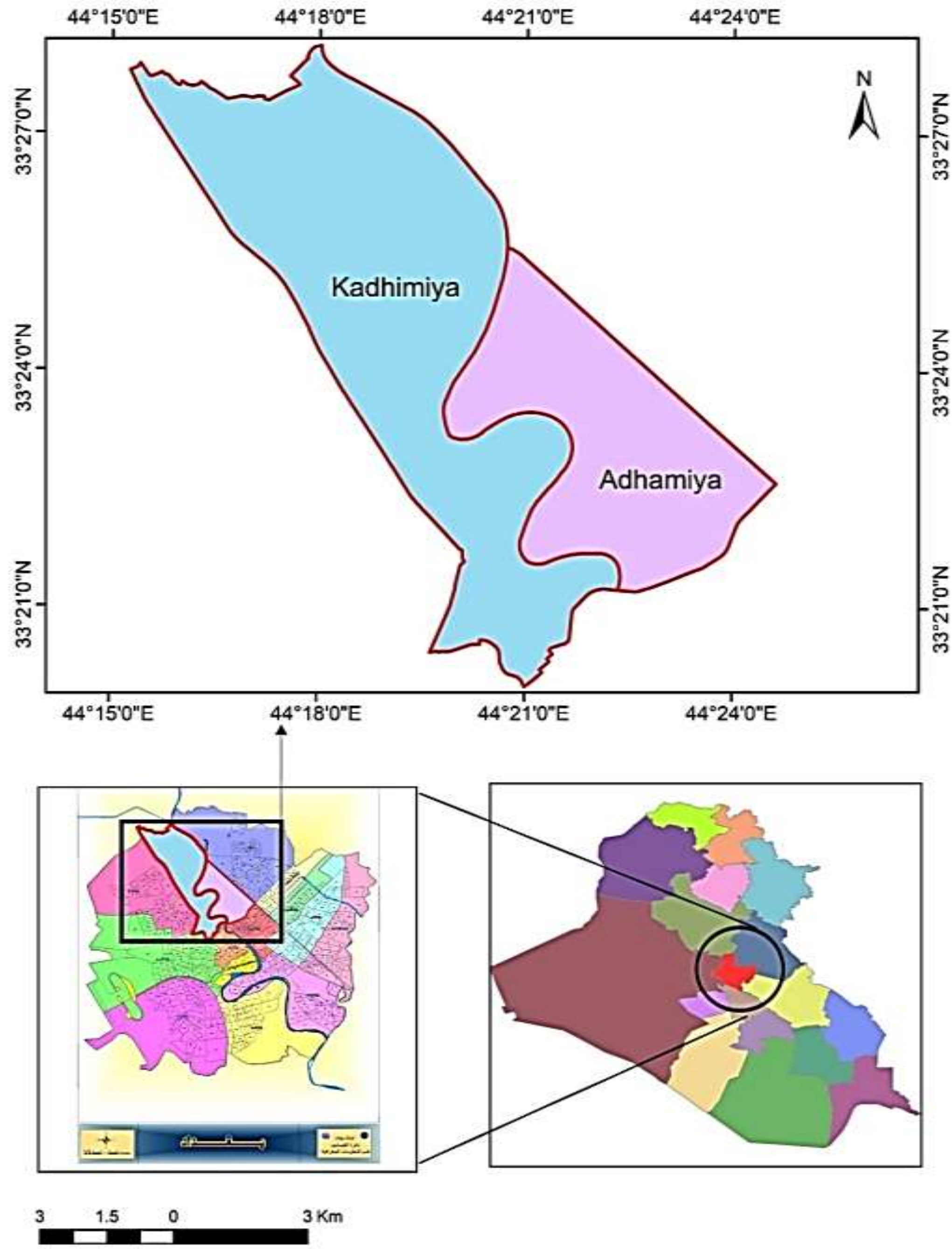

Figure 1. Map of the study area

3.1 Graph Theory

It is the foundation of methodologies for transport network analysis. To reflect the network's structure and not only its form, graph theory also depends on modeling mathematical networks and evaluating their properties **(Gankhuyag et al., 2021)**. The basic structure of a model, which has been abstracted and modeled from the actual reality of street settings, is represented by graphs, which are just a mathematical abstraction.

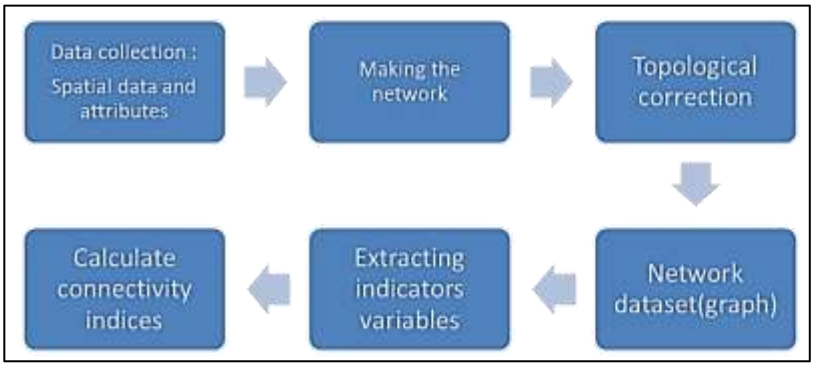

Figure 2. The Flowchart of the methodology.

By selecting the key components of the research and outlining their linkages, it is possible to create a simplified presentation of the road networks. It is essential because it establishes what will be represented in the graph as nodes (vertices) and linkages (edges) and what other street network properties the graph should include. This process, which we refer to as "network modeling," is typically included in a bigger model of a specific phenomenon **(Marshall et al., 2018)**

3.2 Transport Network Measurements

The structure of a transportation system may be assessed, and its effectiveness can be examined using several different approaches. Some of them are based purely on the topological dimension of the network, while others include considering activity level (traffic) and geographical aspects (distance, surface) **(Rodrigue et al., 2016)**. They may be used to compare various transport networks at multiple points in time, define the relationships between elements and the network architecture they reflect, and express the development of a transport network through time.

It is possible to identify several functions that correspond to the attributes of the elements of this structure concerning each vertex and/or edge of the graph by expressing the structure of the transportation networks in the form of a graph. These traits also assess the transmission network's organizational design **(Żochowska and Soczówka, 2018)**.

3.3 Connectivity Indices

The degree of connections in a certain region or the number of transmission network components that are connected may be used to characterize a transmission network's level of connectivity, which is one of its most crucial qualities. The network's connectivity determines how quickly and cheaply people may move. Additionally, communication is crucial for the economic and social advancement of the areas. Kansky created a variety of metrics based on graph theory that may be used to assess the connectedness of transport networks, including alpha, Beta, gamma, eta, cyclomatic number, and aggregate transport score (ATS). It should be highlighted that they are all ratios; in other words, they demonstrate the relationship between the distinguishable components in the network **(Regmi, 2015)**.

The current analysis was also based on a few chosen graph theory metrics. Knowing how connected a certain region is is crucial from a planning perspective. When defining the connectivity of the city's road network, the indicators of traffic volume, the convenience of access, and activity on this network should be considered. Hence, directing the urban government to regions of vulnerability to focus on improving their circumstances and addressing them **(Levinson, 2021)**. The current work was based on choosing some of the graph theory connectivity measurements, as follows:

Alfa index (α)

It is a significant network connection measure. The alpha indicator's value ranges from 0 (the least connectivity) to 1 (the most connectivity). It is evaluated such as **(Nuhu, 2019).**

$$\alpha = (e - v + 1)/(2v - 5) \quad (1)$$

where:
e is the edges or links
v is the vertices or nodes

Beta index (β)

One of the simplest metrics used to assess the connectedness of transportation networks, it describes the relationship among a particular number of edges and vertices in a graph. The beta index has higher values in well-connected networks. Using the formula below:

$$\beta = e/v \quad (2)$$

Gamma index (γ)

Kansky's third graph scale expresses the link between observed amounts of edges in networks and the maximum amount of edges. As indicated in the equation below, it varies from zero to 1, with 1 denoting a completely linked network and 0 denoting a low level of connection.

$$\gamma = e/3(v - 2) \quad (3)$$

Eta index (η)

an average transportation network link's length is as follows:

$$\eta = L/e \quad (4)$$

where L is the total length of the graph

Cyclomatic number (μ)

It is denoted as follows was used to assess the connection network's completeness:

$$\mu = e - v + 1 \quad (5)$$

Aggregate Transport Score (ATS)

The addition of Cyclomatic numbers, Alpha, Beta, Gamma, and Eta, produces ATS, which may assess the general connectedness of an area or place. Greater connection and efficiency result from a higher overall transportation score number.

$$\text{ATS} = \alpha + \beta + \gamma + \eta + \mu \quad (6)$$

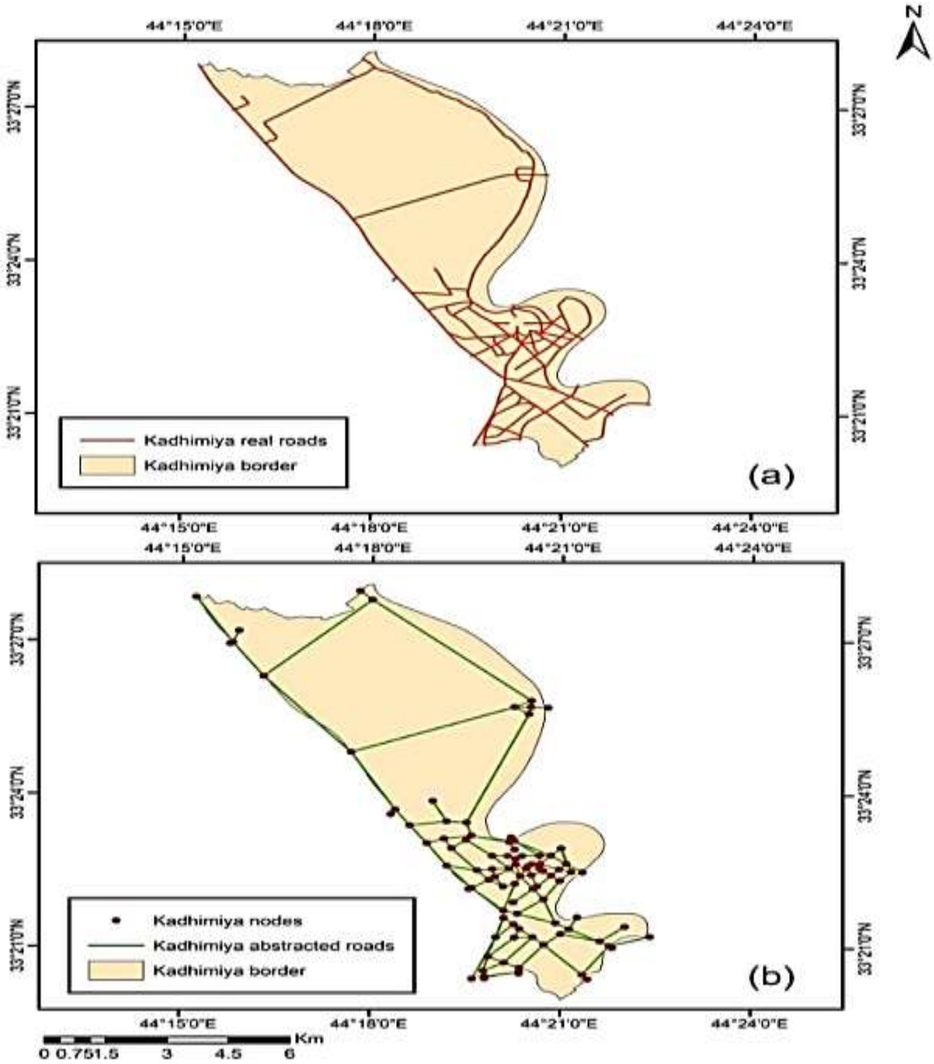

Figure 3. a) The real road network of Al _Kadhimiya municipality, b) Abstracted roads and nodes of Al _Kadhimiya municipality.

4. THE PROCESSING OF ROADS NETWORK DATA

In its real form, the road network is a complicated spatial system that is challenging to describe and evaluate, especially if it includes many stations and roadways. To simplify things, imagine a graph with numerous lines (edges) and nodes (vertices), with the lines representing streets and the nodes representing points where lines intersect. The ArcGIS software was utilized to portray the road network in the research region using a network data set tool, as shown in **Figs. 3** and **4**.

5. RESULTS AND DISCUSSIONS

The primary goal of graphical analysis in transport network evaluation is to assess the level of connection of the abstracted graph. This was also done to figure out how many nodes (vertices) and edges (linkages) were in the generalized graphs. The research uses the main, arterial, and collector roads as part of the study's framework. These roads were selected from the road network in Baghdad. The network of the Al-Adhamiya and Al-Kadhimiya regions is represented visually in an abstract graph, as shown in (**Figs. 3** and **4**). The number of edges and vertices in each of the road network's abstracted graphs were counted, as given in **Table 1**.

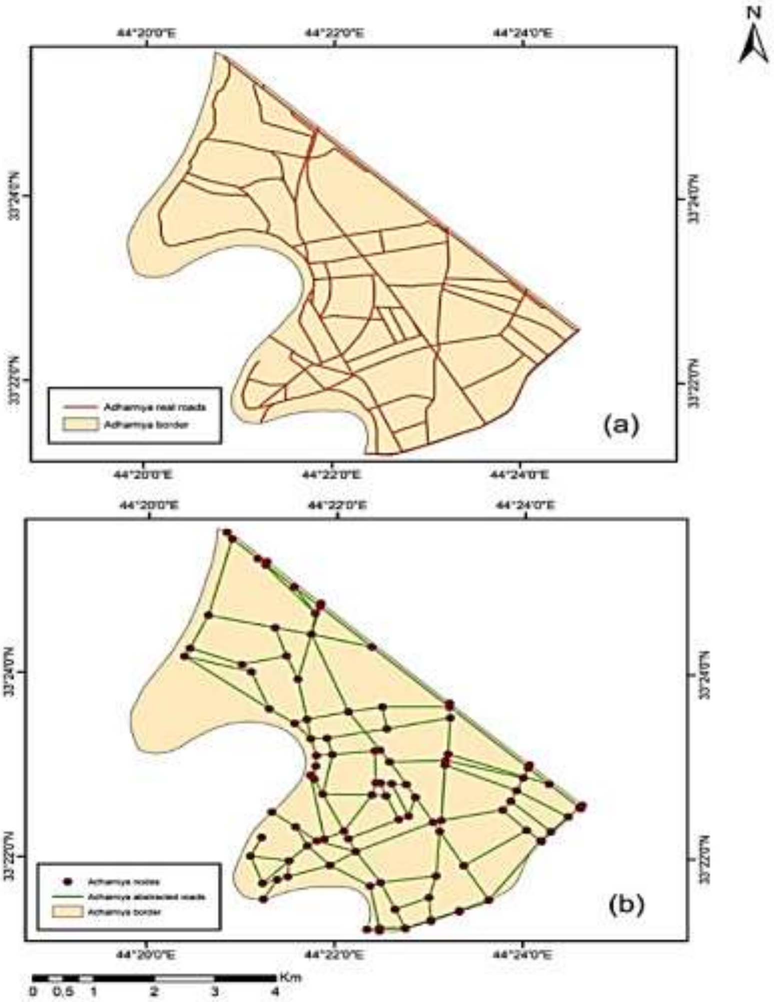

Figure 4. a- The real road network of Al _Adhamiya municipality, b- Abstracted roads and nodes of Al _Adhamiya municipality.

Table 1. The results of the connectivity measures.

Location	Vertices	Edges	Alpha index	Beta index	Gamma index	Eta index	Cyclomatic number	ATS
Al-Adhamiya	101	151	0.26	1.50	0.51	0.59	51	53.26
Al-Kadhimiya	93	133	0.23	1.43	0.49	0.71	41	43.14

The alpha index, which ranges from 0 to 1, indicates the network's maximum desirable circuits as a percentage. It can be between 0% and 100%, where 0% represents the least connected network, and 100% represents the most connected network. Al-Adhamiya region's alpha index value is 0.26, which shows there aren't many circuits in the network and indicates that the network seems to have a branching or minimum tree. We acquired

26% as a percentage, indicating that the networks had accomplished 26% of a circulatory connection. On the other hand, the alpha index of the Al-Kadhimiya region was 0.23, which highlights the network's circuits' vulnerability. It represents 23% of the network's circulatory connection when expressed as a percentage.
The beta value spans between 0 and 1. A Beta value greater than one indicates an increased connection. The beta index value for the Al-Adhamiya region was 1.5, suggesting that the region has more than one completed road network. It is 1.43 for the Kadhimiya region, showing an integrated network. The gamma index is frequently expressed as a network's connection rate and the proportion of current to prospective routes. The index is employed to calculate the network's growth over time. The Al-Adhamiya region has a rating of 0.51, indicating that 51% of its roads are related, whereas, in Al-Kadhimiya, a value of 0.49 indicates that 49% of the networks are connected.
The cyclomatic number indicates how many closed roads are in the network; a greater cyclomatic number indicates a more advanced and complicated transportation system, whereas a lower cyclomatic number indicates a less complex road network. Al-Adhamiya region has a score of 51, which indicates that it is fairly developed, whereas the Al-Kadhimiya region has a value of 41, which indicates that its road network is less dense.
ATS serves as a representation of the network system's overall interconnectedness in a certain location. Al-Adhamiya region had a moderate ATS score of 53.26, indicating moderate connectivity, whereas the Al-Kadhimiya region had a low ATS value of 43.14, indicating a low level of connection.
Al-Adhamiya region suffers from inadequate circulation and has a fair proportion of integration and complexity and a good connectivity ratio between them, according to the research area's analysis of the road network. In addition, it is somewhat dense and developed. Al-Kadhimiya region experiences a lack of rotation, a decent integration rate, a moderate level of interconnection, a low network density, and a low connectivity rate.

6. CONCLUSIONS

One of the key factors influencing a region's expansion and development is its transportation system. Roadways that are well-connected and interconnected provide for easy location linking. The studied regions are under pressure from a growing population, and this need necessitates the development of transportation networks. Connectivity is one of the most crucial structural factors for an urban road network to be examined and assessed. The main focus of this research was to assess some factors associated with the connection of the roads in the Al-Kadhimiya and Al-Adhamiya regions. The outcomes revealed that the Al-Adhamiya road network is more developed, better linked, and has a higher overall connectivity value than the Al-Kadhimiya network. The two locations also have low circuitry and high complexity. The results also might help the planning authority identify and resolve issues with the actual road network in the municipalities of Adhamiya and Kadhimiya. Thus, it would promote building new roads to improve the region's overall quality of life, social stability, and economic growth.
The research recommended planning to build new roads in the areas to solve the traffic congestion problem and make it easier to travel between different sites with the least amount of time and effort by choosing the optimal routes. In addition, increasing the number of roads in the two regions' current network, creating new circular roads, and improving connectivity between the existing centers improve the road network's effectiveness and ease movement and access. This may increase road efficiency and reduce traffic congestion.

Using geographic information systems (GIS) approaches in spatial planning procedures to find the optimal road patterns are also required to construct, organize, and establish a well-thought-out, connected, and advanced transportation network that benefits from high access ease and circulation with minimal effort and expense.

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