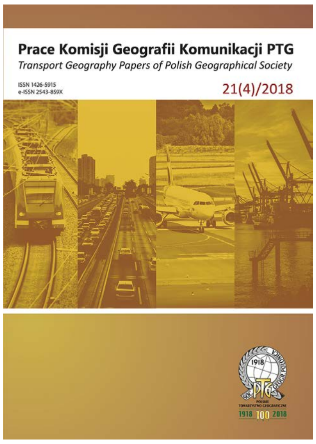

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EVALUATING THE CONNECTIVITY LEVEL OF FAYOUM CITY ROADS NETWORK: A NEW METHOD USING GIS

Ocena poziomu spójności sieci dróg miejskich Fayoum: nowa metoda wykorzystująca GIS

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Abstract: Road networks within cities are a vital component of the socio-economic development processes. Many countries have sought to examine and evaluate the efficiency of road networks within urban areas because of the increasing demand for transportation. Thus, networks should be evaluated to guide the development of transport systems and infrastructure within cities.
This study evaluates the connectivity level of the road network parts in Fayoum city, Egypt, through the application of some indicators of connectivity measurement, such as Beta, Alpha, Gamma, Connectivity degree, and the density of edges and nodes. The study follows a new method for evaluation; it does not apply the indicators on the network as a whole; however, it divides the city into zones and calculates the indicators of each zone using the Arc GIS 10.2.1 program.
The authors applied the map Algebra method to map the results of the six indicators in one index called the Total Connectivity Index (TCI). The TCI gives more consistent results than other indices, and it is more related to different spatial patterns of roads. According to this indicator, most of the city road network seem to have a good connectivity level, whereas the city marginal areas prove to have a poor connectivity level. Therefore, any efforts to develop or construct new roads should be in the marginal areas of the city.

Key words: connectivity, GIS, Map Algebra, Network Analysis, Urban road Network

1. Introduction

Transport geography is concerned with studying the relationships between transport and place. The transport system consists of five basic elements: network, means, trips, traffic, and costs; all these elements have an obvious spatial foundation.

Connectivity is one of the important issues that have occupied the minds of transportation geography researchers in the past and the present; it refers to the connection of network segments to each other, and thus indicates the connection of place parts to each other.

Connectivity derives its importance from its relations with other aspects and issues of transportation systems and their potential for development and sustainability. This has been demonstrated by many studies linking connectivity to these issues. Even though measurement methods vary, such as the relationship between connectivity and public transport systems (Hadas, 2013), the relationship between connectivity and the sustainability of transport through its impact on the walkability and cycling (Dill, 2004; Ellis, 2015; Berrigan et al., 2010), the impact of connectivity on reducing the distance, time and costs of transport (Kumar et al., 2017), its impact in determining the shortest path for travelers, its impact on access to various services and places (Patil, 2014), as well as its impact with accessibility index on urban land use (Ozbil et al, 2011; Huang & Hsieh, 2014). Therefore, the current study is an update of this interest.

Globally, there are several studies on road network analysis using GIS techniques, but few studies focus on connectivity. In the Egyptian geographical studies, there are few studies discussing the subject of network analysis or connectivity as an independent topic. As a general, and to the best of their knowledge, the authors did not encounter a study that analyzed connectivity in the same method as the present study does; most studies have analyzed the connectivity as a part of network analysis, or rather, analyze it as a whole. Therefore, the aim and idea of this study is to analyze connectivity in each part of the road network using geographic information systems application (Arc GIS 10.2.1).

The present paper discusses a new method of roads connectivity analysis and evaluation, which combines all the indicators of connectivity analysis to produce one index to evaluate the connectivity level of the network. Two indicators have been generated to evaluate the connectivity, one of which calculates the overall average of the four indicators (Beta, Alpha, Gamma, and conductivity degree), it is called the connectivity indexes mean (CIM), and the other inserts the index of nodes and edges density to the equation of the previous indicator, it is called the total connectivity index (TCI).

The researcher applies this method to evaluate the overall roads network connectivity of Fayoum city, Egypt, by dividing the city into a grid (zones), assessing roads connectivity in every cell (zone), then extracting the overall connectivity level by map Algebra method in Arc GIS, and visualizing this as a choropleth map.

Finally, the structure of this paper is as follows; section 1 is the introduction. Section 2 is the definitions and connectivity literature review. The research methodology is explained in section 3. Section 4 discusses the study area location and its transportation system profile. Characteristics of Fayoum city road network connectivity is discussed in Section 5. The researcher presents the new method (TCI) to evaluate the network connectivity level in section 6. The paper ends with a conclusion.

2. Network connectivity analysis; definition and literature review

2.1. The connectivity definition

The term **"network"** is defined as „a meshed fabric of intersecting lines and interstices" in a standard dictionary, but from the geographer's point of view, it refers to "a set of geographic locations interconnected in a system by a number of routes" (Kansky, 1963 in Haggett & Chorley, 1969). The Victoria Transport Policy Institute defines **"network connectivity"** as "it refers to the density of connections in path or road networks, and the directness of links. A well-connected network has many short links, numerous intersections, and minimal dead-ends (cul-de-sacs). As connectivity increases, travel distances decrease and route options increase, allowing more direct travel between destinations, creating a more accessible and resilient system that reflects complete streets principles. Connectivity can apply both internally (streets within that area) and externally (connections with arterials and other neighborhoods)" (Online TDM Encyclopedia, www.vtpi.org [10.8.2018]).

2.2. Connectivity analysis: a classical practices

The analysis of networks started in 18th-century by Leonhard Euler (1707-1783) who tried to solve Konigsberg Bridges Problem. The city of Konigsberg (now Kaliningrad) was divided by a river into many places that were linked by seven bridges, and the problem posed as follows: could someone devise a path through Konigsberg so that people could cross each of the seven bridges only once and return home? This question was the launching of network analysis which began with the 1736 Graph theory (Alexanderson, 2006). Euler's work, thus, became the cornerstone of this discipline envisioned almost a century before by Leibniz, the geometric sites, the branch of mathematics known today as topology (Noel Scott et al., 2008).

The statue of roads connectivity in the study area (Fayoum city) is partially like the statue of Konigsberg city. Fayoum city is divided into many parts by the canal of "Pahr Yousuf" and other canals branching from it. Pahr Yousuf is the main canal in the city; it divides the city into two northern and southern parts. The roads network in the two parts are connected together by eight bridges (Fig. 3-a). Thus, the traffic movement between the city parts adheres these bridges.

The network connectivity analysis was discussed in many network analysis studies. For instance, Garrison applied the connectivity index on the American highways network (Garrison, 1960). Moreover, one of the most important works that examine the network connectivity is Haggett and Chorely's work, which discusses the network analysis in geography, and examines the connectivity indices, such as Alpha index, Gamma index, and cyclomatic number. It presents important studies for geographers, and shows how the Graph theory is applied in physical and human geography in drainage and transportation networks (Haggett & Chorley, 1969). Additionally, Bange, and Hoefer, used Beta and Gamma indices, as well as other indexes, to measure the connectivity of geographical regions in Europe (Bange & Hoefer, 1976). There are also some studies which measure connectivity between nodes in airline networks (Cates, 1978).

In the eighties of the twentieth century, Campbell discussed some connectivity indexes, as connectivity ratio, in his study about Growth pole theory (Campbell, 1972). The subject of network connectivity analysis has become the focus of many scientists in different fields in successive decades; Hanson presented some indices of connectivity and applied them in urban transportation networks (Hanson, 1986). In their 1996 book, Taaffe and his colleagues examined some connectivity indicators, such as Gamma index and Node degree (Taaffe et al., 1996). Rodrigue presented in his book a large part about connectivity, its definition and its various measurement indicators, such as Alpha, Beta, Gamma, Theta, … etc. (Rodrigue et al., 2006). The studies on the analysis of road networks have increased, and some connectivity indicators measurement has been discussed in these studies. For example, a study- which analyzed the road network and its relation to traffic performance- included a lengthy discussion of the connectivity degree index (Amini et al., 2015).

2.3. Connectivity indices calculation by GIS tools

Recently, some studies have emerged to calculate and evaluate connectivity indicators more accurately, in detail and easily through using GIS applications. Before the advent of network analysis tools in Arc GIS 9.1, Tresidder tried to use a methodology based on Arc GIS 8 and Arc view3.3 and some developed tools computable with them to study and calculate some connectivity indexes, such as Beta, Alpha, Gamma, edges and nodes density, and nodes links ratio, connected node ratio (CNR), and average block length (Tresidder, 2005). Tresidder's method required different data, which was difficult to obtain at this time, and this model became old after the develop of Network analysis tools in ArcGIS 9.1 (ESRI, https://www.esri.com/news/arcnews/summer05articles/top-ten-benefits.html,[15/8/2018]). Additionally, there are some trade-offs required in terms of accuracy and speed of calculation in processing the data.

In (Nagne et al., 2013) study, the authors used Arc GIS 10 to analyze the network connectivity in Aurangabad City. They compared the connectivity level (roads density) and population density. This study is similar to the present study in the zonal analysis of connectivity indexes; Beta, Eta, Alpha, and Gamma indexes, but the current is different in the use of the map Algebra, and visualization of data.

Another study used GIS for studying road network characteristics of Calicut city based on connectivity, coverage and spatial pattern. It links between the connectivity level and the spatial variation pattern. The authors used a method based on zonal analysis and compared the results and extraction the correlation between connectivity indexes. They found that the road network density is better suited to predict road network fractal dimension even though the data contain some amount of dispersion. (Sreelekha et al., 2016). However, the similarity between Seelekha's study and the current study is shown in the zonal analysis, but the current study differs in the use of Map Algebra tool.

3. Methodology

In order to analyze the road network connectivity in the city, it is necessary to pass through some steps that shown in (Fig. 1).

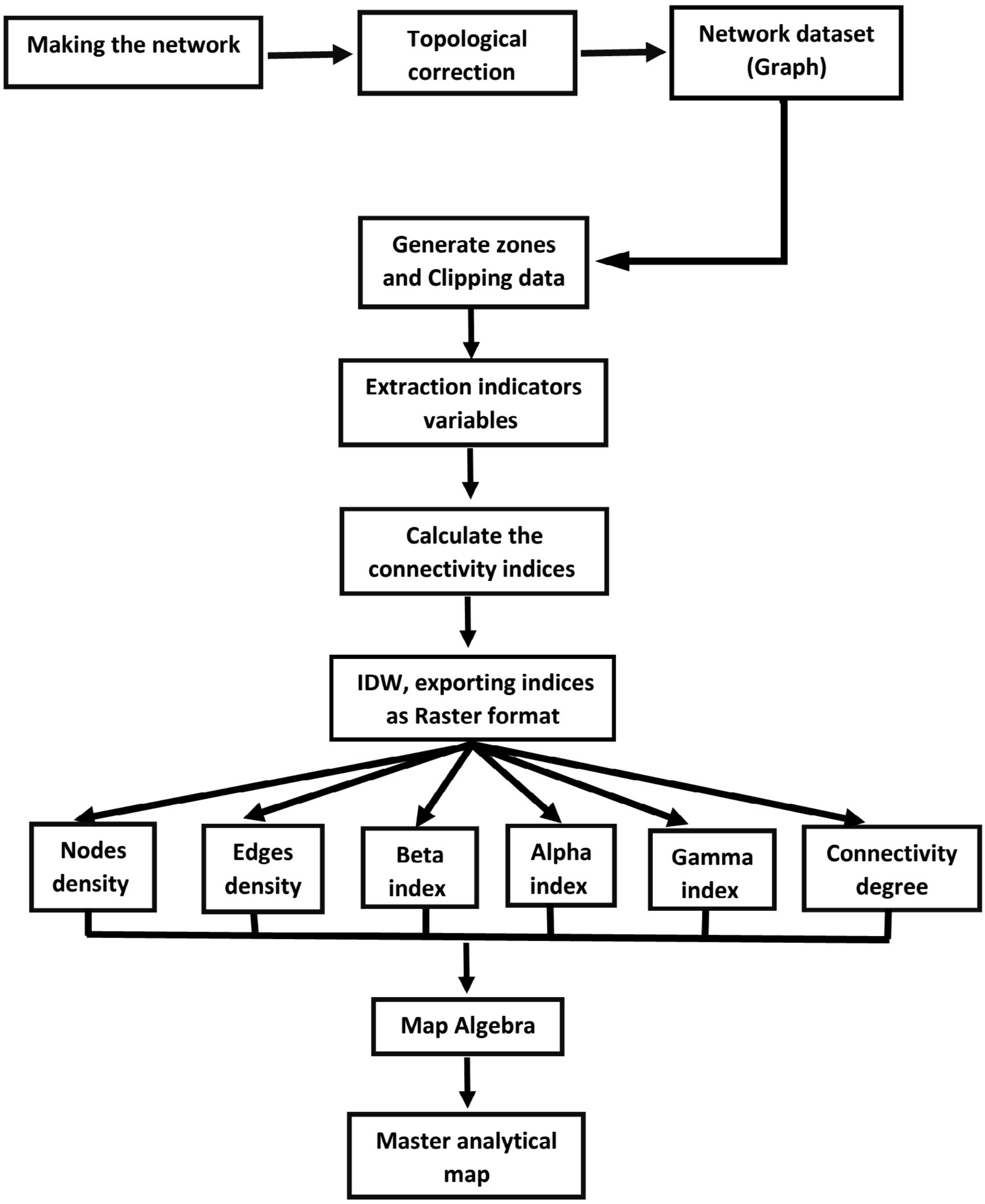

Fig. 1. Connectivity evaluation methodology

3.1. Needed Data

To evaluate the network connectivity in Fayoum city the researchers need the following data.

- Roads network; shape file (polyline),
- Roads network's Graph shape; network dataset (graph),
- Analytical zones grid; shape file polygon),
- Attributed data; like Number of nodes, links, roads length, and area for each zone.

3.2. Data preparing/ provision and extraction

Firstly, we digitize, edit, and export the city's road network **(making the network)** through https://www.openstreetmap.org/ by Arc GIS 10.2.1, and then we make the **topological correction** through the topology tool in Arc Catalog 10.2.1, and by using rule; *Must Not Have a Dangles*, that is important to verify from the connection between the links in the intersection points. In the next step, we make a *Network Dataset* in Arc Catalog 10.2.1, to convert the road shape file to a network dataset. This step is important to convert roads to a "**Graph**" consisting of nodes and edges, then we needed to get all network edges and nodes, and this occurred by using a *Split line at point* tool in Arc toolbox.

To extract the city's road network connectivity indicators in more details, we divided the city into **equal zones** area (0.25 km^2) with adhering to city boundary, so there will be incomplete zones. It was divided to grid by *Fishnet tool* in Arc toolbox.(Fig. 3-b), and we extract the number of nodes in each zone *using Hawth's Analysis Tools*[1] *3.27* compatible with Arc GIS 10.2.1, available at http://www.spatialecology.com/htools/ by *count points in polygon tool*.

By getting the number of nodes in the last step we needed to get the number of edges through 3 steps: 1. Using ***Split tool*** to split the roads according to zones; 2. Converting line features to point by *Feature to point tool;* 3. Using the Hawth's Analysis Tools in the same way to calculate the number of edges in each zone**.**

Finally, we calculate the roads length of each zone by Hawth's Analysis Tools by *sum line lengths in polygons tool,* and we can calculate the zones area by *calculate geometry* of area field in attribute table.

field calculator to write the index equation. Accordingly, we **calculate** the density of the nodes within each zone by writing this equitation in the field calculator «*field of nodes / filed of area* ». Likewise, we calculate the density of edges (as lengths) in each zone by the same way by the equation «*field of e-length / filed of area*».

We calculate Beta index for each zone using the number of edges and nodes, by writing this equitation « *field of edges / field of nodes* » in the Beta field calculator, then we calculate the Alpha index for each zone by writing this equitation « ((*field of edges – field of nodes*)+1) / (*2 * field of nodes – 5)*». Thus in the Gamma index by the equitation « *field of edges / (3 * (field of nodes – 2))* », and the connectivity degree index by the equitation « *field of edges / (3 * field of nodes – 6)* ».

Therefore, we extract the connectivity database for the six indicators to measure the level of connectivity of the city road network, as shown in (Fig. 2). We also convert the zones grid from polygon to point shape file and export every index as a raster map by ***IDW*** tool in interpolation toolbox in Arc Tool box. This step is very important to apply the map

Table

clipping_grid2

FID	Shape *	Id	Zones	aream2	#node	#edges	Node_Denst	edgesL	Edge_Dinst	Beta_index	Gamma_inde	Alpha_inde	Conn_Dgry
23	Polygon	0	aa	250000	42	64	168	5391.794267	256	1.52381	0.533333	0.291139	0.533333
53	Polygon	0	ac	161058.603042	23	26	142.805163	1970.394506	161.431923	1.130435	0.412698	0.097561	0.412698
50	Polygon	0	ad	246957.109072	34	55	137.675729	4046.167145	222.710738	1.617647	0.572917	0.349206	0.572917
56	Polygon	0	ae	146560.33567	21	22	143.285698	2586.054907	150.108827	1.047619	0.385965	0.054054	0.385965
51	Polygon	0	af	49519.485027	12	20	242.328853	1297.887045	403.881421	1.666667	0.666667	0.473684	0.666667
64	Polygon	0	ah	3125.552607	0	0	0	0	0	0	0	0	0
60	Polygon	0	ai	5932.550907	0	0	0	0	0	0	0	0	0
63	Polygon	0	al	9563.466457	0	0	0	0	0	0	0	0	0
65	Polygon	0	am	15217.932261	0	0	0	0	0	0	0	0	0
61	Polygon	0	ao	212596.089562	46	69	216.372747	4089.060146	324.559121	1.5	0.522727	0.275862	0.522727
62	Polygon	0	ap	153218.020349	14	21	91.373064	2587.131078	137.059596	1.5	0.583333	0.347826	0.583333
54	Polygon	0	aq	250000	105	174	420	7498.778038	696	1.657143	0.563107	0.341463	0.563107
57	Polygon	0	ar	22150.827572	2	1	90.29008	68.686392	45.14504	0.5	0.25	0	0
48	Polygon	0	as	249999.999998	35	57	140	5597.793541	228	1.628571	0.575758	0.353846	0.575758
58	Polygon	0	at	60044.805121	6	11	99.925381	720.580211	183.196531	1.833333	0.916667	0.857143	0.916667
55	Polyc	0	aw	250000.000002	15	21	60	2972.531059	84	1.4	[illegible]	0.28	0.538462

Fig. 2. Fayoum city roads network connectivity indices database

Source: by authors based on Arc GIS 10.2.1.

3.3. The Connectivity indices calculation and compilation

3.3.1. The field calculator option

By opening the zones layer attribute table, and making one field for each index to calculate it by clicking a right-click on the field heading and then clicking on

[1] Hawth's Analysis Tools is an extension for ESRI's ArcGIS (specifically ArcMap). It is designed to perform spatial analysis and functions that cannot be conveniently accomplished with out-of-the-box ArcGIS.

Algebra method to create the connectivity master analytical map.

3.3.2. The Map Algebra toolbox

Map Algebra is a simple and powerful Algebra with which we can execute all spatial analyst tools, operators, and functions to perform a geographic analysis. We used *The Raster Calculator tool* that allows creating and executing a Map Algebra expression that output a raster to calculate the Connectivity Indices Mean (CIM) and Total Connectivity Index (TCI) to extract a unified map of indicators as a whole. Through this, we are able to estimate and evaluate the connectivity level in every place in the city and to combine the multi results of the many connectivity indices in **one analytical map**.

4. Study area and its profile of transportation system

Fayoum city, located 90 km south-west of the Egyptian capital (Cairo), is an Egyptian city, which plays the role of the administrative capital of Fayoum governorate. It had a population of approximately 400,000 in 2017, so it occupies the 12th rank among the Egyptian cities in terms of population, and it is the largest city in the governorate of Fayoum in terms of population and area. (Fig.3-a).

The total length of the city's street network is approximately 358 km (31.8% paved). This network is divided into main street (16.4%), collector's streets (20.3%) and local streets (63.3%). The general streets density is 36 km / km^2, but the density of paved streets amounts to 7.2 km / km^2.

The number of the licensed vehicles in the traffic administration of the city amounts to 210 thousand vehicles in 2017 of which 19.7% are private cars, 61.9% motorcycles and 5.7% taxis, and other vehicles (12.7%).

Private cars ownership in 2006 was 8.3 cars/100 households, which rose to 14.8 cars/100 households by 2017. Likewise, the motorcycles ownership increased from seven motorcycles/100 households in 2006 to 15.8 motorcycles/100 households in 2017.

The traffic on the streets of the city consists of different vehicles and means. The percentage of private cars is 22.1%, motorcycles 13.5%, mass transit vehicles 11.1%, taxi 16.6%, the buses, minibuses, bicycles, goods vehicles, and others are 36.7% of total traffic on the street network.

Tab.1. Some characteristics of Fayoum city and its transportation system profile 2017

Population ('000)	Area (km^2)	Roads length (km)	Roads density (km/km^2)	Licensed vehicles ('000)	Vehicle owner (vehicles / 100 households)	
					cars	Motorcycles
400	9.9	335.8	35.8	210	14.8	15.8

Source: The Information center of the Fayoum governorate, 2017.

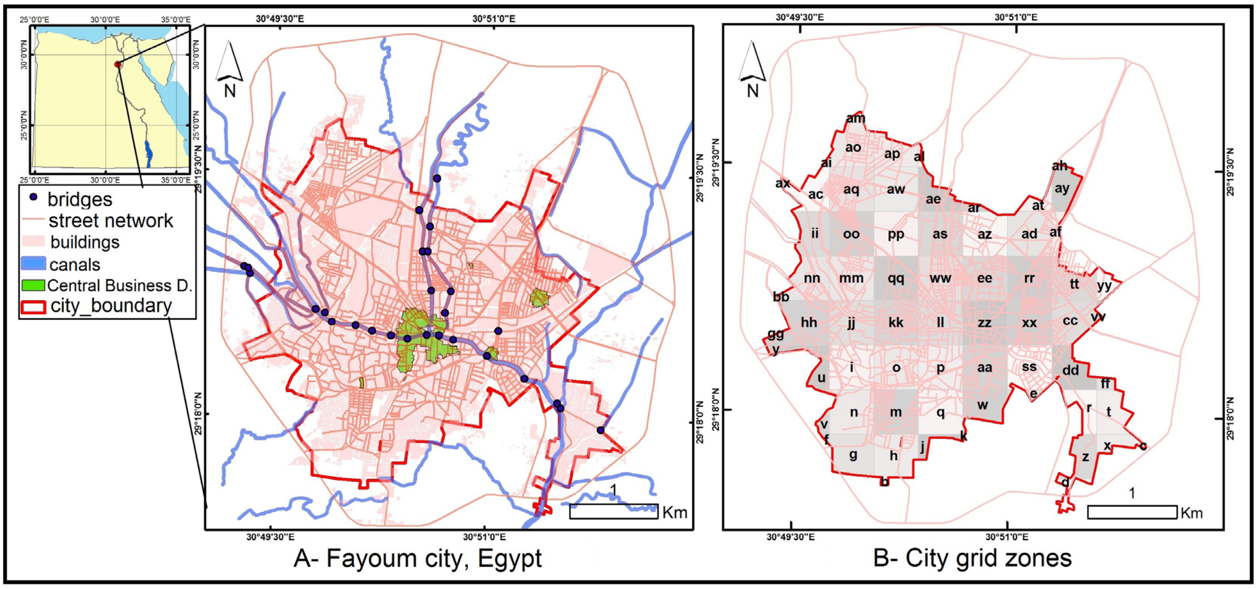

Fig. 3. Study area and dividing it into analytical zones

Source: by authors based on Arc GIS 10.2.1, Google earth Pro, and Open Street Map site.

5. Fayoum city road network connectivity characteristics

After measuring and evaluating the level of connectivity of the city road network, which depends on two variables: the number of nodes (n), and the number of links (e), researchers were able to produce the maps shown in (Fig.4), and Tab. 2. Thus, the characteristics of every index can be explained as follow.

5.1. Nodes Density

This index represents the number of intersections per unit of area, a higher number would indicate more intersections, and presumably, higher connectivity.

$$\textbf{Node D.} = \frac{n}{a} \qquad (1)$$

Where (a) is the zone area and (n) is #nodes inside the zone. The degree of connectivity in the network increases as the nodes density increases, and this is evident in the downtown area, unlike the city's margins, which suffer from a low number of intersections due to the incomplete growth of the road network (Fig. 4-a).

5.2. Edges Density

It measures the length of edges per area; a higher number will indicate more links and more connectivity.

$$\textbf{Edges D.} = \frac{e}{a} * 1000 \qquad (2)$$

Where (a) is the zone area and (e) is edges length in the zone. The density of the edges shows that the level of connectivity also increases in the core of the city (around the Central Business District area) and in the old areas where the number of roads and edges increases (Fig. 4-b). There is a clear correlation between the density of the edges and the density of the nodes, where the Pearson correlation coefficient value is 0.94.

5.3. Beta index

It measures the level of connectivity in a graph, and is expressed by the relationship between the number of links and the number of nodes. The value is between (0-1) but in more complex networks the value will be greater than 1. (Rodrigue et al., 2006, 65).

$$\beta = \frac{e}{n} \qquad (3)$$

Where β is Beta index, (e) #edges, and (n) # nodes. The value of Beta index depends on the number of edges, the higher the number of edges in the zone, the greater value of Beta index, so the connectivity in the city's road network increases according to the Beta index in high-edges number zones, and Pearson correlation coefficient indicates this positive correlation with a value of 0.73. Therefore, the Beta index shows that most parts of the city have a high degree of connectivity (more than 1). (Fig. 4-c).

5.4. Gamma index

This index provides a useful basic ratio for evaluating the relative connectivity of an entire network. It is simply the ratio between the number of edges actually in a given network and the maximum number possible in the network. (Taaffe et al., 1996, 253)

$$\gamma = \frac{e}{3(n-2)} \qquad (4)$$

Gamma index results indicate that most of the city has a medium connectivity level ranging from 0.93 to 1.16. The high-connectivity indicator appears in some marginal areas, and this contradicting the results of the Beta index. (Fig. 4-d).

5.5. Alpha index

A more useful index of the connectivity of networks is the Alpha index or the "redundancy index". This consists of the ratio between the observed number of fundamental circuits to the maximum number of circuits that may exist in a network (Haggett & Chorley, 1969, 35).

$$\alpha = \frac{(e-n)+g}{2n-5} \qquad (5)$$

Where (α) refers to Alpha index, (e) is #edges, (n) is #nodes, and (g) is sup-graph (=1). The Alpha index indicates a low connectivity level in most parts of the city's road network. Somewhat, the result of this index appears to contradict the Gama index, where the higher areas are in the Alpha index in the eastern parts of the city while the higher areas of the Gama index appear in the west. (Fig. 4-e).

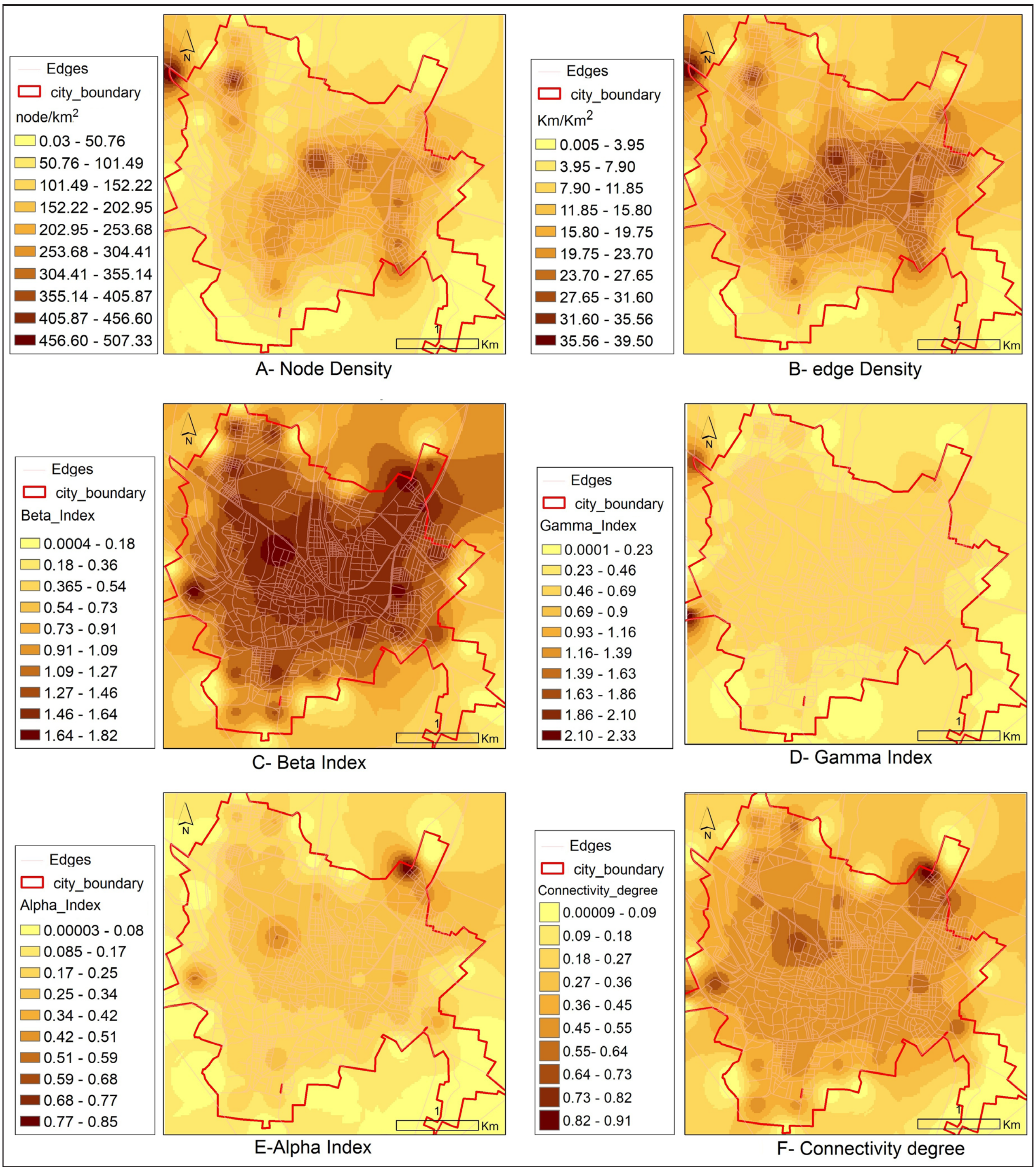

Fig. 4. Fayoum city network connectivity indices

Source: by authors based on IDW tool in Arc GIS 10.2.1.

5.6. Connectivity degree

It is measured by number of edges (e) divided on (3 number of nodes (n) – 6). The higher number, the higher connectivity.

$$Cd=\frac{e}{(3n-6)} \qquad (6)$$

The value of this indicator ranges between (0 - 1), and the closer the value is to 1, the higher the degree of connectivity, and the closer the value is to zero, the weaker the degree of connectivity (Amini et al., 2015, 10).

The connectivity degree index also indicates an average connectivity level; areas of good connectivity are located in some marginal and interior areas of the city. This is consistent with the results of the Alpha index. (Fig. 4-f).

Thus, there is a difference in the results of the last four indicators (Beta, Alpha, Gamma, and connectivity degree). Tab. 2 confirms the previous fact, which is the difference in the level of connectivity through the connectivity measure indexes.

Tab. 2. The statistics summarize of connectivity indicators of Fayoum city road network

Indexes	Minimum	Maximum	Mean	St. Deviation
Nodes density (n/km²)	0	507	131	125
edges density (km/km²)	0	39.5	13.8	10.6
Beta	0	1.82	1	0.63
Alpha	0	0.85	0.18	0.17
Gamma	0	2.3	0.44	0.37
Connectivity degree	0	0.91	0.35	0.25

Source: calculated by authors by Arc GIS 10.2.1.

The road network in the city has a high connectivity level according to the Beta index, which has an average value of 1, but in terms of the connectivity degree index and the Gamma index, the connectivity level is medium (0.35, 0.44), in contrast, according to the Alpha index, the connectivity level is weak because the average value of this index was 0.18. As a result of this difference, the emergence of the need to unify these indexes in one index, through which it can be judged on the level of roads connectivity in the city.

6. New method for Connectivity evaluation

Researchers overcome the problem of connectivity indicators result variation through the method of map Algebra, which allows performing calculations between more than a map (raster files) depending on the value of each pixel, and thus taken the connectivity indices mean (CIM) of the four indices (Beta - Alpha- Gamma - Connectivity Degree) -This is shown in map (A) of (Fig.5), and The mean is then multiplied by the square root of the nodes and edges density according to equation (7) which shown Total Connectivity Index (TCI), and this is shown in map (B) of (Fig. 5).

$$TCI = \left(\frac{\beta+\gamma+\alpha+cd}{4}\right) * \sqrt{\frac{nd}{ed}} \quad (7)$$

Where; (***nd***) is nodes density (node\km^2), and (***ed***) is edges density (km\km^2) . According to the connectivity indices mean, the city road network has a medium connectivity level, where was between 0.67 – 0.78 for most parts of the city road network. However, according to total connectivity index (TCI) the most parts of city road network are characterized by a high connectivity level (1.95 – 2.60). It is worth mentioning that there is a mathematical difference in the output between the two previous indices, but the difference was not spatial, since the areas with a good level of conductivity are almost the same between the two indices.

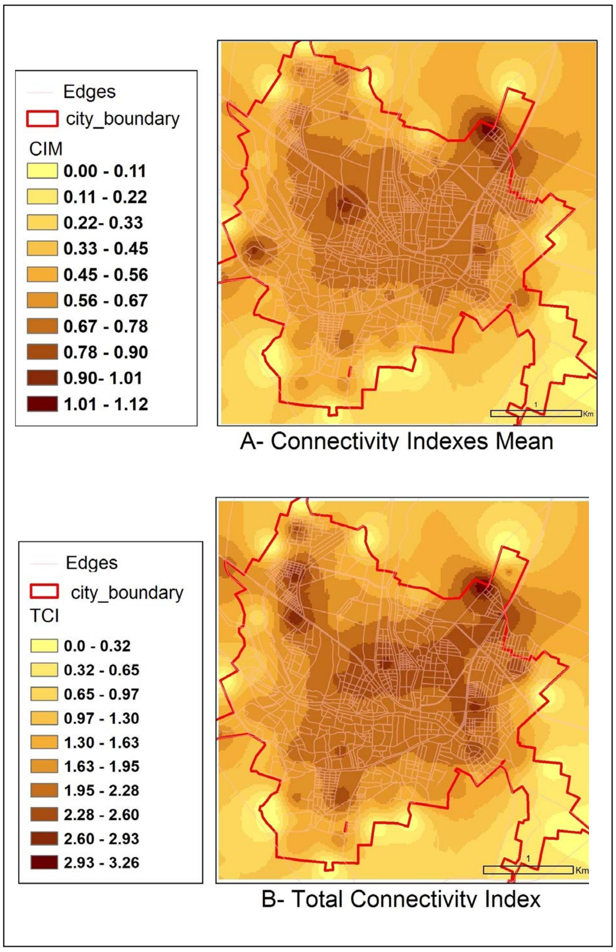

Fig. 5. The connectivity indices mean and TCI of Fayoum city road network

Source: by authors based on Map Algebra toolbox in Arc GIS 10.2.1.

The TCI is the most accurate index to evaluate the connectivity level that is based on matching the different results of other indicators. It gives one result that through which we can judge the level of network connectivity.

As it is clear from Tab.3, the measurement of connectivity using the TCI yields more consistent results. According to calculating the Pearson correlation index between all the indicators, it is found that the TCI is more closely related to the rest of the indicators, it is strongly correlated to all indicators, which confirms that the results of the measurement are more harmonious than others. Furthermore, it is clear that TCI have a higher correlation coefficient with Gamma Index (0.66) and that it is higher than the same relation between Gamma Index and the other indices does.

appears in the marginal areas because of the incomplete growth of road networks in these areas. (Fig. 6).

So far, there is a relation between the distribution of some services and the connectivity levels; this is evident from the concentration of schools, medical services, shops, and others in the high connectivity locations, where the Person correlation coefficient between connectivity level and services is (0.52). The high connectivity locations are important to maximize the benefits from the intersections of the main roads and achieve a good accessibility level for the services centers.

The high connectivity level areas are located around the main traffic flow roads in the city, like Ahmed Shawky, Batal Al Salam, and Al Nabowy Al Mohandes streets (Fig. 6). Therefore, the high connectivity can help to present multi choices for the road users, especially in the rush hours. Additionally, the highest risk of crashes occurs with very low connectivity and safety outcomes improve as the intersection density increases, but the risk of crashes is always greater for the less safe cities (Marshall & Garrick, 2010, 24-32). Therefore, Fayoum city needs more attention to regulate traffic in high-level connectivity areas, such as signage or traffic signals at intersections.

Tab. 3. The Person correlation coefficient matrix for connectivity indices

Indices	***nd***	***ed***	β	α	γ	***cd***	**TCI**	**corrl. average**
nd		0.94	0.60	0.41	0.50	0.49	0.76	0.62
ed	0.94		0.73	0.54	0.55	0.65	0.81	0.70
β	0.60	0.73		0.82	0.21	0.90	0.92	0.70
α	0.41	0.54	0.82		0.35	0.85	0.77	0.62
γ	0.50	0.55	0.21	0.35		0.38	0.66	0.44
cd	0.49	0.65	0.90	0.85	0.38		0.82	0.68
TCI	0.76	0.81	0.92	0.77	0.66	0.82		0.79
corrl. average	0.62	0.70	0.70	0.62	0.44	0.68	0.79	

Source: by authors based on Arc GIS 10.2.1, MS Excel 13.

Generally, the analytical map of the total connectivity index (TCI) shows that there are spatial relations and interactions between the roads network patterns and the connectivity level. This seems clear in the locations that have grid pattern roads, where all roads intersect with each other, which increases the density of nodes. On the other hand, the level of connectivity decreases in the random roads pattern, due to the lower number of main roads, the intersections, and the increase of the minor roads including the dead ends (cul-de-sacs). Moreover, the lack of connectivity

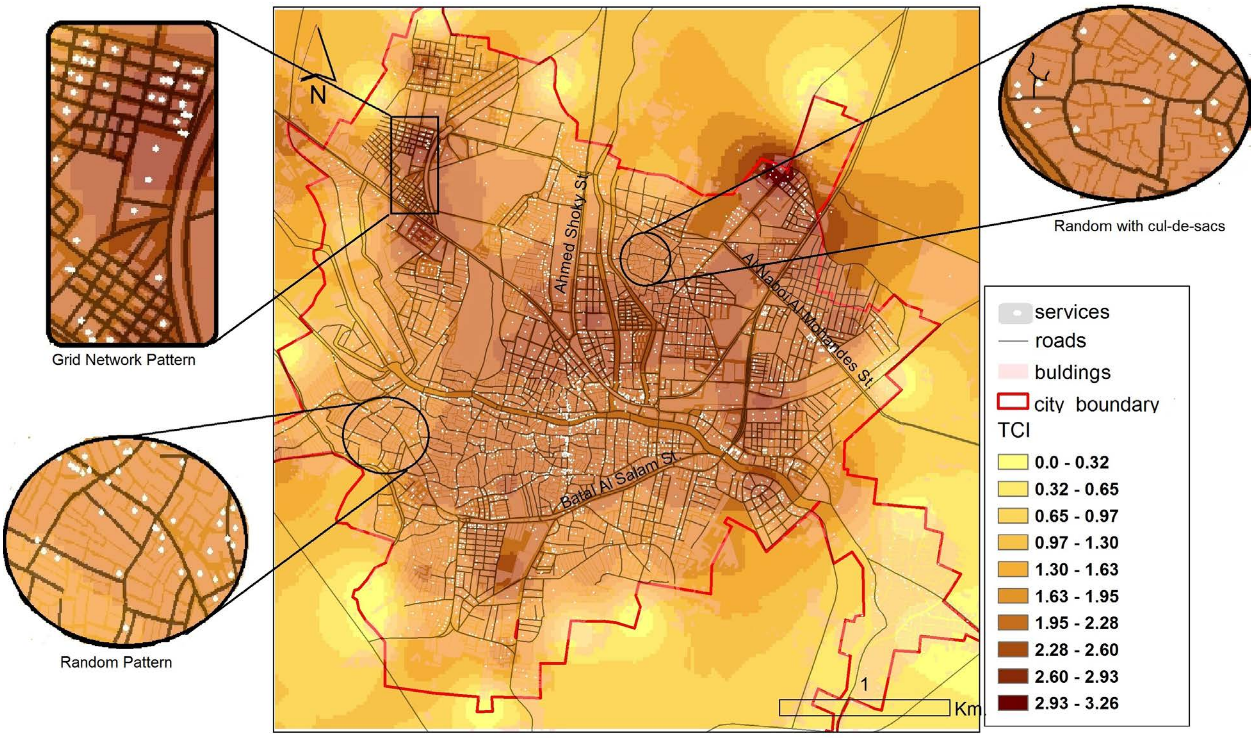

Fig. 6. TCI and Spatial patterns in Fayoum city

Source: by authors based on Arc GIS 10.2.1.

The good level of connectivity in some areas lead to urban sprawl on the agricultural lands around the city, this seems clear at the northeast area (north of Al Nabowy Al Mohandes St.).

Conclusion

The concept of connectivity faces a number of barriers to its practical application, particularly the lack of a universally accepted quantitative measurement and the need for more meaningful comparative studies (Ellis, et al, 2015, p.20). Thus, the research finds a way to reconcile a set of commonly accepted indicators in one measure, which can provide an accurate image for network connectivity.

The evidences above show that we can overcome the problem of the connectivity indices results variance by the total connectivity index (TCI) through the map Algebra method in the Arc GIS 10.2.1. The TCI gives more consistent results than other indices, and it is more related to different spatial patterns of roads, because it shows a higher level of connectivity for grid roads pattern more than randomized pattern.

The method used in the current study is simpler, easier to use and more accurate than the one used in the (Tresidder, 2005) study. The new method is also more detailed and clear than the method used by (Nagne et al., 2013). Additionally, this study goes further than the study of (Sreelekha et al., 2016); the latter concluded that they found that the roads network density is better suited to predict road network connectivity. While the current study combined all indicators, including density of the links and the density of the nodes to reach more accurate results. In addition to the adoption of the map Algebra method and this is not used by any of the previous studies.

The new method helps us to evaluate the road network connectivity of Fayoum city; the city has a good connectivity road network except for marginal areas. The importance of the TCI results comes from its potential multiple uses; we can use these results in the sustainability of city transport system by encouraging the use of bicycles in the high connectivity areas. We can also improve the walkability in these areas by walk paths provision, thus we can reform the modal share of traffic and travel in the city by raising the walker and cyclist percentage, and this will have environmental benefits.

The socio-economic development processes are based on the flexible transportation system. Therefore, the connectivity of roads networks can increase the flexibility and reliability of transportation systems by offering alternative routes to passengers, which will redistribute traffic across the street network, and thus reduce congestion and decreasing journey time and cost. It helps to improve mass transport and increase demand for it.

More importantly, the greater connectivity areas provide greater, quicker and more direct access to the incident areas; therefore, these areas are safe areas. On the other hand, the poor connectivity areas have a connectivity and access troubles; thus, they are less safe areas.

Consequently, development plans should be directed to the marginal areas, which have a poor connectivity level, to be safer and to achieve a good access to services for its residents. Additionally, the old areas in the city need to decrease/ open the Cul-de-sacs streets, to improve the connectivity in it.

Ultimately, we can complete future studies to improve indicators for connectivity measurement and evaluation, and various studies can be planned to discuss the relationships between the connectivity level, the walkability and bicycle usability, and the impacts of these on transport sustainability in the city.

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