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DEVELOPING A TECHNIQUE TO CALCULATE THE HOSPITAL SERVICE AREA AND MEASURE THE ACCESSIBILITY LEVELS TO TERTIARY HOSPITALS USING GIS

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ABSTRACT

***Problem statement**: GIS has several techniques and functions that can be used for health services planning. Each one of these functions can be applied for different health related issues. However, based on previous studies, there is an absence of the method for calculating the hospital service area, taking into account the spatial and social dimensions. **Approach**: The first part of this study reviews the relevant GIS methods that are used to calculate the hospital service area. The second part of the study focuses in developing a technique that can calculate the service area based on spatial and social dimensions. The third part of this study is related to identifying the levels of accessibility to tertiary hospitals in the Gaza Strip. **Results**: The hospital service area covers 74.7 km2, which represents 38.1% of the built-up area with approximately 800,000 of the population. The driving time of 10-15 minutes covers 206.25 km2, which represents 56.5% of the total area of the Gaza Strip with approximately 1,700,000 of the population. The bordering neighbourhoods of the Gaza Strip has a low score of accessibility to tertiary hospitals. **Conclusion**: The approach undertaken in tertiary hospitals defined the hospital service area simply by a circular coverage, and determined the levels of accessibility using spatial analysis and spatial selection method. Thus, it can be concluded that the method used in this study is suitable for remote areas and supports the decision-makers.*

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Keywords: ***Geographic Information System (GIS), Hospital service area, Accessibility, Tertiary hospitals, Gaza Strip.***

1. INTRODUCTION

From a political and social standpoint, the Gaza Strip is considered to be a highly unbalanced area. It falls directly on an active conflict zone and, thus, has a long history of devastating sudden assaults by the Israeli forces against the civilian population. The conflicts have resulted in severe loss of human life and a high number of injured as well as extensive disruption of the already over-stretched health system in the Gaza Strip; including damage to infrastructure, breakdown of services and interruption of health management and coordination structures. The Gaza Strip has 25 hospitals providing various health services to the residents in normal conditions. Hospitals that provide emergency and ICU treatments are considered 3rd class hospitals. These hospitals are the only hospitals operating in a time of crisis. During the last war in 2014, the Israeli occupation directly targeted many hospitals and medical staff. At least two tertiary hospitals were closed and relocated in relatively better secured locations. OCHA (2014) reported that 10 hospitals and 7

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PHC clinics were damaged, 5 hospitals and 44 primary health clinics were closed, 16 ambulances were damaged, 83 health personnel injured and 21 health personnel died, which placed obstacles and difficulties to gain access to those hospitals and health centres [1]. In order to measure the service area and accessibility to hospitals the methods that have been used in this regard were selected from the literature to fit the study area [2,3,4]. The study has used the basic spatial analysis required for the case study in line with the capabilities of the remote areas which did not have the necessary data. Another technique which has been used in this study was developed to calculate the hospital service area according to the factors that were available on the ground. Eventually these methods achieved the objective of the study.

2. LITERATURE REVIEW:

GIS affords numerous spatial analysis methods which can be utilized to characterize and comprehend healthcare service delivery within the spatial spheres, but especially in the affiliation between health outcomes and accessibility [5]. The application of GIS, in the scheming of healthcare service delivery, will represent the most favorable arrangement of healthcare facilities [6]. However, these analyses require, the competence to conjoin healthcare services (hospitals) with prospective patients (the population which will possibly engage their services) A service area is defined as a geographical zone characterized around an institution or business that distinguishes the population which utilizes its services. Usually, a service area divides geographic space into adjoining zones, but in some contexts, they can overlap to mirror competition within a zone between service providers [7]. A service area in itself does not necessarily mirror geographic adjacency though it may, and perhaps, should. Discrepancies in accessibility, preference of administrative boundaries, and supply and demand for services affects the interpretation of service area [8].

There is a short narrative of analytical service area definition that has materialized accordant with increasing utilization of GIS in the spheres of public health and epidemiology. Health accessibility literature is considerably more than health specific service area literature. In reality, one of the few medical accounts of service area definition and utilization criticizes the general absence of research that has formulated and examined the health service area in practice [9]. Currently, the situation is not as acute but there are compelling divergences in health literature but more generally in GIS accounts of methodologies for hospital service area definition. School service area definition [10,11] or formulated healthcare accessibility and utilization [12,13,14] have been discussed by GIS.

The GIS study most relevant to this research has pivoted on primary (or grade) school service area definition so as to ascertain if students are attending the most proximate educational establishments. [10]. Education and healthcare administrators require a balanced method of geographically allocating populations to services given at specific locations. Education and healthcare formulations vary in that hospitals provide differing levels of service requiring a service area that is service level oriented. Schools and hospitals are affected by varying methods of service. A one-off visit to a hospital requires considerably less travel-time than typical commuting to school. Therefore, when travel-time is less of a hindrance the hospital service area is more likely to be affected by the awareness of service levels in non-catacylsmic situations. This scenario, researched by Hanlon and Skedgel [15], discussed cross-district utilization of general hospital care and the researchers emphasize patterns of patient travel from minor centres to tertiary facilities in Halifax, Nova Scotia to access services that, in numerous cases, could be administered locally.

For constructing hospital service areas, more than a dozen probable methods exist but only three predominate: Thiessen polygons, network analysis based on travel-time, and raster grid cells [16]. Thiessen polygons and network analysis adopt vector GIS avenues. Vector GIS refers to the use of uncomplicated points, lines and polygons to represent spatial bodies, whereas raster GIS utilizes tessellations (commonly-shaped pixels) to represent endless surfaces[17].

The most common approach is to use Thiessen polygons to segragate geographic space founded on the locations of providers of healthcare service [13,18]. In this manner each hospital is defined as a point, and Euclidean distance is used to form a polygon around individual points in order that the boundary bisects the straight line between any two points [17]. This method displays numerous deficiencies, most notably, Thiessen polygons which cannot incorporate facility size or capacity [19] or account for morphing elevation or varying road conditions.

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Using road network data together with information on populations and services to model resource allocation utilizes Vector GIS which is a more refined approach to network analysis which is used for formulating healthcare accessibility, as stated by Walsh et al., [14] and is referred to as "…an approach of routing and allocating resource flows through a system connected by a set of linear features (e.g., roads and trails), where distance optimization decisions within the network are made dependent on (a) the nature of the travel conduits; (b) links between conduits; (c) location and characteristics of barriers to movement; (d) directionality of resource flows, position, and conditions of centers having specific resource capacities; and (e) node locations, where resources are deposited or collected along paths throughout the network."

Network analysis utilizes road network data characterized as a sequence of segments or amalgamations which are connected by nodes (intersections), where each amalgamation is accredited a travel cost (or impedance). Hospitals and population centroids are assigned to the adjoining node. When a link or multiple links separate population and hospital nodes, amalgamation values are used to allocate population centroids to the nearest hospital.

Thiessen polygons and network analysis (vector-based approaches) are not satisfactory to represent the variable compliance to service area boundaries by a population. Hospital service area definition using a vector approach is restricted by the fact that individual polygons illustrating a service area are homogeneous thereby unrealistically demonstrating that all persons are equally likely to utilize the hospital within the service area parameter. In reality, utilization of services within a service area by the residing population is not homogeneous, but is characterized by usage of classifications. For example, at the external boundaries of a service area, the feasibility escalates when a person selects to utilize services in an adjoining service area. In a raster-based method to modelling access to healthcare services, a financial surface which outlines classifications of cost (measured in travel-times) between local and proximate hospitals is established by integrating rasterized road network data with other appropriate off-road network impedances (Model developed by Martin et al., [20]).

Accessibility measures, as demonstrated by the literature, exhibit a requirement for quantitive indicators of accessibility for varying types of public services including healthcare. The indicators would act as instruments in comparing accessibility in different areas of the region and in the interpretation of substitute plans for new service facilities and transportation links. Examples of accessibility indicators are; provider-to-population ratio, distance to the nearest provider, average distance to a set of providers and gravitational models of provider influence (Guagliardo et al., 2004). Each of these indicators can be utilized to appraise accessibility of health centers [24, 25].

3. STUDY AREA:

This study focuses mainly on the Gaza Strip. It falls on Latitude 31°25' N and Longitude 34°20' E along the eastern coast of the Mediterranean Sea. It has borders with Egypt in the southwest for 11 km, and Israeli occupation in the east and north along a 51 km border. The Gaza Strip has five governorates of Palestine namely; North Gaza, Gaza, Deir el-Balah, Khan Younis, Rafah. It covers a total area of 365 km2 (PCBS, 2012). According to the Ministry of Interior – Civil Affairs (2014) "the target area has a population of 1,900,069".

Figure 1 Gaza Strip, Palestine.

4. MATERIALS AND METHODS:

Various data types are needed to collect from different sources. Most of these sources are government departments. These data are in different forms, some of them in the form of tables and reports while others in the form of maps. Data involved two-pronged spatial and attribute data,

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which included maps of the study area, and locations of hospitals as spatial data. On the other hand, the attribute data included population; hospitals in terms of statistics and geographic information. Table 1 shows the source of the layers used in the study.

Table 1: The source of the layers used in the study.

No.	Layer	Source
1	Gaza Strip Border	Ministry of Local Government
2	Gaza Strip Governorates	Ministry of Local Government
3	Gaza Strip Neighbourhoods	Ministry of Local Government
4	Gaza Strip Hospitals	Ministry of Health
5	Gaza Strip Aerial Photo	UNRWA

After collecting data the next step was building the geodatabase of the study. The software ArcGIS10.1 has been used as a GIS platform of this study. The geodatabase was created with two feature datasets and many feature classes that represent the study data. Palestine 1923 was set as a datum of the study data. Many topological rules have been used to adjust the data to ensure that the data is ready for the analysis phase.

The new technique shows consideration for the spatial dimension by calculating the radius of the circle serviced from hospital. This calculation is based on service area, population density, and served people; in order to calculate the radius. The following calculations describe the new technique:

$$R = \sqrt{S.A/\pi}$$

Where:

R = Radius

S.A = Service Area (km2)

Service area = Served People/Population Density

Service area calculated based on served people divided by population density.

Served People = Beds number/Average beds number * 1000

Served people was calculated based on the existing beds in the hospital divided by the average beds number. The Palestinian Ministry of Health said that they consider 2.5 beds per 1,000 people as an international standard for average number of beds.

Population Density = Population/Built up area

Population density was calculated based on population divided by built up area. The population was obtained from the Ministry of Interior – Civil Affairs, and the built up area was calculated using satellite imagery and ArcMap software.

The square root of the result of service area divided by Pi (π) was used to calculate the radius of serviced circle. Where Pi represents 3.14 the ratio of the circumference to the diameter of a circle, the square root was utilised to obtain the radius without the square.

Buffer analysis has been used to detect the areas that fall within the service areas of tertiary hospitals in the Gaza Strip. In this study, buffers are zones of specified distance given by the radius of a hospital's service area. The accessibility can be evaluated by measuring the distance from residence or incidence location to the tertiary hospitals (road distance) by estimating travel time. Other buffers were produced, 3 km2 based on previous studies and the researcher's experience, represents about 10-15 minutes drive time [2,3].

After generating the radius values the buffer analysis was undertaken for each hospital separately. The results of the buffer analysis were merged into one layer which represents the service areas for all hospitals. The second buffer was carried out once due to the value of the radius and is the same for all hospitals.

Selection by location function was used for the outline boundary intersection and centroid containment in order to determine the level of accessibility. The parameter used in this study overlapped. The spatial selection methods that have been used to select the neighbourhoods include: (a) having their centroid in the source layer feature, and (b) crossed by the outline of the source layer feature.

The spatial selection method of Have their centroid in the source layer; the neighbourhoods in the input layer will be selected if their centre falls within a service area zone. This method will be applied for both layers of the service area with an individual 3 km2 buffer zone to determine that the neighbourhoods are completely within these areas.

The spatial selection method of Are crossed by the outline of the source layer feature and the neighbourhoods in the input layer will be selected if they are crossed by the outline of a 3 km2 buffer zone. The purpose of this method is to determine neighbourhoods that touch small parts of their areas within the outline of the buffer zone. Figure 2 illustrates the process of selecting neighbourhoods by crossing the outline method.

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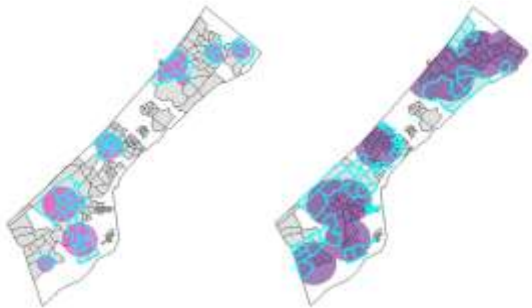

Figure 2: illustrates the buffers and the selection methods.

After processing selected neighbourhood features the next step was to combine the layers and remove the features that exist in the other layers. For example, the first level was selecting features in the service area zone and the second level selecting features in the buffer zone of 3 km2. The buffer zone of 3 km2 already contains the features in the service area zones so that the features which exist in the first level must not be within the second level. The process of removing features was in the same function but using a different method.

In order to remove the features in two layers, the function of selection by location and the spatial selection method are within the source of layers which have been used. The target layer was the second level and the source layer was the first level. After applying, the features which exist in the second level and already within the first level were selected. The selected features were removed by deleting the records in the attributes. This step has been used to check all layers to ensure that there are no features overlapping in all levels.

The next step was to add a field for each layer showing the levels of access to hospitals. Then all layers were merged in one layer that includes all levels of accessibility (Table 2).

Table 2: The levels of accessibility

No.	Accessibility	Clarification
1	Good	Falls within the hospital's service area
2	Fair	Falls within 10-15 minutes driving time
3	Limited	Areas have incomplete coverage
4	Inaccessible	Completely out of hospital service areas

5. RESULTS AND DISCUSSION:

The new technique calculates the real service areas of the hospitals. This calculation can be applied to any hospital not only tertiary hospitals and has been applied to the tertiary hospitals in the Gaza Strip in order to measure the levels of accessibility. The main findings of this calculation represent the radius, which can be applied in the ArcGIS software.

The accessibility to healthcare establishments is a fundamental issue in conflict zones globally. The Gaza Strip, where this study is located, in the conflict zone with the Israeli occupation, has necessitated evaluating accessibility to hospitals. The main aim of studying accessibility is to evaluate the access of the affected areas to the tertiary hospitals. The results and discussion in this regard include maps, tables, and charts. Figure 3 illustrates clearly that the hospital service areas are not covering all the neighbourhoods.

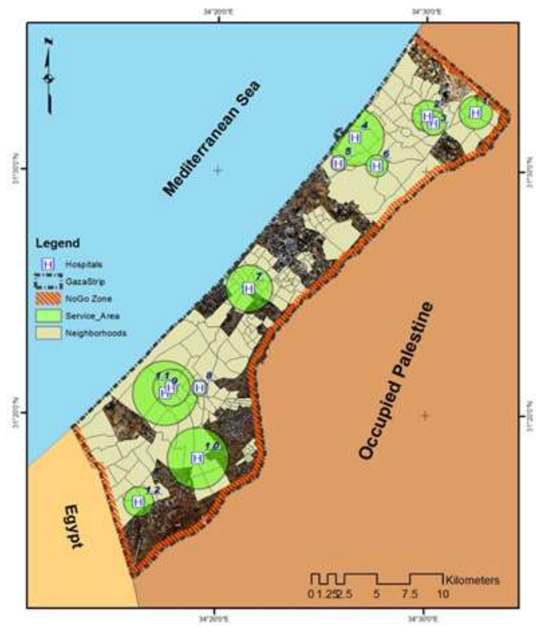

Figure 3: Tertiary hospitals service areas - Calculation Technique.

There are many hospitals which are supposed to cover a large area but have a very small service area in all governorates. The hospital service area covering 74.7 km2 represents 38.1% of the built-up area. Five hospitals overlap with another hospital's service area. The North Gaza Governorate has 3 hospitals covering Beit-Hanoun, Jabaliya, and Bit-Lahiya. The service area of Beit-Hanoun hospital is the best coverage area where the service area covers the built-up area of Beit-Hanoun. The service area of Al-Awda hospital overlaps with the service area of Kamal Adwan hospital and both cover some of the neighbourhoods in Jabaliya and Beit-Lahiya. Five out of twenty neighbourhoods are covered from the hospitals service areas. The total coverage area in North Gaza Governorate is 10.1 km2 representing 5.15% of the built-up area.

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The Gaza Governorate has 3 hospitals covering Gaza city; Moghraqa, Zahra, and Johor Dik. The service area of the three hospitals overlaps with each other in some areas. Al-Shifa hospital, the biggest in Gaza Governorate, is considered a regional hospital in the Gaza Strip. The service area of Al-Shifa hospital covers the western part of Gaza city. Al-Quds hospital covers the south-west part of Gaza city and overlaps with the service area of Al-Shifa hospital. Al-Ahli hospital covers a small area in the middle of Gaza city. The hospitals of Gaza Governorate, as the results show clearly, did not cover the eastern part of Gaza city, as well as Moghraqa Zahra, and Johor Dik. The total coverage area in the Gaza Governorate is 13.8 km2 representing 7.04% of the built-up area.

Deir Al-Balah Governorate has only one hospital, which is supposed to cover 6 towns and camps. Al-Aqsa Martyrs Hospital covers parts of the towns of Deir Al-Balah and Zawaida The total coverage area in Deir Al-Balah Governorate is 9.9 km2 representing 5.05% of the built-up area.

Khan Younis Governorate has 4 hospitals and is considered as tertiary. The service area of the hospitals, Nasser and Dar Salam, has overlapped with each other in some areas and Al-Amal hospital falls completely within the areas served by Nasser hospital. The total coverage area in Khan Younis Governorate is 36.9 km2 representing 18.82% of the built-up area.

Rafah Governorate has only one hospital which is supposed to cover the governorate. Abu Yousef Al-Najjar hospital covers a small part in the east of Rafah governorate. The total coverage area in Rafah Governorate is 4 km2 representing 2.04% of the built-up area.

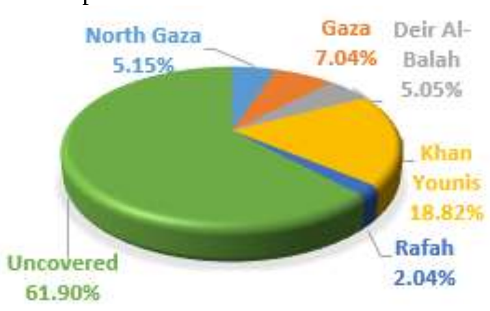

Figure 4: percentage of tertiary hospitals service area in Gaza Strip.

The service area coverage of the tertiary hospitals is less than half of the built-up areas. The areas uncovered by the hospitals services is 121.4 km2 representing 61.90% of the built-up area, this explains the weakness of the service provided and the accumulation of injuries during crises. The overlapping coverage areas take as much as a total of 9 km2 which represents 4.6% of the built-up areas. These results indicate the absence of a true distribution for the tertiary hospitals and the size of hospitals and this indicates that the current distribution is random.

The service area coverage of 3 km2 covers areas within 10-15 minutes driving time. The covering area of 3 km2 includes non-built-up areas and also do not cover some areas of the built-up area. However, it covers most of the Gaza Strip neighbourhoods. The buffer zone of 3 km2 covering 206.25km2 represents 57.29% of the Gaza Strip area.

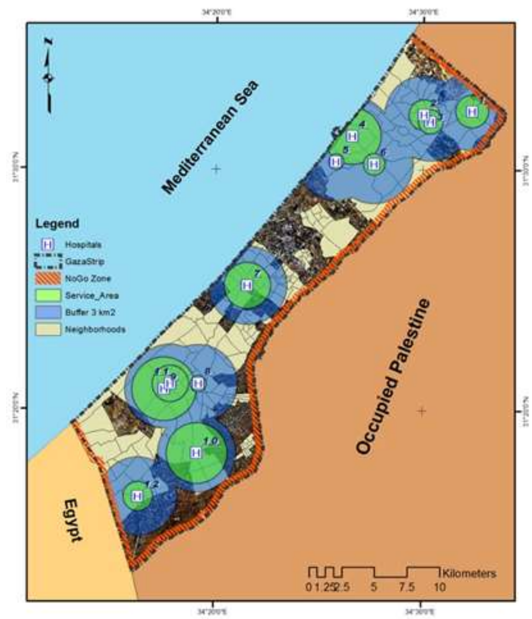

Figure 5: Tertiary hospitals service areas with buffer 3 km2

The results of the calculation technique of hospitals' service area and the 10-15 minutes coverage area show each one has its factors and implications. The new technique of hospital service area is dependent on the study area and the hospitals' factors population density, built-up area, bed capacity and population served. The result of the calculation technique represents the real service area in proportion to the hospitals ability to serve the population. The 10-15 minutes coverage area is dependent on the driving time from any point at the edge of the buffer circle to the hospital. This buffer is not considered in the hospitals abilities which represent the service area in specific time not the real service area of the hospital.

The Gaza Strip has a total of 12 tertiary hospitals. The service area of the hospitals covers about 800,000 representing 42.10% of the population. The driving time of 10-15 minutes

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service area covers about 1,700,000 representing 89.47% of the population including the hospital service areas. The accessibility map shows that there are many parts in the central and southern neighbourhoods of the Gaza Strip with low accessibility scores. The results of accessibility are logical and realistic results, where limited and inaccessible levels are considered the neighbourhoods have less access to hospitals during crises according to the reports and investigations [23]. Moreover, the limited and inaccessible levels are the most areas affected in the crises because they are considered border areas located directly in the conflict zones [24, 25]. The accessibility map undertaken according to hospital shows service area calculation technique and the 10-15 minutes driving time buffer zones.

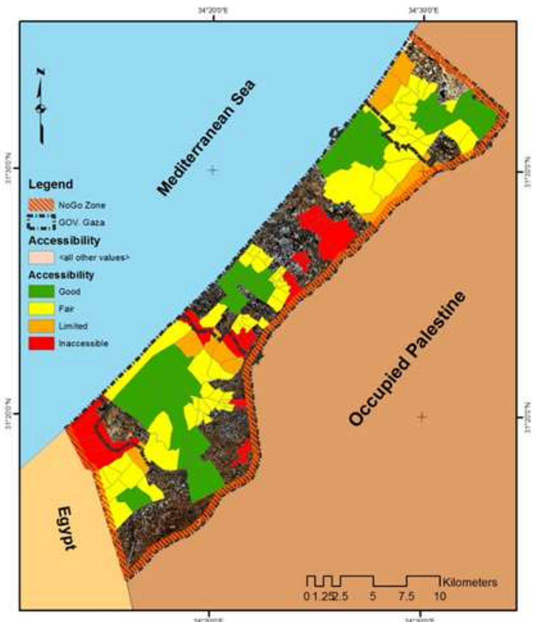

Figure 6: Neighbourhoods levels of accessibility to tertiary hospitals.

The results of the accessibility levels:

- Good level: covers 78.30 km2, which represents 34.28% of the neighbourhoods.
- Fair level: covers 90.62 km2, which represents 39.68% of the neighbourhoods.
- Limited level: covers 24.69 km2, which represents 10.81% of the neighbourhoods.
- Inaccessible level: covers 34.75 km2, which represents 15.21% of the neighbourhoods.

6. CONCLUSION:

This paper aimed to describe the methods calculating the hospital service areas. The methods used were selected from the literature review, as appropriate for the study area. Moreover, this paper described the calculation technique that developed in this study in order to determine the hospital service area.

The process of selecting data was the first step in the phase of collecting data. The data included in the study were collected from government ministries and international institutions. The data involved is spatial data, and attribute data represented the study area and the tertiary hospitals.

The analysis of buffer was used to create the hospital service zones according to the results of the calculation technique and the buffer 3 km2 of 10-15 minutes driving time. Selection by location function was used to select neighbourhoods in order to determine the levels of accessibility of the affected areas.

As a result of this study the hospital service area covering 38.1% of the Gaza Strip built-up area, which contains nearly 800,000 of the population and has overlapping areas represents 4.6% of the built-up areas. The zones of 10-15 minutes driving time covers 206.25 km2, which represents 56.5% of the Gaza Strip with nearly 1,700,000 of the population. The levels of accessibility were determined in this study by four levels; good, fair, limited, and inaccessible. The most areas affected by crises fall in the levels of limited and inaccessible are border areas which fall directly on the conflict line.

Finally, the methods that were used in this study were selected carefully to fit the study area situation. The study has used the basic spatial analysis required for the case study. Ultimately, these methods have achieved the aim and the purpose of the study.

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