

Article

Using GIS for Determining Variations in Health Access in Jeddah City, Saudi Arabia

Abdulkader Murad

Department of Urban and Regional Planning, Faculty of Environmental Design, King Abdulaziz University, Jeddah 21589, Saudi Arabia; amurd@kau.edu.sa; Tel.: +966-126-402-000

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Abstract: The main objective of this paper is to use Geographical Information Systems (GIS) for identifying spatial accessibility to health centers in Jeddah City, Saudi Arabia based on the drive-time analysis technique. A geo-database was created that includes the location of health centers, population distribution, and road networks. ArcGIS Network Analyst and overlay analyses were selected as the analysis tools for this paper. The results of the paper indicate that health centers that are located in the northern districts of Jeddah City have fewer registered patients. There are several areas of Jeddah City that have low accessibility to health centers because they fall outside the 30 min drive-time service area. These are located mainly in western, central, and northern city districts. Local health planners in Jeddah City can use the created application to allocate additional health centers in these less-served districts.

Keywords: GIS; health centers; network analysis; drive-time

1. Introduction

Geographical Information Systems (GIS) play a major role in health care, surveillance of infectious diseases, and mapping and monitoring of the spatial and temporal distributions of vectors of infection, hence allowing researchers to study the relationships between spatial and temporal trends and risks, and between environmental factors and health, at all scales [1]. Using GIS for the spatial representation of health issues helps professionals arrive at conclusions faster and reach better decisions related to deferent public health planning issues [2]. The medical research applications of GIS are numerous and include finding disease clusters and their possible causes, improving deployment for emergency services, and determining if an area is being served adequately by health services. The benefit of using GIS in the health care industry is just now beginning to be realized. Public and private sectors are reaching better decisions based on spatial data integration and GIS. Public health departments and public health policy and research organizations, hospitals, medical centers, and health insurance organizations are all examples of health sectors that benefit from applying GIS in their spatial decision-making process. For instance, public health uses GIS for tracking child immunizations, conducting health policy research, and establishing service areas and districts.

Access to health care can be measured using the straight line or road distance for evaluating existing and future optimal service location. In addition, health care accessibility studies are focused in identifying health catchments, and in examining social groups in relation to health accessibility [3]. Nichols et al., 2014, [4] have presented another recent GIS application for evaluation accessibility to mammography resources in Mississippi, USA, showing the location of the geocoded facilities, along with the counties and major transportation networks in Mississippi, and defining areas within and outside the drive-time distance with respect to all mammography facilities based on an optimum driving route. Bagheri et al., 2005 [5] discussed a GIS application for measuring spatial accessibility

to primary health care services in New Zealand and applied drive-time analysis for estimating the shortest time through road networks between any pair of population and health center locations.

The advantages of using GIS in health care studies lies in its power to analyze, store, and display very large amounts of geo-referenced spatial data. Geographic information systems (GIS) can be defined as computer-based systems for integrating and analyzing geographical data. Fletcher-Lartey and Caprarelli (2016) [1] reviewed applications of the GIS technology in public health and identified its successes and challenges. They summarized the common uses of GIS technology in the public health sector, emphasizing applications related to mapping and the understanding of parasitic diseases. They confirmed that geographical analysis has allowed researchers to interlink health, population, and environmental data, thus enabling them to evaluate and quantify relationships between health-related variables and environmental risk factors at different geographical scales. Mushonga, Banda, and Mulolwa (2017) [6] added that GIS can be successfully used for defining access and utilization of health care services.

Geographic data are known as spatial data which result from the observation and measurement of Earth phenomena referenced to their locations on the Earth's surface. Public health professionals or epidemiologists work with geographical data, such as disease registries with address information, locations of toxic waste disposal sites, or water quality reports from monitoring stations. These spatial data are considered as fundamental components of any GIS application. The success of GIS applications in health care studies depend critically on having access to accurate, timely, and compatible spatial data. For sectors working with GIS applications, spatial data can be viewed as both a cost and a resource. Creating geo-spatial datasets is very costly; it is estimated that well over half the cost of GIS projects are spent on creating and updating the geo-database. The created geo-spatial datasets are often useful for addressing a wide range of policy and planning issues. Their value extends well beyond the scope of the original projects for which they were created, and it increases as the datasets are used. GIS software systems enable public health analysts and planners to do more than simply visualizing map data. GIS supports a range of spatial analysis functions. Spatial analysis refers to "a general ability to manipulate spatial data into different forms and extract additional meaning as a result". Spatial analysis covers the techniques that use both the locations and the attributes of features. Spatial analysis covers a broad range of methods. For example, public health could identify the area within a specified distance of a public drinking water well or surface source, and overlay the footprint of a building to determine whether or not that building would be located far from the source to meet legal requirements. GIS network analysis is another branch of spatial analysis that investigates flows through a network. The network is modeled as a set of nodes and the links that connect the nodes. Network analysis functions are also used to model service areas of facilities and to locate facilities. Geographical analysis helps researchers to overlay health, population, and environmental data, thus enabling them to evaluate and quantify relationships between health-related variables and environmental risk factors at different geographical scales. Today, GIS plays a major role in health care studies, including surveillance of infectious diseases, mapping and monitoring of the spatial and temporal distributions of vectors of infection, studying the relationships between spatial and temporal trends, and risk between environmental factors and health.

In summary, GIS can be used to define access to health services using the straight line distance, network distance, and the road-based travel time [7]. For Jeddah City healthcare centers, only the GIS based straight line service area was applied by Murad, 2008 [8]. However, based on the previous research no study so far has yet covered the GIS based drive time service area for health centers in Jeddah. Therefore, this paper presents a new GIS application created for determining geographical access to health centers at Jeddah City based on a GIS drive time analysis approach.

2. Materials and Methods

2.1. Study Area

Jeddah is a city located in Saudi Arabia on the Red Sea coast, and is an important urban center in Western Saudi Arabia. It is the largest city in Makkah Province, the largest seaport on the Red Sea, an important commercial hub, and the second largest city in Saudi Arabia after the capital, Riyadh. The urban boundary of Jeddah is 1765 km², with the total area of the municipality being 5460 km². The population of the municipality of Jeddah is approximately 3.4 million, with a growth rate of 3.5% per annum. Jeddah is the second largest city in Saudi Arabia, and represents almost 14% of the total population of the kingdom estimated at 25.37 million.

2.2. The Database

In order to build this application, the present study has collected a large set of data that are then entered into the GIS to form the database of this application. This means that all of the collected data were in paper format, i.e., they were not digital. Accordingly, all of the collected data have been entered into the GIS using the digitizing method. The present study has captured three major maps (GIS coverages) then added to them their relevant attribute (non-spatial) data. These coverages are the road network, the health center locations, and the population coverages. The non-spatial data that are linked to those coverages include the health center size (capacity), the number of people living in each district of the city, and the population density of this district. All of these data are then used for the modeling process of health center accessibility.

2.3. Network Analysis

Network analyses can answer a range of questions related to linear networks, such as roads, railways, rivers, facilities, and utilities. This spatial analysis technique uses network data (usually linear features, such as roads and footpaths) to calculate distances between points or nodes in the network. This approach underpins the satellite navigation systems found in many cars. Common applications are route finding, route planning, identifying the closest facility by travel time or distance, calculation of service areas (e.g., areas within a 10 min walk of a bus stop), etc. [9]. ArcGIS Network Analyst, Produced by ESRI, Redlands, CA, USA provides network-based spatial analysis tools for solving complex routing problems. It uses a configurable transportation network data model, allowing organizations to accurately represent their unique network requirements. It can be used to plan routes for an entire fleet, calculate drive-times, locate facilities, and solve other network-related problems. It covers features such as finding the quickest, shortest, or even the most scenic route depending on the cost value chosen to solve for. Routes can accumulate any number of cost values, such as distance, time, slope, or other flow attributes. In addition, ArcGIS Network Analyst can be used for producing network service areas, which are regions that can be reached from a location within a given travel time or travel distance. Once service areas are created, then GIS users can use them to identify how much land, how many people, or how much of anything else is within the neighborhood or region. In most GIS programs, the network analysis module consists of several modeling functions, including finding the shortest path, service area model, allocation model, location-allocation model, and spatial interaction model. The present study has used the allocate and service area functions that are available within ArcGIS Network Analyst for evaluating health center accessibility. These functions can find the accessible streets within certain distances of a site and, accordingly, the streets that are not selected by this function are represented as the problem areas, i.e., they have poor accessibility [10].

3. Results

3.1. Health Center Classification and Analysis

Once the created geo-database has been built by the presented study, the first issue was to gain a clear understanding about the existing condition regarding health center locations and their distribution in Jeddah City. There are 40 health centers located in different parts of the city. The resulting location pattern indicates that existing centers are located in almost every city district and distributed to serve all parts of the city. It is clear that the northern city districts are less served by health centers. Meanwhile, the central city districts are well covered by health centers. In order to have a deeper understanding about the type and size of patients that use these health centers, GIS classification techniques were used to classify health centers using the collected data regarding the number of patients registered in each center. ArcGIS software was used to produce Figure 1 which shows that the number of patients in each center is not equal and indicates that there are some centers that have a large health demand located in the south and northeast parts of the city. Meanwhile, health centers that are located in the northern districts of Jeddah City have fewer registered patients. To analyze this output further, a kernel density model was created to define the spread and concentration of health demand in Jeddah City. Kernel density calculates the density of features in a neighborhood around those features. It can be calculated for both point and line features. The algorithm used to determine the default Kernel search radius, also known as the bandwidth, is as follows:

1. Calculate the mean center of the input points. If a Population field other than None was selected, this, and all the following calculations, will be weighted by the values in that field.
2. Calculate the distance from the (weighted) mean center for all points.
3. Calculate the (weighted) median of these distances, D_m .
4. Calculate the (weighted) Standard Distance, SD.
5. Apply the following formula to calculate the bandwidth:

$$\text{Search Radius} = 0.9 * \min \left(\text{SD}, \sqrt{1} \frac{1}{\ln(2)} * D_m \right) * n^{-0.2}$$

where:

SD is the standard distance

D_m is the median distance

n is the number of points if no population field is used, or if a population field is supplied, n is the sum of the population field value.

For the presented application, the population field is the number of registered patients in every health center. Figure 2 shows the raster service produced out of the kernel density for health centers in Jeddah City. This output shows how health demand expands from high in the south and northeast districts to low in the west and northwest parts of the city. The higher the density, the darker the color, and vice versa. This output can be used by health planners to gain a better understanding about how health demand varies in all parts of the city and have a better view about the existing condition of health demand on a city wide basis.

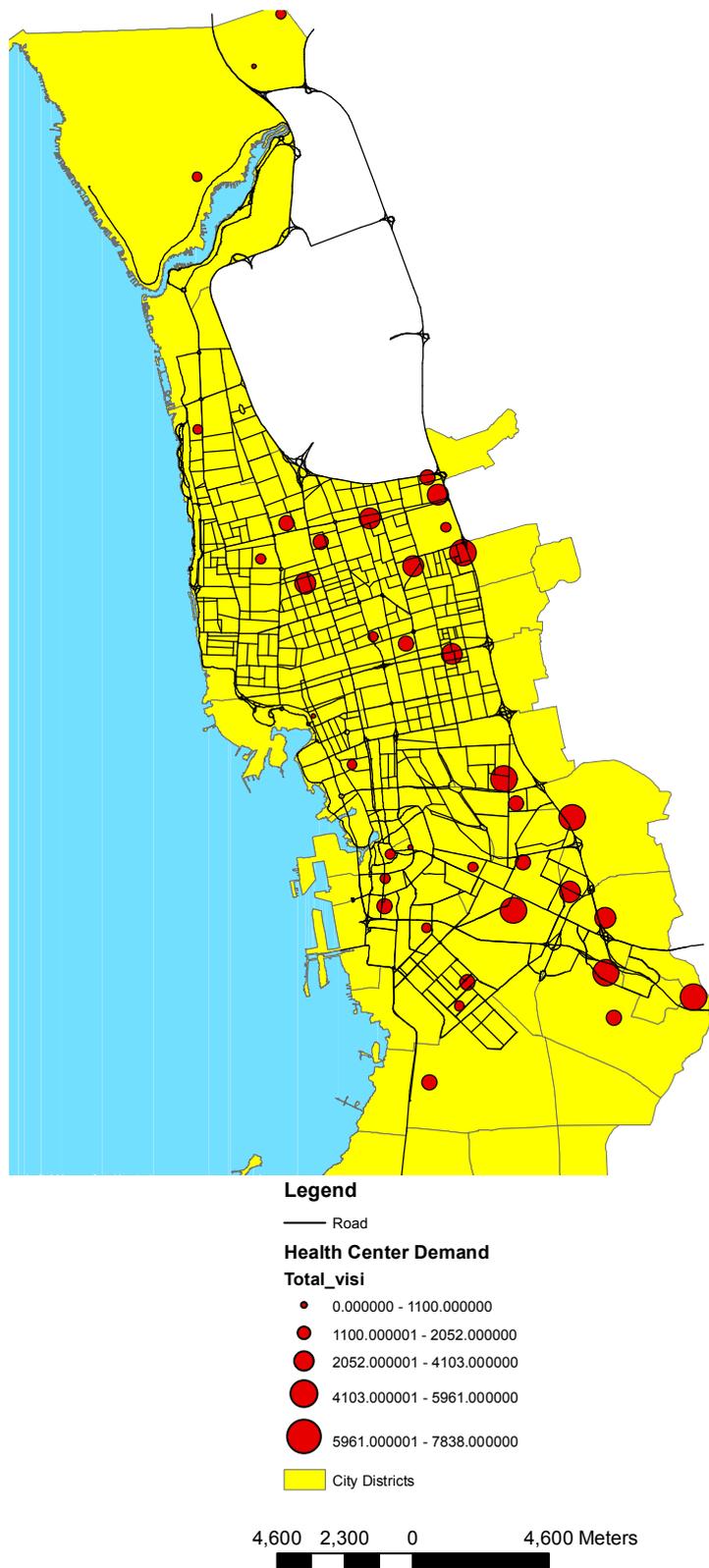
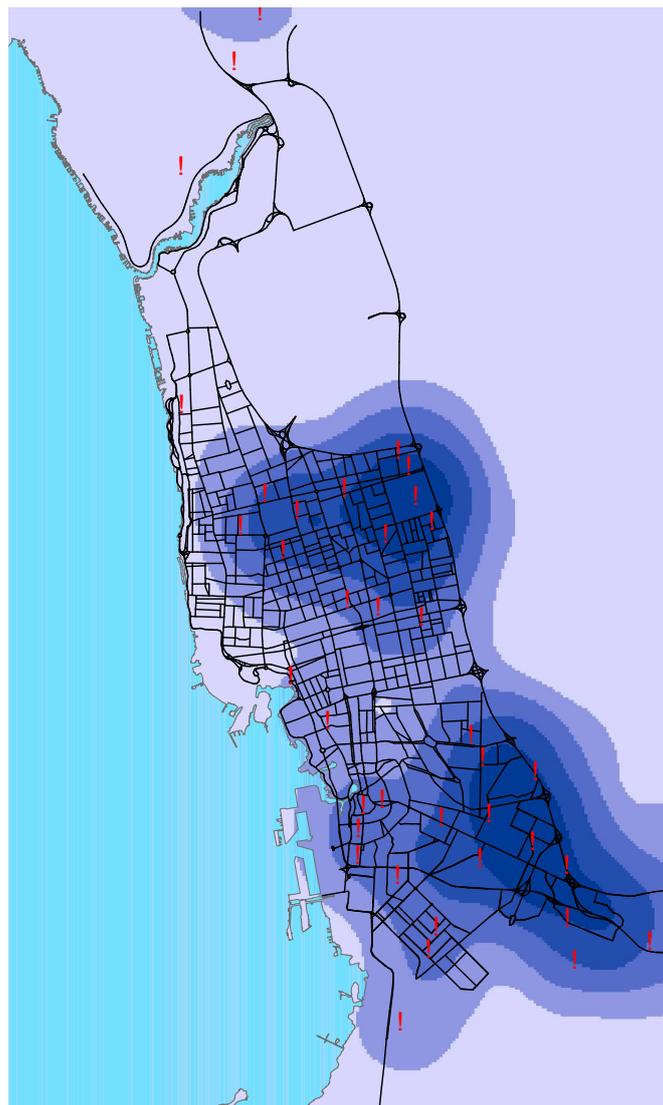


Figure 1. Health demand classification.



Legend

— Road

Health Demand Density

<VALUE>

-  0 - 0.000064766
-  0.000064766 - 0.000207251
-  0.000207251 - 0.000382118
-  0.000382118 - 0.000576416
-  0.000576416 - 0.000825764

! Health Center

4,600 2,300 0 4,600 Meters

Figure 2. Density of health demand.

3.2. Access to Health Centers

Access to health care is a multidimensional concept that describes people's ability to use health services when and where they are needed. It describes the relationship between attributes of service and the characteristics of service delivery systems. Using maps for health service locations is an important GIS application. Such maps can be used to display service location patterns, to provide information to residents about service locations and availability, and to visualize the spatial match between service needs and resources. There are four main ways of measuring accessibility to health location which include: (a) Spherical distance, which measures the distance along a great circle connecting two points (used for small-scale investigations); (b) Euclidean (straight-line) distance, which works with projected geographical coordinates; however, it fails to consider transportation routes and barriers to movement; (c) Manhattan metric, which is used to calculate distance with areas that follow a grid pattern road network; and (d) network distance, which computes the length of the shortest path along the transport network. Looking at these four accessibility techniques, network distance is selected because it is the more accurate and real index that produces accessibility zones which takes into account road network of the city and travel time among these road.

In order to further analyze the location and distribution of health centers, the drive-time analysis technique was applied for the presented application. In order calculate travel times between health locations in Jeddah City, the ArcGIS software is used by the presented application to define the route connecting health center locations and to sum the estimated travel times along each road segment in the route. Rather than using distance to evaluate accessibility to health centers in Jeddah City, travel time is used for providing a better indication of geographical barriers to health centers. This task takes into account average speeds and speed limits on different road types and physical barriers to travel. Nichols et al., 2014, [4] indicated that 30 mins drive time is acceptable for health services at Mississippi, USA. In addition, The Ontario CR Pilot Project found that 66% of health patients could access health centers within 30 min [11]. Therefore, the presented application has applied the same travel time values (30 min) to health centers in Jeddah City using ArcGIS Network analyst extension and generated network service areas for every health center location. The presented application has calculated 30 min travel times to health centers using the ArcGIS Network Analyst extension and generated network service areas for every health center location in Jeddah City. The resulting service area is a region that covers all accessible routes (i.e., streets that are within 30 min travel time to health centers). Figure 3 shows the results of drive-time service areas for health centers in Jeddah City. Figure 3 shows which parts of the city have low accessibility based on the criteria of a 30 min maximum drive-time. These parts are located mainly in the north and east of the city. Based on this output, there are several areas of Jeddah City that have low accessibility to health centers because they fall outside the 30 min drive-time service area. These are located in the western, central, and northern city districts. These results can be used by health planners in Jeddah City to decide on where to add new health centers in the city.

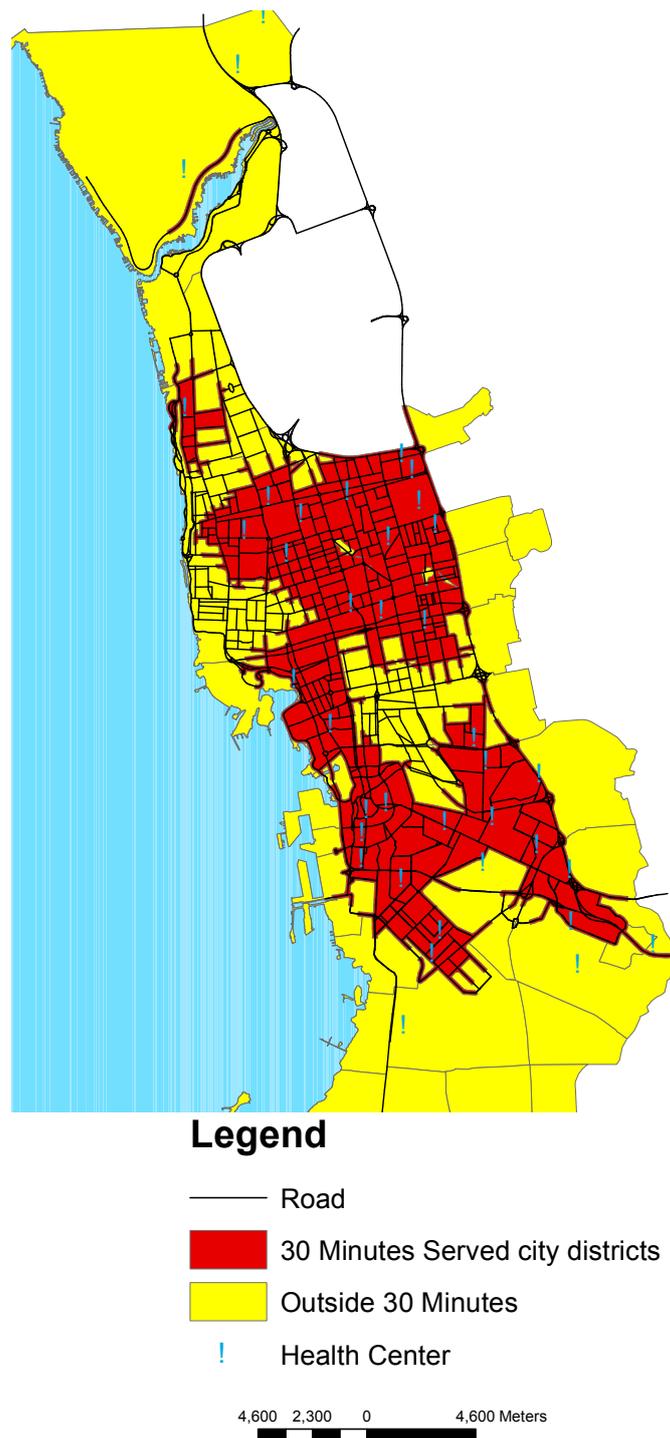


Figure 3. 30-min drive-time health center service areas.

3.3. Population within Access to Health Centers

The purpose of this part of the paper is to discuss how GIS can be used to extract and define the population that falls within the accessible and served zones in the city. Once service areas are created, then GIS users can identify and further analyze the population falling inside the resulting service area. The served zones are the result of drive-time service areas, which are illustrated in the previous section. In order to arrive at this purpose, ArcGIS overlay analysis was used to find the amount and classification of the served population, i.e., the population that has good access to health

centers in Jeddah City. Figure 4 presents the population classification for parts of the city that fall inside the 30 min travel time from health centers. After delineating areas within and outside the 30 min drive-time distance, the paper has identified the population density for the areas which are outside. This information may be useful for policy-makers to prioritize the needs for new health centers for specific areas. Figure 5 shows that there are certain city districts located in the north and center of the city that require more health care centers. Health planners and decision-makers in Jeddah City are advised to increase the size and number of health centers mainly in the districts that fall outside the 30 min drive-time access zones and having large population sizes.

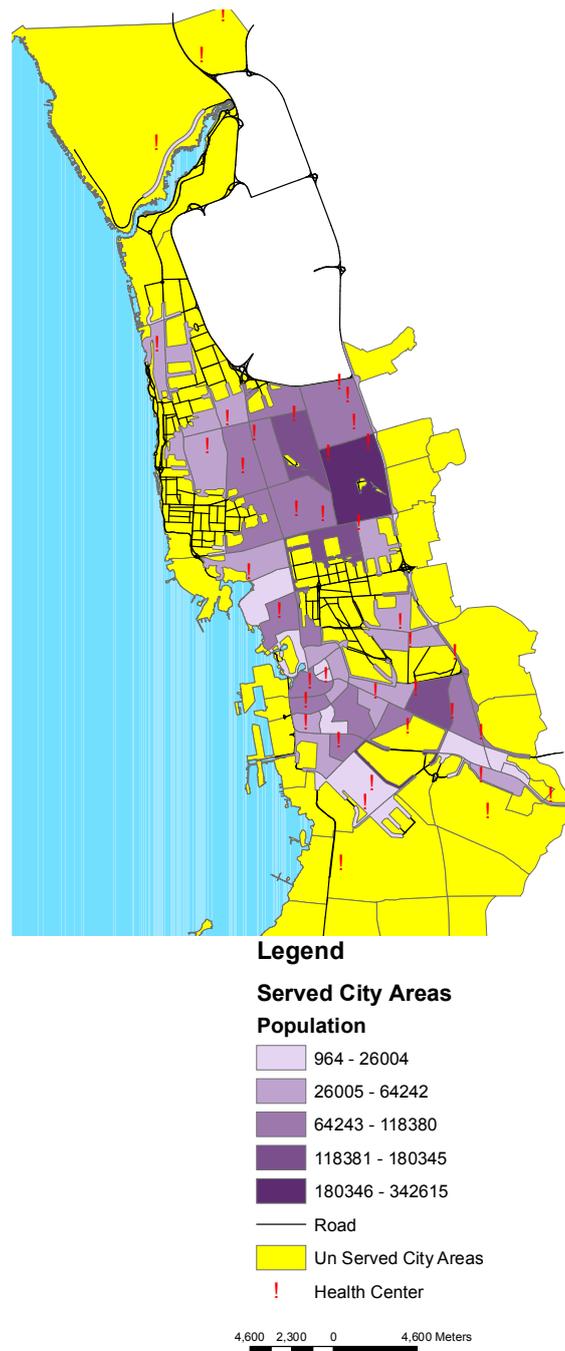
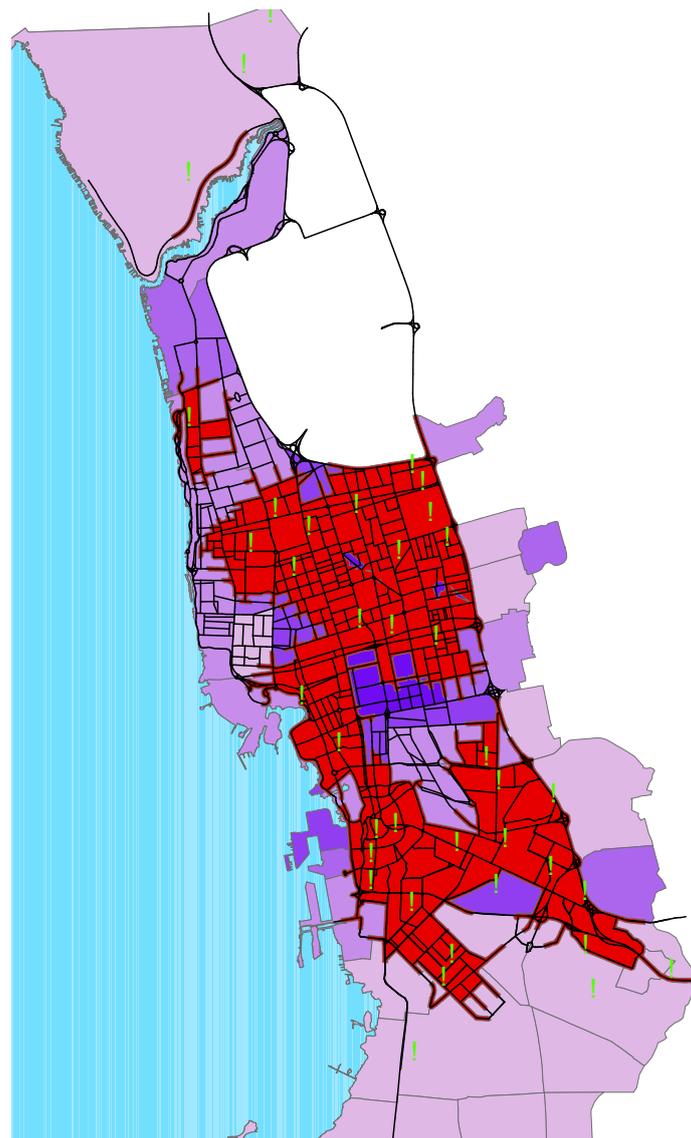


Figure 4. Population served by health centers.



Legend

— Road

■ Served city districts

Population Outside 30 Minutes

popu

■ -1 - 9458

■ 9459 - 32286

■ 32287 - 59026

■ 59027 - 95164

■ 95165 - 159484

! Health Center

4,600 2,300 0 4,600 Meters

Figure 5. Population unserved by health centers.

4. Discussion

Health care accessibility is defined in many studies. For example, Penchansky and Thomas [12], mentioned that “access is most frequently viewed as a concept that somehow relates to consumers ability or willingness to enter into the health care system” and define access as “a concept representing the degree of ‘fit’ between the clients and the system”. Accessibility can be classified based on several issues, including availability, accessibility, accommodation, affordability, and acceptability. Aday and Andersen [13] also consider wider definitions of accessibility that go beyond geographical or spatial accessibility to consider, for example, financial, informational, and behavioral influences. Gulliford et al. [14] indicated that there is a difference between “having access” to health care and “gaining access” to health care. The former is related to the availability of health services. Meanwhile, the latter refers to whether health demand has the ability to overcome financial, organizational, and socio-cultural barriers and utilize health services. Accessibility studies should cover issues including ‘affordability’, ‘physical accessibility’, and ‘acceptability’. In addition, the availability of services, and barriers to access, have also to be considered in the context of the differing perspectives, health needs and socio-economic groups in the society. Based on accessibility studies there are three major factors that need to be covered in accessibility research, which are: (a) the spatial distribution and characteristics of the health services; (b) the transportation system in connecting individuals to health services; and (c) the socio-economic characteristics of individuals utilizing health services [15].

Optimization in the geographical space is tantamount to solving a mathematical problem which eventually leads to finding a minimal length algorithm. In the case of route finding, this algorithm also reflects the minimal distance traveled. This is an interesting theoretical problem which refers to the “traveling salesman” problem (that has been proven to be very hard to solve), and to newer approaches dealing with complexity in geographical studies [16,17].

Health inequalities come from several factors that include the organization and management of space, which could differ between socio-economic groups. For instance, the under-resourcing of health care facilities, fragmentation of care across providers, and the lack of continuity of care can be barriers, which lead to increased health inequalities. Access to health care is one potential driver of health inequalities and is internationally recognized as the primary goal of meeting the essential health needs of individuals. Nevertheless, equitable access has proved difficult to achieve. This paper has used the travel-time approach to calculate accessibility to health centers in Jeddah City. After collecting the required data related to health center locations and road network travel times, ArcGIS software was used to determine how far or how close these centers are from residential districts in Jeddah City. As shown in Figure 3, there are quite large parts of Jeddah City that have low health center accessibility, mainly located in the north city districts. After defining accessibility to health centers, the presented study has overlaid population data over the resulting health accessibility zones to define the amount of people that are falling within the poorly-accessible location in Jeddah City. Figure 5 indicates that there are large population districts that are considered as un-served populations because they fall outside the 30-min travel time accessibility zones. These parts should be given priority for future health center expansion plans made by local health planners in Jeddah City.

5. Conclusions

Using GIS for defining accessibility to health centers is one of the potential GIS applications for health care studies. The presented paper has defined areas that are accessible to health centers in Jeddah City. In addition, areas, as well as populations, that have low health accessibility are defined. Network analysis and drive-time analysis were used to define service zones of health centers. It was found that there are certain parts of Jeddah City, including central and northern districts, which are considered as poor accessible zones to health centers. Therefore, local health planners in Jeddah City should allocate additional health centers in these less-served districts identified by this study according to drive-time analysis.

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