Using GIS for Planning Public General Hospitals at Jeddah City

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Abstract. Geographical Information Systems (GIS) are considered as an important and useful tool in planning and evaluating any health care system. Today, GIS has been applied at several health care studies. The applications are classified into three main groups which are spatial changes in health status, spatial epidemiology, and health care facilities accessibility and utilization. The first part of this research discusses each one of these groups and their relevant GIS applications. The second part illustrates one example of GIS application for evaluating general hospitals accessibility in Jeddah City. For this application, the standard criteria of Saudi Arabia that define the health care locations were applied on hospitals locations in order to determine their levels of accessibility. Network analysis, which is one of GIS modules, is used to produce the required models. The local health authority can use the results of this application for planning further hospital services in Jeddah City.

Keywords: Health Care Planning, GIS, Network Analysis.

1. Introduction

Health care facilities planning is one of the planning fields that uses spatial data in its resources allocation process. Health authorities and officers have been required to keep registers and carry out analysis of costs, benefits and health needs. This is quite a complex procedure as the information needed by the health authorities is extremely varied. Today, Geographical Information Systems (GIS) provide useful techniques for
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capturing, maintaining and analyzing the spatial data. This research tries to identify the ways in which GIS can be applied to help planners in planning and monitoring the locations of Health care facilities.

1.1 Research Objectives

The aim of this paper is to evaluate the spatial distribution of public hospitals at Jeddah city using GIS. To achieve this aim the following objectives were defined:

a – Identifying the development and potentialities of GIS in the health care planning field.

b – Defining the role of GIS in monitoring hospitals service areas.

c – Using GIS for modeling health care accessibility and utilization.

1.2 Research Methodology

One of the major objectives of this study is to build a GIS application for health care facilities in Jeddah city. There are several types of health care facilities available in Jeddah and run by public or private authorities. These include local health care centers, general hospitals, specialized hospitals, and military hospitals. For the purpose of this study, Specialized hospitals such as pediatrics or ophthalmology hospitals and private hospitals are excluded from this study and only public general hospitals that run by the Ministry of Health are selected as the main health care facilities in Jeddah city. To build this application the following sets of data were collected:

a) Locations of public hospitals. This data is entered into the GIS as a point coverage and each hospital has got a unique ID number.

b) Hospitals capacity. In order to evaluate the available supply of hospitals, the maximum bed size of each hospital was collected directly from hospitals authorities. The collected figures were entered into the attribute table of hospitals locations as a descriptive data for these hospitals.

c) Population data. Every hospital is located within the city to serve a number of people. In order to evaluate these hospitals, demand data was required by this study. Usually, population figures can be readily available on a regional or a city scale, but it is difficult to get such data on a local level such as district scale. However, this data was built as polygon coverage where each polygon shows the
boundary of the city district together with its total population. This
data is obtained from the local health authority of Jeddah city.
d) Road network data. In order to evaluate hospitals accessibility a
road network was made for the whole city and it is used for the
modeling stage.

All the above data were in non-digital format and therefore GIS soft-
ware is used to make these data into the suitable GIS format. Once the
needed data is captured at the GIS, the following steps were to manip-
ulate them to produce the required GIS models. These models are as
following:

a – “Hospital catchments area” model, which shows the extent of
every hospital based on planning standards.
b – “Allocation model”, which defines hospitals catchment areas
based on demand and supply size.
c – “What if”, model for defining the impacts of increasing hospitals
supply in Jeddah city.

A detailed discussion about the process of creating these models will
be discussed at section 3.3.

2. Background

2.1 Health Care Planning and GIS

One of the basic objectives of healthcare Planning in any part of the world
is to have an equivalent access to health care for all, regardless of ability to
pay. This means that every residence should have equivalent chance to go to
clinics and hospitals. To meet this objective and other ones, health author-
ities are required to make careful analysis about the real demands and
supplies of health care facilities at their areas. These analyses and studies
can be classified into three main groups, which are a) spatial changes in
health status, b) spatial epidemiology, and c) health care facilities access-
ibility and utilization. Each one of these topics has a spatial dimension,
which means that GIS can be used for their studies. The next part will elab-
orate more on each group and illustrates the possible uses of GIS on them.

2.2 Spatial Changes in Health Status

One of the facts about health status in a micro/macro scale is that it
changes across the space. Health authorities always investigate and
analyze the health status at their areas and make sure that health needs are satisfied.

Locality definition is considered as an important issue for health care facilities planning studies. The idea here is to determine the socio-economic classifications for the area surrounding certain health facilities and then relate the local profiles of such an area with the health care needs. Once the socio-economic status of any location is defined, then GIS can be used to map and tabulate the distributions of such status. A good example of using GIS for linking social profiles with health needs is found by Hirschfield et al., 1995[^1], which has produced patient profiles for a health facility catchment area. Such studies usually involve matching point-referenced, post coded health data with area socio-economic data, particularly deprivation indicators[^2].

For example, health status can be viewed through comparing the actual number of mortalities in an area with the national average, taking into account age and sex variations in the area concerned[^3]. Here GIS can be used successfully for describing spatial variations of mortality at parts of any country. Once the mortality rate of each region is entered into the GIS, the mapping and analysis tools of GIS can be applied to present out the regions that have high rates of mortality. The regions with high rates require more attention from health authorities in order to improve their existing health status. In addition to mortality, there are much other health status indicators that are used by health authorities, such as fertility rates, which help to assess and monitor the required health services.

### 2.3 Spatial Epidemiology

The second area of health care research is known as spatial epidemiology. There are several questions that are commonly asked in spatial epidemiology studies, which include: Where are the incidences located?, what are the environmental characteristics of these areas?, what are the relations between health incidences and the environment at other locations?, and what patterns are evolving?[^4]. GIS is considered as a useful tool for answering the preceding questions. For example, GIS can define the actual location of health events, then overlay analysis can be used to create new spatial relationships and to tag the various socio-economic and environmental information to the health data.
There are several studies that have applied GIS to these issues. For instance, Brown et al., 1991[^5], have used GIS for the mapping of spatial variations in health care provision in Merseyside, UK, Wrigley, 1991[^6], have also used GIS in mapping incidence diseases in relation to population types. Another example of GIS applications in epidemiology is called the Health and Environment Geographical Information System (HEGIS), which is being established in Europe by the World Health Organization (WHO)[^4]. It involves the creation of European wide environment data set, and the aim is to research relationships between health and the environment, to aid policies and management[^4]. Most of spatial epidemiology studies must be based upon accurate knowledge of the population. Therefore, access to details of population composition and socio-economic characteristics are very necessary for these studies.

Spatial epidemiology studies are concerned with finding good description of spatial incidence of diseases as well as the modeling of such incidence. One way of describing the spatial distribution of a certain disease is by visualizing the GIS choropleth maps that show the spatial distributions of such a disease. In such maps, disease rates are plotted over the base map to define the areas that are highly affected from the related disease. Further analysis and modeling of the spatial incidence of diseases can be carried out using for example Kernel or density estimation technique that is used in predicting the spatial variation in diseases risk[^2].

### 2.4 Health Care Facilities Accessibility and Utilization

This area of health care research is concerned with all issues related to the location of the health care facilities. These issues include the optimal location of hospitals and clinics, the relationship between existing locations and health care needs, and the assessment of facilities accessibility. The plan of any health care system should have answers to the following important questions: What are the population needs for health care and how should resources be allocated to the served population?[^2]. GIS can assist in finding comprehensive answers for the proceeding question. For example, Jonhs and Bentham 1995[^7], have used GIS to test the relationship between health outcomes and accessibility. Forbers and Todd, 1995[^8], have also used GIS to evaluate the potential locations for a new radiotherapy unit for cancer treatment in northwest England.
Finding the best location for a health care facility is considered as one of the health authority tasks in order to optimize resources. The best location for a facility can be identified using for example location-allocation models that are now been integrated to the modern GIS softwares such as ArcGIS/Arcinfo Version 8.

Evaluating the accessibility of existing health facilities is also another task carried by health authorities. Here the health planners determine the areas, which have poor accessibility for certain health facility and then prepare proposals for improving such low level of health care accessibility. One way of improving such accessibility is by increasing the capacity of the related health facility, but this can only be achieved after intensive analysis of the area that contains such facility.

### 2.5 Classification of Health Care GIS Users

It is clear from sections 2.1 to 2.4 that GIS is applied at different health care studies. These studies show the importance and the benefits of using this technology at health care field. The aim of this part is to explain possible users groups of GIS as relevant to health care field. These users groups are as follow:

#### a – Public Health Organization

Public health organizations have used GIS to study how disease spreads from place to place and how toxic substances affect people’s health. They also use GIS to show how the amount and type of health care services depend greatly on where people live on both the capacity of the health care system in their area and on the methods practiced by local doctors. Differences in how often hospitals are used, and variations in how care of the terminally ill is delivered, are also area of GIS uses in public health organization[9].

#### b – Planning Authorities

Planning authorities have different tasks to cover including land use planning, and facilities planning. One of the important tasks that urban planners perform is related to health care planning that is concerned with health facilities locations. In this context, urban planners use GIS to evaluate the service area of health facilities and define whether patients had
to drive too far to get to health facilities. In addition, urban planners use GIS to make sitting decisions and figure out how best to allocate health services.

**c – Private Health Organizations**

Business directors at private health organizations have realized the benefits of using GIS in their work. For example, they use GIS to tell sales teams which physicians are most likely to try a new drug or service, or produce driving maps to their offices. They also use GIS to determine whether their client is spending too much or too little for their health care, and whether they are focusing their efforts in the right areas. Private health organizations have used demographic data with GIS to decide how much money they will need to spend to run a health center successfully and where to build new private facilities. Pharmaceutical companies are also an example of private health organizations that use GIS in targeting physicians that are most likely to use their product\(^9\).

### 2.6 Health Care Planning Data

In order to evaluate the existing location of a health service or to prepare a new site location for a health care system, planners have to collect specific data related to the relevant health care issue. Normally, the required data could be found in much larger and broader sets of data in the health care field. There are several ways of classifying this type of data, one of which is based on the GIS data format types, *i.e.*, dividing the health data into three main groups which are point, area and line data.

In GIS, point data can be a model for the locations of residences, hospitals or ambulance stations. Each one of the point data can have different attribute information. For examples the locations of individuals might include attributes for the presence or absence of a disease, age, gender, occupation, and so on.

Population zones or census data are examples of area data format which can be captured and stored in GIS and can be used for different health care studies. For instance census data can be used to analyze the socioeconomic status of certain patient locations.

Finally, line data such as road network are used in GIS to study the travel journey to and from health facilities locations. They are also used
to analyze the routes used by emergency vehicles and to identify how fast do ambulance vehicles reach to patient locations.

3. GIS Application in Hospitals Planning

One area of GIS research in health care planning field is concerned with measuring accessibility to health facilities (Section 2.4). This part will concentrate more on this issue and explain how GIS is used to analyze accessibility to hospitals in Jeddah City, Saudi Arabia. There are three important factors that affect the level of accessibility in any facility location. These are the capacity of the facility, the amount of demand for such facility, and the transportation network that communicate such demand to the relevant capacity. All of these three factors are included in the GIS application of Jeddah hospitals.

3.1 The Data Base

In order to build this application, the present study has collected 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 a 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 Coverage) then added to them their relevant attribute (non-spatial) data. These coverages are the road network, the hospital locations and the population coverage (Fig. 1). The non-spatial data that are linked to that coverage include the hospitals size (capacity), 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 hospital accessibility.

3.2 The Modeling Technique

Once the required data have been captured into the GIS, the following step is to decide about the relevant analysis methods that may be used for determining hospital accessibility. There are three main GIS spatial analysis functions that could be used for analyzing the accessibility of any selected facility location. The first one is known as buffer analysis which draw buffer around existing facilities proportional to their sizes and capacities\(^{[10]}\). The second method is related to the GIS network analysis
Fig. 1. The created data (road, hospitals, and population).
module where population in a network is allocated to the nearest facility locations. Site suitability analysis is the third GIS function that identifies sites according to their suitability for the location of facility under a set of certain conditions[8]. Looking at these three GIS functions, the present study has selected the second method that is the network analysis module as the analysis tool for determining hospital accessibility in Jeddah. The main reason for this selection is that hospital demand can be included in the network analysis functions while it is not possible to do so by using buffer or suitability analysis functions. In most GIS softwares, the network analysis module consists of several modeling functions including finding shortest path, service area model, allocate model, location-allocation model and spatial interaction model. The present study has used the Allocate function that is one of ArcGIS/Arcinfo (a GIS software produce by ESRI, USA) network analysis functions for evaluating hospital accessibility. This function can find the accessible streets within certain distances of a site and accordingly the streets that are not selected by this function are representing the problem areas i.e., they have poor accessibility[11].

3.3 Results and Discussion

The present GIS application is made as a product of three GIS models. These models are called catchments area model, Hospital allocation model, and what if model. Each one of these models is made to help planners in evaluating and planning health facilities of Jeddah city.

3.3.1 Hospitals Catchments Area

Catchments area analysis is one of the major planning techniques that are used to define the performance of any public facilities at a defined area. It is applied at locations of facilities and determines the actual served population by such facilities. Such analysis can play a major role when the authorities of public facilities ask for increasing their existing supply of facilities or when deciding to provide a new additional facility. There are two main types of catchments area, one that is based on real data facilities (location of facilities customers), and the other is based on planning standards. The former plot out location of facilities customers and based on the spatial distribution of such customers, catchments one is defined. Meanwhile, the latter approach applies planning standards such
as the maximum walking distance, on every facility. The result of this approach shows areas that fall inside the maximum walking distance and therefore, these areas are within the standards catchments area. The size of facilities supply plays another important role in the extent of catchments area. This means that the larger the facility size the more people that can use such facilities. GIS can be used to define the catchments area of public facilities either by using planning standards or by using real demand data. The present study has selected the catchments area technique that is based on planning standards and uses GIS to define hospitals catchments area based on the predefined standards. According to the standards of Saudi Arabia[12], every hospital should have a service area of 4 to 8 km depending on its bed size. Small hospitals with a 50-bed size serve a 4 km area. Medium (100 bed) and large (400+ bed) hospitals serve 6 and 8 km area respectively. Table 1 shows hospitals size with their standard catchments areas. These standards are applied on every public hospital of Jeddah city (Fig. 2) and the result shows two main conclusions which are:

1. About 75% of Jeddah city is falling inside hospitals catchments areas and therefore, people falling inside these areas should be served by these hospitals.

2. About 25% of the city is located outside hospitals catchments area and these areas show the non-served parts of the city. These results can be further analyzed when hospitals demand is included in the analysis. Such a step looks at the available demand for every hospital, then defines a more detailed catchments area where the extent of hospital catchments area is subject to its supply. The next section will discuss this step in more detail.

<table>
<thead>
<tr>
<th>Hospital name</th>
<th>Supply (no. of beds)</th>
<th>Catchments area (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>King Fahad</td>
<td>932</td>
<td>8</td>
</tr>
<tr>
<td>King Abdulaziz</td>
<td>417</td>
<td>8</td>
</tr>
<tr>
<td>Al Thagher</td>
<td>90</td>
<td>6</td>
</tr>
<tr>
<td>King Saud</td>
<td>50</td>
<td>4</td>
</tr>
</tbody>
</table>
Fig. 2. Hospitals’ catchments area based on planning standards.
3.3.2 Hospital Allocation Model

The aim of this part of the study is to produce a model that takes into account hospitals supply and the available demand for these hospitals. This has been achieved using GIS allocation function that assigns network links to centers based on available supply at centers and the demand associated with links. A link is assigned to center along least impedance paths. When a link is assigned to the center, the available supply at the center is diminished by the link demand\cite{12}. The allocation function ceases when the center supply is exhausted and a route along the assigned arcs is created in the network coverage. In order to use the allocation function road network coverage is prepared with a node attribute table (NAT) and an arc attribute table (AAT) for nodes and arcs. The NAT is important for making the center file which contains the node ID where the service center is located, maximum impedance, center supply, maximum impedance allocated and total demand allocated. In the case of Jeddah hospitals the center file is made as an info file where every hospital has node ID and its supply size. Each hospital has a defined size in bed numbers. Using the local standard that indicates that each 1000 person should have 2.5 hospital beds, the available hospital supply is transformed into number of persons rather than beds. To include demand data into this model, population coverage is created showing the number of people living inside each district. This coverage is a polygon coverage and therefore, its attribute needs to be assigned to the network coverage so that allocation can use this demand data. This step is achieved using GIS overlay analysis and the result of such analysis creates the required network coverage that has the number of people at every network arc.

Once these modeling parameters have been defined, the allocation function is used and the result of this model is shown in Fig. 3 and Table 2.

One of the main conclusions resulted from this model is that where demand and supply size is incorporated into the network analysis, the extent of the hospitals catchments area is reduced and changed according to each hospital size. This model provides a more detailed modeling technique for hospitals catchments area. It can be used to support health authorities in defining how far their available hospital supply can meet required health care service. In comparing the results of this model with the ones at section 3.3.1 it can be said that the actual served parts of the city is falling from 75% to 40% and the un-served parts rise to 60% of
Fig. 3. Hospitals’ catchments area based on hospitals demand & supply.
Jeddah city. This indicates that there is a need to expand hospital supply for the city either by expanding the available hospital size or by introducing new hospitals at the un-served areas.

Table 2. Results of demand allocation model.

<table>
<thead>
<tr>
<th>Hospital name</th>
<th>Supply (person)</th>
<th>Maximum demand allocated (person)</th>
<th>Maximum catchments area (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>King Fahad</td>
<td>372,800</td>
<td>372,800</td>
<td>5.82</td>
</tr>
<tr>
<td>King Abdulaziz</td>
<td>166,800</td>
<td>166,800</td>
<td>3.34</td>
</tr>
<tr>
<td>Al Thagher</td>
<td>36,000</td>
<td>36,000</td>
<td>1.84</td>
</tr>
<tr>
<td>King Saud</td>
<td>20,000</td>
<td>20,000</td>
<td>0.98</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>595,600</strong></td>
<td><strong>595,600</strong></td>
<td><strong>11.98</strong></td>
</tr>
</tbody>
</table>

3.3.3 “What if” Model

One of the most popular application areas for spatial modeling has been in assessing the impacts of new plans or proposals on the existing situation. This “what if” situation has proved valuable in a number of areas in both public and private sectors\[^3\]. The development and location of a new facility involves large capital investment. It is therefore appropriate to attempt to estimate not only the likely revenue that will occur on that investment but also the impact that the new facility will have on existing outlet.

The purpose of this model is to test the impacts of increasing Al Thagher hospital size from 90 beds to 400 beds. This what if model shows the changes in hospitals catchments area that will result from adding more new beds into such hospital. Figure 4 and Table 3 show the results of this model and define the new hospitals service areas. It shows that the southeast part of the city will benefit from such change and the city hospital catchments area is increased to cover this part of the city. This sort of modeling is very useful to health authorities because it can predict the spatial impacts of any health care planning policy and therefore, the required action towards such policy can be defined before implementing the policy. If the impacts are of positive results such policy can proceed, otherwise a modified policy is required. This sort of modeling can also be used to define the impacts of building, a new hospital...
Fig. 4. Hospitals’ catchments area following supply increase.
location in Jeddah city. Health authorities are encouraged to use this kind of model to make sure that their resources are spent in the right location.

<table>
<thead>
<tr>
<th>Hospital name</th>
<th>Supply (person)</th>
<th>Maximum demand allocated (person)</th>
<th>Maximum catchments area (km)</th>
</tr>
</thead>
<tbody>
<tr>
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</tr>
<tr>
<td>King Abdulaziz</td>
<td>166,800</td>
<td>166,800</td>
<td>3.34</td>
</tr>
<tr>
<td>Al Thager</td>
<td>160,000</td>
<td>160,000</td>
<td>3.94</td>
</tr>
<tr>
<td>King Saud</td>
<td>20,000</td>
<td>20,000</td>
<td>0.98</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>719,600</strong></td>
<td><strong>719,600</strong></td>
<td><strong>14.08</strong></td>
</tr>
</tbody>
</table>

The summary of the results of GIS models is shown in Fig. 5 that describes how hospitals catchment area varies according to the used criteria. It shows that area 1 is the resulted catchment area based on hospital supply, area 2 is the catchment area according to hospital supply and demand, and area 3 is the catchment area following supply increase. These results can be used by local hospital authority to understand and evaluate hospitals supply and hospitals demand.

4. General Conclusions and Recommendations

Identifying health care needs is one of the important tasks that health authorities frequently do. Health planners keep analyzing the changes that occur on health care demand. These changes usually require quick response from health authorities, in order to keep matching health care facilities supply with the relevant demand. This is a big task that needs a huge set of data including health facilities location, catchments areas, population statistics, etc. Information technology in general and GIS in particular can help health authorities to fulfill their required jobs in an efficient manner. For example, GIS can be used to support health planners in reaching a decision regarding increasing hospitals capacities. The present study has illustrated how GIS may be used for Jeddah health care facilities planning. The application created in this study has identified the parts of the city, which require more attention regarding their health care supply. Using this application, health planners can allocate areas of the city which having poor accessibility to hospitals and accordingly, a decision regarding improving hospital accessibility can be easily and quickly reached.
Fig. 5. Changes in hospitals catchments area.
Based on the analysis results, the present research recommends that health supply in Jeddah should be increased to cover the existing non-served areas of the city. This can be achieved by introducing two new hospitals located at the north part of Jeddah with a total capacity of at least 2000 beds. The GIS application which is made by the present study is recommended to be applied at Jeddah health authority because it can be used to support health planners in evaluating and monitoring the changes in health supply and demand and it can help health planners in defining the spatial impacts of any proposed health policy.

References


استخدام نظم المعلومات المكانية في تخطيط المستشفيات الحكومية
العامة بمدينة جدة

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(قدم للنشر في 20/3/1434 هـ، قبل للنشر في 2/1424 هـ)

المستخلص. تعد نظم المعلومات المكانية من أحد الوسائل الفعَّالة في تخطيط وتقدير نظام الرعاية الصحية، حيث استخدمت هذه التقنية في عدة دراسات تتعلق بالتخطيط للخدمات الصحية. تنقسم هذه الدراسات إلى ثلاثة أقسام، تشمل الاختلاف المكاني في الوضع الصحي، وانتشار مواقع مختلف الأمراض، واستخدام وسهولة الوصول للخدمات الصحية.

يناقش الجزء الأول من هذه الدراسة كلاً من هذه الأقسام الثلاثة على حد سواء. أما الجزء الثاني فيحتوي على تطبيق نظم المعلومات المكانية في تقييم مواقع المستشفيات بمدينة جدة، وذلك من خلال الوقوف على مدى ملاءمة هذه المستشفيات للمعايير التخطيطية في التوزيع. لقد تم استخدام التحليل الشبكي، وهو أحد طرق التحليل المتقدمة ببرامج نظم المعلومات المكانية، وذلك للحصول على النماذج المكانية المتعلقة بهذه الدراسة، والتي يستفاد منها في تخطيط مواقع المستشفيات في مدينة جدة.

كلمات مفتاحية: تخطيط الخدمات الصحية، نظم المعلومات المكانية، التحليل الشبكي.