

CASE STUDY

A Case Study on Accessibility of Medical and Healthcare Facilities in Mashhad using GIS

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ARTICLE INFO

Article History:

Received: July 14th, 2017

Accepted: September 26th, 2017

Available Online: October 1st, 2017

Keywords:

Spatial Analysis

Healthcare

Network Analysis

GIS

Mashhad

ABSTRACT

Nowadays, living in cities is more dependent on services than any other period in human life due to the complicated physical-spatial structure of relationships and socio-economic activities, expansion and deepening of social and economic divisions of labor and growing cultural, recreational and social necessities of city-dwellers. Services related to individual health and medical needs of citizens make up a part of these services and are provided to them by hospitals or other medical clinics situated in cities. This present article is an applied descriptive-analytic examination of the spatial analysis of hospitals in the city of Mashhad that uses arc GIS software and network analyst model. The findings of the current paper indicate that hospitals are mostly concentrated in the eighth zone of Mashhad City while the 5th, the 11th and the 12th zones do not have any hospitals at all. Moreover, the eight zone and Samen Zone have the highest access to hospitals in Mashhad. Meanwhile, the best hospital in terms of providing necessary services and accessibility to the center of city zones is located in Samen Zone.

How to cite this article

Bazargan M. A Case Study on Accessibility of Medical and Healthcare Facilities in Mashhad using GIS. Stud. Archit. Urban. Environ. Sci. J., 2018; 1(1):39-48. DOI: 10.22034/saues.2018.01.05

INTRODUCTION

Nowadays, cities are at the front line of national development which means the world is turning into city spots [1]. In the next millennium, we will witness two simultaneous and inevitable processes: the urbanization of world's population on one hand and the globalization of cities on the other hand. Estimates suggest more than 61 percent of the world's population will be living in cities by the year 2030 [2]. The rapid growth of urban population, particularly in developing countries like Iran with 70 percent of its population already living in urban areas, has caused urban planners and managers to face fundamental challenges in urban decision making. The growing population of urban areas in present time have increased the demand for new medical facilities.

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However, one should bear in mind that building new service centers requires great costs and the problem of determining the optimal locations for these centers, in a way that all citizens will be able to benefit from them, is important. Geographical location is the main factor in having access to medical services and has been examined by researchers of various viewpoints using numerous techniques [3]. Equal access to health services, including medical services, are among the basic human rights. In this context, uneven spatial distribution of health sector resources, will impede people's access to health and medical services [4]. In developing countries, due to absence of information, skill and expertise in the field of health and medical planning, resources are usually allocated in an imbalanced way. Therefore, the location of public

centers can be considered as one of the indices for having access to healthcare [5]. As urban environments become complex day by day, the difficulty of planning in this field increases accordingly. The application of geographic information system or GIS could be a basic solution to this problem [6]. In the past years, it has become clear that different techniques for using GIS along with effective use of new digitized data, can give a new life to urban development modeling theories in planning strategies [7]. For this reason, during the previous years, locational information system has been used as a powerful tool for management, evaluation and display of data [8]. Using this system, geographers and planners will be able to play a big part in improvement of city environment by gathering and analyzing information to make environment and urban society healthy along with rational predictions about the issues of the city [9]. The city of Mashhad, as the second largest city in the country, has about 3 million residents; a fact that further emphasizes the need of citizens to medical centers, particularly hospitals. On the other hand, the location of Mashhad among other cities and counties of the province and also eastern and north-eastern provinces of Iran in addition to having specialized medical equipment's has attracted people from other provinces to hospitals in this city. Therefore, given what was said, current article tries to conduct a spatial analysis of hospitals in Mashhad using GIS - based network analysis.

Background Review

Although there is a long history in providing health and medical services in cities, but the location of these centers is a rather recent effort which dates back to 70s decade. In 1979, the British department for health and social security paid attention to the strategic development of health and medical service centers. Thereafter, studies in this field began and were continued in Austria during the years of 1980-1982 [10]. Today, extensive research is done on health and medical services and particularly hospitals in different cities of the world.

Methodology

The method used in this research is descriptive-analytic of the applied-developmental type. First of all, the database for hospitals and passage network of Mashhad was created Using arc GIS. Then, by using network analyst model, hospitals were analyzed based

on the passages network of the city. After the steps to create network analyst, preparedness of Information and network locations for the street network of Mashhad were fully taken, route analysis, finding a service area, finding the closest facility (hospital), OD cost matrix, concentration of hospitals in different zones of Mashhad and network-based spatial analysis were conducted.

Theoretical Framework of Research Network

Network is conceptually simple and consists of two edges and junctions. Streets, roads, power lines, water, oil and gas pipe lines are all examples of edges or connections. Edges meet each other at intersections (junctions) and the flow of resources run through edges [11]. Analysis and network operation: in network-based analysis, the city passages which play a fundamental and vital role in city movements are shown as line features. Therefore, the results obtained from network-based analysis have a much higher degree of certainty than spatial analysis which does not go any further than determining the largest route between two spots.

Network analysis in GIS is carried on for the following three purposes:

- a) Finding the optimal route
- b) Finding the closest facility
- c) Finding a service area [12]

Then, based on the study index, we can estimate the access area of particular services in network analyst model. We can then identify those parts of the city space that are not covered by services or functions followed in the research and therefore we will be able to show the optimal distribution of services or functions based on the accessibility factor [13].

A Geometric network consists of a set of features (like edge, junction and so on) that have a connection with other features around them and follow the connectivity rules to display and model. Water, power and gas distribution networks, firefighting systems, telephone services, river flow networks are all examples of modeling and applications of network analysis in geometric networks. Networks in a geodatabase are stored in a dataset and therefore include feature classes.

Features that are involved in the formation of a network need to have the following characteristics:

- i. They are not superficial;
- ii. They do not have dimension;
- iii. They do not have annotation;
- iv. They are not involved in the formation of another network (it means that those features that are used in a network cannot be used in the formation of another network) [14]

Types of network sources:

Three types of data sources can be defined in the formation of a dataset network which are as following:

- a) Edge feature sources: like linear feature classes;
- b) Junction feature sources: including point feature classes;
- c) Turn feature sources: such as turn classes.

Network features are divided into simple and complex categories.

- Simple edge features which are individual and point features that are on edges.

These features just have two junctions at their beginning and end and if a simple junction comes between them, then they turn into two edge features.

- Complex edge features which consist of a set of simple point features.

Complex edge features have at least two junctions at their beginning and end. These features can also be connected with other junctions in their course and yet, remain an individual feature [14].

Distance measurements

Euclidean distance

In a standard coordinate system, the position of each spot is displayed as an ordered pair denoted by (x, y) where x denotes the distance from the origin along the horizontal axis and y denoted the distance

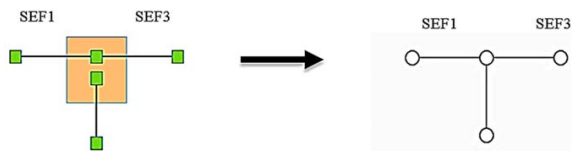


Fig. 1. simple edge features



Fig. 2: complex edge Features

from the origin along the vertical axis. There are different ways of measuring distances in GIS. The Euclidean distance (direct distance) is one of a variety of distances between two points on a sheet with Cartesian coordinates which is defined as follows:

$$D_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}$$

Manhattan distance

An alternative measurement for distance is the Manhattan distance, also known as the city block distance, which measures the distance between two points on a grid by counting the number of blocks needed to go along the x-direction and the y-direction from the origin to the point. The formula is as follows:

$$D_{ij} = |x_i - x_j| + |y_i - y_j|$$



Fig. 3: measurement of distance between two points based on Euclidean distance



Fig. 4: Measurement of Distance between two points based on Manhattan distance

Network distance

The measurements are totally real in this method and the distance between two spots is determined by measuring the length between them through real routes in the network. In fact, network distance is the most accurate measurement of length between different features in GIS which can be calculated after obtaining the maps of the network of passages in a city. The following figure shows the aforementioned three methods of measuring distance between different spots [15].

Graph-theoretic measures

From the geographic point of view, graph-theoretic measures are a powerful tool not only to illustrate structural problems of transport networks, but also to describe and analyze the network structure and accessibility, and to evaluate and compare the evolution of networks through time. The use of graph theoretic measures allows us to understand how objects covering the surface interact with each other and what implications they have on spatial organization. We can split graph-theoretic measures into two groups: the



Fig. 5: Measurement of Distance between two points based on Network distance

connectivity measures and the accessibility measures. To compare the structural complexity of networks, we need measurements that allow us to describe the degree of network connectivity. This is what connectivity measures do. However, if we need to identify what has changed individually on a network and what causes these structural changes then accessibility measures (table 1) are what we need. Graph-theoretic measures of nodal accessibility can be considered as an upgrade of network analysis, as they can analyze a network as a whole as well as considering individual properties of the network, e.g. node accessibility, which are fundamental for understanding spatial networks and their territorial impacts [16].

To measure the accessibility impact of nodes in a network we need to treat its graph as a matrix. There are numerous graph-theoretic accessibility measures derived from a set of matrices such as: 1. C matrix which gives you the directed edges between the nodes, 2. T matrix which gives you the directed and undirected edges between the nodes, 3. D matrix or Shamble matrix which gives you the topological shortest-distance between any pair of the nodes and 4. L matrix which gives you the real shortest-distance between any pair of nodes. In this paper, only the resulting matrices obtained from the matrices D, L (extremely important when studying spatial networks) and Pi (the gravity model– interaction potential matrix) will be considered. Later, spatial analysis tools, namely mean center, standard deviational ellipse and cross-tabulation for land-use changes will be used in combination [17].

Unlike the matrices C, D and T, the matrix L is weighted by the physical distance (km²) between any pair of nodes of the road network. We can compute the matrices L^2, L^3, \dots, L^n based on the following algorithm:

$$L_{ij}^2 = \min_k (L_{ik}^1 + L_{kj}^1) \quad , \quad k \in \{1, \dots, n\}$$

Table 1: Graph-theoretic measures of nodes accessibility [17]

| Index | Formula | What does it measure? | Remarks |
|--|---------------------------------------|--|--|
| Shimble Index of Accessibility | $ac_i = \sum_{j=1}^n dij$ | indicates the sum of distances to get from node i to each node j, taking the shortest path. | The lower the value is, the higher the node accessibility will be. |
| Average Shimbel Index of Accessibility | $AC_i = \frac{\sum_{j=1}^n dij}{n-1}$ | indicates the average of the sum of the Shimble index of a node to all other networks nodes. | The lower the value is, the higher the node accessibility will be. |

This sets the accessibility measures consider in our model (geo_graph) evaluating and measuring the impact of road networks on the territory and in particular, for the last two time periods in analysis, on land-use changes. In addition, we have also integrated into the geo_graph model some algorithms from complex networks, as the between ness centrality index, which measures how often a node appears on shortest path between nodes in the network [17].

Computing Network Distance and Time

A network consists of a set of nodes (or vertices) and a set of arcs (or edges or links) that connect the nodes. If the arcs are directed (e.g., one-way streets), the network is a directed network. A network without direction may be considered a special case of a directed network with each arc having two permissible directions. Finding the shortest path from a specified origin to a specified destination is the shortest route problem, which records the shortest distance or the least time (cost) if a traffic load (e.g., travel speed) is provided on each arc [18].

The popular label setting algorithm was first described by Dijkstra (1959). The method assigns “labels” to nodes, and each label is actually the shortest distance from an initial point. To simplify the notation, the initial point is taken to be node 1. The

method has four steps:

1- Assign the permanent label $y_1 = 0$ to the initial point (node 1), and a temporary label $y_j = M$ to every other node, where M is taken to be an arbitrarily very large number. Set $i = 1$.

2- From node i , recalculate the temporary labels $y_j = \min(y_j, y_i + d_{ij})$, where node j has been temporarily labeled and $d_{ij} < M$ (d_{ij} is the distance from i to j).

3- Find the minimum of the temporary labels, say y_i . Node i is now permanently labeled with value y_i .

4- Stop if all the nodes have been permanently labeled. Otherwise, go to step 2.

Valued Graph Approach to the Shortest Route Problem

The valued graph, or L-matrix, provides another way to solve the shortest route problem [19]. For example, a network is shown in Figure A2.1. The network resembles the highway network in North Ohio, with node 1 for Toledo, 2 for Cleveland, 3 for Cambridge, 4 for Columbus, and 5 for Dayton. We use a matrix L^1 to represent the network, where each cell is the distance on a direct link (one-step link). If there is no direct link between two nodes, the entry is M (a very large number). We enter 0 for all diagonal cells $L^1(i, i)$ because the distance is 0 to connect a node to itself.

The next matrix L^2 represents two-step

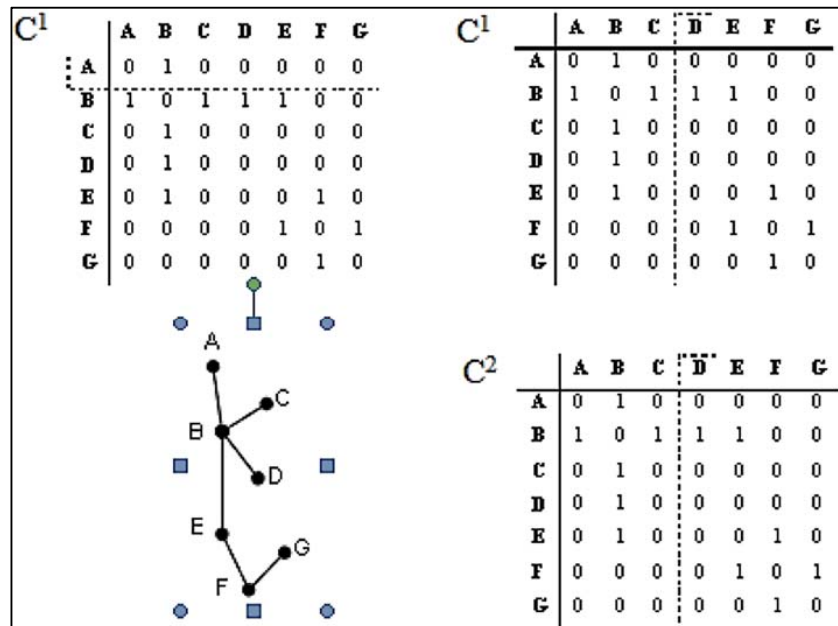


Fig. 6: Matrix C^n

connections. All cells in L^1 with values other than M remain unchanged because no distances by two-step connections can be shorter than a one-step (direct) link. We only need to update the cells with the value M . For example, $L^1(1, 3) = M$ needs to be updated. All possible “two-step” links are examined:

$$\begin{aligned} L^1(1, 1) + L^1(1, 3) &= 0 + M = M \\ L^1(1, 2) + L^1(2, 3) &= 116 + 113 = 229 \\ L^1(1, 3) + L^1(3, 3) &= M + 0 = M \\ L^1(1, 4) + L^1(4, 3) &= M + 76 = M \\ L^1(1, 5) + L^1(5, 3) &= 155 + M = M \end{aligned}$$

The cell value $L^2(1, 3)$ is the minimum of all the above links, which is $L^1(1, 2) + L^1(2, 3) = 229$. Note that it records not only the shortest distance from 1 to 3, but also the route (through node 2). Similarly, other cells are updated such as $L^2(1, 4) = L^1(1, 5) + L^1(5, 4) = 155 + 77 = 232$, $L^2(2, 5) = L^1(2, 4) + L^1(4, 5) = 142 + 77 = 219$, $L^2(3, 5) = L^1(3, 4) + L^1(4, 5) = 76 + 77 = 153$, and so on. The final matrix L^2 is shown in Figure A2.1.

By now, all cells in L^2 have values other than M , and the shortest route problem is solved. Otherwise, the process continues until all cells have values other

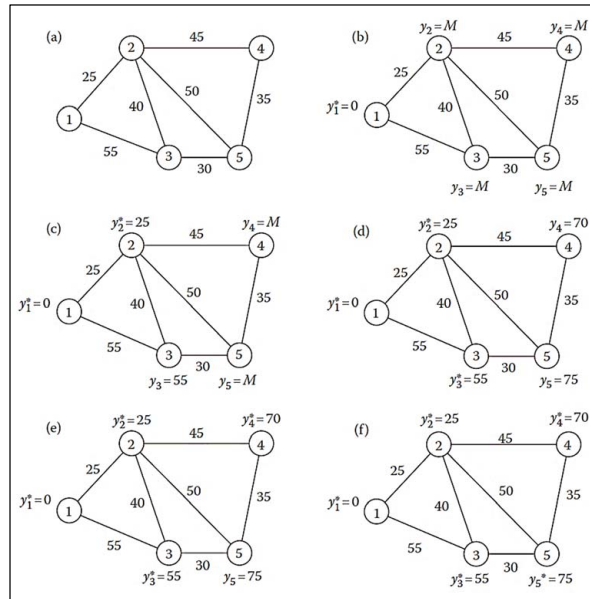


Fig. 7: an example for the label-setting algorithm

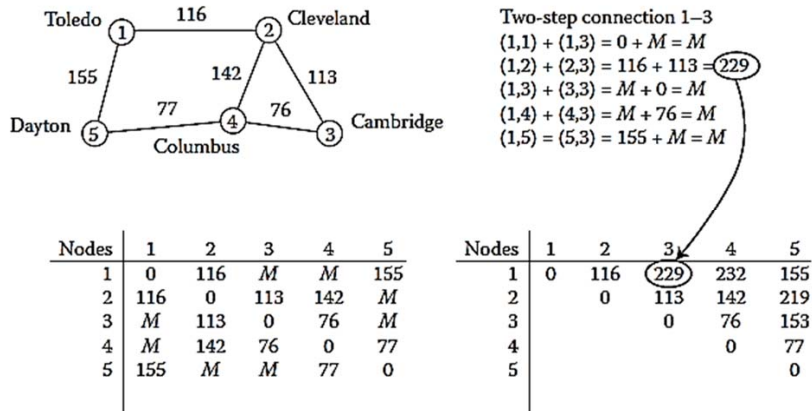


Fig. 8: A valued-graph example

than M. For example, L^3 would be computed as

$$L_{ij}^3 = \min_k (L_{ik}^1 + L_{kj}^2) \quad , \quad k \in \{1, \dots, n\}$$

Findings

The results of the current research were obtained through data analysis in arc GIS software using network analyst model. Figure (9) shows the network of passages of Mashhad City and hospital spatial

distribution in it. Based on this figure, hospitals are mostly concentrated in the 8th urban zone of Mashhad. Figure (10) shows the shortest access route from the center of city zones to hospitals; the city zone of Samen offers the best access compared to other zones.

As it is evident in figure (11), the standard distance between hospitals in Samen Zone, includes parts of the first, the second, the 8th and the 11th city zones. It also shows that the central hospital is located in

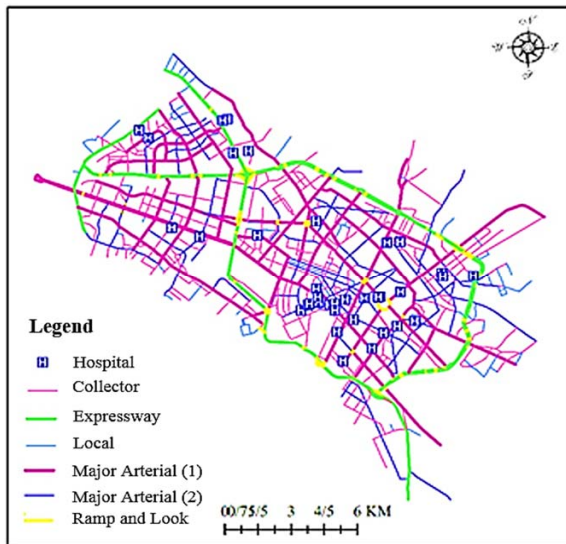


Fig. 9: the passages network of the Mashhad city and hospitals spatial distribution

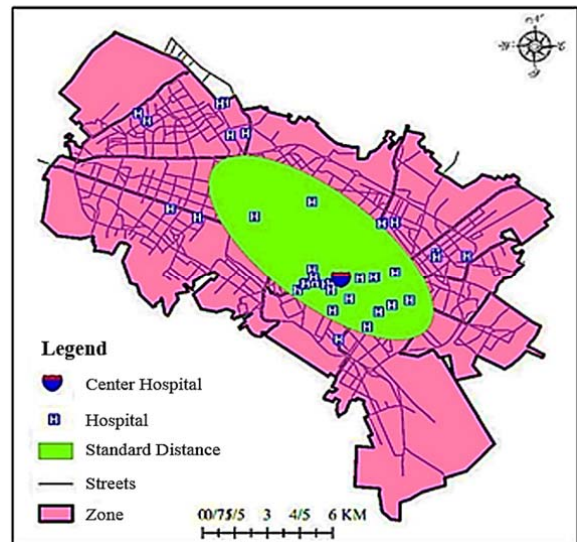


Fig. 11: spatial concentration of hospitals in Mashhad

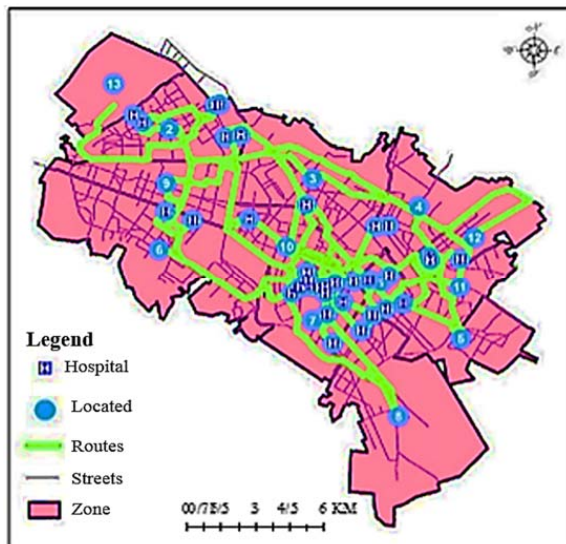


Fig. 10: shortest access route from center of city zones to hospitals

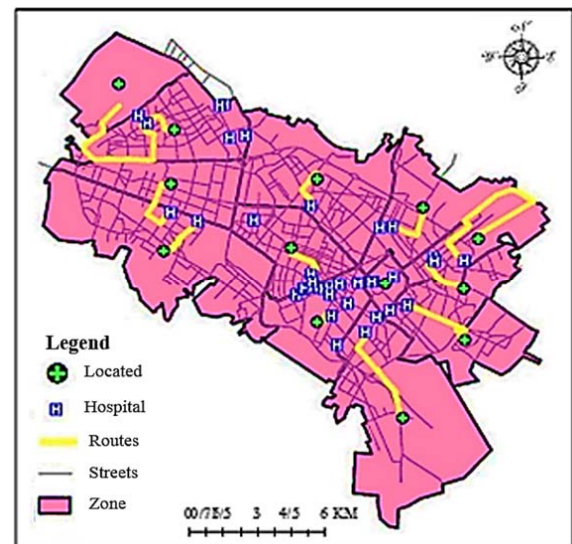


Fig. 12: the closest hospital to the center of Mashhad City Zones

Samen Zone of Mashhad City. Figure (12) shows the closest hospital to center of every city zone which demonstrates the 8th zone has the least access route while the 4th zone offers the best access route.

Figure (13) shows the directional distribution of hospitals in Mashhad. Based on the figure, the central zones of Mashhad have most directional distribution in terms of accessibility to hospitals. Figure (14) shows the optimal hospital in terms of having access

to the center of city zones and therefore this hospital is situated in Samen zone of Mashhad city.

Figure (15) shows the cost matrix between hospitals and the centers of city zones based on which the quality of services provided by hospitals is determined. Figure (16) shows the areas covered by hospitals in the city of Mashhad which have been highlighted based on a 1000-meter impedance.

Table 2 shows the number of hospitals and hospital

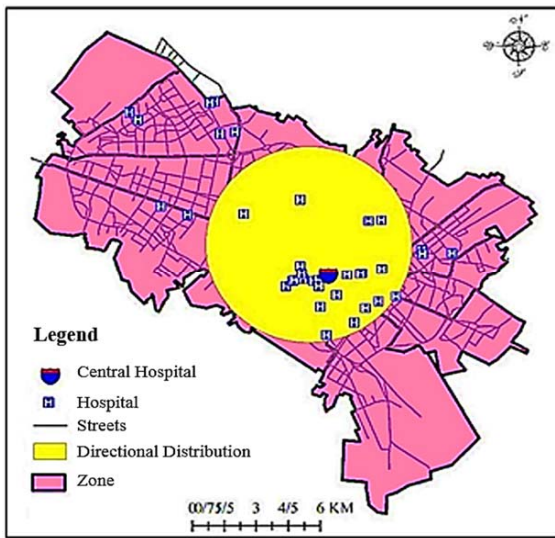


Fig. 13: the directional distribution of hospitals in Mashhad

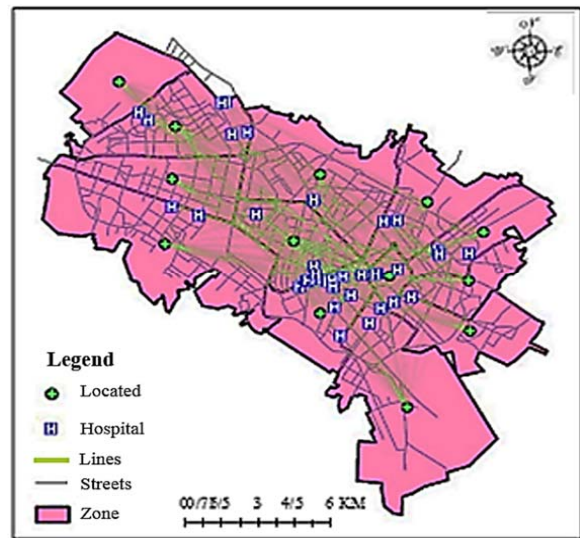


Fig. 15: the cost matrix between hospitals and centers city of Mashhad

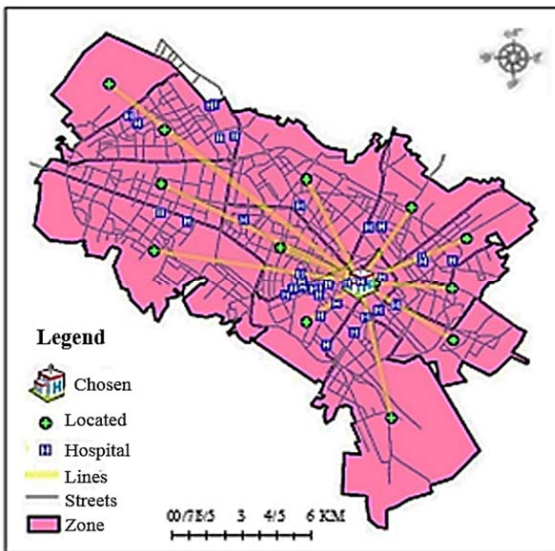


Fig. 14: the optimal hospital in terms of having access to the center of zones in Mashhad

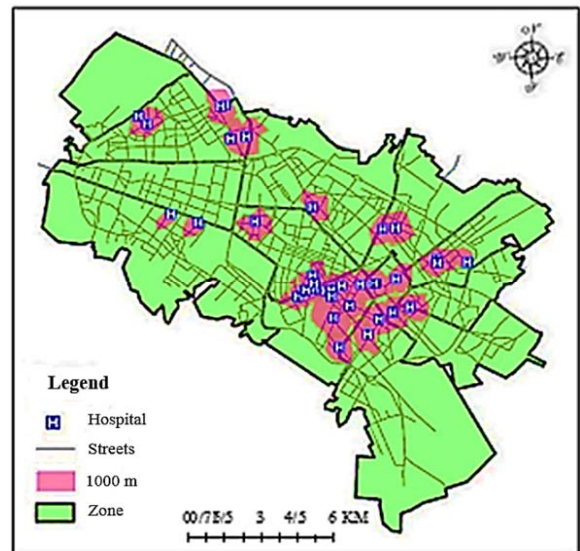


Fig. 16: the areas covered by hospitals in the city of Mashhad

Table 2: Number of hospitals and hospital beds per capita

| District | Population | Percent of the overall population | Number of hospitals | Number of hospital beds | Area of the hospitals (m ²) | Area of the hospitals per capita (m ²) | Number of hospital beds per capita |
|--------------|------------|-----------------------------------|---------------------|-------------------------|---|--|------------------------------------|
| Zone 1 | 176039 | 6.27 | 5 | 1377 | 121450 | 0.69 | 0.008 |
| Zone 2 | 434729 | 15.48 | 3 | 976 | 39535 | 0.09 | 0.002 |
| Zone 3 | 387862 | 13.82 | 2 | 448 | 11442 | 0.03 | 0.001 |
| Zone 4 | 246296 | 8.77 | 3 | 676 | 27657 | 0.11 | 0.003 |
| Zone 5 | 168154 | 5.99 | 2 | 323 | 12300 | 0.07 | 0.002 |
| Zone 6 | 230289 | 8.20 | 0 | 0 | 0 | 0 | 0 |
| Zone 7 | 229940 | 8.19 | 1 | 371 | 5922 | 0.03 | 0.002 |
| Zone 8 | 94227 | 3.36 | 10 | 2069 | 184362 | 1.96 | 0.022 |
| Zone 9 | 300539 | 10.70 | 3 | 501 | 62346 | 0.21 | 0.002 |
| Zone 10 | 265205 | 9.45 | 2 | 538 | 61000 | 0.23 | 0.002 |
| Zone 11 | 192355 | 6.85 | 0 | 0 | 0 | 0 | 0 |
| Zone 12 | 60373 | 2.15 | 1 | 206 | 3400 | 0.06 | 0.003 |
| Zone 13 | 21456 | 0.76 | 2 | 196 | 7450 | 0.35 | 0.009 |
| Mashhad City | 2807464 | 100 | 34 | 7681 | 536864 | 0.19 | 0.003 |

Remark: Zone 13 is also called by the name Samen.

beds per capita for each district of Mashhad City separately. As it can be seen, the city of Mashhad with a population of more than 2,807,464 residents has 34 hospitals overall, i.e., the number of hospitals per capita is 0.19. The District 8 of Mashhad enjoys the highest number of hospitals per capita at 1.96. Districts 6 and 9 do not have any hospitals. Meanwhile, the city of Mashhad has 7681 hospital beds of which 26.9% are located in District 8 alone. The number of hospital beds per capita is 0.003 respectively.

CONCLUSIONS

Equal access to health services, including hospitals, is a basic human right. Inequality in spatial distribution of resources in the health sector could be a challenge in the way of equal access for people to health and medical services. In developing countries, due to absence of information, skill and expertise in the field of health and medical planning, resources are usually allocated in an imbalanced way. A fact which shows that the location of public centers can be considered as one of the indices of having access to healthcare. Findings of the current research suggest that hospitals are mostly concentrated in the 8th zone of Mashhad City while the 5th and the 11th zones have no hospitals at all. It also shows that Zone 8 and Zone 13 (Samen) have the highest access to hospitals in Mashhad.

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