Research Paper

The Optimized Location of Hospitals Using an Integrated Approach GIS and Analytic Hierarchy Process: A Case Study in Iran

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ABSTRACT

Background and Purpose: Adopting a proper location for a hospital will result in allocating optimal resources, improving access to health care, improving the quality of hospital services, reducing the waste of time, reducing energy consumption, decreasing costs, and reducing traffic. Accordingly, this study was conducted to adopt the optimal location for hospitals in Yazd City, Iran.

Materials and Methods: This research is descriptive in terms of type and applied in terms of objectives. The used criteria for this study covered data related to military, residential, sports, industrial, green space, education, population density, communication roads, and available hospitals. All effective criteria were distinguished, and a map of each criterion was provided to locate the hospitals optimally. The weight of each criterion was determined by the analytic hierarchy process method and applied to the maps in the GIS software environment. The final land valuation map was prepared by combining the maps to construct the hospital.

Results: The highest weight was calculated for the population density layer (0.24) and the lowest for the sports layer (0.025). The classified map to construct a hospital in Yazd City, Iran was classified into 5 categories, from very appropriate to very inappropriate. The map revealed that about 34% of the studied area is appropriate for building a hospital.

Conclusion: Due to the importance of proper geographical access to hospital treatment facilities, it is recommended that new hospitals in Yazd be constructed on very appropriate land plots, and the priority in building a hospital to be very appropriate land plots located in the fourth district.

Keywords: Geographic Information Systems, Analytic hierarchy process, Hospital, Yazd Province

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1. Introduction

Providing adequate health care is becoming increasingly complicated in developing countries [1]. The increasing population causes more demand for healthcare facilities and the construction of new hospitals, which demands high costs. Hence, it is important to determine the optimal locations of these centers, so all citizens can use them. If this process is done without analyzing the impact and interaction of users, it may aggravate the current problems and create other unsolvable problems [2]. Determining a location for a hospital starts with the success or failure of such a facility. The success of such a facility depends on how it serves the patients [3, 4].

According to hospital investors and operators, determining the hospital's appropriate location will unquestionably save money on the capital strategy. It is an unavoidable process for hospitals to adopt cost accounting to adapt to a market economy's development. Also, determining a better hospital location will enhance brand strategy, marketing, differentiation, human resources, and competition [5].

Facility locating is a branch of operational research associated with finding and determining the location of at least one new facility among several available ones to optimize (minimize or maximize) at least one objective function (such as cost, profit, revenue, commute distance, services, waiting time, coverage and market shares) [6].

The decision-maker wishes to pursue more than one objective or regard more than one factor or scale. Such a tendency turns the decision problem into a multi-objective decision problem (MODM) or a multi-attribute decision problem (MADM). These two groups of problems are classified into multi-criteria decision problems (MCDM) [6].

Determining the optimal location of the hospital is an MCDM. There are several ways to make multi-criteria decisions; some are better for specific cases than others. These techniques, such as the PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluations) technique, the ELECTRE (Elimination and Choice Translating Reality) technique, and the TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) technique, have been applied to solve site selection problems, which are used to rank alternative sites, especially in the case of environmental problems. The analytic hierarchy process (AHP) described by Satay is one of the most beneficial methods and is important in choosing the optimal variables [7].

Determining the appropriate location using GIS technology is a comprehensive method applied in various fields such as regional and urban planning, water resources management, healthcare resource allocation, and natural jeopardies. The role of GIS in spatial decision-making is to help the decision-maker determine the weight of criteria, measure practical options, and visualize the wanted results [8].

In a study on locating hospitals in Shiraz City, Iran utilizing GIS, Rahimi et al. revealed that none of the 33 current hospitals were in a suitable location. Also, 15 areas north of the city were recognized as the best lands to construct hospitals [9].

The Gillianeh site was selected as the best place to construct a new hospital in a study conducted by Ibrahim et al. in Benghazi, Libya, after evaluating 3 sites proposed by the AHP method [7]. In the study conducted by Chatterji Dembali on India's rural areas, adopting the AHP method, land price, population density, and proximity to public transportation have been viewed as 3 important sub-criteria among 11 introduced sub-criteria [10].

Given the lack of research on residents' access to medical centers, comparison of medical facilities against the existing standards, and the per capita medical services usage, investigating this issue is required.

Based on the importance of the stated content, this study has been conducted using GIS to determine suitable locations to construct hospitals in Yazd City, applying the AHP method. It is hoped that the results of this study can help policymakers and administrators plan and provide the best possible access for people to medical facilities.

2. Materials and Methods

This research is descriptive in terms of type and applied in terms of objectives. This research was

conducted on 11 public and private hospitals. Various data such as military, residential, sports, industrial, green space, educational, population density, current hospitals, and road networks have been applied to provide a database in a GIS environment. The study criteria (compatible and incompatible layers) were determined using previous studies.

The data needed for this study were obtained from the Statistics Center of Iran, the University of Medical Sciences and Health Services, and the Municipality of Yazd.

Determining the optimal Locations to construct hospitals in Yazd

We will first require identifying and determining effective criteria in assessing the area to recognize proper areas to construct hospital centers. The boundaries of the studied area were first determined to conduct this project. Effective factors (compatible and incompatible layers) were then identified using ground visits, the opinion of 10 experts and specialists in different fields, such as urban planning experts, GIS experts, environmental health, environment, and health management, and also according to local conditions and also based on previous research conducted in this field. These factors are these layers: residential centers, current hospitals, green space, communication ways, industrial centers, educational centers, military centers, sports venues, and population density.

Providing the database and preparing information layers

At this stage, it is necessary to examine the collected information and prepare it for the required analyses. In this way, the scale and image system of the layers should be the same if they are different because to perform the analysis in the GIS environment, the data must be coordinated. Therefore, it is necessary to prepare and edit the data and convert them to contain all the information required for the intended user and have a suitable structure to perform the analysis.

After identifying and preparing all the criteria and effective factors in this stage, each layer's factor map must be prepared. The preparation of factor maps consists of processing and weighing stages to information layers.

At this research stage, a database was created for the considered layers. Then, using information and reports, data conversion, map, and geographic information system, the map of each factor was prepared and analyzed.

First, all maps were scaled to achieve this goal, and then their raster layers were prepared in ARC GIS10.3 software. For this purpose, the usual data processing methods available in GIS, such as converting vector structure to raster structure, reclassification, etc., are used.

The average nearest neighbor index is based on measuring the distance of each user to their closest neighbor. The results obtained from the nearest neighbor model, which is one of the appropriate models for showing the distribution pattern in three levels is presented: scattered or regular (z-score: -1.65 to -2.85), random or random with (z-score: 1.65 up to -1.65) and a cluster pattern (z-score: 1.65 to 2.85).

Except for the population density layer, which was converted into a raster using the feature to raster command, the other criteria were converted into a raster using the Euclidean Distance function. Then with the Mask command, we separated the city border from the rasterized map, and each rasterized layer was converted into 5 layers using the Reclass command. In this thesis, the distance from the strata is divided into compatible (closeness to residential centers, proximity to communication routes, proximity to green spaces, proximity to densely populated areas) and incompatible categories (distance from educational centers, distance from an existing hospital, distance from industrial centers, distance from military centers, distance from sports centers). Finally, in the results section, the position of each hospital is stated based on the existing standards [11-23] in compatible and non-compliant categories.

The hierarchical analysis process in Expert Choice software was used to weigh and prioritize the indicators, make decisions, and choose the best points.

This method was carried out in several steps: creating a hierarchical structure of standards, forming a pairwise comparison matrix, weight calculation in hierarchical analysis, and examining the consistency of judgments.

Integrating layers utilizing multi-criteria decision analysis

All weights achieved by the AHP method in the Arc GIS software environment were applied to the maps, and the final map of each factor was developed. The total score concerning each option is achieved by adding the final map of each layer in relation to all the qualities. Eventually, the option with the highest score is chosen, and appropriate and inappropriate zones were determined.

3. Results

Determined indicators effective in locating the hospital

The probability of inconsistency in judgments is increased in the AHP method by selecting many criteria. Table 1 exhibits the number of times the criteria have been used (28 criteria) in 20 studies conducted in the country.

Table 1. Criteria determined in earlier studies and the frequency of their use [2, 9, 12-15, 17-22, 24-34]

Row	Determined Criterion	Studied Cities	Number
1	Proximity to green space	Ilam, Jahrom, Hamedan, District 11 of Tehran, District 6 of Tehran, Kermanshah, Saqez, Zanjan, Dezful, District 7 of Tehran, Miandoab, Noorabad, Najafabad, Shiraz, Tabriz, Birjand, Bandar Abbas, Ardabil, and Sabzevar	19
2	Distance from the first-class communication network - distance from the main roadways	Ilam, Jahrom, Saqez, District 7 of Tehran, District 6 of Tehran, Hamedan, Kermanshah, Zanjan, Dezful, Ardabil, Bandar Abbas, Birjand, Tabriz, Najafabad Miandoab, Sabzevar, Shiraz (2 studies), and Nourabad	19
3	Distance from industrial centers	Ilam, Jahrom, Hamedan, District 11 of Tehran, District 6 of Tehran, Kermanshah, Ardabil, Zanjan, Dezful, District 7 of Tehran, Bandar Abbas, Tabriz, Shiraz (2 studies), Najafabad, Nourabad, and Miandoab	17
4	Proximity to fire stations	Ilam, Jahrom, Hamedan, Kermanshah, Sabzevar, Saqez, Zanjan, Dezful, Ardabil, Bandar Abbas, Shiraz (2 studies), Nourabad, Najafabad, Tabriz, District 6 of Tehran, and Birjand	17
5	Distance from available hospitals	Ilam, Jahrom, Kermanshah, Sabzevar, Ardabil, Tabriz, Najafabad, District 11 of Tehran, Saqez, Bandar Abbas, Birjand, Shiraz (2 studies), District 6 of Tehran, and Nourabad	15
6	Slope	Jahrom, Hamedan, Kermanshah, Sabzevar, Saqez, Zanjan, Dezful, Ardabil, Bandar Abbas, Tabriz, Miandoab, and Nourabad	12
7	Land use	Ilam, Jahrom, Hamedan, Ardabil, Zanjan, Dezful, Birjand, Najafabad, Miandoab, Shiraz, and Nourabad	11
8	Population density	Sabzevar, Bandar Abbas, Saqez, Ardabil, Birjand, Tabriz, Najafabad, Nourabad, Miandoab, and Shiraz	10
9	Avoid military bases	Ilam, District 11 of Tehran, District 6 of Tehran, Kermanshah, Sabzevar, District 7 of Tehran, Ardabil, Bandar Abbas, Tabriz	9
10	Distance from the centers of districts-areas-neighborhoods	Jahrom, Hamedan, Sabzevar, Saqez, Zanjan, Dezful, Tabriz, Najafabad, and Nourabad	9
11	Distance from residential centers	Bandar Abbas, Shiraz, Ardabil, District 11 of Tehran, Kermanshah, and District 6 of Tehran	6
12	Distance from educational centers	District 11 of Tehran, Kermanshah, Saqez, Ardabil, and Birjand	5
13	River	Sabzevar, Ardabil, Tabriz, Shiraz and Saqez	5
14	Distance from passenger terminals and warehouses	District 11 of Tehran, District 6 of Tehran, Kermanshah, Sabzevar, and Tabriz	5
15	Distance from service-office centers	District 11 of Tehran, District 7 of Tehran, District 6 of Tehran, and Kermanshah	4
16	Distance from urban facilities	Birjand, District 11 of Tehran, and Kermanshah	3
17	Distance from urban facilities	Birjand, District 11 of Tehran, and Kermanshah	3
18	Cemetery	Ardabil, Sabzevar, and Tabriz	3
19	Avoiding fault lines	District 7 of Tehran, Sabzevar, and Tabriz	3
20	Distance from shopping malls	District 11 of Tehran, District 6 of Tehran, and Kermanshah	3
21	Cultural or sports	Ardabil and Birjand	2
22	Barren lands	District 11 of Tehran and Kermanshah	2
23	Distance from religious centers	District 11 of Tehran and Kermanshah	2
24	Distance from the fuel station	Saqez	1
25	Distance from the quadratic communication network	Miandoab	1
26	Distance from the airport	Shiraz	1
27	Distance from the subway	District 6 of Tehran	1

Table 2. Hospitals location according to criteria

Hospital	Industrial Layer	Educational Layer	Green Space Layer	Residential Layer	Military Layer	Road Layer	Population Density Layer	Sport Layer	Distance Of Current Hospitals	Final Map
(1)	5	2	4	5	2	5	1	2	2	3
(2)	5	5	3	5	5	4	5	5	2	2
(3)	2	5	4	5	5	4	2	3	5	3
(4)	2	5	4	5	5	5	2	2	5	4
(5)	3	2	4	5	2	5	5	5	2	3
(6)	5	5	5	4	3	3	5	5	2	2
(7)	2	5	5	5	5	5	5	5	2	4
(8)	2	2	5	5	5	5	2	2	2	5
(9)	2	5	2	5	2	4	5	2	2	2
(10)	2	5	2	5	5	5	5	2	5	2
(11)	5	5	5	5	5	5	5	4	5	2

Consequently, only 9 criteria of effective location have been determined according to ground visits, experts' opinions, and earlier studies.

Prepared layers

The standard maps and classified provinces were obtained at this research stage as follows (Figures 1-9).

Table 2 presents the results explain that hospitals' locations in Yazd according to each criterion.

After providing an order of parameters in Expert Choice software and entering the scores, the system calculated the final weights (Figure 10), and the calculated inconsistency rate was controlled. The consistency ratio of this comparison is equal to 0.09, which is acceptable considering that this value is less than or equal to 0.1 in a consistent judgment.

After combining various layers of information, the map of optimal land locations to construct the hospital and the classified zoning map in 5 floors (very appropriate =5, appropriate =4, average=3, inappropriate=2, and very inappropriate =1) was achieved according to Figure 11. The final map indicates that only the current locations of No. 4 and No. 7 hospitals are appropriate. No.1, No. 3, No. 5, and No. 8 hospitals are in average condition. The current locations of other hospitals (No. 2, No. 6, No. 9, No. 10, and No. 11) are inappropriate.

Table 3. Floor area for new hospitals

Suitability Classification	Floor Area Per Hectare	% of Each Zone Area
Very inappropriate	1529.99	16.05
Inappropriate	2104.5	22.08
Average	2628.8	27.59
Appropriate	2220.22	23.30
Very appropriate	1044.37	10.96

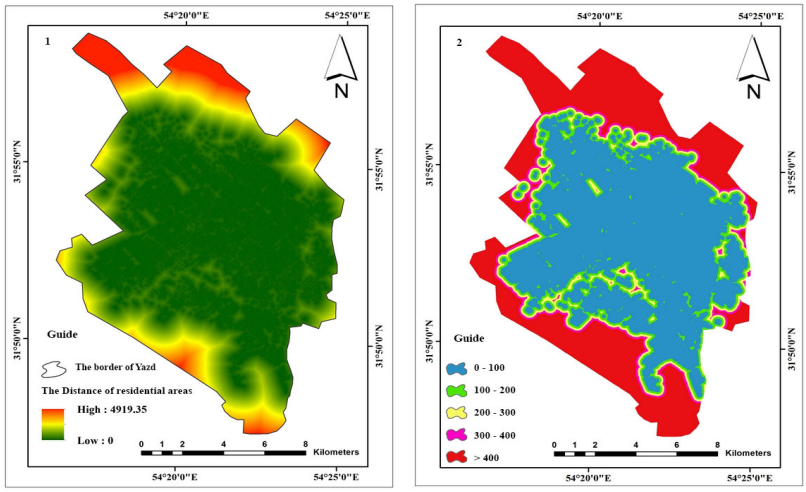

Figure 1. Map No. (1): Distance from residential areas; Map No. (2): Classified map of distance from residential areas

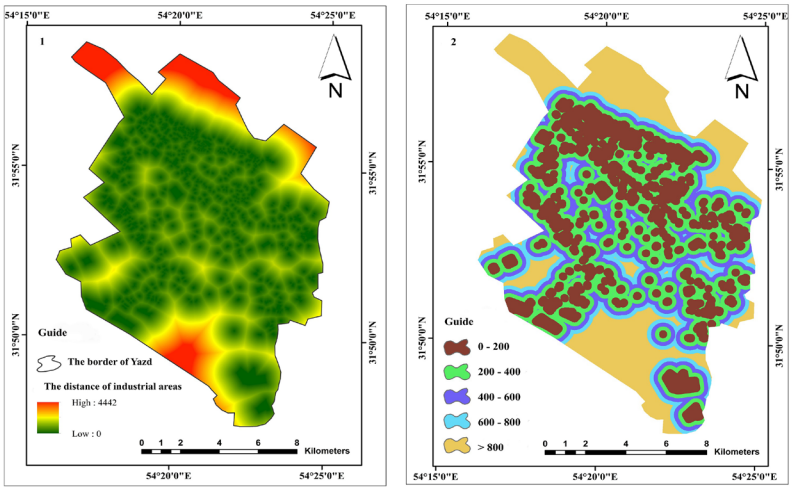

Figure 2. Map No. (1): Distance from industrial areas; Map No. (2): Classified map of distance from industrial areas

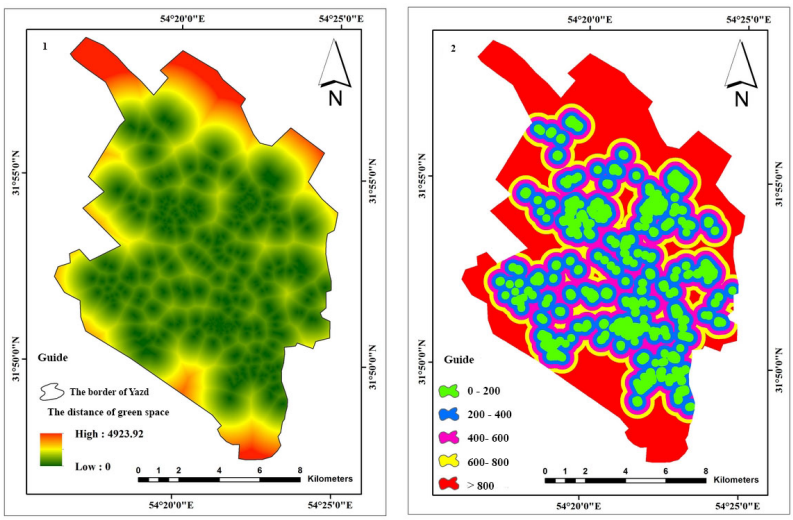

Figure 3. Map No. (1): Distance from Green areas; Map No. (2): Classified map of distance from Green areas

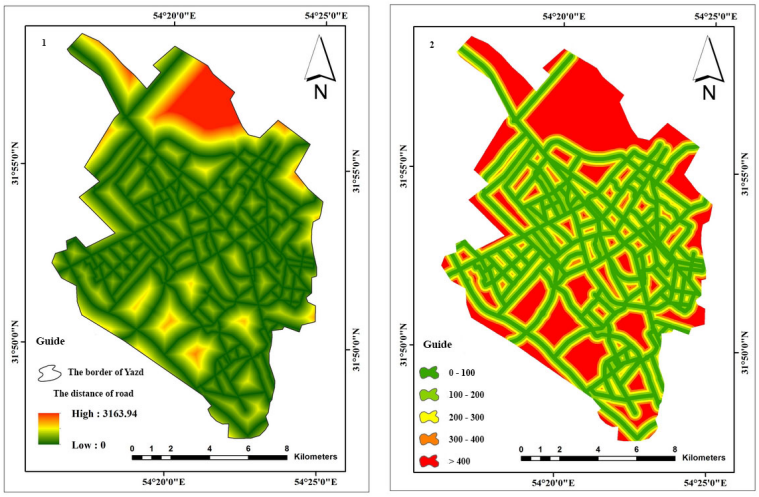

Figure 4. Map No (1): Distance from the communication network; Map No (2): Classified map of distance from the communication network

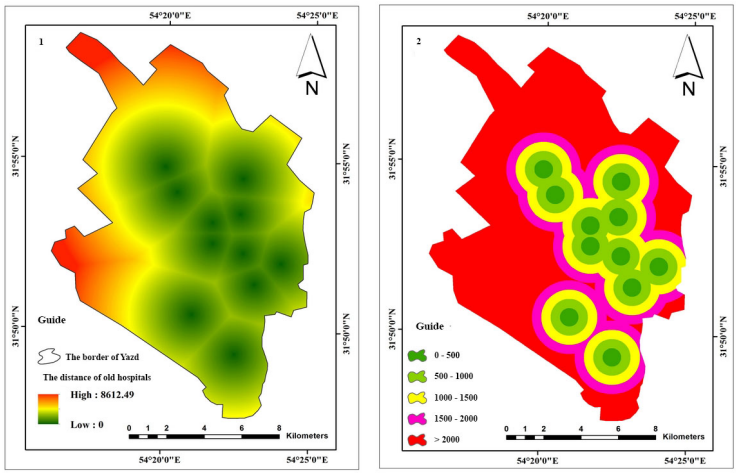

Figure 5. Map No. (1): Distance from available hospitals; Map No. (2): Classified map of distance from available hospitals

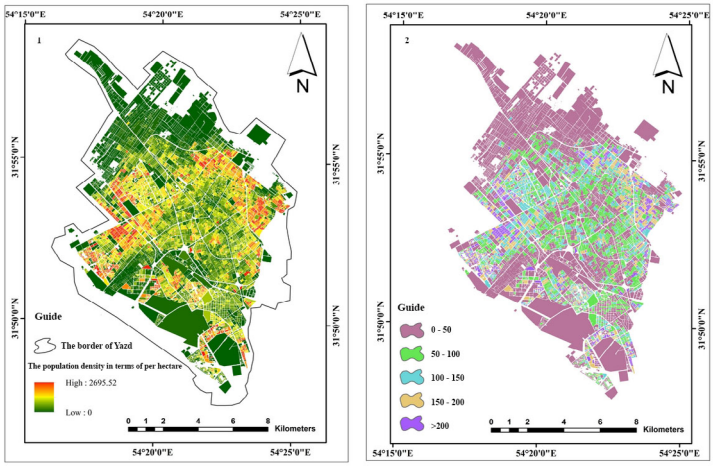

Figure 6. Map No (1): Population density; Map No (2): Classified map of population density

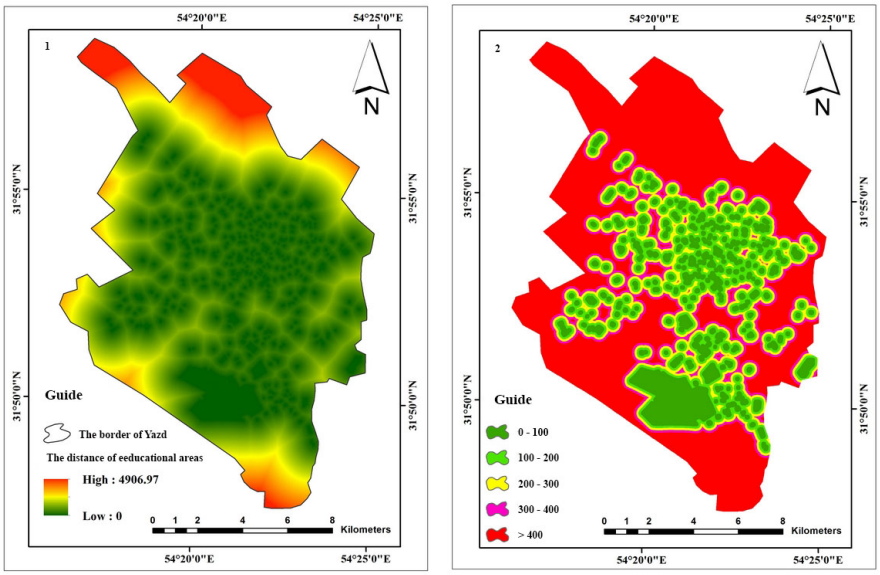

Figure 7. Map No. (1): Distance from educational centers; Map No. (2): Classified map of distance from educational centers

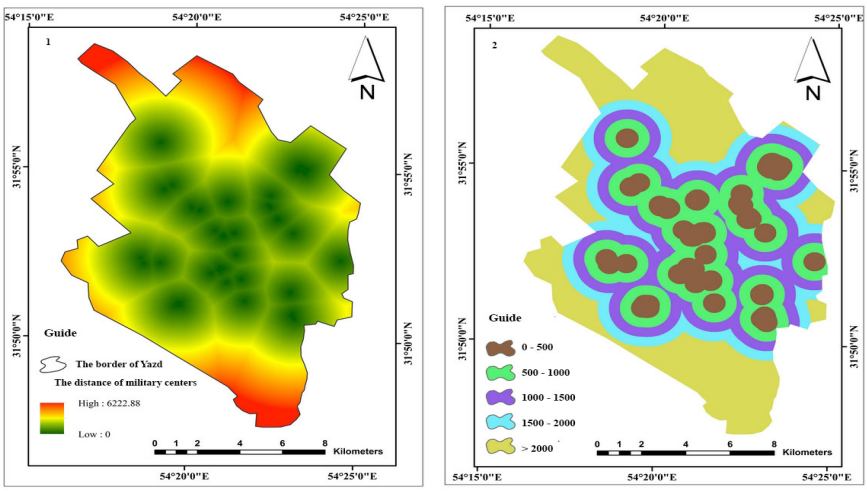

Figure 8. Map No (1): Distance from military centers; Map No (2): Classified map of distance from military centers

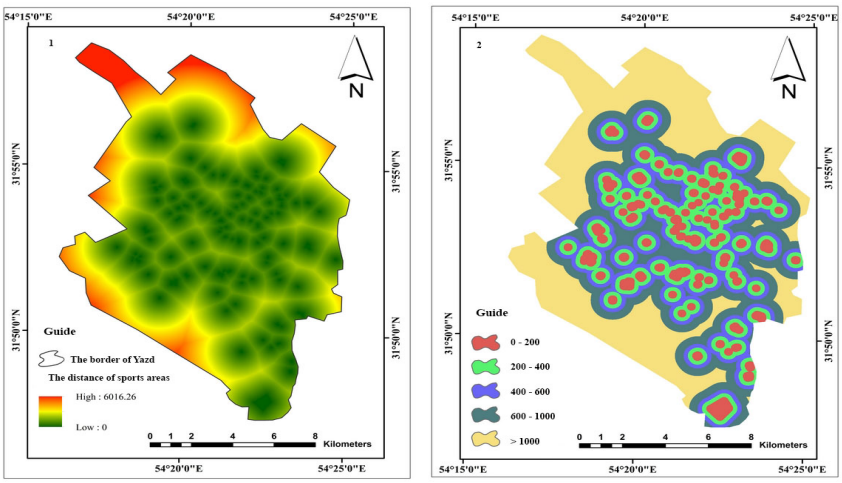

Figure 9. Map No. (1): Distance from sports centers; Map No. (2): Classified map of distance from sports centers

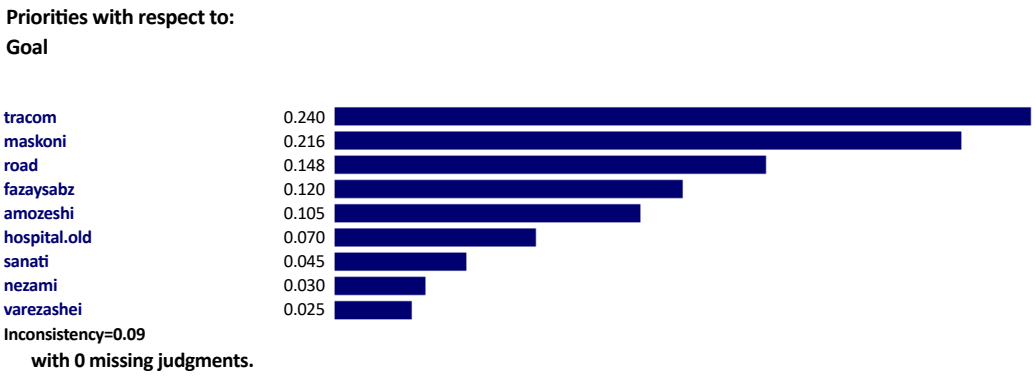

Figure 10. The final weight of the layers

According to Table 3, 38.13% of the studied area (3634.49 hectares) is in the inappropriate and very inappropriate class, about 27.59% (1628.8 hectares) in the average class, and about 34.26%, (3264.59 hectares) in the appropriate and very appropriate class. Consequently, it was determined that about 62% of the studied area is inappropriate for constructing the hospital.

4. Discussion

Based on the map of optimal land locations for hospital construction, the study's results showed that most studied hospitals are not in good condition in terms of location. Also, 62% of the studied area is unsuitable for hospital buildings.

Due to surveys conducted on the current location of hospitals in Yazd, 9% in terms of distance from industrial centers, 36% in terms of distance from educational centers, 55% in terms of distance from green space, 82% in terms of distance from residential centers, 18% in terms of distance from military centers, 91% in terms of distance from the communication network, 9% in terms of distance from sports centers, 18% in terms of distance from current hospitals have been placed in an appropriate and very appropriate situation. All hospitals are in inappropriate or very inappropriate sites regarding population density. Hence, the mentioned criteria, extensively used in earlier studies, have been less considered in locating hospitals in Yazd.

The results from this study indicated no overlap between the radius of 1500 m around No.11 and No.10 hospitals located in the south of Yazd and other hospitals. But in the case of other hospitals, there is overlap

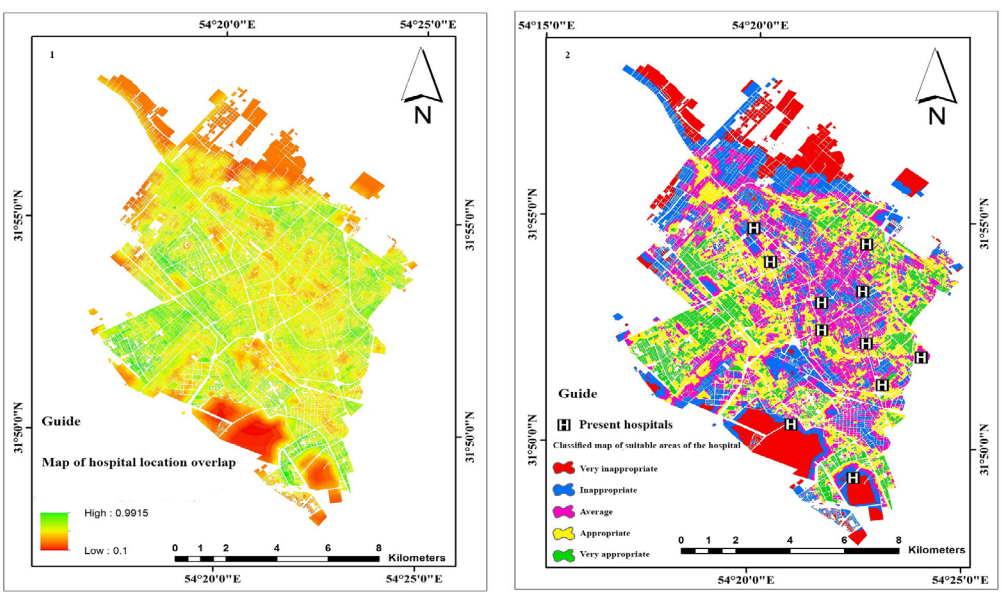

Figure 11. Final valuation and prioritization of land to construct a hospital

No. (1) Overlap map of hospital location; No. (2): Classified map of appropriate areas of the hospital

even within a radius of 1000 m. Accordingly, the number of hospitals in Yazd is proportionate to the population, and there is no hospital shortage [35]. However, geographical access in locating hospitals has been less considered. Hence, the distance between hospitals is close to the standard 1500 m distance between hospitals only in the south of Yazd. Less space between hospitals in the center and east of Yazd has caused a large part of the area of Yazd in the north and west of this city not to be located even within a radius of 2000 m around hospitals.

In this study, AHP has been applied to weigh the criteria. The highest weight was calculated for the population density layer (0.24). Consequently, this study is in agreement with the study conducted by Ahadnejad on the optimal location of medical centers in District 11 of Tehran City, Iran [12], the study conducted by Zangiabadi on spatial analysis of the distribution of hospitals in Saqez City, Iran, and their optimal location [25], the study conducted by Parsai Moghadam on the location of urban hospitals using GIS in Ardabil City, Iran [31], the study conducted by Rahimi on the optimal location of hospitals in Shiraz City, Iran and the study conducted by Jamali with the subject of evaluating the location patterns of hospitals in Tabriz City, Iran [15] in which the population density layer had the highest weight. Additionally, in this study, the minimum weight was calculated for the sports layer (0.025), which agrees with the study conducted by Parsai Moghadam in Ardabil City, Iran [31].

According to the criteria for locating the hospital, only 11% of Yazd's area has very appropriate conditions, and 24% has appropriate conditions to construct the hospital.

There is no hospital in District 4 of Yazd [35]. On the other hand, a high density of land with a very appropriate class can be observed in this area in the final map of optimal places to construct hospitals, obtained from the overlap of 9 effective layers in hospitals' location. Consequently, the priority for building new hospitals is to erect them in a very appropriate class in District 4.

Since the final valuation and prioritization of land to construct the hospital is greatly influenced by the selected criteria and their effective weights in locating the hospital, it is advisable to choose and weigh these criteria with the collective opinion provided by urban planning experts, health management and treatment, environmental health, remote sensing and GIS, environment, social sciences, and other experts according to local conditions and earlier studies.

However, constructing hospitals in most cities of Iran has been performed without planning and studying the access status and other effective criteria in locating hospitals. This issue has disturbed the efficiency of hospitals in providing services. Consequently, according to the results of this study, it is recommended that new hospitals in Yazd be constructed on very appropriate sites, and the first priority in constructing a hospital is in the very appropriate sites lin the fourth district.

Study limitations

One of the limitations of the implementation of this research was collecting the required items (maps). The organizations and departments lacked the cooperation to deliver the maps, and the needed items were prepared after months of effort.

Ethical Considerations

Compliance with ethical guidelines

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Authors contributions

Conceptualization, methodology, writing, review, and editing: Roohollah Askari and Seyed Mohammad Afrazandeh; Validation and supervision: Milad Shafii and Zabihollah CharRahi; Formal analysis, investigation, resources, writing original draft preparation: Seyed Ali Al-Modaresi.

Conflict of interest

The authors declared no conflict of interest.

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