

A Comparative Study on Site Selection Methods for Modeling Hospital Locating in Urban Area, A Case Study in Iran

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Abstract. Urban managers are faced with complex decisions, including the decision to select a suitable location for service centers, based on several conflicting criteria noted. The purpose of this research is a comparative study on site selection methods for modeling hospital locating. According to the present article, new locations were found to manage better and complete Amol city coverage with eight specified criteria. The research area in terms of proximity to major roads, green spaces, fire stations and distance from the river, industrial land uses, education land uses, hospitals and sport land uses has been studied. As well as for weighing the criteria, the model of AHP was implemented. Then, using the TOPSIS model in ArcGIS software, the valuation of standards was analyzed, and suitable maps were created that show the best place for the hospital building. In the next step, using the Fuzzy Logic model in ArcGIS, another appropriate map is prepared, and the results of the two models have been compared together. The results revealed that the Multi-Criteria Decision Making (MCDM) system with GIS could be an effective hospital site selection tool. Anyway, there are some differences between the results of the models. Fuzzy Logic is better suited to the hospital locating. The location of hospitals away from existing spaces in the Fuzzy Logic model shows this model's ability in comparison with the TOPSIS model.

Keywords: Hospital planning · Site selection · TOPSIS · Fuzzy logic · Amol city

1 Introduction

Health is the product of a dynamic relationship between socioeconomic conditions, the natural environment, and the built environment as emerging on individual and social levels (Rydin et al. 2012; Rydin 2012; Sarkar et al. 2014). Despite the considerable advancements in today's healthcare, studies show a massive gap in healthcare access and

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health outcomes. One of the essential public services is the hospital that provides the citizens' health. The selection of a hospital site is essential to hospital management (Zhou and Wu 2012). Several researchers have used geographical information systems (GIS) to help with hospital site selection. To overcome the MCDA problems of hospital site placement, Vahidnia et al. (2009) implemented the model of FAHP. Their observations demonstrate the best way to figure out how much each alternative is worth. Zhou and Wu (2012) applied the GIS-based MCA method with AHP and ROM for the weighting factor criteria. Senvar et al. (2016) used a TFHFWA operator. They claim that it is possible to propose their methodology for other multi-criteria site selection issues. Şahin et al. (2017) used the AHP method for hospital site selection. They believe that the best hospital site selection must consider both macro and micro parameters to work effectively for several years. Choosing the best hospital location would also help to improve public health in the region.

This paper focused on the choice of proper hospital sites in Amol city, Iran. Therefore, the GIS program is used to assess hospital building positions in a comparative analysis of two techniques (TOPSIS and Fuzzy Logic). To this goal, multiple factors were included in the screening process based on literature and related study experiences.

Table 1. Recent researches about hospital site selection

Researchers	Year	Applied method
Wu et al.	2007	AHP
Behzadi & Alesheikh	2013	Belief-Desire-Intention (BDI)
Chiu & Tsai	2013	AHP
Abdullahi et al.	2014	OLS technique
Kumar et al.	2016	ELECTRE

2 Study Area

Amol is in Iran's province of Mazandaran. It is situated on the southern side of the Caspian Sea, spanning between latitudes 26°25′N and longitudes 52°2′E and covers a total area of about 31 km^2. (Iranian Statistics Centre 2016). (Fig. 1).



Fig. 1. Study area of Amol City, Iran

3 Methodology

Generally, scientific research needs to apply proper methods and tools while doing any investigation. Regarding the research identity, the method is analytical and descriptive. "Hospital site selection is one of the multi-criteria decision-making problems" (Şahin et al. 2019). In this research, GIS techniques were used within field data to select the hospitals sites. Furthermore, the method of TOPSIS and Fuzzy Logic were implemented. At first, in this paper, for assessing hospitals' spatial distribution patterns, the "Nearest Neighborhood" method is used. Then effective criteria in identifying appropriate locations for hospitals are listed. According to literature and the views of the experts, we determined the following criteria: distances from industrial land use, education land uses, river, hospitals, sport land uses and proximity to fire stations, areas of green space,

and major roads. The use of multi-attribute decision-making methods and spatial analysis capability by the ArcGIS assess the data and the location of hospitals in Amol city (Fig. 2).

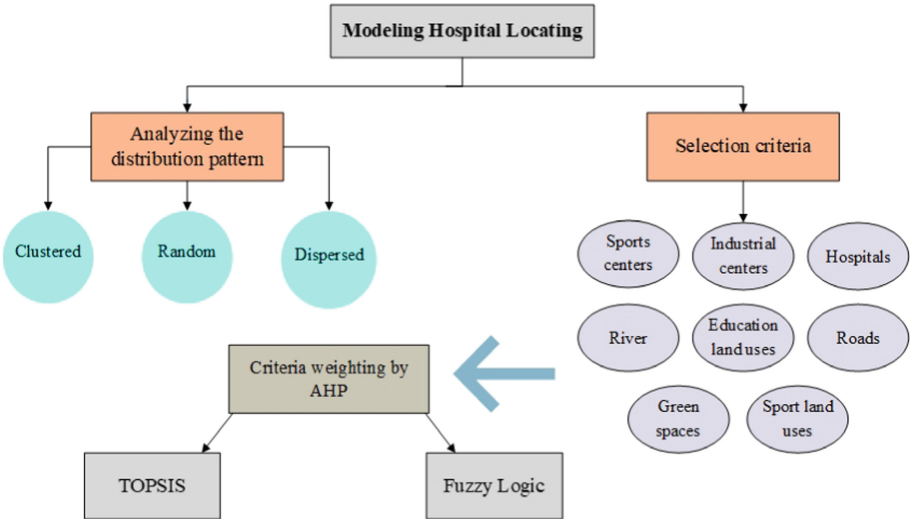

Fig. 2. Research methodology

4 Results

One of the most crucial approaches for analyzing urban land usage is the Nearest Neighborhood technique. According to this formula, when the criterion is between 0 and 0.5 the distribution form is clustered; it is random when between 0.5 and 1.5. When it is between 1.5 and 2.15 the distribution form is regular and ordered (Ali Akbari and Emadodin 2012).

According to numeric results, the observed nearest neighborhood among hospitals is 1461 m, and the expected average distance is 369 m. Thus, the nearest neighbor ratio is 3.95 that presents a dispersed distribution of hospitals in Amol. Z-Score is applied to explain the disparity in the number found with a random distribution. This value amounts to 9.80. On the basis of this quantity and the presumption that the trend of distribution was dispersed, the assumption is accepted with a significance level of 95%, and there was no significant difference between the distribution observed and the random distribution. The P-value of 0.00 demonstrates the credibility of the findings (Fig. 3).

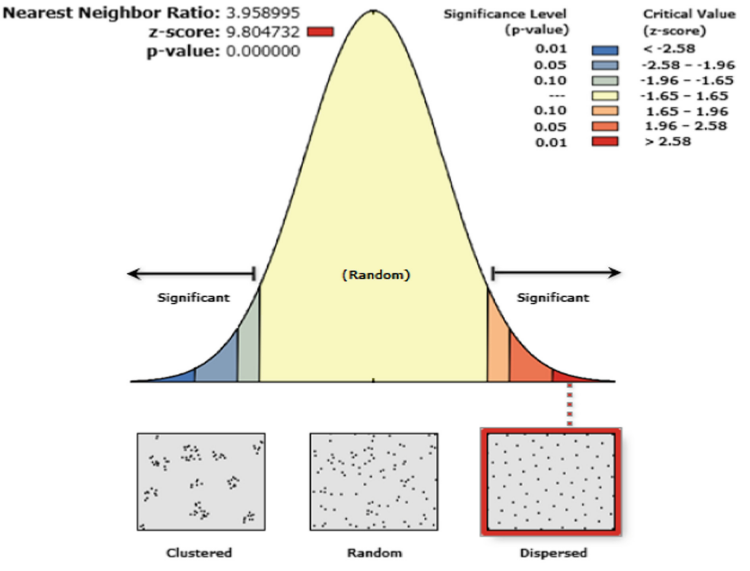

Fig. 3. Graphical display of hospital distribution in Amol city

The Nearest Neighborhood analysis results show that the hospital distribution is not acceptable and does not have a rational foundation in the case study. This issue provides rise to the notion that these hospitals must be organized. Table 2 shows the results of the ANN (Tables 1 and 3).

Table 2. The results of Nearest Neighborhood for analysis of the hospitals

The observed average distance	1461.4711 m
The expected average distance	369.1520 m
Nearest Neighbor Ratio (R)	3.958995
z-score	9.804732
p-value	0.000000

Table 3. Weights of criteria

Criteria	Proximity to major roads	Proximity to areas of green space	Proximity to fire stations	Distance from sport land uses
Weight	0.210	0.124	0.164	0.078
Criteria	Distance from hospitals	Distance from education land uses	Distance from industrial land uses	Distance from river
Weight	0.136	0.136	0.080	0.072

TOPSIS technique has been presented in Chen and Hwang (1992), concerning Hwang and Yoon (1981) that alternatives should have the shortest distance from a positive ideal solution and the most distant from a negative ideal solution (Jahanshahloo et al. 2009). After defining effective criteria in locating urban hospitals, data layers of criteria were entered in GIS. In the first step, raster layers were created based on the number of criteria used in this study using spatial analyst and the distance tool. Raster layers of used criteria are shown within the following figures (Figs. 4, 5, 6, 7, 8, 9, 10, 11).

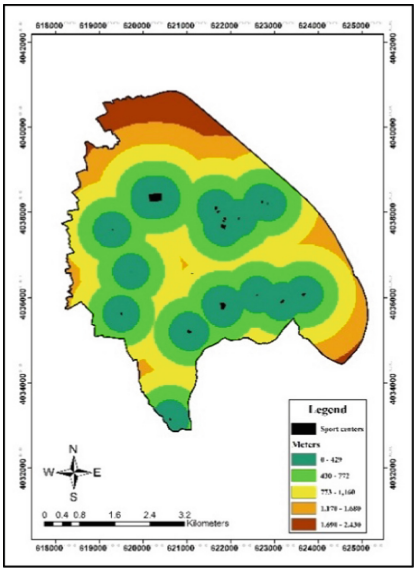

Fig. 4. Sports centers

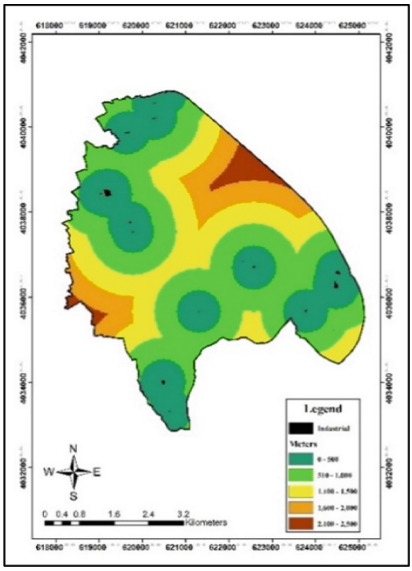

Fig. 5. Industrial centers

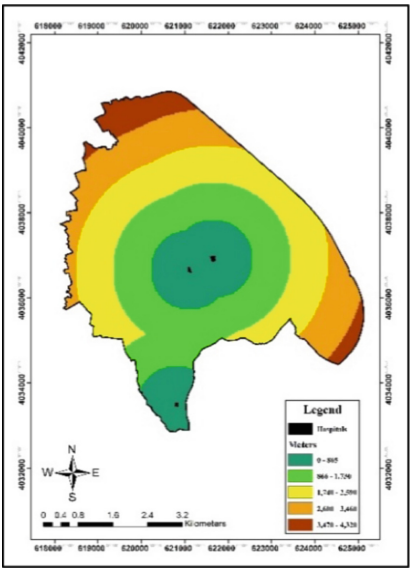

Fig. 6. Hospitals

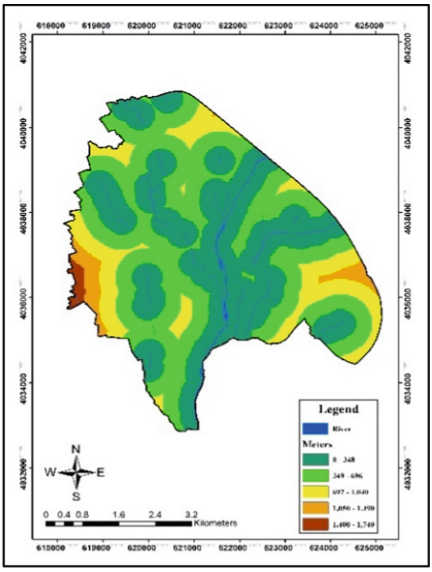

Fig. 7. River

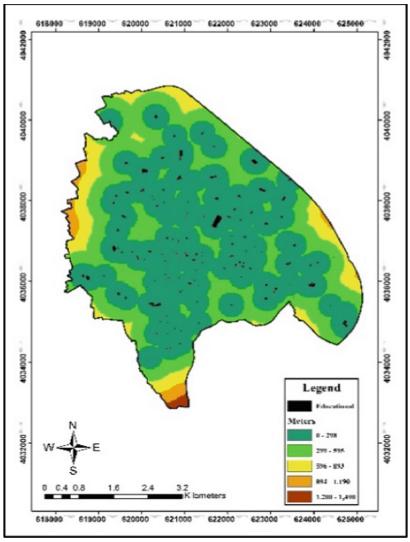

Fig. 8. Education land uses

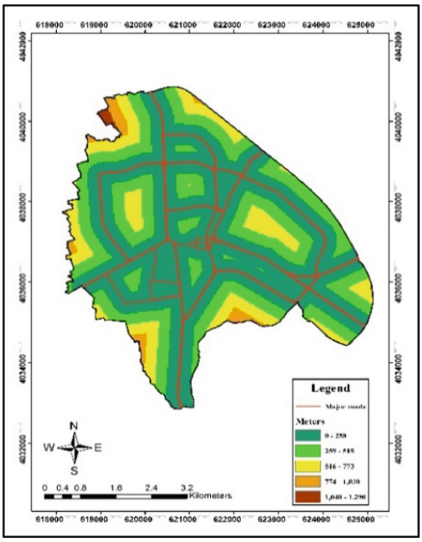

Fig. 9. Roads

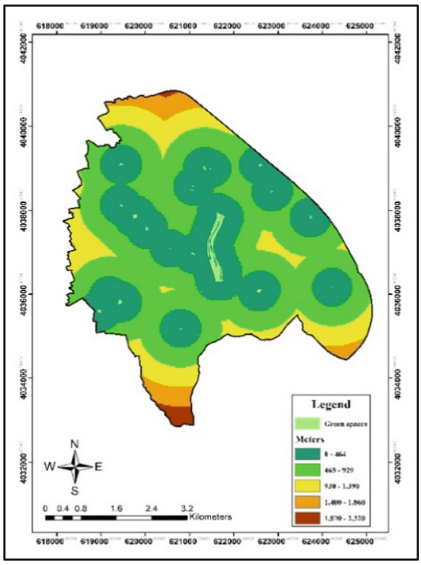

Fig. 10. Green spaces

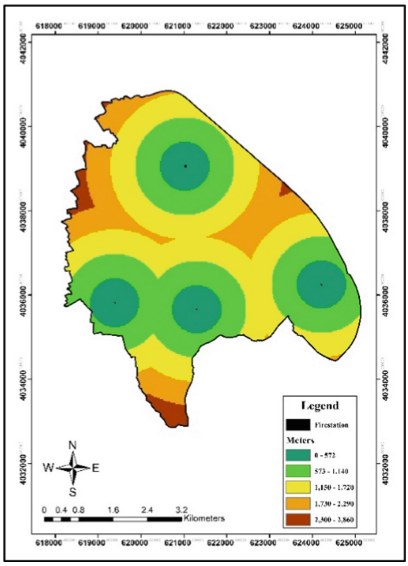

Fig. 11. Sport land uses

(Raster output of hospital locating criteria in the study area)

In hospital locating, the next step of TOPSIS is normalizing criteria that each of the criterion based on their effect (positive or negative) normalized by using the following formula, and a linear method is used for this purpose:

$$N_{ij} = \frac{r_{ij}}{Max\, r_{ij}}$$

After normalization, each layer is assigned a weight depending on its relative value in locating hospitals. For this purpose, the AHP model is used in Expert Choice software. AHP is one of the weighting methods that formulate the problem hierarchically. AHP is based on (1) hierarchy construction, (2) pairwise comparison, (3) relative-weight computation, (4) consistency ratio, and finally (5) aggregation of relative weights. In this research, we used the Expert Choice software that computes each criterion's weight according to the AHP model (Fig. 12). The consistency ratio of pairwise comparison is 0.01. That is acceptable because it is less than 0.1. In Fig. 12, see weights obtained from the AHP model.

Weights obtained from the AHP model in Expert Choice software, through Raster Calculator's command, were multiplied in normalized layers, and each of the criteria was weighted normalized. The map of weighted normalized criteria in this analysis is shown in Figs. 13, 14, 15, 16, 17, 18, 19 and 20.

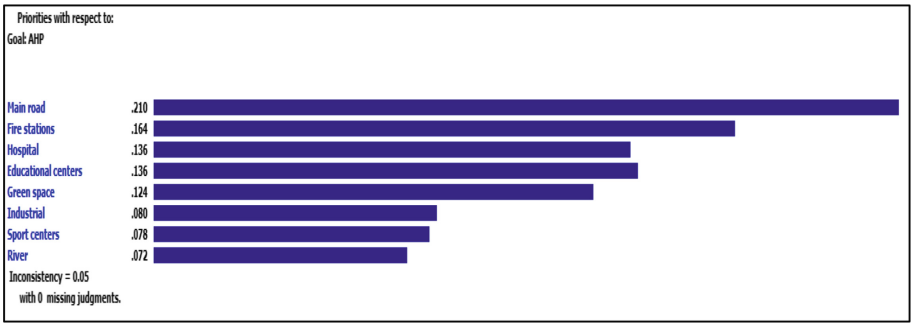

Fig. 12. The weights produced by AHP

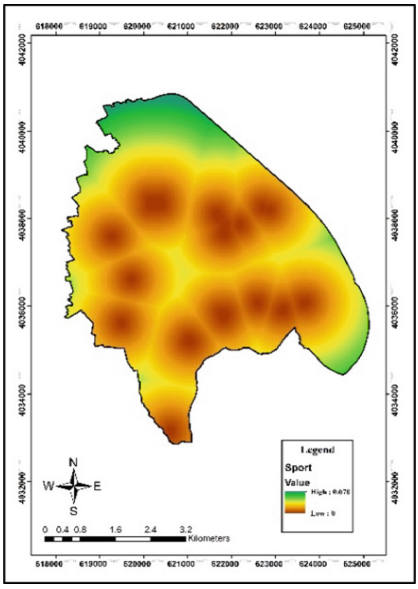

Fig. 13. Sports centers

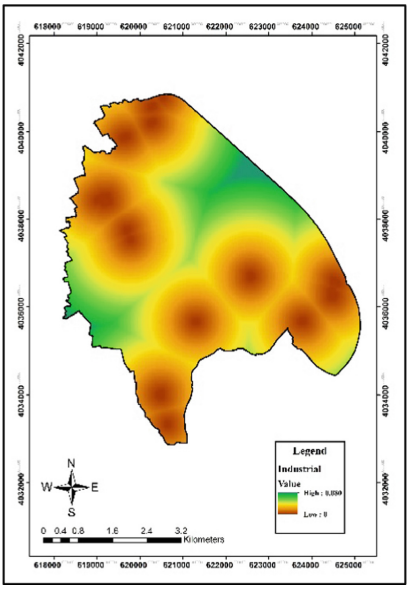

Fig. 14. Industrial centers

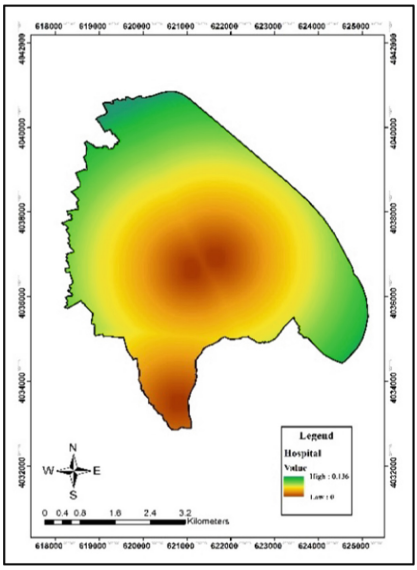

Fig. 15. Hospitals

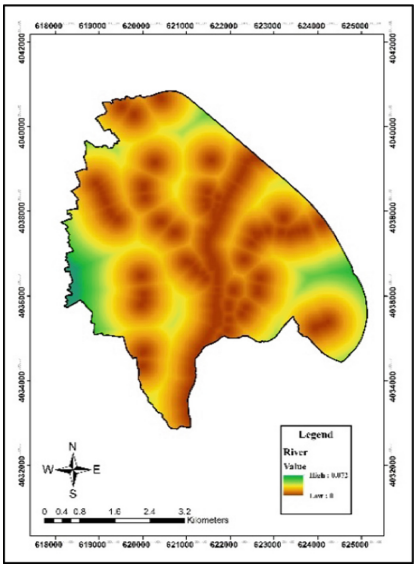

Fig. 16. River

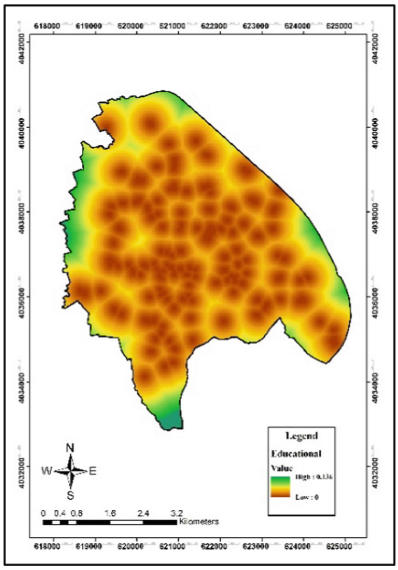

Fig. 17. Education land uses

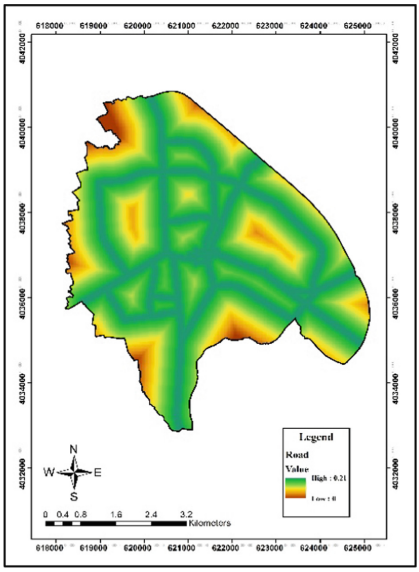

Fig. 18. Roads

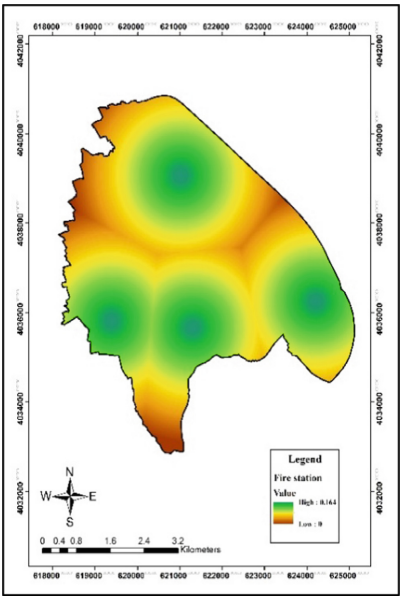

Fig. 19. Green spaces

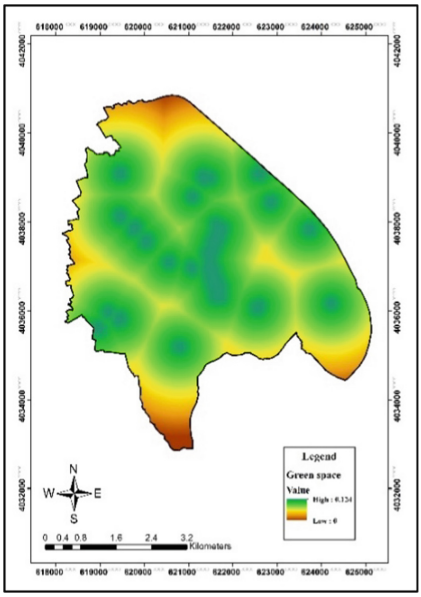

Fig. 20. Sport land uses

(The maps of weighted normalized for each option).

The distance between each alternative and the ideal solution will be calculated in the following step. For positive parameters, the highest pixels are the best values. For negative parameters, the lowest pixels and the worst values for positive parameters are the lowest pixels, and negative parameters are the highest pixels. Brown pixels are closest to the ideal positive and vice versa; whatever we are close to, the yellow hue represents the ideal is negative. The Separation measures from the positive and negative ideal solution are estimated (Figs. 21 and 22). The formulae used for this step are:

$$d_i^+ = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^+)^2}, \quad i = 1, 2, \ldots, m,$$

and

$$d_i^- = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^-)^2}, \quad i = 1, 2, \ldots, m.$$

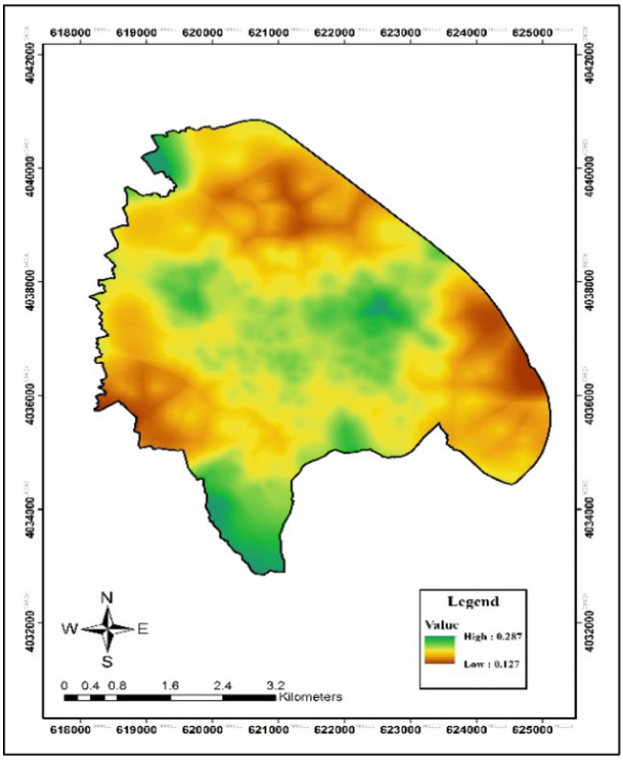

Fig. 21. Separation measure from positive ideal solution

For the positive ideal, the value of the pixels is between 0.29 and 0.13 which means that pixels closer to 0.29 have a good capability, and pixels with the value of 0.13 have the minimum ability for locating the hospitals. On the other hand, for the negative ideal layer, the location's value is also between 0.31 and 0.12, which means that pixels closer to 0.31 have the minor capability, and pixels with a value of 0.12 have a better ability for locating the hospitals.

Following the TOPSIS model for the spatial classification, for finding suitable places to locate hospitals in the case study, Ri factor is anticipated in a spectrum between 0.31 and 0.69. Ri factor is predicted by the following formula (Soufi et al. 2015):

$$R_i = \frac{d_i^-}{d_i^- + d_i^+}$$

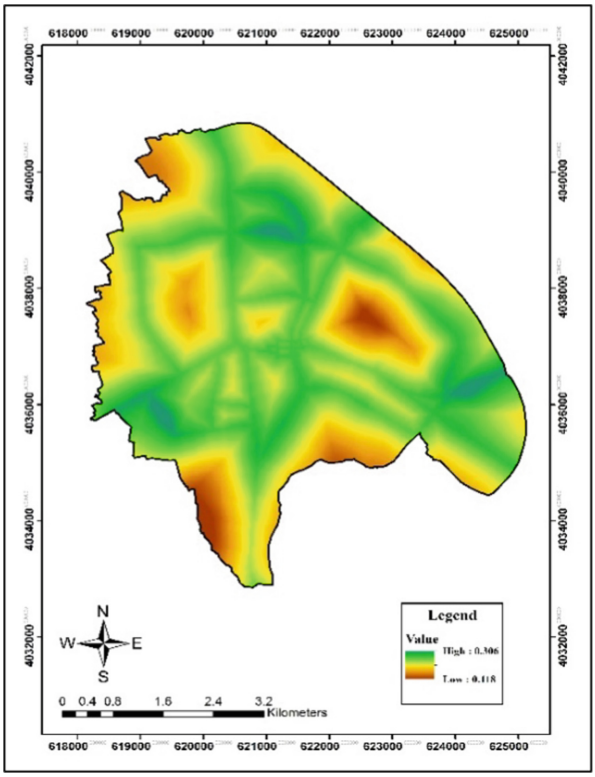

Fig. 22. Separation measure from the negative ideal solution

Spatial multifactor decision-making analysis reveals that if the location value is high, that place will be a good choice for locating a hospital. With this worth decreasing, this location loses its suitability for hospital building.

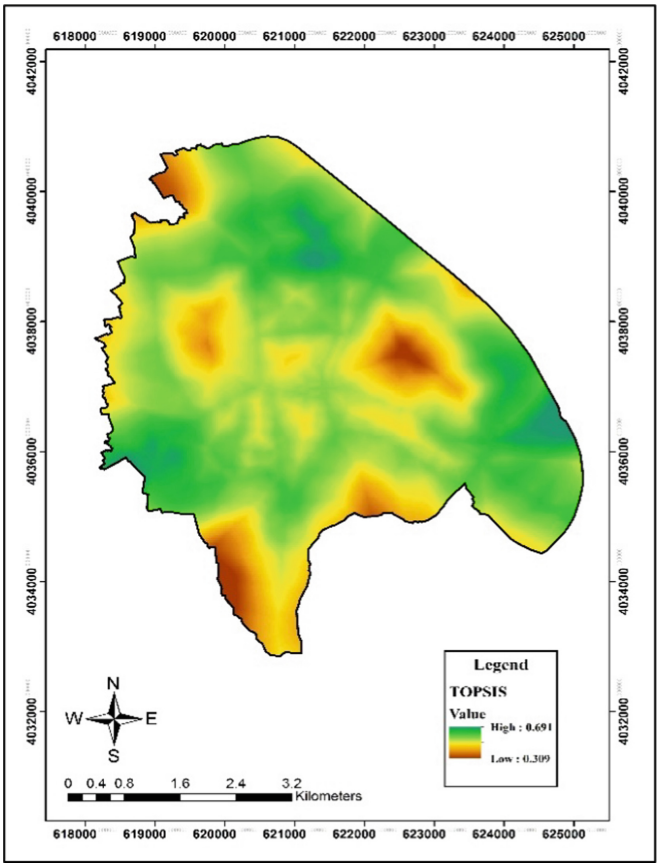

Fig. 23. Hospital site selection using TOPSIS model

The Fuzzy Logic theory was first suggested by Zadeh (1965), who believes that a descriptive variable of linguistics would more adequately represent a complex system (Cox et al. 1998); Dixon (2005). Due to the Fuzzy membership functions having more excellent compatibility with urban issues, using this system to analyze urban systems in decision making would be more effective. In Fuzzy Logic, an element's membership in a set was determined with a value ranging from 0 (non-membership) to 1 (entire membership) (Bonham-Carter 1994). It can prepare the map of a factor so that each pixel's amount includes the relative value of parameters compared with other hospital site selection parameters (Beheshtifar et al. 2010). For overlying the factors, some Fuzzy operators, like AND, OR, Product, Sum, and Gamma operator can be implemented (Kamran 2008; Esri (2011). The Overlay type for hospital locating was Gamma. Figure 24 is the final map and presents the best spaces for locating hospitals in the study area.

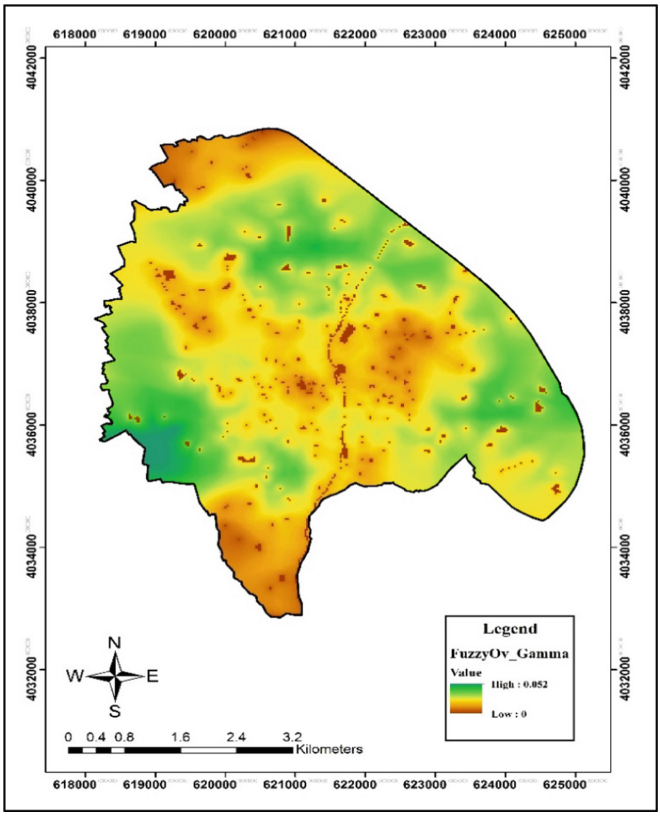

Fig. 24. Map of Fuzzy overlay for eight parameters

The TOPSIS method results show that the existing hospitals in the city are under the appropriate spaces. Still, in the Fuzzy Logic method, the existing hospitals are in concordance with the new hospitals' appropriate areas.

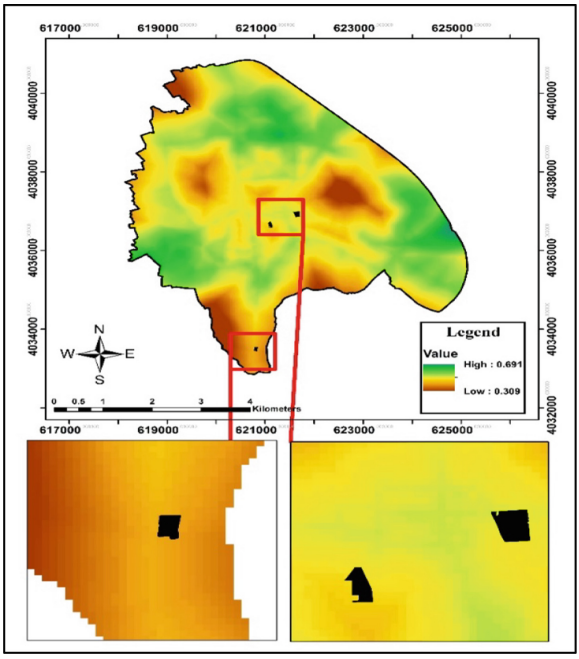

Fig. 25. Hospital locating map extracted by TOPSIS

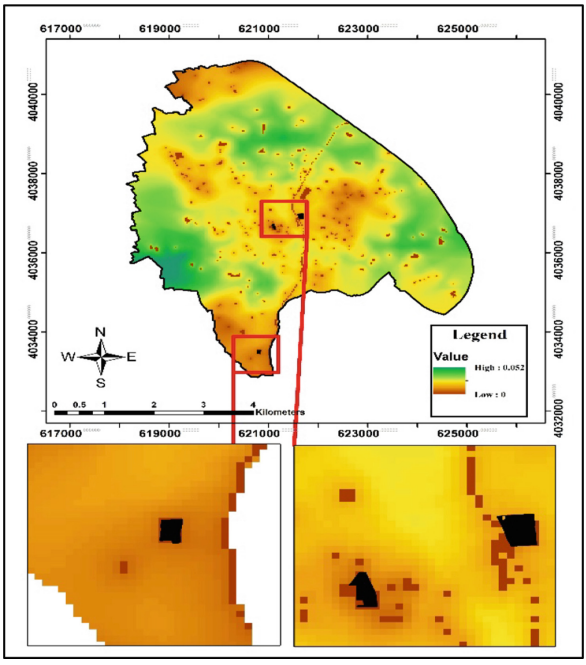

Fig. 26. Hospital locating map extracted by Fuzzy Logic

5 Conclusion

The shortage of land in urban areas moved cities toward adopting excessive density policies to respond to the growing demand for services, especially in big urban areas (Ranjbarnia et al. 2017). An important issue in health geography and health policy is the analysis of the accessibility to hospitals (Paez et al. 2010).

This research examined the application of two site selection methods for modeling hospital locating in urban land use. This study provides an application of the GIS for modeling hospital locating in cities. Studying the parameters and storing them in GIS software calculates each criterion's weight using the AHP technique (by Expert Choice software) and makes combined maps.

For analyzing the distribution pattern of hospitals, the Nearest Neighborhood method was used to understand spatial patterns of urban phenomena before assessment. The results of the Nearest Neighborhood demonstrate the inappropriate distribution of hospitals in the area of study. The distribution hypothesis's dispersed pattern with a 95% level of significance is confirmed concerning standardized scores. So, for reorganizing the inappropriate distribution of these hospitals the following eight criteria were used from the AHP technique: distances from the river, industrial land uses, education land uses, hospitals, sport land uses, and proximity to fire stations, areas of green space and major roads.

Results show that the efficiency of considered models is not the same in hospital site selection. The case study indicated the Fuzzy Logic model's desirable function in hospitals' location in Amol city. The TOPSIS method results show that the existing hospitals in the city are under the appropriate spaces. Still, in the Fuzzy Logic method, the existing hospitals are in concordance with the new hospitals' appropriate areas. Therefore, the ability of the Fuzzy Logic method is close to reality. In general, GIS is a powerful tool for locating urban facilities and demonstrates its capabilities by employing diverse and robust methods at the same time.

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