Centre for Research on Settlements and Urbanism

Journal of Settlements and Spatial Planning

Journal homepage: http://jssp.reviste.ubbcluj.ro

Selection of Appropriate Locations for Industrial Areas Using GIS-Fuzzy Methods. A Case Study of Yazd Township, Iran

Amir Reza KHAVARIAN-GARMSIR[1], Mohammad Reza REZAEI[2]

[1] *University of Tehran, Faculty of Geography and Urban Planning, Tehran, IRAN*

[2] *Yazd University, Department of Geography, Yazd, IRAN*

E-mail: amir.khavarian@yahoo.com, rezaei58@gmail.com

Keywords: *site selection, industrial area/town, Fuzzy GIS, Yazd Township*

ABSTRACT

One of the sites that may be developed in urban areas is the industrial town. Selecting a location for an industrial town is a complex problem that involves the evaluation of several factors of different types. This paper deals with the problem of finding an optimum site for such an area in Yazd Township, Iran, using Fuzzy-GIS methods. Nine criteria including road, fault, rail road, water resource, urban area, mountain, agricultural land, soil-protected area, wildlife and slope were determined and split into two categories, anthropological and geographical criteria. As a result, after making fuzzy maps and integration maps using fuzzy operators, appropriate locations were spotted for industrial areas in Yazd Township. The most suitable areas were extensively found in the eastern, northeast and southeast parts of Yazd city.

1. INTRODUCTION

Site selection for establishing urban activities/facilities is one of the crucial policy-related decisions made by urban planners and policy makers. The process of site selection is complicated inherently [27]. This complexity is mainly due to the fact that a large number of influential factors or variables have to be considered and that interactions and internal dependencies among these different factors are sometimes difficult to understand [31]. Industrial areas are one of the urban land uses that should be considered particularly because they involve 15-20% of total urban land uses [21].

Nowadays, industrial towns/areas are one of the urban spaces that have found their own place in the cities [18]. The location of industrial areas is a key factor in regional planning due to their social, economic and environmental impacts on any territory [22]. Therefore, how to locate industrial areas in a city is a key factor in regional planning, and the social, economic and environmental effects of these areas should be considered in regional development planning. Appropriate site selection for industrial areas in cities is, thus, faced with a wide range of factors to be evaluated in terms of both harms and benefits [1]. Access to transportation and communication infrastructures, work force availability, proximity to main markets, and raw materials are still major issues to be addressed [9], [15], [28].

In the past few years, researchers have shown interest in site selection of urban activities and facilities, but, so far, little attention has been paid to site selection of industrial areas and cities. This is in spite of the wealth of rather general texts as well as research on very specific features about site selection. Some of them are as follows: Önüt, Efendigil, and Soner Kara (2010) in shopping center site selection using fuzzy AHP [20];

Kuo, Lu, Tzeng, Lin, and Huang (2013) about developing an enhanced assessment approach to evaluate candidate sites for building an optoelectronics factory [14]; Soltani and Marandi (2011) in hospital site selection using two-stage fuzzy multi-criteria decision-making process [27]; Bailey, Goonetilleke, and Campbell (2003) in multi-criteria group site selection in GIS by providing a new fuzzy algorithm [3]; Koc-San, San, Bakis, Helvaci, and Eker (2013) about the final decision on the best location for an astronomical observatory, site testing measurements and atmospheric observations [13]; Mohajeri and Amin (2010) in railway station site selection using the methods of analytical hierarchy process (AHP) and data envelopment analysis (DEA) [17]; Nwogugu (2006) in US retailing industry site selection [19]; Vahidnia, Alesheikh, and Alimohammadi (2009) in hospital site selection using fuzzy AHP and its derivatives [29], and Wang, Qin, Li, and Chen (2009) in landfill site selection using spatial information technologies and AHP [30]. The aim of this study is to select the most appropriate location for an industrial area in Yazd Township, Iran, using fuzzy GIS.

The fuzzy GIS method was selected for dynamic modelling because it provides all the necessary outputs, it is easy to use, and has been extensively tested in other fields (Badenko and Kurtener, 2004 [2]; Chang, Parvathinathan, and Breeden, 2008 [6]; Dixon, 2005 [8]; Güler, Kurt, Alpaslan, and Akbulut, 2012 [10]; Jiang and Eastman, 2000 [11]; Mesgari, Pirmoradi, and Fallahi, 2008 [16]).

2. FUZZY SET THEORY AND GIS

The theory of fuzzy logic based on fuzzy sets was proposed by Zadeh (1965), who states that a complex system will be better represented by descriptive variables of linguistic type than by the traditional representation of differential equations [7], [8]. On the other hand, upon the development of computer-based geographic information systems (GIS), the potential of fuzzy set theory in GIS has begun to be addressed. For instance, in his article on the principles of logic in GIS, Robinove (1986) discusses the potential value of fuzzy set theory [24]. Indeed, the relevance of fuzzy sets to GIS was recognized by a relatively small group of researchers many years ago [25].

In fuzzy logic, the membership of an element in a set is defined by a value ranging from 0 (non-membership) to 1 (full membership). Usually, the membership degree is stated with a membership function whose shape can be continuous or discontinuous, and linear or nonlinear [5].

In fuzzy GIS, pixels are assigned an amount from 0 to 1, which indicates the suitability of the pixel location with respect to factors and indexes for the intended purpose (industrial area site selection in this context). The map of a factor can be prepared so as for the amount of each pixel to include the relative importance of factors in comparison with other site selection factors [4]. Factor maps may integrate some fuzzy operators, such as the fuzzy AND, fuzzy OR, fuzzy algebraic product, fuzzy algebraic sum and fuzzy gamma operator [12]. These operators are defined as follows:

Fuzzy intersection operator (AND). The fuzzy intersection operator is defined in Equation (1). Eq. (1).

$$\mu AND = MIN\ (\mu A, \mu B, \mu C....,)$$

In this equation, μA, μB and μC show the fuzzy membership values of the pixels in a specific location on maps of different factors.

Fuzzy Union Operator (OR). This operator is defined in Equation (2). Eq. (2).

$$\mu OR = MAX\ (\mu A, \mu B, \mu C, ...)$$

In this equation, μA, μB and μC are similar to those in Equation (1).

Fuzzy Algebraic Product Operator (Product). The fuzzy multiplication operator is defined in Equation (3). Eq. (3).

$$\mu Product = \prod_{i=1}^{n} \mu i$$

In this equation, μi shows the membership value on the map of *i* factors. By using this operator, the membership values prove to be small on the export map and tend towards zero. Therefore, combining the elements will have a depressing effect. In other words, they weaken each other.

Fuzzy Algebraic Sum Operator (Sum). This operator is defined in Equation (4). Eq. (4).

$$\mu Sum = 1-(\prod_{i=1}^{n}(1-\mu i))$$

In this equation, μi shows the membership value on the map of *i* factors, too. By using this operator, the membership values turn out to be large and tend towards 1. Therefore, combining elements will have an increasing effect. In other words, they reinforce each other. Unlike union and intersection operators, in algebraic products and sum operators, all of the input maps membership values affect the output map.

Fuzzy Gamma Operator. This operator is obtained by multiplying operators of product and sum as defined in Equation (5): Eq. (5).

μγ = (Fuzzy algebraic Sum)γ × (Fuzzy Algebraic product)1-γ

In equation (5), the amount of γ is a number from 0 to 1. A correct and conscious choice from 0 and 1 for γ creates values in the output that show flexible compatibility between the decreasing trends of the fuzzy algebraic product and the increasing trends of the fuzzy algebraic sum [4], [5], [12]. Usually, one sole fuzzy operator cannot be used to integrate all of the data layers. Different fuzzy operators provide a high level of flexibility in data integration. Selecting an operator is based on the characteristics of the data layers and their role in the application [12].

3. LOCATION OF THE STUDY

The study area, Yazd Township, is the capital of Yazd Province located in the centre of Iran. Yazd has an area of 99.5 km² and a population of 432,194. It is the second historical city in the world and the seventh largest city in Iran. According to some historians, the first foundation of Yazd dates back to Alexander the Great. On the other hand, some other historians hold that the city was founded and named Yazd at the order of Yazdgerd I (339-421 A.D). The city is located at 54°22´ east and 31°53´ [26].

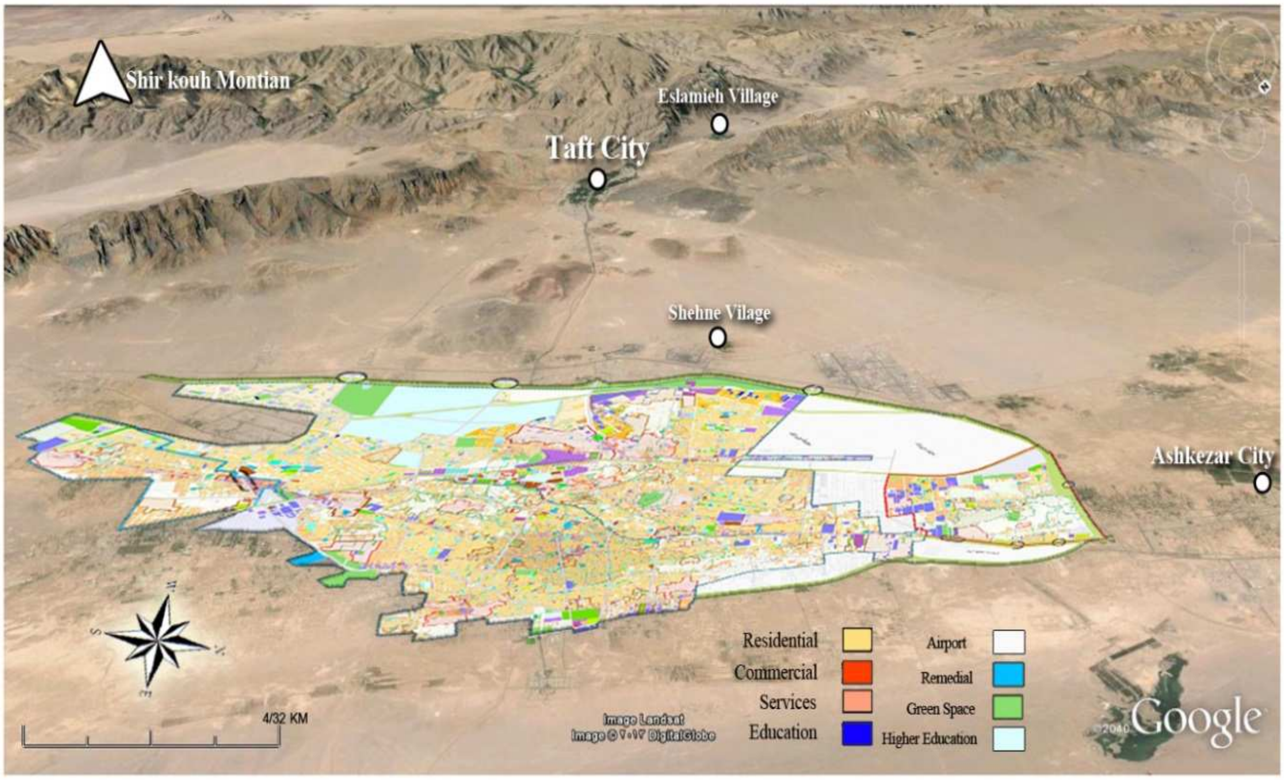

Fig. 1. Spatial location of Yazd Township and Yazd City in the region.

4. METHODOLOGY

The general approach used in this research combines the results of a four-stage analysis involved in the selection of an appropriate site for industrial areas. Stage one considers the criteria/factors and stores them in the GIS environment. Stage two determines the weight of each criterion using the AHP method and Expert Choice software. Stage three makes a Euclidean distance map for fuzzification and reclassifying. Stage four combines the maps with suitable operators and creates a final map.

5. SELECTION OF APPROPRIATE LOCATIONS FOR AN INDUSTRIAL AREA IN YAZD TOWNSHIP

A "Weighted Suitability Model" is developed using GIS techniques depending on a number of thematic layers. In this study, the main thematic layers are generated as an input for selecting suitable sites for industrial areas. A number of processes are performed to prepare these layers to use as an input in a Fuzzy-GIS model [23]. In GIS site selection, all of the criteria are in the form of layers. The criteria used in this study are faults, railroads, roads, water resources, urban areas, agricultural lands, mountains, soil, protected areas, wildlife and slopes. Table 1 shows a classification of the criteria.

Table 1. Classification of criteria.

Anthropogenic data sets	Geographical data sets
Road Railroad Urban area Agricultural land	Fault Water resource Mountain Soil Protected area and wildlife Slope

Since there is no protected area or wildlife in our study area, and the soil is of one type, these factors are excluded from the set of the criteria. Finally, the selected layers are railroads, roads, Yazd city area, other city areas, mountains, faults, water resources, agricultural lands, and slopes. In the next step, the weight of each layer is determined. For this purpose, Expert Choice software is used. The weight of each criterion is presented in Table 2. In the next step, all the layers are recruited, and output maps of Euclidean Distance are made. Then, all of the layers are reclassified and transformed into a fuzzy spectrum. Finally, the layers are given the calculated weights. Figure 2 shows the spatial distribution of memberships.

Table 2. Layer criteria.

Layer	Membership function	Weight	Layer	Membership function	Weight	Layer	Membership function	Weight
1. Railroads	Linear	0/182	4. Water resources	Linear	0/051	7. Mountain	Linear	0/040
2. Roads	Linear	0/144	5. Yazd City area	Linear	0/241	8. Cities	Linear	0/096
3. Faults	Linear	0/036	6. Agricultural lands	Linear	0/101	9. Slope	Non-linear	0/110

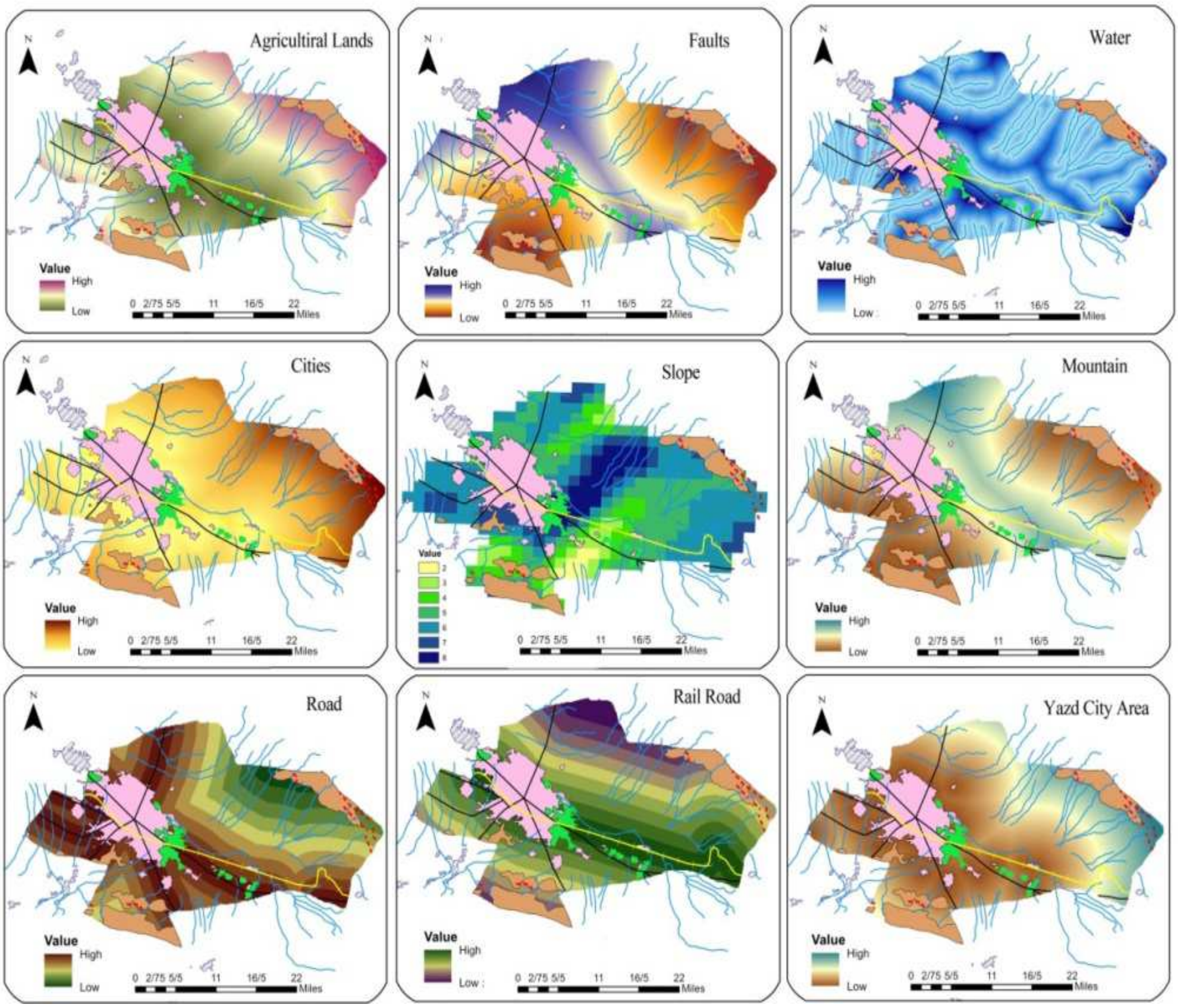

Fig. 2. Maps showing the spatial distribution of memberships of nine input parameters in the study area.

In Figure 2, the map of *"agricultural lands"* has a linear membership in which the cells get a higher value with the increase of distance. The maps of *"faults"*, *"water"*, *"Yazd city area"*, *"cities"*, *"slopes"*, and *"mountains"* have the same function as the agricultural lands. The maps of roads and railroads have a linear membership, but the cells get a lower value with the increase of distance. After making the fuzzy model maps, it is necessary to integrate these maps using fuzzy operators. The selection of appropriate operators for combining different layers is in accordance with the relationship and interaction among the layers. Usually all the layers cannot be combined with one operator. In this study, the "OR" operator is used to combine two layers of roads with the railroads as well as cities with the Yazd city area. The other layers are combined with the "AND" operator. Figure 4 is the final map and shows the appropriate locations for industrial areas in Yazd Township.

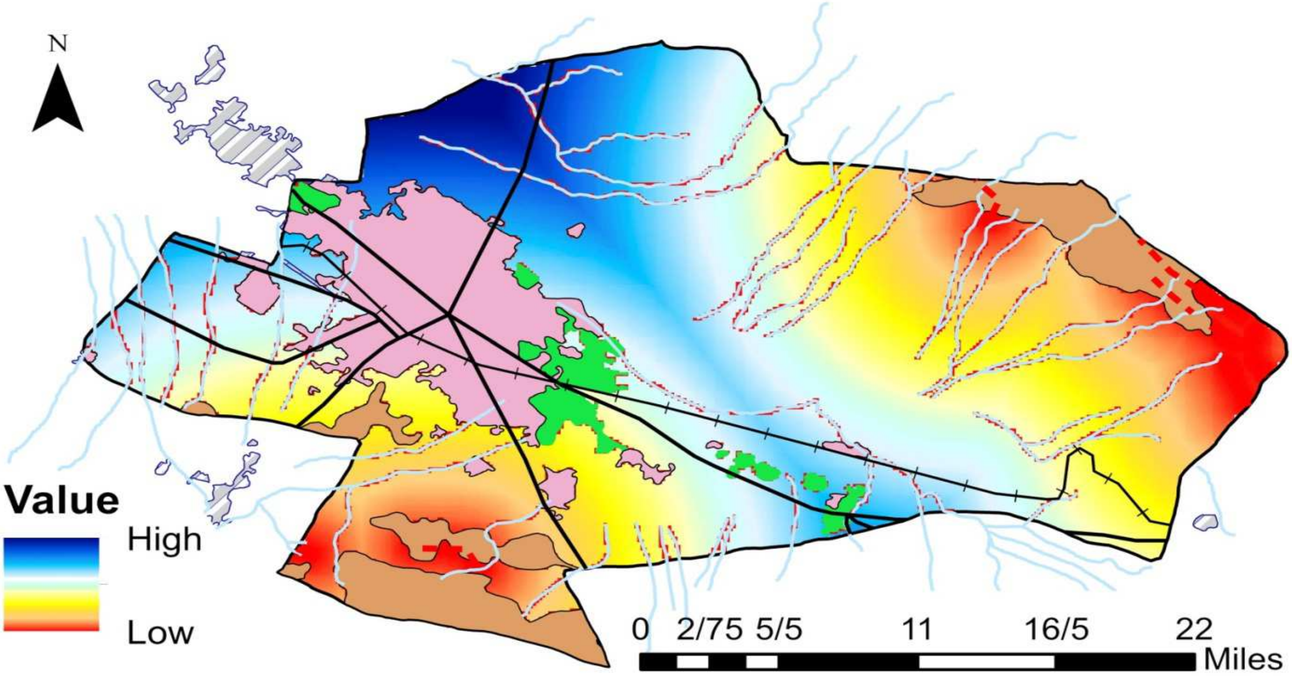

Fig. 3. Map of site selection for industrial areas in Yazd Township.

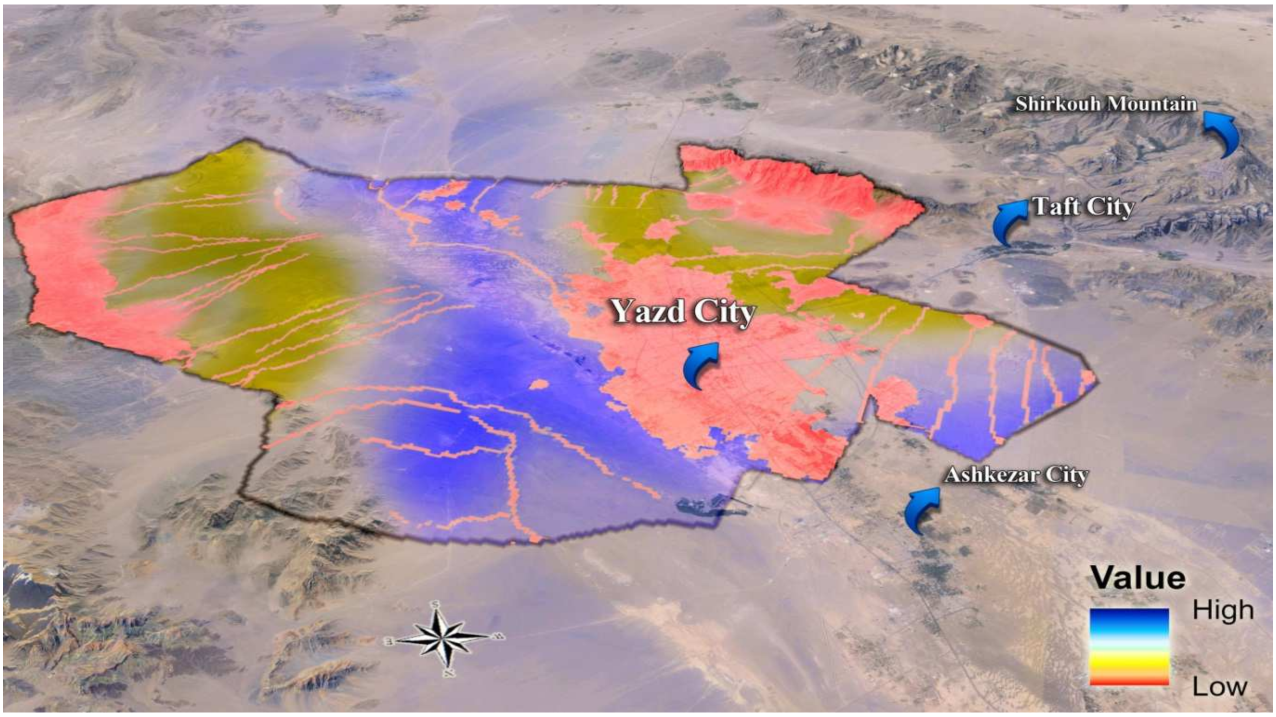

Fig. 4. The proportion of appropriateness of different points in the study area for locating industrial areas.

A better indication of optimum locations for industrial areas is provided in Figure 4. To produce this figure, Arc GIS, Google Earth and Adobe Photoshop software were employed. As it can be seen in the figure, the most suitable areas are located in the east, northeast and southeast of Yazd city.

6. CONCLUSION

This study provides an example of how to apply Fuzzy GIS to site selection for industrial areas. By handling and evaluating complex criteria, our approach proves to be an efficient and powerful one for industrial area site selection studies. The general approach used in this work combines the results of a four-stage analysis and considers the corresponding criteria/factors and stores them in a GIS environment. The criteria used in this study are selected according to the factors that are significant in the study area. They are as follows: roads, faults, railroads, water resources, urban areas, mountains, agricultural land, soil-protected areas, wildlife and slopes. To determine the weight of each criterion, AHP method and Expert Choice software were employed. Also, Euclidean distances were determined, fuzzification and reclassification of maps were performed, combining maps was done with suitable operators, and eventually the final maps were created.

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