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ORIGINAL RESEARCH PAPER

Modelling fuzzy multi-criteria decision-making method to locate industrial estates based on geographic information system

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Abstract : Existing conditions for locating urban equipment and facilities require a set of limiting and reinforcing factors. Interaction of environmental, industrial, social and political changes in our rapid growth adds to the complexity of regional systems. Locating takes place by various methods, in which the priority is the application of modern methods leading to reduced uncertainty. The present study aimed to select the best location using nine criteria (slope, distance from fault, distance from river, distance from road, and distance from villages, soil type, land use, average temperature, and average rainfall) in GIS software for mapping. Fuzzy logic and fuzzy-analytical hierarchy process (FAHP) model were applied to reduce location uncertainty. The accuracy of the results was checked using field data, in which six stations designated for the establishment of industrial estates in the study area were compared with the results of the FAHP model. The results of FAHP model in GIS software and their validation showed that the proposed model has excellent capabilities in locating industrial estates.
Keywords: GIS, Fuzzy Logic, Spatial planning, Industrial Estate

Introduction

The Industrial Revolution has brought about a fundamental change on the face of the earth in recent centuries. Altered production methods and increased productivity alongside accelerated communication and transportation have led to changes in urban fabric. The population explosion and the growing need for advanced and modern industries and factories strengthened the idea of constructing and developing production and industrial spaces in the form of industrial estates. The current situation in Iran and the establishment of industrial estates in different parts, even after the passage of the law on Company towns in Iran, shows that not only is the issue of spatial planning, whether on a national or regional scale, not considered even in the current situation, and the division of labour and scope of tasks are not considered from an expert point of view, but also policies and influences cause the formation of problems related to the implementation of spatial planning (Jafari and karimi, 2005). This will interfere with the tasks and reduce the efficiency of industrial estates.

Basic approaches to locating each development activity require a set of limiting factors such as slope, altitude, and environmentally protected areas, as well as reinforcing factors such as access to resources, roads, markets, and suitable land (Keneth, 2000). Interaction of environmental, industrial, social and political changes in our rapid growth adds to the complexity of regional systems. Locating estates is based on the accumulation of related industries and environmental issues, representing the need of society for special spaces for the production and distribution of goods. Tourism development, preservation of beautiful natural landscapes, expansion of environmentally protected areas and location of service centres, factories, production units and warehouses are among the topics that most spatial planners deal with. Each country is forced to select and organize axes, poles and places with industrial units as a town or complex in terms of spatial planning and division of labor in different regions of the country with the aim of industrial development (Forslid et al., 2002; Alipour et al., 2019). This organization is influenced by factors such as population growth, employment, land constraints, environmental protection and development, and determination of industrial land use. Accordingly, both the uncontrolled growth of industry in different regions and also the pollution of the environment is prevented (Pooladdezh, 1997; Chiu and et al, 2004; Mirata and et al, 2005; Alipour et al., 2015).

Various methods and algorithms for locating have been performed by researchers (Densham et al, 1988; Witlox et al, 2000; Jaszkiewicz, 2002; Brookes, 2001; Sial et al, 2006; Nidumolu et al, 2006; Fataei and Al-Sheikh, 2009; Fataei et al, 2015; Feyzi et al, 2019;). Fernandez et al. (2009) used an integrated model of index overlap (IO) and analytical hierarchy process (AHP) weighting method to simplify the decision-making process and location of industrial estates. Esmaeili Hyderabad (2007) in a study to locate the industries of Ardabil city (Iran) considering primary and secondary prevailing winds, has proposed the current

situation of industries in terms of location and type of industrial production in optimal places for the establishment of Ardabil industries. Babaei and Ownegh (2006) in Iran evaluated the development potential and land use planning of Posht-e-kouh watershed. In this study, using the current system model in land use planning with bi-compound and manual methods, the main data layers were combined sequentially and finally 387 non-repeatedly environmental units were separated and mapped as work units for potential assessment and land use management. Then, possible land use priority was determined and watershed land use planning map was organized using comparative qualitative method. Fataei (2015) investigated the feasibility of constructing a border industrial estate using TOPSIS and AHP (a case study in Ardabil province, Iran). Aalipour et al. (2020) studied the Assessing the Conformity of Industrial Development with the Development in Ardebil Province Using Fuzzy Multi Criteria Decision-Making Method. In this study, using fuzzy logic and GIS, a model was proposed to locate and implement a new industrial estate in Bileh Savar county. In order to verify and determine the best model, a field visit was made to different areas and existing industrial estates in the area.

Study area:

Bileh Savar is a city located in Ardabil province and in the northwest of Iran between the geographical coordinates of 47 ,36 -47 ,22 east longitude and 39 ,12 - 39 ,33 north latitude. This city is adjacent to Parsabad city from the north and west, to the Republic of Azerbaijan from the east, and to Germi city from the south. According to 2011 statistics, the population of the city is 53,768 people, about 48% of whom are men and the remaining 52% are women (General Census of Population and Housing, 2011; Alipour et al., 2018). The main occupation of Bileh Savar residents is agriculture and trade. Fertile soil, favorable climate for agriculture and animal husbandry, and the presence of active manpower led to the prosperity of agriculture. Animal husbandry is also thriving in this city, and all kinds of animal products are considered as export products of the city.

Bileh Savar city has been important because of the facilities built in this city in the past in terms of the exchange center between Iran and the Republic of Azerbaijan. The border bazaar of this city is the center of presenting and distributing the items needed by the people of the region and based on border communications and border exchanges. Active customs in the region indicate high daily exchanges across the border between the two countries. Most exchanges are even for the entry and exit of many people from the border into the country and in fact the entry of currency and capital into the country. Figure (1) shows the location of the study area in the country and province.

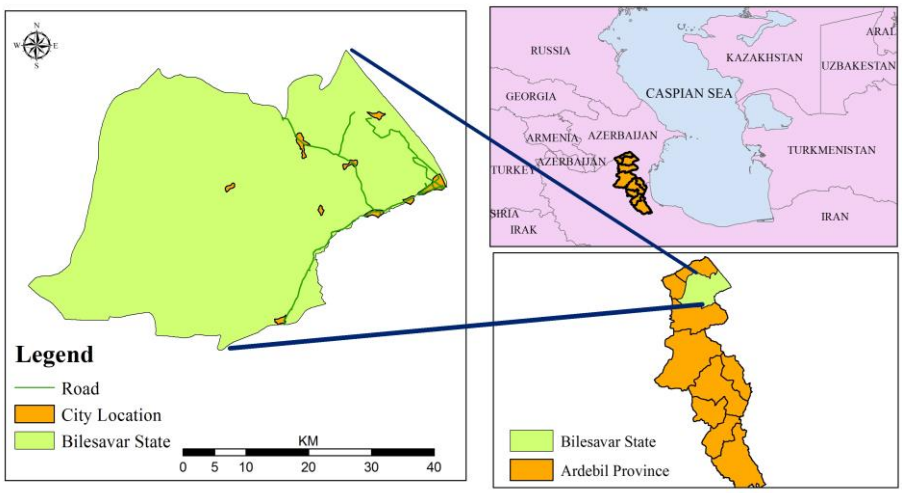

Figure 1: Location of Bileh Savar city in Ardabil province, Iran

Materials and Methods

The industrial estate of Bileh Savar was located using Fuzzy-analytical hierarchy process (FAHP) model and GIS software based on nine criteria (including slope, distance from fault, distance from river, distance from road, distance from villages, soil type, land use, average temperature, average rainfall). Figure 2 shows the research algorithm. The multi-criteria decision-making process in GIS can be thought of as a process that combines spatial data and evaluation values. The current multi-criteria analytical methods in GIS such as Boolean operators and AHP model have been used in many land use evaluation and assessment issues (Nami et al, 2017; Molaei et al, 2018).

Fuzzy-analytical hierarchy process (FAHP) model

The concept of being fuzzy in the AHP method has been considered indirectly without the use of fuzzy sets. In this method, using Linguistic terms, the concept of being fuzzy is involved in determining pairwise comparison matrices. However, by generalizing the above method, researchers have proposed methods in which fuzzy numbers are used to express the preference of elements. In the meantime, we can refer to the methods proposed by Larhon and Pedricz and Buckley.

The Larhon and Pedricz method suffers from some weaknesses that have been addressed in the Buckley method (Motiei-langroudi et al., 2012). Therefore, this study benefited from the Buckley's fuzzy analytic hierarchy process (FAHP) method.

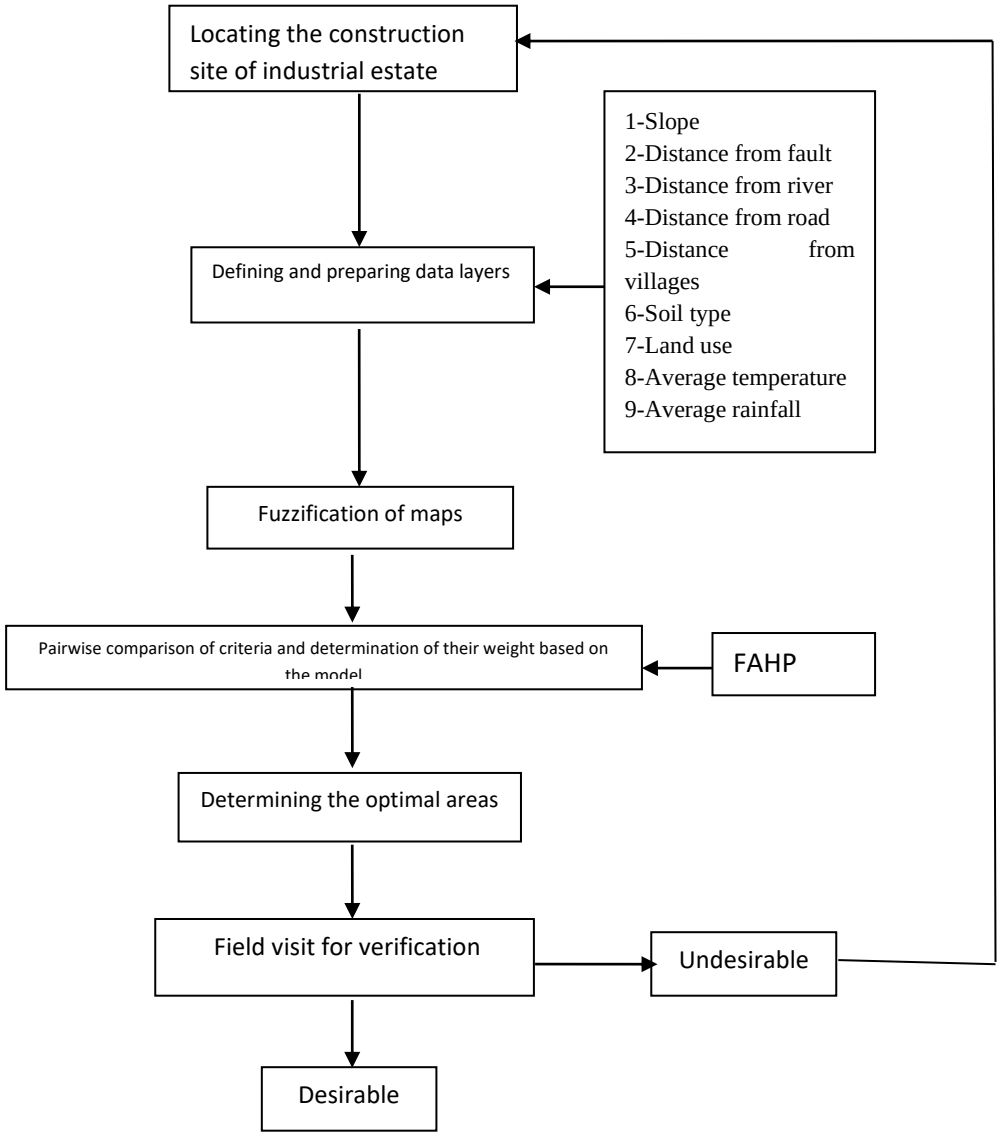

Figure 2: Proposed location model

Buckley's FAHP method is a generalized form of the classical AHP method. In this method, fuzzy numbers are used for pairwise comparison of options and geometric mean is employed to calculated weights and preferences, because this method can be easily generalized to fuzzy mode; it also determines a single response for the matrix of pairwise comparisons. In this method, the decision maker can express the pairwise comparisons of the elements of each level as trapezoidal fuzzy numbers. For example, the trapezoidal fuzzy number of (6, 5, 5, 4) indicates a preference of "about 5 to 1" and the number of (9, 8, 6, 5) represents a preference of "between about 6 to 1 and about 8 to 1 "(Samadi Khadem et al., 2020).

Data analysis

First, the parameters and criteria for screening suitable locations for industrial estate were evaluated and selected. Then, by preparing data layers related to each parameter and digitizing, the layers were imported into GIS. In this phase, each of these layers was evaluated based on their effects in determining suitable land, and was prepared and fuzzified. In the fuzzy step, the inputs are converted to fuzzy information. This means that the numbers and information to be processed will become fuzzy sets and numbers. The input data, as measured by sensors in a control system, is thus modified and prepared for fuzzy logic processing. The FAHP model was recruited to weight the criteria for determination of the appropriate location. The weights were calculated programmatically in Matlab software $V_{9.10}$. All criteria

were compared pairwise. Experts in the region were recruited to perform these calculations. Suitable locations were selected using the layers obtained from the standardization of the maps with the aid of limiting criteria and based on the weight computed for different layers. To perform this operation in Arc GIS10 software, the data layers were first combined using overlay functions.

Locating the industrial estate of study area was performed on the basis of nine criteria, including slope, distance from fault, distance from river, distance from road, distance from villages, soil type, land use, average temperature, average precipitations. Fuzzification of related maps for the final analysis was performed to reduce the uncertainty and impact of the different units of the layers used; Figure 3 shows the fuzzified map of the criteria:

Results

- Fuzzification of criteria

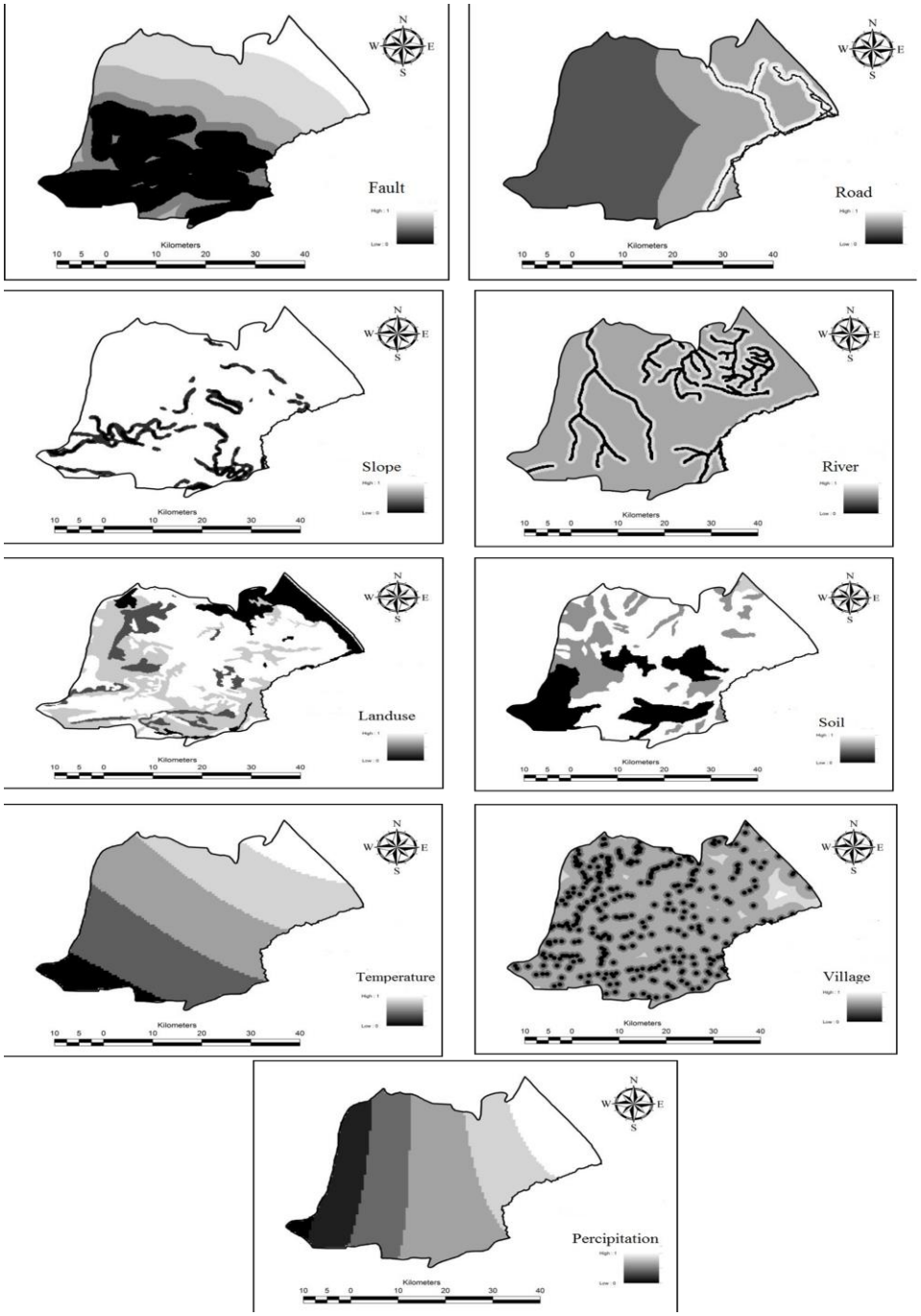

Figure 3: Fuzzified map of the main criteria in the modelling process

- Outcomes of FAHP model

Implementation of this model requires weights and numbers related to pairwise comparisons for input factors. For this purpose, a questionnaire was prepared containing pairwise comparison of study criteria. Linguistic terms were applied to perform pairwise comparisons and then these comparisons were imported into the model. FAHP programming was utilized to obtain the final weight (Table 1) for the criteria. Then in the GIS, the weight of each layer was assigned; The results for areas suitable for industrial estate using the FAHP model are shown in Figure (4).

Table 1- Final weights obtained for the criteria used in locating industrial estate using the FAHP model

Criteria	Weights	Criteria	Weights	Criteria	Weights
Slope	0.165	Distance from road	0.1	Land use	0.17
Distance from fault	0.117	Distance from villages	0.08	Average temperature	0.061
Distance from river	0.143	Soil type	0.11	Average rainfall	0.054

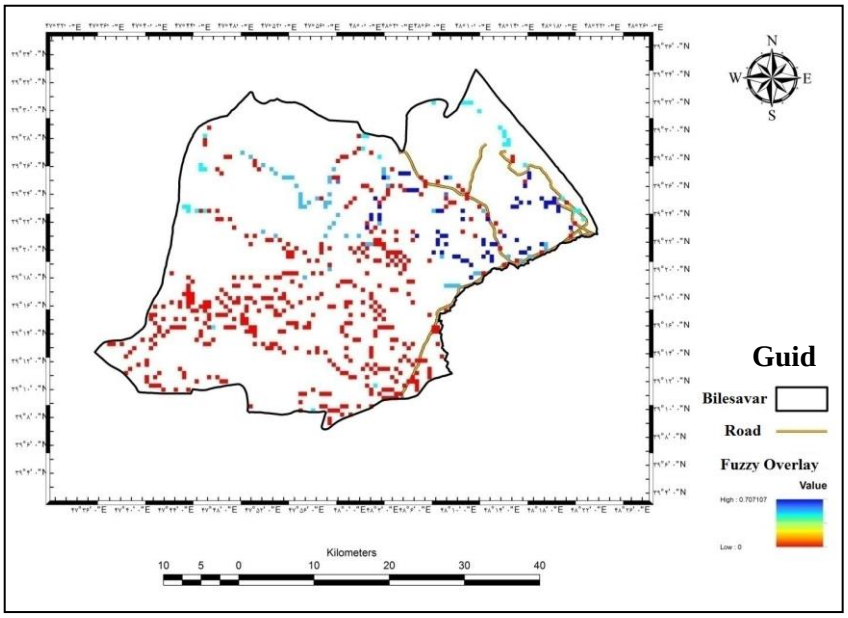

Figure 4: Results of analysis based on FAHP model

Validation of results

In order to evaluate the results of locating suitable areas for the establishment of border industrial estate using a combination of fuzzy model and GIS technique, six candidates were selected as potential locations based on social, economic and environmental issues as a target for validating the final location of industrial estate (Figure 4).

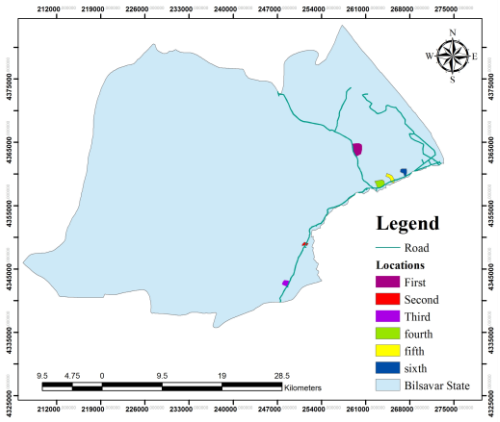

Figure 4: Prioritization of suitable locations based on ecological, economic and social relations

In order to evaluate and validate the FAHP model, the value of the analyzed options was extracted from Figure 3 and shown in Table 2.

Table 2 - Values related to validation locations for different operators and their accuracy

	First	Second	Third	Fourth	Fifth	Sixth	Model Final Accuracy
FAHP model Accuracy	0.58	0.32	0.34	0.61	0.7	0.69	0.6

Based on the table, it can be seen that the value of the studied and preferred locations in the FAHP model has a value of 0.6, which has a satisfactory value and indicates the accuracy of the results.

Discussion and Conclusion

Industrial development is one of the main requirements for the comprehensive development of a region. In order to establish and develop various industries, the first stage of the development process is locating the construction site of industrial estate. There are various criteria for improving the location process, the most important of which are ecological criteria. Bileh Savar region, due to its special characteristics both ecologically and socio-economically, needed to establish a new industrial estate to continue the processes of industrial development in the region. The topological pattern of the area shows high altitudes near the urban area (Bileh Savar city). On the other hand, the proximity of an industrial estate to an urban area (with respect to privacy) is a prominent feature of an industrial estate. These topological features have affected the location pattern in the area both in terms of traffic in the area and in terms of the slope of the area. An important advantage for the region is the existence of a border with the Republic of Azerbaijan in terms of economic exchanges and the relative proximity of Bileh Savar to other major cities in the province to the provincial capital (Ardabil) and also the rich resources in the region. According to the mentioned cases, the desired location was done for this area. In this study, fuzzy logic and their output were compared with field results. This study revealed that GIS and fuzzy logic, which have analytical ability and work with a variety of criteria as well as are able to analyse large volumes of data, can be considered suitable tools for locating industrial estates. Moreover, the results of this study demonstrated that the implementation of fuzzy model using the capabilities of GIS in locating industrial estates is highly efficient, and provides the capacity to compare and evaluate different sites and select the admirable sites according to the desired criteria. Accordingly, the proposed model can be generalized to other cities in the country and can be used in locating industrial areas. On the other hand, given the characteristics of other cities, the criteria can be revised and scrutinized, and this will not interfere with the overall model.

Conflict of interest

The authors declare that they have no conflict of interest.

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