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CASE STUDY

An integrated environmental management approach to industrial site selection by genetic algorithm and fuzzy analytic hierarchy process in geographical information system

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ABSTRACT: Environmental planning and management can have positive effects on development of some land uses including industrial areas that have a major effect on economic, social and environmental conditions. Considering the most important problems associated with modeling, the fundamental methods and functions of site-selection laid inside the geographical information system are not accounted for the multi-purpose experimental programs. The main purpose of this study is to present a systematic pattern for environmental management using genetic algorithm and fuzzy analytic hierarchy process in geographical information system in order to reduce uncertainty. Through fuzzy analytic hierarchy process, the weight of criteria was calculated after extracting the criteria by Delphi technique and identifying all the effective criteria and factors involved in site selection. After preparation of intended layers, each map was prepared in the form of raster layers on geographical information system. Information layers were combined after being valued and finally the map of suitable areas was prepared. Finally, the conformity of all the obtained maps was checked out with field conditions. In this study, the genetic algorithm was used as an optimization method applied for natural selection. It was also attempted to find better solutions among others. The results showed the best site for developing industries.

KEYWORDS: *Environmental management; Fuzzy analytic hierarchy process (FAHP); Genetic algorithm (GA); Geographical information system (GIS); Industrial site selection.*

INTRODUCTION

Nowadays, protection of natural resources and environment has become important as one of the major global issues (Dengiz *et al*., 2010). In this respect, governments and environmental organizations considered some limitations for the decision-maker centers involved in field of site selection, construction and implementation of major industrial projects (Corti and Senatore, 2000). Growing industrial and economic activities along with population growth and neglecting the optimum usage of natural resources all may disturb the balance of environment (Al-Mulali *et al*., 2015). Improper changes in land-use (Ozcan *et al*., 2003, Tu *et al*., 2014), producing pollution (Lin and Wang, 2015, Nabernegg *et al*., 2017, Motevali and Koloor, 2017), and destroying natural resources (Razif and Persada, 2016, Fischer *et al*., 2015) are serious problems causing environment imbalance in many parts of the world. All these problems indicate the limited ecological power of the natural environment to tolerate human exploitation (Aung, 2017, Fischer *et al*., 2015, Blankendaal *et al*., 2014). Site selection for industrial areas is a key factor in the regional planning considering the environmental effects (Francis, 2015). An appropriate site selection for establishing an industry should cover various number of criteria to achieve the economic advantages along

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with environmental issues (Rikhtegar *et al*., 2014). To achieve the sustainable development, the negative effects of construction and operation industries should be minimized (Norgate *et al*., 2007). Basically, site selection for industrial centers is an important decision that influences the sustainability of industrial activity and also the sustainability of development in the region (Dey, 2006). Various studies have confirmed this subject (Eldrandaly *et al*., 2003, Reisi *et al*., 2011, Rikalovic *et al*., 2015, Rikalovic *et al*., 2017). However, there is not a fixed standard for regional environment planning and management of industries in a planning system. In other words, the conducted studies and their results are not combined in an appropriate context (Arabsheibani *et al*., 2016). Thus, one of the essential requirements for environment management is to utilize the modern scientific methods in order to combine all the effective factors in an appropriate context for planning the industrial sites optimally. The smart inductive and deductive methods of fuzzy and genetic algorithm (GA) and their advantages in site selection have encouraged the movement towards smartness approaches and replacing them with humans (Rikalovic *et al*., 2014). Due to the complexity of geographical decisions and non-determined nature of geographical objects, or uncertainty through various resources transposed to them, a method is needed to model the uncertainty (Chehreghan *et al*., 2013). Site selection for industries often requires the considerations of various planning objectives. The current methods can only generate approximate results for industrial site selection. They can only process the search under simple assumptions and when multiple-sites and multiple-constraints are involved, the method cannot guarantee that the search results are suitable. In this study, it has been attempted to evaluate the fuzzy and GA methods in geographical information system (GIS) environment for site-selection and to screen the industries in terms of environment planning and management in an integrated approach in Markazi province of Iran in 2017.

MATERIALS AND METHODS

Case study

In this study, Markazi province with an area of 29.127 km^2 (Noorollahi *et al*., 2016) has been selected as one of the industrial centers in Iran (Fig. 1). It is located at 34°37′27″ N latitude and 49°59′11″ E longitude. In the two past decades, the province has possessed an industrial image and changed into one of the biggest centers of strategic industries in Iran by introducing many projects to energy intensive industries (Jamshidi Zanjani and Rezaei, 2017). The major products in this province are: aluminum, aluminum products, heavy metals, under pressure

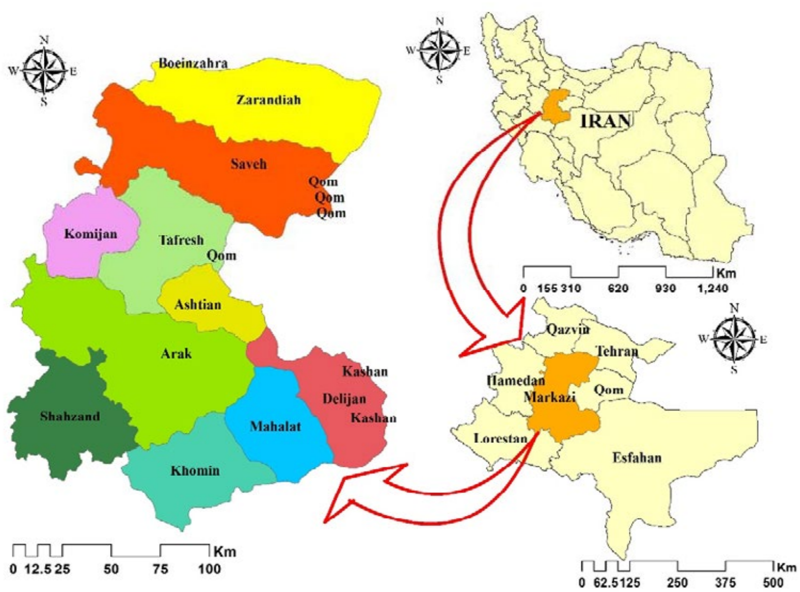

Fig. 1: Location of Markazi province in Iran

tanks, power-plant and industrial boilers, agriculture and road machineries, petrochemical and refinery products, industrial colors, textile, glass, crystal, car tire, wire and cable, detergents, industrial soot, artificial fibers, building rocks, home appliances, tile, pipe and steel profile, PVC and etc. The major focus of industry in the province is located in Arak, Saveh, and Mahallat, respectively (Rajabi and Ghorbani, 2016). There are 35 industrial parks in Markazi province which seem to be ranked as the second in terms of the fields occupied (Jamshidi Zanjani and Rezaei, 2017).

Methodology

The integrated approach of GA and fuzzy for site selection in geographic information system is shown in Fig. 2. In step 1, the effective criteria for industrial site selection were identified using Delphi method, expert opinion and literature review (Rikalovic *et al.* ,2017, Rikalovic *et al.,* 2015, Rikhtegar *et al.,* 2014, Reisi *et al.,* 2011). In step 2, ten information layers were prepared and converted into a raster format (Table 1) and the preliminary spatial analyses were performed on them to establish a database in the GIS. In step 3, FAHP was used to weight the criteria (Jamshidi Zanjani and Rezaei, 2017). The calculations were done in Matlab® (Cao and Wu, 1999). Overlaying was done using GIS in step 4 and the land suitability map was reclassified into five equally scored zones from least suitable to most suitable in step 5. In step 6, the output sites of GIS were studied based on the optimal sites using GA. Finally, in step 7, the sensitivity analysis was carried out.

Fuzzy AHP is an extension of the AHP. In fuzzy AHP procedures, the goal, criteria, and sub-criteria are arranged into a hierarchical structure and evaluated by an expert (Jamshidi Zanjani and Rezaei, 2017). The relative importance of each criterion was determined by linguistic variables (Table 2) which were represented as triangular fuzzy numbers (Figs. 3 and 4).

Main steps of fuzzy AHP conducted in this study are as follows:

Step 1: Defining the decision-making problem.

Step 2: Decomposing the complex problem in a hierarchical structure with decision elements.

Step 3: Establishing pairwise comparison matrix of the criteria using triangular fuzzy numbers and calculating the weight of criteria.

Step 4: Conversion to crisp values. The method of center of gravity defuzzification was used to convert the fuzzy evaluations into their corresponding crisp values.

Step 5: Consistency check.

Consistency ratio (CR) is required to determine whether the weight assigned by the decision maker is correct or not. CR< 0.1 indicates consistent judgment in pairwise comparisons (Jamshidi Zanjani and Rezaei, 2017). The process of NSGA II is shown in Fig. 5.

Table 1: Data sources for input layers in land suitability assessment in Markazi province

Layers	Source
Distance from rivers Distance from protected areas Distance from urban areas Distance from rural areas Distance from industrial areas Slope Elevation Distance from main roads	1:25,000 topographic maps prepared by the National Cartographic Center of Iran (NCC)
Land cover/use	Images taken from the TM sensor in 2016
Distance from fault lines	1:100,000 geological map prepared by the National Cartographic Center of Iran (NCC)

Table 2: Trapezoidal fuzzy numbers of linguistic variables

Trapezoidal fuzzy numbers (TFN)	Trapezoidal fuzzy reciprocal numbers
(La)	$(L_{1/b})$
(a-Lb)	$(1/a-L_{1/b})$
(La-b)	$(L_{1/a}-1/b)$
(La-Lb)	$(L_{1/a}-L_{1/b})$

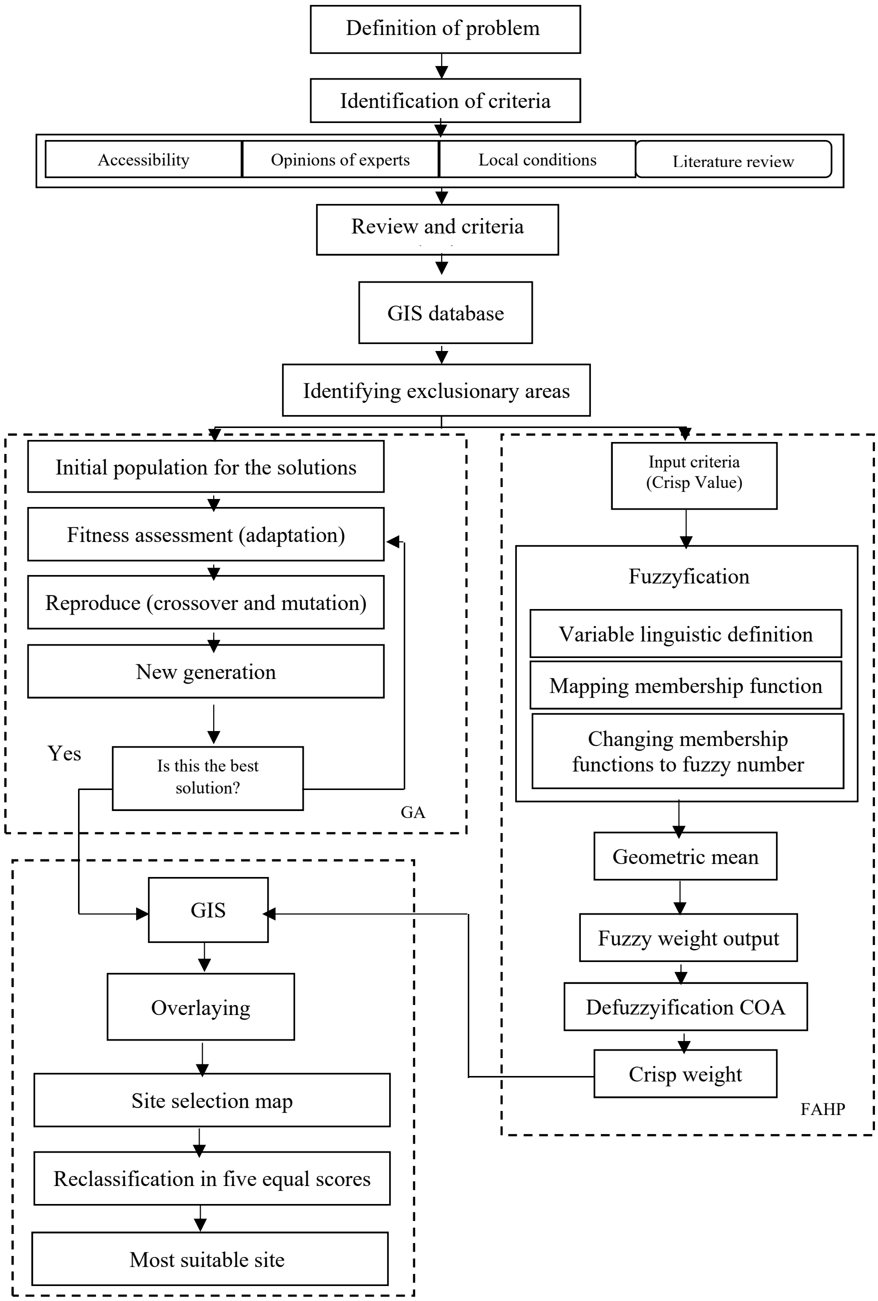

Fig. 2: Integrated approach of genetic algorithm and fuzzy for site selection in geographic information system

GAs have been applied for solution of optimization problems in many disciplines (Chehreghan *et al*., 2013). One of the advantages of GAs is that specific programs are not required for seeking the optimal solution (Crossland *et al*., 2014). This is very useful for dealing with many difficult spatial decision problems. The optimization procedure is based on the concept of natural selection (Houck *et al*., 1995).

The main steps of GA conducted in this study are as follows:

Step 1: Data were prepared in GIS in raster-formed maps with geometric dimensions of 1024px*1024px

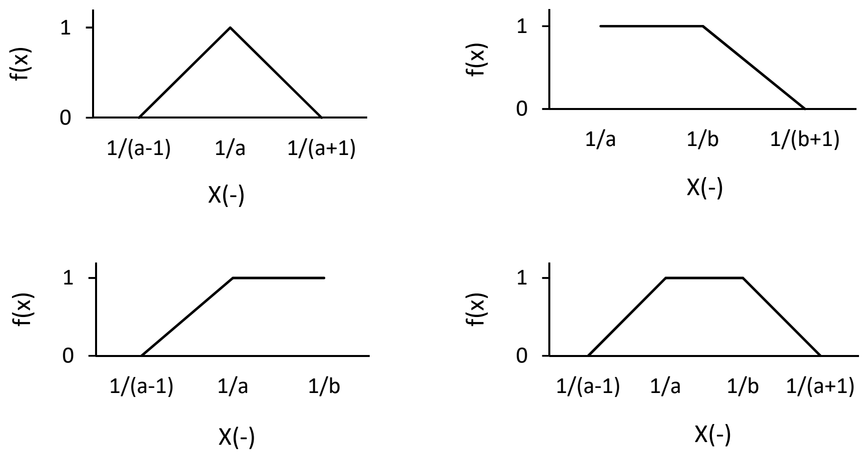

Fig. 3: Membership functions for trapezoidal fuzzy numbers of linguistic variables

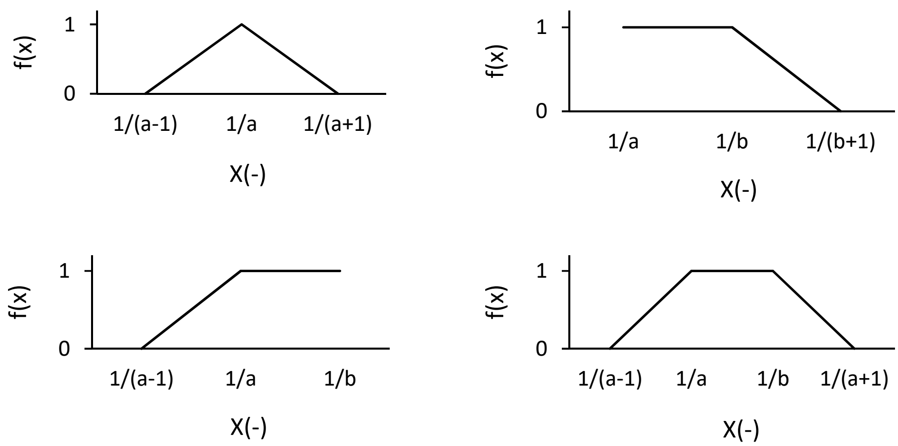

Fig. 4: Membership functions for trapezoidal fuzzy reciprocal numbers of linguistic variables

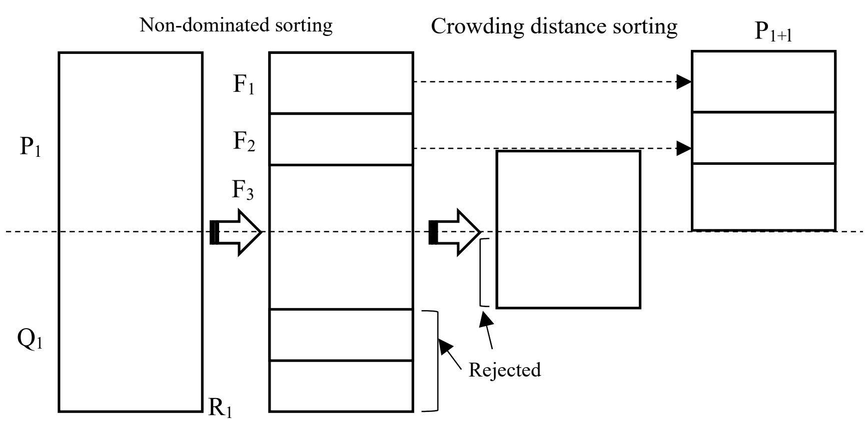

Fig. 5: Arrangement of population in non-dominated sorting genetic algorithm II (NSGA-II) algorithm, where P stands for population, Q represents the population resulted from crossover and mutation, and Fi shows the front.

Table 3: Paired comparison matrix and slope classes (Arabsheibani *et al.,* 2016)

Classes (%)	<5	5-15	15-30	30-45	45<
<5	1	L3-4	L4	L5	L7
5-15	1/4-L1/3	1	3-L4	L5	L7
15-30	L1/4	L1/4-1/3	1	L3-4	L5
30-45	L1/5	L1/5	1/4-L1/3	1	L3
45<	L1/7	L1/7	L1/5	L1/3	1

Table 4: Paired comparison matrix of fuzzy numbers, slope classes

Class	Slope (%)	<5	5-15	15-30	30-45	45<	Fuzzy weight	Crisp weight
1	<5	(1,1,1,1)	(4,4,3,2)	(5,4,4,3)	(6,5,5,4)	(8,7,7,6)	0.4005,0.4971, 0.5937,0.7503	0.5519
2	5-15	(1/2,4/3,4/1 ,1/1)	(1,1,1,1)	(5,4,4,3)	(6,5,5,4)	(8,7,7,6)	0.1482,0.1960, 0.2354,0.3149	0.2187
3	15-30	(4/3,4/1,5/1 ,1/1)	(3/3,4/1,5/ 1,1/1)	(1,1,1,1)	(4,4,3,2)	(6,5,5,4)	0.0851,0.1076, 0.1553,0.1916	0.1336
4	30-45	(5/4,5/1,6/1 ,1/1)	(5/4,5/1,6/ 1,1/1)	(3/2,4/1,4/1, 1/1)	(1,1,1,1)	(6,3,3,2)	0.0389,0.0578, 0.0699,0.0895	0.0639
5	45<	(7/6,7/1,8/1 ,1/1)	(7/6,7/1,8/ 1,1/1)	(5/4,5/1,6/1, 1/1)	(3/2,4/1,4/1, 1/1)	(1,1,1,1)	0.0315,0.0444, 0.0533,0.0735	0.0495

in approximate 10.000 m^2 area which was executed in 27 separate frames.

Step 2: Fuzzy analytic hierarchy process results were analyzed to extract the cost function of problem (industrial site selection), and the effective indexes in cost function were determined due to the effective criteria of site selection.

Step 3: GA was implemented in Matlab®. This part deals with the explanation of details in Matlab®. The software includes tools which provide the possibility of optimization using GA (Houck *et al*., 1995). To use this software, the proper input should be produced and introduced to software (Cao and Wu, 1999). Therefore, the maps of criteria provided in GIS after output were introduced to Matlab in the forms of numerical matrixes. GA components were introduced to the software. The components consist of cost function, number of decision variables, number of population, number of generations, selection method, rate of multiplication and composition operators, mutation and end-loop condition (Crossland *et al.,* 2014).

RESULTS AND DISCUSSION

Fuzzy analytic hierarchy process analysis

After preparing the information layers, fuzzy AHP was utilized to weigh the criteria and classes of each criterion. Weight calculation was programmed on Matlab. The comparison of the experts' opinions based on Buckley's method was used to state the priority of criteria. The matrix of fuzzy numbers was normalized

Table 5: The final weights for criteria land suitability assessment in Markazi province

Criteria	Weight	Rank
Distance from rivers	0.238	1
Land cover/use	0.184	2
Distance from protected areas	0.143	3
Distance from fault lines	0.114	4
Distance from urban areas	0.096	5
Distance from rural areas	0.081	6
Distance from industrial areas	0.052	7
Slope	0.039	8
Elevation	0.032	9
Distance from main roads	0.021	10

and the final weight was used in GIS. Due to the large number of tables, only the paired comparison matrix for slope classes (Table 3) and fuzzy numbers matrix and tables of fuzzy numbers matrix along with final weight (Tables 4 and 5) have been shown. The consistency ratio (0.04) for criteria and sub-criteria are checked. All values for consistency ratio are less than 0.1, indicating that the weights are consistent

After obtaining the final weight of elements, the spatial databases (geodatabase) were created for model implementation in the study area, and various information layers were entered into database based on the determined indexes (Fig. 6). In the next step, the map factors were prepared for each layer. Preparation of the layers of each criterion was done in Arc GIS in the form of raster layers. The following figures show the weight maps for each input parameter.

The final map extracted in the form of raster layers

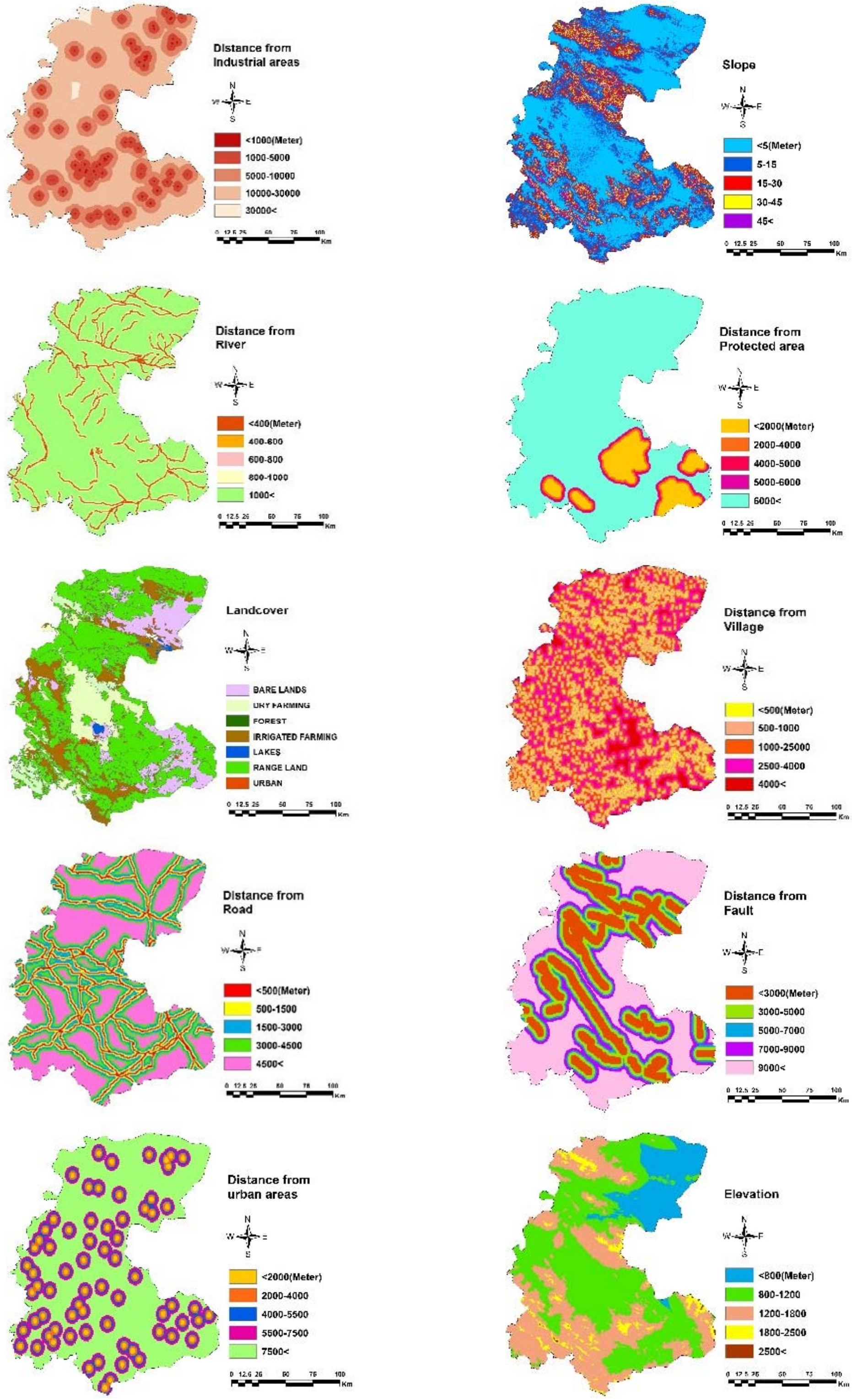

Fig. 6: Input data layers in industrial plants site selection in Markazi province

indicates the suitable sites for land-use development of industries in the area. To ensure of the validity of suitable sites of GIS output, the area was re-studied using GA based on the suitable sites. The final coefficient obtained from fuzzy AHP was applied to the classified layers using Arc-GIS with raster calculator tool (Fig. 7). Then, the area of five zones was extracted (Table 6).

Based on the map of final zonation and total area of Markazi province, about 13.5, 15.9, 22.4, 18 and 5.2 % of the fields had less suitable, suitable, moderately suitable, highly suitable, and extremely suitable ratios respectively for the development of industries. The limitation layers included environmental standards and natural limitations.

Genetic algorithm analysis

Input layers (Fig. 6) were prepared in GIS in raster-formed maps with geometric dimensions of 1024px*1024px in an area of approximately 10.000 m^2, which was executed in 27 separate frames. In selecting the initial population, 100 chromosomes were randomly selected using Round and Rand functions in the form of a 20-bit string from 0-1 range. Then, the first ten numbers of each string were encoded as X coordinate and the second ten numbers were encoded as Y coordinate in binary form, so that the coordinates of chromosome-related pixel are identified in criteria-related maps which have been defined in the form of a 1024 × 1024 component matrix in Matlab®. To choose the parents, experts' method was used. In the next step, one-point method was used for crossover activity. Subsequently, a new generation with 100 chromosomes was analyzed based on cost function according to experts' intended situations taken from the questionnaire. Since the optimal solution was located in this generation based on cost function, the algorithm ends (Fig. 5). Otherwise, the algorithm in a repetitive loop starts the production of new generations to reach convergence and optimal solution (Peng and

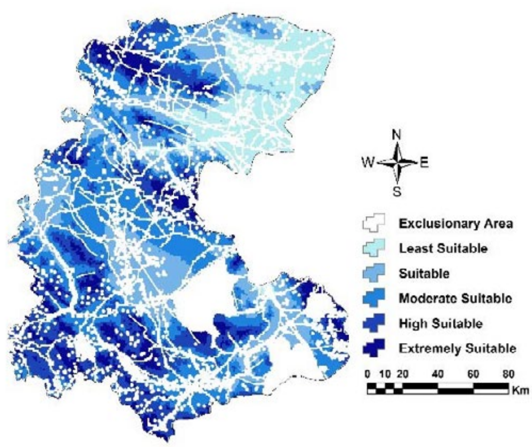

Fig. 7: Final map in fuzzy analytic hierarchy process in Markazi province

Table. 6: The area of final land suitability map classes obtained by fuzzy analytic hierarchy process

Classes	Areas	
	(km^2)	(%)
Exclusion zone	7281.75	25.0
Less suitable	3938.82	13.5
Suitable	4629.414	15.9
Moderately suitable	6525.44	22.4
Highly suitable	5250.35	18.0
Extremely suitable	1501.22	5.2
Total	29127	100

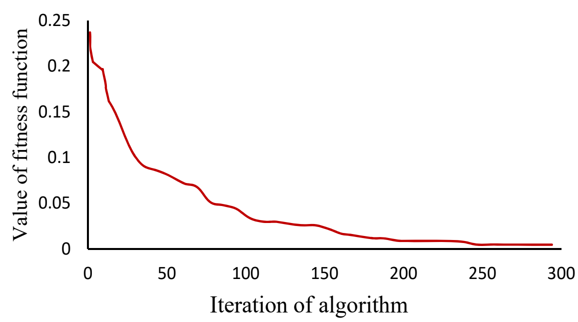

Fig. 8: Convergence behavior of genetic algorithm

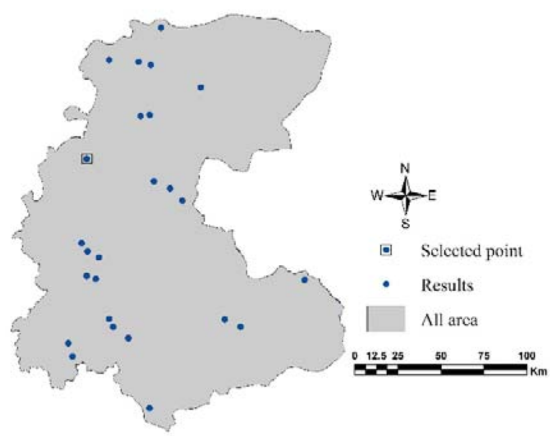

Fig. 9: Result of applying genetic algorithm

Li, 2015). The convergence behavior of the proposed GA is shown in Fig. 8.

Fig. 9 shows the result of applying GA on the area layers. 25 locations are suitable for the development of industries and one site is the best. The results of GA demonstrate that GA is capable of producing very satisfactory results for optimal location search under complex situations.

Analyses of the results and sensitivity

GA and fuzzy AHP methods were used for industrial site selection. The fuzzy AHP was developed and the results of the two methods were compared to evaluate their efficiency and accuracy. The prominent experts were selected from different organizations in the study area. Overall, 31 experts' opinions were applied in this study. Opinions were collected from 11 environmentalists, 10 regional and industrial planners, 5 alternative energy experts, and 5 GIS experts by questionnaire and forums of experts. After establishing a database, the areas unsuitable for site selection were identified as exclusionary areas based on a literature review and knowledge of local conditions. Fuzzy AHP was developed in Matlab (Rikalovic *et al.,* 2017) and the relationships between the criteria and their strengths were identified. Final weights of the criteria for fuzzy AHP are shown in Table 5. In fuzzy AHP, the distance from river was weighted as highest and the distance from main road was weighted as lowest. Fuzzy AHP established relationships regardless of strength, thus the criteria with weak relations were paired with others in the comparison process. This means that the overall weight is not distributed properly among the criteria, as observed in Table 5. Comparison of the priorities of the criteria from the questionnaires, was performed to identify the most influential criteria. The results from the models presented in Table 5 emphasized the better performance of the model. Fig. 6 was presented based on the information from Table 1 to prepare input layers and convert them to raster format. By applying the weights in Table 5, overlaying was done in GIS and a land suitability map was obtained. The final zoning maps of the fuzzy AHP was reclassified and presented (Fig. 7). Table 6 shows the five zones derived from the FAHP. Overlapping layers were classified into five classes: less suitable, suitable, moderately suitable, highly suitable, and extremely suitable. Fuzzy AHP determined that about 1501.22 km^2 of the total area of the province is very suitable for industrial sites. The most suitable areas are at the south of Arak city near the political boundaries of Khomein town. Most of these areas are located in northeastern and southeastern parts of Markazi province (Fig. 7). This area has a significant industrial potential and is located in an area with relatively suitable slope. These areas are also dry lands and pastures which decrease the cost of land. In GA, 25 locations in the province are very suitable for industrial sites (Fig.9). According to local conditions and input layers, these locations have a potential to be placed in the extremely suitable class. However, due to improper distribution weights in the fuzzy AHP model, less areas are located in the extremely suitable class as compared to GA.

Fig. 10 shows the results of sensitivity analysis of both models regarding suitable sites for each criterion (Fig. 6) and the final map (Figs. 7 and 9). Fig. 10 shows

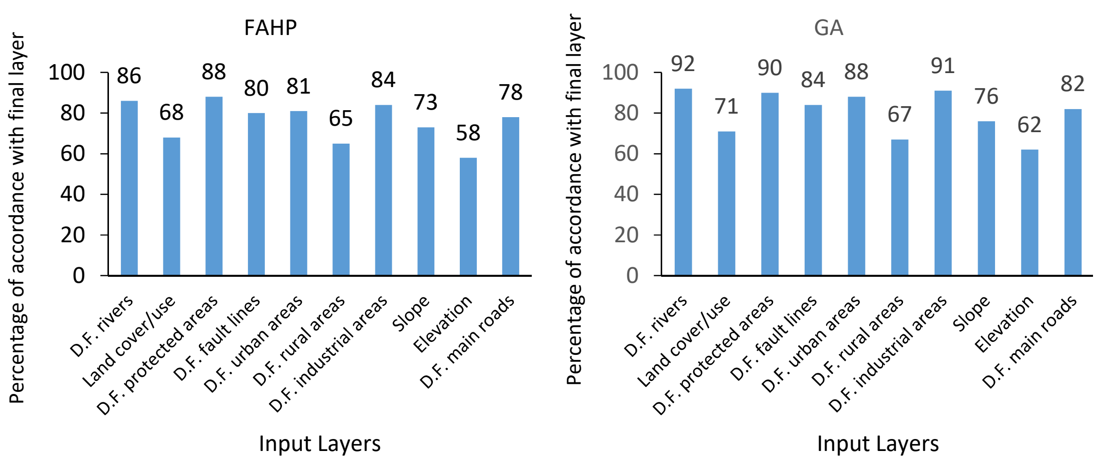

Fig. 10: Results of sensitivity analysis on fuzzy analytic hierarchy process and genetic algorithm

the degree to which each criterion coincides with the final map. Obviously, all input layers in both models coincide well with the final map (+64%) except for the elevation layer. Comparison of the sensitivity analyses shows that the overlaps between suitable sites of the final map and the input layers are more compatible with the GA model. These results show that the GA is more accurate and efficient than the FAHP in finding suitable areas for industry. Houck *et al*. (1995) concluded that necessary steps in the GA method include numerical quantification of criteria and prioritization of the alternatives regarding the considered attributes. As the number of the alternatives increases, there is a high probability that the preferred option is primarily determined based on the distance difference. Peng and Li (2015) introduced GA as one of the best known site selection method. Jamshidi Zanjani and Rezaei (2017) stated that due to the fact that the decision makers of industry are faced with the issues of uncertainty and imprecision, by means of fuzzy, uncertainty and ambiguity in personal perceptions and experiences of decision makers move effectively towards making efficient decisions. Rikalovic *et al*. (2017) concluded that the proposed model is indeed an integrated process and it will be easily applicable to industrial site selection without increasing the computational burden. The results show the efficiency of the proposed model. This study also shows the significance of precision in determining the values related to each criterion that has an important role in final results and output plan. If the values are determined carefully, the obtained results will be closer to facts and will have a higher reliability. This closeness occurs when the relationships between the criteria are specified correctly and it is done by experts. This point was constantly considered at all the stages of this study.

CONCLUSION

This study presents a genetic algorithm approach that overcomes the limitations of traditional multiple criteria decision analysis for site selection of industrial areas. It also demonstrates that GAs are capable of producing very satisfactory results for site selection under complex situations. GA becomes very effective through the use of the mechanics of natural selection in biology. The proposed method, which has been tested in Markazi province, can be used as a planning tool to solve location search problems under multiple-objectives. This study indicates that the proposed GA method can be conveniently integrated with GIS to retrieve spatial data. These spatial data are used to calculate the fitness values. The proposed method was compared with FAHP and demonstrated that FAHP method can only generate approximate results for site selection as it can only process the search under simple assumptions and when multiple-sites and multiple-constraints are involved, the method cannot guarantee that the search results are optimal. FAHP can deal with the optimization problems of high dimensions, but its performance is far below that of the proposed GA method. Much better performances can be obtained by using the proposed GA method under the same conditions. GA can be incorporated in the GIS to deal with the issues of multiple-objectives. Site selection for industries often requires the considerations of various planning objectives which can be combined into a single fitness function using a linear weighted equation in the GA program. The proposed method was found to be well adapted to the solution of site selection problems subject to multiple planning objectives. Much better performance can be achieved by applying the proposed method rather than FAHP. This method can be applied to solve a variety of siting problems, such as site selection for energy industries, industrial towns and large industrial centers. Due to the cost function and conditions defined for GA, it is left to the managers to come up with the final decision and they can select the final site based on their intellectual criteria and parameters not involved in the model. Although the evolution algorithms have been practiced in many issues of real world in recent years, the complexity in designing and executing them in the old GIS contexts has made them inappropriate for site problem-solving such as site selection. Nowadays, these complexities have been limited to the knowledge in combining the evolution algorithms and GIS by developing GIS software and other computational software. The results of GA show that they can be advantageously employed for finding the optimal solution by designing a strong and thorough algorithm with accurate cost functions and by using the software with the ability to handle a large volume of site data, because the usage cycle of applying this models is to find the optimal points.

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CONFLICT OF INTERESTS

The authors declare that there are no conflict of interests regarding the publication of this manuscript.

ABBREVIATIONS

AHP	Analytic hierarchy process
CR	Consistency ratio
DF	Distance from
F_1	First front
F_2	Second front
F3	Third front
GA	Genetic algorithm
GIS	Geographic information system
II	Roman numeral two
km^2	Square kilometer
NCC	National Cartographic Center
NSGA	Non-dominated sorting genetic algorithm
P	Population
P_1	Initial population
PVC	Polyvinyl chloride
Q	The population is caused by crossover and mutation
Q_1	The first population is caused by cross-over and mutation
R1	First repeat
TFN	Trapezoidal fuzzy numbers

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