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CASE STUDY

A geographic information system for gas power plant location using analytical hierarchy process and fuzzy logic

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ABSTRACT: This research recommends a geographic information system-based and multi-criteria evaluation for locating a gas power plant in Natanz City in Iran. The multi-criteria decision framework offers a hierarchy model to select a suitable place for a gas power plant. This framework includes analytic hierarchy process, fuzzy set theory and weighted linear combination. The analytic hierarchy process was applied to compare the importance of criteria among hierarchy elements classified by environmental group criteria. In the next step, the fuzzy logic was used to regulate the criteria through various fuzzy membership functions and fuzzy layers were formed by using fuzzy operators in the Arc-GIS environment. Subsequently, they were categorized into 6 classes using reclassify function. Then weighted linear combination was applied to combine the research layers. Finally, the two approaches were analyzed to find the most suitable place to set up a gas power plant. According to the results, the utilization of GAMMA fuzzy operator was shown to be suitable for this site selection.

KEYWORDS: *Analytic hierarchy process (AHP); Consistency ratio (CR); Fuzzy logic; GAMMA operator; Gas power plant; Geographic information system; Multi-criteria decision making (MCDM); weighted linear combination (WLC)*

INTRODUCTION

In the fuel industry, the problem of site selection for a gas power plant consists of many measurable and non-measurable components (Semih and Seyhan, 2011). The choice of a facility site from other sites is a multi-criteria decision-making (MCDM) problem containing both measurable and non-measurable criteria. In many real cases, finding the precise values for MCDM problems, especially for facility site selection, is difficult or inconceivable. Consequently, the values of options with regard to the criteria and/or the values of criteria weighs are reflected as fuzzy values. The common approaches to solve facility location problems and other MCDM problems tend to be less operative due to dealing with imprecise or ambiguous nature of linguistic assessments (Mokhtarian, 2011). Muti-criteria evaluation (MCE) is also applied to cope with the problems decision makers face in managing the enormous amounts of collected information. This approached is based on the following principles:

- Classification of decision-making problems into smaller understandable groups
- Performing analysis on each segment separately
- Collocation of the segments (Malczewski, 1997)

Wood and Dragicevic, (2007) investigated the use of an integrated spatial decision support framework based on GIS, MCE and fuzzy sets to accurately recognize and arrange sites for future aquatic protection

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(Navas *et al*., 2011). Fuzzy set theory is known to be appropriate for situations when degree of uncertainty and fuzziness in our input information is high. Common multi-criteria decision making methods are often not easy to be implemented due to imprecision in data obtained from the interviewees. Since the theory of fuzzy sets in multi-criteria decision-making (Bellman and Zadeh, 1970) was presented, hundreds of methods have been offered on this new topic, known as fuzzy multi-criteria decision-making (Alipour *et al*., 2010; Chen and Niou, 2011; Chu and Lin, 2009; Fu, 2008; Kahraman and Kaya, 2010; Krohling and Campanharo, 2011; Ye, 2010; Yeh and Kuo, 2003; Ban and Ban, 2012). Teng (2000) applied multi-criteria decision-making method for locating restaurants. Tzeng *et al*. (2002) applied it for location of a restaurant site in Taipei. Other academics applied the same method in the navigation trade (Chang *et al.,* 1997), partial business (Kuo *et al.,* 2002), distribution center (Chen, 2001), and sale-delivery facility site (Aberbakh and Berman, 1995; Chou *et al.,* 2008). Locating rules will be specified by using proper instruction of GIS. Major advantages of GIS include its ability to:

(a) take, hold, and arrange spatially referenced data; (b) prepare the enormous amounts of spatially referenced input data and handle analysis of the data; (c) analyze sensitivity and optimization clearly (Vatalis and Manoliadis, 2002). The studies of Pereira and Duckstein, 1993; Heywood *et al*., 1995 and Malczewski, 1996 are a few good instances for the application of MCE and GIS together (Hossain *et al*., 2008). The application of analytical techniques to resolve the multi-criteria problems in GIS can provide the user a further and valuable alternative to how the GIS toolbox function (Carver, 1991). GIS is an influential instrument to manage spatial analysis, providing functionality accompanied by other systems and approaches such as decision-making systems (DSS) and the method for the analytic hierarchy process (Hadipour and Kishani, 2014). The analytic hierarchy process is a common approach for multi criteria decision support based on the hierarchical classification of goals, the assessment of preferences through pairwise comparisons, and a further integration into overall evaluations (Durbach *et al.,* 2014). Due to the ambiguity over judgments of the decision-makers, the crisp pair wise comparison in the normal analytic hierarchy process (AHP) seems to be insufficient and inexact to make the sound judgments of decision-makers. Therefore, fuzzy numbers are introduced to balance this insufficiency in the normal AHP in the pairwise comparison (Ayað and Özdemir, 2006). Bilal *et al.* (1999) used an AHP methodology to perform a comparison among different options for electricity power production in Jordan. Uyan in 2013 applied GIS-based solar farm site selection using the AHP in Karapinar region in Turkey. Silva *et al.* (2014) selected a suitable site for biogas plants by integrating multi-criteria decision aid methods and GIS techniques. Chang *et al*. Due to the ambiguity over judgments of the decision-makers, the crisp pair wise comparison in the normal analytic hierarchy process (AHP) seems to be insufficient and inexact to make the sound judgments of decision-makers. Therefore, fuzzy numbers are introduced to balance this insufficiency in the normal AHP in the pairwise comparison (Ayað and Özdemir, 2006). Bilal *et al.* (1999) used an AHP methodology to perform a comparison among different options for electricity power production in Jordan. Uyan in 2013 applied GIS-based solar farm site selection using the AHP in Karapinar region in Turkey. Silva *et al.* (2014) selected a suitable site for biogas plants by integrating multi-criteria decision aid methods and GIS techniques. Chang *et al*. (2015) found suitable ocean current power generation places with the bin average method. Jafari *et al.* (2015) used AHP and WLC methods in GIS environment for locating the nuclear power plant in Hormozgan, a province in Iran. A weighted linear combination (WLC) is an analytical method that can be used when dealing with multi-attribute decision making (MADM) or when more than one attribute must be taken into consideration (Donevska *et al.,* 2012). The aim of this research is to specify the most suitable site for gas power plant in Natanz City by using two approaches: fuzzy modeling and WLC. This study has been performed in Natanz City in 2015 (Fig. 1).

MATERIALS AND METHODS

Study area

Geographic information of Natanz City where the study has been performed is given below:

The area is located between 33 degrees and 25 minutes to 33 degrees 40 minutes north latitude and 51 degrees and 25 minutes to 52 degrees east longitude (northeastern of Isfahan Province). In addition, it stands in the altitude of 1600 meters from the sea level. The area of the chosen place is 3,397 Km^2 and it has the population of over 43 thousand habitants. The city suffers from shortage of electricity energy. However, it holds huge industries, such as Shahid Ahmadi Roshan nuclear site and Natanz steel, spinning and weaving

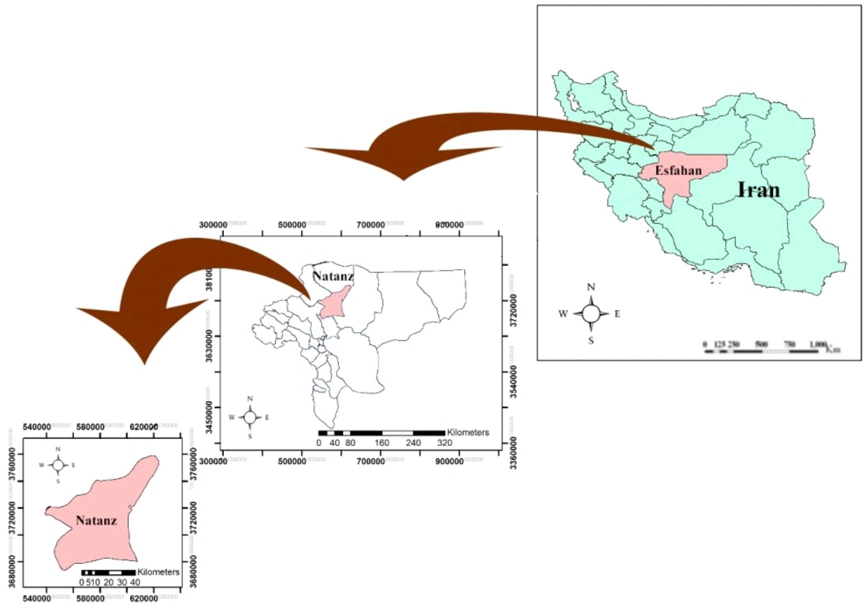

Fig 1: Location of Natanz City, the study area, on the map

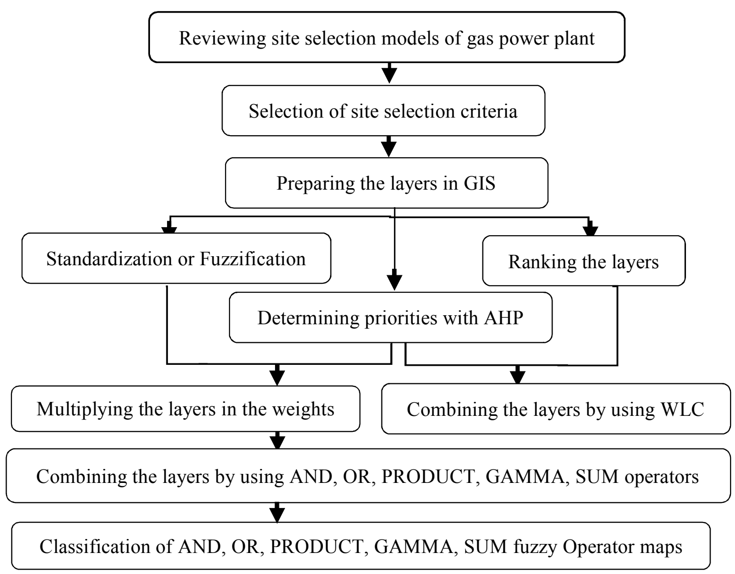

Fig 2: The flowchart of the study procedure

industries. It is worth noting that the city is still going through unprecedented technological advancement. Hence the lack of energy causes deep concerns for the years ahead.

Methodology

ArcGIS 9.3 was utilized as the GIS tool since it is believed to be efficient for both appropriate investigation and MCE analysis. An MCE analysis investigates some possible options for a location allocation problem by multiple criteria and conflicting purposes. In order to use GIS for this problem, the available information for the study area is digitized and saved in the information system.

The flowchart of research procedure is also shown in Fig. 2.

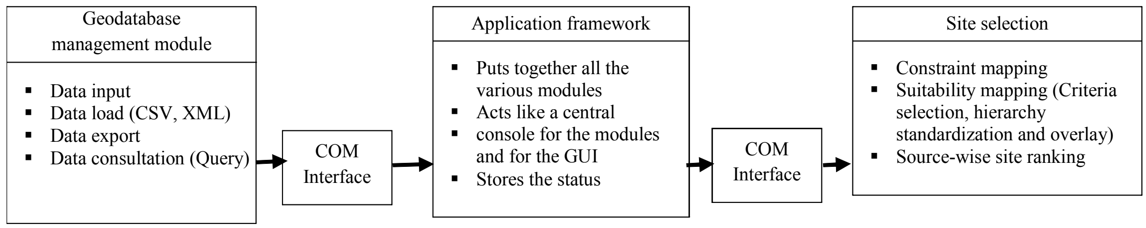

Fig. 3. Structure of the site selection tool developed in the ArcGIS environment (Rahman *et al.,* 2012)

Multi criteria evaluation (MCE)

The evaluation of several criteria to meet a specific objective is a prevailing matter in the multi-criteria evaluation approach (Voogd, 1983; Carver, 1991; Eastman, 2012). In this method, the possibility of analyzing and presenting all the existing information is related to the options resting against various and multidimensional criteria (Eastman, 2012).

As the first step of MCE, the effective criteria layers must be prepared. Since various data of covered area in this research are analyzed together, all data should be consistent altogether in terms of geometry and comply unique geographic coordinate system. In addition, the cell size of all entries must be equal. Furthermore, since the criteria are measured on different scales, standardization will be elaborated in the next step. This means that the transformation process is performed on the vectors. Ultimately, aforementioned factors are combined with a weighted linear combination approach after gasification.

Analytic hierarchy process (AHP)

One of the methods for analyzing complex decision-making is AHP (Saaty, 1980). As decision makers specify the comparative importance of weights for complex multi objective issues with difficulty this decision method decreases the difficulty of the decision problem into a series of pairwise comparisons among competing features. Moreover, AHP considers both measurable and non-measurable information for making decisions. At first, a decision hierarchy is created. Then the complex decision problem is decomposed into some easier sub-problems. Every sub-problem should be independent for further analyses. A pairwise comparison matrix is created in each level of this hierarchy. Different parts of hierarchy are investigated by decision makers. This action is done by comparison of each pair of criteria in order to specify the priority and importance of each criterion.

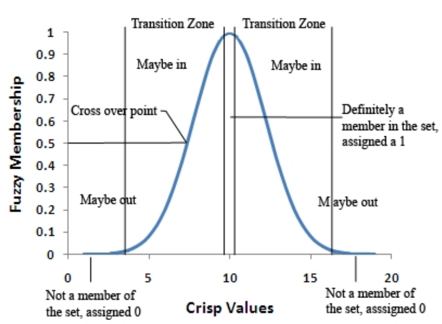

Fig 4: Fuzzy membership function diagram (Dombi, 1990).

The set {1/9, 1/8, 1/7, 1/6, 1/5, 1/4, 1/3, 1/2, 1, 2, 3, 4, 5, 6, 7, 8, 9} is used for evaluation of relative importance of each criterion pair. The values 1/9, 1 and 9 respectively show the least important, equally important and the most important criteria. These scores are entered arranged in arrays of a square comparison matrix. Values of 1 are placed in the main diagonal the matrix. By normalizing the matrix columns, the weights for each criterion are obtained. Computing the consistency ratio (CR) leads to check the consistency of the performed comparisons. Finally, values of CR ≤ 0.1 indicate that this matrix is consistent. If CR does not reach the threshold value, the matrix will be inconsistent, so the process should be revised. The weights specified to standardized criteria are the inputs to an aggregation model. Fig. 3 depicts the implementation steps of the location-allocation method developed in the ArcGIS environment.

Weighted linear combination (WLC)

WLC method is a decision technique to derive compound maps in GIS environment. The approach used in this research is one of the most common decision making models. This model is often used to analyze suitability, land use, site selection, and issues related to the resource assessment. There several reasons as to why it is used universally, such as its

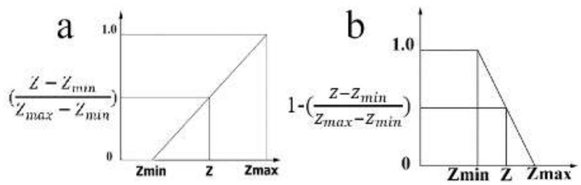

Fig. 5: Equation and diagram of fuzzy membership function; a) increasing linear and b) decreasing linear (Liu *et al*., 2014)

algebraic processes, cartography modeling and easy application without GIS environment (Tomlin, 1990; Berry, 1993; Malczewski, 2000).

$$V(X_i) = \sum_j w_j v_j (x_i) = \sum_j w_j r_{i.}$$

Where w_i's are normalized weights satisfying $\Sigma w_i=1$ w_j is the value function for the j-th attribute, $x_i = (x_{i1}, x_{i2}, \ldots, x_{in})$ and r_{ij} are the attributes converted into the measurable scale. The weights represent the comparative importance of the attributes. The most preferred option is selected by identifying the greatest value of $V(x_i)$, i= 1, 2, …, m.

According to the decision rule ($V(x_i)$= $Sw_i r_{ij}$), the GIS/WLC method includes the following steps:
1) describing the criteria
2) determining the group of offered options
3) getting criteria layers
4) presenting weights of criteria assigned to every criterion
5) combining the criteria layers and weights using the multiplication and overlay operations to obtain the total score for each cell (option)
6) ranking the options according to the total score. The highest score is the best option (Malczewski, 2000).

Two types of ranked or fuzzy criteria layers can be used in this approach. Due to utilizing ranked layers, there will be some weakness points referring to its impossibility to give cell-based analyses; therefore we can obtain just a polygon map. In other words, selected areas in the output map cannot be sorted based on the degree of variability. This approach has limited decision-making power and provides fewer options to risk management. For this purpose, an approach or model must be used to create various management scenarios. The aim of this research is to obtain the best site for constructing a gas power plant. Fuzzy approach can do so. Therefore, all the criteria layers were modeled by fuzzy logic.

Fuzzy modeling approach

With this approach, all factors are combined together in one step and can use a purposeful pattern of integrating the maps. The idea of fuzzy logic considers spatial features on the map such as the members of a set. In fuzzification, membership value can take any value between 0 and 1 which reflects certain degree of membership and there is no practical limit on the choice of fuzzy membership values (Hansen, 2005; Lee, 2007; Kabir *et al*., 2014; Ghosh *et al*., 2012). The fuzzy logic approach creates more flexible compositions of weighted maps and it can be easily implemented with GIS modeling language (Lee, 2007). Values are selected

Table 1: Types of fuzzy operators

Operator	Equation	Explanations
AND	$\mu_{combination} = \min(\mu_A, \mu_B, \ldots)$	Control of output map with the smallest amount of fuzzy membership
OR	$\mu_{combination} = \max(\mu_A, \mu_B, \ldots)$	Control of output map with the largest amount of fuzzy membership
PRODUCT	$\mu_{combination} = \prod_{i=1}^{n} \mu_i$	1. The output value of any position is less than or equal to the smallest value of fuzzy membership at corresponding positions on entry maps 2. The impact of decreasing 3. The impact of overall membership values of entry maps in output map
SUM	$\mu_{combination} = 1 - \prod_{i=1}^{n}(1 - \mu_i)$	1. Fuzzy membership value of output map at any position is always greater than or equal to the largest value of fuzzy membership value at corresponding positions on entry maps 2. The impact of increasing
GAMMA	$\mu_{combination} =$ $(FuzzySum)^{\gamma} \times (FuzzyProduct)^{1-\gamma}$ $\gamma Î[0,1]$	1. γ Value between zero and one 2. The nearer γ value is to one; the more important the fuzzy Algebraic sum approach will be shown. 3. The nearer γ value is to zero; the more important the fuzzy Algebraic product approach will be shown.

Table 2: Weights and classes of criteria

Criterion	Class	Class weight (0-10)	Weight criterion (%)
Elevation	0-1000 m	10	11
	1000 m	8	
	1400-1800 m	4	
	>1800	0	
Slope	%0-6	10	11
	%6-10	7	
	<10%	0	
Geology	Limestone, marl, gypsiferous marl, sandy marl	10	11
	MILA FM	9	
	Andesitic and basaltic volcanic Diorite	8	
	Grey thick – orbitolina limestone	7	
	Andesitic volcanic tuff conglomerate and sandstone	6	
	Polymathic conglomerate and sandstone	5	
	Low level piedmont fan and valley terrace deposits	4	
	Clay flat stream channel,	2	
	Unconsolidated windblown sand deposit, including sand dunes	1	
River	0-500 m	0	11
	500-10000 m	10	
	10000-20000 m	5	
	>20000 m	0	
Gas pipeline	0-500 m	0	18
	500-5000 m	10	
	5000-10000 m	8	
	10000-20000 m	6	
	20000-30000 m	3	
	>30000	0	
Land use	Arid, poor soil	10	9
	Pebble areas	9	
	Agricultural and salt marsh areas	5	
	Gardens, forest planting	4	
	Natural forest	2	
	Cities and villages	1	
	Military, sabulous	0	
Groundwater level (fuzzy)	The highest level (17.8 m).	10	14
	The lowest level (135 m)	1	
Distance from related paths	0 – 500 m	0	15
	500-10000 m	10	
	10000-20000 m	7	
	20000-40000 m	3	
	>40000 m	0	

based on subjective judgment to show the membership degree of the set (Fig. 4). Fuzzy membership functions can be classified from two aspects: Type and Shape. Types include an S-shaped (Sigmoidal), J-shaped (J-shaped), and linear. Shapes include monotonically increasing, monotonically decreasing, and symmetric (Eastman, 2012).

In this research, a linear and monotically increasing type of fuzzy membership function was used.

$$X_i = \frac{(R_i - R_{min})}{(R_{max} - R_{min})} * \text{standardized\_range}$$

(Eastman, 2012; Alavipoor *et al.*, 2016)

Where is:

Xi: cell value after standardization; Ri: cell value before standardization; Rmin: minimum value of factor; Rmax: maximum value of factor; standardized range: the range of standardization variable.

Generally, the range of standardization variations are as two types 0-1 (actual numerical scale) and 0-255 (byte scale). The higher score indicates the higher suitability of the cell for decision making. Meanwhile, the zones having zero score were considered redundant.

Five fuzzy operators named OR, AND, SUM, PRODUCT and GAMMA and used to combine sets of GIS data are indicated in Table 1 (Lewis *et al*., 2014). Weights and classes of research criteria are presented in Table 2, based on reviewing scientific literature and reading technical reports, related articles and expert opinions.

RESULTS AND DISCUSSION

Site selection of this area was done based on multi-criteria evaluation. An important result of this study was the obtainment of reliable quantitative results from GIS (Karimi *et al.,* 2014), which the following consequences were achieved:

In site selection studies using GIS, spatial data on factors, consisting of measurable and non-measurable explanatory information, are visually combined (Tchobanoglous *et al*., 1993). In this research, in order to find suitable sites for a gas power plant, a GIS-aided methodology is developed. The evaluation criteria were used to calculate the suitability criteria. Then eight gas power plant criteria were chosen. This choice was done by studying the investigation area. The suitability map of gas power plant was generated by combining eight criteria layers with their weights which were obtained from the AHP method in ArcGIS software (Fig 7). For fuzzification of the criteria layers, the fuzzy linear membership function was selected in ArcGIS software. This option was selected due to the nature of criteria. Their values changed linearly. After fuzzification of criteria layers, the final criteria layers were classified into six categories with an equal interval classification approach (Fig 6). As a result, each operator has a range of suitability percentage. Hence, based on Fig 7, the following classes have the largest area: Class 3 in AND operator, Class 6 in OR operator, Class 3 in SUM operator, Class 2 in PRODUCT operator and Class 3 in GAMMA operator (Table 3). Nevertheless, the study is going to make decisions for the best result in which the operator indicates the lowest area with high suitability for the most suitable site. For this purpose, the GAMMA operator shows the best result. In addition, it makes increasing and decreasing trends of SUM and PRODUCT operators compatible, so class 6 with 0.4% area is the best operator for constructing a gas power plant. Furthermore, WLC approach indicates that class 6 (the lowest area) is the best construction site for this project. Histogram of fuzzy operators' reclassifications in Fig. 8 proves this fact. Due to capability of this approach for combining the layers, it seems that all aspects of site selection are considered and the results are the best. By means of comparison of the weighted linear combination and fuzzy models, it was found that the suggested locations by the two approaches are different (Fig 7). Results obtained from fuzzy operators suggest that the most suitable site for construction of a gas power plant is in the south and southeastern of Natanz City. In addition, WLC method suggests the southern part of the city as the most suitable location; however, the distribution

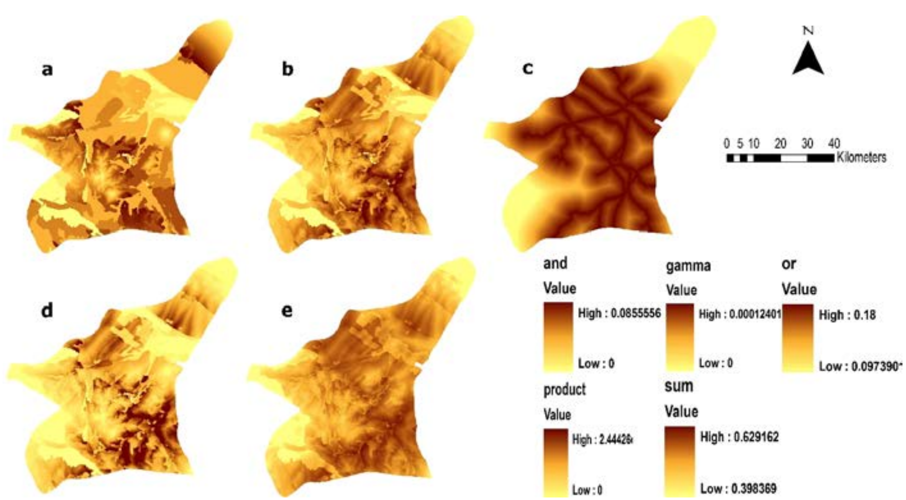

Fig. 6: Site selection of gas power plant by fuzzy operators; a) AND; b) GAMMA; c) SUM; d) PRODUCT; e) OR

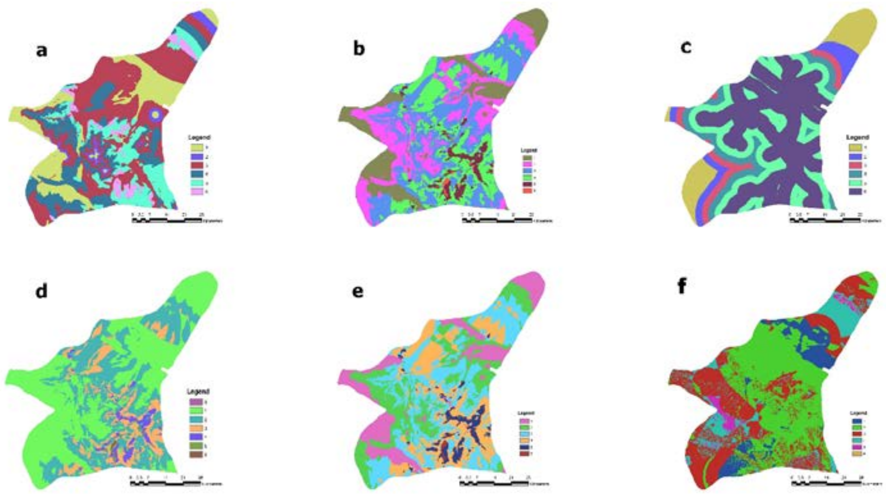

Fig 7: Classification of the gas power plant by fuzzy operator maps and classified fuzzy weighted map (WLC); a) AND; b) GAMMA; c) SUM; d) PRODUCT; e) OR; f) WLC

Table 3: The suitability amount of operator classes

Operator	Classes	Area (%)	Description of suitability
AND	1	19.3	Very poor
	2	2.5	Poor
	3	39.1	Moderate
	4	19.7	Good
	5	15	Very good
	6	4.4	Excellent
GAMMA	1	17.2	Very poor
	2	23.6	poor
	3	32.5	Moderate
	4	22.1	Good
	5	4.2	Very good
	6	0.4	Excellent
OR	1	11.7	Very poor
	2	6.4	poor
	3	9.7	Moderate
	4	5.3	Good
	5	21.7	Very good
	6	45.2	Excellent
PRODUCT	1	0.2	Very poor
	2	50.2	poor
	3	34.7	Moderate
	4	13.2	Good
	5	1.3	Very good
	6	0.4	Excellent
SUM	1	16.9	Very poor
	2	23.6	Poor
	3	32.3	Moderate
	4	22.4	Good
	5	4.4	Very good
	6	0.4	Excellent
WLC	1	8.9	Very poor
	2	43.2	Poor
	3	32.5	Moderate
	4	12.8	Good
	5	2.2	Very good
	6	0.4	Excellent

of suitable points in WLC method is different from those obtained by the fuzzy method. Investigation of the study area proves that the fuzzy method has proposed better construction sites.

CONCLUSION

The multi criteria decision making technique integrated with spatial tools (GIS) were applied to locate potential suitable places for a gas power plant in Natanz, a city in the center of Iran. Integrating multi-criteria evaluation approach along with GIS tools helped the authors to obtain proper results and could provide an optimal decision to reduce human errors and uncertainty. The research had also provided the application of fuzzy and WLC methods. At first, AHP was applied to weight the criteria and the sub- criteria were standardized and mapped by fuzzy linear membership function in ArcGIS software environment. Finally, the results of AHP weights and fuzzy linear function entered in a GIS environment to overlay with fuzzy operators and WLC method. Consequently, there were many options for construction of gas power plant location. The Class 6 was almost related to one area in all of the fuzzy layers, but it showed a different area in WLC map. Therefore, it seemed that using GAMMA compounds had introduced more general results. According to OR fuzzy operator formula, OR fuzzy operator almost entered all values in the final map. Consequently, it detected the most suitable areas whereas these areas had less suitability in the other

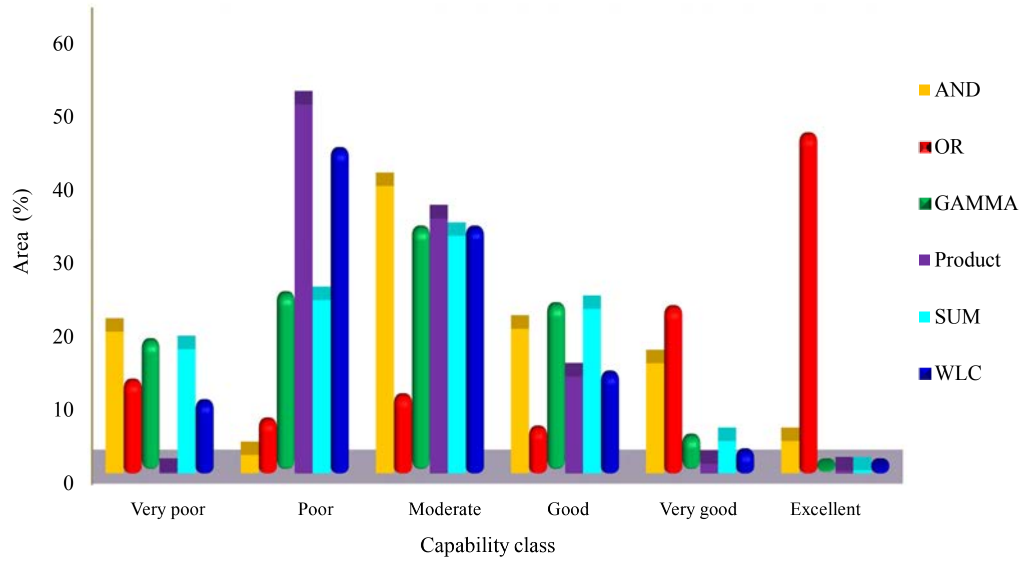

Fig. 8: Histograms of fuzzy operators reclassifications: a) AND; b) OR; c) GAMMA; d) PRODUCT; e) SUM; f) WLC

maps. In AND fuzzy operator set, the fits were distributed moderately and they possess a normal set. As AND fuzzy operator and OR fuzzy operator histograms showed, area classifications would have a reverse curve to one another. The results of SUM set which were the best class among GAMMA, SUM, and PRODUCT had roughly the same area. In other words, they had the least amount of area. If a location for the project with the lowest risk was desired, it also seemed that three above-mentioned operators had this trait. Due to the greater flexibility of GAMMA fuzzy operator to decision makers, it could help to produce scenario and more favorable outcomes.

CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

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