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The Wind Energy Potential Zoning using GIS and Fuzzy MCDM-based Approach (Study Area: Zanjan Province, Iran)

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Abstract

This study analyzes wind energy potentials of Zanjan province which located in northwest of Iran. Renewable energy plans are not fully environmentally safe and different renewable energy plans have different environmental impacts. Therefore, site selection is an important issue in the wind turbine installation and therefore, selecting an appropriate wind turbine site requires consideration of multiple alternative solution and evaluation criteria because of the system complexities. In this paper, using AHP and fuzzy TOPSIS techniques in conjunction with GIS, wind turbine potentials of the study area are evaluated. Criteria weights are obtained from pairwise comparison of identified criteria and after fuzzification of both criteria weights and criteria map layers using triangular fuzzy numbers, fuzzy TOPSIS technique is utilized to integrate and rank more suitable alternatives for the wind turbine installation. The results shows the ability of multi-criteria methods to evaluate suitable sites in geographic areas on one side and good potentials sites of Zanjan province to establish new energy plans on the other.

Keywords: Wind Energy; Multicriteria Analysis; GIS; Zanjan Province.

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1. Introduction

Increasing use of fossil fuels due to population growth has exhausted these resources and has damaged environment on the other hand. Nowadays, scientists have found that the safest options to prevent greenhouse gases and ever-growing demand of energy by the world population are renewable energies. According to Tester et al. (2005), the definition of sustainable energy is the combination of providing energy equally to all people and protecting the environment for the next generation. The renewable energy systems have a common approval as a form of sustainable energy that has attracted the attention recently (Omer, 2008). The exploitation of renewable energy resources such as wind energy reduces dependency on fossil fuels. In other words, Wind energy compared to fossil fuels causes less environmental damage. One of the major contributions of wind energy to environmental protection is through decreasing CO_2 emission (Caralis et al., 2008). Wind turbines do not release any atmospheric emissions while generating power; nonetheless, there are still some negative impacts on both society and ecology (International Energy Agency, 2003).

Interest in the wind energy is growing around the world because of environmental benefits and improvements of its technology, which is competitive with other conventional energy technology. The wind energy can be harnessed for grid and non-grid electricity such as water pumping, irrigation and, milling (Zarma, 2005).

In Iran, regarding to existence of windy sites, designing and establishing wind mills have been since around 2000 B.C. and now there is suitable situation to improve utilization of wind turbines. The wind data collection indicates existence of 26 ideal sites with the total potential wind power of 6500MW, while the nameplate capacity of the power plants is 34000 MW. The wind generators are practical where the average wind speed is 5-25m/s (SUNA, 2007). The above average wind speed should be considered at 40m height above the ground.

Although, as a result of existence of great gas and oil resources in Iran, renewable energy resources such as wind have been paid less attention and did not consider as important source of energy, ecological problems and exhausting of fossil fuels in the future have caused to take advantage of wind energy potentials at least for some non-grid usage.

In spite of environmental safety of the renewable energies, inconsideration of accurate site selection could have unexpected and unsafe consequences, so multicriteria decision making methods can be useful to avoid unsafe consequences.

The paper mainly attempts to introduce new wind energy sites in Zanjan province based on aforementioned multicriteria analysis using powerful GIS tools.

2. Material and Methods

2.1. Study Area

The study is applied in Zanjan province that has a surface area of 22164km^2, which corresponds to about 1.5% of the total surface area of Iran. The province is located in the middle of northwestern Iran (Fig. 1). Although there are some good resources of wind power at least for some uses, there is no wind turbine farm in the study area but in the northern province of the study area i.e. in Gilan province. Fig.1 shows the geographical location of the study area as well as the wind speed which is 40 m above ground level. Fig. 2 shows interpolated wind speed in Zanjan an indication that all areas of the province have wind energy potentials.

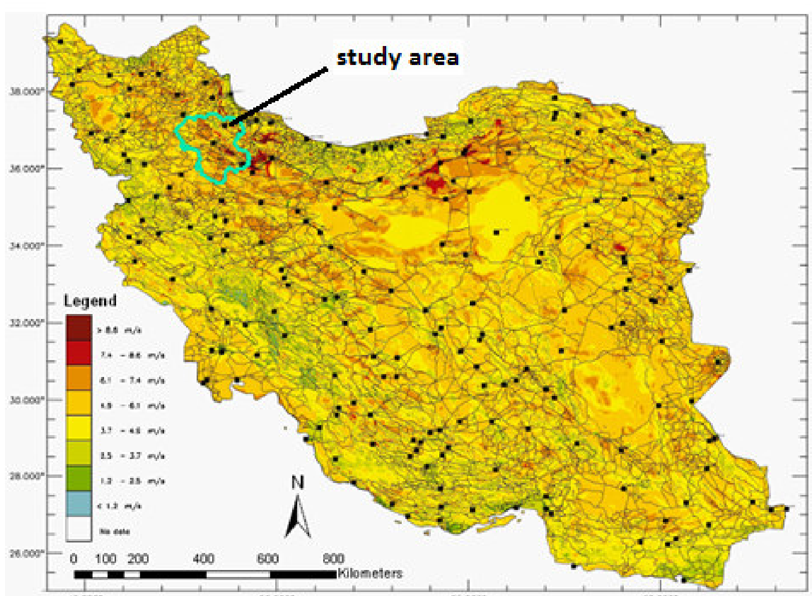

Fig 1. Study Area on Iran's Map and Wind Speed Shwoing at 40m above Ground Level

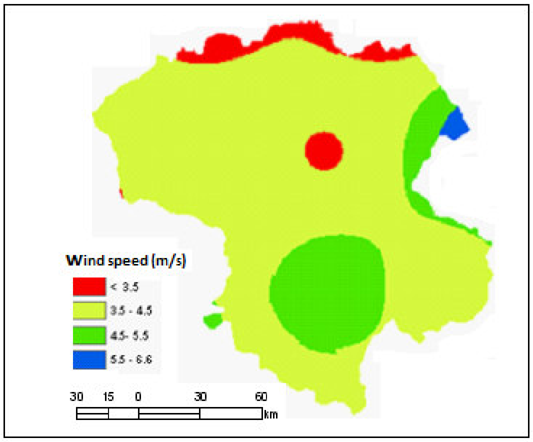

Fig 2. Interpolated Wind Speed at 40m above Ground Level in Zanjan Province

2.2. Data

2.2.1. Climatic Data

There are five weather stations in the study area i.e. Khodabande, Khorramdareh, Zanjan, Mahnashan and, Abbar with an average wind speed of 7.7, 5.7, 4.7, 5, 5.5 respectively at 50m above the ground level. Fig. 3 shows the location of these weather stations.

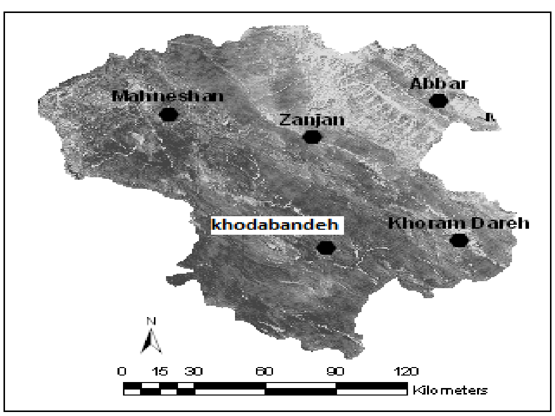

Fig 3 Location of 5 Weather Stations used in the Study

2.2.2. Environmental Data

Environmental data which are used in this study are proximity to access roads, vegetation type, soil conditions, DEM, distance from urban and rural centers, land use, distance from rivers and water bodies.

2.3. Methods

Fig. 4 shows flowchart of the method applied in the current research. In order to select the wind turbine site, first options or alternatives of the study area are determined. Then by means of reviewing different related studies, a significant criterion is identified. The next steps are data collection and pair-wise comparison of the determined criteria. The pair- wise comparison is done using AHP technique. After generating fuzzy criteria maps and making fuzzy criteria weights through fuzzy numbers, TOPSIS technique under fuzzy circumstances is utilized for the wind turbine site selection in Zanjan province.

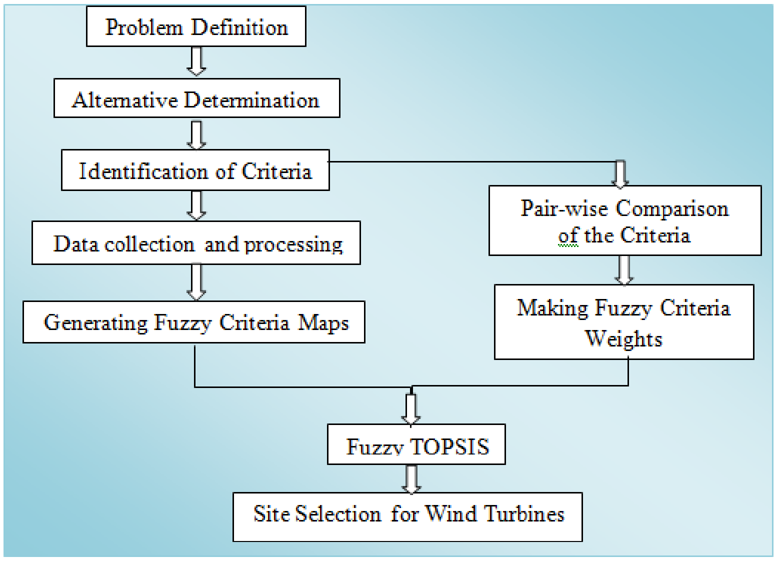

Fig 4. Flowchart of Methodology

2.3.1. Alterative Determination

To determine comparable alternatives, criterion maps of the study area are generated with grid size 100*100m where each cell is considered as an alternative that can be selected satisfying all or most criteria.

2.3.2. Identification of Criteria

The environmental and associated criteria of the wind turbines site are obtained reviewing literature (Table 1). Since there are many related studies using different attributes or criteria for wind turbine site selection, in the current study, the widely used criteria are applied. The recognized criteria are wind speed, proximity to access roads, vegetation type, soil conditions, DEM, distance from urban and rural centers, land use, distance from rivers and water bodies.

Table 1. Environmental Objectives and Associated Criteria from Previous Studies

Criteria	Reference
Topography, soil types	Finardi, 1998
Climate, rain	Durak and Şen, 2002
Wind speed, proximity to transmission lines, accessibility, complexity, terrain orientation to prevailing wind, land owners, cost of land, vegetation, soil types	Conover, 2001
Land use, topography, vegetation, proximity to settlements, rain, elevation, climate	Ramachandra and Shruthim, 2005
Soil types, topography, accessibility	Vivontas et al. 1998
Land use, elevation	Cellura et al., 2008
Land use, elevation, soil types, distance to rivers and water bodies	Isabel, 2009
Land use, climate	Ucar, 2009
Away from areas of ecological value, away from water bodies, away from large settlements	Baban and Parry, 2001
Away from ecologically sensitive areas, away from nearest habitat, away from wildlife conservation areas	Yue and Hung, 2007
Away from airports, away from towns	Vivontas et al. 1998
Away from airports, away from cities, urban centers	Nguyen, 2007
Study area boundaries, potential locations for wind turbines, wind energy potential, settlement areas, roads, water bodies, natural reserves.	Nazli and Kentel, 2010

2.3.3. Data Collection and Processing

A data-set of eight mentioned criteria are obtained from different resources. To get GIS raster data sets, the acquired vector criteria map layers are buffered using literature values which is widely used in the site selection process. Criteria maps are classified into 4 classes and weighted with linguistic terms. The buffer zones of each criterion map are weighted according to distance of the zones from determined features. The buffer vector map layers are then converted into raster map layers of uniform grid size. The raster calculator available in Arc GIS is utilized to make constraint map layer based on different criteria. Table 2 indicates the data used for analysis

Table 2 Data Associated with Classes, Linguistic Terms and Fuzzy Coefficients

Parameters	Classes	Linguistic terms	Fuzzy		
			a	b	c
Wind Density (w/m^2)	*< 150*	*Very weak*	*0*	*0*	*.2*
	150-200	*Weak*	*0.1*	*0.3*	*0.5*
	200-250	*medium*	*0.4*	*0.6*	*0.9*
	> 250	*Good*	*0.8*	*1*	*1*
Land use	*Forest, industrial, residential, surface waters*	*Very weak*	*0*	*0*	*0.2*
	Agricultural, wetland	*Weak*	*0.1*	*0.3*	*0.5*
	Pasture and dry land mixed	*medium*	*0.4*	*0.6*	*0.9*
	Pastures	*Good*	*0.8*	*1*	*1*
Altitude (m)	*> 2000*	*Very weak*	*0*	*0*	*0.2*
	1500-2000	*Weak*	*0.1*	*0.3*	*0.5*
	1000-1500	*medium*	*0.4*	*0.6*	*0.9*
	< 1000	*Good*	*0.8*	*1*	*1*
Slope Gradient	*> 45*	*Very weak*	*0*	*0*	*0.2*
	30-45	*Weak*	*0.1*	*0.3*	*0.5*
	15-30	*medium*	*0.4*	*0.6*	*0.9*
	< 15	*Good*	*0.8*	*1*	*1*
Climate	*A*	*Very weak*	*0*	*0*	*0.2*
	B	*Weak*	*0.1*	*0.3*	*0.5*
	C	*medium*	*0.4*	*0.6*	*0.9*
	D	*Good*	*0.8*	*1*	*1*
Rainfall (mm)	*> 700*	*Very weak*	*0*	*0*	*0.2*
	500 - 700	*Weak*	*0.1*	*0.3*	*0.5*
	300 - 500	*medium*	*0.4*	*0.6*	*0.9*
	< 300	*Good*	*0.8*	*1*	*1*
Vegetation Spices	*Juniperus*	*Very weak*	*0*	*0*	*0.2*
	Crophill, carpinentum , orientalis, quercus, marcanthera	*Weak*	*0.1*	*0.3*	*0.5*
	Amigdalus reuteri, Baberis Cartegus	*medium*	*0.4*	*0.6*	*0.9*
	Steppique Artimesia Asrragalus	*Good*	*0.8*	*1*	*1*
Distance from Urban (m)	*< 3000*	*Very weak*	*0*	*0*	*0.2*
	3000 - 4000	*Weak*	*0.1*	*0.3*	*0.5*
	4000 - 5000	*medium*	*0.4*	*0.6*	*0.9*
	> 5000	*Good*	*0.8*	*1*	*1*
Distance from Rrural (m)	*< 1000*	*Very weak*	*0*	*0*	*0.2*
	1000 - 2000	*Weak*	*0.1*	*0.3*	*0.5*
	2000 - 3000	*medium*	*0.4*	*0.6*	*0.9*
	> 3000	*Good*	*0.8*	*1*	*1*

Distance from Road (m)	*< 100* *> 2500*	*Very weak*	*0*	*0*	*0.2*
	2000 - 2500	*Weak*	*0.1*	*0.3*	*0.5*
	1000 - 2000	*medium*	*0.4*	*0.6*	*0.9*
	100 - 1000	*Good*	*0.8*	*1*	*1*
Distance from Surface Water (m)	*< 400*	*Very weak*	*0*	*0*	*0.2*
	400 - 800	*Weak*	*0.1*	*0.3*	*0.5*
	800 - 1000	*medium*	*0.4*	*0.6*	*0.9*
	> 1000	*Good*	*0.8*	*1*	*1*
Distance from Faults (m)	*< 2000*	*Very weak*	*0*	*0.1*	*0.4*
	2000 - 3000	*Weak*	*0.1*	*0.3*	*0.6*
	3000 - 4000	*medium*	*0.2*	*0.5*	*0.7*
	> 4000	*Good*	*0.6*	*0.8*	*1*
Bedrock Types	*Very hard*	*Very weak*	*0*	*0*	*0.2*
	hard	*Weak*	*0.1*	*0.3*	*0.5*
	Semi hard	*medium*	*0.4*	*0.6*	*0.9*
	Usual	*Good*	*0.8*	*1*	*1*

2.3.4. Pair-comparison of the Criteria

After determining evaluation criteria using different studies, AHP technique was utilized to get the criteria weights. The AHP is a multi-attribute decision tool that allows financial and non-financial, quantitative and qualitative measures to be considered and trade-off among them to be addressed (Önüt and Soner, 2007). The description is developed with three steps (Saaty, 1980).

Step1: A pair wise comparison decision matrix is composed

Step2: The decision matrix is normalized

Step3: A consistency analysis is performed

The pair-wise comparison decision matrix is a matrix that obtains criteria weights. In other words, weighing of the criteria is an important work. As such, this must be carried out taking into account experts opinions. Due to the importance of the weights and decision matrix criteria, opinions of Iranian renewable energies organization SUNA's experts are included and to ensure accuracy of the comparison, three comparison matrix are filled with three different experts. Therefore, eight determined criteria were compared by experts whereas Step 2 and Step 3 were performed for any of the three matrices. In order to determine the relative preferences for two elements of the hierarchy in the comparison matrix, an underlying semantical scale was employed with values from 1 to 9 to rate (Table 2). After making sure of consistency ratio of three pair-wise comparison matrices, average of the three different matrixes is calculated to obtain a unified matrix.

Table 2. Scales for Pair-wise Comparison (Saaty, 1980)

Preferences Expressed in Numeric Variables	Preferences Expressed in Linguistic Variables
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance
2,4,6,8	Intermediate values between adjacent scale values

2.3.5. Fuzzification of Criteria Maps and Weights

Since some uncertainties are involved in the decision-making process in the wind turbine site selection, each criterion map is presented by linguistic terms in four classes. Table 3 shows fuzzy preferences used in the study. As can be seen from Table 3, triangular fuzzy numbers are used in order to fuzzify the criteria maps and criteria weights. Getting triangular criteria maps, any of the criteria maps are presented in three map layers where each of them includes four classes of fuzzy preferences. It is necessary to fuzzify unified pair-wise comparison matrix to make integration of criteria map layers and criteria weights possible. The obtained the pair-wise comparison matrix from last section is fuzzified and finally fuzzy criteria weights are calculated from the matrix.

Table 3 Fuzzy Preferences used in St**udy**

Linguistic Terms		Fuzzy Preference
Very low	1	(0,0,0.2)
Fairly low	2	(0.1,0.3,0.5)
Fairly high	3	(0.4,0.6,0.9)
High	4	(0.8,1,1)

2.3.6. TOPSIS

General TOPSIS process can be illustrated with six activities as follows (Olsen, 2004):

Activity 1: Establishing a decision matrix for ranking. The structure of the matrix can be expressed as follows:

$$D = \begin{array}{c} \\ A_1 \\ A_2 \\ . \\ . \\ . \\ A_n \end{array} \begin{array}{c} \begin{array}{cccccc} F_1 & F_2 & . & . & . & F_n \end{array} \\ \begin{bmatrix} f_{11} & f_{12} & . & . & . & f_{1n} \\ f_{21} & f_{22} & . & . & . & f_{2n} \\ . & & . & & & . \\ . & & & . & & . \\ . & & & & . & . \\ f_{m1} & f_{m2} & . & . & . & f_{mn} \end{bmatrix} \end{array} \quad (1)$$

Where A_i denotes the alternatives i, i=1,…, m;

F_{ith} represents jth criterion, j=1,…,n, related to i alternative; and f_{ij} is a crisp value indicating the performance rating of each alternative A_i with respect to each criterion F_j.

Activity 2: Calculating the normalized decision matrix $R(=[r_{ij}])$. The normalized value r_{ij} is calculated as:

$$r_{ij} = \frac{fij}{\sqrt{\sum_{j=1}^{n} f_{ij}^2}} \quad (2)$$

Where j=1,…,n; i=1,…,m.

Activity 3: Calculating the weighed normalized decision matrix by multiplying the normalized decision matrix with its associated weights. The weighed normalized value v_{ij} is calculated as:

$V_{ij}=w_{ij}.r_{ij}$

Where w_j represents the weight of the j^{th} criterion.

Activity 4: Determining the positive ideal solution and negative ideal solution, respectively:

$$v^+ = \{1 \quad (3)$$

$$v^- = \{v_1^-, \ldots, v_n^-\} = \{(Min\ v_{ij} | j\epsilon j), (Max\ v_{ij} | j\epsilon J')\} \quad (4)$$

Where j is associated with the positive criteria and J′ is associated with the negative criteria.

Activity 5: Calculating the separate measures, using the m-dimensional Euclidean distance. The separation measure of each alternative from the positive Ideal solution. Similarly, the separation measure of each alternative from the negative ideal solution.

Activity 6: Calculating the relative closeness to the ideal solution and rank the alternatives in descending order. The relative closeness of the alternative A_i with respect to positive ideal solution V^+ can be expressed as:

$$\bar{C}_i = \frac{D_i^-}{D_i^{|} + D_i} \quad (5)$$

Where the index value lies between 0 and 1. The larger the index value, better the performance of the alternative.

2.3.7. Fuzzy TOPSIS

Reviewing different definitions from Zimmerman (1991), Buckley (1985), Zadeh (1965), Yang and Hung (2007) and Chen et al. (2006) can be summarize below. Assigning a precise rating to an alternative often is not possible. So, fuzzy approach can be applied to assign the relative importance of alternative under fuzzy different criteria. In this study, fuzzy Topsis technique (Fig. 2) is used to integrate the criteria maps and weights.

Assigning a precise rating to an alternative often is not possible so, fuzzy approach can be applied to assign the relative importance of alternative under different criteria. Fuzzy Topsis can be presented as follows (Önüt and Soner, 2007):

Definition 1: A fuzzy set in a universe of discourse X is characterized by a membership function which associates with each element x in X, a real member in the interval [0, 1]. The function value is termed in the grade of membership function of x.

The present study uses triangular fuzzy numbers. A triangular fuzzy number can be defined by a triple.

Definition 2: In triangular fuzzy numbers, the vertex method is defined to calculate the distance between them.

Definition 3: Considering the different importance values of each criterion, the weighed normalized fuzzy-decision matrix is constructed as:

$$\tilde{V} = [\tilde{v}_{ij}]_{n \times J}, \quad i = 1,2,\ldots,n, \quad j = 1,2,\ldots,J$$

3. Results

The mentioned methodology is applied for site selection of wind turbine in the study area. For the purpose of wind turbine site selection in Zanjan province, the identified criteria have to be represented as GIS map layers. After generating vector map layer for any of the criteria, vector map layers are buffered using the specified buffer distances around the features. The obtained buffered vector map layers then are converted into raster layers utilizing Spatial Analyst tool available in Arc GIS 9.2. In the next step, the fuzzy raster map layers are generated using triangular fuzzy numbers (Table 3), so there would be three map layers for any of the layer with fuzzy numbers.

As stated earlier, criteria weights are attained using the AHP technique. The identified criteria wind speed, proximity to access roads, vegetation types, soil condition, DEM, distances from urban and rural centers, land uses and, distances from rivers and water bodies are compared by three groups of SUNA’s experts using preference numbers. To obtain integrated weights taking into consideration three group’s opinions, after normalizing the pair-wise comparison matrix, average of the three group’s opinions is calculated. The acquired crisp weights are fuzzified using triangular fuzzy numbers to be integrated with related criteria layers. Finally, the Topsis method is utilized to combine both the criteria weights and map layers

As mentioned, the Fuzzy TOPSIS is going to have final results which are both positive and negative ideals. Similarities to ideal solution then are calculated using positive and negative ideal solutions. In this study, more than .7 satisfactions are considered as acceptable alternatives for further study. Fig. 5A shows the more appropriate options in the form of Boolean based on the TOPSIS method. Also, Fig. 5B shows the result based on the fuzzy TOPSIS method.

In order to compare the two applied methods, the correlation coefficient is 0.7112 that presents a good relation. The area calculated for the best location is based on two methods i.e. 575 and 605 square kilometers respectively that are very close to each other (Table 4). The study to check the accuracy shows that the selected area in two methods are suitable.

The prepared maps indicated that the selected alternatives located in the north-east of the study area in Tarom region which is a mountainous and one of the steepest areas in Zanjan. This is the windiest zone in the study area and as stated earlier the wind speed is the most important factor for selecting the wind farm. In other words, perhaps as a result of high wind speed potential in Tarom region, options are located there. In the north of Tarom, Manjil is yet another region that has high wind speed. Compare to Manjil, Tarom has lower wind speed but the least yearly fluctuations. Considering the constraint layer, it can be said that Tarom has lower constraints with respect to other used layers. In the case of land use, Tarom is the mountainous and lacks suitable agricultural lands. In case of noise, it has much distance from cities and villages. Also, locating in the northern part of study area, Tarom region has partially different climate compare to other parts of Zanjan province. In other words, it has more precipitation and rain hence, unrestricted vegetation. Selected points at the fringe of Gezelozan River, with moderate slope, are more appropriate for wind turbine.

As the study indicates, the installation of wind turbine in the Tarom region would be useful and help produce portion of required energy.

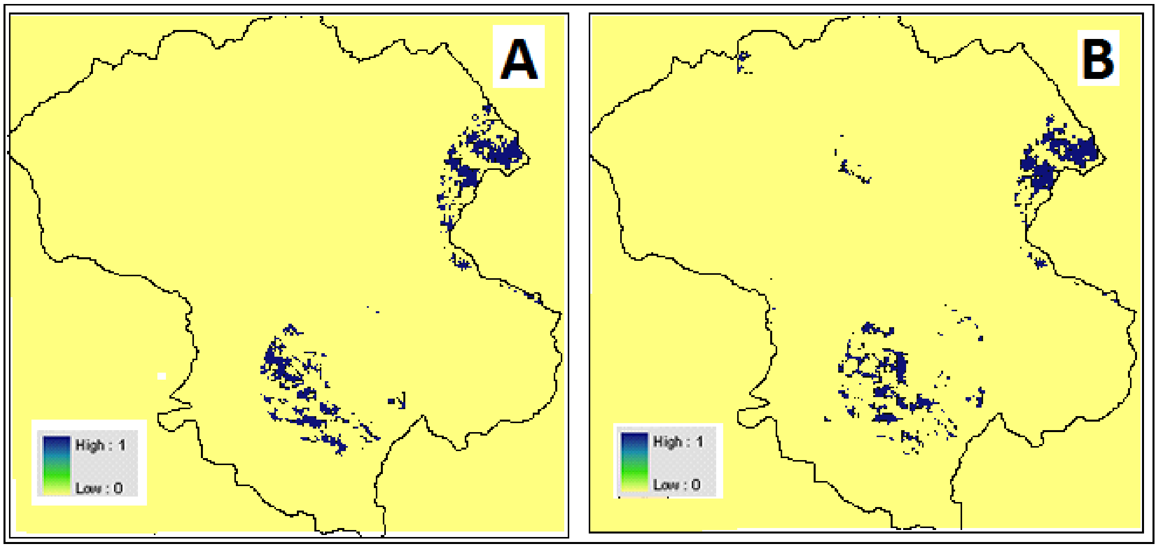

Fig 5. Location of Best Place for Wind Farm Based on TOPSIS (A) and Fuzzy TOPSIS (B) Methods

Table 4. Total Area Extracted based on TOPSIS and Fuzzy TOPSIS Methods (km^2)

Method	Ares (km^2)
TOPSIS	575
Fuzzy TOPSIS	605

4. Conclusion

Investments in renewable energies are increasing as a result of environmental effects and degradation of the fossil fuels. Renewable energies have enough advantages over conventional energies especially inconsideration of environmental criteria could have environmental impacts. Multicriteria decision making can be conducted to avoid unexpected results. In Iran, wind data indicate the existence of 26 ideal sites with a total potential wind power of 6500 MW, while the nameplate capacity of the power plants is 34000 MW. The wind generators are practical where the average wind speed is 5-25m/s (SUNA, 2007). In Zanjan province, availability of acceptable wind resources and considering other effective environmental criteria, wind turbines at least for some local uses could be affective. Using Fuzzy TOPSIS and AHP techniques while considering eight environmental factors such as wind speed, proximity to roads, vegetation type, soil conditions, DEM, distance from urban and rural centers, land use, distance from rivers and water bodies, can be helpful to achieve the goal of wind turbine site selection.

In this paper, some alternatives are proposed for wind turbine establishment which satisfy most of the criteria. The selected alternatives are mostly in south and east of the study area that lack wind turbine and wind turbine projects. The proposed sites need to be studied in detail in any future study.

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پهنه بندی مناطق بالقوه انرژی باد با استفاده از مدل تصمیم گیری چندشاخصه مبتنی بر فازی دراستان زنجان در محیط سیستم اطلاعات جغرافیایی

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هدف این مقاله مطالعه پتانسیل های بادی استان زنجان که در شمال غرب ایران قرار گرفته می باشد. پروژه‌های انرژی‌های تجدید پذیر کاملا با محیط سازگاری ندارند و طرح‌های متفاوت انرژی‌های تجدید پذیر تاثیرات متفاوتی بر روی محیط دارند. بنابراین انتخاب مکان بهینه یک موضوع مهم در احداث توربین‌های بادی می‌باشد و انتخاب مکان مناسب برای مزارع بادی به دلیل پیچیدگی موضوع نیاز به در نظر گیری فاکتورهای متعدد به طور همزمان و ارزیابی آنها دارد. در این پژوهش با استفاده از تکنیک‌های فرایند تحلیل سلسله مراتبی و تاپسیس و منطق فازی و تلفیق آن با سیستم اطلاعات جغرافیایی، پتانسیل های احداث توربین های بادی منطقه مورد مطالعه ارزیابی شده است. وزن معیارها از مقایسه زوجی حاصل شده و سپس عمل فازی سازی لایه‌های اطلاعاتی انجام گرفته است. فازی سازی لایه‌ها به وسیله اعداد مثلثی صورت گرفته و تکنیک تاپسیس فازی جهت ترکیب لایه ها و نتیجه‌گیری نهایی استفاه گردیده است. نتیجه این مطالعه توانایی روش‌های چند معیاره مکانی در ارزیابی مکانهای مناسب برای احداث مزارع بادی در منطقه مورد مطالعه را نشان می دهد.

واژگان کلیدی: تحلیل چند معیاره، سیستم اطلاعات جغرافیایی، تاپسیس، فازی، زنجان.

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