The Wind Energy Potential Zoning Using GIS And Fuzzy Mcdm Based Approach; Study Area: Zanjan Province-Iran

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Abstract

This study, analyses wind energy potentials of Zanjan province which located in northwest of Iran. Renewable energy plans are not fully environmental safe and different renewable energy plans have different environmental impacts. Therefore, site selection is an important issue in wind turbine installation and selection of the appropriate wind turbine site requires consideration of multiple alternative solution and evaluation criteria because system complexity. In this paper, by using AHP and fuzzy TOPSIS technique 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 wind turbine installation. The results of this study shows ability of multicriteria methods to evaluate of suitable sits in geographic areas in one side and good potentials sites of Zanjan province to establish new energy plans in other side.

Keywords: wind energy, multicriteria analysis, GIS, Zanjan Province

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 spreading and the world population energy requests 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 next generations. The renewable energy systems have a common approval as a form of sustainable energy that keeps the attention recently (Omer, 2008). Exploitation of renewable energy resources such as wind energy reduces dependency on fossil fuels. 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 wind energy is growing around the world because of environmental benefits and improvements of its technology, which is competitive with other conventional energy technology. 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 paid less attention and not considered 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 taking into account several factors to avoid unsafe consequences.

The main of this paper is introduce of new wind energy sites in Zanjan province based on multicriteria analysis using powerful GIS tools.

2. Material and Methods

2.1. Study Area

The study is applied in Zanjan province that has surface area of 22164km2, which corresponds to about 1.5% of the total surface area of Iran. The province is located in middle north west of 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 study area in Gilan. Also Fig. 1 is given wind speed of Iran at height of 40 m above ground level and geographical location of the study area. Fig. 2 show interpolated wind speed in zanjan province that indicated that all the areas of province have wind energy potential.

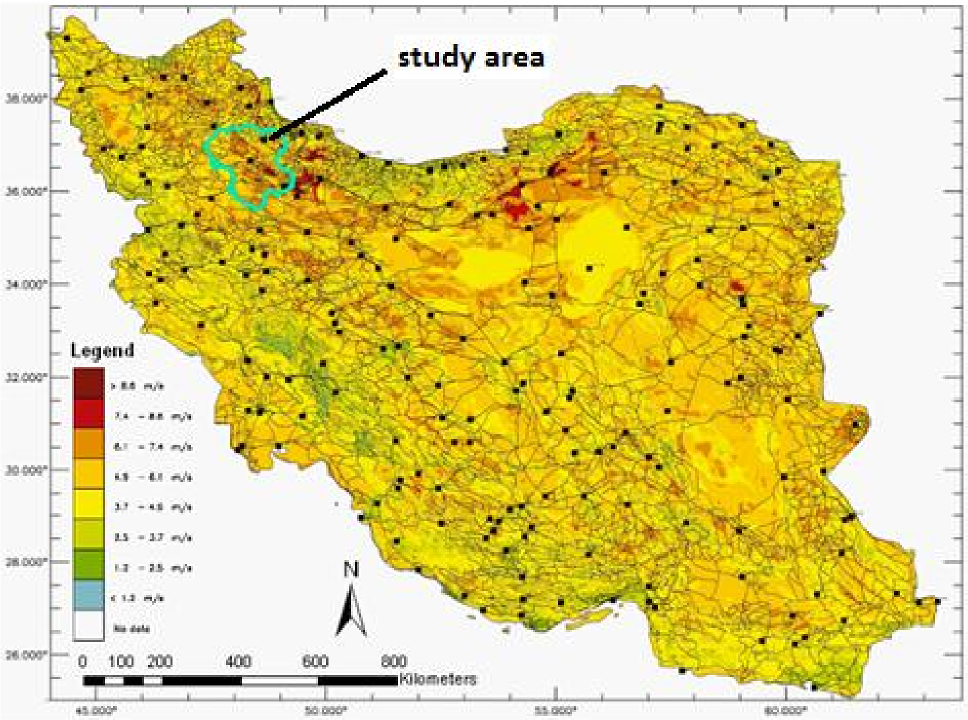

Fig. 1. Study area on Iran map and wind speed at 40m above ground level

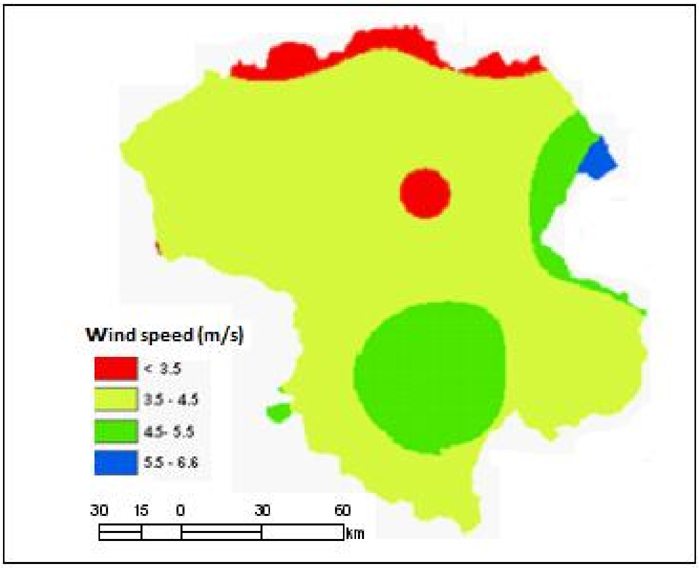

Fig. 2. interpolated wind speed at 40m above ground level on Zanjan province

2.2. Data

2.2.1. Climatic Data

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

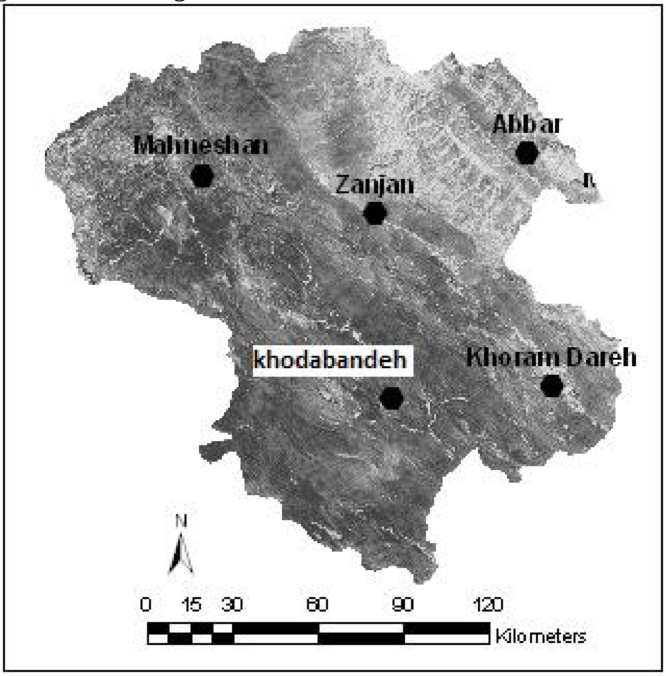

Fig. 3. Location of 5 weather station used in this study

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 used method in generally approach. In order to wind turbine site selection, in first options or alternatives of the study area were determined. Then by means of reviewing different related studies, significant criteria of the study are identified. The next steps are data collection and pair-wise comparison of the determined criteria. Pair- wise comparison is done using AHP technique. After generating fuzzy criteria maps and making fuzzy criteria weights by means of fuzzy numbers, TOPSIS technique under fuzzy circumstances is utilized for wind turbine site selection in Zanjan province. Fig. 3 shows the flowchart of research.

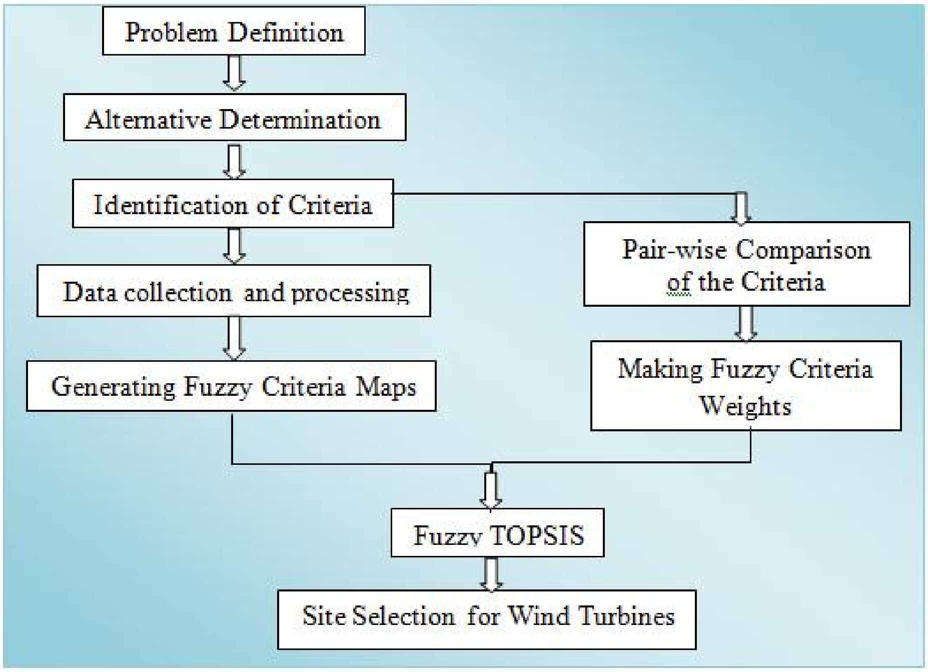

Fig. 4. Flowchart of methodology

2.3.1. Alterative Determination

In order to determining comparable alternatives, criterion maps of study area with grid size 100*100m are generated while 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 selection obtained reviewing literature of the wind turbine sit selection (Table 1). Since there are many related studies using different attributes or criteria for wind turbine site selection, in the current study 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

Data sets of eight mentioned criteria are obtained from different resources. To get GIS raster data sets, obtained vector criteria map layers are buffered using literature values widely used in 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 were then converted into raster map layers of uniform grid size. The raster calculator available in Arc GIS was utilized to make constraint map layer based on different criteria. Table 2 indicates data used associated with different weighting were used for analysis.

2.3.4. Pair-Comparison of The Criteria

After determining evaluation criteria using different studies, AHP technique were utilized to get 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 in three steps (Saaty, 1980).

Step1: compose a pair wise comparison decision matrix

Step2: normalize the decision matrix

Step3: do consistency analysis.

Pair-wise comparison decision matrix is a matrix obtains criteria weights. Weighting of the criteria is an important work. Therefore, this section must be done including experts opinions. As a reason of the importance of criteria weights and decision matrix, opinions of Iranian renewable energies organization SUNA's experts are included and to ensure accuracy of the comparison, three comparison matrix filled out by three different experts individually. Therefore, eight determined criteria are compared by experts and step 2 and step 3 are done for any of the three matrixes. In order to determine the relative preferences for two elements of the hierarchy in comparison matrix, an underlying semantical scale is employs with values from 1 to 9 to rate

(Table 2). After making sure of consistency ratio of three pair-wise comparison matrixes, to obtain a unified matrix, average of the three different matrix is calculated.

Table 2. data used associated with clases, linguistic terms and fuzzy coeficents

Parameters	Classes	Linguistic terms	Fuzzy		
			a	b	c
Wind density (w/m2)	< 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
Raimfall (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 rural (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

Table 2. Scales for pairwise 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 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 fuzzifying the criteria maps and criteria weights. Getting use of triangular criteria maps, any of the criteria maps are presented in three map layers which 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 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 the study

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

$$D = \begin{array}{c} \\ A1 \\ A2 \\ \vdots \\ An \end{array} \begin{array}{c} F1 \quad F2 \quad \ldots \quad Fn \\ \begin{bmatrix} f11 & f12 & \ldots & f1n \\ f21 & f22 & \ldots & f2n \\ \vdots & & \ddots & \vdots \\ fm1 & fm2 & \ldots & fmn \end{bmatrix} \end{array} \quad (1)$$

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

Fith represents jth criterion, j=1,…,n, related to i alternative; and fij is a crisp value indicating the performance rating of each alternative Ai with respect to each criterion Fj.

Activity 2: Calculate the normalized decision matrix R(=[rij]). The normalized value rij 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: Calculate the weighted normalized decision matrix by multiplying the normalized decision matrix by its associated weights. The weighted normalized value vij is calculated as:

Vij=wij.rij

Where wj represents the weight of the jth criterion.

Activity 4: Determine the positive Ideal solution and negative Ideal solution, respectively:

$$v^{+} = \{v_1^{+}, \ldots, v_n^{+}\} = \{(Max\ v_{ij}|j\epsilon J), (Min\ v_{ij}|j\epsilon J')\} \quad (3)$$

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

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

Activity 5: Calculate 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: Calculate the relative closeness to the ideal solution and rank the alternatives in descending order. The relative closeness of the alternative Ai 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 of lies between 0 and 1. The larger the index value, the 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 following definitions. 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 criteria maps and criteria 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):

Definition1. 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 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 weighted normalized fuzzy-decision matrix is constructed as:

$$\tilde{V} = \left[\tilde{v}_{ij}\right]_{n\times J}, \quad i = 1,2,\ldots,n, \quad j = 1,2,\ldots,J \qquad (11)$$

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, fuzzy raster map layers are generated using triangular fuzzy numbers (Table 3), so there would be three map layers for any of the layers with fuzzy numbers.

As stated earlier, criteria weights are attained using 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 Topsis method is utilized to combine both the criteria weights and criteria map layers

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

In order to compare the two applied method, the correlation coefficient between them is 0.7112 that present a good relation. Area calculated for best location based on two methods is 575 and 605 square kilometers respectively that is very near to each other (Table 4). The field study to check the accuracy map show the selected area in two methods are good, but fuzzy TOPSIS the good results.

The prepared maps indicated that the selected alternatives located in the north east of the study area in Tarom region. Tarom is a mountainous area and is one of the steepest areas in the Zanjan county. This region has the most windy area in the study area and as stated earlier wind speed is the most important factor for wind farm site selection, so perhaps as a result of high wind speed potential in Tarom region, selected proposed options are located there. In the northern proximity of Tarom region located Manjil as a region with high wind speed in Iran. Although Tarom has lower wind speed in comparison with Manjil, has the highest wind speed and the lowest yearly fluctuations in the study area. In the other hand with the consideration of constraint layer, it can be recognized Tarom has lower constraints in the sense of other used information layers. In the case of land use, Tarom is mountainous and it doesn't consist more suitable agricultural lands. In the case of noise and distance from cities and villages, suggested options have enough distances. Tarom region as a result of locating in northern part of study area, has partially different climate in comparison with other parts of Zanjan county. In other words, it has more precipitation and rain. In the case of vegetation, there is no restriction in the region. Selected options are in the margin of Gezelozan river and although the region is mountainous, this part has moderate slope and more appropriate for wind turbine site selection. There is good local wind resource in the region that has been provided installation of Manjil wind farm.

According to the study, installation of wind turbine in the Tarom region would be useful and will make some portion of energy necessities.

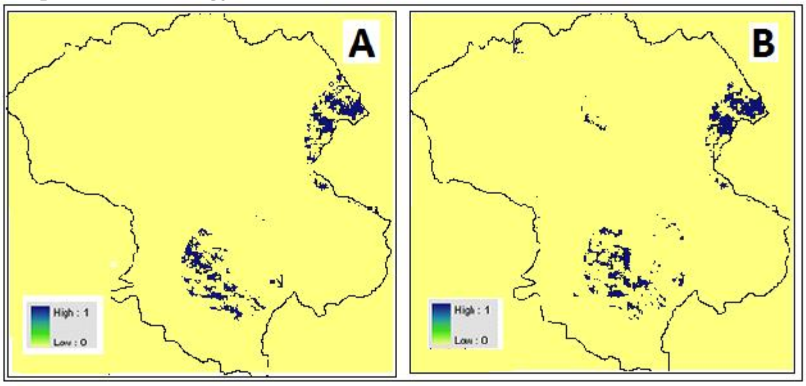

Fig. 5-location of best place for wind farm based TOPSIS (A) and Fuzzy TOPSIS (B) methods

Table 4- the total areas 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 deployment of the fossil fuels. Renewable energies have lots of advantages over conventional energies; inconsideration of environmental criteria could have environmental impacts though. Multicriteria decision making can conduct to avoid unexpected results. In Iran, the wind data collection indicates existence of 26 ideal sites with the 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 with the existence of acceptable resources of wind speed considering other effective environmental criteria, establishing wind turbines at least for some local uses will be useful. Using Fuzzy TOPSIS and AHP while considering eight environmental factors, 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, can be helpful to get the goal of wind turbine site selection.

In this paper, some alternatives are selected as more suitable sites for wind turbine establishment which are satisfied most of the criteria. The selected alternatives are mostly in south and east of the study area that there are no wind turbine and nor wind turbine projects in the future. The proposed sites need to be studied in detail in the future so this can be the topic of the future study.

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