Article

Site selection of wind power plant using multi-criteria decision-making methods in GIS: A case study

E. Chamanehpour, **Ahmadizadeh**, **Akbarpour**
University of Birjand, Birjand, Iran
E-mail: elham.chamanehpour@gmail.com, Sahmadi@birjand.ac.ir, Akbarpour@birjand.ac.ir

Received 21 January 2017; Accepted 28 February 2017; Published online 1 June 2017

Abstract
Wind energy due to abundance, minimal environmental pollution and high cost-effectiveness are considered as one of the best clean energies. One of the most important issues in the use of wind energy is the correct layout of suitable extraction locations of wind energy to generate electricity. The suitablesite selection to establish wind power plants based on the principles and criteria of a sustainable environmental advancement which in addition to cost-effectiveness and employment generation results in a cheap and inexhaustible energy source besides providing the basic information to attract domestic as well as foreign investments to use the wind energy. In the present study, 16 information layer consisting of: wind speed, temperature, altitude, slope, towns, villages, main and secondary routes, airport, protected areas, land use, rivers, wells, springs and aqueducts, earthquake acceleration and faults was considered as the basic decision-making criteria. Using multi-criteria decision-making methods in GIS environment viz. Analytical Hierarchy Process (AHP) and Fuzzy methods, modelling of the suitable extraction sites of wind energy was carried out. The results exhibited that the best regions that can be nestled in the excellent class include Zirkouh of Ghaen, east of Darmian, east of Sarbishe, north of Khoosf and east of Deyhouk. Considering the calculations of the present study, from the total case study area, 3.3% in AHP method and 4.5% in Fuzzy method had excellent potential to use wind energy. Finally, the area located in the north-west of Khoosf was proposed as the best area to establish the wind power plant.

Keywords South Khorasan; exploitation of wind energy; site selection.

Computational Ecology and Software
ISSN 2220-721X
URL: http://www.iaees.org/publications/journals/ces/online-version.asp
RSS: http://www.iaees.org/publications/journals/ces/rss.xml
E-mail: ces@iaees.org
Editor-in-Chief: WenJun Zhang
Publisher: International Academy of Ecology and Environmental Sciences

1 Introduction

An extensive need of a human for energy resources has always been the fundamental issues in the life of a human being. Besides an endeavorto access a sustainable energy source is accounted as one of the ancient wishes of a mankind (Renewable Energy Organization of Iran, 2015). The population explosion and everincreasing growth of energy demand, increment of living standards, the danger of global warming due to greenhouse phenomenon, precipitation of acidic rains, the environmental issues and threat to human health and eventually the lack of fossil fuel resources are namely the issues that have attracted the attention of countries worldwide to use renewable energies (Jafari et al., 2011).

Among this the wind energy is namely the renewable energy that due to extend, high efficiency power, economics, and even in comparison to the other renewable energies in the wider dimensions have been exploited indeed encounters a special status (Morshedi et al., 2010).Iran due to special geographical position and its location on the route of prevailing winds has a potential to exploit the wind energy (RasooliKoohi et al., 2002). The conducted studies and calculations in wind energy potential estimation in Iran exhibited that only in 26 regions of the country,thenominalcapacity rate of sites considering an overall efficiency of 33%, is approximately 6500 mw and this is in the condition that presently the nominal capacity of the total electrical power plants is approximately 34,000 mw (Mirzaei and Bagherinejad, 2012).

As far as use of wind energy is concerned,AsgharipourDashtBozorg et al (2011)conducted the assessment of Geographical Information System (GIS) in site selection to establish the wind power plants of Khuzestan province. The aim of this study was to determine the role of climatic, geographical, socio-economical, environmental and geological factors to determine a suitable location to establish the wind power plants in Khuzestan province. The results showed that the southern, southwestern, west and north of Khuzestan province are accounted as the best locales to construct wind power plants.

Kamau et al (2010) used wind data from the Kenya Meteorological Department for the period 2001–2006 to calculate the Weibull parameter values. Result sindicated that the site was suitable for grid connected power generation and also for other application ssuchaswater pumping and battery charging.

Sliz-Szkliniarz and Vogt (2011) evaluated wind energy potential using a GIS based approach in Poland. They developed an approach to support the decision-making process for site selection for wind energy projects using GIS.

Al-Yahyai et al (2012) applied MCDM using AHP with an Ordered Weigh Averaging (OWA) aggregation function to derive a wind farm land suitability index and classification under a GIS environment in Oman. The selection criteria considered were economic (distance to road, terrain, slope), social (urban area), environmental (historical sites, wildlife, natural reserves) and technical (wind power density, energy demand, percentage of sustainable wind, turbulence intensity, sand dunes).

Azizi et al (2014) used ANP-DEMATEL in a GIS environment for wind power plant site selection. They used 13 information layers in three main criteria including environmental, technical and economical, the land suitability map was produced and reclassified into 5 equally scored divisions from least suitable to most suitable areas. The results showed that about 6.68 % of the area of Ardabil province is most suitable for establishment of wind turbines.

As mentioned energy supply is accounted as the main distress of modern societies wherein even southKhorasan due to lack of fossil energy resources faces a serious challenge of energy supply. So, the use of renewable energies, especially wind energy is considered as one of the best administrational policies to reduce this issue. In this research, it is assumed that according to Wind Atlas of the country, South Khorasan province possesses a high capacity of wind energy usage that in case of proper exploitation and based on the environmental parameters can supply a part of the needed energy.

Besides, it is a step towards accessing the sustainable and diversified advancement targets of the country's energy conservations. Although the Wind Atlas of the country have been prepared, but the importance of the land ratio assessment studies and shortage of basic knowledge,besides from one hand the high vastness of the country and on the other hand its topographic variations has caused that the native assessment of wind energy potential is discussed as a sustained need in each region. So that in addition to the qualitative and quantitative cognition of the province's wind status, the feasibility to establish wind power plants in the region is also assessed. In most of the studies, the potential assessment of wind energy has been conducted based on the meteorological parameters. This study is among the prime studies that in addition to assessment of climatic characteristics have as well investigated the natural, socio-economical, geological and environmental indexes. In addition, the efforts have been taken whereinvia the combination of qualitative and quantitative parameters and use of dual methods viz. the multi-criteria decision-making and Geographical Information System (GIS), a higher simulation of existing conditions with reality is carried out so that suitable exploitationsites of wind energy are selected with much preciseness.

2 Material and Methods

2.1 Study area

South Khorasan province is nestled in eastern Iran and its center is the city of Birjand. This province is constituted of 11 counties: Birjand, Ferdows, Tabas, Qaen, Nehbandan, Darmian, Sarbishe, Boshruyeh, Sarayan, Zirkouh and Khoosf. Fig. 1 – Depicts border of the political divisions of south Khorasan in the country (South Khorasan Governor, 2008).

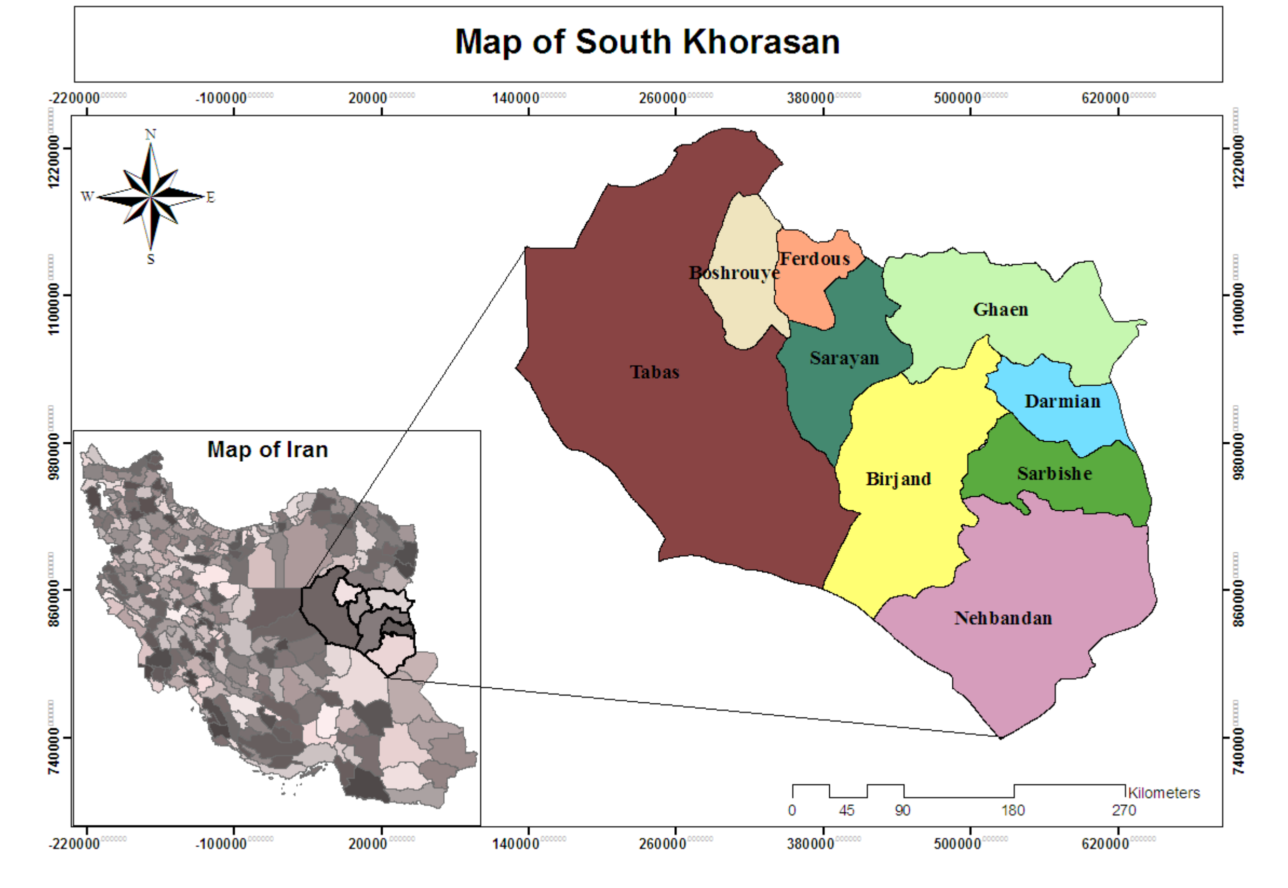

Fig. 1 The border of political divisions of the case study.

2.2 Research methodology

2.2.1 Criteria

In site selection of wind power plants, numerous criteria can be involved that as the number of these criteria in a model is higher it requisites a more accurate output, but considering the inaccessibility to entire interfering information in the site selection and existing limitations, the most effective and most essential factors were selected. Primarily, considering the library studies, scientific literatures and resources and relevantexperts' opinion besides climatic, natural, socio-economical, geological and environmental criteria were set as the main criteria. Later each criterion and sub-criteria and relevant options were divided that further the importance of each of them are addressed.

Wind speed: The most fundamental issue to use wind energy is wind speed rate of the region wherein as wind speed is higher, the power generation via wind turbines increases. Indeed, herein, as well some restrictions exists that include the minimum and maximum wind speed to convert the wind energy into electrical energy that generally is determined via the turbine manufacturing company (Noorallahi et al., 2011). The wind speed initiates with efficiency and halting speed of most of the wind turbines are 3 and 25 meters per second respectively (Weisser, 2003).

The statistical distribution of wind speeds varies from place to place around the globe, depending upon local climate conditions, the landscape and its surface. The wind speed distribution for a typical site is usually described using the so-called Weibull distribution (Al-Nhoudand Al-Smairan, 2015).

The Weibull probability density function can be given by:

$$f(v) = \frac{k}{c}\left(\frac{u}{c}\right)^{k-1} \exp\left[-\left(\frac{u}{c}\right)^{k}\right] \qquad (1)$$

(c> 1, v > 0, k > 0)

Wherep(v)is the probability of observing wind speed, k is the unitless shape parameter, c is the scale parameter in m/s and vis the wind speed (Weibull, 1952).

The cumulative Weibull distribution P(v) gives the probability of the wind speed exceeding the value V, it is expressed as (Olayinka and Olaolu, 2012):

$$P(v) = 1 - \exp\left[-\left(\frac{v}{c}\right)^{k}\right] \qquad (2)$$

One of the benefits of selecting Weibull function for wind speed distribution is ability to covert the wind speed distribution in an altitude of 10 m to any other altitude. This affair occurs via adoption of a law known as ``one seventh power law''(Bagiorgas et al., 2007).

$$\frac{c_1}{c_2} = \left(\frac{z_1}{z_2}\right)^{1/7} (3)$$

Here c_1 and c_2 are the meta-assessments to scale Weibull function, in the altitudes z_1 and $z_2$respectively (Omidvar and DehganTarazjani, 2010).

In the present study, initially the wind speed average in the considered stations was calculated in a statistical period of 25 years and then using the Weibull probability distribution function (Equation 1), wind speed is calculatedwith a return period of 50 years. Later, considering that an altitude of 50 m, is an axis altitude of most of the wind turbines (Eskin et al., 2008). Therefore, wind characteristics obtained from 10 m altitude using one seventh power law (Equation 3) were extended to an altitude of 50 meters. Eventually, the wind speed map was prepared by using the Kriging interpolationmodelin GIS software (Fig. 2).

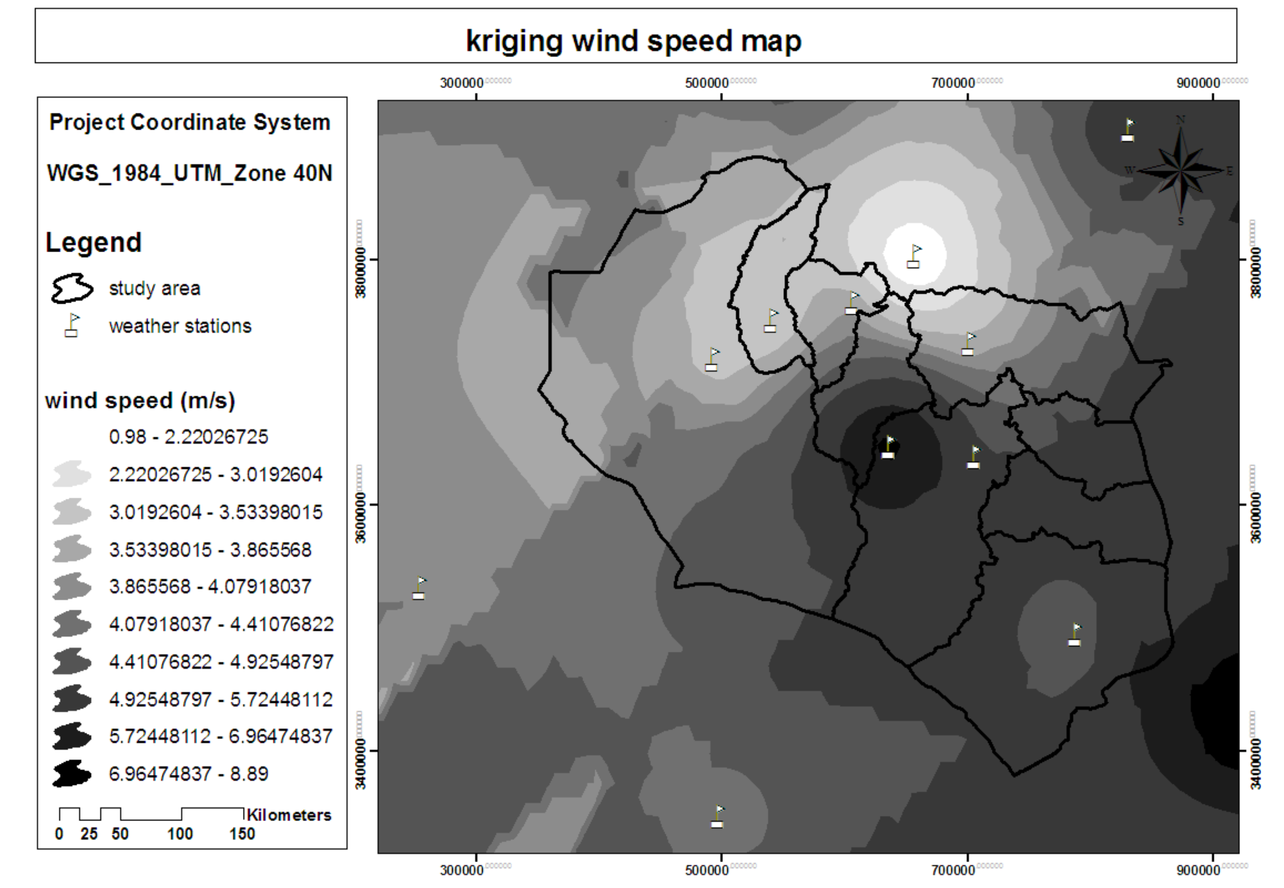

Fig. 2 Kriging wind energy potential map.

Temperature: With temperature reduction the extractable turbine power and its useful life increases. Thus, the regions having lower temperature are more suitable to install a turbine. Even for the preparation of this layer,the 25 years information on the average temperature of case study stations was used and adopting the simple Kriging method the considered layer was prepared in GIS environment.

Altitude: The altitude rate from the sea level should be in a quantum that doesn't associate equipments transmission with difficulty. Besides, in the selection of a suitable site for wind power plant we are forced to avoid highlands, since with altitude increase the investment costs accelerates (Jafari et al., 2011). The altitude layer was prepared using the region topography layer and Digital Elevation Model (DEM).

Slope: The region slope is also one of the main factors in the appropriate functioning of a wind turbine and its installation. Sometimes in an event the entire or a part of wind turbine is hidden via hills and mountains which may hinder access to an effective power needed by a turbine. The topography criterion observance could overcome these issues (Noorallahi et al., 2011). In addition, with the increase of slope rate the turbine construction cost increases,thus slope should be at a level wherein the establishment of a turbine is affordable. Even slope layer was prepared using topography region and Digital Elevation Model (DEM) of the province.

Distance from the town and village: A suitable distance from the population centers is of importance due to some reasons: 1- The noise pollution of wind turbines. 2- Reduction of wind speed: the artificial environments on small-scale lead to climate change and generally in constructional areas, the wind speed should be 25% lesser in comparison to the other regions. 3- The development of future residential sections. 4- Financial costs (Jafari et al., 2011).5- Supply of human resources needed at the turbine establishment site.

Distance from the routes: In order to access the locale and equipment transport are of importance and as we get closer to the communication routes it is more cost-effective economically.

Distance from airport: The wind turbines can cause interference in the performance of air traffic control radars. In a radar system, airplanes are cognized and tracked via return signal frequency change (Doppler Effect). Although the position of wind turbines due to lack of change is not followed by Doppler Effect, but rotation and turning of turbine wings causes Doppler Effect wherein this issue causes an interference in the tracking and disruptsidentification of an airplane (Soleimaniet al., 2014).

Distance from protected areas: The wind power stations due to changes of natural landscapes besides the creation of noise pollution have a negative impact on intrinsic property of these regions. For this reason wind turbines should be nestled in a suitable distance in relation to the protected areas.

Land use: In some of the land uses, such as forests, lakes, urban areas, etc., there is nil possibility to establish a wind power station and these regions should be eliminated from the site selection. The other land uses also should be selected in a manner that in addition to costbenefit from the environmental viewpoint, no damage is introduced to the area.

Distance from the ground water: To maintain the natural environment, the standard distances of aqueducts surroundings should be observed.

Distance from the surface water: Considering that dynamically the route of rivers are perpetually in the state of change and besides flood occurrence, and farness of wind power plants from the river beds causes an increase in the security of the facilities (Jafari et al., 2011).

Distance from fault: Having an appropriate distance from the area faults is a necessary and inevitable affair in order to preserve the safety of existing facilities in wind power plants.

Earthquake acceleration: Earthquakes have the highest destruction effect in their centers and with distancing from them the security rate of the area increases.

2.2.2 Prohibition

Initially with reference to related organizations the raw information related to 16 layer information was prepared and was entered in ArcGIS 9.3 software. Then the prohibition amount of each factor was conducted according to the relevant standards (Table 1) for each criterion and the case study prohibition layer was prepared (Fig. 3).

2.2.3 Weighted layers

In the next stage each criterion using both methods viz. AHP and Fuzzy were divided into the corresponding options and its weight was calculated wherein each of the methods used will be discussed as follows:

a. AHP method: AHP is a multi-criteria decision method that uses hierarchical structures to represent a problem and then develop priorities for alternatives based on the judgment of the user (Zhang, 2012). It is an effective tool for make the best decision. By reducing complex decisions to a series of pairwise comparisons, and then synthesizing the results, the AHP helps to capture both subjective and objective aspects of a decision. In addition, the AHP incorporates a useful technique for checking the consistency of the decision maker's evaluations, thus reducing the bias in the decision making process (Saaty, 1980).

The last ratio that has to be calculated is CR (Consistency Ratio). Generally, if CR is less than 0.1, the judgments are consistent, so the derived weights can be used (Vahidnia et al., 2008; Vasileiou et al., 2017).

Initially the hierarchy structure of the criteria was traced in accordance with the AHP method (Fig. 4). Later,considering the importance degree of criteria in relation to one another the conjugal comparison of factors was carried out at each level and eventually the weights were calculated.

Table 1 The prohibition rate presented for each criterion (Shaeri and Rahmati, 2012)(DEADP, 2006)(Ministry of energy, 2005)(Department of geology, 2015)(Shabani et al., 2008) (Latinopoulos and Kechagia, 2015) (Noorollahi et al., 2016) (Satkin et al.,2014)

Criterion	Prohibition rate (m)	Source
Distance from river	150	Decree No. 58977/T29101, Surface water quality guideline privacy, 2005.
Distance from town	1000	Controls and criteria for industry establishment, Environmental Organization, 2012
Distance from village	500	Controls and criteria for industry establishment, Environmental Organization, 2012
Distance from airport	2500	DEADP, 2006; Noorollahi et al., 2016
Secondary route	30	Land use guide surrounding roads and railway limits, Department of Transportation, 2008
Highway and main route	150	Controls and criteria for industry establishment, Environmental Organization, 2012;Latinopoulos and Kechagia, 2015
Wildlife Sanctuary, Protected areas	200	Controls and criteria for industry establishment, Environmental Organization, 2012
Distance from main fault	500	Department of Geology, 2012; Satkin et al.,2014
Well and spring	100	Controls and criteria for industry establishment, Environmental Organization, 2012
Open aqueduct	200	Controls and criteria for industry establishment, Environmental Organization, 2012
Land use	Residential, pond, stream, drop, rock	Controls and criteria for industry establishment, Environmental Organization, 2012

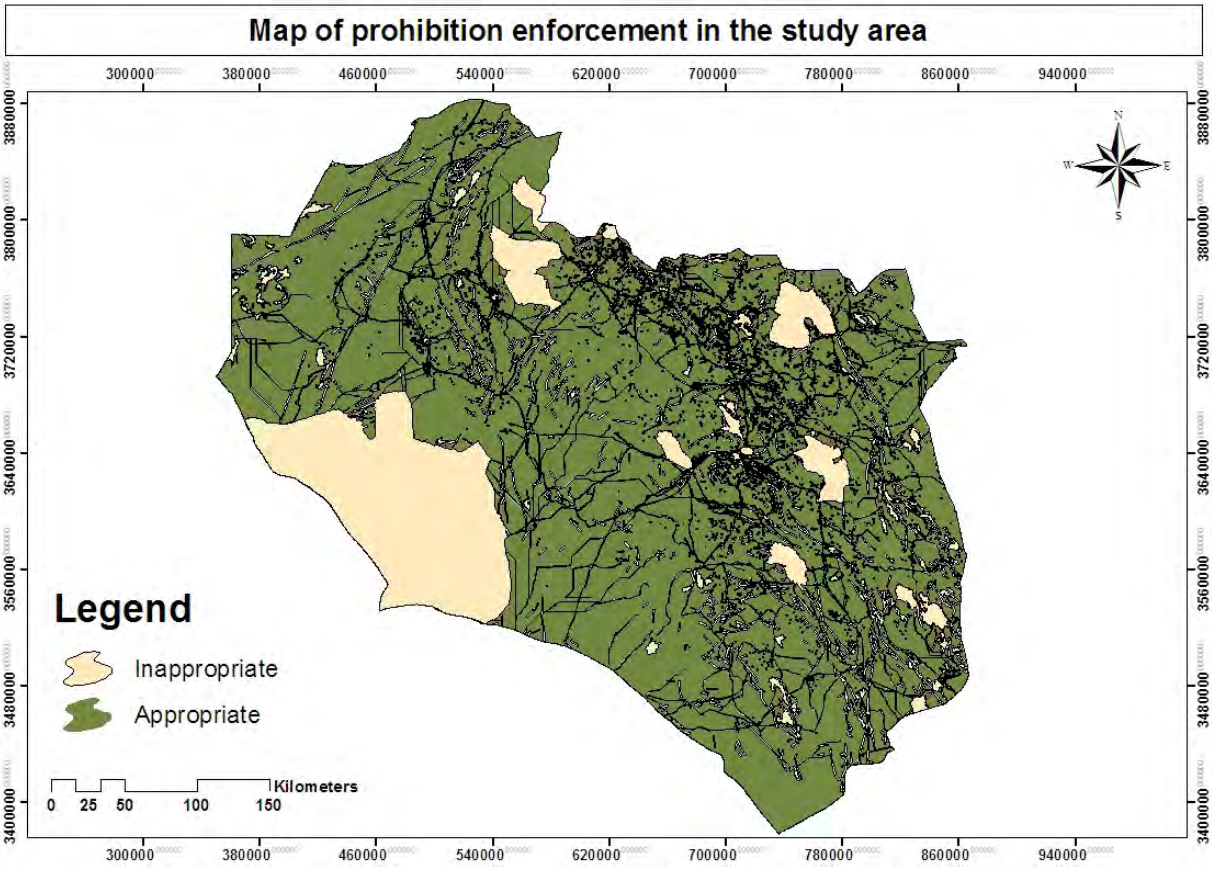

Fig. 3 Map of prohibition enforcement in the case study area.

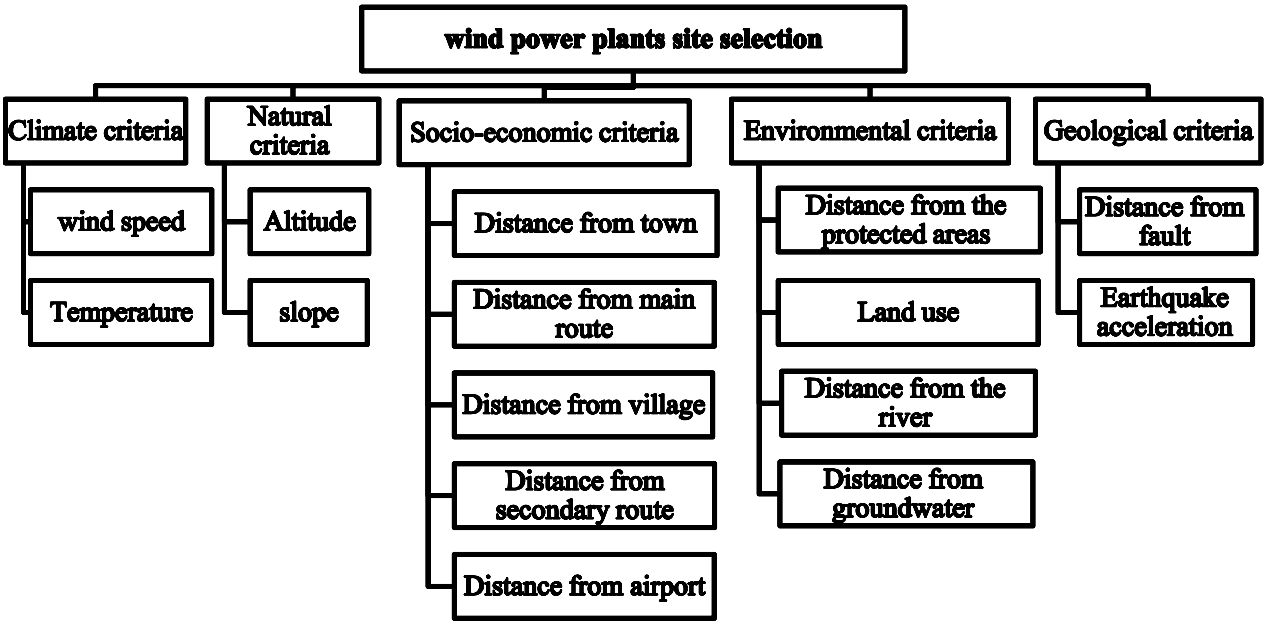

Fig. 4 Hierarchal analysis of the site selection of wind power plants chart.

b. Fuzzy method: In the fuzzy region, is defined as the membership rate of an element in a collection, with a value in the span of one (total membership) to zero (lack of total membership). The membership degree generally is expressed with a membership function, wherein the function shape can be linear, non-linear, continuous or discontinuous.

In the fuzzy model, to each of the pixels (the smallest structural component of map) in each criterion a value is assigned between zero to one that indicates suitable pixel location rate from the viewpoint of relevant criteria for considered aim (the establishment of power stations wherein in his study the pixel size was considered 100 * 100). The map of each criterion should be prepared in a manner that the amount of each pixel includes a relative importance of a relevant criterion in relation to other criteria of site selection. After the formation of related maps to each criterion, the existing membership values in them are also combined using fuzzy operators (Ahmadizade and Daraei, 2014).

Fuzzy intersection operator: Fuzzy intersection is defined as the following equation (4):

$$\mu_{combination} = \min(\mu_A, \mu_B, \mu_C, \ldots) \quad (4)$$

In the equation (4) μ_A, μ_B and $\mu_C$is an indicator of the Fuzzy membership values of the existing pixels in a determined position on the different factor maps.

Fuzzy Union operator: This operator is defined as the following equation (5):

$$\mu_{Combination} = \max(\mu_A, \mu_B, \mu_C, \ldots.) \quad (5)$$

Where μ_A, μ_B and μ_C in this equation are similar to equation (4).

Fuzzy Product operator: This operator is defined as the following equation (6):

$$\mu_{Combination} = \prod_{i=1}^{n} \mu_i \quad (6)$$

In this equation $\mu_i$indicates the membership value in i-th factor map. Using this operator the fuzzy membership value is reduced in the exit plan and moves towards zero, therefore this combination of factors will have a reducing effect. In other words, the factors will undermine one another.

Fuzzy sum operator: This operator is defined using the following equation (7):

$$\mu_{Combination} = 1 - \left(\prod_{i-1}^{n}(1 - \mu_i)\right) \quad (7)$$

Even in this equation μ_i indicates the membership value in i-th factor. Using this function the fuzzy membership value is increased in the exit plan and moves towards zero, which will have an increasing effect on the result of factors combination. In other words, the other words, the factors will reinforce one another. In contrast to intersection and union fuzzy operators, in product and sum fuzzy operators, the entire membership values of input maps will have an influence on the output map.

Fuzzy gamma operator: This operatorwhichis product of a multiply and sum fuzzy operators is defined using the following equation (8):

$$\mu_{\text{Combination}} = (\text{ Fuzzy Algeabric Sum})^{\gamma} * (\text{Fuzzy Algeabric Product })^{1-\gamma} \quad (8)$$

In equation (8), the γ value is a number between zero to one. The informed and correct selection of γbetween zero and one, creates a value in the output, which is an indicator of flexible compatibility between the reducing trends of fuzzy product and increasing trend of fuzzy sum (Beheshtifar et al., 2010)Even the options weight is in concurrence with the fuzzy logic between 1 to 10 weighted in a manner that has the best and worst scores as 10 and 1 respectively.

2.2.4 Maps integration

Finally, after weights calculation in both applied methods, fuzzy and AHP maps of each criterion were prepared in the Arc GIS software. Later, using the existing functions of GIS software the related maps were integrated. For the integration of the fuzzy maps the function 0.8 gamma and for integration of AHP maps the Product function was used and the final maps obtained from the two applied methods were divided into 6 classes; unsuitable, very weak, weak, fair, good and excellent and suitable locations to establish wind power plants were delivered in the form of descriptive maps and eventually the compliance rate of two maps created in both methods Fuzzy and AHP was calculated using the Tabulate area function.

3 Results and Discussion

In the present study, with implementation of 16 layer information, including: speed, temperature, altitude, slope, distance from town and village, distance from main and secondary route, the distance from the airport, land use, distance from the protected areas, distance from river, well, spring and aqueducts, distance from the fault and earthquake acceleration wherein the most important influencing factors in site selection of wind power plants were based on the environmental indicators, whereby efforts were taken to adopt integration of multi-criteria decision-making and Geographical Information System (GIS) methods to identify the suitable regions for construction of the wind power plants that in continuation, the result is presented in the forms of tables, maps and charts.

3.1 AHP

The reason for weighting the relevant criteria and sub-criteria via a panel of 7 experts wherein the average comments of individuals was the basis of priority criteria. According to the results, it was observed that the most effective criterion in the site selection of wind power plants is climatic factors (Fig. 5). Besides, the two factors viz. wind speed and altitude respectively, were the most important effective sub-criteria in the site selection of wind energy which has the highest weight (Fig. 6). The weights obtained from paired comparison in the AHP method is in accordance with the Table2,depicting options of each sub-criterion. As it is observed, high speed, low temperature, altitude and slope, the normal distance from city and village, the low distance from the main and secondary routes, high distance from the protected areas, airport, river, well, spring, aqueducts and fault, low earthquake acceleration and weak pastures, are the best areas with the highest scores.

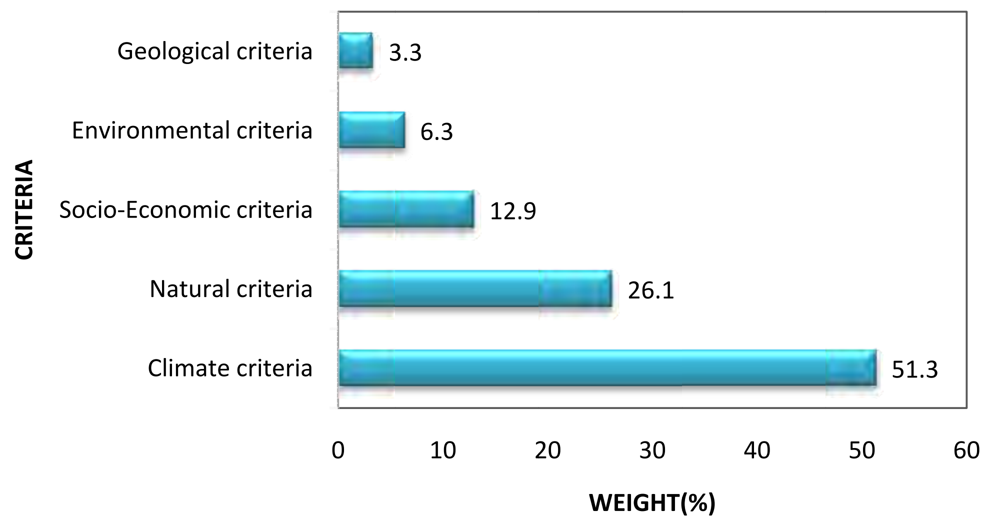

Fig.5 The effective weight of criteria in terms of percentage in site selection of wind power plants.

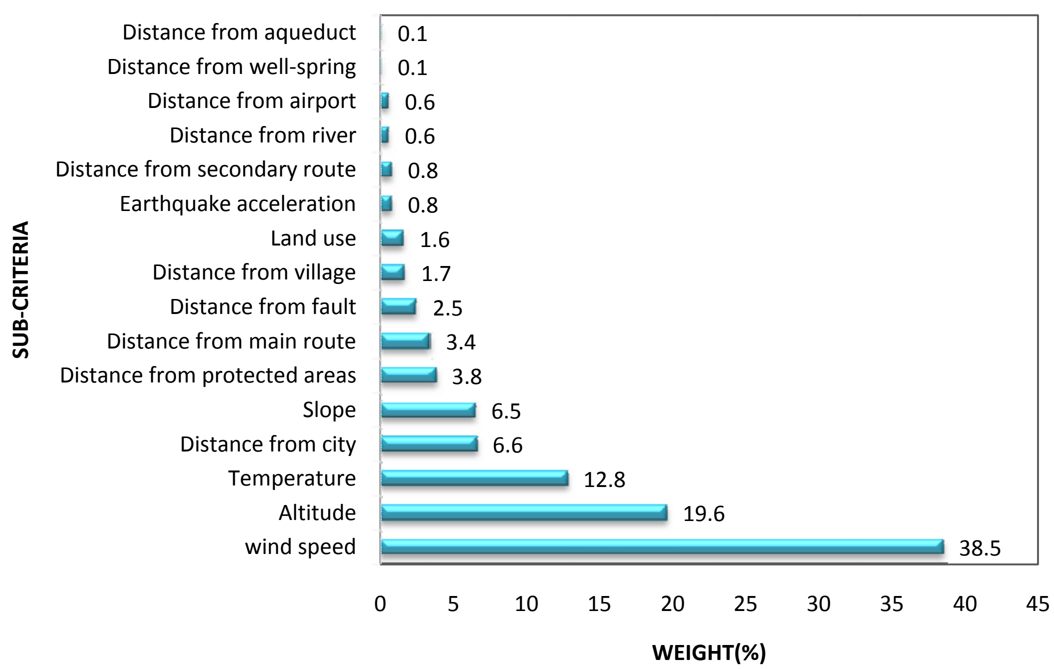

Fig. 6 The effective weight of sub-criteria in terms of percentage in site selection of wind power plants.

Table 2 The calculated weight of each sub-criteria options in the AHP method.

Sub criteria	Options	AHP weight	Sub criteria	Options	AHP weight
wind speed (m/s)	1/05-3/5	0/032	Temperature (°c)	18/66-19/59	0/514
	3/5-4/19	0/061		19/59-20/52	0/261
	4/19-4/86	0/126		20/52-21/21	0/129
	4/86-5/92	0/263		21/21-21/78	0/063
	5/92-8/79	0/518		21/78-22/84	0/033
Slope (%)	0-3	0/518	Altitude (m)	600-950	0/514
	3-8	0/263		950-1300	0/261
	8-12	0/126		1300-1650	0/129
	12-20	0/061		1650-2000	0/063
	>20	0/031		>2000	0/033
distance from towns (m)	1000-3000	0/065	distance from main route (m)	150-500	0/514
	3000-5000	0/492		500-1000	0/261
	5000-7000	0/270		1000-1500	0/129
	7000-10000	0/135		1500-10000	0/063
	>10000	0/037		>10000	0/033
distance from villages (m)	500-1000	0/065	distance from secondary route (m)	35-500	0/514
	1000-2500	0/270		500-1000	0/261
	2500-5000	0/492		1000-1500	0/129
	5000-10000	0/135		1500-10000	0/063
	>10000	0/037		>10000	0/033
distance from airport (m)	2500-5000	0/033	distance from protected areas (m)	200-500	0/033
	5000-7500	0/063		500-1000	0/063
	7500-10000	0/129		1000-1500	0/129
	10000-12500	0/261		1500-2000	0/261
	>12500	0/514		>2000	0/514
distance from aqueducts (m)	200-400	0/033	distance from wells and fountains (m)	100-300	0/033
	400-600	0/063		300-500	0/063
	600-800	0/129		500-700	0/129
	800-1000	0/261		700-1000	0/261
	>1000	0/514		>1000	0/514
distance from rivers (m)	150-500	0/033	Land use	Water farming, Orchard, Desert, Woodland	0/033
	500-1000	0/063		Without coverage, sand	0/063
	1000-1500	0/129		Dry farming, Good pasture, Grassland	0/129
	1500-2000	0/261		Mix land, Median pasture	0/261
	>2000	0/514		Weak pasture	0/514
distance from fault (m)	500-1000	0/033	Earthquak acceleration (m/s^2)	0/1-0/2	0/514
	1000-1500	0/063		0/2-0/3	0/261
	1500-2000	0/129		0/3-0/4	0/129
	2000-2500	0/261		0/4-0/5	0/063
	>2500	0/514		0/5-0/6	0/033

The final map obtained from the integration of AHP maps according to Table 3 was classified into 6 classes of unsuitable, very weak, weak, fair, good and excellent and was introduced as a descriptive map. As observed on the AHP map of the area (Fig. 7), the most suitable areas that are located in the excellent status include parts of the areas: ZirkouhGhaen, east of Darmian, east of Sarbishe, the central part of Nehbandan, north of Khoosf, south of Sarayan and east of Deyhoukthat have the potential to use wind energy. From the total region area, 4887.7 square kilometers, equivalent to 3.3 % of the study area are located in the excellent condition.

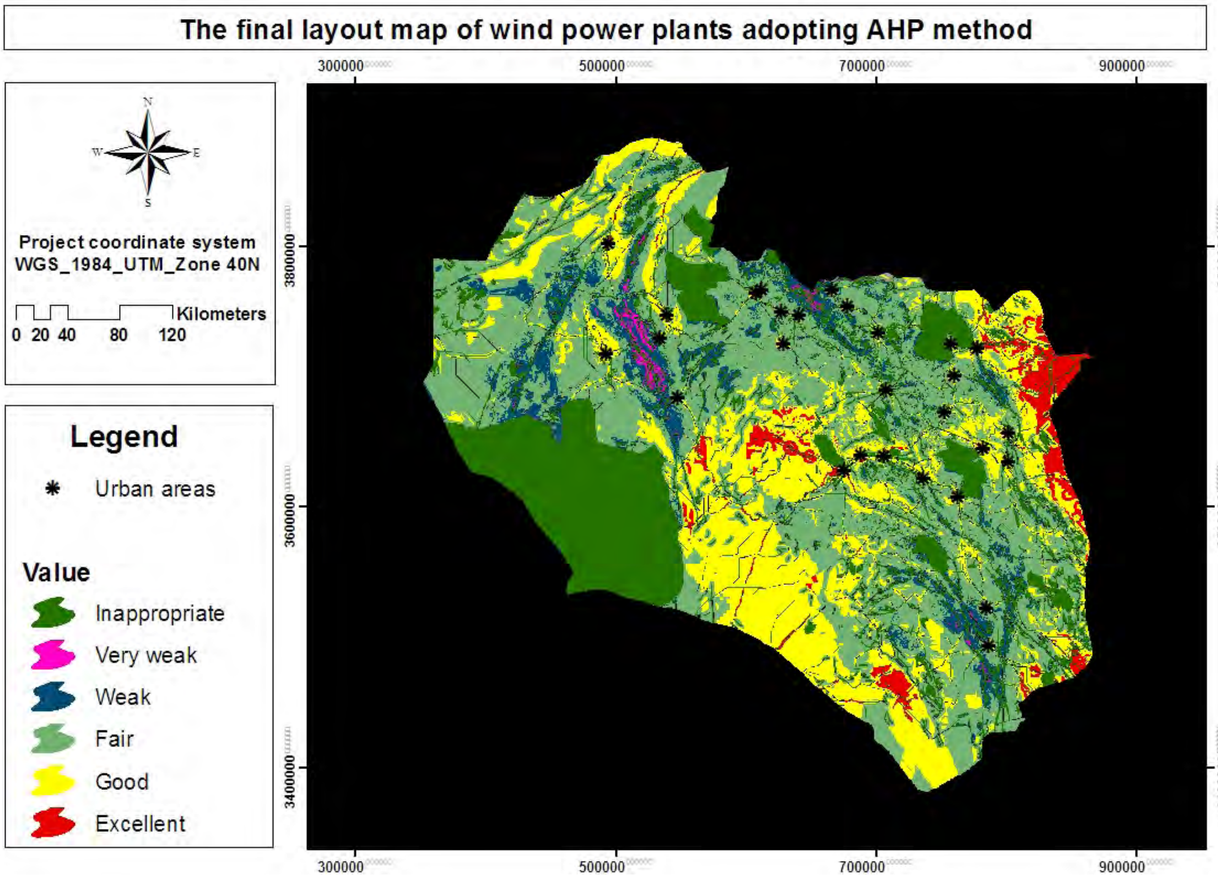

Fig. 7 The final site selection map of wind power plants according to AHP method.

3.2 Fuzzy

In fuzzy logic, each sub-criteria option was scored in the range of 1 to 10. The scores sequence was equivalent to AHP method only the divisions have become more accurate. Among the criteria assessed viz. speed, distance from the protected areas, airport, river, well, spring, aqueduct and fault follow the increasing function i.e. with the increase of the considered parameter value its fuzzy value also increases and the criteria viz. temperature, slope, altitude, earthquake acceleration, and the distance from the main and secondary routes are following a reducing function. Even the two criterion distance from city and village operate in accordance with normal function.

After the integration of criteria fuzzy maps, the final layer is classified in accordance to Table 3 and the final map was presented. According to fuzzy map of the area (Fig. 8), it is observed that the main sections of Zirkouh, Zohan, central and Sade of Ghaenat county, Darmian, Sarbishe, Birjand, Khoosf, Northeast Ferdows and a small part in the east Deyhouk nestle in the excellent range that have an ability to extract wind energy.

From the total study area 4.5 % i.e. equivalent to 6709.3 square kilometers nestles in excellent condition in the fuzzy method. As it is observed in figure the suitable area in fuzzy method is more accurate and is presented with smaller areas besides, excellent and good areas were almost observed in the entire counties of the province.

Table 3 Classification of final maps in the two functional models.

Classification	Score	Normalized rating interval in AHP method	Area (km^2)	Normalized rating interval in Fuzzy method	Area (km^2)
Excellent	5	75-100	4887/7	50-100	6709/3
Good	4	60-75	33580/9	35-50	35530/1
Fair	3	40-60	61818/1	25-35	45287/1
Weak	2	20-40	10010/1	15-25	21346/8
Very weak	1	0-20	626/4	0-15	2049/9
Inappropriate	0	0	37270/8	0	37270/8

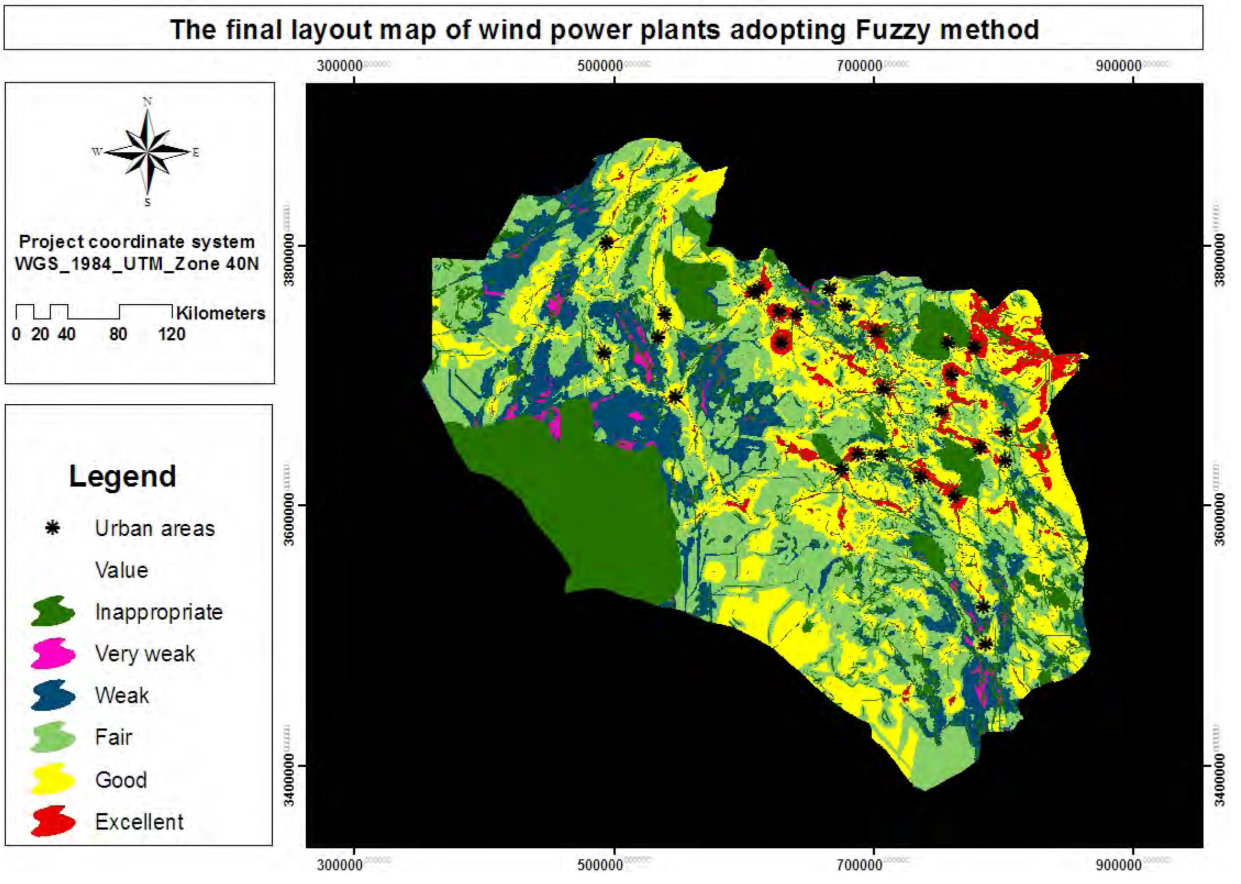

Fig. 8 The final map of the wind power plant siteselected according to Fuzzy method.

4 Conclusion

Based on the conducted researches in Iran, generally the climatic factors are adopted for the site selection of the wind power plants and few environmental and socio-economical indicators are considered wherein in this research, the effort is taken that all the effective factors are employed in the entire environmental, natural, climatic, socio-economical and geological aspects. According tothe results, it was observed that the suitable areas from the viewpoint of slope, altitude, distance from the fault, well, spring and aqueduct, distance from the river, the distance from the protected areas and airport are located in the best possible condition. Likewise, the wind speed in these areas nestles in good condition (over 6 meters per second).

Of the total study area 3.3% (equivalent to 4887.7 km^2) in AHP method and 4.5% (equivalent to 6709.3 km^2) in Fuzzy method were located in the excellent region that has an ability to construct wind power plants. Besides, the compliancerate of two final maps was 54.2%. According to the present study, KhoosfCounty that is the windiest region atthe province level and even in terms of other assessed indicator locates in afavorable condition. In addition, the areas of Sarbishe, Zirkouh, Darmian and Sarayan in both applied methods were identified as suitable. The results of this study can be summarized as follows:

1. According to the pair comparison test conducted on AHP method, the most effective factors in the site selection of wind energy (power plants) are the wind speed weighing 0.225 and an altitude weighing 0.175, wherein the present study result is in concurrence with the results of AsgharipourDashtBozorg and associates.
2. The use of the Multi-criteria Decision-making with Geographical Information System (GIS) systems can provide a suitable method for the site selection of human facility and environmental planning so that in addition to high accuracy, low cost and simultaneous use of qualitative and quantitative criteria, even the human intellect is exploited for information conjunction.
3. AHP method provides a possibility of suitable weighting to criteria and sub-criteria separately and with the formation of hierarchical structure carries out the simplification of complex issues and provides the possibility to directly use expert views and is very much efficient in contrast to the fuzzy method to assess the high data volume and avails acceptable results.
4. Due to the difference in the number of classes and varied values of each class in the two applied models, the final output maps are different in the two methods. The fuzzy method due to consideration of a range of probabilities instead of numbers has resolved the limitations of quantitative methods and offers a more precised analysis. In this regard, the obtained fuzzy map offers a higher and more accurate range value.

References

Ahmadizadeh SR, Daraei R. 2014. The site selection of developmental areas of Birjand city based on the scenario planning with Fuzzy and AHP methods in GIS.The first national conference on science and environmental engineering and sustainable development, Tehran, Iran

Al-Nhoud O, Al-Smairan M. 2015. Assessment of wind energy potential as a powerb generation source in the Azraq South, Northeast Badia, Jordan. Modern Mechanical Engineering, 5: 87-96

Al-Yahyai S, Charabi Y, Gastli A, et al. 2012. Wind farm land suitability indexing using multi-criteria analysis. Renewable Energy, 44: 80-87

AsgharipourDashtBozorg A,Morshedi J, Borna R. 2011. Use of Geographical Information System to select the construction site of wind power plants (Case study:Khuzestan province). Journal of Remote Sensing and GIS in Natural Resources Sciences, 2(3): 77-95

Azizi A, Malekmohammadi B, Jafarri HR, et al. 2014. Land suitability assessment for wind power plant site selection using ANP-DEMATEL in a GIS environment: case study of Ardabil province, Iran. Environ Monit Assess, 186: 6695-6709

Bagiorgas H, Assimakopoulos M, Theoharopoulos D, et al. 2007. Electricity generation using wind energy conversion systems in the area of Western Greece. Energy Conversion and Management, 48: 1640-1655

Beheshtifar S, SadimesgariM, Veldanzoj MJ, et al. 2010. Using fuzzy logic in GIS for site selection of gas stations. Journal of Civil engineering and Surveying, 44(4): 583-595

Department of Environmental Affairs and Development Planning of the United States (DEADP). 2006. Strategic initiative to introduce commercial land based wind energy development to the Western Cape: Towards a regional methodology for wind energy site selection, Western. DEADP, USA

Department of Geology.2015. fault's privacy. 8 November 2015. Available: http://www.gsi.ir/Science/Lang_fa/Page01-0911/ReplyId_3314/Start0/Action_SubCategoryView/faq.html. Accessed on January 2, 2016

Eskin N, Artar H,Tolun S. 2008. Wind energy potential of Go KC-eada Island in Turkey. Renewable and Sustainable Energy Reviews, 12: 839-851

Jafari H, Azizi A, Nasiri H, et al. 2011. Analysis of land suitability to establish wind power plants in Ardabil province using AHP and SAW models in GIS. Journal of Environmental Science and Technology, 15(2): 23-41

Kamau JN, Kinyua R,Gathua JK. 2010. 6 years of wind data for Marsabit, Kenya average over 14 m/s at 100 m hub height: an analysis of the wind energy potential. Renewable Energy, 35: 1298-1302

LatinopoulosD, Kechagia K. 2015. A GIS-based multi-criteria evaluation for wind farm site selection. A regional scale application in Greece. Renewable Energy, 78: 550-560

Ministry of Energy. 2005. Quality protection of surface water guideline. Iran Water Resources Management Company, Tehran, Iran

Mirzaei M, Bagherinejad J. 2012. Presentation of AHP Model to prioritize the renewable energies with fuzzy logic.The second conference of planning and environmental management, Tehran, Iran

Morshedi J, Borna R, AsgharipourDashtBozorg A, et al. 2010. The site selection of wind power plants using Analytical Hierarchy Process (AHP) in GIS. Journal of Remote Sensing and GIS Applications in Planning, 1(2): 97-111

Noorollahi Y, Ashraf MA, Zamani M.2011. Wind energy potentiometric of Bakhtar regional electricity using GIS. Iran Energy Publication, 14(1): 2-22

Noorollahi Y, Yousefi H, Mohammadi M. 2016. Multi-criteria decision support system for wind farm site selection using GIS. Sustainable Energy Technologies and Assessments, 13: 38-50

Olayinka S, Olaolu O. 2012. Assessment of wind energy potential and the economics of wind power generation in Jos, Plateau state, Nigeria. Energy for Sustainable Development, 16: 78-83

Omidvar K, Dehgan Tarazjani M.2010. Potential assessment and evaluation of wind power characteristics for energy production in Yazd synoptic stations. Journal of Geographical Research, 27(2): 149-168

Rasooli Koohi M, Khalji Asadi M, Safaei B. 2002. Assessment of influencing factors on wind power turbines.The second conferences of fuel consumption optimizing in buildings, Tehran, Iran

Renewable Energy Organization of Iran. 2012. Wind Energy Report. Ministry of energy, Tehran, Iran

Saaty TL. 1980. The analytic hierarchy process: planning, priority setting, Resource Allocation. McGraw-Hill, New York, USA

Satkin M, Noorollahi Y, Abbaspour M, Yousfi H.2014. Multi criteria site selection model for wind-compressed air energy storage power plants in Iran. Renewable and Sustainable Energy Reviews, 32: 579-590

ShabaniSh, Sheikheslami A, Ebrahimi A,et al.2008. The guideline of land use surrounding the roads and railways boundaries, Road and Transportation Publications. Ministry of Transportation, Tehran, Iran

Shaeri AM,Rahmati A. 2012. Laws, policies, regulations and standards of Human Environment.Hak Publications, Tehran, Iran

Sliz-Szkliniarz B,Vogt J.2011. GIS-based approach for the evaluation of wind energy potential: a case study for the Kujawsko–PomorskieVoivodeship. Renewable and Sustainable Energy Reviews, 15: 1696-1707

Soleimani H, FarajzadehAsl M, Karami J. 2014. Assessment of land suitability to establish wind power plants using the Multi-criteria Decision-making and GIS techniques (Case study: East Azerbaijan). Journal of Geography and Environmental Planning, 25(3): 21-42

South Khorasan Governor. 2008. Birjand Country Advancement Document.Ministry of Interior, Birjand, Iran

Vahidnia MH, Alesheikh A, Alimohammadi A, et al. 2008. Fuzzy analytical hierarchy process in GIS application, The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 37: 592-596

Vasileiou M, Loukogeorgaki E, Vagiona D. 2017.GIS-based multi-criteria decision analysis for site selection of hybrid offshore wind and wave energy system in Greece. Renewable and sustainable energy reviews, 73: 745-757

Weibull W. 1952. A statistical distribution function of wide applicability. Journal of Applied Mechanics, 1: 293-299

Weisser D. 2003. A wind energy analysis of Granada: an estimation using the Weibull Density Function. Renewable Energy, 28: 1803-1812

Zhang WJ. 2012. Computational Ecology: Graphs, Networks and Agent-based Modeling. World Scientific, Singapore