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Application of Fuzzy GIS and ANP for Wind Power Plant Site Selection in East Azerbaijan Province of Iran

Saeedeh Nasehi*, Saeed Karimi, Hamidreza Jafari

Faculty of Environment, University of Tehran, Tehran, Iran

Keywords

Wind power plant,
Fuzzy GIS,
ANP,
East Azerbaijan province,
Criteria.

Abstract

Unique features of wind energy have caused increasing demands for such resources in various countries. In order to use wind energy as a natural resource, environmental circumstances and geographical location related to the wind intensity must be considered. The possibility of establishing wind farms in East Azerbaijan province in northeastern Iran was assessed by using a combination of fuzzy geographic Information System (GIS) and Analytic Network Process (ANP). The objectives of this paper are the site selection based on the fuzzy logic and weighted linear combination (WLC). In this way, after the identification, evaluation of criteria layers by using fuzzy method due to their uncertainty and determination of their importance, the layers are combined. Overally, the results show that the combination of fuzzy logic, WLC and MCDM have a high accuracy and positioning in locating optimal wind sites. Final map was divided into four classes: suitable, moderately suitable, relatively unsuitable and unsuitable. The obtained results further show that the central parts are the most appropriate and suitable site for establishing wind power plant. However, more specific results of this study indicate that some areas in Haris, Tabriz and Bostan Abad have a higher potential in this regard.

1. Introduction

Due to the increasing industrialization, world population and electricity demand in recent years, utilization of natural resources such as oil, gas and coal have raised. Increasing utilization of hydrocarbon-based fuels leads to increasing environmental emissions of various forms of air pollution, greenhouses gases such as carbon dioxide, and other substances [1].

As the effects of global warming and climate change become more pronounced, the need to increase the penetration of renewable energy resources in the energy mix is growing globally [2]. Today, the use of wind energy has been developing very fast as it is a local, clean and environmentally friendly resource [3]. As the environmental policy and energy policy always go hand in hand, it is quite clear that wind as a renewable resource should be competitive with conventional power generation sources from technical, environmental, socio-economical and socio-political standpoint [4]. So, it is vital to conduct the required technical and economic feasibility researches in order to make use of this energy to overcome the current energy crises [3]. Wind power can play an important role in the solution to the current energy and environmental crisis. Its non-polluting nature, increasing cost effectiveness, the compatibility of wind power with other land uses and the abundance of the wind resources all qualify it as a powerful option for meeting future energy needs [5]. One main advantage of new energy sources is the reduction in CO_2 emissions [6]. One kilowatt hour of electricity produced by WPPs decreases emission of about 1 kg of CO_2 over that of fossil power plants [7]. According to the statistics of each kilowatt hour of electricity produced from renewable resources and wind power, the release of approximately 0.7 and 1 kg of CO_2, respectively, compared with fossil fuel thermal power plants to be prevented [8]. Determining the priority of different locations, has special importance for utilizing wind systems. In order to harness the wind power, the initial step should be the determination of the potentiality of the wind power as well as its features in the possible region or area [9]. In Iran, regarding to the existence of windy sites, designing and establishing wind mills have emerged since around 2000 B.C. and now there is suitable situation to improve utilization of the wind turbines. The wind data collection indicates the existence of 26 ideal sites

* Corresponding Author:
E-mail address: nasehi_sa@ut.ac.ir – Tel, (+98) 9171972250

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with the total potential wind power of 6500 MW, while the nameplate capacity of the power plants is 34000 MW [10].

1.1. Literature Review

The number of studies aiming at an evaluation of the locational suitability or the optimization of sites for wind plant development which require applying appropriate MCDM methods, is low and some of them are to be reviewed here. Togo et al. combined AHP with GIS to find the suitable areas for wind energy development on the Greek island of Lesvos [11]. Benue et al. [12] applied a GIS-based AHP model to select feasible sites for wind farms in five provinces in Thailand. Gorsevski et al. [13] conducted a suitability analysis for wind farms in north-west Ohio, USA. They demonstrated a prototype for this collaborative group-based SDSS for wind farm selection for regional planning using traditional GIS. The framework integrated environmental and economic criteria to develop a hierarchy for wind farm siting through WLC techniques and GIS functionality. The maps created by the individual's preferences were aggregated for producing a group solution and subsequent sensitivity analysis that intended to examine conflicting areas associated with the final solution from all participants. Beacham et al. used Boolean overlay analysis in ArcGIS to identify suitable offshore wind sites in South Carolina. In this study, the raster format criteria were reclassified as suitable (1) and non-suitable (0); then they used Boolean multiplication of the reclassified layers to identify suitable sites [14]. Another study which accomplished by Schillings et al. [15], illustrated the use of a web-based SDSS to locate and assess offshore wind potential at the North Sea. This SDSS tool uses overlay analysis of raster layers weighted by users inputs to generate the final offshore wind farm suitability map. Similarly, Vagiona and Karanikolas used GIS and MCDM to identify offshore wind sites in Greece. In this research, they applied constraints to all coastal areas to identify places that did not fulfill a certain set of criteria and excluded them from further analysis. Then, they used the AHP and pairwise comparison of the evaluation criteria to determine weights which show the importance of each criterion. They also performed pairwise comparisons of the candidate sites with respect to each criterion, generating weights, and then aggregated the weights for each candidate site from each criterion to locate the most appropriate sites for an offshore wind [16]. Mekkonen and Gorsevski [17] presented the design and implementation of a web-based PGIS for offshore wind farm suitability within Lake Erie, Ohio. The PGIS prototype presented, integrates GIS and decision-making tools that were intended to involve different stakeholders and the public for solving complex planning problems and building consensus. Riccardo Mari et al. used a GIS-based interactive web decision support system for planning wind farms in Tuscany (Italy). It was achieved by developing an integrated geographic information system (GIS) based DSS, compliant with Directive 2007/2/EC, which was designed to help public operators in the preliminary location of sites eligible for wind harness [18]. Amici et al. [19] conducted a research dealing with the site selection problems for wind power plants and aimed to propose a structural procedure for determining the most feasible sites. The application area was western Turkey. The methodology was mainly composed of two stages, the first stage was pre-elimination of infeasible sites, and the second stage was evaluation of the available ones. Sanchez-Lozano et al. presented a study for selecting the sites for onshore wind farms on the coast of the Region of Murcia, in the southeast of Spain. As the objective of the study was to select the locations and obtain a ranking, two different models were applied, initially a categorical assessment through a lexicographic order was performed using the tools available in the GIS and, later it was applied the ELECTRE-TRI methodology, was applied in order to make a comparison between the methods [20].

Researches In Iran showed that the city of Manila has been demonstrated to be one of the best locations in the world to install wind turbines and to invest for building wind farms. Another analysis employed the Weibull distribution function on the wind energy potential for five cities of Biarjmand, Damghan, Garmsar, Semnan, Shahrood in Semnan province of Iran showed that the wind energy potential to be the best source of energy for Damghan and Garmsar [21]. The literature review indicates that thus far, a comprehensive research has not been done using a combination of ANP and fuzzy GIS models for wind power plant site selection. ANP has been used to overcome interdependence and feedback problems between criteria or alternatives. In this research, multi-criteria assessment approach includes fuzzy GIS and ANP are utilized in energy potential in the East Azerbaijan, located in the northwest of Iran by using GIS.

2. Material and Methods

2.1. Case Study

Eastern-Azerbaijan province is located in North-West of Iran and has an area about 47830 km² (2.8% of Iran's area) and is located between 36.45° and 39. 26' north latitude and 45.5° and 48. 22' east longitudes (Figure 1). Population counts of this province are 3,724,620 capita for 2011, which is equivalent to 4.95% of the total population in Iran. Because of the number of major industrial workshops and industries and industrial estates, East Azerbaijan province is one of the most important industrial center in Iran. All the factors mentioned above have caused a high consumption for electricity power in this province. Topography of the area is an important factor in the creation of the climatic characteristics of the province and the main factors in its diversity. Sahand peak with the height of 3722 meters is the highest point and the coastal lands with Kaleybar County the altitude of 160 meters are the lowest point of the city. Most synoptic stations of the province have the highest percentage of the windy weather (over 50%). However, because of topography conditions, the province's climate varies in different areas. However, because of the high wind speed and high wind power density, East Azerbaijan province is one of the most suitable regions for a wind energy project.

2.2. Defining the Criteria

Defining the suitable locations for a wind power plant depends on the complete and precise understanding of factors and the way of choosing them. Factors selected in this research were based on various studies and expert opinions.

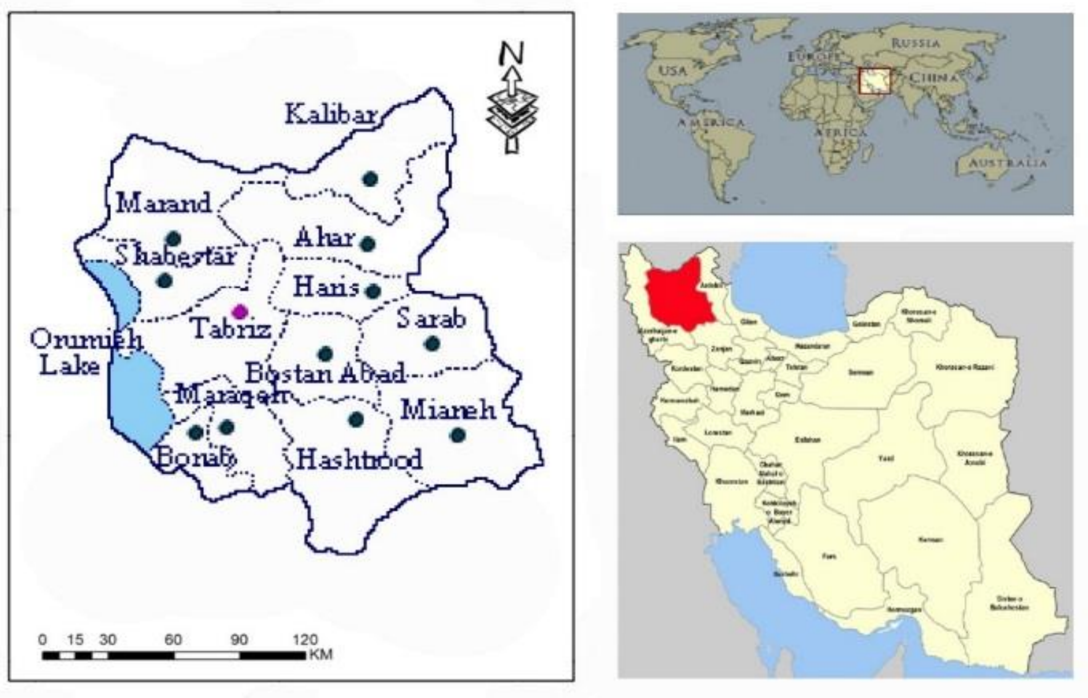


Figure 1. Location and specification of East Azerbaijan Province in Iran

Wind energy potential: wind energy potential criterion is included in almost every study and is mainly considered to be one of the most valuable criteria [6]. A wind potential map plays a crucial role in the selection of the appropriate sites for the wind farm. So, Annual wind speed average is very important features for choosing a suitable site for wind power plants [22].

Wind speed: the average wind speed in a given area is a key criterion regarding the determination of the economic performance of a wind turbine.

Elevation: the speed of wind and its direction highly depends on the topography of the region [4]. We confirm that when the height increases, making facilities would be difficult. High lands would definitely increase the investment cost [23]. Therefore, in order to select the appropriate site, we have to avoid the high lands [12].

Slop: for establishing each structure existence of a set of topographical conditions is important. For example, incline, geographical direction and the height of construction are samples of these conditions. Steep slopes of a surface can reduce the accessibility of cranes and trucks and increase building costs [9]. Recommendations for the maximum slope threshold range from 10% [24] to 30% [11]. Therefore, determining the suitable locations from topographical viewpoint is also necessary.

Distance from the airport: wind turbines can interfere with signals of aviation radars. So, they would require a significant buffer around areas such as airports [25]. Also, they interfere with electromagnetic waves in a way that they reflect, scatter or break electromagnetic waves and interfere with the telecommunication networks [26].

Distance from the main road: transport is considered as one of the most crucial criteria for locating industries. The proximity of this industry to roads will reduce transportation costs of power plant equipment, personnel transport and plant support [27].

Distance from fault: wind farm sites like other constructional projects should be away from the fault lines in order to avoid dangerous hazards caused by these lines [26].

Distance from the protected area: protected areas play an important role in the protection and conservation of the world's natural and cultural resources [26]. Impacts of wind turbines can be categorized in three groups: collision hazards for birds and bats, destruction of wildlife habitat and destruction of vegetation. Strategic placement of turbines outside important breeding grounds and high population areas can reduce the ecological impact [28].

Distance from the residential areas (cities and villages): wind power plant is usually located outside of urban or residential areas as large populations are generally housed in these areas and there are concerns over safety as well as visual and noise impacts [25]. Regarding the distance from the residential areas, it should be mentioned that the physical development of the city is a dynamic and continuous process. Therefore, the surrounding lands should be considered for the future developments in residential areas [26].

Distance from the water extent: coasts and rivers are special habitats and places of recreation. The footprint of towers, roads and associated structures disturbs vegetation and habitat areas. Wind turbines also present a collision risk to birds and may have negative effects on the bird populations, especially migratory birds [25]. Finally, since the river routes are dynamic ever-changing and there is also risk of flood, the wind farms' being away from the river-beds will increase the safety of the facilities [26].

Land use/cover: the suitability of an area for the siting of wind turbines also depends on the prevalent land cover type. From a social acceptance point of view, some land cover types can be considered to be more preferable than others. [29]. It is not possible to establish wind farm in some areas including forests, lakes, farmland, protected areas etc.

For mapping the wind speed, we used the best method – the interpolation method. In order to provide the other layers in the study, we used the countries' vector topographic maps.

2.3. Data Analysis and Methods

For getting the wind potential layer we have used 16 synoptic stations within the province and 29 stations outside the province. Since the wind speed in synoptic stations is measured in knot and at 10 meter height, the height of most wind turbines is 50 meters. Using the following formula, we calculate the wind speed in the related height and convert it to meters per second.

$$V/V_r = (H/H_r)a \quad (1)$$

where V denotes the wind speed at desired height, H, V_r stands for the wind speed at height H_r (baseline) and a is the ground roughness coefficient [26].

11 related factors are identified in order to locate wind farms using environmental parameters. These criteria as depicted in Figure 2 are categorized into three groups: environmental (distance from fault, distance from flood line, and distance from coastline) social (distance from urban, distance from rural, distance from road, distance from airport) and economic (wind speed, elevation, geology, slop). All the layers are being assessed and processed by the same reference system (UTM WGS 1984 zone 40N), the same scale, and the same cell size (30×30) within GIS. In order to determine the importance of the index for positioning, the relative importance of each criterion was determined by using ANP model. Then, using ARCGIS10 system they became Fuzzy and between a numerical range of zero to one. After that, integrating ANP and Fuzzy models, we would multiply all the standardized layers by each of the weights of ANP model. In this case, the layers become fuzzy and weighted. Then we combine the layers using a weighted linear combination (WLC). In the end, the restriction layer would be removed from the final map.

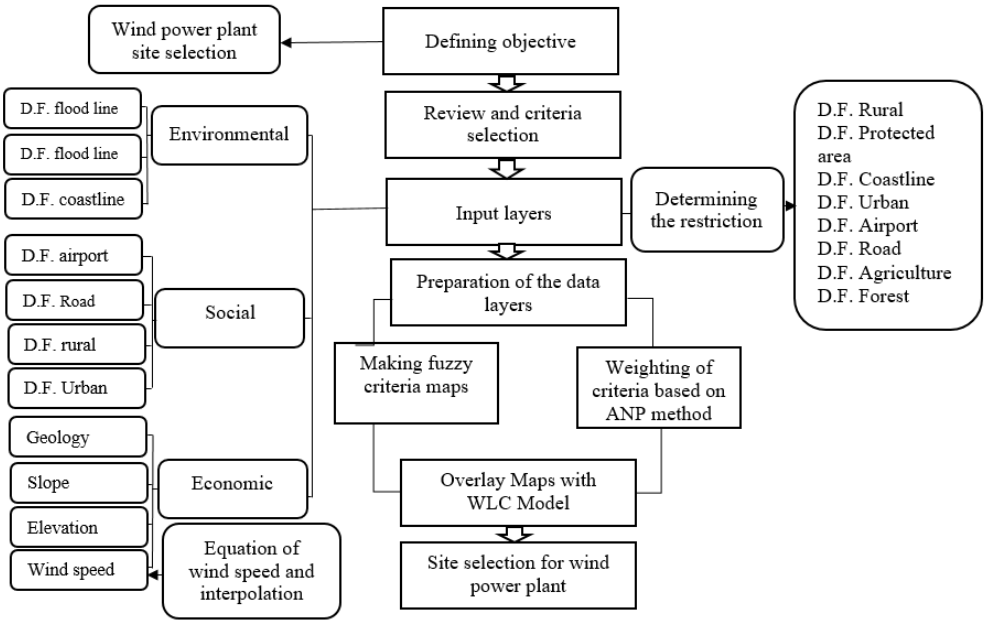


Figure 2. Conceptual model for wind power plant site selection (D.F. distance from)

2.3.1. Representation of Criteria as Fuzzy Set

Fuzzy logic is capable of formulating many inaccurate and unambiguous concepts, variables and systems and provide control and decision making under uncertainty conditions. The ability of GIS systems in Raster map analysis, makes it possible to implement different techniques such as Fuzzy because the positive and negative threshold data (0 to 1, not binary) the degree of membership of the variables would be determined. Parameters of positioning problems have Fuzzy nature to a large extent. For example, factors relating to proper distance from some complications are Fuzzy collections. Each pixel according to its distance from complication has a different membership degree in this collection. Pixels membership criterion in the collection is being appropriate or inappropriate and is determined between 0 and 1. These values are determined using the knowledge of experts. One of the most important steps in fuzzy logic is defining Fuzzy membership value for each criterion. In this model, the membership of an element in the collection would be defined in a range of 1 (full membership) to zero (non-membership) [30].

For this purpose, the Membership Fuzzy operating instruction is used. In fact, the definition of the Fuzzy membership (or standardizing the criteria) is one of the important steps of multiple criteria decision making (MCDM).

Membership functions in Fuzzy degrees include S-shaped, J-shaped, linear and defined by the user [31]. Table 1 shows control points and the functions used for criteria. Also, Figure 3 shows digital layers of Fuzzy membership.

2.3.2. Weighting Criteria Process

Analytic network process (ANP) is one of the multiple criteria decision making techniques and fall into the category of compensation models. This model is designed on the basis of analytic hierarchy process (AHP) and replaced “hierarchy” with “network”. One of the assumptions of AHP is that the above divisions and branches of the hierarchy are independent of the below ones. However, in many decisions, it is not possible to model decision elements as hierarchical and dependent of each other. Therefore, to solve such matters, they make various elements independent of each other and suggest an hour to use ANP. In AHP, the relationships between different levels of decision-making are considered unilateral. The main advantage of this approach is that the assessment of the various measures is carried out on the basis of their relationships and not hierarchy [32]. Since ANP is a general and advanced mode of AHP, it contains AHP’s positive features such as simplicity, flexibility, simultaneous usage of qualitative and quantitative criteria, and the ability to check the compatibility of judgments. In addition, it can consider the complex relationships (interdependencies and feedbacks) among the decision elements via applying the network structure rather than a hierarchical structure. All elements in a network can be associated with each other in any way. In other words, feedbacks and interactions between and among the clusters are possible in a network. The mentioned feature of ANP makes it possible to consider the interdependencies between the elements thus provides precise attitude to the issues.

Step 1: Performing a paired comparison and estimating the relative weight

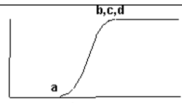
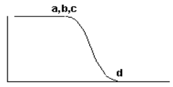
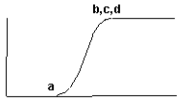
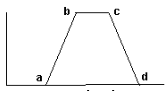
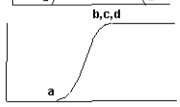
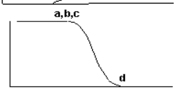
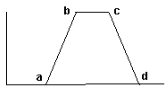
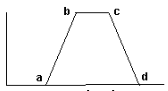
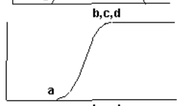
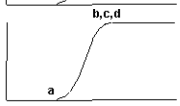
Step 2: Forming the primary super matrices

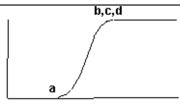
Step 3: Forming the weight super matrices

Step 4: Calculating the general weight vector [33]

For weighting criteria in ANP method, problem should be stated clearly and decomposed into a rational system such as a network. The structure can be obtained from the opinion of decision makers through brainstorming or other appropriate methods. The first step is to construct a conceptual model and to determine relationships between/among clusters and nodes. In the next step, weighting is scored in terms of the hourly rate between 1 and 9, so that the interaction among weights and priorities take place, according to the expertise, ideas on the basis of technical and administrative rules for the wind power plants as well as the environmental regulations. Then, weight matrix is prepared and the final weight of each layer is calculated and normalized with respect to its degree of importance and obtained weight is applied to each layer in the combination stage. The resultant intervals of fuzzy values associated with obtaining weight are presented in Table 1 for each measurement using the ANP Method.

Table 1. The final weights and control point for criteria land suitability assessment for East Azerbaijan

Criteria	Weight	Fuzzy function				Chart type	Chart type
		a	b	c	d		
Wind speed	0.224	4 m/s	7.5m/s	-	-	Sigmoidal /Monotonically increasing	
Elevation	0.147	1800	-	-	3000	Sigmoidal - Monotonically decreasing	
Distance from airport	0.057	3000	5500	-	-	Sigmoidal /Monotonically increasing	
Distance from urban	0.116	2000	4500	8000	25000	Linear/Symmetric	
Distance from faults	0.080	2000	4000	-	-	Sigmoidal /Monotonically increasing	
Slope	0.065	10	-	-	30	Sigmoidal - Monotonically decreasing	
Distance from rural	0.082	800	2000	3500	5000	Linear/Symmetric	
Distance from roads	0.042	500	1000	10000	20000	Linear/Symmetric	
Distance from 1:50 flood line	0.052	1000	2000	-	-	Sigmoidal /Monotonically increasing	
Distance from coastlines	0.033	1500	3000	-	-	Sigmoidal /Monotonically increasing	

Geology	0.102	hard	usual	-	-	Sigmoidal /Monotonically increasing		
Constraint Parameter	Urban area 2000 m	Main road 500 m	airport 3000 m	Forest 500m		rural areas 800 m	coastlines 1500 m	agriculture 500 m	Protected area 1000 m

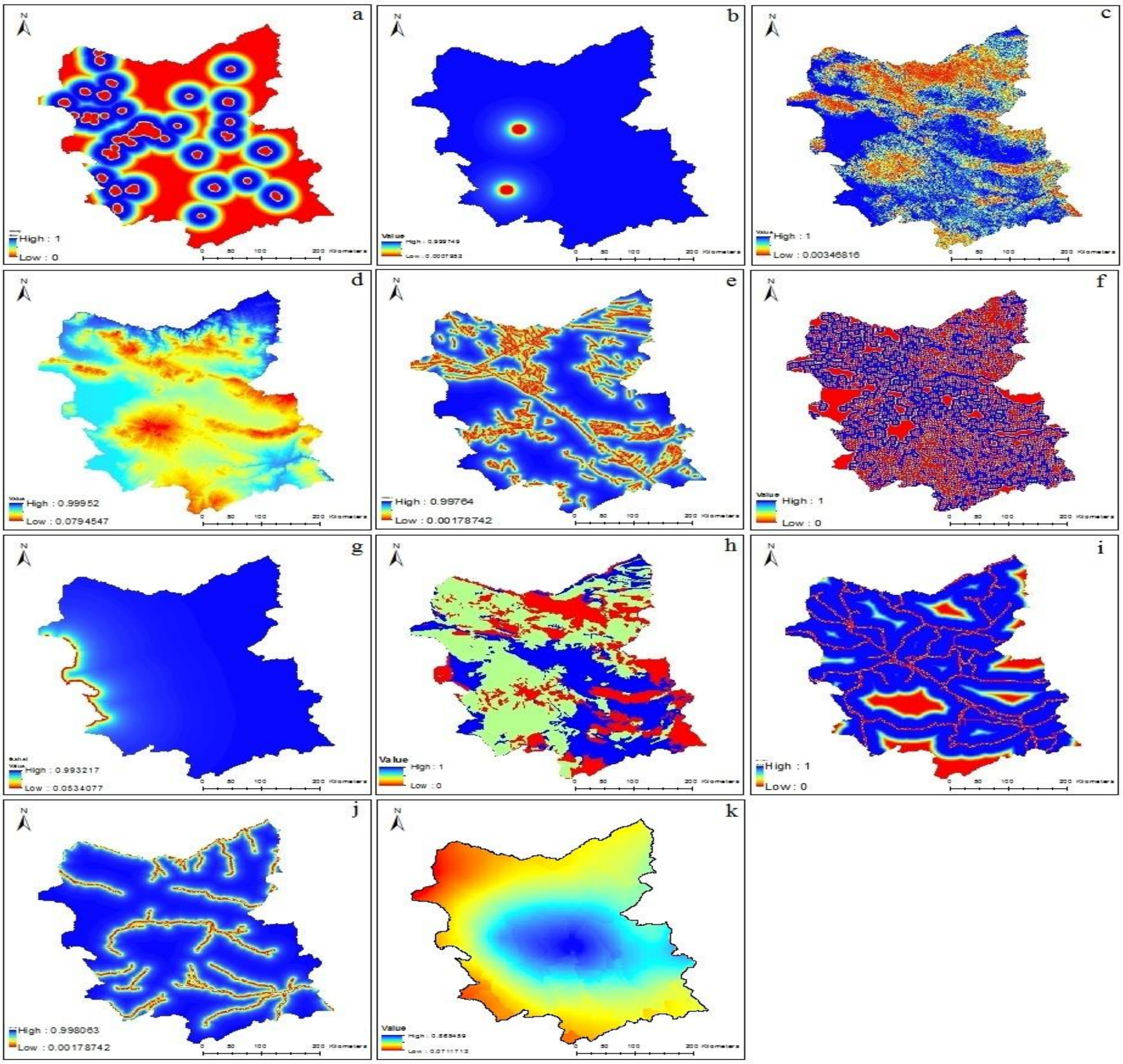


Figure 3. (a) City (b) Airport (c) Slop (d) Elevation (e) Fault (f) Rural (g) Coastline (h) Geology (i) Road (j) Flood line (k) Wind speed

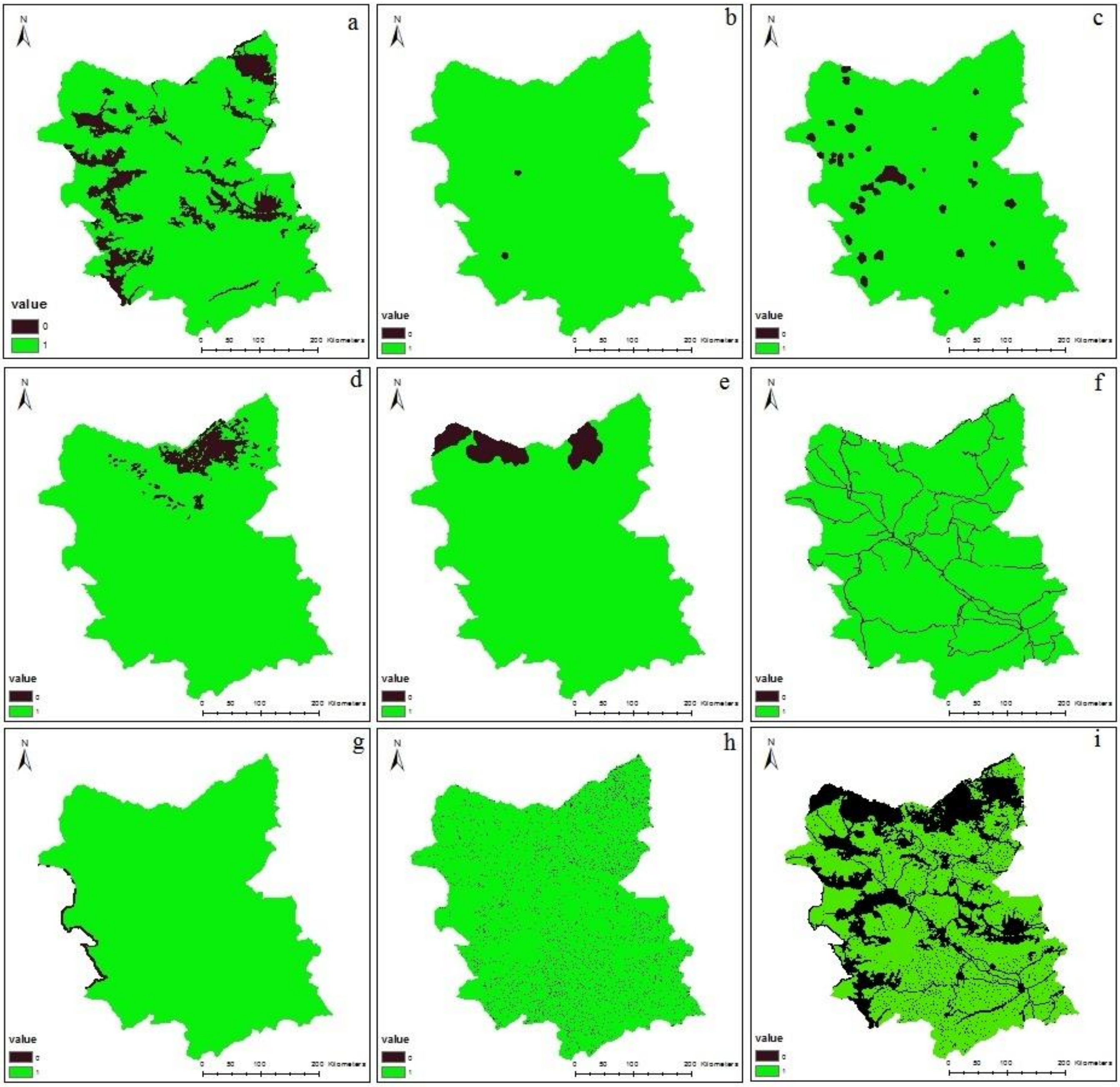


Figure 4. (a) Agriculture lands (b) Airport (c) Urban area (d) Forest (e) Protected area (f) Road (g) Coast line (h) Rural area (i) Final exclusionary map for wind power plants site selection in East Azerbaijan province

2.3.3. Extracting the Restrictive Layer

Special inappropriate occasion for a given user would be determined based on a series of criteria. Restrictions are barriers imposed by man or nature and make the options inapplicable. We studied and analyzed the region, resources, and standards. Then, we considered the several layers as restricted areas and removed them from the final map. These layers conclude cities, villages, forests and agricultural lands, roads, airports, lakes and protected areas. Restriction maps are shown in Figure 4.

2.3.4. Final Combination of Criteria

To combine the layers obtained by using the calculated weights, WLC method is used. WLC is the most common technique in analyzing the multi scale evaluation. This method is based on the content of weight average. Analyzer or decision maker based on relative importance weighted directly to the scales. Then through multiplying relative weight in feature value, a final measure can be obtained for each option (Such as picture element in spatial analysis). After specifying the final value for each options, alternatives which have higher value, will be most proper options for desired purpose. Determining earth proportion for a specific operation or evaluating the potential of particular occurrence can be considered as desired purpose. In this method, decision making principle calculated the value of each Ai options by Eq. (2) as

$$A_i = \sum_{j=1}^{n} W_j \times X_{ij} \quad (2)$$

where, W_j is the *j*th criterion weight, X_{ij} is a value which accepted *i*th place in relation to *j*th criterion. In other word, this value can indicate appropriate degree of i location in relation to j criterion; n is total number of criteria and A_i is a value which finally will attach to *i*th location. In this method, total weight should be equal with 1, otherwise in last stage A_i should be divided on total of all weight thus A_i output will be between 0 and 1. Because higher or lower amount of output can be due to an appropriate or inappropriate option, weight normalizing can be withdrawn. At the end, ideal option will be one which has more amount of A_i [34] . The final classified map obtained from fuzzy models, ANP and WLC in combination with the city maps of the province is shown in Figure 5.

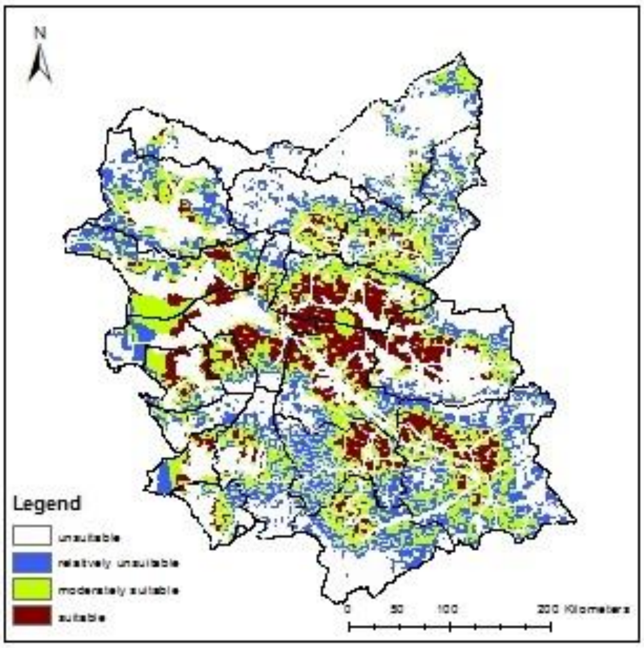


Figure 5. The final wind plant site selection map

3. Discussion of the Results

Wind energy has been attractive because it is an accessible and consistent energy and its application does not remain environmental adverse impacts. Therefore, in this study, positioning these power plants is carried out in order to accelerate the development of wind power generation. One of the earliest studies on the exploitation of this energy is the identification of suitable areas with high potential. Obviously, this requires a high wind speed, an appropriate geology, slope, and height. Other human factors, including access routes, distance from residential centers, and land use and deployment of equipment and skilled manpower are other factors that play a supplementary role. The thing important is that such a situation especially geomorphology and climatic conditions are not the same everywhere. Based on the map resulted from important factors in constructing a wind power plant, it can be seen that when we move from north to south, it has different circumstances of different factors. The north of the province is inappropriate due to the existing high slope (more than optimum), the high height, forests, protected areas, many faults, and generally it is inappropriate in terms of geology and geomorphology and land use. Also, these areas increase the cost of the electricity transmission because they are far from cities. Moving to the southern and central regions of the province, we can see the wind speed increasing around the Bostan Abad, Sahand, and Tabriz stations. Also these areas are appropriate in terms of geology, distance from the fault, and residential centers. Eastern parts have high slope and inappropriate geology, and their altitudes are higher than desirable level. Therefore, they are less favorable. Western areas has low wind speed. They are near the lake sensitive ecosystems. They have inappropriate geology and are near agricultural lands. In this sense they are less favorable (Figure 4). In general, according to the final map obtained from the effective factors in the construction of wind power plant, after removing the restrictions (Figure 5), it can be seen that the more we move toward the center of the province, the more constructing a wind power plant would be desirable. This is because the factors of height, geomorphology, residential centers, and specially the factor of wind speed have more weigh among the other factors. It can also be said that in terms of administrative divisions some areas in the cities of Tabriz, Harris, and Bostanabad are located in areas with good potential.

4. Conclusion

Wind power is a safe form of renewable energy and is one of the most promising alternative energy sources. Worldwide, the wind power industry has been rapidly growing recently. An increase in public awareness regarding the negative impact of traditional power-generating methods, especially coal and oil-fired power stations, has created a demand for using environmentally friendly renewable energy sources. Developing electrical energy from renewable sources is becoming a necessity because it does not release harmful emissions into the environment. In this research identifying environmental features for East Azerbaijan province with an emphasis on natural parameters was considered for proper positioning of wind power. In this study, the potential in the East Azerbaijan province for locating wind power plant was investigated based on a number of natural factors of environmental, economic and technical criteria by using ANP, FUZZY and WLC methods. The final map was classified in a GIS environment and it was found that 18% of the study area equivalent with 8413.24 square kilometers were in the class of unsuitable, 33% of the study area equivalent with 14938.71 square kilometers were in the class of relatively unsuitable, 31% of the study area equivalent with 13994.82 square kilometers were in the class of moderately suitable and finally 18% of the study area equivalent with 7732.95 square kilometers were in the class of suitable. Regarding the final map of land suitability for wind power plant construction, the most suitable areas were central regions that constitute favorable zones. Due to security issues, power transmission lines layer and birds' migration route are not available. In this regard, it is better not to consider these layers in order to prevent damages to the environment and reducing the costs.We hope this research help planners make better decisions.

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