The Evaluation of Khorasan Razavi Range for the construction of wind power plants through multi-criteria decision making in GIS environment

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Abstract. The purpose of this research was to determine the suitable location of wind power plants in Khorasan Razavi province according to the climate criteria and conditions (wind speed, prevailing wind speed, pressure and temperature), geography (elevation, slope), socioeconomic factors (distance, distance from the cities and distance from the villages), environmental factors (distance from protected areas, land use and distance from the river) and geology (distance from faults). The process has been carried out in the geographical information system environment using the analytical hierarchical process. Based on the role and effect of these factors, a map of the Effective Factors was prepared in ArcGIS10.6 environments. The weight of the criteria was determined by the Analytical Hierarchy Process Analysis (AHP) method in the EC2000 software environment. The ArcGIS10.6 software was used for spatial modelling, analysis and overlaying the different layers. The final map of suitable wind power plants was carried out in four different classes (very suitable, suitable, somewhat suitable and unsuitable). The results showed that 10.37% (1239871 ha) of the area was identified as very suitable for construction, including areas in the northwest of the province (around Sabzevar) and relatively slightly in the southeast (around Taibad) and eastern area (around Sarakhs). The results also showed that the GIS, as a decision support system in building a power plant, can be used to prepare data and prioritize experts’ models and opinions regarding various factors in choosing the appropriate location for an effective wind power plant.

Keywords: Wind power site location, Analytical Hierarchy Process (AHP), Geographic Information System (GIS), Razavi Khorasan Province.

1. Introduction

One of the best ways to supply energy is the wind energy that is produced by installing wind turbines [1]. The rapid development of wind energy extraction technologies has made it a safer alternative to today’s energy systems [2]. Many countries have started to extract this kind of energy because of the easy installation and rapid commissioning of wind turbines and low costs [3]. Among the studies that
carried out in this regard is Ebrahimi and Kamalimoghadam [3] who used the GIS to allow the construction of wind farms in the southern Khorasan province. Bennui et al. used the GIS, multi-criteria decision making, and hierarchical analysis process (AHP) to locate wind turbines in Thailand. The study found that the East Coast of Thailand was one of the most prone areas for wind turbines [5]. Soltani et al. examined the potential of wind energy for determining the feasibility of establishing wind power plants in Amir Abad, Iran [6]. Nooralahi et al. evaluated the potential of the western region in Iran to construct a wind power plant, taking into account technical, environmental, and economic criteria in the GIS environment [7]. Based on the wind direction and velocity data for three hours wind stations in Kermanshah, Islamabad, West, Ravansar, Kangavar and Sarpol Zahab, over the course of 9 years (2009-1997), Mohammadi et al. examined the potential of these areas for using wind energy [8]. The results showed that the three stations of Ravansar, Sarpol Zahab and Kangavar had the potential to produce wind energy. The Islamabad area of the West was suitable for using wind energy if using high wind turbines, and Kermanshah does not have the potential to use wind power [8]. Nasrollahi, in a study using the GIS, prioritized the use of wind and power plants in different parts of Iran [9]. The results indicated high potential of the cities of Manjil, Khoreh, Birjand, Zabol and Sabzevar for the construction of wind farms. Nguyen (2007) [10], considering the suitable criteria for building wind farms in Vietnam, considered the potential of this country to be the use of wind energy. Prabamroong et al. evaluated the development of wind farms in Thailand using GIS, taking into account 20 criteria such as distance from city center, distance from roads, distance from fault and etc. [11]. The results showed that about 30% of the total area was suitable for installing a wind power plant and most of the places were located in rural areas. In Bazzi, (2008) [12], wind turbines were used to design wind farms in Lebanon using the GIS to meet the data requirements of wind, urban areas, turbine types, and the distance between wind turbines. Using GIS and remote sensing, identified suitable sites for the construction of windmills in the Andaman and Nicobar Islands, India [13]. The results showed that Andaman and Nicobar Islands had a high potential for wind energy and had good conditions for the construction of windmills. Due to the windy situation of the Khorasan Razavi province climate, there is a lack of related studies in the use of wind power capacity and the failure to complete a study in this regard. Therefore, the purpose of this study was to obtain the necessary factors for selecting suitable sites for the construction of Wind power plants. These factors are our Major Criteria such as climate, geography, socio-economic, environmental and geology. to this end, according to selected criteria, Geospatial information systems (GIS) have been used to evaluate the appropriate locations of wind power plants in the study area.

The climate criterion in the weighting process was more important than the other criteria and thus had a higher weight. Climate parameters are wind speed, prevailing wind speed, pressure and temperature from climatic options [8]. Geographic criteria are height from sea level and slope. In areas with high altitudes and roughnesses, it is difficult to move equipment. Moreover, an increase in altitude is effective in wind speeds, and as altitude increases, wind speed increases [14]. The socio-economic criterion includes options for minimum distance from communication paths, at least distance from cities and villages (population centers). The more distance the communication paths area, the easier it will be to access the place. Availability of access roads, as well as being close to areas where access to the national electricity grid and electricity consumers can increase the district's potential for the construction of a wind power plant [15]. Cities and populations with a large population may be affected by wind farms in terms of safety, noise and landscape. Environmental criteria include distance from protected areas, land use and distance from rivers. Protected areas have been protected because of the presence of valuable forests or valuable meadows and beautiful landscapes to prevent the degradation of vegetation and
animal life. Wind farms have a negative impact on the inherent nature of these areas due to the addition of a natural technology factor [16]. The only geological criterion option in this study is the distance from the faults. The mild fault activity causes major changes in the earth's crust and the stability of the regions. Therefore, the selected location for the power plant should be located at an appropriate distance from the fault center [17-18].

1.1. Area of study

Khorasan Razavi province is one of the provinces of Khorasan located in northeastern Iran and its capital is Mashhad. The area of Khorasan Razavi province is 11544664.7744 ha, which covers 7% of the total area of Iran. Forty-nine point two % of the province is mountainous and 50.8% is plain. This province consists of 4 watersheds including Atrak, Qarahagh, Central Desert and East of Iran. Figure 1 shows the geographic location of the Khorasan Razavi province and its counties. Khorasan Razavi province is very diverse due to the vast variety of natural conditions, and each of its different areas has certain characteristics. The province has a total length of 531.6 km from the north and northeast, with a common border with Turkmenistan from the east, with a total length of about 302 km, and a border with Afghanistan. The highlands can be divided into northern and southern highlands. The northern heights of Khorasan are generally eastern-western, while the south-east highlands are north-south. The highest point of the province is Binalood Peak at 3615 meters and the lowest point of the province in the Sarakhs plain with a height of 299 meters above sea level.

![Figure 1. Location of study area (Khorasan Razavi province).](image)

2. Materials and methods

2.1. Research Methodology

In order to locate the appropriate areas for wind power plant construction, the first layer of information is 5 main criteria and 13 sub-criteria (1) climate (wind speed, wind speed prevailing, pressure and
temperature), (2) socio-economic factors (distance from towns and villages and distance from roads communication), (3) environmental factors (distance from the waterways, land use and distance from protected areas), (4) geographic (height from sea level and slope), and (5) geology (distance from faults); and from the integration of the criteria and sub-criteria maps, a final map of the construction sites of the wind farm was prepared (Figure 2).

**Figure 2.** Stages of preparation and integration of information layers and preparation of final maps of suitable sites for wind power plant construction.

Maps of distances from cities, villages, protected areas, communication paths, streams and faults, after providing data related to each of the mentioned criteria from relevant organizations (Table 1) by using the Spatial Analysis Tools extension in Arc Gis toolbox and the Distance function in the Arc GIS 10.6 software environment. Wind velocity map, prevailing wind speed, pressure and temperature. After creating the dotted point 13 of the synoptic station in the Arc GIS 10.6 environment, we use the Inverse Distance Weighting (IDW) method and according to the preferred classes (Table 2), it turned out that the map of the classes of effective options for the construction of a wind power plant is shown in Figures 3-7.
### Table 1. Research data

| Data name         | Type       | Aim                        | source                                |
|-------------------|------------|----------------------------|---------------------------------------|
| Wind speed        | Excel      | Preparation of zoning map  | Meteorological Organization           |
| Wind speed prevailing | Excel      | Preparation of zoning map  | Meteorological Organization           |
| Pressure          | Excel      | Preparation of zoning map  | Meteorological Organization           |
| Temperature       | Excel      | Preparation of zoning map  | Meteorological Organization           |
| DEM               | raster     | Preparing a gradient map   | Prepared from digital cameras         |
| Land use          | vector     | Reference data for location analysis | Produced by the researcher |
| Network of watercourses | vector     | For location analysis     | Regional Water Organization          |
| protected areas   | vector     | For location analysis     | Department of Environment             |
| City Network      | vector     | For location analysis     | Agricultural and Natural Resources Research Center |
| Village network   | vector     | For location analysis     | Agricultural and Natural Resources Research Center |
| Communication path network | vector     | For location analysis     | Agricultural and Natural Resources Research Center |
| Faults            | vector     | For location analysis     | Geology organization                 |

![Figure 3. Map of the subclasses of climatic classes.](image)

![Figure 4. Map of the subclasses of geographic.](image)
Table 2. Land use classes for the construction of wind power plants and their desirability

| Subcategories | Inappropriate | fairly inappropriate | Somewhat appropriate | Proper | Very convenient |
|---------------|---------------|----------------------|----------------------|--------|-----------------|
| wind speed (m/s) | 10-11.5 | 11.5-13 | 13-16 | 16-17.5 | >17.5 |
| Wind speed prevailing (m/s) | 10-13.5 | 13.5-15.5 | 15.5-17.24 | 17.24-19.5 | >19.5 |
| Pressure (hectopascal) | 875-854 | 875-895 | 895-910 | 910-940 | >940 |
| Temperature (℃) | 13-14.5 | 14.5-16 | 16-17.5 | 17.5-18.5 | >18.5 |
| Height from sea level (m) | >1600 | 0-400 | 400-800 | 800-1200 | 1200-1600 |
| Slope (percent) | >15 | 10-15 | 5-10 | 2.5 | 0-2 |
| protected areas (km) | 0-2 | 2-4 | 4-6 | 6-8 | >8 |
| Land use | Agriculture | Forest | lake meadows and landscapes | wetlands and rocky marshland | sand |
| The watercourses (km) | 0-1 | 1-2 | 2-3 | 3-4 | >4 |
| Cities (km) | 0-3 | >12 | 9-12 | 6-9 | 3-6 |
| Villages (km) | 0-2 | >11 | 8-11 | 5-8 | 2-5 |
| communication paths (km) | >8 | 6-8 | 4-6 | 2-4 | 0-2 |
| Faults (km) | 0-1 | 1-6 | 6-10 | 10-15 | >15 |
Figure 5. Map of the subclasses of geology classes.

Figure 6. Map of the subclasses of socio-Economic classes.

Figure 7. Map of the subclasses of the ecological class.

The weight of the parameters is obtained by pairwise comparing between them and using the analytical hierarchical process [19]. A fair comparison between the parameters was made according to experts' judgment and based on that, the importance and weight of each criterion were determined. Then, by
multiplying the map of each criterion in its weight and aggregating the weighted layers, the final map of land suitability was calculated with equation 1.

The final weight of the option \( j = \sum_{k=1}^{n} \sum_{i=1}^{m} W_k W_i (g_{ij}) \) (1)

In this regard, \( W_k \) is the significance coefficient of \( k \), \( W_i \) the significance coefficient of sub-criterion \( i \), \( g_{ij} \) is the value of \( j \) in relation to the sub-criterion \( i \) [20]. The map was categorized based on four equal parts in four classes, i.e. inappropriate, relatively appropriate, appropriate and very appropriate.

In this research, weight of the criteria and sub-criteria in the Expert Choice2000 software environment was determined by collecting expert opinions and identifying the value and importance of the criteria against each other and finally creating Paired comparison matrix of criteria. According to Table 3, the results showed that among the main criteria, climatic criteria, with 0.515, had highest degree of importance and geological criterion, with 0.08, had the least importance in the construction of wind power plants. Also, among the sub-criteria of climate, the wind speed with 0.549 and the temperature with 0.074 had the highest and lowest values respectively (Table 4). Among the geographic criteria, height from the sea level with value of 0.8 was the most important (Table 5) because it plays a big role in the location of the wind power plant and, in geological field, the distance from the faults as the only importance factor in locating the wind power plant. In the socioeconomic factors, the distance from communication paths with the importance of 0.655 was the most important (Table 6). Among the environmental criteria, the distance from protected areas with a significance of 0.54 was the highest importance (Table 7). Pairwise comparison of the criteria showed that the climate and geology, respectively, had the most and the least importance among the effective criteria in locating the wind power plant in the study area.

**Table 3.** Comparison of the main layer’s criteria in the location of wind power plants

| criteria          | The climate | Geographical | Economic-social | environmental | Geology | weight |
|-------------------|-------------|--------------|-----------------|--------------|---------|--------|
| The climate       | 1           | 3            | 6               | 6            | 6       | 0.515  |
| Geographical      | -           | 1            | 3               | 3            | 3       | 0.221  |
| Economic-social   | -           | -            | 1               | 3            | 3       | 0.129  |
| environmental     | -           | -            | -               | 1            | 3       | 0.082  |
| Geology           | -           | -            | -               | -            | 1       | 0.053  |
| Compatibility factor |           |              |                 |              |         | 0.08   |

**Table 4.** Comparison of climatic sub-criteria in locating wind power plants

| Climate sub criteria | wind speed | Wind speed prevailing | Pressure | Temperature | weight |
|----------------------|------------|-----------------------|----------|-------------|--------|
| wind speed           | 1          | 3                     | 5        | 5           | 0.549  |
| Wind speed prevailing| -          | 1                     | 3        | 3           | 0.248  |
| Pressure             | -          | -                     | 1        | 3           | 0.129  |
| Temperature          | -          | -                     | -        | 1           | 0.074  |
| Compatibility factor | -          | -                     | -        | -           | 0.07   |

**Table 5.** Comparison of geographic subcategories in location of wind power plants

| Geographical sub criteria | Height from Sea level | Slope | weight |
|---------------------------|-----------------------|-------|--------|
| Height from Sea level     | 1                     | 4     | 0.8    |
| Slope                     | -                     | 1     | 0.2    |
| Compatibility factor      | -                     |       | 0      |
Table 6. Comparison of socio-economic sub-criteria in locating wind power plants

| socio-economic sub-criteria | Communication paths | Towns | Villages | weight |
|-----------------------------|---------------------|-------|----------|--------|
| Communication paths         | 1                   | 3     | 6        | 0.655  |
| Towns                       | -                   | 1     | 3        | 0.25   |
| Villages                    | -                   | -     | 1        | 0.095  |
| Compatibility factor        |                     |       |          | 0.02   |

Table 7. Comparison of environmental sub-criteria in the locating of wind power plants

| environmental sub-criteria            | Distance from Protected Areas | Land use | Distance from the rivers | weight |
|---------------------------------------|-------------------------------|----------|--------------------------|--------|
| Distance from Protected Areas         | 1                             | 2        | 3                       | 0.54   |
| Land use                              | -                             | 1        | 2                       | 0.297  |
| Distance from the rivers              | -                             | -        | 1                       | 0.163  |
| Compatibility factor                  |                               |          |                          | 0.008  |

2.2. Final map and integration of criteria

After weighing the effective layers in the location of wind power plants using the Analytical Hierarchy Process (AHP) process, Arc GIS 10.6 was used to combine and overlap the maps. Finally, the map of suitable locations for construction of wind power plants in the final deck was categorized in four classes including, inappropriate, relatively suitable, appropriate and very appropriate (Figure 8). Areas suitable for the construction of wind power plants were in the appropriate classroom, in the western area and a small area in the east and southeast with an area of 1239871 hectares. Restricted areas of the province with inappropriate potential are located in the north and center of the province with an area of 3477116 hectares (Table 8).

Table 8. Specifications of the location of wind power plants by AHP method

| Row | class              | area (ha)       | Portion of province |
|-----|--------------------|-----------------|---------------------|
| 1   | Inappropriate      | 3477116.8062    | 30.11%              |
| 2   | Somewhat appropriate| 4369444.5484    | 37.84%              |
| 3   | Suitable           | 2458231.6228    | 21.29%              |
| 4   | Very convenient    | 1239871.7970    | 10.73%              |
3. Discussion

In this study, the criteria for wind farm site selection were categorized into 5 classes including climatic, socioeconomic, environmental, geographic and geological groups. The climate criterion in the weighting process was more important than the other criteria and thus had a higher weight. Climate parameters are wind speed, prevailing wind speed, pressure and temperature from climatic options. Wind speed is the most important factor in installing wind power plants. The higher wind speed, the greater the wind turbine power produced. Because the wind energy rotates two or three feathers that are placed behind the wind turbine rotor and As the wind speed increases, the turbine output will increase. Usually, the minimum wind speed for starting wind turbines is between 3 and 4 m/s depending on the type and design turbine [21]. According to the wind speed classification map of the province, more than 95% of the province area has a wind speed of more than 4 m/s, which indicates the potential of the region to build a wind power plant in the region. The higher the wind speed, the greater the wind power produced by wind turbines. The dominant wind direction is very important when using wind energy, and wind turbines must be installed in places that have the least obstacles in the dominant wind directions [8-9]. Increasing the height leads to lower air pressure. This reduction in pressure will be effective on the output power from turbines, because the pressure affects the performance of turbine components [22]. Hence, the pressure is also one of the most important parameters in the construction of wind power plants. The other parameter of the climate that contribute to the location of the wind power plant is temperature. Increasing the height reduces the air temperature. Reducing the temperature will be effective in the amount of power to be extracted from the turbine [15].

Geographic criteria are height from sea level and slope. In areas with high altitudes and roughnesses, it is difficult to move equipment. Moreover, an increase in altitude is effective in wind speeds, and as altitude increases, wind speed increases. So, the height should not be too high to make any significant
changes in the amount of turbines power [14]. The slope of the area is also an important factor in the proper operation of turbines and their installation. The slope of the earth will increase turbine maintenance costs, shortened life and reduced energy production. The slope should not be too high to prevent the installation of a turbine [10].

The socio-economic criterion includes options for minimum distance from communication paths, at least distance from cities and villages (population centers). The more distance the communication paths area, the easier it will be to access the place. Availability of access roads, as well as being close to areas where access to the national electricity grid and electricity consumers can increase the district's potential for the construction of a wind power plant [15]. Cities and populations with a large population may be affected by wind farms in terms of safety, noise and landscape. On the other hand, these population centers are considered as major consumers of power, and the proximity of the chosen location makes them closer to the centers of production and power consumption [10]. Due to the nature of wind energy that focuses on production, often in remote and rural areas, the development of this industry, both in developed and Developing countries, has led to clear developments in rural areas.

One of the important factors in locating wind power plants is considering environmental issues. Environmental criteria include distance from protected areas, land use and distance from rivers. Protected areas have been protected because of the presence of valuable forests or valuable meadows and beautiful landscapes to prevent the degradation of vegetation and animal life. Wind farms have a negative impact on the inherent nature of these areas due to the addition of a natural technology factor [16]. The purpose of land use survey is to determine the value of land for locating wind power plants. This classification is based on the types of agricultural land use, pastures and forest lands, lakes, wetlands and lands with intersection, rocky, Non-fertile and smooth sand. The wind turbines located on the beaches and close to them and adjacent to the rivers, will have adverse effects on these areas. These areas are also ecologically the habitat of many specific birds, which have always been important for their care [16].

The only geological criterion option in this study is the distance from the faults. the mild fault activity causes major changes in the earth's crust and the stability of the regions. Therefore, the selected location for the power plant should be located at an appropriate distance from the fault center [17-18]. According to the results, the zones identified in the region with the most suitable location accounted for 10.73% of the total area with an area of 1239871 ha. High-power areas have been designated in the selected regions in order to locate wind power plants in the area. These areas are in the western region and small areas in the east and southeast of Khorasan Razavi province.

4. Conclusion

In this research, after determining the effective factors in locating wind power plants and their role, spatial information layers were prepared and by combining these layers, suitable sites for the construction of wind power plants were determined. Deciding on the right location for a power plant requires simultaneous attention to a number of factors that the GIS allows for the integration of spatial layers. Selected sites are fully influenced by the parameters involved in the analysis and the relevant weights. Analytical Hierarchical process allows for proper weighting of options and criteria by creating a hierarchical structure to find suitable weight and sites for the construction of wind power plants.
One of the challenges in this study was to convert the daily statistical data of wind speed, prevailing wind speed, temperature and pressure into information layers, which were provided by 13 weather stations throughout the province of Khorasan Razavi. Hence, the survey data was compiled from the beginning of 2014 to the end of 2016, and average of this data was taken. Then, using interpolation in ArcGis10.6 software, these values were calculated for the whole Khorasan Razavi province.

Another problem in this study was the accuracy of the layers of information provided, including the streets and cities, villages, protected areas, waterways and faults, because the higher the accuracy of the input layers, the higher the precision is.

We can use other multi-criteria weighing methods to locate wind power plants and compare the results with the results of this study.

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