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Assessment of Wind Energy Potential in Golestan Province of Iran

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ABSTRACT: Renewable energy sources are estimated to have a thriving future in many countries as well as Iran. The aim of this work is the evaluation of wind energy potentiality for the five counties of Golestan province in the northern region of Iran. A long term data source, consisting of 30 years in Gorgan, 22 years in Gonbade-e Qabus, 21 years in Maraveh Tappeh, 9 years in Aliabad, and 7 years in Bandar-e Turkaman of eight-hourly mean wind data, was adopted and analyzed. Mean wind power based on quantified data, Weibull distribution function, the relative percentage error (RPE) and wind direction between obtaining values of wind power has been considered. According to these data, it was found that the numerical values of the shape parameter and scale parameter for Golestan varied a tight range. Annual values of ''k'' ranged from 2.7 to 6.7 where it is constant in different elevation because of better performance of this method in estimating wind energy potential, while annual values of ''c'' were in the range of 2.6 m/s to 5.9 m/s. Wind power densities have been estimated and relatively low for large wind turbines. The consequences indicate that in some months Maraveh Tappeh and Bandar-e Turkaman has best wind energy potential, as class 2, in order to establish some small wind turbine models for the sustainable development of Golestan province.

Keywords: Wind energy, Weibull distribution function, Golestan, Iran

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1. Introduction

Global warming and the recent nuclear plant accidents like Fukushima core meltdown due to increasing usage of limited fossil fuel resources is along with the more energy demand of renewable energy resources like wind energy. Most economic electricity produced from the wind is sustainable and it does not lead to the greenhouse issue. In areas with a weak grid, wind energy can be harnessed on a local basis for charging batteries or can be combined with a diesel engine to save fuel. However, the disadvantages of renewable energy are low density and variability, which results in higher initial cost because of the need for large capture area and storage or backup power. Along with the development of wind energy in other countries, there is a lot of studies regarding the determination of wind energy potential in various areas of Iran such as Manjil in Gilan province (Mostafaeipour and Abarghooei 2008), Tehran, the capital city of Iran (Keyhani et al. 2010), five cities in Semnan province (Mirhosseini et al. 2011), Shahrbabak in Kerman province (Mostafaeipour et al. 2011), Zarrineh in Kurdistan province (Mohammadi and Mostafaeipour 2013a), Aligoodarz in the west of Iran (Mohammadi and Mostafaeipour 2013b), Kerman in Iran (Mostafaeipour 2013), Zahedan in Iran (Mostafaeipour et al. 2014), Binalood in Iran (Mostafaeipour et al. 2013), Hormozgan province (Nedaei 2014), Abadan airport in Khuzestan province (Nedaei 2012a), Chalus in Mazandaran province (Nedaei 2012b), port of Chabahar in southeast of Iran (Biglari et al. 2013), Mah-shahr station in Iran (Nedaei et al. 2014), Two northeast provinces; North and South Khorasan (Saeidi et al. 2011), Baladeh and Nur in Mazandaran Province (Janbaz Ghobadi et al. 2011) Firouzkouh in Iran (Emami and Behbahani-Nia 2012), the province of Sistan and Baluchestan (Razavieh et al. 2014), three free economic and industrial zones, Chabahar, Kish and Salafchegan (Mohammadi et al. 2014). On that point are also written reports about the feasibility of an offshore wind turbine facility in Iran and comparison with the world (Mostafaeipour 2010), and winds energy status of Iran (Bagheri Moghaddam et al. 2011). The Renewable Energy Organization of Iran (SUNA) carried out a wind energy resource assessment during 2004–2009. The survey disclosed that most of the Iranian

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windiest sites ranked seventh, according to a wind energy classification by the US department of energy. The study estimated that the nominal capacity of more than forty-five sites all over the country is 6500 MW and the minimum installable wind capacity about 10,000 MW (Sedaghat and Mirhosseini 2012; SUNA 2014). This continuous study is conducted to evaluate the wind potentiality in a northern province of Iran, Golestan province.

2. Description of Golestan

Iran is located in a low-pressure location and has strong air flows in the summer and winter in some locations (Mirhosseini et al. 2011; Mostafaeipour 2013). The country is influenced by two main winds. First, winds from the Atlantic Ocean and Mediterranean Sea and also from central Asia in the winter. Second, winds from Indian Ocean and the Atlantic Ocean in the summer. Golestan province is one of the 31 provinces of Iran, located in the northeast of the country south of the Caspian Sea, between 36° 44′ N (north latitude) to 38° 05′ N and 53° 51′ E (East longitude) to 56° 14′ E. Golestan enjoys mild weather and a temperate climate most of the year. Geographically, it is divided into two sections; the plains, and the mountains of the Alborz range. The ground slope reduces from the heights to the plains towards the Caspian Sea. In the southern and eastern plains of the Caspian Sea, influenced by the movements of the earth and local winds, sandy hills have formed and a natural shallow dam has been created between the plain and the sea. In the eastern Alborz, the direction of the mountains is towards the northeast and gradually reduces in height. Its southern mountains are Abar Kooh Mountains and its highest summit being Shavar, 3,945 m in elevation. The northern range is Shahkooh which confronts the plain of Gorgan like a wall. Its highest peak being Pirgard, reaching a height of 3,204 m. It was an important city of Persia located on the Silk Road. It has a population about 2 million and covers an area of 20,380 km^2. The province of Golestan is bordered from east by the province of North Khorasan, from the west by the province of Mazandaran, from south by the province of Semnan, and from north, country of Turkmenistan. The province is divided into the following twelve counties, Aliabad, Aqqala, Azadshahr, Bandar-e Gaz, Gonbad-e Qabus, Gorgan, Kalaleh, Kordkuy, Maraveh Tappeh, Minudasht , Ramian, and Bandar-e Torkaman. Its capital is Gorgan. The feasibility of using the wind energy in the different areas of Golestan province has been studied. According to the Iranian wind atlas (SUNA 2014) and an Iranian GIS map of average wind speed at different elevation (Alamdari et al. 2012), five counties of Golestan province with higher wind energy potentiality have been selected in this study. In accordance with certain factors such as geographical location, influenced by the latitude and geographical elevation; the Alborz Mountain Ranges, its distance from the sea, the desert areas south of Turkmenistan, local winds and forest density, brings about a variable climate. In the northeast of the province, particularly to the east of the Caspian Sea and the distance between Gorgan River till the borders of Turkmenistan, due to non-influential effects of the Caspian Sea, decrease in the elevation of the eastern Alborz, the extension of the coastal plain and its proximity of Central Asia, a warm and dry climate is experienced. Whereas this changes to a semi desert type in areas further off. The annual rainfall is scarce in this area and due to this, the effect of the heat is overpowering. There are many farms around the province; therefore wind pumps could be alternative source in order to provide the required water for agriculture without using fossil fuel.

3. Analysis procedure

3.1 Wind data

The wind data used in the present study consist of eight hours average wind speeds recorded at the anemometer height of 10 m in the five selected counties. Data collected from sites corresponded to Gorgan from 1982-2012, Gonbad-e Qabus from 1990 to 2012, Maraveh Tappeh from 1991 to 2012, Aliabad from 2003 to 2012, and Bandar-e Turkaman from 2005 to 2012. The data of synoptic sites were measured during unequal periods where some synoptic sites are newer. Wind speed data at other elevations can be obtained by extrapolating the 10 m data using the power law. By using the power law formula, wind speed data can be calculated as follows (Mostafaeipour et al. 2011; Mohammadi and Mostafaeipour, 2013a):

$$\frac{v}{v_0} = \left(\frac{h}{h_0}\right)^{\alpha} \quad (1)$$

where v_0 is the measured known wind speed at the original height h_0, and v is the calculated wind speed at the required height h. Also, the coefficient of surface roughness (α) lies in the range from 0.08 to 0.39. Value of surface roughness coefficient considered 0.15 upon the location and topography of five synoptic sites where the anemometer was cited to measure the wind speed at 10 m elevation (Jain 2011).

3.2 Measured wind power density

Knowledge of the wind speed frequency distribution plays a substantial role in order to estimate the potential of wind in any location. As long as the distribution of wind speed is known wind power potential of the sites can be easily calculated. The first and the most accurate method to calculate wind power potential is based on measured values that record at the meteorological station. The wind power is proportional to cube of wind speed and can be calculated using the following equation:

$$P = \frac{1}{2}\rho v^3 \left(\frac{W}{m^2}\right) \quad (2)$$

where ρ is the air density and for standard condition (i.e. at sea level with a temperature of 15 °C and a pressure of 1 atmosphere) is equal to 1.225 kg/m3 and v is the wind speed (m/s). Therefore, mean wind power density for any specified periods of time can be calculated as follows:

$$\bar{P} = \frac{1}{2n}\rho\sum_{i=1}^{n} v^3 = \frac{1}{2}\rho\overline{v^3} \left(\frac{W}{m^2}\right) \quad (3)$$

n is the number of all data that was used in the specified period of time. Once the wind power is estimated, the wind energy for a specific period of time can be calculated:

$$\bar{E} = \bar{P}T \quad (4)$$

3.3 Weibull distribution function

The second method to asses wind power potential is using a probability distribution function. There are various probability density functions, which can be utilized to describe the wind speed frequency over a period of time. These probability functions include the Weibull, Rayleigh, Gamma, Beta, Gaussian, and Lognormal distribution. The two parameter Weibull distribution function usually known as the most qualified function due to its simplicity and acceptable accuracy level for wind speed data analysis. The Weibull probability density function (WPDF) is given as (Mostafaeipour et al. 2011; Mohammadi and Mostafaeipour, 2013a):

$$fw(v) = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1} \exp\left(-\left(\frac{v}{c}\right)^k\right) \quad (5)$$

The cumulative density function (CDF) of the Weibull distribution is expressed as:

$$F_w(v) = 1 - \exp\left(-\left(\frac{v}{c}\right)^k\right), (k > 0, v > 0, c > 1) \quad (6)$$

where $f_w(v)$ is the wind speed probability for speed v, k is dimensionless shape parameter and c is the scale parameter (m/s). The shape parameters, k, resemble the wind potential of the location and indicates how peaked the wind distribution is (i.e. if the wind speeds tend to be very close to a certain value, the distribution will have a high k value and is very peaked) and the scale parameter, c, indicates how 'windy' a location under consideration is (Mostafaeipour et al. 2011; Mohammadi and Mostafaeipour, 2013a). Several methods have been proposed to estimate the Weibull parameters. Some of these methods are graphical method, moment method, standard deviation method, maximum likelihood method, energy pattern factor method, and power density method. In this study power density method was selected.

3.3.1 Power density method

To obtain shape factor and scale factor through this method, firstly the energy pattern factor E_{pf} is computed. The energy pattern factor usage is for turbine aerodynamic design and defined as a ratio between mean of cubic wind speed to cube of mean wind speed (Mostafaeipour et al. 2011; Mohammadi and Mostafaeipour, 2013a):

$$E_{pf} = \frac{\frac{1}{n}\sum_{i=1}^{n} v_i^3}{\left(\frac{1}{n}\sum_{i=1}^{n} v_i\right)^3} = \frac{\overline{v^3}}{\bar{v}^3} = \frac{\Gamma\left(1+\frac{3}{k}\right)}{\Gamma^3\left(1+\frac{3}{k}\right)} \quad (7)$$

where n is the amount of data in a year. Once, energy pattern factor was calculated, shape factor can be estimated from the following formula (Mostafaeipour et al. 2011; Mohammadi and Mostafaeipour, 2013a):

$$k = 1 + \frac{3.69}{\left(E_{pf}\right)^2} \quad (8)$$

The calculation method for scale factor is same as the standard deviation method and can be obtained as:

$$c = \frac{\bar{v}}{\Gamma\left(1+\frac{1}{k}\right)} \quad (9)$$

where Γ(x) is the gamma function and is defined as:

$$\Gamma(x) = \int_0^\infty \exp(-u)u^{x-1}dx \quad (10)$$

3.3.2 Calculated wind power per unit area

The wind power per unit area based on Weibull's probability density function can be expressed as (Mostafaeipour et al. 2011; Mohammadi and Mostafaeipour, 2013a):

$$P = \frac{1}{2}\rho\int_0^\infty v^3 f_w(v)dv = \frac{1}{2}\rho c^3\Gamma(1+\frac{1}{3}) \quad (11)$$

RPE is defined as (Mostafaeipour et al. 2011; Mohammadi and Mostafaeipour, 2013a):

$$RPE = \left(\frac{P_w - P_{md}}{P_{md}}\right)x100 \quad (12)$$

Where P_w and P_{md} are calculated power values from Weibull distribution and from measured data, respectively.

3.3.3 Maximum energy and most probable wind speed

In the study of wind energy feasibility, to determine the maximum energy in all over the year, the nominal wind speed is used, as a speed that produces maximum energy along the year. This speed is one of the significant characters in turbine designing and is given by (Mostafaeipour et al. 2011; Mohammadi and Mostafaeipour, 2013a):

$$U_{me} = c\left(\frac{k+2}{k}\right)^{\frac{1}{k}} \quad (13)$$

It can be also found that the most probable wind speed in the area by (Mostafaeipour et al. 2011; Mohammadi and Mostafaeipour, 2013a):

$$U_{mp} = c\left(1-\frac{1}{k}\right)^{\frac{1}{k}} \quad (14)$$

4. Result and discussion

4.1 Monthly wind pattern

The monthly wind speed of Gorgan, Gonbad-e Qabus, Maraveh Tappeh, Aliabad, and Bandar-e Turkaman counties at 10 m is shown in Fig. 1. Scale parameter and shape parameter, two required parameters in Weibull distribution function are shown.

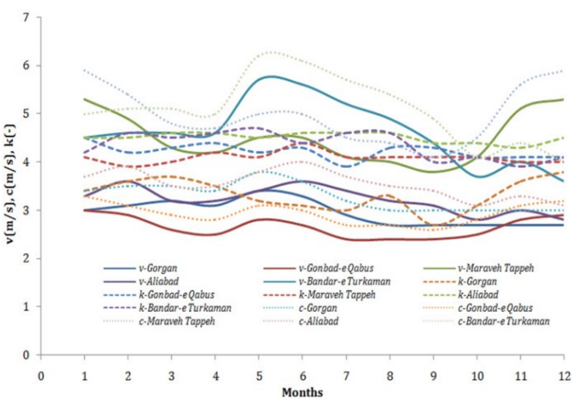


Fig. 1: Wind speed pattern, scale parameters, and shape parameter of 5 counties

From the figure "k" ranged annually from 2.7 to 4.7 and values of ''c'' is in the range of 2.6 m/s to 5.9 m/s. The values of wind speed in a annual pattern show that Maraveh Tappeh and Bandar-e Turkaman should be considered as higher potential counties rather than three others.

4.2 Power distribution

Wind power values included the measured power in 10 m and Weibull calculated power in W/m^2 is shown in Fig. 2. It is interesting in the figure that Bandar-e Turkaman has the highest power potentiality. However, in months with minimum power values, Bandar-e Turkaman can be replaced by Maraveh Tappeh in a distributed generation system. According to the Fig. 2 and statistical error (RPE) evaluation by equation 12, it is found that the difference between mean wind powers based on measured data and Weibull function is little in all months. RPE values for the 4 counties range from 17% to 25%, while RPE values for Gorgan is higher than other counties and range from 25% to 50%.

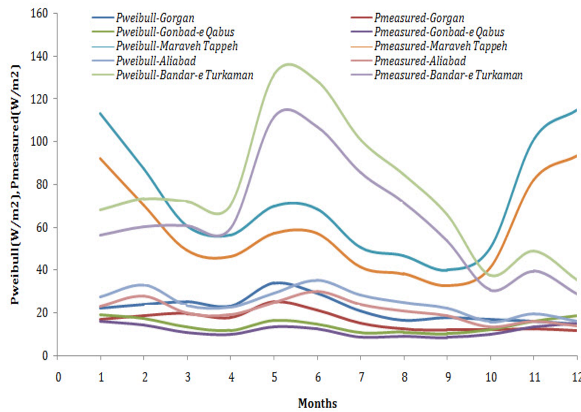


Figure 2 Annually measured power (Pmeasured) and calculated power by Weibull function (Pweibull)

The highest value of the monthly mean wind power density based on measured data, which located in Marveh Tappeh, is 226.7 W/m^2 in December.

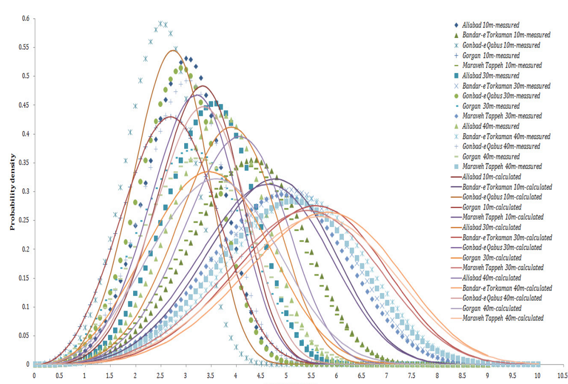


Figure 3. Wind speed probability distribution at three heights for five counties of Golestan province

In addition, it is concluded that Maraveh Tappeh and Bandar-e Turkaman have higher Power density. By using the Pacific Northwest Laboratory (PNL) wind power classification scheme at 10 m elevation (Mostafaeipour 2013), five counties in most of the months except January and February in Maraveh Tappeh and May and June in Bandar-e Turkaman wind power falls in class 1 (P≤100 W/m2) which indicates unsuitable condition. The mentioned exception months of Maraveh Tappeh and Bandar-e Turkaman ranked in class 2 (100≤P6≤150 W/m²). The corresponding probability density distribution at heights of 10 m, and extrapolated heights of 30 m and 40 m for Golestan five selected counties is shown in Fig. 3.

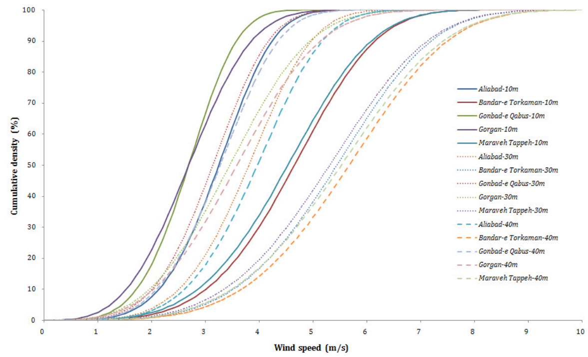


Figure 4. Cumulative density at three heights for five counties of Golestan province

It is noticed that the Weibull distribution gives a good fit to experimental data. It is obvious from the Fig. 3 that the probability densities in 30m and 40m calculated from Weibull distribution have extended shape in higher speed for Bandar-e Turkaman and Maraveh Tappeh, respectively. So, these two counties with a higher scale parameter, c, values have a better wind energy potential. However Bandar-e Turkaman has a lower probability density. Besides the probability density calculation, the cumulative distribution function is helpful for estimation of the time for which wind is within a certain velocity interval. Fig. 4 presents the cumulative distribution curves of the studied wind speeds for the five counties of Golestan province at three different heights.

It can be noted that, for example, the wind speed of Maraveh Tappeh and Bandar-e Turkaman at 30 m and 40 m heights is greater than 4 m/s for about 70% of the time in the year. Moreover, the wind speed of these counties in the reference elevation of 10m is about 60% of the time in the year. The 4 m/s wind speed limit is important, because it is the cut-in speed of many commercial turbines. The cut-out speed is usually between 20 m/s and 25 m/s. However, the cut-out wind speed does not exceed 25 m/s at these sites.

4.3 Maximum energy and most probable wind speed for each region

Maximum energy and most probable wind speed in (m/s) which used to select the proper wind turbine are calculated for the five counties. Figure 5 shows these speeds.

4.4 Wind rose diagram

Knowledge of the wind direction plays a remarkable role in the optimal position of the wind turbine. A wind rose is a convenient tool for displaying anemometer data (wind speed and direction) in wind energy studies. Changes in wind direction are due to the general circulation of the atmosphere, again on an annual basis (seasonal) to the mesoscale (4–5 days). This wind rose figure illustrates the most common form, which consists of several equally spaced concentric circles with 16 equally spaced radial lines (each represents a compass point). The line length is proportional to the frequency of the wind from the compass point, with the circles forming a scale. The legend of the wind rose shows, special colors for each wind velocity limit. The frequency of calm conditions is indicated in the center. The longest lines identify the prevailing wind directions. Fig. 6 shows the annual wind rose diagrams based on frequency in five counties of Golestan province during the sampling periods in each synoptic.

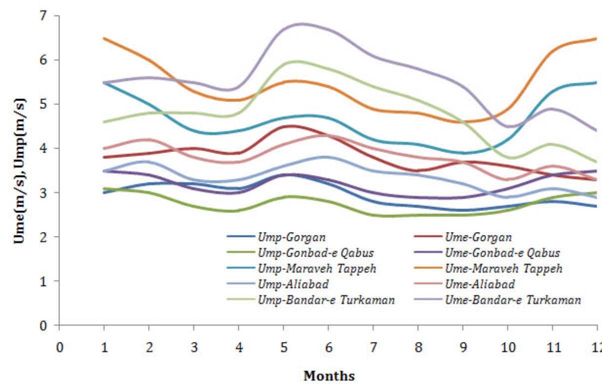


Figure 5. Annually maximum energy and most probable energy of the five counties

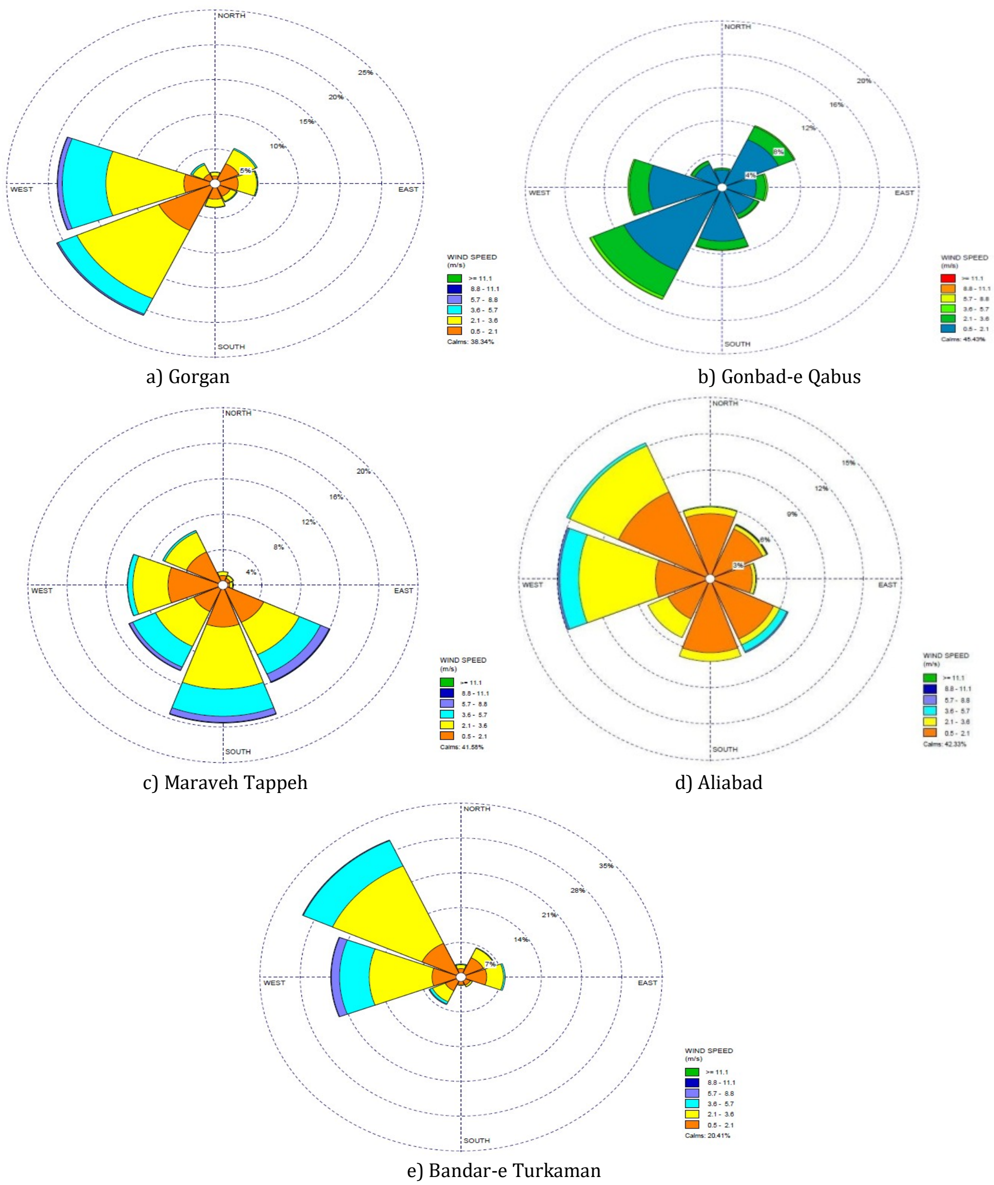
It is from the figure that the most frequent directions in Gorgan and Gonbad-e Qabus are SW, with an average wind speed of 4.6 m/s and 0.7 m/s. This is in agreement with our result that shows the most windward direction of Maraveh Tappeh is S with an average wind speed of 1.4 m/s. The most windward directions at Aliabad and Bandar-e Turkaman are W and NW, with an average wind speed of 3.4 m/s and 4.7 m/s, respectively. From this figure, it can be concluded that the Bandar-e Turkaman station is a better location for wind turbine installation since the wind direction has least variation among all studied stations and its average wind speed is higher rather than other counties.

5. Conclusion

This paper presented long-term eight hour period wind speed data at different height of five counties in Golestan province. Based on monthly analysis the Weibull distribution function is suitable to estimate wind energy resource for Golestan. The most important outcomes of the study can be summarized as follows:

- Wind speeds are modeled using the Weibull probability function with an acceptable RPE values. The Weibull parameters k (dimensionless) and c (m/s) are shown in Fig. 1. In addition, since k is independent of the average speed and the height of elevation in power density method thus, the power density method is simpler calculation method rather than other methods.

- The results of different years wind speed, wind direction of wind rose analysis, and Weibull distribution show that Bandar-e Torkaman has the good condition.
- An evaluation of the wind resource available in five potential counties of Golestan proves that this northern province falls into class 1 wind power site (with consideration to wind power density classes published by U.S. department of Energy) or poor location and is not suitable for construction of large-scale wind turbines but has sufficient wind for small wind turbines. Moreover, some months in Maraveh Tappeh and Bandar-e Turkaman, the wind power sites reach to class 2. These seasonal sites are marginal and suitable location for wind power development to stand-alone activities such as water pumping and battery charging and not for grid connection. It is notable that, since some surveyed synoptic sites with a long term sampling period about 30 years missed 10 min data acquisition, thus the turbulence intensity could not be calculated in this study.



a) Gorgan

b) Gonbad-e Qabus

c) Maraveh Tappeh

d) Aliabad

e) Bandar-e Turkaman

Figure 6. Wind rose diagram at 10 m for selected five counties of Golestan province

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