Wind Power Assessment and Site Matching of Wind Turbines in Lootak of Zabol

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Abstract- Essentially, there are some effectiveness parameters on variation of measured wind data including season and date, hub height, roughness of land and climate conditions at a specific location. Wind potential assessment based on specifications of wind (data) as the most important factors can be performed for each sites. In this paper, the measured data of wind such as wind speed and wind direction for three year from 2007 to 2009 at different elevations (10, 30 and 40 m) were statically evaluated for Lootak of Zabol. The potential of wind energy as one of the renewable energies resources for power production were evaluated. The three years mean value of some parameters such as wind energy density, wind speed, standard deviation, Weibull parameters (k and c), the most probable wind speed and the optimal wind speed during the whole three years were calculated. Moreover, among five different wind turbines, the monthly and annual variations of capacity factor were investigated for choosing the suitable wind turbine.

Keywords—Potential of wind power; wind turbine; site matching; Lootak.

1. Introduction

Energy is a fundamental factor in the production process so that the lack or shortage of energy has an essential effect on the social and economic development. Climate change and global warming concerns integrated with the increasing population and demand for energy sources have pushed most of countries to identify alternatives of fossil fuels using renewable energy resources. Therefore, the idea of renewable energy usage that are considered as part of clean energy is fundamentally attractive and many studies have been done in this area [1]. According to many advantages of wind energy among renewable energies, rapid development of this energy source can be observed in the world [2].

Iran is located in Middle East and different energy resources, whether as non-renewable or renewable such as wind, solar, geothermal, bio-energy, hydrogen and fossil fuels are currently under development in this country [2]. Iran is a developing country with more than 76 million populations [3] and area of 1,648,195 km^2 with high power demand. Wind energy is one of the best energy resources for solving the demand growing problem. Iran offers some tax and investment credits to support renewable energies development [4]. Therefore, important role of wind energy development will found in Iran's energy package. Figure 1 shows Iran's wind capacity dispersion based on the measured wind speeds taken from 60 stations at an altitude of 80m in different areas of the country. This was prepared by Iran Renewable Energy Organization (SUNA) in 2009 and the data are available for three different altitudes (40m, 60m and 80m) [5].

Assessment of wind power potential is one of the important studies for turbine installation and development of large-scale wind turbine in a given site. Many studies have been performed on the estimation of wind power production in a specific location [6-8]. Additionally, some researches have been investigated to match the features of site with wind turbine models [9,10].

Abul'Wafa [11] introduced turbine performance index (TPI) factor for site matching of wind turbines. Two parameters including maximum energy generation and minimum energy cost are considered in their proposed method.

Şahin and Aksakal [12] presented the energy potential of wind at a coastal location in eastern Saudi Arabia. They found that small-scale wind energy systems are appropriate in this area for power production and irrigation goals.

Ko et.al. [13] investigated the wind energy variation for seven regions with complex terrain in Jeju Island, Korea. They reported that wind speed blows strongly at night and value of this parameter in winter is higher than it in summer. In addition, they found that wind energy change significantly in different areas of Jeju Island.

Ucar and Balo [14] evaluated the potential of wind energy for some littoral locations in Turkey. They reported that two zones have maximum value of annual mean wind speed among their case studies locations. In addition, capacity factor and yearly production of energy for different wind turbines were determined by them.

Fueyo et.al. [15] estimated the potential of wind power production in Spain. They found that the total energy potential is about 1100 TWh/y. Moreover, they reported that installed wind power could operate with high range value of capacity factors in over 24% which are about 70 GW.

The Wind of 120 days of Sistan is the famous local wind in Iran, which known as Levar wind. The Levar is one of the most persistent and intense wind systems in the world. This local wind blow strongly during the summer months on wide land of the east from about middle of May through middle of September. Also, the air pressure difference among the atmospheres can be observed in the cold months over Iran. Generally, the wind flow is available in Sistan in all seasons, particularly around the Lootak of Zabol region [16,17].

In current study, the potential of wind energy is evaluated for Lootak-Zabol station in Sistan and Baluchestan province located in the east of Iran. This station is on the path of the 120 days wind of Sistan region. Therefore, the 120 day wind is one of the important factors which have a significant affection in hot months of the year in this area. The recorded wind speed data are analyzed for investigating the wind power in a particular site.

Statistical analysis of wind speed data recorded for a long time is needed to estimate the potential of wind energy in desired location. Therefore, the measured 10 minutes mean wind speed data from January 2007 to December 2009 by Suna organization [4] are applied at three altitudes of 10, 30 and 40 meters for Lootak-Zabol station. Also, Weibull distribution function is considered to fit a measured wind speed probability distribution in Lootak site over a specific period of time. Moreover, site matching of various wind turbines are investigated at altitude of 40 m for Lootak and the appropriate wind turbine is proposed.

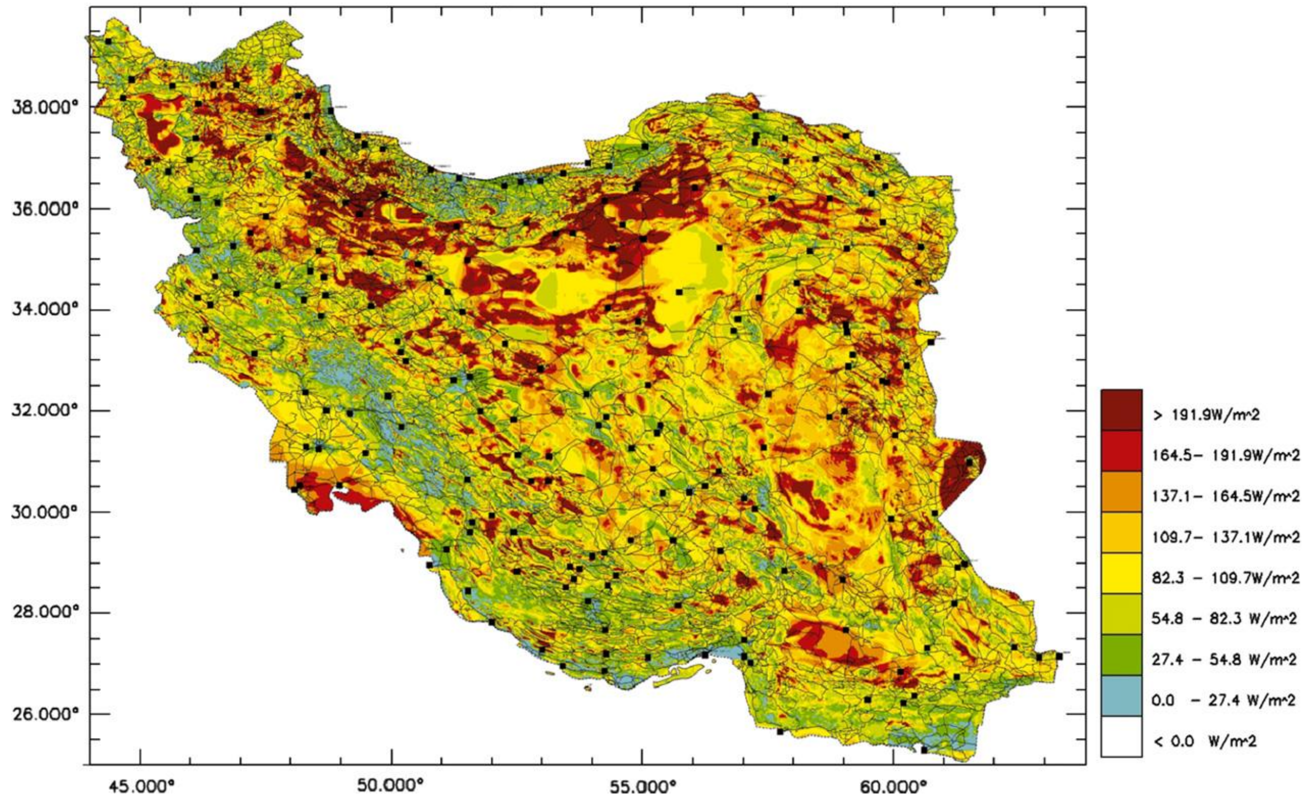

Fig. 1. Wind power density at altitude of 80 m in Iran [5]

2. Study Area and Its Climate

Iran is a country with changeable climate and its geographical situation is such that the pressure differences of different geographical zones create powerful air flows over it during hot and cold months. The wind flow is available in Sistan at all seasons, particularly around the Lootak region. This station has the longest and the fastest winds and is one of the best places to invest in wind energy. During the winter months, there are differences in the air pressure and temperature between the mountains and the central desert of Iran over there. During the spring and summer months, Lootak is also affected by the 120 days winds from the east of Sistan which are known as the Levar winds [16].

We assessed potential of wind energy for power generation duration of 3 years in Lootak region. This land is located at the northern latitude of 30°35′and the eastern longitude of 61° 20′. Lootak position is shown at Figure 2. [18].

Fig. 2. The Lootak position on the map [18]

3. Analysis of Wind Data

In order to estimate the wind energy potential of the region accurately and find its specifications, some meteorological information of station which recorded in long-time are statistically analyzed. The utilized data in the study were collected from 2007 to 2009. The applied data logger has three velocity sensors which install at various altitudes (10, 3. and 40 m). Moreover, two direction sensors are used to install at 30 m and 37.5 m heights [4].

3.1. Wind Speed Distribution

Wind speed frequency distribution is one of the main factors which identify to assess the potential of wind power in windy regions. There are various density functions which can be applied to demonstrate a suitable wind speed frequency curve. Gumbel distribution is the most popular statistical model for assessing highest wind speeds. According to Gumbel [19], Weibull distribution can be matched to experimental data carve in a good adjustment. Therefore, this distribution is chosen to describe the wind speed distribution among common functions. The wind speed probability density function (pdf) can be expressed as [20]:

$$f(U) = (k/c)(v/c)^{k-1}\, exp(-(v/c)^k) \quad (1)$$

where c and k are Weibull parameters which introduce as scale and shape parameter, respectively and v is wind speed. Weibull parameters can be determined by following equations [20]:

$$k = (\sigma_v/\bar{v})^{-1.086} \quad (2)$$

$$c = \frac{\bar{U}}{\Gamma(1+1/k)} \quad (3)$$

where $\bar{v}$ is mean of wind speed and σ_v is variance of the wind speed. Based on N as the number of wind speed records, $\bar{v}$ can be calculated as following [20]:

$$\bar{v} = (1/N)\sum_{i=1}^{N} V_i \quad (4)$$

Moreover, the standard deviation σ_v for wind velocity recordings is also determines as following [20]:

$$\sigma_v = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(V_i - \bar{V})^2} \quad (5)$$

The Weibull distribution of wind speeds for three altitudes at different years from 2007 to 2009 are shown in Figures (3-5).

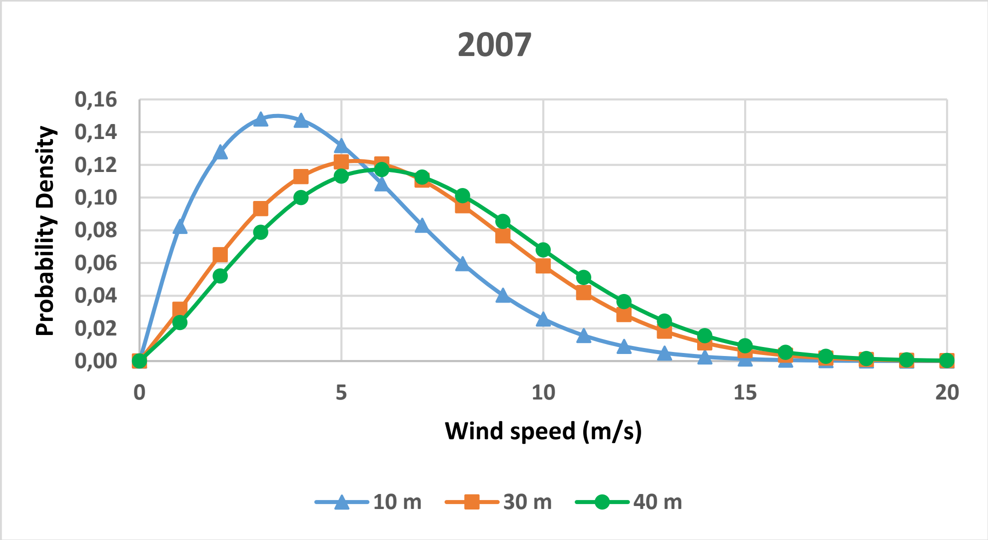

Fig. 3. The Weibull distribution of wind speeds for 2007

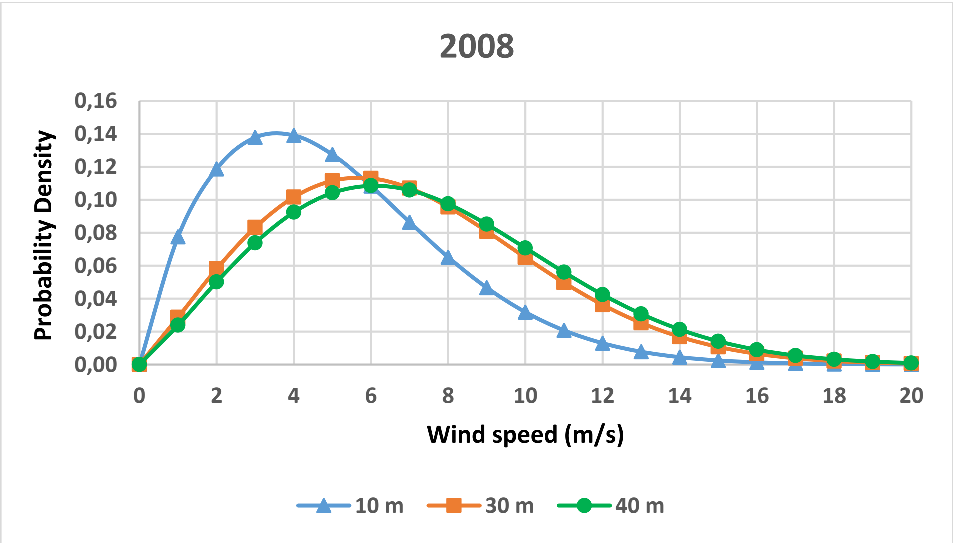

Fig. 4. The Weibull distribution of wind speeds for 2008

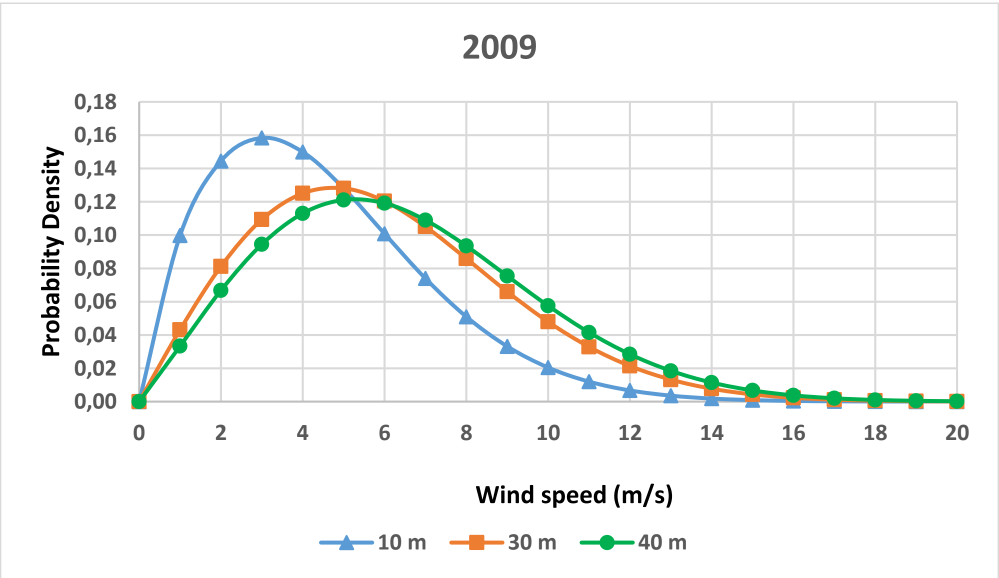

Fig. 5. The Weibull distribution of wind speeds for 2009

3.2. The Most Probable and The Optimal Wind Speed

In the study of wind energy potential, the optimal wind speed, as a speed that produces maximum energy along the year, is used to determine maximum energy in all over the year. This speed may be calculated from k and c values and is given by [20]:

$$V_{op} = c(1 + 2/k)^{1/k} \quad (6)$$

In addition, V_{mp} as the most probable wind speed indicates the most frequent wind speed for a wind probability distribution that can be calculated as [20]:

$$V_{mp} = c(1 - 1/k)^{1/k} \quad (7)$$

The three-year mean of some parameters including wind speed, standard deviation, Weibull parameters (k and c), the most probable and optimal wind speed for Lootak station in different month of year at three measured heights (10, 30 and 40 m) are shown in Tables 1, 2 and 3, respectively.

Table1. The calculated parameters for years 2007–2009 in Lootak at height of 10 m

Month	$\overline{V}$	σ_u	k	c	V_{mp}	V_{op}
Jan.	2.606	1.757	1.534	2.894	1.456	4.987
Feb.	3.635	2.731	1.366	3.971	1.508	7.697
Mar.	4.083	2.718	1.543	4.534	2.332	7.754
Apr.	4.656	2.774	1.741	5.223	3.220	8.084
May.	5.533	3.236	1.788	6.219	3.936	9.462
Jun.	7.175	3.414	2.251	8.096	6.205	10.784
Jul.	7.770	3.422	2.440	8.758	7.037	11.219
Aug.	7.255	3.133	2.495	8.176	6.647	10.368
Sep.	5.502	3.398	1.682	6.156	3.603	9.820
Oct.	4.204	2.741	1.588	4.685	2.512	7.823
Nov.	2.676	2.022	1.375	2.917	1.087	5.716
Dec.	2.377	1.701	1.483	2.612	1.137	4.832
Mean	**4.789**	**2.754**	**1.774**	**5.353**	**3.390**	**8.212**

Table 2. The calculated parameters for years 2007–2009 in Lootak at height of 30 m

Month	$\overline{V}$	σ_u	k	c	V_{mp}	V_{op}
Jan.	3.569	2.172	1.716	4.000	2.397	6.289
Feb.	4.837	3.327	1.505	5.357	2.579	9.422
Mar.	5.517	3.205	1.790	6.188	3.917	9.445
Apr.	6.293	3.266	2.018	7.090	5.061	9.975
May.	7.462	3.742	2.114	8.425	6.225	11.541
Jun.	9.549	3.932	2.685	10.726	8.867	13.401
Jul.	10.432	3.956	2.874	11.699	10.057	14.092
Aug.	9.962	3.435	3.189	11.124	9.871	12.979
Sep.	7.680	4.031	2.011	8.656	6.130	12.239
Oct.	5.579	3.218	1.809	6.262	4.008	9.491
Nov.	3.538	2.477	1.491	3.907	1.802	7.015
Dec.	3.149	2.082	1.601	3.501	1.826	5.941
Mean	**6.464**	**3.237**	**2.067**	**7.245**	**5.228**	**10.152**

Table 3. The calculated parameters for years 2007–2009 in Lootak at height of 40 m

Month	$\overline{V}$	σ_u	k	c	V_{mp}	V_{op}
Jan.	3.862	2.291	1.765	4.337	2.695	6.672
Feb.	5.164	3.514	1.525	5.727	2.821	9.968
Mar.	5.924	3.349	1.843	6.648	4.335	9.965
Apr.	6.729	3.424	2.056	7.579	5.491	10.552
May.	7.938	3.887	2.168	8.962	6.740	12.113
Jun.	10.105	4.045	2.757	11.345	9.512	13.993
Jul.	10.945	4.068	2.948	12.259	10.602	14.679
Aug.	10.483	3.528	3.282	11.689	10.435	13.549
Sep.	8.090	4.172	2.052	9.117	6.547	12.766
Oct.	6.347	3.379	1.978	7.158	5.018	10.187
Nov.	4.003	2.728	1.532	4.437	2.178	7.743
Dec.	3.540	2.232	1.709	3.948	2.225	6.447
Mean	**6.928**	**3.385**	**2.135**	**7.767**	**5.717**	**10.719**

It can be seen from Tables 1, 2 and 3 that maximum mean wind speed occur in July, while minimum mean wind speeds occur in December for each investigated altitude. Moreover, minimum value of standard deviation σ_u is obtained in December. This means that amount of measurement wind speeds have minimum variation from the average wind speed in this month. The three-years mean wind speed is found to be 4.789 m/s for 10 m, 6.464 m/s for 30 m and 6.928 m/s for 40 m. In addition, the values of "k" are increased from elevation of 10 m to 40 m with a three year mean value of 1.774for 10 m, 2.067 for 30 m and 2.135 for 40 m. Also, the value of "c" varies increasingly with the heights as 5.353m/s for 10m, 7.245m/s for 30 m, and 7.767m/s for 40m.

Figure 6 demonstrates the average wind speed variation of Lootak station in different months for three heights from 2007 to 2009. Results show that monthly average wind speeds for 10, 30 and 40 m elevations are between 2.377-7.77 m/s, 3.149-10.432 m/s and 3.54-10.945 m/s, respectively.

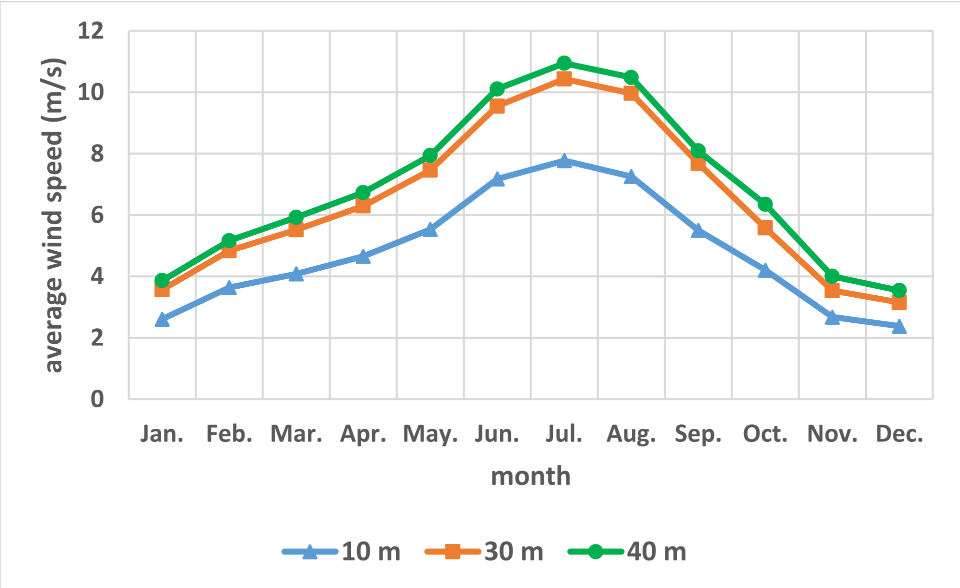

Fig. 6. The average wind speed variation of Lootak in different months from 2007 to 2009

3.3. Wind Direction and Wind Rose Diagram

According to the nature of wind, the amount of wind speed and its direction always change continuously. Wind direction is an important factor for selecting the suitable position of wind turbine in a wind farm. On the other hand, wind turbines have to be installed in main direction of wind which can capture most of wind energy.

In general, variation of wind direction and angular distribution of wind speed for desired area can be specified using a wind rose diagram [21]. Therefore, the collected data are reported as wind rose diagram using WRPLOT software. Wind rose diagram at altitude of 37.5m is shown in Figure 7. Based on this diagram, wind blows toward the northwest direction. In addition, Table 4. shows the annual mean wind direction for 30m and 37.5m heights.

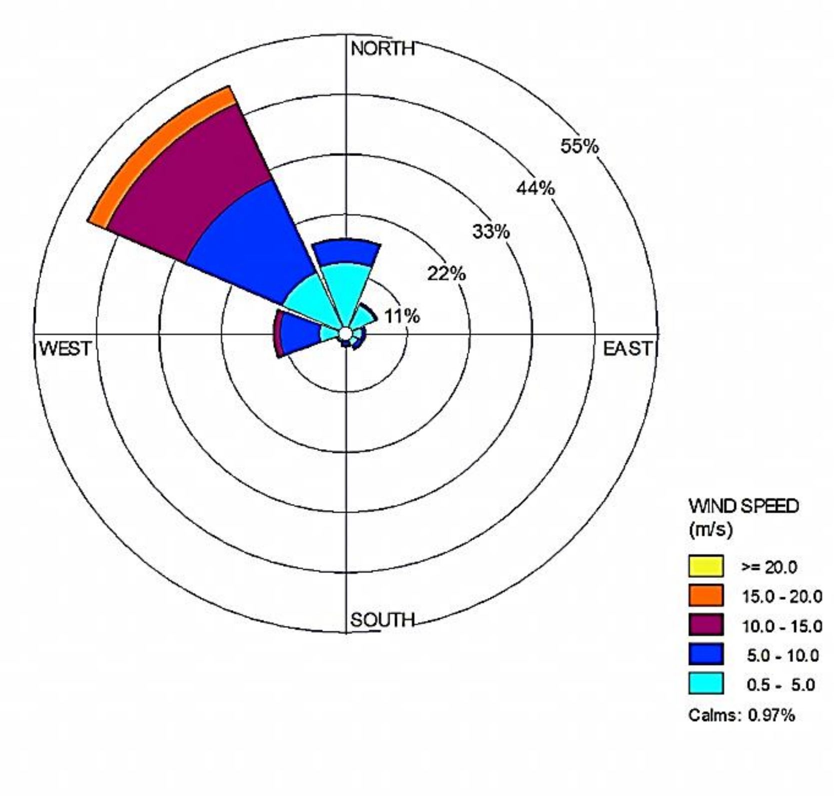

Fig. 7. Wind rose diagram at 37.5 for 2009

Table 4. Yearly wind direction for Lootak station at two different heights

Parameter	wind direction (degree)					
Height	30 m			37.5 m		
Month/ year	2007	2008	2009	2007	2008	2009
Jan.	220.13	210.83	197.91	215.37	196.07	189.79
Feb.	199.76	215.99	187.09	194.22	211.51	180.24
Mar.	190.88	189.24	193.03	185.41	186.03	186.80
Apr.	187.12	185.56	217.52	183.54	180.47	214.26
May.	277.29	246.63	255.98	273.94	240.80	250.83
Jun.	285.52	308.93	318.87	284.38	307.63	317.23
Jul.	323.07	305.84	299.78	323.42	301.71	300.14
Aug.	319.18	309.77	318.20	320.61	309.96	318.34
Sep.	309.45	267.21	252.13	308.51	265.99	249.35
Oct.	297.51	243.83	266.39	291.29	238.54	259.58
Nov.	200.20	238.08	214.98	190.92	230.72	207.77
Dec.	218.45	213.97	175.79	212.28	202.11	169.86
Mean	**252.38**	**244.66**	**241.47**	**248.66**	**239.29**	**237.02**

3.4. Wind Power Density and Energy Calculation

Generally, power of wind has cube relationship with wind velocity. Wind power density is defined as a main factor for evaluating wind potential of site. It is expressed as [20]:

$$\bar{P}/A = 0.5\rho c^3 \Gamma(1 + 3/k) \quad 8)$$

where, ρ is air density in kg/m^3 which is given as ρ = 1.225 kg/m^3, k and c are Weibull parameters. A is swept area by wind turbine blades and $\bar{P}$ is mean wind power available.

Furthermore, density of wind energy per unit area for a specific time NΔt long is illustrated as following [20]:

$$\bar{E}/A = (\bar{P}/A)(N\Delta t) \quad (9)$$

In Figures (8-10), the three years mean wind power density at three different altitudes is estimated by recorded data. Maximum amount of monthly power density for 10, 30 and 40 m heights are obtained 465.3, 1008.2 and 1152.5 W/m^2, respectively in July. While minimum values of power density are found 26.6, 56.5 and 71.3 W/m^2 respectively, in December. Table 5. illustrates the yearly average wind power and energy density of site for three heights. A classification [20] indicates the wind characteristics and evaluations as followings:

$\bar{P}/A < 100\ w/m^2$ is low

$\bar{P}/A \approx 400\ w/m^2$ is good

$\bar{P}/A > 700\ w/m^2$ is great

Lootak site has a relatively good situation at 30 m and 40 m elevations according to above classification of power density.

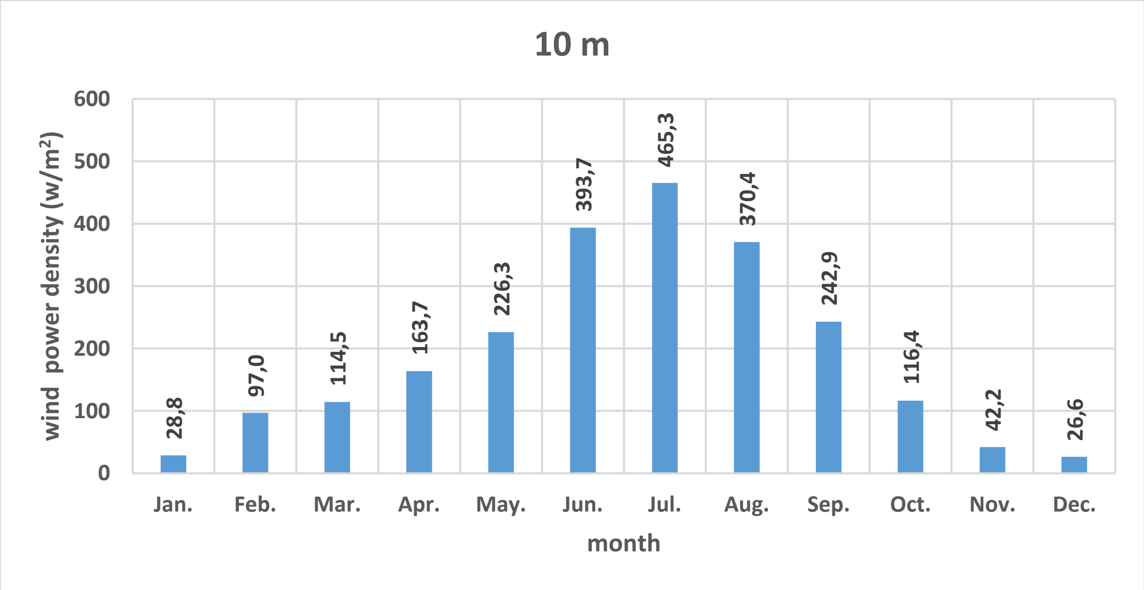

Fig. 8. Monthly wind power density at 10 m

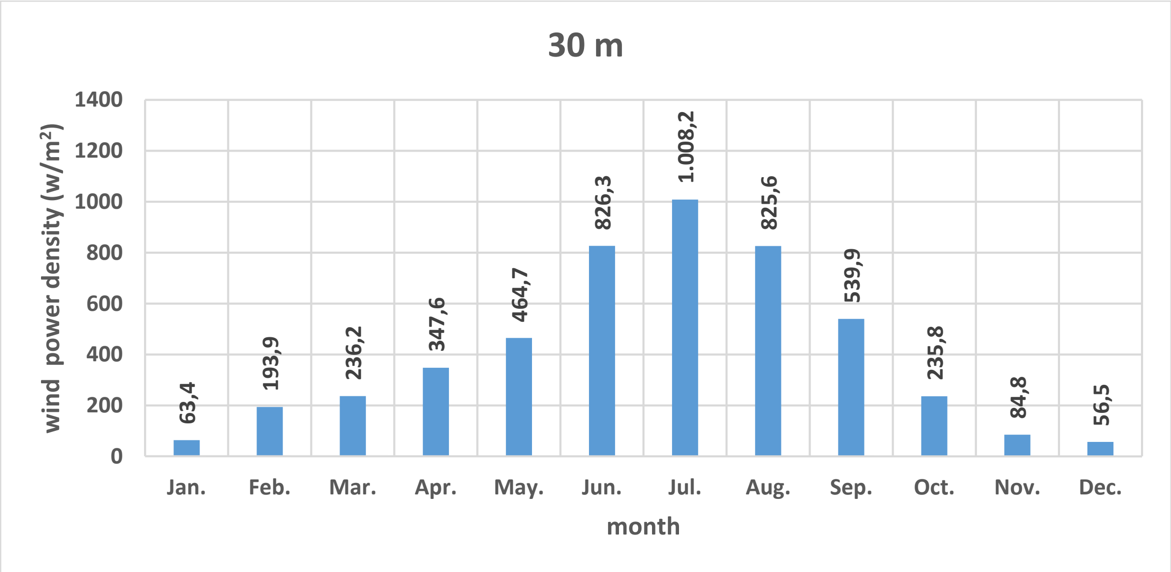

Fig. 9. Monthly wind power density at 30 m

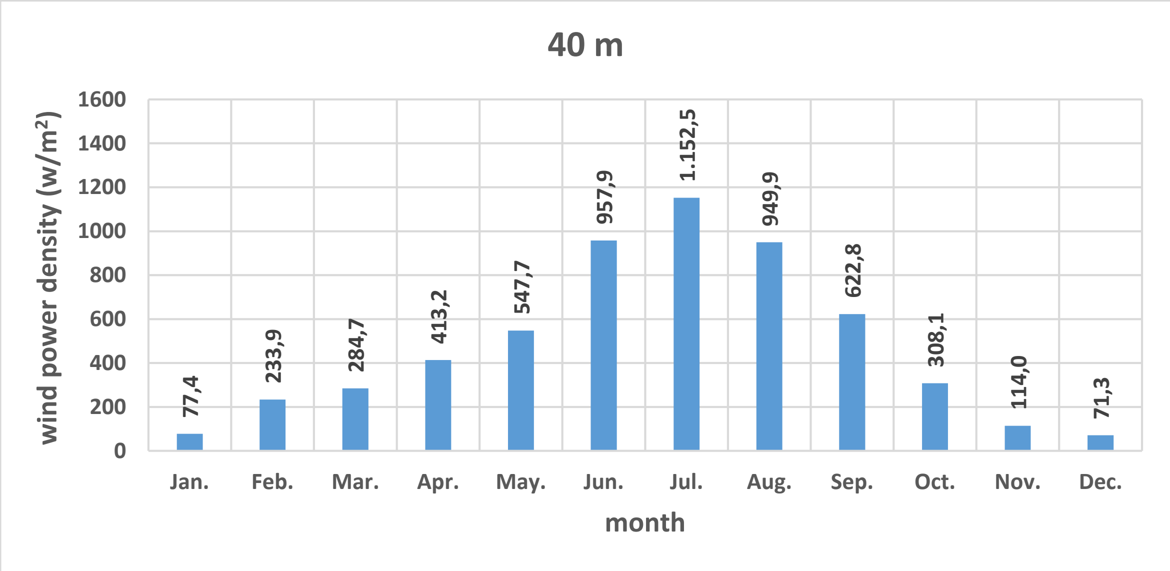

Fig. 10. Monthly wind power density at 40 m

Table 5. Yearly average wind powers and energy densities

Height	**10 m**		**30 m**		**40 m**	
Year	P/A (W/m^2)	E/A ($kWh/m^2/year$)	P/A (W/m^2)	E/A ($kWh/m^2/year$)	P/A (W/m^2)	E/A ($kWh/m^2/year$)
2007	194.49	1703.694	409.10	3583.723	488.99	4283.577
2008	215.71	1889.593	464.61	4070.017	539.73	4728.033
2009	161.72	1416.669	347.02	3039.927	404.61	3544.367
Whole year	190.64	1669.99	406.91	3564.56	477.78	4185.33

4. Estimation of Capacity Factor

Wind turbines can't produce power at all time of year due to periodic behavior of wind flow. Capacity factor is a parameter which considers stop times and times that there isn't any power generation for calculating actual power production of wind turbine. In general, amount of capacity factor can be determined by division of actual power output of wind turbine in a specific time (e.g. a year) on ideal power output of wind turbine when it operates in all times. Actually, wind turbine capacity factor is very sensitive to the average wind speed. Wind power generation (G) during period (T) is calculated from [22]:

$$G = T\int_0^{\infty} P(v).f(v)dv \qquad (10)$$

where P(v) is power curve function of wind turbine and f(v) is probability density function of wind flow. Both of them are function of wind speed v. The designed maximum wind turbine generation (G_R) based on an assumption that wind turbine constantly operates at the rated power (P_{rated}) for a specific time (T) is given by following function:

$$G_R = P_{rated}.T \qquad (11)$$

Rated power production of wind turbine can be expressed as following:

$$P_{rated} = 0.5\rho A C_P \eta_{mech}\eta_{ele}V_R^3 \qquad (12)$$

where, ρ is the air density with amount of 1.225 kg/m^3; A is swept area; C_p is coefficient of power; η_{mech} is mechanical system efficiency; η_{ele} is electrical system efficiency; V_R is rated speed. Therefore, capacity factor (CF) can be defined as:

$$CF = G/G_R \qquad (13)$$

Adopting the Weibull probability distribution f(v) for wind speed v, capacity factor in Eq. (13) is read as:

$$CF = (1/V_R^3)\int_{V_C}^{V_R} v^3.f(v)dv + \int_{V_R}^{V_F} f(v)dv \qquad (14)$$

By description and substituted of two equations including Gamma, $\Gamma(a) = \int_0^{\infty} t^{a-1}\varepsilon^{-t}dt$, and incomplete Gamma,$\gamma(u,a) = (1/\Gamma(a))\int_0^{u} t^{a-1}\varepsilon^{-t}dt$ in Eq. (14), it can be changed as following [22]:

$$CF = (V_C/V_R)p^3\varepsilon^{-(V_C/C)}[3\Gamma(3/k)/k(V_R/c)^3].[\gamma((V_R/c)^k,3/k) - \gamma((V_C/c),3/\,k)]\varepsilon^{-(V_F/c)^k} \qquad (15)$$

where V_C , V_R and V_F are cut-in, rated and cut-out wind speed of wind turbine in m/s, respectively; Γ is Gamma function and γ is incomplete Gamma function.

Based on our statistical calculations, five different horizontal axis wind turbines were selected at 40 m tower height to calculate the amount of the monthly capacity factor variation. The wind turbines characteristics are shown in Table 6. [23-26]. Figures 11 and 12 show the monthly capacity factor variation and the annual capacity factor at altitude of 40 m for five various wind turbines of Table 6, respectively. It can be found from Figure 11 that the turbine AWE52/900 has maximum capacity factor and the turbine V47/660 has the minimum one in each months. A reasonable capacity factor would be in the range of 0.25–0.30 and a very good capacity factor would be around 0.40 [22]. Furthermore, as can be seen from Figure 12, the AWE52/900 and D4/48 wind turbines have the highest annual capacity factor with values of 0.384 and 0.364, respectively.

Table 6. Wind turbine data for altitude of 40 m [23-26]

Wind Machine	Rated Power (kW)	Rotor Diameter (m)	Hub Height (m)	Cut-in Speed (m/s)	Cut-out Speed (m/s)	Rated Speed (m/s)
WESPA750/47	750	47	40-65	4	25	14.5
V47/660	660	47	40-55	4	25	15
D4/48	600	48	40-70	3	22	11.5
HW43/600	600	43	38.5-48.5	3.8	14.5	25
AWE52/900	900	52	40	2	25	11.5

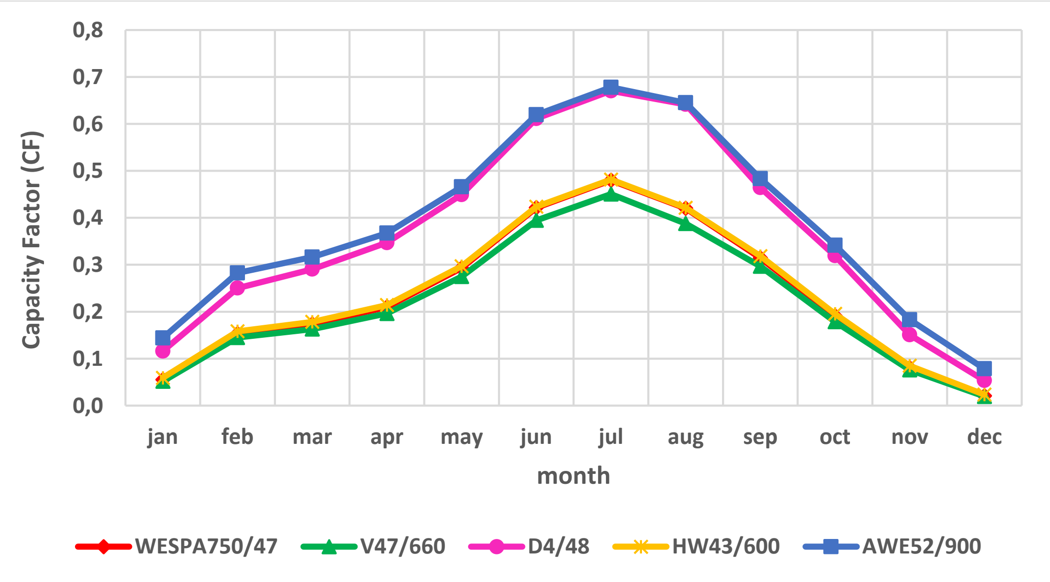

Figure 11. Monthly capacity factor at 40 m height for five wind turbines of Table 6.

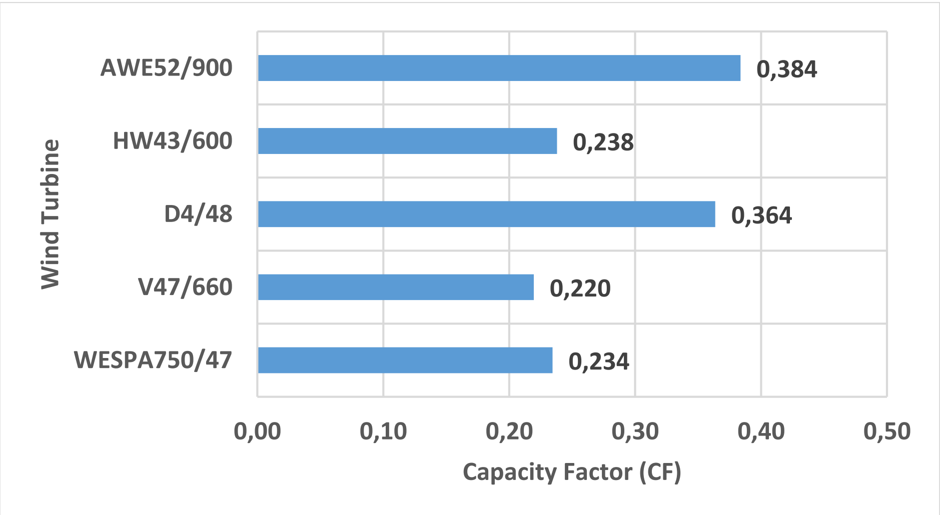

Fig. 12. Annual capacity factor at 40 m height for five wind turbines of Table 6.

5. Conclusion

In current study, the measurement data of wind flow of Lootak-Zabol station for three consecutive years at three different elevations are statistically evaluated to specify potential of wind energy in this region. Maximum wind power density for 10, 30 and 40 m altitude are obtained 465.3, 1008.2 and 1152.5 W/m^2 in July, respectively while minimum wind power density are estimated 26.6, 56.5 and 71.3 W/m^2 in December, respectively. According to amount of mean wind power and energy density, it is found that this area is a suitable location to install large-scale wind turbine. Moreover, status of wind power density at both elevations of 30 and 40 m cause good conditions for wind turbine usage to generate power.

Furthermore, the monthly and annual capacity factor variations for five different horizontal axis wind turbines are compared. The highest annual capacity factor with values of 0.384 and 0.364 were determined for the AWE52/900 and D4/48 wind turbines, respectively. These wind turbines are proposed to be installed in the Lootak area.

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