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Wind Data Analysis of Coastal Region of Balochistan (Pakistan) by Weibull and Rayleigh Method

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Abstract

Objectives: To analyze wind data to examine the prospect of wind energy as an alternative source of energy to overcome the lack of fuel and power supply in the coastal belt of Balochistan which is the largest province of Pakistan in terms of area. **Methods/Statistical Analysis:** For our studies we have selected four sites of coastal region of Balochistan (Gwadar, Pasni, Jiwani and Ormara) and taken data for these selected sites from Pakistan Metrological Department for a period of five years (2010–2014) we have done the statistical analysis of wind data by Weibull and Rayleigh probability distribution. **Findings**: Weibull and Rayleigh distribution functions have been derived from the available wind data, its parameters are estimated. The annual cycle of Weibull functions is fitted on yearly basis; it is found that the Weibull distribution that is fitting to the measured yearly probability distributions is better and suitable than the Rayleigh distribution for the five years period (2010–2014). **Application/Improvements:** From the result derived it is suggested that selected observations of coastal belt have good wind potential and as wind energy makes economic sense it will cover the issues like lack of fuel risk and will provide regional economic development to overcome the lack of power facilities in the province.

Keywords: Balochistan, Coastal Region, Rayleigh Method, Weibull Method, Wind Data Analysis

1. Introduction

Wind is originated by inconsistent heating of sun on the surface of the earth. It is one of the most important sources of renewable energy. Wind plays a significant role in determining and controlling climate and weather on our globe. The actual status of the wind is like a naturally replenished source of energy direct from the sun and this clean and rich renewable energy resource is used to produce electricity and for many other purposes. The uses of wind energy are clearly increasing and could become a source to produce electricity, as wind is widely available in many parts of the world and in almost every continent significant resource are found. It has been found

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through research that five countries, namely China, USA, Germany, Spain and India, together represents a total share of of the global wind capacity and are the global leaders in wind energy generation. Prospects for end of the year of wind cover almost of the worldwide electricity demand. Many other countries have also introduced new and ambitious legislation for wind power[1].

In the development of wind energy prospects Pakistan is also playing an important role. Pakistan has the potential to produce up to of electricity through wind energy alone, provided we utilize the God gifted wind energy potential and more companies should take initiative to start their work on building the wind energy projects in the country. According to World Energy Statistics, published by IEA, Pakistan's per capita electricity consumption is one-sixth of the World Average. World average per capita electricity Consumption is compared to Pakistan's per capita electricity consumption of. Forty percent of Pakistanis still have no access to electricity[2].

As we know that a continual supply of reasonably strong wind is necessary requirement for utilizing the power in the wind. Development of wind energy depends upon a clear understanding of wind resources, site location, turbine performance and physical effects of turbulence and energy extraction. Generally, the coastal belts are considered favorable for the reliable and the consistent wind resources. Pakistan has evidently tremendous wind potential by considering the geological and geomorphologic setups, climatic cycles and geographical position[3]. The theoretical and technical potential of available wind data of the coastal areas of Baluchistan are estimated by considering population density and excluding low wind areas[4]. Beside this Pakistan Meteorological department plays an important role by expanding the network of regular meteorological stations all over the country which provide recorded wind data for research purposes. Many probability functions were fitted with the field data to categorize appropriate statistical distributions for representing wind regimes, but the Weibull and Rayleigh distributions are considered more suitable with an acceptable accuracy level and can be used to describe the wind variations in a regime. The statistical analysis of wind data is done by Weibull and Rayleigh probability distribution, as Weibull density function method is considered as a standard approach and is generally accepted for evaluating local wind load probabilities[5–7]. This method has a great agility and simplicity. However, the main limitation of the Weibull density function is its incapability to calculate the probabilities of observing zero or very low wind velocities accurately[8].

2. Methodology

As we know that wind is continuously changing with respect to time and space, in this regard it is desirable to find the wind speed by statistical methods. In this paper we have done the statistical analysis of wind data by Weibull and Rayleigh probability distribution, as Weibull density function method is considered as a standard approach and is generally accepted for evaluating local wind load probabilities. The wind data is statistically analyzed by selecting four locations of coastal belt (Gwadar, Pasni, Jiwani and Ormara) of Balochistan, for a period of five years from 2010–2014. A brief discription of the wind data as a statistical model by means of Weibull and Rayleigh probablity distribution are discussed below;

For continuous random variable *'v'* has a Weibull distribution, with parameter& of its density function is given by [9]

$$f(v) = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1} e^{-\left(\frac{v}{c}\right)^{k}} \tag{1}$$

The cumulative Weibull distribution function is defined by an equation;

$$F(v) = 1 - e^{-\left(\frac{v}{c}\right)^{k}} \tag{2}$$

Weibull distribution is used for analysing the wind regime therefore its parameters can be determined by various methods but most frequent and simple method for acceptable approximation of *'k'* is

$$k = \left(\frac{\sigma}{\bar{v}}\right)^{-1.086} \tag{3}$$

Over the range 1≤ k≤ 10 , when 'k' is found then

$$c = \frac{\bar{v}}{\Gamma\left(1 + {}^{1}/_{k}\right)} \quad (4)$$

This method of evaluating the parameters 'k' & 'c' is called standard deviation method[10].

The Rayleigh distribution is also continuous probability distribution for finding the variation in wind velocity over a given period of time. It is the simplified form of Weibull distribution by taking 'k' as 2 (shape parameter). A continuous random variable 'v' has its probability density function of Rayleigh distribution and mathematically written as

$$f(v) = \frac{\pi v_i}{2\bar{v}} exp[-\frac{\pi}{4}\left(\frac{v_i}{\bar{v}}\right)^2] \quad (5)$$

Here $\bar{v}$ is the mean wind velocityand its cumulative distribution function is represented as

$$F(v) = 1 - exp[-\frac{\pi}{4}\left(\frac{v_i}{\bar{v}}\right)^2] \quad (6)$$

The probability density function and cumulative distribution of wind using Rayleigh probability distribution is standardize on the basis of its wind velocity[11].

Under the conditions, when simplified case of Weibull distribution is derived by approximating k is equal to 2 then average wind speed is given by

$$\bar{v} = c\,\Gamma(3/2) \quad (7)$$

All desired Computations are performed by using MS Excel program; derived results are presented in next section with related discussion.

3. Results and Discussions

Probability distribution of wind speed is described by fitting the measured wind speed probability distributions to Weibull, Rayleigh functions.

Table 1. Values of 'k' and 'c' for Weibull distribution evaluation (Gwadar)

Gwadar										
Years	**2010**		**2011**		**2012**		**2013**		**2014**	
Months	**K**	**c**	**k**	**c**	**k**	**c**	**k**	**c**	**k**	**c**
Jan	3.49	3.37	3.89	3.04	5.85	3.99	2.78	3.11	3.92	3.84
Feb	4.75	4.01	4.68	3.78	4.59	3.84	2.74	3.25	4.18	4.01
Mar	5.7	4.27	3.98	3.61	8.15	4.27	4.3	3.84	3.27	3.09
Apr	4.66	3.98	5.36	4.5	9.45	4.02	5.91	3.97	7.12	4.43
May	8.25	4.89	6.49	4.41	6.56	4.97	5.57	4.11	4.84	4.07
June	8.84	4.19	6.30	4.23	9.08	4.07	6.53	4.18	7.76	7.78
July	7.25	3.78	3.75	3.49	8.35	4.09	6.29	3.84	4.55	3.88

Table 1 Continued

Aug	7.81	3.62	4.61	3.79	4.02	3.83	6.80	3.76	9.34	4.31
Sep	5.93	3.65	4.0	3.49	7.96	3.74	5.81	4.07	7.2	3.68
Oct	5.36	3.59	5.42	4.03	5.74	3.89	5.28	3.6	5.67	3.50
Nov	5.72	3.36	3.99	3.76	4.38	3.75	5.76	3.67	5.9	3.29
Dec	5.47	3.50	5.38	4.14	5.29	3.97	5.36	3.86	5.28	3.85

Table 2. Value of ' k' and 'c' for Weibull distribution evaluation (Pasni)

Pasni										
Years	**2010**		**2011**		**2012**		**2013**		**2014**	
Months										
Jan	3.59	3.53	5.67	5.01	6.75	5.28	5.92	5.49	6.16	5.39
Feb	4.03	4.11	7.17	5.44	6.82	6.08	5.10	5.66	8.99	6.06
Mar	3.73	4.04	5.34	5.54	7.46	5.97	5.16	6.01	7.41	6.33
Apr	5.84	4.11	7.08	5.29	5.28	6.54	7.48	5.57	6.32	6.75
May	5.97	4.95	6.16	5.34	7.08	6.47	6.62	6.36	7.83	6.29
June	4.35	5.62	6.50	5.96	6.87	6.56	6.44	6.86	9.04	7.30
July	4.53	5.82	5.51	6.15	8.00	6.49	6.76	6.84	8.35	6.28
Aug	5.69	5.69	3.24	5.18	6.41	6.29	5.40	6.20	6.88	6.26
Sep	5.52	4.91	3.41	4.0	6.28	6.95	6.80	6.07	7.31	6.26
Oct	4.19	5.27	4.56	6.42	4.38	6.07	9.82	5.81	4.51	6.22
Nov	4.52	5.60	8.96	5.34	5.11	6.16	8.23	5.68	9.46	6.34
Dec	3.94	4.99	4.79	6.05	7.44	6.29	8.79	5.92	8.89	6.35

Table 3. Value of ‘ k’ and ‘c’ for Weibull distribution evaluation (Jiwani)

Jiwani										
Years	**2010**		**2011**		**2012**		**2013**		**2014**	
Months	**K**	**c**	**k**	**c**	**k**	**c**	**k**	**c**	**k**	**C**
Jan	3.17	3.17	3.86	3.95	3.79	3.59	3.28	3.27	4.08	3.92
Feb	3.67	3.73	4.27	5.44	3.97	4.3	4.59	4.13	5.43	4.41
Mar	1.99	3.72	7.47	4.26	4.79	4.43	4.48	4.49	2.5	4.01
Apr	5.1	4.07	4.2	4.01	3.36	4.13	4.94	4.71	4.67	4.75
May	3.94	4.24	6.63	4.24	4.81	4.81	5.42	5.08	4.75	4.86
June	3.89	4.63	5.44	4.49	4.71	4.57	4.86	4.86	4.84	4.85
July	4.74	4.61	3.98	5.16	4.19	4.46	4.87	4.74	5.92	4.77
Aug	4.26	4.53	5.14	4.37	4.35	4.95	5.59	4.58	5.31	4.99
Sep	4.9	4.12	3.51	4.05	3.84	4.08	4.6	4.7	2.25	2.59
Oct	4.76	4.31	5.23	4.79	5.31	4.01	5.16	5.6	5.49	4.14
Nov	4.32	4.29	5.14	4.69	4.52	4.29	4.07	4.39	5.23	4.14
Dec	4.67	4.33	4.22	4.28	2.77	4.47	4.51	4.23	4.56	4.36

As discussed earlier that Weibull and Rayleigh Probability distributions are very suitable for approximating wind regime, so it is most preferably calculated for analysis of wind speed data. The obtained results of c & k on monthly basis for evaluating Weibull Probability distribution for the period at four different coastal belt locations are given in Tables 1–3.

The Weibull shape parameter ‘k’ is also known as the Weibull slope. This is because the value of k is equal to the slope of the line in a probability plot the shape parameter can have clear effects on the behavior of the distribution. Basically, the scale parameter, *c*, indicates how ‘windy’ a wind site under consideration is, whereas the shape parameter, *k*, indicates how peaked the wind distribution is (that is, the wind speeds tend to be very close to a certain value, the distribution will have a high value and be very peaked). Here we see that at four different sites of coastal belt the value of is low in winter as compare to other seasons. The values of scale parameter indicate nearly small pattern in five years period. The Weibull parameters calculated analytically from the available data are presented in Table 4. As shown, the shape parameter ranges from 2.74 (Feb-2013) to (April) for the data analyzed in Gwadar, while the scale parameter varies between 3.04 (Jan 2007) to 7.78 m/s (June 2014), similarly if we observe in other locations like in Pasni the shape parameter ranges from 3.41 (Sep 2011) to 9.82 m/s (Oct 2013), while the scale parameter varies between 3.53

Table 4. Value of ‘ k’ and ‘c’ for Weibull distribution evaluation (Ormara)

Ormara										
Years	**2010**		**2011**		**2012**		**2013**		**2014**	
Months										
Jan	3.59	3.54	4.53	4.75	6.06	4.52	6.16	4.56	5.44	4.55
Feb	4.03	4.12	6.72	5.31	6.04	5.15	7.05	4.95	5.07	4.73
Mar	3.37	4.04	5.18	5.32	6.51	5.13	7.48	5.22	4.94	6.09
Apr	5.86	4.11	6.65	5.35	4.65	5.36	7.11	5.58	6.09	6.11
May	5.97	4.95	6.36	5.32	8.73	6.08	6.26	5.58	6.66	5.42
June	4.34	5.62	5.75	5.86	7.97	6.11	7.64	6.15	7.01	7.49
July	4.52	5.82	6.58	5.98	7.76	5.66	8.07	5.89	5.33	5.35
Aug	6.69	5.69	3.60	5.18	5.74	4.99	5.94	5.65	8.96	5.16
Sep	5.58	4.93	6.38	4.49	5.07	5.73	7.59	5.41	5.89	5.52
Oct	4.19	5.32	4.71	5.85	5.45	5.11	8.46	5.55	5.21	5.15
Nov	4.52	5.59	9.89	5.10	4.86	5.41	6.21	5.42	6.13	5.23
Dec	3.94	4.99	7.63	4.91	6.40	5.61	7.45	5.37	7.15	5.43

(Jan 2006) to 7.30 m/s (June 2014), In Jiwani the shape parameter ranges from 2.25 (Sep 2014) to 7.47 m/s (Mar 2011), while the scale parameter varies between 2.59 (Sep 2014) to 5.60 m/s (Oct 2013) and in Ormara it is examined that the shape parameter ranges from 3.37 (Mar 2010) to 9.89m/s (Nov 2011), while the scale parameter varies between 3.54 (Jan 2010) to 7.49 m/s (June 2014). It is clear that the parameter 'c' has a smaller variation than that of the parameter 'k'. Similarly, necessary calculations are done by dealing with Rayleigh probability distribution.

The difference of wind speed is normally described by using the Weibull two-parameter density function. The yearly probability density and the cumulative distributions derived from the wind data of four selected locations for the period of five years. In order to observe the Weibull distribution of coastal belt, the Weibull probability density distributions for each of the five years were analyzed. It can be seen that the distribution is similar for a five years period and represents a narrow peak at a wind speed of about 3.5 m/s in Gwadar. The Rayleigh probability density distribution of wind speeds for the five years are calculated and a comparison of the two approximations that is Weibull and Rayleigh distribution is done. It is clear that probability density function of Weibull distribution is dissimilar from that of obtained from Raleigh distribution, similarly, the case for cumulative distribution function. Rayleigh distribution requires more data points to fit as compare to Weibull distribution[12,13].

4. Conclusion

By using statistical techniques on wind data at the four locations of Balochistan belt, it is concluded that the wind data collected from the selected meteorological observatories can be reasonably well described by Weibull density function if the total time of recording is not too short.

The Weibull distribution parameters k & c indicates good wind pattern during the five years observed at four sites of coastal belt of Balochistan under the range . Since the nature of wind incessantly change, this makes it desirable to describe wind speed by statistical methods.

The statistical analysis of wind obtained is likely to serve as a legalization test for wind energy applications, in general along the coastline of Balochistan. From the result derived it is suggested that selected observations of coastal belt have good wind potential and as wind energy makes economic sense it will cover the issues from lack of fuel risk to the costs of wind energy, and provides regional economic development to overcome the lack of power facilities in the province.

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