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Research Article

Wind Speed Analysis of Some Coastal Areas near Karachi

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Abstract: This communication attempts to analyze Karachi coastal area (Paradise Point 24.84º E, 66.77º N)) for an understanding of underlying probability distribution. It has been found that at this site the annual wind speed at a height of 30 meters remains very close to 7 m/s whereas at a height of 61 meters the wind speed reaches to 9 m/s. Moreover, the wind mostly remains directed towards southwest. Furthermore, the annual average wind speed follows Weibull distribution and the annual average wind speed goes on increasing with the passage of time. Maximum energy together with the energy density for different values of the wind mill blade diameters is also calculated. Our analysis shows that the wind speed is increasing as a consequence of global climate change. Though the global climate change has created many threats to the humanity by influencing the local urban microclimate but the positive aspect of this finding is that the increase in wind speed will increase the feasibility and economic viability of the construction of wind farms near Karachi coast and offshore. Of course these calculations will be useful for urban and energy planners.

Keywords: Global warming, Karachi Nuclear Power Complex (KNPC), maximum likelihood (ML), cumulative distribution function (cdf)

1. INTRODUCTION

Probable effects of the link between human induced global warming and climate change is not yet fully understood [1]. However, in [2] it is shown that in addition to its other consequences the global climate change has influenced the local urban microclimate adversely. For example is the case of ozone layer depletion. Like the rest of the world it has statistically significant impacts on Arabian Sea and the Pakistan air space [3]. Global warming is also found responsible for the expansion of the seawater volume. Significant links of eleven years sun spots cycles with climatic phenomena particularly with ozone layer depletion over arctic region have also been detected [4]. Moreover, the frequency of occurrence of high magnitude earthquake is affecting the magnetic field around the earth which in turn is accelerating global warming rate [5]. Persistency analysis performed on 120 years Arabian Sea cyclone data also shows a positive trend in cyclone frequency [6]. The significant impact of global climate change has been observed in North America, East Asia and the Caribbean [7-10] also.

We know that wind power is a clean, renewable source of energy, which produces no greenhouse gases. Wind power thus appearing a CO_2 free source for energy generation. Current estimates show that one modern wind turbine can save over 4,000 metric ton of CO_2 emissions annually. It also reveals that present wind turbine is designed to operate for more than 20 years, produces electricity for 70 – 85 % of the time (depending on available wind speed), and at the end of its working life, the area can be restored at minimum financial costs. Wind energy is a form of development, which is reversible – in contrast to conventional power stations [11].

Pakistan coast is about 1120 km long [12]. In most parts of our country the wind speed is relatively

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low. However, there are various places where wind power can be effectively generated. The potential areas for the installation of windmills are coastal areas and some hilly regions in the country [13]. This paper analyses the wind data collected at heights of 10, 30 and 61 meters at Karachi Nuclear Power Complex (KNPC), near Paradise Point, Karachi. Preliminary analyses show that the wind resource fluctuates greatly depending on the season, which suggests that using it as the sole source of energy would likely be impractical. The best estimate of wind power potential can be made with the help of long-term wind record at the site where the turbines are to be installed, but unfortunately this information is rarely available. However, a dataset of two hours average wind speed for one year (1995) reveal that the annual mean wind speed in the vicinity of KNPC is about 7 m/s. Hourly averaged data (collected in 2002 and 2003) at height of 61 meters, also show that the wind speed remains close to 9 m/s. This communication attempts to estimate the wind speeds in the last decade at the coast of Karachi, taking Paradise Point as a case study. It uses Weibull distribution as the underlying distribution of wind data as revealed by Histograms of wind data. It also tries to estimate the wind energy potential at this site. The wind data and modeling is performed in Section 2.1. Details of assessment procedure and mathematical descriptions are provided in Section 3. Section 4 depicts important outcomes of the analysis performed in the previous section. Finally, Section 5 concludes the paper.

2. MATERIAL AND METHODS

Wind Data analysis is performed with the help of Weibull Distribution parameters. Weibull Distribution parameters are estimated with the help of Direct Method of Parameters Estimation and Maximum Likelihood Estimation method. Matlab is used for performing the calculation. Histogram is used to confirm the analysis regarding wind speed and frequency. Rose Diagrams are used to study the wind direction profile.

2.1 Wind Data and Analysis Approach

As discussed in the introduction, the wind speed measurements were made at KNPC meteorological tower, at the heights of 10, 30 and 61 meters. The site of the measurements is located very close to the Paradise Point coast of Karachi. The results from the full year analysis are used as the base for energy production estimates. As for as the wind direction is concerned, we can say that wind at KNPC site mostly blows in the southwest direction (see Fig. 1). However, in the months of October, November, December, January, February and March, the wind directions show high degree of fluctuations and direction of wind seems to cover 220 to 330 degrees as depicted in Fig. 2.

3. ESTIMATION OF WEIBULL DISTRIBUTION PARAMETERS

Before going into the details of distribution parameters estimation techniques, we briefly outline the data analysis approach adopted in this paper. Wei bull probability distribution appropriately models coastal wind data of Karachi, Sindh [14]. Histograms (see Figs. 3-5) also reveal that Wei bull probability distribution is adequate for the modeling of Karachi coast wind data. The Weibull distribution function has two parameters: the shape factor (β) and the scale factor (η). We obtain these parameters using two different parameter estimation methods (direct and maximum likelihood estimation). After estimating the Weibull distribution parameters, we compute the site average wind speeds. To calculate the available energy and wind power density at the site we use the Weibull parameters, estimated using the maximum likelihood (ML) function as this method gives more precise results [15]. Then, we calculate the maximum energy and the energy density, in kWh/m^2, that can be produced or extracted by a wind turbine at the site.

The Weibull probability density function (pdf) is defined as follows:

$$f(x) = \frac{\beta}{\eta}\left(\frac{x}{\eta}\right)^{\beta-1} e^{-\left(\frac{x}{\eta}\right)^{\beta}}, \quad x \geq 0, \beta > 1, \eta > 0 \tag{2.1}$$

The parameter β is known as the shape factor, and the parameter η is known as the scale factor. In wind probability analysis, the variable x is

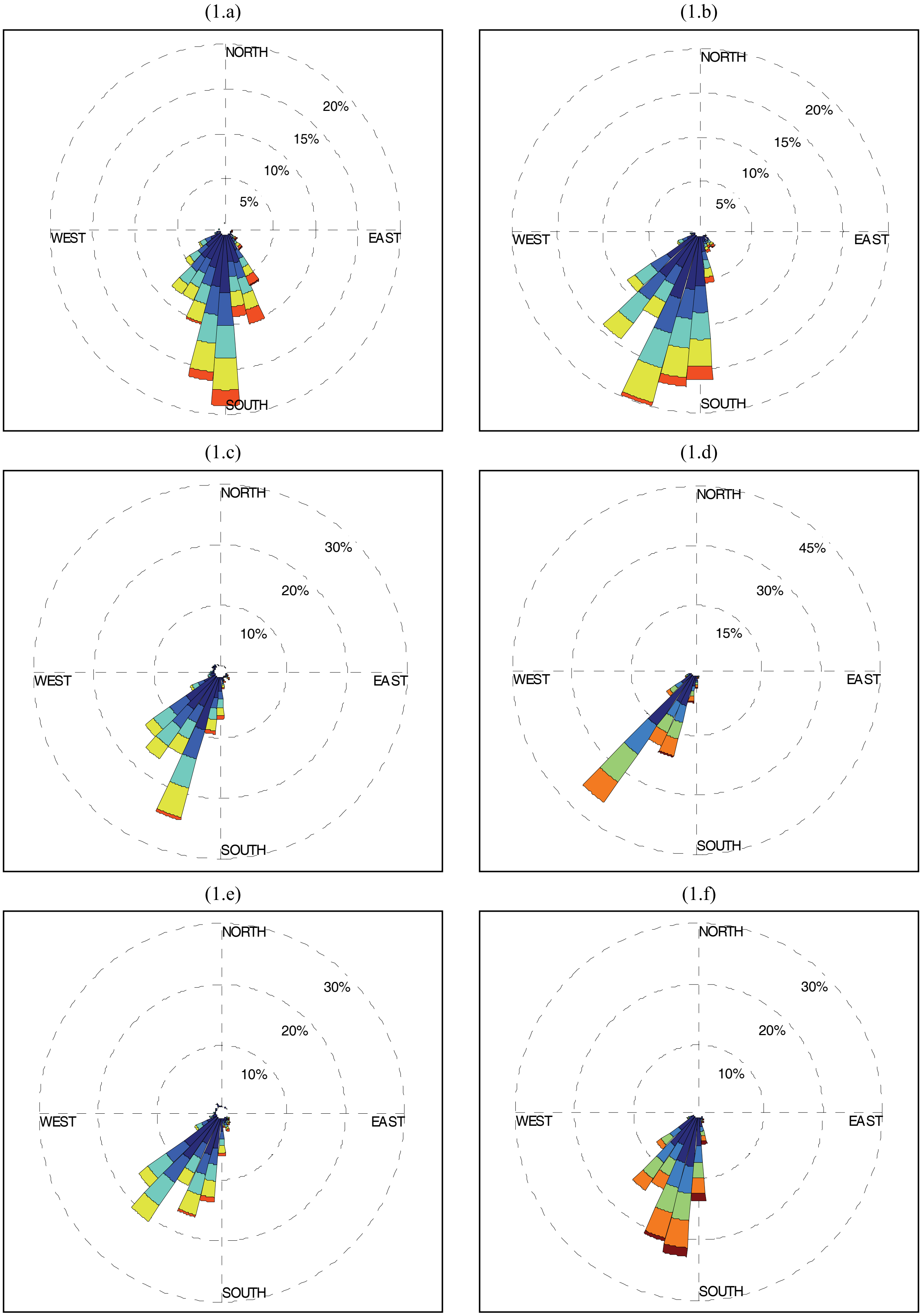

Fig. 1 (a-f). Wind rose diagrams for the months from April to September 2002.

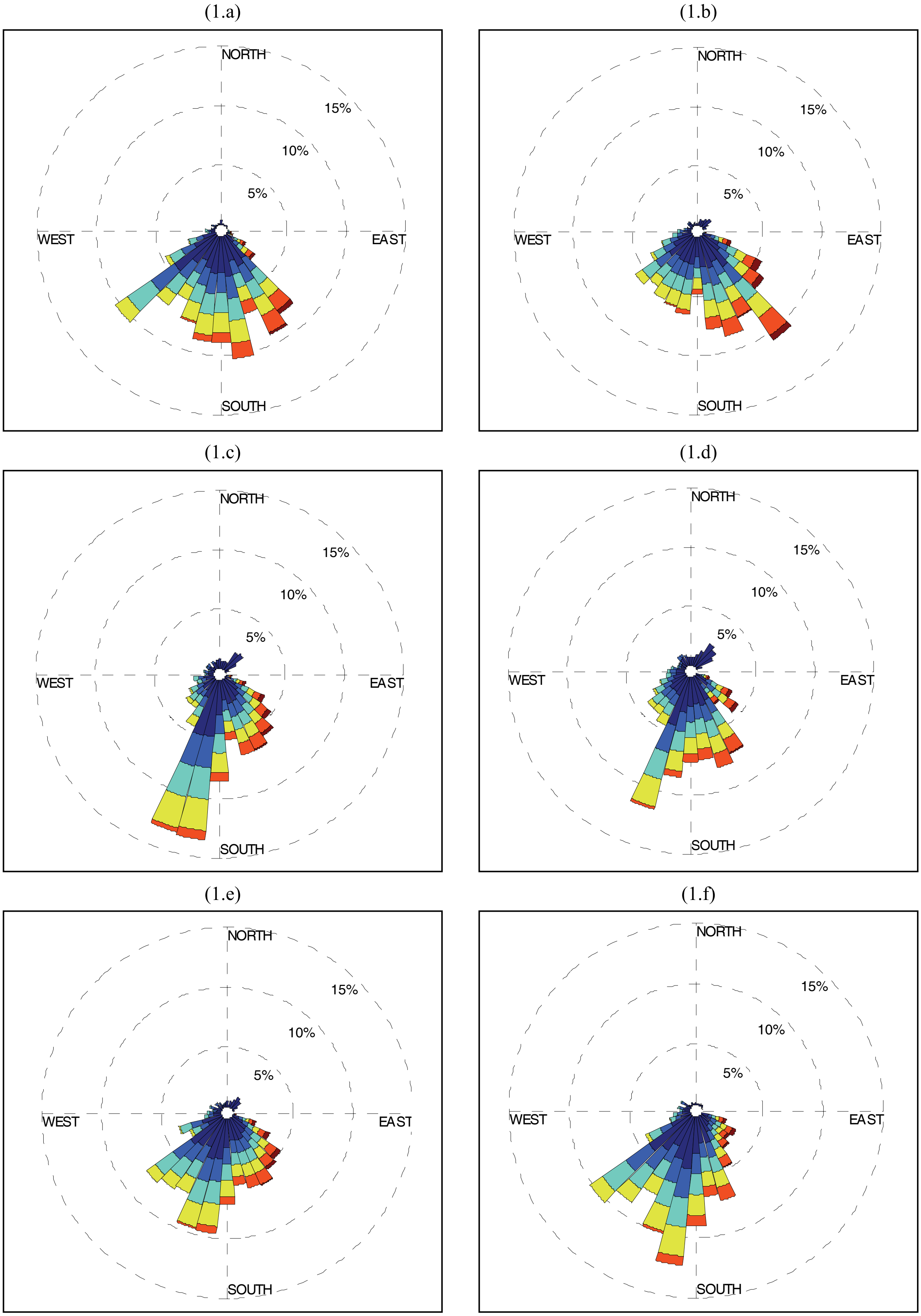

Fig. 2 (a-f). Wind rose diagrams for the months from Oct to Dec, 2002, and from Jan to March 2003.

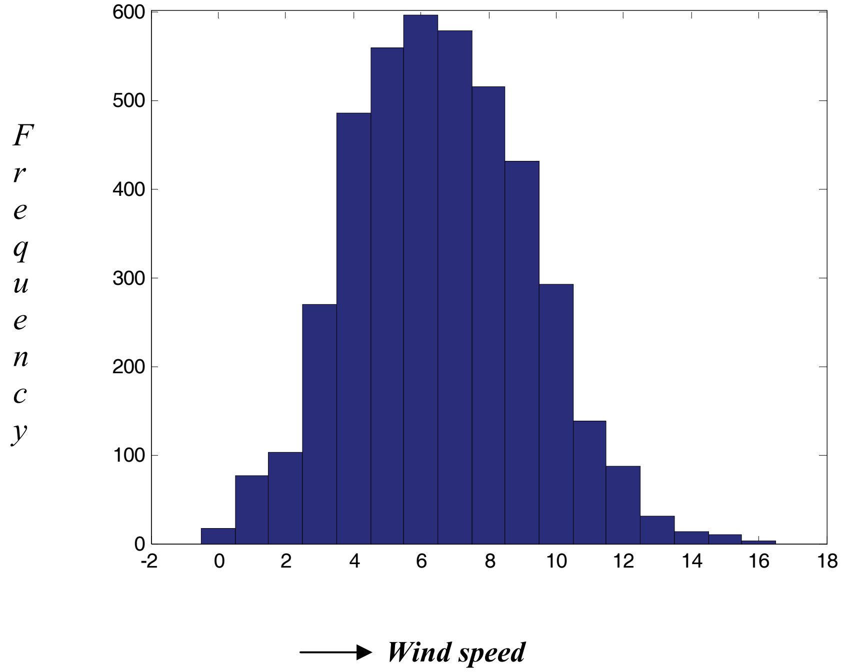

Fig. 3. Annual wind speed data (taken at 30 meters height) histogram for the year 1995. Two hourly data gives a wind velocity of 6.7 m/s.

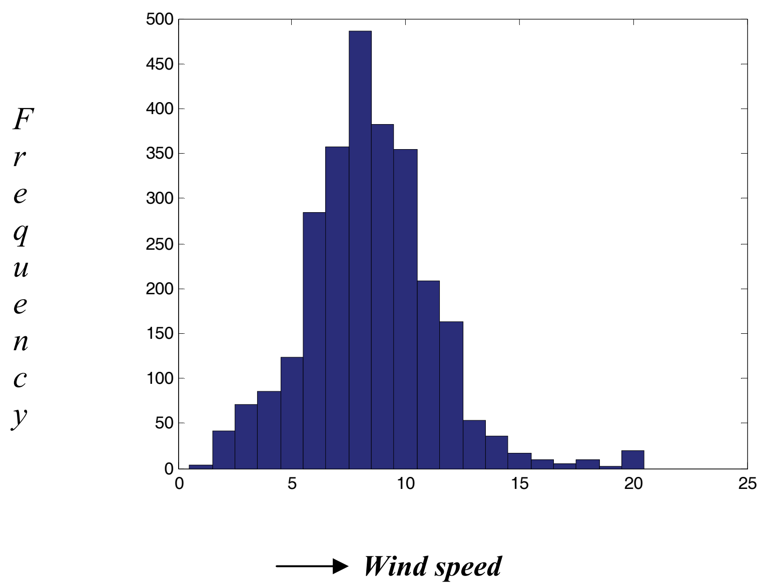

Fig 4. Annual wind speed data (taken at 61 meters height) histogram for the year 2002.

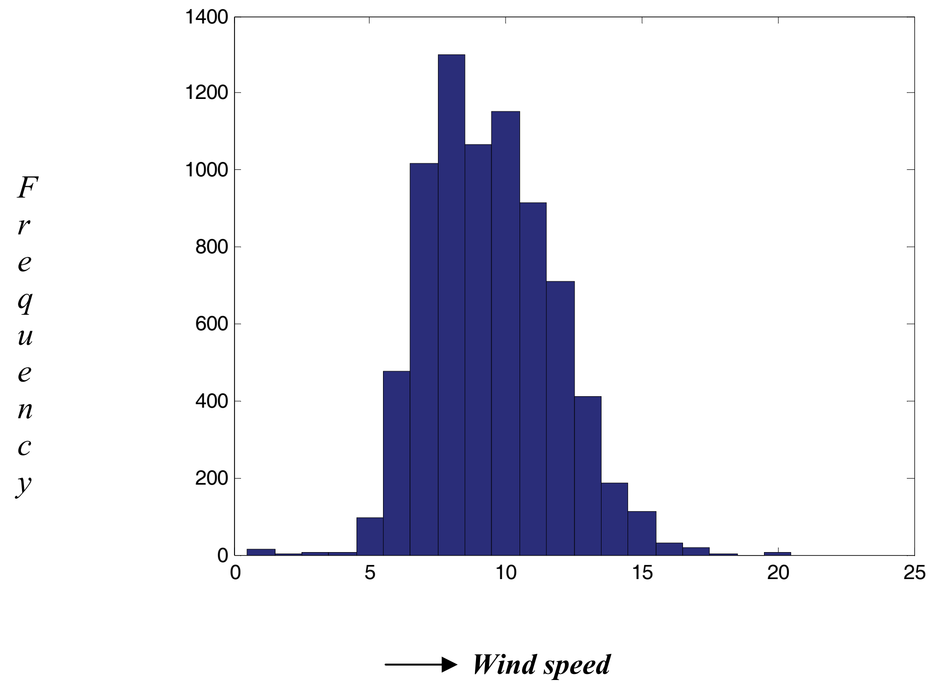

Fig. 5. Annual wind speed data (hourly averaged taken at 61 meters height) histogram for the year 2003.

replaced by the wind speeds v. A Weibull pdf with a shape factor bigger than one reflects the shape of a bell. The scale factor defines that where the bulk of the distribution lies and how stretched out the distribution is. The cumulative distribution function (cdf) of (2.1) is obtained by the integration of pdf, as shown by (2.2),

$$F(x) = 1 - e^{-\left(\frac{x}{\eta}\right)^{\beta}}, \quad x \geq 0,\ \beta > 1,\ \eta > 0 \tag{2.2}$$

In wind engineering, the shape factor is referred to as k parameter, whereas scale factor is known as c parameter (also known as velocity parameter). Shape factor gives the wind characteristic at a location as shown in Table 1.

Table 1. Typical shape factor values.

Type of Winds	Shape Factor (k)
Inland winds	1.5 to 2.5
Coastal winds	2.5 to 3.5
Trade winds	3 to 4

Inland winds represent the winds at inland locations. Similarly, coastal winds are present at coastal locations of the area under study. The trade winds (also called trades) are the prevailing pattern of easterly surface winds found in the tropics near the Earth's equator. The trade winds blow predominantly from the northeast in the Northern Hemisphere and from the southeast in the Southern Hemisphere. Next, we define parameter estimation methods.

3.1 Direct Method of Parameters Estimation

To obtain crude estimates of shape factor, β, and scale factor, η, one can utilize the following formulae.

$$B = \left(\frac{\sigma}{\bar{v}}\right)^{-1.086} \tag{3.1}$$

where, $$\sigma = \frac{\sum_{i=1}^{N}\left(v_i - \bar{v}\right)^2}{N-1} \tag{3.2}$$

$$\bar{v} = \frac{\sum_{i=1}^{N} v_i}{N} \tag{3.3}$$

$$\frac{\bar{v}}{\Gamma\left(1+\frac{1}{\beta}\right)} \tag{3.4}$$

The above formulae, (3.1) and (3.4), in general, provide accuracy up to one decimal place. As we know that the maximum likelihood estimation (MLE) method give the most precise values of distribution parameters, therefore, these values are obtained by using MATLAB command *wblfit* (*data*), and the two values are compared.

3.2 Maximum Likelihood Estimation

This section gives some details of Weibull distribution parameters estimation by Maximum Likelihood Estimation (MLE) method. There are several techniques of Weibull distribution parameter estimation. The parameter β is calculated using the following relation:

$$B = \frac{\sum_{i=1}^{N} (\ln x_i) Y_i - \frac{\left(\sum_{i=1}^{N} \ln x_i\right)\left(\sum_{i=1}^{N} Y_i\right)}{N}}{\sum_{i=1}^{N} (\ln x_i)^2 - \frac{\left(\sum_{i=1}^{N} \ln x_i\right)^2}{N}} \quad (3.5)$$

where $Y = \ln(-\ln(1 - F(x_i))$

The parameter ***a*** given below is used to estimate η the second parameter of Weibull distribution.

$$\boldsymbol{a} = \frac{\sum_{i=1}^{N} Y_i}{N} - \beta \left(\frac{\sum_{i=1}^{N} \ln x_i}{N} \right) \quad (3.6)$$

where η is obtained by

$$\eta = e^{-\frac{a}{\beta}} \quad (3.7)$$

Table 2 summarizes the Weibull distribution parameters estimated by MLE method using MATLAB.

Table 2. Wind speed at KNPC site at 10, 30 and 61 meters.

Year	1995 (10 m)	1995 (30 m)	2002 (61 m)	2003 (61 m)
Wind Speed	5.9 m/s	6.8 m/s	8.6 m/s	9.6 m/s
Weibull pdf Parameters	$c = 6.6$	$c = 7.5$	$c = 9.6$	$c = 10.5$
	$k = 3.3$	$k = 2.3$	$k = 2.1$	$k = 2.5$

Using above values of k (shape parameter) and c (scale parameter), we can obtain variance and mean of wind speed data using the following relationships.

Variance:= $\sigma^2 = c^2 * [\text{gamma}(1+2/k) - (\text{gamma}(1+1/k))^2]$,

and

Mean: = $\mu = c * \text{gamma}(1+1/k)$.

Wind Power Formulae:

In general, the following equation is used for energy recovery from the wind:

$$P = \frac{C_p \mu_c A \rho V^3}{2} \quad (3.8)$$

Where P is power in watts C_p is the Coefficient of performance μ_c is Conversion efficiency A is the blade swept area (m^2) ρ is the density of air (1.225 kg/m^3 for dry air at sea level) V is the wind speed (m/s)

One can only increase the available power in low winds by sweeping a larger area with the blades and that's the second key concept obtained from this formula [16]. The available power increases by a factor of 4 by doubling the diameter of the blades. Similarly, the absolute maximum that can be extracted from the available power is 59.3%. One can also utilize shape parameter, k, to estimate the average power using the following formula:

$$\overline{P} = \frac{\rho A (\overline{v})^3 \, gamma(1 + \frac{3}{k})}{2\left(gamma(1 + \frac{1}{k}) \right)^3} \quad (3.9)$$

Rated and cut-in wind velocities are related by the following expression:

$$V_{ci} = (0.15)^{\frac{1}{3}} V_r \quad (3.10)$$

Rated wind speed for slow and fast wind machines are respectively 5.3 m/s and 8.5 m/s. Similarly, the cut-in speeds for these machines are 2.5 m/s and 3.5 m/s respectively.

For a three-bladed horizontal fast wind machine with blade diameters of 5 to 10 m, the compact formula of (3.11) [17] can be utilized to estimate the maximum power.

$$P = (0.20)D^2V^3 \qquad (3.11)$$

Where, P is in watts and D (diameter of blade) in meters.

3.3 Wind Speed Histograms

Histograms can be utilized to estimate frequency of a particular wind speed in a month or year. These histograms show that, more or less, 70 - 80% of the time the wind speed remains higher than 6 m/s at 61 meters height. The shapes of the histograms also suggest that the underlying distribution of annual wind speed at Paradise Point is a Weibull probability distribution.

4. RESULTS AND DISCUSSION

Here we discuss the results of wind data analysis obtained in Section 3. The measurements were taken in the years 1995, 2002, and 2003. Table.1 gives typical values of shape parameter at different geological locations. In Table.2, wind speeds at KNPC site at 10, 30 and 61 meters are shown. In addition, it also mentions the estimated parameters of Weibull distribution. It is clear that the wind speed for the year 2003 seems to be on higher side and is close to 8.8 m/s. On the average, we can say that wind speed at 61 meters height is approximately 9 m/s. Overall wind energy potential is reasonable at this height at KNPC site. So, we can safely say that small or medium size windmills can be installed in the vicinity of KNPC. In general, it is better to collect ten minutes (or five minutes) average wind speed data for 10-20 years. This will reveal more insights of the performed analysis. In future analysis, more data will be procured and dynamical analysis approach will be employed to explore further insights of the fluctuating pattern of coastal wind speed at the site under consideration. This will in turn give better estimates of the impact of global climate change on local climate parameters. Table3 gives power output values for fast wind machines with different blade diameters.

Table 3. Power output (in kW) for fast wind machine using different blade diameters.

Year	1995 (10 m)	1995 (30 m)	2002 (61 m)	2003 (61 m)
Wind Speed	5.9 m/s	6.8 m/s	8.6 m/s	9.6 m/s
D = 5m	1.03 kW	1.60 kW	3.20 kW	4.42 kW
D = 10m	4.11 kW	6.30 kW	12.70 kW	17.70 kW
D = 30m	36.97 kW	56.60 kW	114.50 kW	159.25 kW

5. SUMMARY AND CONCLUSIONS

This communication attempted to estimate the wind speeds in the last decade at the Paradise Point coast of Karachi. It used Weibull distribution as the underlying distribution of wind data as revealed by Histograms of wind data. It also tried to estimate the wind energy potential at this site. Different mathematical formulae have been explained for the estimation of distribution parameters. MATLAB program was utilized to carry out distribution parameters estimation. In addition, MATLAB program was also used to obtain rose plot to represent wind direction at the site. Our conclusions are:

a) Wind speed data at Paradise Point follow Weibull probability distribution.

b) Average annual wind speed remains above 7 m/s at 30 meters height, and 9 m/s at 61 meters height. Most of the time wind remains in the direction covering 220 to 330 degrees.

c) It has been observed that the wind speeds in the winter are very low and there is no consistency in the wind direction.

d) As global climate change is affecting the natural wind pattern all over the world [18- 19], so, in future a better analysis for exploring the wind dynamics at the site under consideration will be possible only if more data can be procured.

e) Since wind speed is increasing as a consequence of global climate change, therefore, in near future wind farm near Karachi coast as well as offshore wind farm will be feasible and economically viable. Finally, the analysis done in the paper seems to be basic. Nevertheless, it is hoped that the study performed will be useful for further analysis in the wind energy discipline by taking larger data sets and economic analysis into account.

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