Wind Energy Analysis for 3 Prospective Costal Sites of Bangladesh

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Abstract

Wind Energy Resource Mapping (WERM) project for Bangladesh was the first of its kind in the country to make a reliable wind energy database, on the basis of which future wind energy conversion systems (WECS) could be installed without failure. The initiative was taken as a part of fulfilling the objectives of our National Renewable Energy Policy to produce 5% of total generation of electricity from renewable sources by 2015 and 10% by 2020. At present per capita energy consumption in Bangladesh is one of the lowest in the world. As it has limited reserves of conventional fuels, there is no other alternative to improve the situation other than to go for renewable sources. In this study wind speed data for Kuakata, Sitakunda and Kutubdia from January to December, 2006 have been analyzed to determine the potential for wind power generation. The variation of wind speed and direction with year, month and time of the day have been studied for proper selection of wind turbines based on Weibull Parameters. The study recommends considering operating WECS for six months from April to September in which energy densities are 147 W/m^2, 104 W/m^2 and 89 W/m^2 in Kuakata, Sitakunda and Kutubdia respectively.

Keywords
Wind energy, Renewable energy policy, Weibull parameters, wind energy conversion systems (WECS)

Introduction

Bangladesh is a developing country situated between 20.30° to 29.38° North latitudes and 88.04° to 92.44° East longitudes. Although wind energy potential is high due to its 724 km long 'V' shaped coastal belt, there is no mentionable WECS in Bangladesh that are now running successfully (Azad and Alam 2012). This is because of the fact that most of the earlier wind energy researches were based on data available from Meteorological Department (Alam and Azad 2012). In 1996-97 Bangladesh Centre for Advanced Studies (BCAS) with support from the Local Government Engineering Department (LGED) measured wind speed and direction at 25m height for 7 locations near the coast. The Bangladesh Council for Scientific and Industrial Research (BCSIR) measured wind speed for Dhaka, Teknaf and Saint Martin Islands from 1999–2001 (Azad 2010). The LGED assessed 20 locations all over Bangladesh under the WERM project at different heights (Alam 2006). In the present study wind speed data from this project for Kuakata, Sitakundu and Kutubdia from January 2006 to December 2006 have been evaluated. The analyses and the evaluations were performed in the department of Mechanical Engineering at Bangladesh University of Engineering and Technology (BUET) by a group of graduate and undergraduate students and some of the values were collected from their Project & Thesis works.

A contemporary study by Shrinivas and Parikshit (2012) demonstrates a similar analysis for 4 locations in Ireland. According to European wind atlas at 50m from ground level, Ireland is one of the countries that have the highest wind energy potential but it is using only a part of its huge potential. On the other hand India already ranked 5th in the world in terms of installed capacity of wind power. In recent years, despite the global financial crisis India's energy demand continues to rise and it has emerged as one of the leading destinations for investors from developing countries (Gera et al. 2013). This attraction is partially due to the lower cost of manpower. Therefore, there is an enormous possibility of utilizing wind power in Bangladesh since India is a neighboring country to Bangladesh having similarity in wind power availability with similar socio-economic conditions. In this study, the Weibull distribution function has been used to predict different wind characteristics. The wind energy analysis has been done to get the information about the potential of wind energy in Bangladesh, which can be extracted in near future.

1. Wind Data Selection and Analysis

Among the 20 wind monitoring stations of the WERM project, wind characteristics and potential were analyzed for the following 3 coastal areas:

- Kuakata
- Sitakunda
- Kutubdia

This is because of the fact that in Bangladesh the possible WECS utility and wind energy availability are among the best matches in these areas. The details of the following 3 locations are presented in Figure 1.

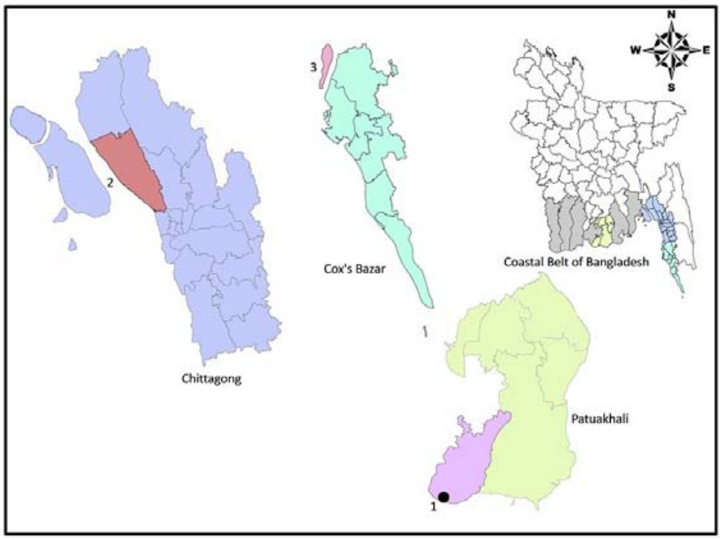


Figure 1: Location of 3 wind sites: Kuakata (1), Sitakunda (2) and Kutubdia (3)

Kuakata (referred to point 1 as indicated in Figure 1 having geographical coordinates: 21.82°N, 90.12°E) is around the center of the south-west coastline of Bangladesh in Patuakhali district. It is situated 320 km from Dhaka and 70 km from Patuakhali. It is one of the most extraordinary tourist places in the world from where both sunrise and sunset can be observed. Sitakunda (point 2 in Figure 1 with coordinates: 122.65°N, 91.66° E) is situated in the intersection of two coastlines making an obtuse angle with Chittagong district. It is 212 km south east from Dhaka and 44 km from Chittagong. The main activities are related to agriculture 24%, fishing 4%, industrial labor 5% and services 33%. Kutubdia (point 3 in Figure 1 with coordinates: 21.87°N, 91.87°E) is around the center of the south-east coastline in Cox's Bazar district. The main activities are related to agriculture 55% fishing 5% and industries 2%.

1.1 Weibull Distribution Functions

As the hourly time-series wind speed data may always be enormous, it is desirable to have only few key parameters, which can simplify the characteristics of a wide range of wind speed data. As stated by Ramirez and Carta (2005), a large number of studies have been published that proposed the use of variety of standard probability distribution functions. Although many distribution functions were suggested to describe the wind speed characteristics, namely: the Pearson, the Chi-Square, the Weibull, the Rayleigh and the Johnson functions, the Weibull distribution function is considered as the best fitting with the observed long term wind speeds besides its simplicity and flexibility (Rahman et al.2012), expressed as follows:

$$f(v) = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1} exp\left[-\left(\frac{v}{c}\right)^{k}\right] \quad (1)$$

Where, $f(v)$ is the distribution probability of wind speed v, c is the scale parameter (m/s) and k is the dimensionless shape parameter.

There are several methods to calculate the two Weibull parameters, k and c (Mathew 2006). Here, maximum likelihood method is used to estimate the parameter k and c. The likelihood function of the Weibull probability density distribution is given by Gene (2005) as:

$$L(c,k|v) = \prod_{i=1}^{n} \frac{k}{c}\left(\frac{v}{c}\right)^{k-1} exp\left[-\left(\frac{v}{c}\right)^{k}\right] \quad (2)$$

Since the logarithmic likelihood function is easier to maximize, one can get first the natural logarithm of the likelihood function of n observation which yields (Akdag 2009):

$$\ln L(c,k|v) = n \ln k - nk \ln c + (k-1)\sum_{i=1}^{n} \ln v_i \; - c^{-k}\sum_{i=1}^{n} v_i^k \quad (3)$$

The method is based on estimating those parameters that maximize the likelihood function $L(\theta \;|Y\;)$, where the necessary condition for maximizing $L(\theta \mid Y\;)$ is the likelihood equation (4)

$$\frac{\partial \ln L(\theta|Y)}{\partial\theta} = 0 \quad (4)$$

Using Equation (4), parameter k and c can be determined by the following equations

$$C = \left[\left(\frac{1}{n}\right)\sum_{i=1}^{n} v_i^k\right]^{\frac{1}{k}} \quad (5)$$

$$K = \frac{n}{\frac{k}{c}\sum_{i=1}^{n} v_i^k \ln v_i - \sum_{i=1}^{n} \ln v_i} \quad (6)$$

1.2 Comparative Study of Sites

In the present study, the annual Weibull functions and its two parameters are derived from the available data and are shown in Figure 2 and Table 1. Figure 2 shows the frequency distribution throughout the year in selected sites. It shows that Kuakata is the most ‘windy’ place with largest scale factor c and its most frequent wind speed is 3.39 m/s; Kutubdia has the most ‘peaked’ Weibull wind distribution with the intermediate shape factor k with lowest standard deviation and its most frequent wind speed is 2.91 m/s, but it has less opportunity to experience wind speed beyond 5m/s because of its less standard deviation than Kuakata.

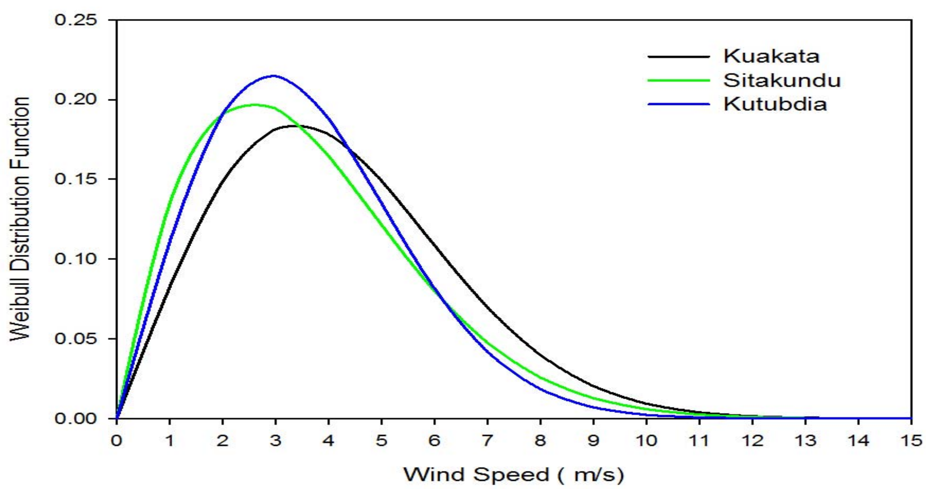


Figure 2: Annual wind speed Weibull distribution

Table 1: Two parameter of Weibull Function

Location	Shape factor, K	Scale factor, C (m/s)	Standard Deviation	Mean Velocity (m/s)	Most Probable Velocity (m/s)	Maximum Energy Velocity (m/s)
Kuakata	2.04	4.72	2.15	4.18	3.39	7.20

Sitakunda	1.79	4.05	2.09	3.60	2.56	6.15
Kutubdia	1.97	4.04	1.91	3.59	2.82	5.76

For Sitakunda, it has lowest shape factor k, intermediate scale factor c and standard deviation which permit it to experience more wind speed beyond 6m/s compared to Kutubdia but lower than Kuakata. The probability of wind speed more than 13m/s is more in Sitakunda. The most frequent wind speed is 2.56 m/s. The wind speed more than 15m/s is very rare in all the locations. An obvious calculation is that the Weibull distribution function and its two parameters are quite different for different places, so it is very important to choose a suitable site with good wind field for WECS.

1.3 Operating Probability of Design Wind Speeds

The cumulative Weibull distribution gives the probability of the wind speed exceeding the value u; which is expressed as (Rahman et al.2012):

$$P(v > u) = exp\left[-\left(\frac{u}{c}\right)^k\right] \quad (7)$$

The probability of a wind speeds between u_1 and u_2 is given by

$$P(u_1 > v > u_2) = exp\left[-\left(\frac{u_1}{c}\right)^k\right] - exp\left[-\left(\frac{u_2}{c}\right)^k\right] \quad (8)$$

In general wind turbines are designed with a cut-in wind speed, or the wind speed at which it begins to produce power, and a cut-out speed, or the wind speed at which the turbine will be shut down to prevent the drive train from being damaged. For most of the turbines, the range of cut-in and cut-out speed is 3-4.5 to 25m/s. As in concerning locations, wind speed more than 15 m/s is very rare; the cut-out speed is chosen as 15m/s reducing the cost of the system. From Figure 3, wind speed exceeding the 15m/s is negligible. Setting this value, operating probabilities of wind turbines in these areas are: Kuakata 67% (5891 hr./year), Sitakundu 56% (4883 hr./year) and Kutubdia 58% (5094 hr./year).

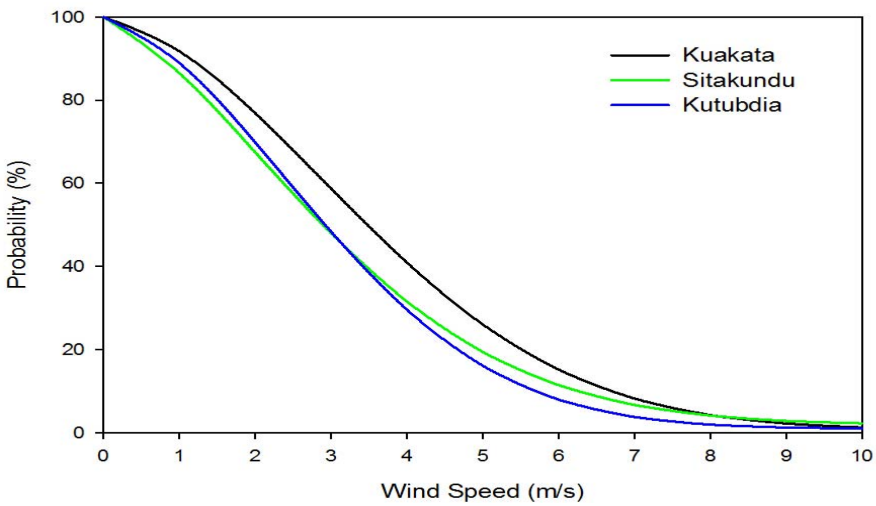


Figure 3: Probability of the wind speed exceeding a certain value

1.4 Monthly Variation of the Mean Wind Speed

In Kuakata, higher wind speed occurs during April to September (Figure 4) but during October to March wind speed is much lower as indicated by the lower mean speed. For Sitakunda, wind speed follows the same pattern as Kutubdia with the highest mean in July. For Kuakata the highest mean speed occurs in August but the pattern is like Sitakunda. Though Kutubdia has more wind speed in latter part of the year it has lower wind speeds in earlier part of the year. A common trend is observed in all the locations that there are sharp changes in wind speeds during the months of March-April and July-August. This is due to the location of the country which is characterized by the tropical monsoon with reversal wind circulation. The heating of south coast of the Asiatic continent gives rise to a higher wind speed in summer and its cooling effect results in a relatively low wind speed in winter.

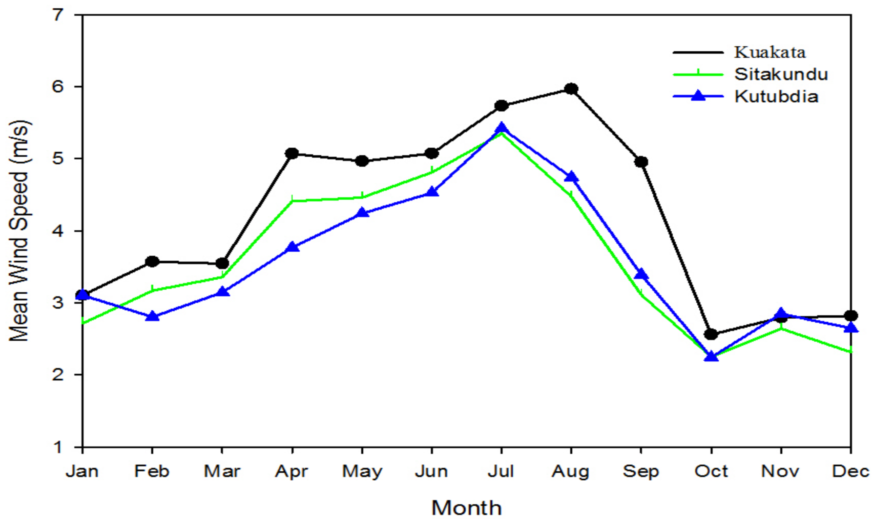


Figure 4: Monthly variation of mean wind speed

1.5 Wind Data and Weibull Function Predictions

In Figure 5 the columns of bar graphs indicate the probability, or the fraction of time the wind speed is within the interval given by the width of the columns (i.e., 1 m/s) derived for 3 locations. The simple and useful interpretation of the column is that it shows the probability of a wind speed being in a 1 m/s interval centered on a certain value of *v*. This is very important in determining the power available from a wind turbine installed at a site for a particular range of wind speed (Zhou at al. 2005). It is obvious that the discrepancies between the Weibull function predictions and the wind speed distribution are much wider as the wind speeds approaches its lower limit. However, for the purpose of estimating wind power potential, the higher wind speeds are more. In Kuakata and Sitakunda, higher wind is over-predicted while in Kutubdia it is under-predicted as seen in Figure 5.

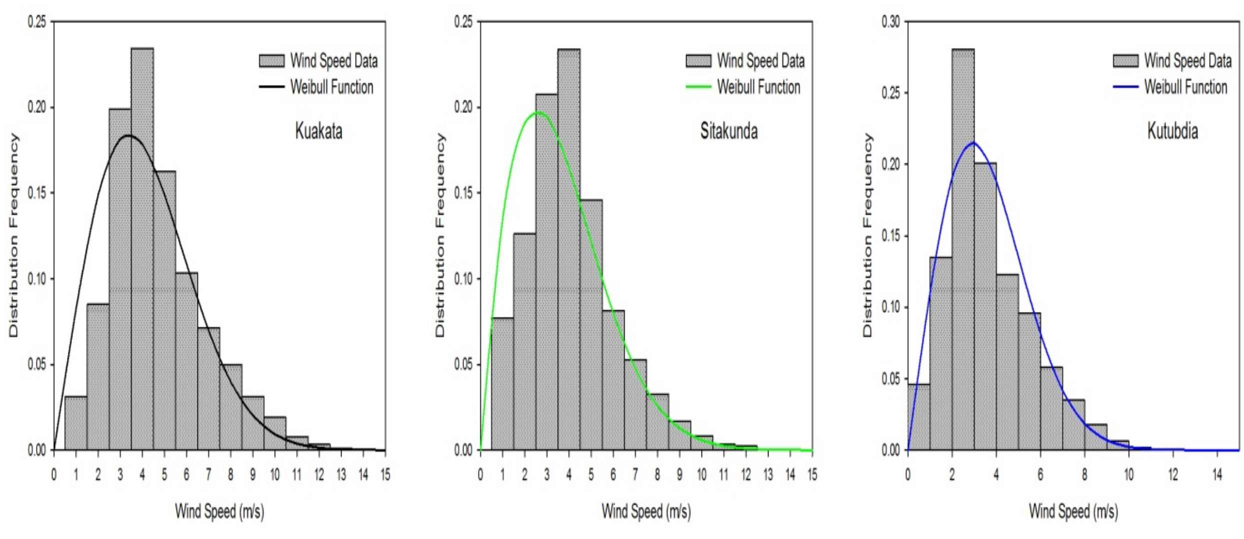


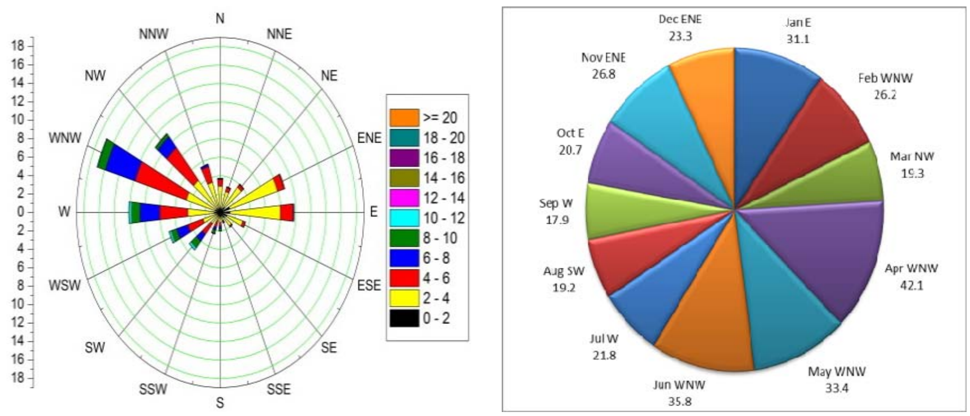
Figure 5: Comparison between Wind speed distributions and Weibull function predictions

2. Wind Direction

Usually, in wind data analysis, the prediction of the wind direction is also very important, especially when planning the installation and the micro sitting of a wind turbine or a wind farm.

2.1 Comparative features of 3 sites

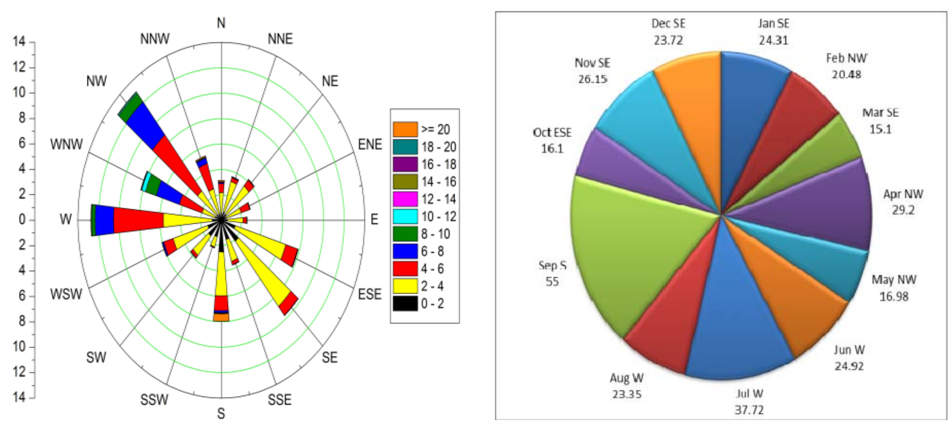
Figure 6(a) shows that in Kuakata, most of the time of year wind comes from the direction between SW and NW with a significant amount from direction E and ENE. This is well-expected outcome since this particular region is influenced by the winds blowing from south-west and north- east. The long converging south–west coastal line of Bangladesh has its influence which changes the general direction slightly.



a) Wind Rose b) Monthly prevailing wind

Figure 6: Wind direction of Kuakata

Figure 6(b) shows the prevailing wind direction of each month throughout the year and also indicates that the characteristic of country's climate reversal wind circulation is present. The reversal wind starts blowing at February and remains until September with a general trend for stabilizing one wind direction. This is true for the months of October to January.

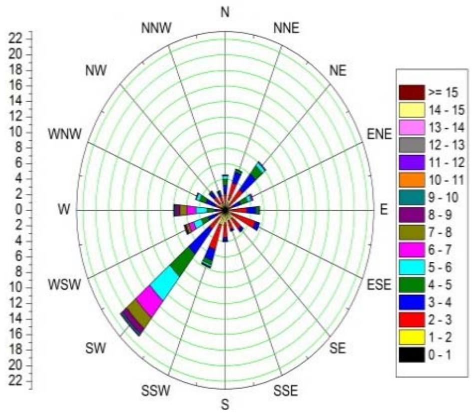


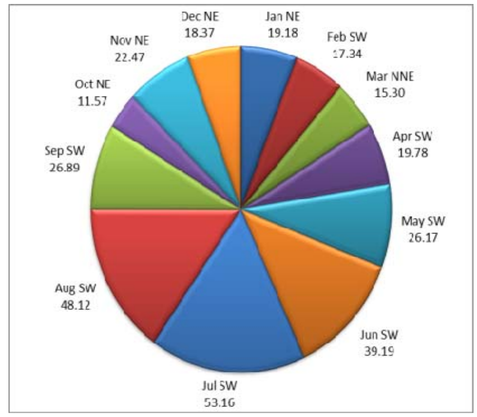
a) Wind Rose b) Monthly prevailing wind

Figure 7: Wind direction of Sitakunda

Figure 7(a) shows the wind rose of Sitakunda location for whole year. The prevailing wind direction is between W and NW with a less significant between S to ESE. The geographic location at the vertex of obtuse angle and the blocking effect of hills are the reasons for violating the general wind direction trends of the country. Although, the reversal wind circulation is also present which is shown in Figure 7(b). Reversal of wind starts at February but stabilize at April and lasts until September. In September to January with March wind blows from S to ESE. For unusual storm in September the wind direction is also unusual (Alam and Azad 2012).

Figure 8(a) shows that in Kutubdia, most of the time of year wind comes from between SW and with a significant amount from NE direction. For the location of Kutubdia, in middle of south-east coastal line, this is well-expected outcome since this particular region is influenced by the winds blowing from south-west and north-east.





a) Wind Rose b) Monthly prevailing wind

Figure 8: Wind direction of Kutubdia

Figure 8(b) shows the prevailing wind direction of each month throughout the year and also clears that the characteristic of country's climate reversal wind circulation is present. The reversal wind starts blowing at February but stabilizes in April and remains until October with a general trend for stabilizing it in one direction. This is true for the months of October to January and March. In general, in the months of March and October, the wind direction is not stable in all locations indicating the change of seasonal reversal of wind circulation.

3. Wind Power

The evaluation of the wind power per unit area is of fundamental importance in evaluating WECS projects. If the air density is assumed constant (of value $\bar{\rho}$) and independent of the wind speed (Himri at al. 2008), then the long-term wind speed distribution $f(v)$ is combined with the available wind power to give the average wind power density, which can be expressed as follows

$$\bar{P} = \frac{1}{2}\rho \int_0^\infty v^3 f(v)\,dv \quad (9)$$

Where ρ is the air density, kg/m^3; v is the speed of the wind, m/s. Once Weibull function is chosen to be the distribution function $f(v)$, the average wind power density becomes [12]

$$\bar{P} = \frac{\rho \bar{v}^3}{2} \frac{\Gamma\left(1+\frac{3}{k}\right)}{\left[\Gamma\left(1+\frac{1}{k}\right)\right]^3} \quad (10)$$

3.1 Monthly variation of the wind power density

Figure 9 shows the monthly variation of the wind power density in the three locations calculated with the above equations. The seasonal effect is prominent in the monthly wind power density. For Kuakata, remarkable monthly changes in the wind power density have found from March to October with maximum of 206 W/m^2 in August being about 14 times of the minimum 15 W/m^2 in October.

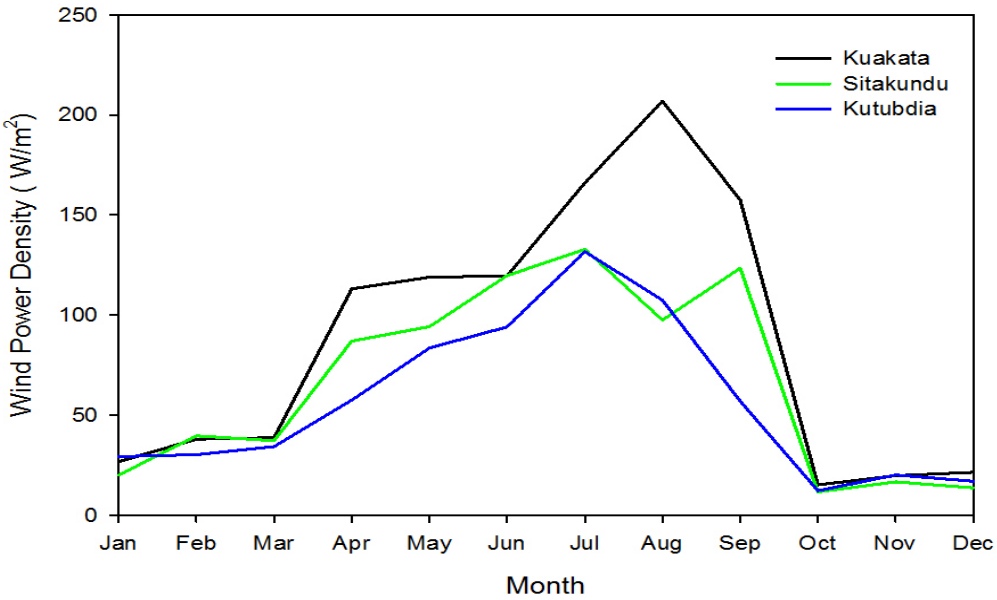


Figure 9: Monthly variation of the wind power density

For Sitakunda, similar monthly changes in the wind power density have found from March to October with maximum of 133 W/m^2 in July being about 11 times of the minimum 12 W/m^2 in October. For Kutubdia, monthly changes in the wind power density have found from March to October with maximum of 132 W/m^2 in July being about 11 times of the minimum 12 W/m^2 in October.

A detailed examination of Figure 4 and Figure 9 has revealed some oddness about the wind power densities in Sitakunda. For example, though the mean wind speed is found in September is less than in Kutubdia, the power density is much more in Sitakunda. This irregularity can be accounted for by difference in their standard deviations of the wind speed in this month, as shown in Table 2.

Table 2: Monthly standard deviation of each location

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Kuakata	1.19	1.20	1.27	1.85	2.13	2.01	2.13	2.60	2.68	0.99	1.01	1.18
Sitakundu	1.26	1.79	1.46	1.96	2.08	2.30	1.88	2.15	2.91	1.04	1.02	1.20
Kutubdia	1.33	1.64	1.45	1.73	2.03	2.02	1.80	2.14	2.10	1.08	1.02	0.99

With a larger standard deviation but minor mean wind speed, a higher wind power density is possible because the wind power density expressed by Equation (10) repetitively increases with the standard deviation when the mean speed is given. This fact is also true for the month of Februrary, March and June.

Figure 9 also shows that Kuakata has fairly more potential and seasonal variation is quiet large. For considering WECS for these locations, it is better to consider only April to September, not for whole year. Table 3 shows the different in average wind power potential between the whole year and duration ranging from April to September.

Table 3: Difference of parameter between two time span for considering WECS

Time Span	Whole Year				Ranging April – September			
Location	Mean Velocity (m/s)	Shape factor, K	Scale factor, C (m/s)	Mean Energy (W/m^2)	Mean Velocity (m/s)	Shape factor, K	Scale factor, C(m/s)	Mean Energy (W/m^2)
Kuakata	4.18	2.04	4.72	84.68	5.30	2.47	5.98	146.70
Sitakundu	3.60	1.79	4.05	62.19	4.47	2.03	5.04	103.99
Kutubdia	3.59	1.97	4.04	55.65	4.36	2.21	4.92	89.17

Conclusion

Annual mean wind speed of 4.18, 3.60 and 3.59 m/s are derived from the 10 minute interval measured time-series wind speed data at 20 m hub height for Kuakata, Sitakunda and Kutubdia respectively. Their average wind power densities are 85, 62 and 56 W/m^2 respectively. If the cut-in and cut-out speeds of 3.0 and 15.0 m/s are used, their operating possibilities amount to 67% (5891 hr./year), 56% (4883 hr./year) and 58% (5094 hr./year), respectively.

Although wind resources are not very high in Bangladesh, there is an urgent need for transition from conventional energy sources to renewable sources. This is characterized by one of the targets by the country's recently formed Sustainable and Renewable Energy (RE) Development Authority on September 11, 2012 as consequences of RE policy dialogues. The main focusing objectives are to:

- Enable, encourage and facilitate both public and private sector investment in RE projects
- Promote development of local technology in the field of RE
- Achieve the targets for developing RE resources to meet 5% of the total power demand by 2015 and 10% by 2020.

The present study, using available data of 20 wind monitoring sites under WERM project for Bangladesh, these 3 coastal sites follow general trends of wind characteristics for implementing possible wind energy conversion systems (WECS). Seasonal variations demonstrate that the monthly mean wind speed and power density in each area under this investigation is prominent. Moreover, there is a remarkable distinction between April-September and October-March, in hourly mean wind speed and power density, thus dividing the whole year in 2 subdivisions. Therefore, it is recommended that instead of the whole year, if duration between April and September is used for installation of WECS, it would be more advantageous. With this concept the average wind power densities would be 147, 104 and 89 W/m^2 and operating possibilities would be 83 %(3661 hr./year), 71 %(3098hr./year) and 72 %(3141 hr./year) in Kuakata, Sitakunda and Kutubdia, respectively. Keeping in mind, examples of similar research regarding harnessing wind power in coastal sites of Ireland and India, it is also recommended that, these 3 coastal sites of Bangladesh need to be investigated further with at least 10 years data for complete understanding.

Acknowledgements

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Biography

Muhammad M. Alam is currently a full-time professor and former Head of the Department of Mechanical Engineering at Bangladesh University of Engineering and Technology (BUET), Dhaka, Bangladesh; a part-time instructor at Military Institute of Science and Technology (MIST), Dhaka. He earned B.S. Engineering (Mechanical) from BUET in 1983 and employed in the Department as a Lecturer in the same year. He obtained M.S. Engineering in Stability of Wind Turbines from BUET; PhD in Wind-driven Rotodynamic Pumps from University of Reading, UK; published papers in Conference Proceedings, National and International journals. He was the Chief Investigator and Project Coordinator of Wind Energy Resource Mapping Project (WERM) for Bangladesh funded by UNDP. He is a member of the Joint working Group (JWG) on Renewable Energy Cooperation between Bangladesh and India. His research interests include: Wind Energy, Conventional and Renewable Energies, Automobiles, Air-conditioning. Further information at: www.buet.ac.bd./me/faculty/mahbubul/index.html

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