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Statistical analysis of wind characteristics and wind energy potential of Port Blair, India

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सार – इस अध्ययन का उद्देश्य पोर्ट ब्लेयर की पवन विशेषताओं और पवन ऊर्जा क्षमता का पता लगाना है। इस अध्ययन से यह भी स्पष्ट होता है कि ऐसे क्षेत्र में जहां शांत पवन की संभावना महत्वपूर्ण है वहाँ पवन विशेषताओं और पवन ऊर्जा की क्षमता का निर्धारण करने के लिए सबसे प्रसिद्ध वीबुल वितरण फलन उपयुक्त है या नहीं। इसमें शांत पवन को शामिल करने के लिए डिराक डेल्टा फ़ंक्शन को जोड़कर विबुल वितरण फलन को संशोधित किया गया है। यहाँ पवन गति औसत, पवन ऊर्जा और ऊर्जा घनत्व की गणना डेटा, वीबुल वितरण और वीबुल डिराक वितरण से की गई है। डेटा से प्राप्त वार्षिक पवन गति औसत, वीबुल और वीबुल डीराक फ़ंक्शन क्रमशः 2.40 m/s, 3.011 m/s और 2.406 m/s हैं। इसी प्रकार प्राप्त वार्षिक पवन ऊर्जा घनत्व क्रमशः 30.82 W/m^2, 33.30 W/m^2 और 28.41 W/m^2 है तथा वार्षिक पवन ऊर्जा घनत्व क्रमशः 270.79 kWh/m^2/ वर्ष, 291.71 kWh/m^2 / वर्ष और 248.87 kWh/m^2/ वर्ष रहा। इस अध्ययन में इस स्थान पर पवन गति की मासिक और दैनिक परिवर्तिता तथा अलगअलग ऊंचाई में पवन गति का पता - लगाया गया है।

ABSTRACT. This study aims to find out the wind characteristics and wind energy potential of Port Blair. Besides it also testifies whether most famous Weibull distribution function is suitable or not to determine the wind characteristics and wind energy potential in a region where probability of calm wind is significant. Here Weibull distribution function is modified with adding Dirac Delta function to incorporate the calm winds. Here mean wind speed, wind power and energy densities have been calculated from the data, Weibull distribution and Weibull Dirac distribution. It is found that annual mean wind speeds obtained from data, Weibull and Weibull dirac functions are 2.40 m/s, 3.011 m/s and 2.406 m/s respectively. Similarly annual wind power densities obtained are 30.82 W/m^2, 33.30 W/m^2 and 28.41 W/m^2 respectively. And annual wind energy densities obtained to be 270.79 kWh/m^2/year, 291.71 kWh/m^2/year and 248.87 kWh/m^2/year respectively. This study also finds the monthly and diurnal variations of wind speed and wind speed at different heights at this location.

Key words – Weibull Dirac distribution, Wind energy density, Wind power density, Mean wind speed, Wind rose diagram, Port Blair.

1. Introduction

Wind speed and directions are very important meteorological parameters. Detail knowledge about wind speed and direction of a place is very useful in many ways. The knowledge of wind speed and direction are required for runway orientation of an airport, establishment of new township, slender structures, establishment of high rise buildings, establishment of large telescopes, indoor ventilation etc.

It is also very essential to determine the wind energy density of a particular region and hence wind energy potential. Wind energy is very popular now-a-days due to the shifting focus from non fossil fuel based energy to the renewable energy. It is very clean and cheap compared to other renewable energies. This energy can be used for the regions where no or little gridded electricity have been reached. Port Blair is the capital of Andaman and Nicobar Islands, remotely located Union Territory of India. In these Islands there are many remote locations where there is no grid connectivity and the main source of energy is the diesel generated electricity. Therefore an attempt has been made to find the wind characteristics and the wind energy potential of Port Blair. A few studies (Chand *et al*., 1985; Sarkar *et al*., 2017) of this kind have been done earlier in India but with an all India perspective and not particularly for this region. They have differed in their results, one showing moderate and other showing poor wind energy potential for Port Blair. Moreover the data used were very old and from different wind instruments. Here this study has been carried out with recent data.

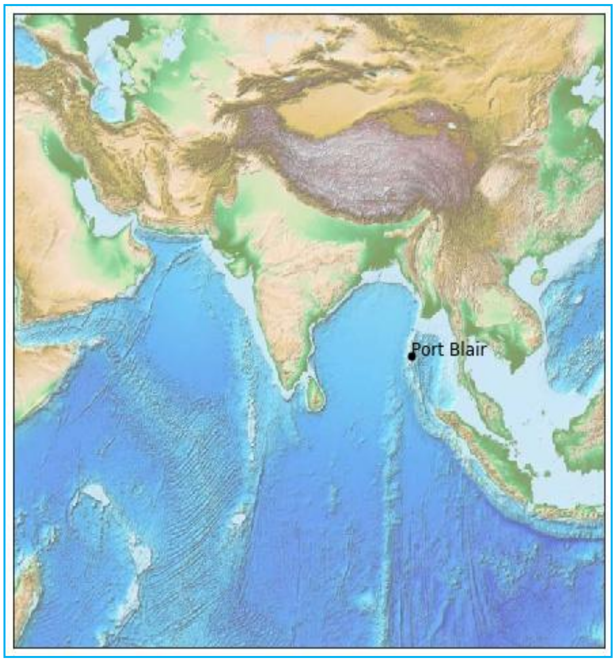


Fig. 1. Position of Port Blair in India

Such kind of studies on wind characteristics and wind energy potential have been undertaken previously by many scholars all over the world (Weisser, 2003; Akpinar *et al*., 2009; Genc *et al*., 2005; Gokcek *et al*., 2007; Merzouk, 2000; Eskin *et al*., 2008; Fadare, 2008). They have mostly used Weibull distribution function to assess wind energy potential due to its flexibility, simplicity and suitability to fit a wide collection of recorded wind data (Ulgen *et al*., 2002; Dorvlo, 2002; Karsli, 2003; Sulaiman *et al*., 2002; Celik, 2004). (Chaurasia *et al*., 2018) have studied different parameters estimation methods of Weibull distribution to determine wind power density using ground based Doppler SODAR instruments and found maximum likelihood method as a more efficient Weibull parameter assessment method for calculating the wind power density. (Mahmood *et al*., 2019) have done wind characteristic analysis of Al-Salman site, Iraq based on Weibull distribution and found that Weibull probability density function and actual data closely matching. (Hassane *et al*., 2018) have also calculated the wind power and energy density using Weibull distribution. (Keyhani *et al.*, 2010) have also calculated wind energy and wind power density using Weibull distribution function. Their results show that Weibull predicted mean wind speed and the mean wind speed calculated from the data closely matching.

The same have been tried with the wind data of Port Blair but the result obtained is quite different than the actual. The main problem with the Weibull distribution function is that it does not account the zero values. According to Weibull distribution function probability of calm wind is zero. But in reality there are calm winds and the mean wind speed varies if we exclude these zero values. Therefore in this study an attempt has been made to modify the Weibull function by combining it with Dirac delta function to find the mean wind speed and energy density. This kind of attempt has been made earlier (Takle *et al*., 1978; Merzouk, 2000). Now using modified Weibull distribution function the result obtained is in good agreement as that obtained from the raw data.

2. Study area and data

The present study area is Port Blair which is the capital of Andaman and Nicobar islands, union territory of India. The place has been shown in Fig. 1. Port Blair is the only place in this union territory where a W.M.O. class I observatory of India Meteorological Department is situated. The latitude, longitude and elevation of this observatory are 11°41' N, 92°43' E and 79 (m a.s.l.) respectively. Daily eight synoptic hours wind speed and direction data for the period 2012-2019 have been collected from this observatory. The wind speed measured continuously by a cup anemometer placed at a height 6m above the ground level.

3. Analysis procedure

In this section the analysis procedures those are used in this study have been discussed:

3.1. *Weibull and Weibulldirac distribution function*

There are diverse distribution functions to model the wind speed namely Gamma, Gumble, Fretchet, inverse-Weibull etc. but the Weibull is the mostly accepted distribution due its capacity to fit a broad range of data (Fazelpour *et al*., 2017). The Weibull probability function is expressed as (Chang *et al*., 2003; Jager *et al*., 2016; Soltani *et al*., 2016):

$$f(v)=\left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{(k-1)}\exp\left[-\left(\frac{v}{c}\right)^{k}\right], k>0, v>0, c>1 \tag{1}$$

where, $f(v)$ represents Weibull probability distribution function, k is the dimensionless shape parameter, c is the Weibull scale parameter and v is the wind speed.

The cumulative distribution function represents the fraction of time when the wind speed is equal or less than speed v. Cumulative distribution function of Weibull can be expressed as (Bilbao *et al*., 2008):

$$f(v) = 1 - \exp\left[-\left(\frac{v}{c}\right)^k\right] \quad (2)$$

The main drawback of Weibull distribution is that the distribution shows zero probability for calm winds. But calm winds exist and they influence mean wind speed as well as wind energy density calculation. Weibull function is combined with Dirac delta function to incorporate the calm winds. The Weibull-Dirac distribution function is expressed as (Takle *et al*., 1978):

$$g(v) = a\delta(v) + (1-a)\left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{k-1} \exp\left[-\left(\frac{v}{c}\right)^k\right], \quad \text{for all real } v \quad (3)$$

where, $g(v)$ is the Weibull Dirac distribution function, a is the probability of calm winds and c, k, v are same parameters as expressed in equation 1.

The cumulative distribution function for Weibull Dirac distribution function is expressed as (Takle *et al*., 1978):

$$G(v) = a + (1 - a)\, F(v) \quad (4)$$

where, $G(v)$ is the Weibull Dirac Cumulative distribution function and $F(v)$ is the Weibull Cumulative distribution function.

There are many methods to estimate Weibull parameters (Arslan *et al*., 2014) such as graphical method, moment method, power density method, empirical method, energy pattern factor method, maximum likelihood method etc but according to studies (Chaurasiya *et al*., 2018; Gugliani *et al*., 2018) the maximum likelihood method is the most efficient Weibull parameters estimation method for calculating wind power density.

The Weibull k and c parameters can be evaluated from the following equations (Chaurasiya *et al*., 2018) as:

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

$$c = \left[\frac{\sum_{i=1}^{n} \left(v_i^k\right)}{n}\right]^{\frac{1}{k}} \quad (6)$$

where, n is the total number of observations of nonzero wind speed and v_i is the wind speed.

Average wind speed and the variance of wind speed can be calculated for Weibull distribution in terms of Weibull parameters as (Fazelpour *et al*., 2017):

$$\bar{v}(\text{Weibull}) = c\Gamma\left(1 + \frac{1}{k}\right) \quad (7)$$

$$\sigma^2(\text{Weibull}) = c^2\left[\Gamma\left(1 + \frac{2}{k}\right) - \Gamma^2\left(1 + \frac{1}{k}\right)\right] \quad (8)$$

where, $\Gamma(x)$ represents the Gamma function which is defined as:

$$\Gamma(x) = \int_0^\infty e^{-u} u^{x-1} du \quad (9)$$

For Weibull Dirac distribution the average wind speed and variance of the wind speed in terms of c and k as (Takle *et al*., 1978):

$$\bar{v}\,(\text{Weibull Dirac}) = c(1-a)\Gamma\left(1 + \frac{1}{k}\right) \quad (10)$$

$$\sigma^2\,(\text{Weibull Dirac}) = c^2(1-a)\left[\Gamma\left(1 + \frac{2}{k}\right) - (1-a)\Gamma^2\left(1 + \frac{1}{k}\right)\right] \quad (11)$$

3.2. *Wind power density*

The wind power density at speed v is given as (Tizpar *et al*., 2014):

$$P(v) = \frac{1}{2}\rho v^3\left(\frac{w}{m^2}\right) \quad (12)$$

where, ρ is the standard air density with the value of 1.225 kg/m^3 which is measured at mean sea level, pressure of 1 atm and mean temperature 15 °C.

The wind power density is considered to be a better indicator as it considers the frequency distribution of the wind speed, the air density and cube of wind speed. The wind power density is expressed as (Mostafaeipour *et al*., 2011):

$$\mathrm{WPD} = \sum_{i=1}^{N} \frac{1}{2}\rho v_i^3 \tag{13}$$

where, v_i is the measured wind speed in three hour intervals and N is the total number of sample data for which the power density is being calculated.

The wind power density from Weibull (Ouammi *et al*., 2010) and Weibull Dirac distribution are given as :

$$\frac{P}{A}(\mathrm{Weibull}) = \int_0^\infty \frac{1}{2}\rho v^3 f(v)dv = \frac{1}{2}\rho c^3 \Gamma\left(1+\frac{3}{k}\right) \tag{14}$$

$$\frac{P}{A}(\mathrm{Weibull\,Dirac}) = \int_0^\infty \frac{1}{2}\rho v^3 g(v)dv = \frac{1}{2}\rho(1-a)c^3 \Gamma\left(1+\frac{3}{k}\right) \tag{15}$$

3.3. *Wind energy density*

The energy density at a site is calculated from Weibull and Weibull Dirac as:

$$\frac{E}{A}(\mathrm{Weibull}) = \frac{1}{2}\rho c^3\, \Gamma\left(1+\frac{3}{k}\right)T \tag{16}$$

$$\frac{E}{A}(\mathrm{Weibull\,Dirac}) = \frac{1}{2}\rho(1-a)c^3 \Gamma\left(1+\frac{3}{k}\right)T \tag{17}$$

where, T is the desired duration for which the wind energy density is being calculated.

3.4. *Most probable wind speed and wind speed having maximum energy*

The most probable wind speed and the wind speed carrying maximum energy obtained from Weibull function (Fazelpour *et al*., 2015) and Weibull Dirac function as :

$$v_{mp}(\mathrm{Weibull}) = c\left(1-\frac{1}{k}\right)^{\frac{1}{k}} \tag{18}$$

$$v_{mp}(\mathrm{Weibull\,Dirac}) = c(1-a)\left(1-\frac{1}{k}\right)^{\frac{1}{k}} \tag{19}$$

$$v_{\max,E}(\mathrm{Weibull}) = c\left(1+\frac{2}{k}\right)^{\frac{1}{k}} \tag{20}$$

$$v_{\max,E}(\mathrm{Weibull\,Dirac}) = c(1-a)\left(1+\frac{2}{k}\right)^{\frac{1}{k}} \tag{21}$$

3.5. *Wind speed at different heights*

The raw wind speed data obtained from an anemometer placed at a height 6 m above the ground which were converted to the standards anemometer height 10 m from the ground using (Mahmood *et al*., 2019) as:

$$c_2 = c_1\left(\frac{z_2}{z_1}\right)^n \tag{22}$$

$$k_2 = k_1 \frac{1-0.088\ln\left(\frac{z_1}{10}\right)}{1-0.088\ln\left(\frac{z_2}{10}\right)} \tag{23}$$

$$n = \frac{0.37-0.088\ln c_1}{1-0.088\ln\left(\frac{z_2}{10}\right)} \tag{24}$$

where, c_2 and k_2 is the Weibull parameters at the desired height z_2 and n is the power law exponent.

3.6. *Error analysis*

To verify the accuracy of the Weibull and Weibull Dirac distribution in determining mean wind speed, mean power and energy densities absolute error, relative error and percent error have been calculated using:

$$\in = \left|v - v_{\mathrm{approx}}\right| \tag{25}$$

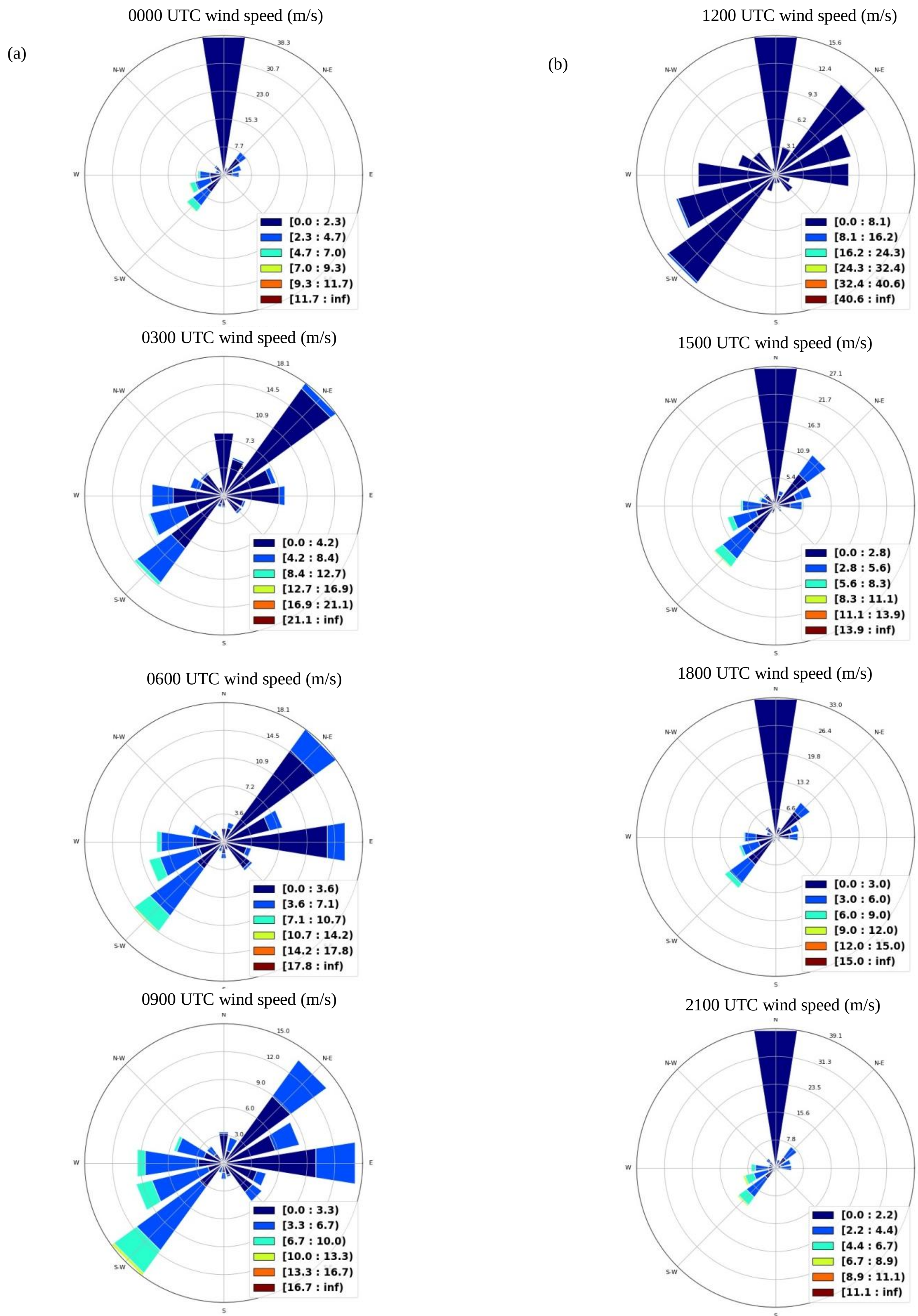
$$\eta = \frac{\left|v - v_{\mathrm{approx}}\right|}{\mathrm{mod}(v)} \tag{26}$$

$$\delta = \eta \times 100\% \tag{27}$$

3.7 *Goodness of fit*

To verify the accuracy of the fitted Weibull Dirac distribution two-sample Kolmogorov-Smirnov test and Chi square test were performed.

The two sample Kolmogorov-Smirnov test is used to test where the two probability distributions differ. It is given as (https://en.wikipedia.org/wiki/Kolmogorov%E2%80%93Smirnov_test):



Figs. 2(a&b). (a) 0000-0900 UTC and (b) 1200-2100 UTC wind rose diagram

$$D_{n,m} = \sup_x \left| F_{1,n}(x) - F_{2,m}(x) \right| \tag{28}$$

where, $F_{1,n}$ and $F_{2,m}$ are the empirical distribution functions of the first and second sample respectively and sup is the supremum function.

The Chi square test of goodness of fit is used to see whether the number of observation in each category fits the theoretical expectations. It is expressed as:

$$\chi^2 = \sum \frac{(O-E)^2}{E} \tag{29}$$

where, O and E are observed and expected frequencies respectively.

4. Results and discussion

In this study, wind speed data of Port Blair obtained from a cup anemometer placed at a height 6 m above the ground over the period 2012-2019 were analyzed. The results obtained are summarized below:

4.1. *Wind pattern*

4.1.1. *Monthly mean wind speeds*

The monthly mean wind speed $\bar{v}$ and standard deviations obtained from the data are presented in Table 1. The mean wind speed and standard deviation varies from month to month. The mean wind speed is minimum in April and maximum in July with values 1.24 m/s and 3.73 m/s respectively. The standard deviation is maximum in June and minimum in March with values 2.39 and 1.19 respectively. The average wind speed and standard deviation for whole year are 2.39 m/s and 1.73 respectively.

4.1.2. *Diurnal variations wind speed and directions*

In Port Blair wind speed and directions varies throughout the day and night. Wind rose diagram for each synoptic hours have been shown in Figs. 2(a&b). It is clear from wind rose diagrams that most of the calm winds are observed in 0000 UTC and 2100 UTC and wind speed reaches maximum values during 0600 UTC and 0900 UTC. The wind blows mostly N-E and S-W directions. In Fig. 3 wind speed profile of Port Blair where monthly as well as synoptic hour wind speed variation has been shown. From this figure also it is clear that highest and lowest wind speeds are observed in the months of July and April respectively and minimum wind speed is at 0000 UTC and 2100 UTC and maximum wind speed at 0600 UTC and 0900 UTC.

TABLE 1

Monthly mean wind speed and standard deviation obtained from the data

Month	Mean wind speed (m/s)	Standard deviation
January	2.32	1.44
February	1.88	1.35
March	1.33	1.19
April	1.24	1.30
May	2.15	2.06
June	3.72	2.39
July	3.73	1.99
August	3.51	2.00
September	2.54	2.13
October	1.66	1.63
November	1.99	1.55
December	2.62	1.68
Annual	2.40	1.96

4.2. *Weibull and Weibull Dirac distributions*

In Fig. 4 the probability distribution obtained from the data have been plotted and fitted with Weibull and Weibull Dirac distributions. It is clearly seen that Weibull distribution is close to the distribution of the raw data except the zero wind speeds. The Weibull Dirac distribution accounts the zero values.

In Fig. 5 cumulative frequency obtained from the data and cumulative frequency of the Weibull Dirac distribution function have been plotted. It is clear from the figure that both agree well.

Weibull parameters c and k have been calculated for each month and for the entire data set and predicted standard deviation, mean wind speed, most probable speed and wind speed carrying maximum energy using these parameters. These are shown in Table 2. The standard deviation, probability of calm winds, mean wind speed, most probable speed and wind speed carrying maximum energy predicted from Weibull Dirac distribution is shown in Table 3. From Tables 2 and 3, it is seen that mean wind speed, most probable wind speed and wind speed carrying maximum energy is higher than that obtained from data as predicted by Weibull distribution whereas the same is almost closely predicted by Weibull Dirac distribution.

The variations of monthly mean wind speed obtained from data, Weibull distribution and Weibull Dirac distribution is shown in Fig. 6. It is seen that mean wind speed obtained from Weibull Dirac and the data exactly

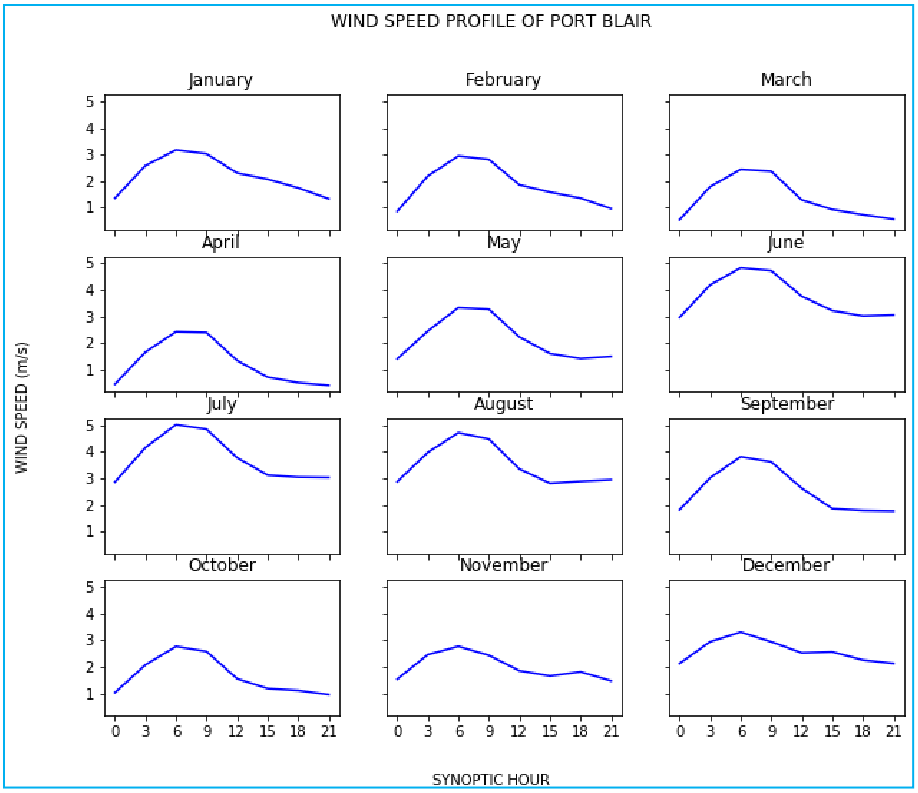


Fig. 3. Wind speed profile of Port Blair

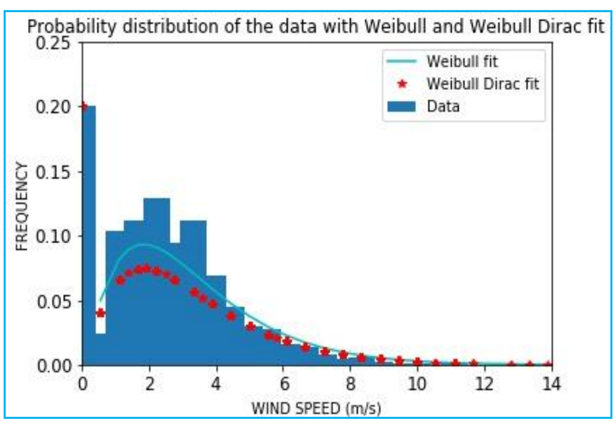


Fig. 4. Probability distribution of the data, Weibull and Weibull Dirac fit

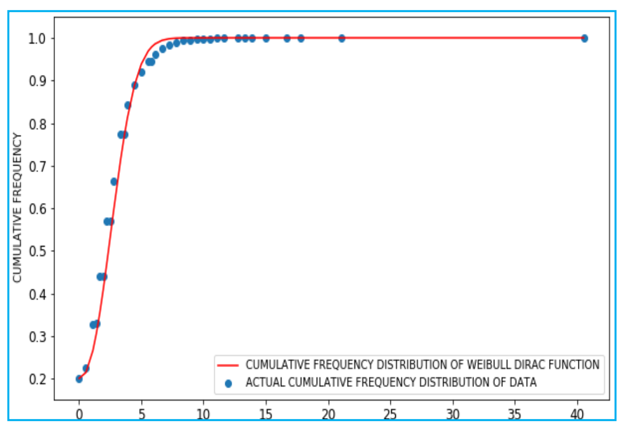


Fig. 5. Cumulative frequency of data and cumulative frequency of Weibull Dirac function

matches. The two curves are overlapping whereas the mean speed curve obtained from Weibull distribution lying apart from actual mean curve.

The monthly variations of most probable wind speed obtained from Weibull distribution and Weibull Dirac distribution is shown in Fig. 7. It is seen that there is clear difference between the most probable wind speeds obtained from two distributions. The difference arises due to the calm winds. It is seen that when the probability of calm wind becomes smaller the difference also becomes smaller. That is why difference is larger during January to April, October to December and Smaller during June to September.

TABLE 2

Monthly and annual Weibull parameters, standard deviation, characteristic speeds obtained from Weibull Distribution in Port Blair

Month	k	c (m/s)	v_{mp} (m/s)	$v_{max,E}$ (m/s)	$\overline{v}$ (predicted)	σ (predicted)
January	2.40	3.04	2.43	3.91	2.695	1.20
February	2.43	2.70	2.17	3.46	2.394	1.05
March	2.38	2.25	1.79	2.91	1.994	0.89
April	1.99	2.29	1.61	3.25	1.240	1.07
May	1.69	3.33	1.96	5.29	2.030	1.81
June	1.99	4.64	3.27	6.58	2.972	2.16
July	2.27	4.45	3.45	5.88	4.112	1.84
August	2.20	4.27	3.24	5.73	3.942	1.81
September	1.78	3.56	2.24	5.43	3.782	1.84
October	1.85	2.76	1.81	4.10	3.168	1.37
November	1.98	2.81	1.97	4.00	2.451	1.31
December	2.21	3.41	2.60	4.56	3.020	1.44
Annual	1.85	3.39	2.23	5.04	3.011	1.69

TABLE 3

Monthly and annual standard deviation, characteristic speeds obtained from Weibull Dirac Distribution in Port Blair

Month	v_{mp} (m/s)	$v_{max,E}$ (m/s)	$\overline{v}$ (predicted)	σ (predicted)	Calm wind prob
January	2.10	3.38	2.326	1.58	0.137
February	1.70	2.71	1.879	1.33	0.215
March	1.20	1.95	1.336	1.03	0.330
April	0.99	1.98	1.240	1.10	0.389
May	1.42	3.84	2.161	1.92	0.273
June	2.96	5.96	3.726	2.70	0.094
July	3.27	5.57	3.737	2.48	0.052
August	3.01	5.33	3.517	2.39	0.070
September	1.80	4.37	2.547	2.08	0.196
October	1.24	2.80	1.672	1.45	0.318
November	1.57	3.19	1.988	1.54	0.202
December	2.25	3.96	2.618	1.84	0.133
Annual	1.78	4.03	2.406	1.93	0.201

The monthly variations of wind speed carrying maximum energy obtained from Weibull distribution and Weibull Dirac distribution is shown in Fig. 8. It is seen that there is a clear difference between the two results.

4.3. *Wind speed at different heights*

The wind speed data obtained is of 6 m height but to transform this data to 10 m, 30 m height equations 22-24 have been used. The mean wind speed predicted at different heights obtained from Weibull and Weibull Dirac distributions are shown in Table 4.

From Table 4 it is seen that at 10 m and 30 m heights Weibull Dirac predicted wind speed is lower than Weibull predicted wind speed. Weibull Dirac wind speeds at these heights have been calculated assuming that probability of calm winds remains same at these heights as at 6 m height. But this is not true. Probability of calm wind decreases with increase in heights. Therefore we can get little higher values than those shown in the table.

4.4. *Wind power density and energy density*

Wind power and energy density is calculated from the raw data, Weibull and Weibull Dirac distribution

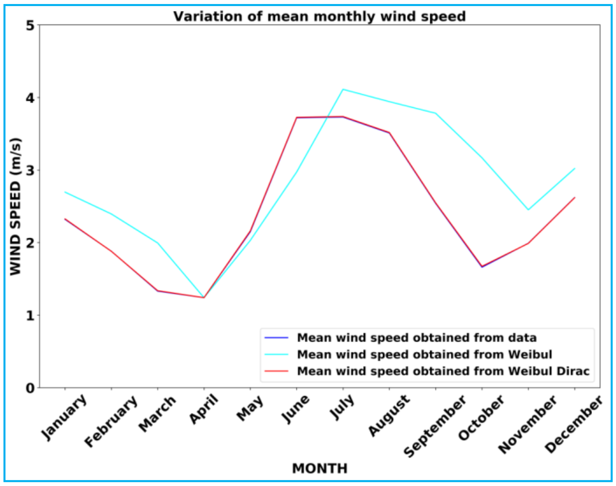


Fig. 6. Variations of monthly mean wind speed obtained from data, Weibull and Weibull Dirac function

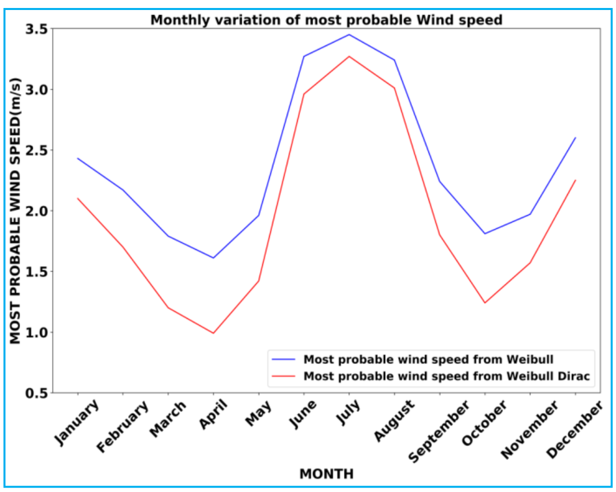


Fig. 7. Monthly variation of most probable wind speed obtained from Weibull and Weibull Dirac distribution

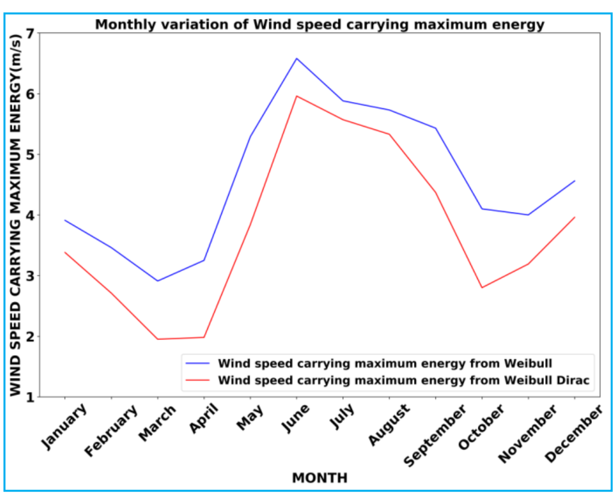


Fig. 8. Monthly variation of wind speed carrying maximum energy obtained from Weibull and Weibull Dirac distribution

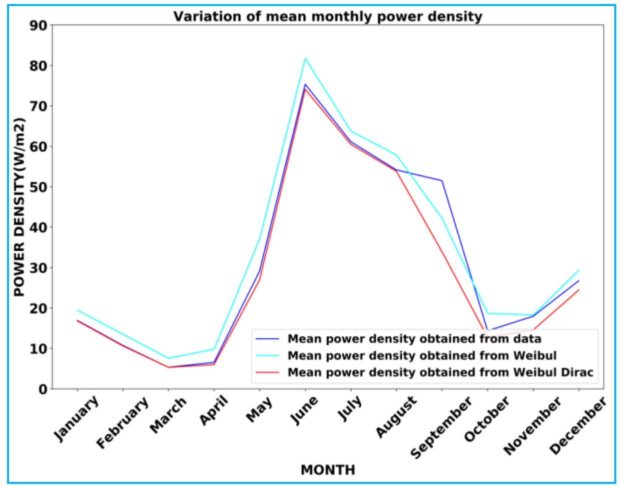


Fig. 9. Variation of monthly power density obtained from raw data, Weibull and Weibull Dirac functions

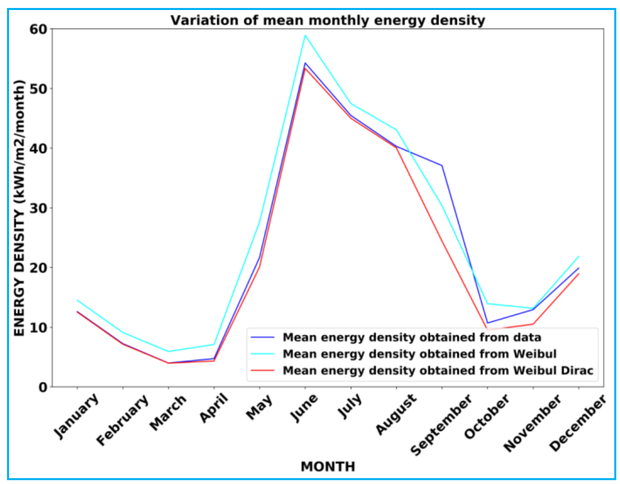


Fig. 10. Variation of monthly energy density obtained from raw data, Weibull and Weibull Dirac functions

function are shown in Table 5. It is seen that energy and power density as estimated by Weibulland Weibull Dirac have a difference. But Weibull Dirac estimated values closely match with that obtained from data. The maximum and minimum power densities and energy densities obtained from raw data are 75.34 W/m^2, 5.34 W/m^2 in June and March respectively. And 54.25 kWh/m^2/month, 3.98 kWh/m^2/month respectively in the month of June and March. The maximum and minimum wind power densities estimated from Weibull distributionare 81.772 and 7.593 W/m^2 in the month June and March respectively. The maximum and minimum wind energy densities estimated from Weibull distribution are 58.88 kWh/m^2/month and 5.92 kWh/m^2/month in the month June and March respectively. But maximum power density, minimum power density estimated from Weibull Dirac distribution are 74.085 W/m^2 and 5.328 W/m^2 for

TABLE 4

Mean wind speed at different heights predicted by Weibull and Weibull Dirac functions

Month	Weibull predicted wind speed (m/s) at		Weibull Dirac predicted wind speed (m/s) at	
	10 meter	30 meter	10 meter	30 meter
January	3.08	3.98	2.66	3.43
February	2.75	3.60	2.16	2.83
March	2.32	3.04	1.55	2.04
April	2.34	3.08	1.43	1.88
May	3.36	4.27	2.44	3.10
June	4.60	5.77	4.17	5.23
July	4.43	5.54	4.20	5.25
August	4.25	5.32	3.95	4.95
September	3.59	4.56	2.89	3.67
October	2.81	3.66	1.92	2.50
November	2.86	3.66	2.28	2.92
December	3.43	4.39	2.97	3.81
Annual	3.41	4.35	2.72	3.48

TABLE 5

Monthly averaged power and energy densities obtained from data, Weibull and Weibull Dirac functions

Month	Power density from data (W/m^2)	Power density from Weibull (W/m^2)	Power density from Weibull Dirac (W/m^2)	Energy density from data (kWh/m^2/month)	Energy density from Weibull (kWh/m^2/month)	Energy density from Weibull Dirac (kWh/m^2/month)
January	16.94	19.497	16.826	12.60	14.51	12.52
February	10.75	13.540	10.629	07.23	09.10	07.14
March	05.34	07.593	05.328	03.98	05.92	03.96
April	06.55	09.830	06.006	04.72	07.08	04.32
May	29.14	37.139	27.000	21.68	27.63	20.09
June	75.34	81.772	74.085	54.25	58.88	53.34
July	61.12	63.801	60.484	45.47	47.47	45.00
August	54.14	57.864	53.814	40.28	43.05	40.04
September	51.49	42.195	33.925	37.07	30.38	24.43
October	14.37	18.714	12.763	10.69	13.92	09.50
November	17.96	18.260	14.572	12.93	13.15	10.49
December	26.73	29.356	25.451	19.89	21.84	18.94
Annual	30.82	33.30	28.41	270.79	291.71	248.87

the month of June and March respectively and Maximum, minimum energy densities are 53.34 and 3.96 kWh/m^2/month in the month of June and March respectively. The wind energy density for entire year obtained from the data is 270.79 kWh/m^2/year. The variation of power and energy densities calculated from raw data, estimated from Weibull and Weibull Dirac distribution are shown in Figs. 9 and 10 respectively. The wind power and energy density for different height is also calculated from Weibull and Weibull Dirac distribution functions and shown in Tables 6&7.

It is seen that annual energy density at 10 m and 30 m heights estimated by Weibull are 423.21 kWh/m^2/year and 789.89 kWh/m^2/year respectively. The same estimated by Weibull Dirac are 338.40 kWh/m^2/year and 631.12 kWh/m^2/year respectively.

TABLE 6

Wind power density at different heights

Month	Weibullpower density (W/m^2) at		Weibull Dirac power density (W/m^2) at	
	10 meter	30 meter	10 meter	30 meter
January	28.12	56.68	24.27	48.91
February	19.90	41.62	15.62	32.67
March	12.03	25.53	08.06	17.10
April	14.40	30.20	08.80	18.45
May	50.89	93.71	37.00	68.13
June	109.39	197.67	99.11	179.09
July	87.54	158.92	82.99	150.66
August	79.24	143.57	73.69	133.52
September	58.30	107.90	46.88	86.75
October	26.97	53.66	18.39	36.60
November	26.49	50.65	21.14	40.42
December	41.39	80.14	35.88	69.48
Annual	48.31	90.17	38.60	72.05

TABLE 7

Wind energy density at different heights

Month	Weibullenergy density (kWh/m^2/month) at		Weibull Dirac energy density (kWh/m^2/month) at	
	10 meter	30 meter	10 meter	30 meter
January	20.92	42.17	18.06	36.39
February	13.37	27.97	10.50	21.96
March	08.95	18.99	06.00	12.73
April	10.37	21.74	06.33	13.28
May	37.86	69.72	27.53	50.69
June	78.76	142.32	71.36	128.95
July	65.13	118.24	61.74	112.09
August	58.95	106.82	54.83	99.34
September	41.98	77.69	33.75	62.46
October	20.06	39.92	13.68	27.23
November	19.08	36.47	15.22	29.10
December	30.79	59.62	26.70	51.69
Annual	423.21	789.89	338.40	631.12

4.5. *Error calculation*

In order to find out the error in estimating the mean wind speed, power density and energy density by using Weibull and Weibull Dirac distribution equations 25-27 have been used. The result is shown in Tables 8-10. Where, it is seen that Weibull Dirac distribution function is having less error in estimating the aforementioned parameters compared to Weibull distribution function.

4.6. *Goodness of fit*

In order to find out whether the Weibull Dirac distribution fits the actual data the two sample Kolmogorov-Smirnov test and Chi square test has been performed using python scipy module (scipy.stats.ks_2samp, scipy.stats.chisquare). The results obtained are summarized in Table 11.

From Table 11 it is seen that for Kolmogorov-Smirnov test p value is higher than test statistics and

TABLE 8

Error in calculating mean wind

Month	Absolute Error		Relative Error		Percentage Error	
	Weibull	Weibull Dirac	Weibull	Weibull Dirac	Weibull	Weibull Dirac
January	0.375	0.006	0.1616	0.0025	16.16	0.25
February	0.514	0.001	0.2734	0.0005	27.34	0.05
March	0.664	0.006	0.4992	0.0045	49.92	0.45
April	0	0	0	0	0	0
May	0.120	0.011	0.0558	0.0051	05.58	0.51
June	0.748	0.006	0.2010	0.0016	20.10	0.16
July	0.382	0.007	0.1024	0.0018	10.24	0.18
August	0.432	0.007	0.1230	0.0019	12.30	0.19
September	1.242	0.007	0.4489	0.0027	44.89	0.27
October	1.508	0.012	0.9084	0.0072	90.84	0.72
November	0.461	0.002	0.2316	0.0010	23.16	0.10
December	0.400	0.002	0.1526	0.0007	15.26	0.07

TABLE 9

Error in calculating power density

Month	Absolute Error		Relative Error		Percentage Error	
	Weibull	Weibull Dirac	Weibull	Weibull Dirac	Weibull	Weibull Dirac
January	2.557	0.114	0.1509	0.0067	15.09	00.67
February	2.790	0.121	0.2595	0.0112	25.95	01.12
March	2.613	0.012	0.4893	0.0022	48.93	00.22
April	3.280	0.544	0.5007	0.0830	50.07	08.30
May	7.999	2.140	0.2745	0.0734	27.45	07.34
June	6.432	1.255	0.0853	0.0166	08.53	01.66
July	2.681	0.636	0.0438	0.0104	04.38	01.04
August	3.724	0.326	0.0687	0.0060	06.87	00.60
September	9.929	17.565	0.1805	0.3411	18.05	34.11
October	4.374	1.607	0.3043	0.1118	30.43	11.18
November	0.300	3.388	0.0167	0.1886	01.67	18.86
December	2.626	1.279	0.0982	0.0478	09.82	04.78

hence null hypothesis cannot be rejected at 10% or lower confidence level. For chisquare test *p* value is 1 and test statistics is 0.473 that means *p* value is higher. Hence it is evident that data closely follows Weibull Dirac distribution.

5. Conclusions

In the present study synoptic hour wind speeds of Port Blair during 2012-2019 have been analyzed. The frequency distribution of the data is plotted and it is fitted with Weibull and Weibull Dirac frequencies. The main outcomes of the study can be summarized as follows:

(*i*) The wind energy potential of Port Blair is moderate at 10 m standard height. Maximum and minimum energy and power density obtained in the month of June and March respectively. Mean annual power density at 10 m obtained from Weibull is 48.31 W/m^2 and Weibull Dirac is 38.60 W/m^2. The wind energy density at 10 m obtained

TABLE 10

Error in calculating energy density

Month	Absolute Error		Relative Error		Percentage Error	
	Weibull	Weibull Dirac	Weibull	Weibull Dirac	Weibull	Weibull Dirac
January	1.91	0.08	0.1515	0.0063	15.15	00.63
February	1.87	0.09	0.2586	0.0124	25.86	01.24
March	1.94	0.02	0.4874	0.0050	48.74	00.50
April	2.36	0.40	0.5000	0.0847	50.00	08.47
May	5.95	1.59	0.2749	0.0733	27.49	07.33
June	4.63	0.91	0.0853	0.0167	08.53	01.67
July	3.00	0.47	0.0659	0.0103	06.59	01.03
August	2.77	0.24	0.0687	0.0059	06.87	00.59
September	6.69	12.64	0.1804	0.3409	18.04	34.09
October	3.23	1.19	0.3021	0.1113	30.21	11.13
November	0.22	2.44	0.0170	0.1887	01.70	18.87
December	1.95	0.95	0.0980	0.0477	09.80	04.77

TABLE 11

Goodness of fit test result

Test name	Test statistics	*p* value
Two sample Kolmogorov-Smirnov test	0.229	0.281
Chi square test	0.473	1.000

from Weibull and Weibull Dirac are 423.21 kWh/m^2/year and 338.40 kWh/m^2/year respectively. This is not suitable for large scale wind electricity generation. But this is adequate for off grid connected electrical and mechanical applications, such as wind generators, battery charging water pumping as well as agricultural applications.

(*ii*) Mean wind speed at 6 m obtained from data varies from 1.23 m/s in April to 3.73 m/s in July. Mean wind speed at 10 m obtained from Weibull varies from 2.32 m/s in March to 4.60 m/s in June. Mean wind speed at 10 m obtained from Weibull Dirac varies from 1.43 m/s in April to 4.20 m/s in July. June, July and August are the three months having the highest wind speed and March and April having the lowest wind speed all around the year. The wind speed reaches its peak during day time at 0600 and 0900 UTC. The wind mostly blows in North East and South West directions.

(*iii*) Weibull Dirac calculated wind speed, power density and energy density more closely matches with that obtained from data than Weibull. Weibulldirac distribution also takes care of calm winds and frequency distribution matches with that obtained from the data. Hence it may be concluded that Weibull Dirac distribution is better fit for this location.

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