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Wind Speed Data And Statistical Analysis For Rangpur District In Bangladesh

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Abstract – **Wind speed is the prominent power energy resource that is used to evaluate the suitable location. This study examines the characteristics of wind speed and the potential of the wind power of Rangpur, Bangladesh over the period from 2016 to 2020 by using the statistical methods. The distributions of probability density are obtained from data over time series as well as the distributional parameters are signified. Two probability density functions; Weibull distribution and Rayleigh distribution, are used to assess the probability distributions on the monthly basis. This study is relevant with the process of decision-making regarding the significant effect of the wind power**.

Keywords-component; Weibull parameter; Shape factor; Scale factor; Wind power; R^2.

I. Introduction

"Pollution, pollution, you can use the latest toothpaste" which represents the concern of environmental by the famous USA singer Tom Lehrer. Regarding environment, the wind power is the valuable resource among the different renewable energies based on environmental case specially as non-polluting and the cost effective over time [1-3]. So, wind variations for the typical site are generally depicted by the so-called probability distribution; Weibull [4-6]. In the last several decades, many researchers have driven the ample of research relied on the assessment of wind power throughout the world. Regarding Bangladesh, several researchers have evaluated the wind power optimization in many places [7-13] based on the Weibull parameters; the shape parameter, k and the scale parameter, c.

This study reveals the analysis of the results of the measured data based on wind speed at 10 m height from 2016 to 2020 [14-15] for the city of Rangpur (located at $25^0 44^{/}$N and $89^0 16^{/}$E) in Bangladesh. As a result, long-term wind data was analyzed from the year 2016 to 2020. It should be mentioned that there is no research work about wind energy system relied on wind speed data for Rangpur, Bangladesh. The central objective of this study is to determine statistically significant or not according to wind speed data for Rangpur, Bangladesh to predict the wind energy output systems based on the rational decision-making procedure [16].

The remaining of the paper proceeds on as: Section II shows the theoretical analysis; Section III indicates results and discussion; and Section IV displays the conclusion.

II. Theoretical analysis

A. *Frequency distribution of the wind speed*

Probability density distributions of wind speed and their functional activities present major aspects of wind related researches. There are two functions used for fitting the measured wind speed probability distribution for the given site in the certain period over time by using Weibull and the Rayleigh distribution. The Weibull probability density function, that is represented as follow [5,15,17],

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

$f(v)$ is wind speed probability of v ; c is scaling parameter of Weibull distribution & k is Weibull shape factor.

The cumulative probability function based on the Weibull distribution [18-20] which is shown as,

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

The Rayleigh distribution coming from the Weibull distribution in which value of shape parameter k is 2. From the equation 1, Rayleigh distribution is expressed as [5-6],

$$f(v) = \left(\frac{2v}{c^2}\right) \exp\left[\left(-\frac{v}{c}\right)^{k}\right] \quad (3)$$

In the Weibull distribution, the mean value v_m and the standard deviation σ is computed as [5-6],

$$v_m = c\Gamma\left(1 + \frac{1}{k}\right) \quad (4)$$

and

$$\sigma = c\left[\Gamma\left(1+\frac{2}{k}\right) - \Gamma^2\left(1+\frac{1}{k}\right)\right]^{0.5} \quad (5)$$

here Γ ( ) is gamma function.

There are two meaningful factors of wind speeds for the estimation of wind energy; the maximum probable wind speed and the wind speed carrying the maximum energy, which can be achieved. The maximum probable wind speed shows the maximum frequent wind speed for the wind probability distribution that can be shown as [5],

$$v_{MP} = c\left(\frac{k-1}{k}\right)^{1/k} \quad (6)$$

The maximum energy carrying by the wind speed can be represented as follows [5],

$$v_{MaxE} = c\left(\frac{k+2}{k}\right)^{1/k} \quad (7)$$

There are the different methods which can be used in the literature to evaluate the Weibull factors; 1. the graphical method, 2. the moment method, 3. the standard deviation method, 4. the maximum likelihood method, 5. the energy pattern factor method and 6. the power density method. Among these methods standard deviation method is chosen to evaluate k and c.

A.1 Standard deviation method

Weibull parameters can be calculated from the following equations [21],

$$k = \left(\frac{\sigma}{v_m}\right)^{-1.086} \quad (8)$$

$$c = \frac{v_m}{\Gamma(1+\frac{1}{k})} \quad (9)$$

B. The vaariation of the wind speed with the height

Wind speed changes with height based on ground. The pivotal equation for the variation of the wind speed regarding height is represented as follows [5-6],

$$\frac{v_1}{v_2} = \left(\frac{h_1}{h_2}\right)^p \quad (10)$$

here v_1 and v_2 are the mean of wind speeds at the height of $h_1$and h_2. The exponent p relies on several factors such as the stability of atmosphere and the surface roughness.

C. The density of wind power

The wind power speed through the area of blade sweep; A, rises as the cubic form of its velocity which is shown as,

$$P(v) = \frac{1}{2}\rho A v^3 \quad (11)$$

here ρ is average air density (1.225 kg/m^3, according to the average atmospheric pressure from sea level at the temperature of 15° C), which relies on the temperature, altitude, and the air pressure.

The expected wind power density per unit area in a Weibull probability density function of the site based for the monthly or annual wind can be revealed as,

$$P_w = \frac{1}{2}\rho c^3 \Gamma\left(1+\frac{3}{k}\right) \quad (12)$$

The scale parameter of Weibull (m/s) is demonstrated as,

$$c = \frac{v_m}{\Gamma(1+\frac{1}{k})} \quad (13)$$

When $k = 2$, from equation (9), the Rayleigh power density model can be shown as [5-6],

$$P_R = \frac{3}{\pi}\rho {v_m}^3 \quad (14)$$

$P_{m,\ R}$ is wind power density regarding probability density distribution that can be found as,

$$P_{m,\ R} = \sum_{j=1}^{n}\left[\frac{1}{2}\rho {v_m}^3 f(v_j)\right] \quad (15)$$

The error of power densities by using the probability distributions is calculated from the following equation [5],

$$\text{Error } (\%) = \frac{P_{w,\ R} - P_{m,\ R}}{P_{m,\ R}} \quad (16)$$

Where $P_{w,\ R}$ is average power density obtained from either the Weibull or Rayleigh function used in the error calculation.

The yearly average error can be obtained from the power density by the Weibull function shown as,

$$\text{Error } (\%) = \frac{1}{12}\sum_{i=1}^{12}\frac{P_{w,\ R} - P_{m,\ R}}{P_{m,\ R}} \quad (17)$$

D. The statistical analysis based on distributions

The statistical analysis parameters; the correlation coefficient (R^2), chi-square (χ^2), and root mean square error (RMSE), are executed to estimate the performances of different distributions relied on Weibull and Rayleigh [5]. These parameters are determined as,

$$R^2 = \frac{\sum_{i=1}^{N}(y_i - z_i)^2 - \sum_{i=1}^{N}(x_i - y_i)^2}{\sum_{i=1}^{N}(y_i - z_i)^2} \quad (18)$$

$$\chi^2 = \frac{\sum_{i=1}^{n}(y_i - x_i)^2}{N - n} \quad (19)$$

$$\text{RMSE} = \left[\frac{1}{\text{N}}\sum_{i=1}^{N}(y_i - x_i)^2\right]^{1/2} \quad (20)$$

here y_i is ith measured data, the mean value is called as z_i, x_i is predicted data related with the Weibull or Rayleigh distribution, N is denoted as number of observations and n is number of constants [5-6]. So, when the value of R^2 is maximum and the value of RMSE, and χ^2 is minimum as a result the more probability distribution will be selected.

III. RESULTS AND THE DISCUSSION

Wind speed data from the period of 2016-2020 for Rangpur, Bangladesh was analyzed at the height of 10 m from the ground. Relied on this information, the wind speeds were analyzed by statistical methods. The most important results achieved from this study are briefed as in Table I.

Calculated the value of monthly mean wind speed and the standard deviation from the data based on time series; Figure 1 [14-15], are shown in Table I. It is observed that the maximum wind speed is observed in June and July month in whole year whereas the minimum value is found in month of October and November in the whole year.

Monthly mean wind speed data of Rangpur between years 2016 to 2020 are demonstrated in Figure 1. This figure reveals that the trend of monthly mean wind speed for the different years are almost similar. It is also indicated, the wind speed has the lowest value in December and the highest value in June for the whole year.

The derivations of the time-series data of Rangpur relied on probability density distributions on monthly basis and the cumulative distributions for whole year be represented in Figure 2, and Figure 3. It shows that all the curves have almost alike tendency regarding wind speed for the cumulative density and probability density. In addition, Figure 4 provides yearly probability density distribution and the cumulative distribution, respectively.

The calculated Weibull parameters from the available data time series are represented in Table II. It is observed from table that the shape parameter ranges from between 1.893 (September 2016) and 3.289 m/s (July 2017), while scale parameter varies between 6.547 (December 2017) and 20.211 m/s (May 2019) for that site, respectively. It is analyzed that the variation of the parameter k has much lower than that of the parameter c.

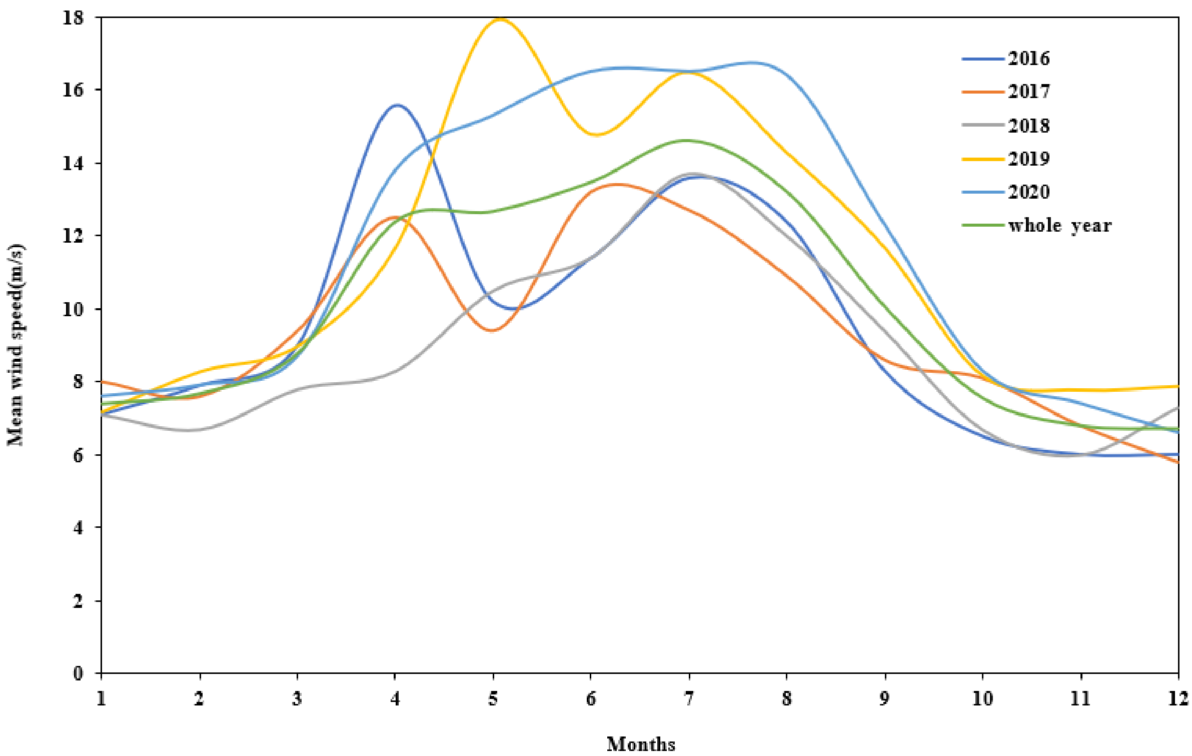

Figure 1. Monthly wind speed of Rangpur 2016-2020.

TABLE I: THE MONTHLY MEAN WIND SPEED AND STANDARD DEVIATION IN RANGPUR, 2016-2020.

Time period	2016		2017		2018		2019		2020		**Whole year**	
Parameter	v_m	σ	v_m	σ	v_m	σ	v_m	σ	v_m	σ	$\boldsymbol{v_m}$	**σ**
January	7.1	3.37	8	3.5992	7.1	3.447	7.2	3.012	7.6	3.389	**7.4**	**3.4634**
February	7.9	3.2235	7.6	3.245	6.7	2.849	8.3	4.082	7.9	4.254	**7.68**	**3.5308**
March	9	4.645	9.4	4.2150	7.8	4.194	9	4.9713	8.7	5.149	**8.78**	**4.6348**
April	15.6	6.1969	12.5	4.8213	8.3	3.1	11.7	5.621	13.8	7.958	**12.38**	**5.5394**
May	10.2	5.16	9.4	4.7114	10.5	4.0204	17.9	8.911	15.3	7.0687	**12.66**	**5.9741**
June	11.4	5.0096	13.2	5.9645	11.4	5.41	14.8	7.1508	16.5	7.183	**13.46**	**6.143**
July	13.6	5.868	12.7	4.2429	13.7	4.9569	16.5	6.5831	16.5	6.177	**14.6**	**5.565**
August	12.4	5.67	10.9	4.3322	12	4.517	14.3	5.5334	16.4	6.606	**13.2**	**5.331**
September	8.3	4.6106	8.6	4.1968	9.4	4.229	11.7	5.481	12.3	5.531	**10.06**	**4.809**
October	6.5	3.1784	8.1	3.7984	6.7	3.0249	8.2	3.591	8.3	3.9637	**7.56**	**3.511**
November	6	2.9487	6.8	2.8189	6	2.8738	7.8	3.9233	7.4	3.952	**6.8**	**3.303**
December	6	2.8767	5.8	2.9678	7.3	2.9964	7.9	3.3525	6.6	2.9371	**6.72**	**3.025**
Yearly	**9.5**	**4.396**	**9.42**	**4.076**	**8.91**	**3.801**	**11.275**	**5.184**	**11.441**	**5.347**	**10.108**	**4.561**

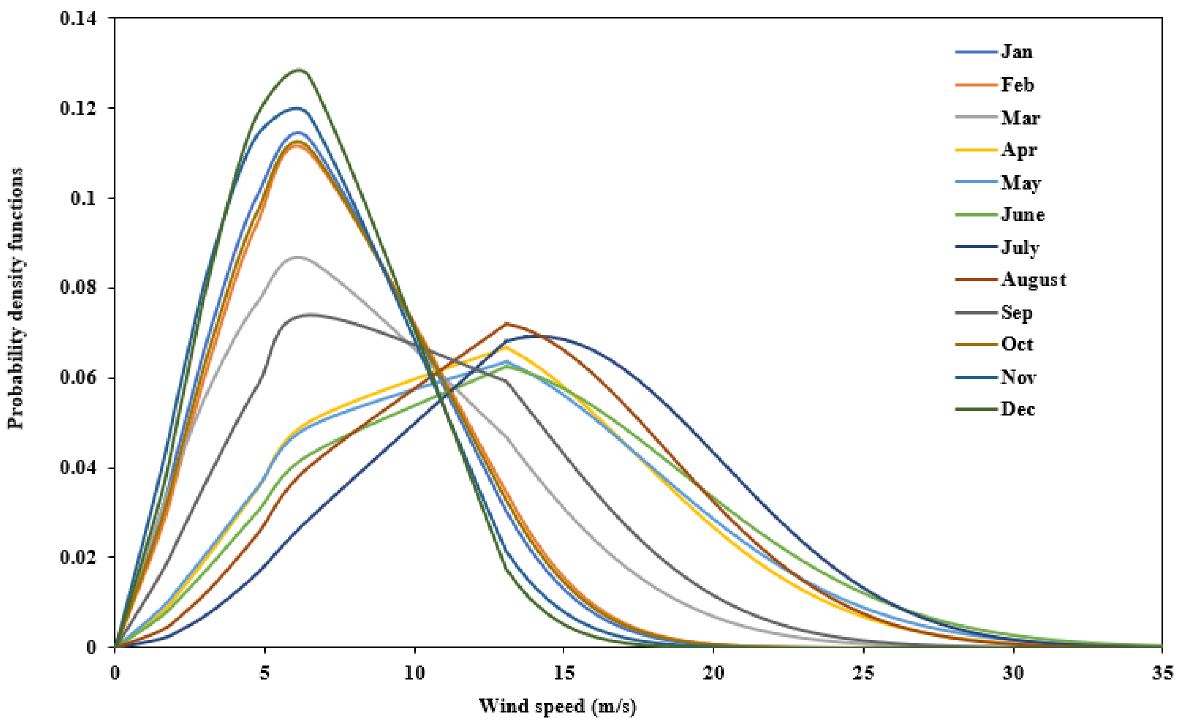

Figure 2. The monthly wind speed probability density distributions resulted from time series data of Rangpur for the whole year

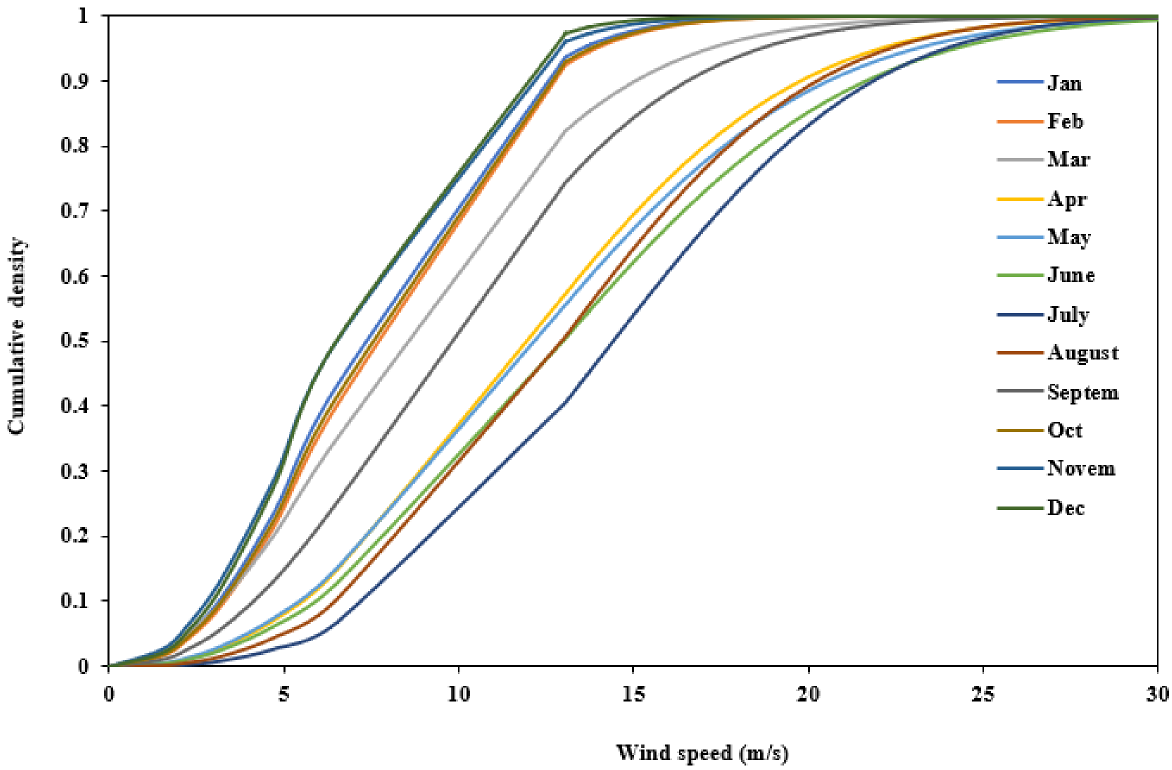

Figure 3. The cumulative probability density distributions of the monthly wind speed coming from measured data of Rangpur for the whole year

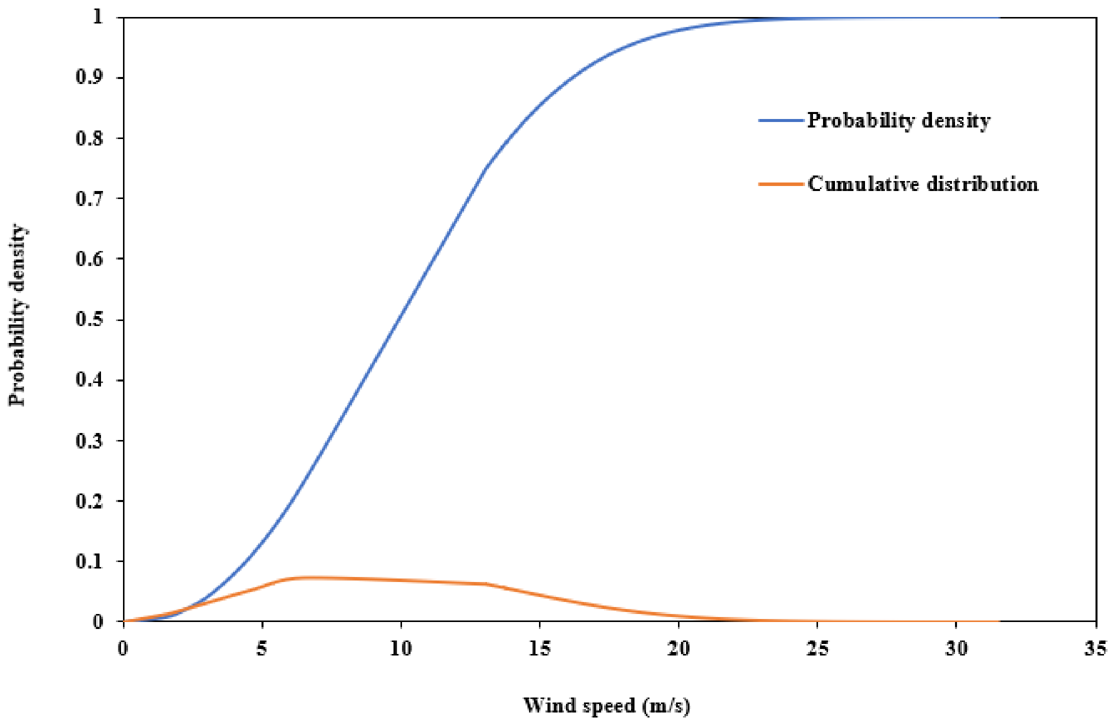

Figure 4. The yearly probability density and cumulative probability distributions of wind speed, obtained from measured data of Rangpur for the whole year

TABLE II. THE MONTHLY SHAPE PARAMETER; K, AND SCALE PARAMETER;C, IN RANGPUR, 2016-2020.

Years	2016		2017		2018		2019		2020		**Whole year**	
Parameter	k	c	k	c	k	c	k	c	k	c	$\boldsymbol{k}$	$\boldsymbol{c}$
January	2.246	8.016	2.38	9.025	2.191	8.017	2.576	8.108	2.403	8.572	**2.359**	**8.347**
February	2.647	8.889	2.519	8.563	2.161	9.372	2.161	9.372	1.958	8.91	**2.363**	**8.654**
March	2.051	10.159	2.389	10.604	1.961	8.797	1.905	10.143	1.767	9.773	**2.014**	**9.895**
April	2.725	17.536	2.814	14.035	2.914	6.306	2.216	18.551	1.818	15.525	**2.497**	**14.278**
May	2.096	11.516	2.117	10.613	2.836	11.785	2.132	20.211	2.313	17.269	**2.298**	**14.278**
June	2.442	12.855	2.369	14.893	2.246	12.87	2.203	16.711	2.467	18.602	**2.345**	**15.186**
July	2.491	15.329	3.289	14.16	3.016	15.338	2.712	18.551	2.906	18.502	**2.88**	**16.376**
August	2.339	13.993	2.723	12.253	2.889	13.459	2.804	16.058	2.684	18.445	**2.6878**	**14.842**
September	1.893	9.352	2.179	9.711	2.38	10.605	2.278	13.208	2.382	13.876	**2.222**	**11.351**
October	2.175	7.339	2.276	9.144	2.371	7.559	2.451	9.246	2.231	9.376	**2.3**	**8.533**
November	2.162	6.775	2.602	7.655	2.224	6.774	2.109	8.806	1.976	8.348	**2.214**	**7.672**
December	2.221	6.774	2.07	6.547	2.63	8.215	2.536	8.9	2.409	7.444	**2.3732**	**7.576**
Yearly	**2.309**	**10.722**	**2.483**	**10.614**	**2.521**	**10.037**	**2.325**	**12.725**	**2.284**	**12.915**	**2.384**	**11.403**

TABLE.III: COMPARISON OF WIND SPEED OF ACTUAL PROBABILITY DISTRIBUTION WITH WEIBULL AND RAYLEIGH APPROXIMATION FOR THE WHOLE YEAR

$f(v)$			
Data of wind speed	Actual data	Probability density function	Rayleigh
1	0.011911826	0.007337598	0.015331
2	0.018017797	0.018760187	0.030267
3	0.025974452	0.031895135	0.044238
4	0.035687199	0.045434112	0.056602
5	0.046730442	0.058237734	0.066781
6	0.058318813	0.069293405	0.07421
7	0.069364748	0.077772036	0.078635
8	0.078630369	0.08309871	0.079939
9	0.084949959	0.085005091	0.078258
10	0.087469649	0.083546825	0.073952
11	0.085836689	0.079079552	0.067553
12	0.080280467	0.072196624	0.059704
13	0.071559645	0.063639507	0.051217
14	0.060792194	0.054196873	0.042399
15	0.049220818	0.044609517	0.033945
16	0.037981419	0.035495588	0.026368
R^2		0.96407	0.82089
χ^2		0.00084	0.000423
RMSE		0.00602	0.01316

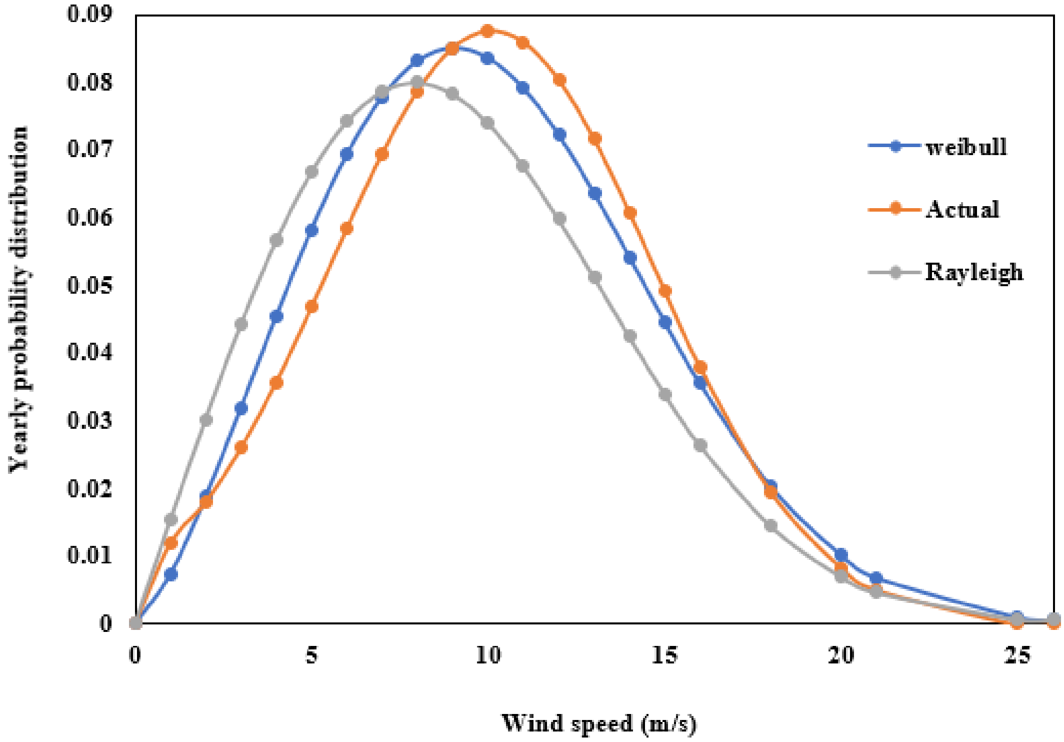

Figure 5. The wind speed of the actual probability distributions of Weibull and Rayleigh approximations .

TABLE. IV: YEARLY WIND SPEED CHARACTERISTICS 2016-2020, RANGPUR.

Year	v_m (m/s)	K	c (m/s)	v_{MP} (m/s)	v_{MaxE} (m/s)	P (w/m^2)
2016	9.5	2.309	10.7228	8.3860769	14.049294	880.648381
2017	9.416	2.483	10.614	8.6244589	13.46538	810.583155
2018	8.908	2.521	10.037	8.214056	12.65387	678.689564
2019	11.275	2.325	12.725	9.9913112	16.618772	1463.97031
2020	11.441	2.284	12.915	10.036445	17.009389	1551.98838

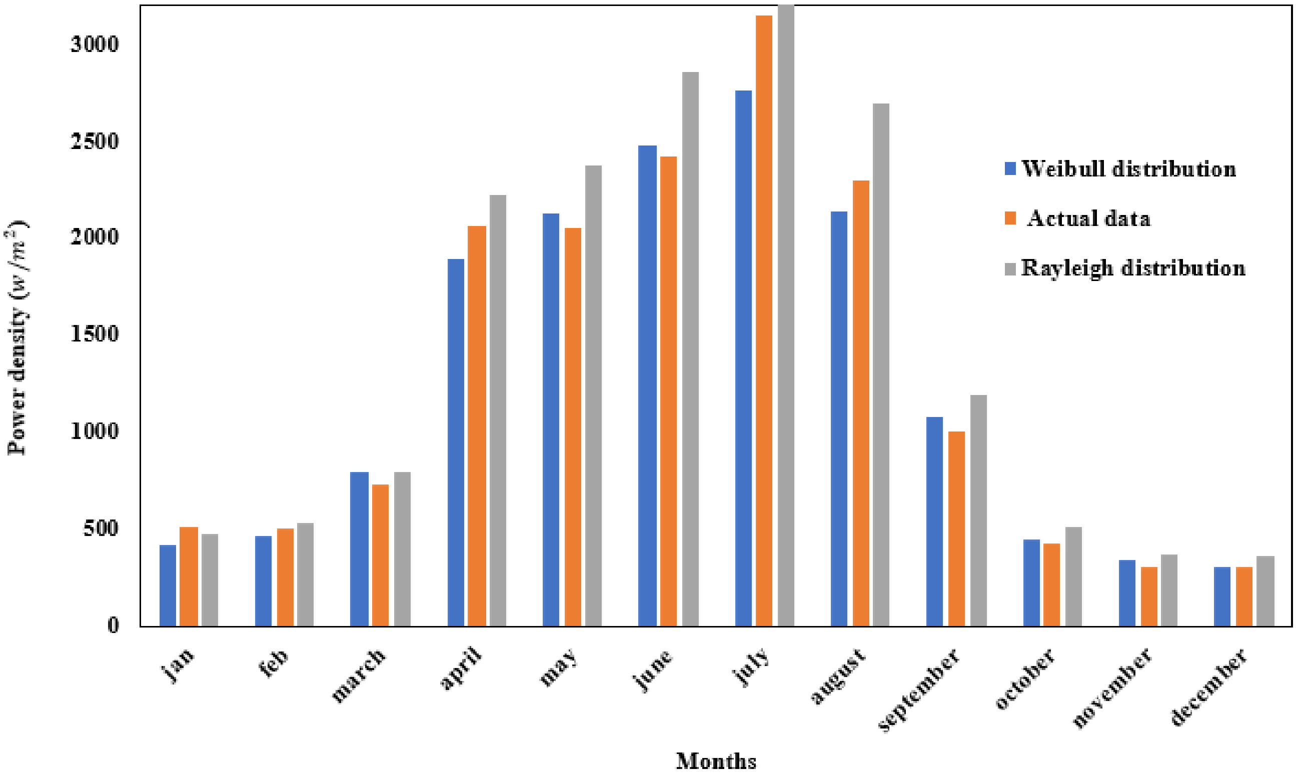

Figure 6. The wind power densities achieved from actual data versus those data obtained from Weibull and Rayleigh models on the basis of month

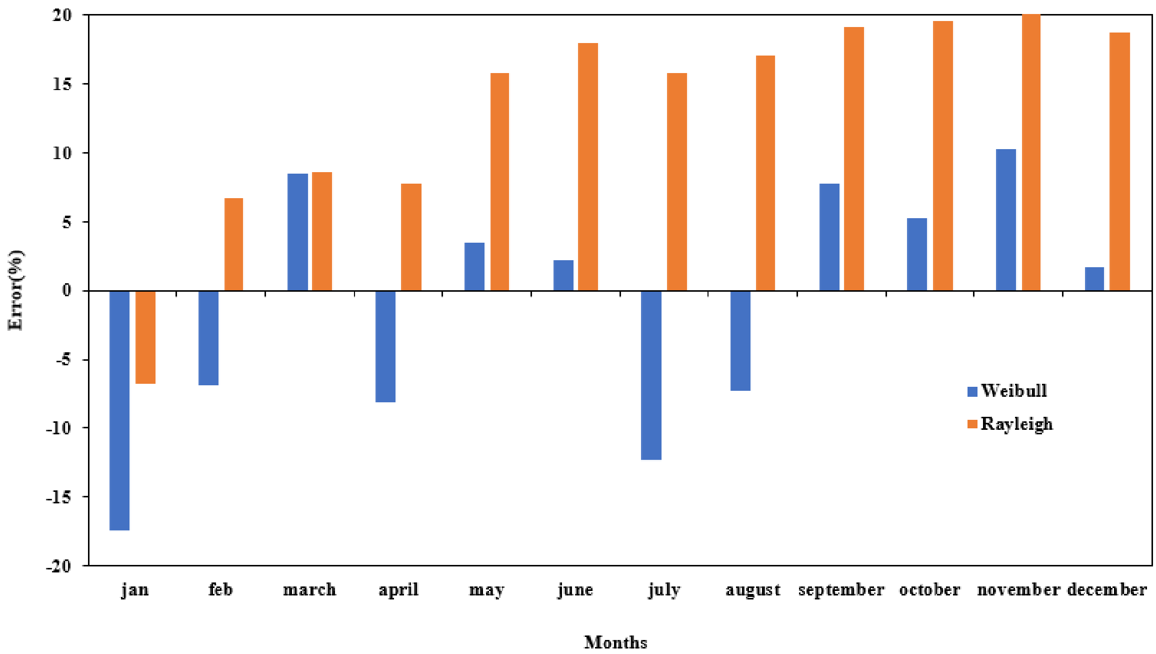

Figure 7. The calculating of error values of the wind power density on the basis of month achieved from the models of Weibull and Rayleigh based on power density achieved from the measured data.

The Weibull and Rayleigh approximate distributions of the actual probability distribution of the wind speed for the whole year are described in Figure 5, while the comparison of the two approximations with the actual probability distribution are shown in Table III. From the Table III, the maximum R^2 value was achieved by Weibull distribution. By contrast, the results value of the RMSE and χ^2 of Weibull distribution are smaller than that of Rayleigh distribution. As a result, the Weibull approximation is appeared as the most perfect distribution based on the maximum R^2 value and the minimum RMSE and χ^2 values. In addition, these comparisons are used to the evaluated the distributions to study the suitability.

Table IV indicates the yearly Weibull parameters, yearly mean wind speed, and yearly wind power density. It shows that the wind power density value is minimum in 2018, but it is maximum in 2020.

The power density obtained from calculated probability density distributions and those achieved from the Weibull and Rayleigh distributions which are displayed in Figure 6. The minimum power densities are found in November and December and in contrast, the maximum value of power density obtained in June and July month. The power density of rest months lies between these groups of maximum and minimum. The errors of power densities using distributions in comparison with calculated probability distributions are demonstrated in Figure 7. The lowest error values regarding power densities are found almost in Weibull model than that of Rayleigh model. The maximum error value arises in January with 17.39% for the Weibull model and the minimum error value occurs in December with 1.6%, respectively. According to Rayleigh model, highest error value is in the November with 20.17%, and minimum error is in the February with 6.75%.

CONCLUSION

The characteristics of wind of Rangpur from the period of 2016-2020 are analyzed by statistically. The probability density distribution and the power density distribution have been obtained from wind speed data over time. Two probability density functions are used to calculate the probability distributions based on the monthly basis. The potential of wind energy of this site has been analyzed regarding the models of Weibull and Rayleigh. The key features as outcome are that Weibull distribution shows better power density mostly than Rayleigh distribution based on R^2, RMSE and χ^2 values. The wind power density may indicate the significant variation due to wind speed over time. This paper is immensely useful in the accurate and efficient estimation of the wind speed data.

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