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Assessment of Wind Power Potentials in Chittagong, Bangladesh Using Weibull Distribution Function

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ABSTRACT

Wind resource assessment is a key stage in planning for a wind energy project to predict the output power. Therefore, a full understanding of the wind characteristics at the potential site is required. This study examines the potential wind power of twelve meteorological stations in the Chittagong division over a tenure of ten-year ranges from 2010 to 2019. The statistical analyzer as the Weibull two-parameter distribution method has been utilized to determine the characteristics of wind speed and wind energy potential at the selected locations. The "WRPLOT" software has also been used to display the wind direction and the corresponding wind speed direction. Among these stations, Ambagan has a high wind factor, ranging from 2.1 to 3.2 m/s. The highest wind speed for Ambagan station was recorded in April (3.26 m/s) and the lowest was in November (1.06 m/s) compared to other selected stations. The Weibull form parameter (k) and scale parameter (c) at Ambagan station had the highest values of 1.5 and 3.5 m/s, respectively. With additional analysis and observation of these parameters, it became possible to predict the location in Chittagong with the greatest wind energy potential. In terms of wind direction, the prevailing wind direction of all stations is generally in the south. Furthermore, the results concluded that all of the analyzed parameters considered for wind behavior were numerically higher for Ambagan in contrast to other stations of the Chittagong division. This study clearly indicates that the Ambagan station should be used to maximize the potential of wind energy to attain the future goals of sustainable development for Bangladesh.

1. Introduction

Any country's industrial development is based on achieving a balance between energy generation and utilization. The energy supply depends on the available renewable and non-renewable resources of energy. However, non-renewable resources of energy are decimating continuously, and their shortage is particularly seen in developing countries [1-3]. Besides, the negative impacts of using fossil fuels for energy generation lead to environmental pollution due to the emission of Carbon

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dioxide. Hence, using renewable energy choices not only manages to decrease fossil-fuel demand but also helps to minimize the risk of the greenhouse effect [4-6]. Given that green energy resources are continually produced by nature, hence, mankind has access to an endless supply of environmentally sustainable energy. As a result, it is one of the most highly researched sources of energy that is quickly replacing conventional energy sources [7-9]. Furthermore, due to the current rising population around the globe, economic development, and technology development, today's energy demands are on the rise [10]. In addition, given the existing energy consumption rates and new energy development circumstances, discovered assets will be reduced in a few decades. Therefore, energy is identified as a significant factor in our lives [11,12].

Similarly, in comparison to the rest of the world, Bangladesh's main energy supply situation is also devastating. Bangladesh's existing resources of natural gas, coal, oil, and hydropower are limited. Therefore, a larger scaled infrastructure production is required [13]. However, although the world's overall primary energy consumption per capita is equal to 21980.33 kWh, Bangladesh's government provided 70% of electric energy to the country's 160 million citizens in 2015, and per capita energy generation is currently only 372 kWh [14]. This consumption is significantly lower than the world's energy consumption per capita [15]. Bangladesh generates most of its electrical energy from national grid gas and petrol which is nearly 62.31%. According to the "Bangla" report, gas energy provides 80% of Bangladesh's power production [16]. As a result, the overall generation of electricity is operated by local energy sources, with just 4.28% imported, which is the main factor of the challenges for future electrification of Bangladesh [17]. However, although the electric generation capacity of Bangladesh reported was a maximum of 8122 MW in 2015, however, the demand was 10,283 MW at that time, and the installed capacity was 13265 MW [18,19]. Thus, Bangladesh has a higher power generation deficit than demand, which is a barrier to the country's development and advancement.

Bangladesh is a country with promising potential in terms of renewable energy resources. The main source of renewable energy is biomass or biofuel, and it is used in both cooking and the production of electricity. Moreover, solar energy is another significant energy source in Bangladesh, and solar photovoltaic cells are one of the widest ranges of used technologies particularly in rural areas [20]. Furthermore, the country has also a lengthy history of hydroelectric power generation typically with small scale hydropower generation. Another renewable energy resource utilized in Bangladesh is wind energy with mini and micro wind power sites for electricity generation [21]. In recent years, the country has experienced great growth, with an average gross domestic product growth rate of 6%. The need for electricity in the country has expanded as a result of the country's fast economic expansion, fast urbanization, and rising industrialization and development. It is well acknowledged that energy is an essential aspect in reducing poverty and strengthening the socioeconomic situation of Bangladesh people. The government's goal is to guarantee the supply of electricity to everyone by 2021. Therefore, to realize the strategy, the government of Bangladesh has given high priority to the power sector and established short, medium, and long-term power generating projections focused on gas, coal, dual fuel, nuclear, and renewable energy resources. Whereas renewable energy will be a significant aspect in satisfying electricity demand, particularly in off-grid parts of this country. The government is aiming to produce 5% of total electricity production using renewable energy sources by 2015, and 10% by 2020. The government has launched a variety of renewable energy programs in order to reach this aim. Most of the new capacity should be provided by using solar energy with 54% and by using wind energy with 44 % capacity. However, when data from 2016 to 2018 is examined, it indicates that, to meet the target requirements for wind energy will be difficult [15,17,22]. However, Bangladesh has a limited number of wind power plants. Even at stated heights, wind evaluation for longer durations is unavailable.

On the other hand, there are several statistical techniques that can be used to assess the wind potential of a site, such as Weibull distribution and Rayleigh distribution functions. Weibull distribution function is commonly used to model wind speed data. By fitting a Weibull distribution to wind speed data, the shape and scale parameters of the distribution can be determined, which can be used to calculate the annual energy production (AEP) of a wind turbine. The Weibull distribution is characterized by two parameters which are the shape parameter (k) and scale parameter (c). Through this technique, the frequency of occurrence of different wind speed ranges at a site can be determined. This can be used to identify the most common wind speed ranges, which can be used to estimate the AEP of a wind turbine. Moreover, the power density analysis can also be estimated based on the wind speed and the power output of a wind turbine. Furthermore, the wind direction is estimated using wind rose analysis. It is a graphical technique that provides information about the direction and frequency of wind at a site. A wind rose diagram is a circular diagram that shows the percentage of time the wind blows from different directions [23-25].

Therefore, this study seeks to assess and identify the wind power and wind energy potentials including the seasonal variations and prevailing wind direction of the Chittagong division which will undoubtedly help to come out with a suitable solution in the identification of appropriate and available wind resources for attaining the goal of sustainable development in Bangladesh as a whole.

2. Materials and Methods

2.1 Wind Data Collection and Site Description

The wind data for this study was gathered from the Bangladesh Meteorological Department (BMD) and which is the national meteorological organization of Bangladesh. The geographical coordinates of twelve stations in Chittagong divisions throughout the country are provided in Table 1. This data significantly covers a wide range of ten years (2010-2019), and it was recorded every month in averaged form, at a standard 10m height above the ground level. These locations in twelve stations signify various geographical and climatological conditions, namely, Comilla, Chandpur, Feni, Magistrate court, Hatiya, Sitakunda, Sandwip, Kutubdia, Cox's Bazar, Teknaf, Rangamati, Ambagan, as shown in Figure 1.

Table 1
Physical features of the meteorological stations in the Chittagong division

Name of Station	Latitude (N)	Longitude (E)		Elevation (m)	
Comilla	23	45	91	19	72
Chandpur	23	23	90	66	51
Feni	23	01	91	39	12
M.court	22	35	91	78	29
Hatiya	23	30	85	30	6
Sitakunda	22	61	91	68	37
Sandwip	22	49	91	27	7
Kutubdia	21	82	91	85	37
Cox's bazar	21	42	92	00	3
Teknaf	20	85	92	29	7
Rangamati	22	65	92	17	45
Ambagan	22	25	84	86	29

Fig. 1. Division map of Bangladesh

2.2 Weibull Distribution Function

The wind speed characteristics and the wind power potentials of any specified area can be estimated by using several statistical methods among which the widely acceptable technique is the Weibull distribution [22]. This method comprises different techniques to estimate the scale and shape parameters of Weibull based on the form of accessible data and the required level of complexity. Eq. (2) and Eq. (6) represent the "probability density function" (PDF) and "cumulative distribution function" (CDF), respectively to characterize the variations in wind speed of this method. The PDF specifies the portion of time or the probability of which the wind speed prevails in a particular way. Whereas the CDF represents the probability of which the wind speed is lower than or equal to its mean speed [27]. Therefore, the two-parameter Weibull distribution function which is flexible, simple, and has the capability to provide good agreement with the perceived data, was implemented in this work to statistically analyze the meteorological data [28-37]. The wind energy density and the wind speed characteristics can be effectively studied by applying this method. Even, this two-parameter Weibull distribution function is used in most of the commercially available software to estimate the Annual Energy Production (AEP) [38]. Eq. (3) and Eq. (4) show the two parameters of the Weibull distribution function, i.e., the scale function, c in meters per second unit, and the dimensionless shape function, k in meters per second unit, correspondingly, representing the wind's stability and strength at a specific location [39,40].

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

where v is the probability of observing the wind speed v. c is the Weibull scale parameter and k is the dimensionless Weibull shape parameter and they are given as follows:

$$k = 0 \cdot 83\, \bar{V}^{0\cdot 5} \quad (2)$$

$$c = \frac{\bar{v}}{\Gamma\left(1+\frac{1}{k}\right)} \quad (3)$$

Γ is the gamma function and $\bar{v}$ is the average wind speed and can be expressed as

$$\bar{v} = \frac{1}{n}\left[\sum_{i=-1}^{n} v_i\right] \quad (4)$$

The cumulative distribution, as given in the below equation, is the integral of the probability density function

$$\mathrm{F(v)} = 1 - \mathrm{e}^{-\left(\frac{\mathrm{v}}{\mathrm{c}}\right)^{\mathrm{k}}} \quad (5)$$

2.3 Wind Speed Carrying Maximum Energy

The shape and scale parameters of the Weibull distribution provide the formula for wind speed, i.e., Vmax.E when maximum wind energy is carried at a specified site and it is presented by Eq. (6) [41]. The wind speed with maximum energy indicates the wind's strength, stability, and persistence at that specified site and it is not the same as the average and highest wind speed. Therefore, it is important to estimate the wind speed of a specified site that can carry maximum energy. At the same time, the suitable wind turbine and the rated wind speed can also be determined by using this because when the wind turbine operates at the rated speed, the maximum energy is carried out by the wind speed

$$V_{max}E = c\left(1 + \frac{2}{k}\right)^{1/k} \quad (6)$$

2.4 Wind Power Density

Eq. (8) describes the formula of producing energy from the wind's kinetic energy that is proportional to the cube of the velocity where it is considered that the wind flows through a blade of swept area, A. The generation of energy that is started by a wind turbine after starting its operation increases with the increasing wind speed and continues to increase up to the cut-out speed of the wind turbine. Power generation reaches its peak by running the wind turbine at the rated speed. Whereas steady power generation is possible by operating the wind turbine at a speed in between the rated and cut-out speeds. The turbine stops working as a precaution of safety by avoiding any damage when the wind speed exceeds its cut-out speed.

$$P(v) = \frac{1}{2} A\rho v^3 \quad (7)$$

The wind power density based on Weibull distribution analysis is calculated using the following Eq. (9).

$$\Gamma(z) = \int_0^{\infty} \frac{1}{2}\rho v^3 f(v)dv = \frac{1}{2}\rho c^3 \Gamma\left(\frac{k+3}{k}\right) \quad (8)$$

where ρ defines the air density (1.225 kg/m^3) at sea level with 1 atmospheric pressure and a mean temperature of 15°C.

2.5 Wind Energy Density

Wind energy density, a vital wind characteristic can be estimated if a site's wind power density is known for a particular period or duration. Eq. (10) is used to calculate the wind energy density for the chosen time duration [42].

$$\frac{E}{A} = \frac{1}{2}\rho c^3 \Gamma(\frac{k+3}{k})T \quad (9)$$

where T is the chosen time duration, e.g., 720h or 8640h can be considered as T, for the wind energy density of one month or a year time, respectively.

3. Results and Discussion

3.1 Seasonal Variation of Wind Speed

The monthly variations of wind speed of all stations under study are shown in Figure 2. It is observed that the monthly maximum values of wind speed during the ten years of the study, were almost in the range of 0.6 m/s to 3.2 m/s for all the twelve stations of the Chittagong division and monthly minimum values were in the range of 0.14 m/s to 1.94 m/s respectively.

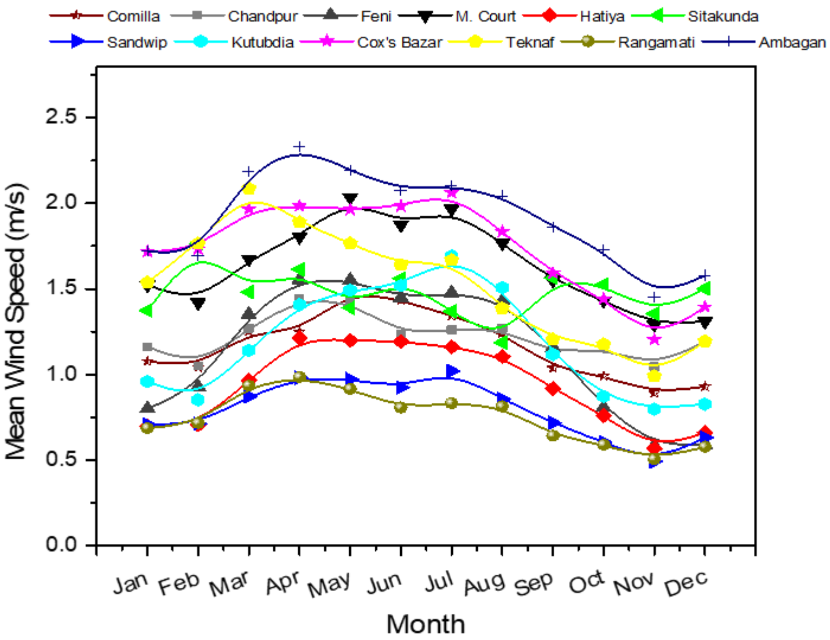

Fig. 2. Monthly average wind speed for all stations

Among these stations, the Ambagan station possesses a high wind factor with a range of 2.1 m/s to 3.2 m/s and the Magistrate court is listed as the second station with high wind speed values among the remaining stations. The wind speed for the Magistrate court ranged from 1.6 m/s to 3 m/s. The highest wind speed for Ambagan station was recorded in April (3.26 m/s) and the lowest was in November (1.06 m/s). While the highest average wind speed for the Magistrate court station was recorded in July (3.0 m/s) and the lowest was in November (0.48 m/s). The monthly analysis for wind speed clarifies that the continuous increment in wind speed was observable from January to July and after the drop in values occurs up to the end of the year. This analysis also elaborates that the Rangamati station consistently possesses the last position with the high and low accuracy of wind speed.

3.2 Weibull Parameters

For all the stations under analysis, the annual mean scale parameter c (m/s) and form parameter k (dimensionless) of the Weibull distribution has been calculated and tabulated in Table 2. For almost all the stations, the annual values of parameter k ranged between 0.645 and 1.258, except for Ambagan station, where it was between 1.042 to 1.258. This indicates that this station has high stability and high persistence compared to the others. The scale parameter c, which was slightly greater than other stations, ranged from 1.602 to 2.470, respectively. The annual variation of wind speed with maximum and minimum parameters is shown in Figure 3. It is observed that the annual maximum values of wind speed during the period of study (ten years), were almost in the range of 0.71 m/s to 2.29 m/s for all the stations of the Chittagong divisions. Among these stations, the Ambagan station possesses a high wind factor with a range of 1.57 m/s to 2.29 m/s. As a result, the complete analysis was carried out utilizing the formulated equations that acknowledge Ambagan station as a prospective wind energy site.

Table 2
Annually averaged Weibull parameters

Station	Parameters	
	K (-)	*c (m/s)*
Comilla	0.89	1.12
Chandpur	0.92	1.19
Feni	0.88	1.06
M. Court	1.03	1.56
Hatiya	0.80	0.82
Sitakunda	1.01	1.48
Sandwip	0.74	0.65
Kutubdia	0.91	1.13
Cox's Bazar	1.09	1.80
Teknaf	1.02	1.54
Rangamati	0.72	0.61
Ambagan	1.15	2.01

3.3 Wind Power Density

The Annual average wind power density and wind energy density of selected twelve stations of the Chittagong division ranging from the year 2010-2019 were analyzed at the selected height of 10 m with attained values, as shown in Figure 3 and Table 3 below respectively. The average wind power density ranges between about 5 kW/m^2 and 20 kW/m^2. The highest power density is seen at Ambagan station, while the lowest potential is found at Rangamati station. Similarly, the corresponding annually averaged wind energy density and average wind speeds are witnessed at the same stations since the power density and wind energy density are a function of wind speed with the maximum and minimum wind energy densities of 167.63 kWh/m^2 and 38.29 kWh/m^2, respectively at Ambagan and Rangamati stations.

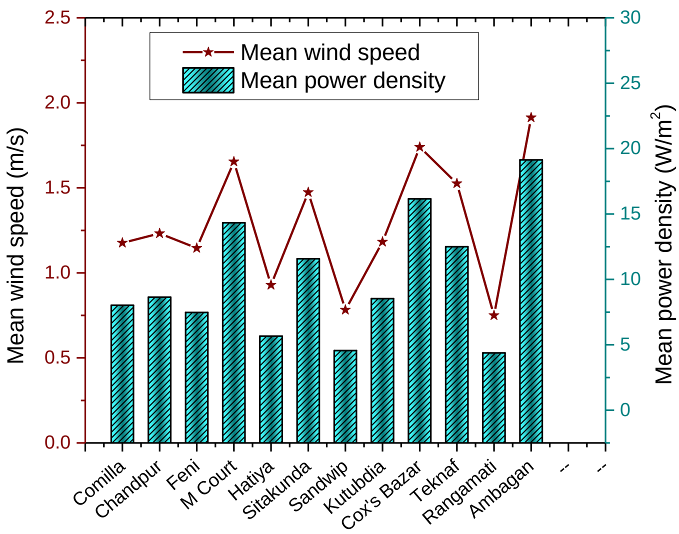

Fig. 3. Annual average wind power density and wind speed for all stations

Moreover, the present method of analysis also evaluated the wind speed carrying maximum energy for the timeline of 2010 to 2019 of selected 12 stations in the Chittagong Division, as shown in Table 3. However, unlike the average wind speed which has seen a significant variation between the stations, the variation of the wind speed carrying maximum energy is rather small. This is because although wind speeds Chittagong division are different, the wind speed that could produce actual energy in the region is about 4 m/s.

Table 3
Annual average wind power density, wind energy density and wind speed carrying maximum energy

Station	Wind power density (kW/m^2)	Wind energy density (kWh/m^2)	Vmax.E (m/s)
Comilla	8.02	70.28	4.11
Chandpur	8.64	75.70	4.16
Feni	7.47	65.41	4.10
M. court	14.33	125.53	4.56
Hatiya	5.66	49.61	3.94
Sitakunda	11.58	101.41	4.38
Sandwip	4.55	39.89	3.82
Kutubdia	8.53	74.72	4.15
Cox's Bazar	16.16	141.52	4.66
Teknaf	12.50	109.47	4.44
Rangamati	4.37	38.29	3.90
Ambagan	19.14	167.63	4.84

3.4 Wind Direction

In order to obtain an efficient assessment of the wind potentials at a site, in addition to other parameters such as the wind speed carrying maximum energy, wind power and energy densities, the identification of the prevailing wind direction is rather significant. Thus, the polar diagrams were calculated and elaborated as shown below to identify the level of proper wind direction or the prevailing wind direction. By looking at figures from Figure 4 to Figure 11, it is apparent that the prevailing wind direction in the Chittagong division is generally south. This indicates that any adaptation of wind turbines in the region needs to be in accordance with the identified prevailing wind direction, particularly for horizontal axis wind turbines. However, for vertical axis wind turbines, the wind direction is not important since it is insensitive to wind direction and accommodates wind from any direction to swing.

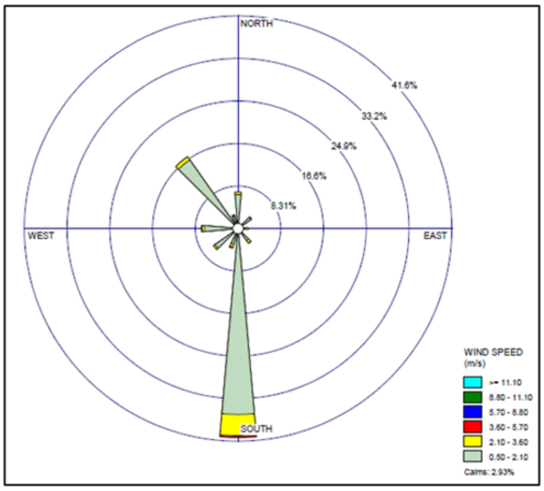

Fig. 4. Wind direction of Comilla

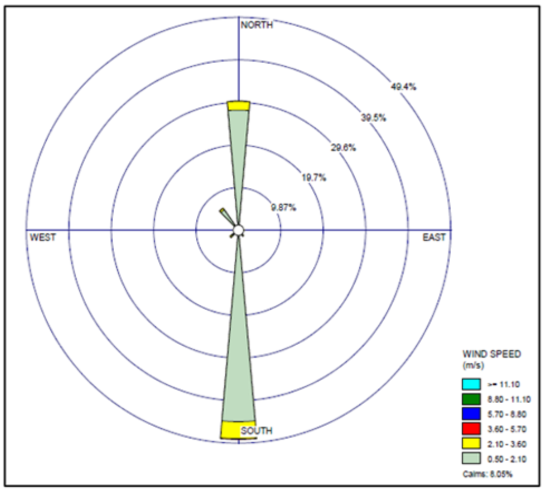

Fig. 5. Wind direction of Chandpur

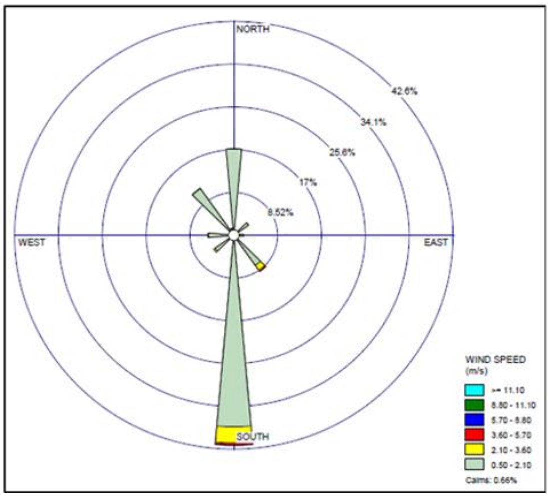

Fig. 6. Wind direction of Feni

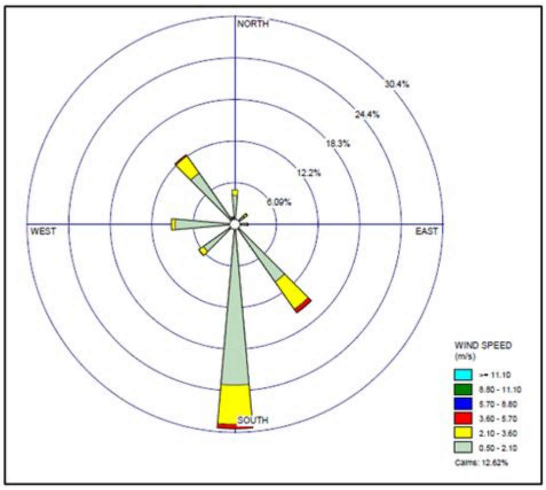

Fig. 7. Wind direction of Magistrate Court

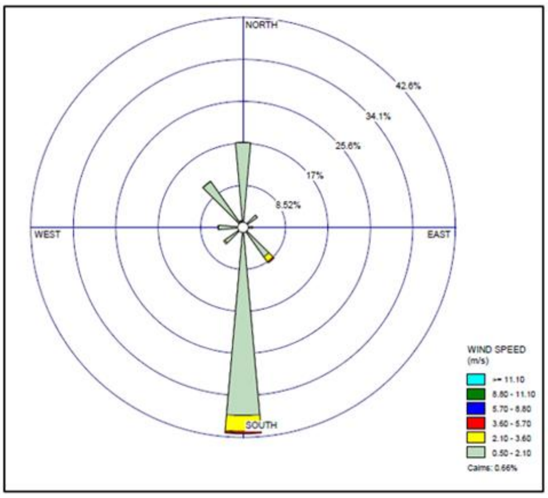

Fig. 8. Wind direction of Hatiya

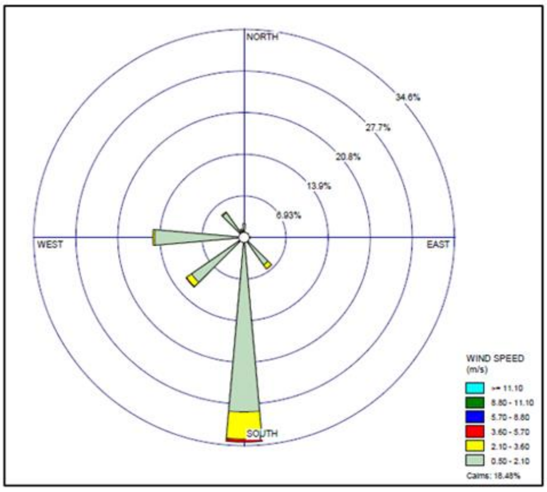

Fig. 9. Wind direction of Sitakunda

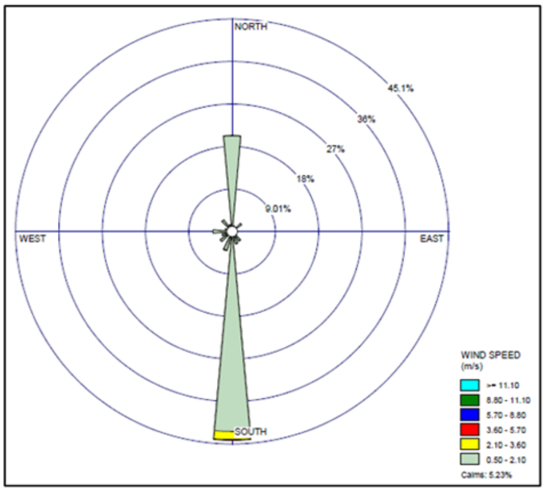

Fig. 10. Wind direction of Sandwip

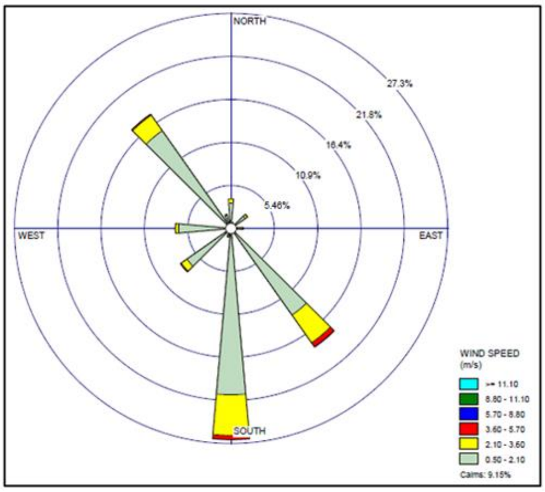

Fig. 11. Wind direction of Kutubdia

4. Conclusions

In this study, the assessment of wind power potentials in the Chittagong division is studied using the statistical Weibull distribution function for ten years of data from 2010 up to 2019 at 10 m height. The performed analysis is seeking to identify the seasonal variation of wind speed, the prevailing direction of the wind, wind speed carrying maximum energy, wind power and wind energy density and Weibull parameters. Twelve stations of the Chittagong division were selected for assessment and analysis purposes.

The performed study elaborates that among the twelve stations assessment with the proposed method the Ambagan station has the most potential and is more effective to utilize the wind energy plants and Magistrate Court is the second highest division to install a wind turbine. While the least significant station is identified as Rangamati. The highest annual average wind speed was recorded in April 2016 with 3.27 m/s and 1.5 and 3.5 m/s Weibull parameters of k and c, respectively. In contrast to the Magistrate Court which indicated an average wind speed of 3.07 m/s in July 2014. The corresponding highest annual average wind power and energy density for Ambagan station were calculated as 19.14 kW/m^2 and 167.63 kWh/m^2, respectively. While the lowest power and energy densities were seen at Rangamati station with annual average wind power and energy density of 4.37 kW/m^2 and 38.29 kWh/m^2 respectively. In terms of wind direction, the prevailing wind direction of all stations is generally in the south.

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