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Article

Evaluation of wind energy-based electricity potential at 40m height in 3 districts of Bihar

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Abstract: In this study, three northern districts of Bihar, namely, Bettiah, Madhubani, and Muzaffarpur, were carefully chosen to understand the wind energy resource availability for energy conversion. The wind speed data set was gathered from local meteorological station for a period of 12 years from April 2008 to March 2020. For evaluating wind resources, the widely used two-parameter Weibull distribution was combined with other statistical techniques. The obtained results exhibited that the wind speed in the three districts of Bihar fluctuated from 3.2 m/s to 4.7 m/s while the scale and shape parameters (also known as the Weibull parameters) are discovered to be in the ranges of 10.247 to 11.432 and 3.5718 to 4.0477, respectively. Further, wind power density was 22.729, 26.288, and 28.021 W/m^2 at 40 m above the ground for the three districts considered in the study. These findings suggested that the places of the study are not suitable for widespread wind power extraction at a hub height of 40 m but suitable for small-scale wind turbine setup.

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1. Introduction

Fuels are indispensable for sustaining human life—from cooking food to launching satellites, almost every human activity requires fuel. India is undergoing rapid modernization and infrastructure development, and availability of ample power has become essential. Currently, India is largely reliant on non-renewable energy for fulfilling its electricity requirements. However, owing to their limited availability and severe pollution caused by their burning, fossil fuels are being increasingly replaced with environmentally friendly renewable energy locates amidst the earth [1–3]. Among the several inexhaustible sources of energy, the

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energy from moving air called wind is most widely used universally. According to Lehmann, wind energy is an unpolluted type of energy and due to its widespread use, it turns out to be gaining popularity as an emerging energy source [4]. The kinetic energy possessed by the moving air is converted into electric current via the mechanism called wind turbine, which is subsequently employed for various day to day activities. The elementary sources of energy globally available are coal, oil, natural gas, among others. are also one of the largest birth place of ecological degradation [5]. Therefore, the need for renewable power sources has grown tremendously in the last 20 years. The most frequently used renewable energy source globally over the years has been wind energy. To tackle the rising demand of power at Bettiah, Madhubani, and Muzaffarpur, it was required to think about the readiness of wind energy for electricity production at three districts of Bihar. No assessment of wind energy has yet been done in the three selected districts of Bihar, India. Wind energy potential is unevenly distributed across India. For better understanding of wind energy availability across a region, wind energy per unit area and other connected factors needs to be calculated for various sites in the region. Three districts in Bihar—Bettiah, Madhubani, and Muzaffarpur were chosen for this study and estimation of the wind energy sector's readiness to produce electricity.

2. Methods and Materials

Using data on wind speed for a period of 12 years, from April 2008 to March 2020, at an elevation of 40m above ground level, the wind energy resources in the three districts was calculated. The data was obtained over a 12 year period from the local meteorological station. Table 1 lists data such as site coordinates, elevation from sea level, and air density for the three particular districts of Bihar.

Table 1. Information about the three districts of Bihar.

Bettiah			
26.8 N Latitude	84.5E Longitude	64 m Altitude	1.131 kgm^{-3} Air Density
Madhubani			
26.4 N Latitude	86.1 E Longitude	151 m Altitude	1.091 kgm^{-3} Air Density
Muzaffarpur			
26.1 N Latitude	85.4 E Longitude	60 m Altitude	1.113 kgm^{-3} Air Density

The three Bihar districts of Bettiah, Madhubani, and Muzaffarpur were chosen due of their rapid growth and the fact that conventional coal-based thermal power plants alone will not be able to meet their future energy needs. To overcome the issue of energy shortage, the policy makers in the government of India are looking forward to inexhaustible wind energy source for power generation.

2.1. Weibull Distribution

The Weibull probability distribution, which has remained the most reliable of the numerous statistical distributions available, was used in this study to measure the potential for wind energy [6]. Furthermore, according to Malinowski et al. compared to the 3-parameter Weibull distribution, the 2-parameter Weibull statistical distribution is more specific and correct [7]. Weibull distribution with two parameters was put on to the monthly average wind speed data, along with other statistical techniques [8]. In terms of 2-Weibull parameters, and wind speed, the Equations (1) and (2) reflect the probability density function and cumulative density function as per Sulaiman et al., one-to one [9], as

$$\mathbf{G}(u) = 1 - \exp\left[-\left(\frac{u}{C}\right)^{K}\right], \tag{1}$$

$$\mathbf{g}(u) = \left(\frac{K}{C}\right)\left(\frac{u}{C}\right)^{K-1} \exp\left[-\left(\frac{u}{C}\right)^{K}\right], \tag{2}$$

where K is having no unit and C is having unit of m/s which signifies the Weibull shape and scale parameter, respectively, and $\mathbf{g}(u)$ and $\mathbf{G}(u)$ denotes the probability density function and and cumulative density function [10].

The standard deviation and the mean of wind speed numbers set throughout the duration of 12 years are reckoned for the three districts using Equations (3) and (4) [11] as

$$\mathbf{u}_m = \frac{1}{n}\sum_{i=1}^{n} u_i, \tag{3}$$

$$\sigma^2 = \frac{1}{n-1}\sum_{i=1}^{n} (u_i - u_m)^2, \tag{4}$$

were, i represents the wind figures, and n is the overall numeral of wind measurement over the 12 years of measurements.

The standard deviation of wind data and mean of wind speed are the first step to work out the shape parameter and scale parameter applying the Equations (5) and (6), separately [12] as

$$K = \left(\frac{\sigma}{u_m}\right)^{-1.086}, \tag{5}$$

$$C = \frac{u_m}{\Gamma\left(1 + \frac{1}{K}\right)}, \tag{6}$$

were, Γ is the well-known gamma function used in the denominator.

The other two central parameters: most probable wind speed (u_{mp}) and wind speed carrying maximum energy (u_{Emax}) of a region are used to predict the likelihood of wind to electricity generation at any site. With the use of calculated value of K and C and substituting it in the Equations (7) and (8), most probable wind speed (u_{mp}) and wind speed carrying maximum energy (u_{Emax}) are calculated [13,14] as

$$u_{\mathrm{mp}} = C\left(\frac{K-1}{K}\right)^{\frac{1}{K}}, \tag{7}$$

$$u_{\mathrm{Emax}} = C\left(\frac{K+2}{K}\right)^{\frac{1}{K}}. \tag{8}$$

2.2. Wind Power Density (WPD)

For any region, the energy extracted from wind per unit area known as wind power density gives a sounder clue than average wind speed about the power production possibility from the available wind resources. Through means of the two Weibull parameters, the wind power density $P(u)$ is worked out using the Equation (9) [15] as,

$$P(u) = \frac{1}{2}\rho C^3 \left(1 + \frac{3}{k}\right), \tag{9}$$

where, $\rho(\mathrm{kg/m^3})$ denote the density of the atmospheric air of the site selected. The higher the numerical value of WPD, the greater the wind to electricity generation likelihood.

3. Results and discussion

The wind figures gathered from local meteorological station for a period of 12 years from April 2008 to March 2020 for a 12-year-period for Bettiah, Madhubani, and Muzaffarpur, are depicted in Table 2.

Table 2. Average wind speed data for the three places of Bihar

Month		Wind Speed (2009-2020)		
		Bettiah	**Madhubani**	**Muzaffarpur**
Jan.	(2009-2020)	3.6	3.9	3.7
Feb.	(2009-2020)	3.9	4.3	4.0
Mar.	(2009-2020)	3.9	4.4	4.1
Apr.	(2008-2019)	4.3	4.7	4.4
May.	(2008-2019)	4.5	4.7	4.5
Jun.	(2008-2019)	4.3	4.4	4.3
Jul.	(2008-2019)	3.8	3.9	3.8
Aug.	(2008-2019)	3.5	3.6	3.5
Sep.	(2008-2019)	3.4	3.6	3.5
Oct.	(2008-2019)	3.3	3.6	3.4
Nov.	(2008-2019)	3.2	3.8	3.5
Dec.	(2008-2019)	3.3	3.8	3.6

The comprehensive analysis of the monthly mean wind speed among the three opted districts are shown in Figure 1. It clearly shows that Madhubani has the highest monthly average wind speed. The above-stated information is in the range 3.2–4.5 m/s for Bettiah, 3.6–4.7 m/s for Madhubani, and 3.4–4.5 m/s for Muzaffarpur. Figures Figures 2 to 4 display the month wise fluctuation of wind speed in the three regions. The figures visibly indicate that wind speed is non uniform across twelve months for three regions of Bihar. In addition, the wind data numbers help in predicting the months with the largest and smallest wind energy possibility. Table 3 provides a listing of the main statistical and Weibull parameters. The Weibull distribution's scale parameter (C) is in the span of 3.5718 to 4.0477, while the shape parameter (K) is in the span of 10.247 to 11.432.

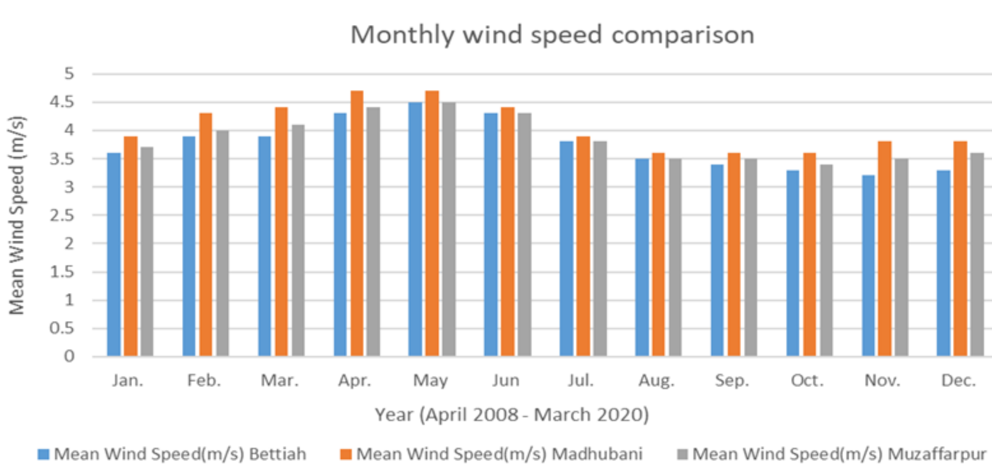

Figure 1. Monthly wind speed variation in the three regions of Bihar.

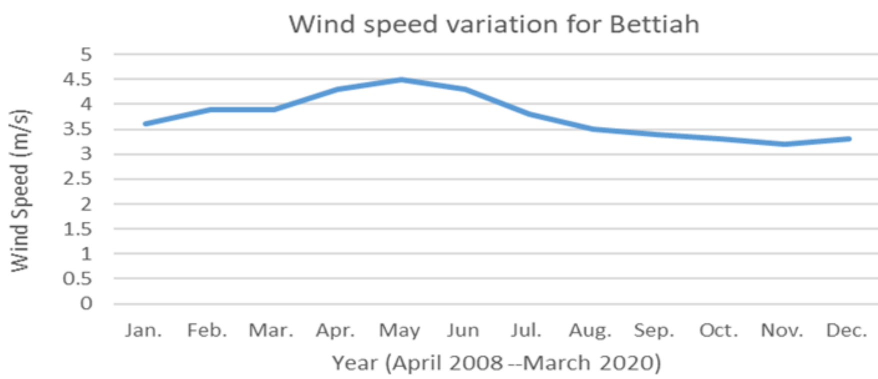

Figure 2. Monthly wind speed variation for Bettiah district.

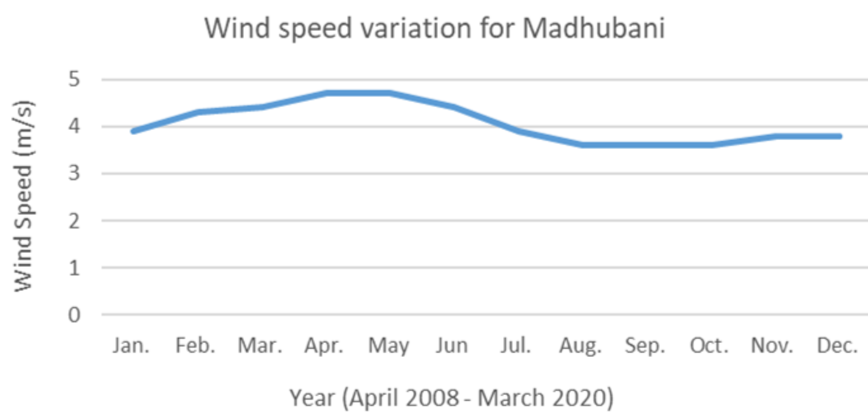

Figure 3. Monthly wind speed variation for Madhubani district.

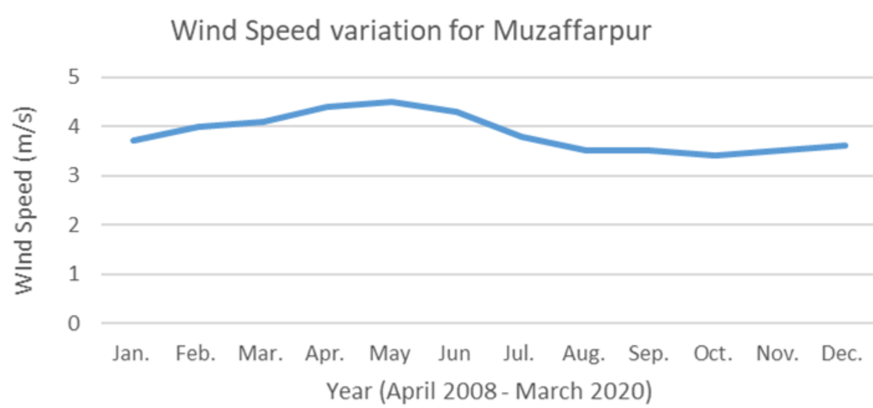

Figure 4. Monthly wind speed variation for Muzaffarpur district.

For Bettiah, Madhubani, and Muzaffarpur, the most likely wind speeds are 3.8823, 4.1192, and 3.9771 m/s, one-to-one. The associated wind speed carrying maximum energy values are: 4.1200, 4.3251, and 4.1676 m/s. The related wind power density figures are 35.729, 44.288, and 46.021 W/m2, respectively. Numerous studies have evaluated the possibilities for generating electricity from windat

Table 3. Conclusions of Weibull statistical analysis.

	u_m	σ	$u_{\max}$	K	u_{mp}	u_{Emax}	P(u)	C
Bettiah	3.75	0.4400	4.5	10.247	3.8823	4.1200	35.729	3.5718
Madhubani	4.05	0.4187	4.7	11.198	4.1192	4.3251	44.288	4.0123
Muzaffarpur	3.85	0.3895	4.5	11.432	3.9771	4.1676	46.021	4.0477

various locations. These investigations have concluded that wind speed and direction are highlylocation- and time-dependent [16,17]. According to Ajayi et al. "the potential wind power is directlydependent to the third power of the wind speed, therefore slight alterations in wind speed will be laidup with an influence on the output of wind energy systems" [18].

A district is rated as extremely respectable for wind power generation if the numerical figureof wind power density is more than 700 W/m2, decent if it is sandwiched between 300 and 700 W/m2,justly decent if it is in the middle of 100 and 300 W/m2, and deprived if it is under 100 W/m2established on the calculated size of wind power density [19]. Since wind is the only resource used inwind energy-based power generation, the output is reliant on the availability of wind energy on site.All wind energy-based power production projects begin with an evaluation of the site's wind resources [20].

The most time-consuming and crucial stage in a good number of wind energy-based power projects is the wind resource estimation which regulates the practicability of a wind energy-based power generation set up [21–23].

4. Conclusions

With the help of wind speed numbers gathered over a 12-year period (April 2008–March 2020), the destination of this research was to evaluate the wind energy possible resource to produce electric current at an elevation of 40 m over the land in the three districts of Bihar, including Bettiah, Madhubani, and Muzaffarpur. The key findings of this analysis are listed below (the values listed below are for Bettiah, Madhubani, and Muzaffarpur, in that order):

- The magnitude of most probable wind speed were 3.8823, 4.1192, and 3.9771 m/s. This parameter eventually specified the apex of the probability function. The magnitude of wind speed carrying maximum energy were 4.1200, 4.3251, and 4.1676 m/s. This parameter was employed to compute the rated wind speed.
- The magnitude of the dimensionless shape parameter (K) was in the span of 10.247 to 11.432. This parameter showed the peak of wind distribution. The magnitude of the scale parameter (C) was in the span of 3.5718 to 4.0477 m/s. This parameter shows the windy nature of a site.
- The values of wind power density were 35.729, 44.288, and 46.021 W/m^2. More the wind energy per unit area (WPD), the greater the wind power producing volume of the location.

These results led to a conclusion that the three Bihar districts that were the subject of this study are not suitable for significant wind energy production at a altitude of 40 m over the land. Small-scale wind turbines perhaps having 10-100 kW capacity can be erected, albeit ideally, they should be placed more than 40 metres above the ground level, to harvest energy from low-speed wind for the purpose of producing power [24,25].

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