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Statistical analysis of wind characteristic in Yanco agricultural institute, Australia

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Abstract

In this study, energy potential and the wind speed characteristics in Yanco agricultural institute in southwestern New South Wales (Australia) were investigated using wind speed from database at a height of 10 m during the period of April 2018 until August 2019. The objective of this study is to assess the wind speed profile using different probability distribution functions in order to evaluate the most suitable function depending on statistical indicators. The performance of Gamma, Lognormal, Rayleigh, and Weibull were compared with measured data. Results showed that the most accurate function is the Weibull distribution and hence it is used to calculate the wind power density. The annual average wind power is 43.404 W/m^2 at an elevation of 10 m. The power-law exponent equation was utilized to create the variations of monthly mean wind speed at the heights of 40 m and 50 m. Finally, wind rose diagram showed that an even distribution of wind direction although the most prevailing wind direction falls between 180° and 240°.

Keywords: Probability distribution function, wind power density, mean wind speed, wind rose

1. Introduction

The rapid development of industry, economy, and population played a major role to increase demands for energy. The most popular resources of energy consumption are fossil fuels, which released carbon dioxide and other harmful gases, which take part in the global warming problems. Currently, there is a lot of attention and awareness of clean energy resources. Wind energy is considered one of the essential renewable resources and has more developed designs of wind energy projects. Besides many studies are focused on the design and planning of wind farms. Assessing the potential of wind energy resources in a specific region is a very important step in developing an efficient and effective design of wind farms [1]. Studying the statistical characteristics of wind speeds is essential to determine the method used in the assessment of wind energy potential in a specific site [2]. As such, there is a requirement to develop an efficient method used in order to present the distribution of wind speeds.

Recently, different probability distributions are used to present a frequency distribution of wind speed, the most common probability function is the Weibull distribution function [3-6]. For example, Irwanto[7] used Weibull function to analyse wind speed characteristics and wind power potential at two sites (Chuping and Kangar), in Perlis, Malaysia. At Chuping, the result showed the wind speed and probability density are, 0.97 m/s and 73% respectively, while the wind speed and probability density at Kangar was 2.5 m/s and 45% respectively. Oner [8] used Weibull and Rayleigh probability distribution functions are to describe the wind speed frequency at Çanakkale, Intepe region, Turkey. The results showed the Weibull function is better than Rayleigh when compared with actual data. In contrast with the results from the wind potential at Darling City, South Africa, Rayleigh method showed more accuracy in presenting wind speed distribution than Weibull distribution [9]. Furthermore, Gamma [10-12] and

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Lognormal [13] distribution functions have been applied to statistical analysis of wind speed. Therefore, different analysis have been used to define the best distribution models to specify the wind speed data in a specific site.

There is a lack of a detailed research about defining the appropriate probability functions to determine the frequency of wind speed distribution in NSW, Australia. Consequently, in this study, the capability of four distribution functions is evaluated to give a better fit for the recorded wind speed data in Yanco agricultural institute using different statistical indicators. Furthermore, the study performed a statistical analysis of recorded wind data to define the wind power potential and wind rose diagram analysis.

2. Statistical Analysis of Wind Speed Procedure

The wind data of the Yanco agricultural institute are selected to analyze the wind energy potentials in this study. Yanco agricultural institute is located in NSW, Australia and has a station number 061287 with a coordinate of -34.6222, 146.4326. In order to have a clear view of the availability of wind resources in the Yanco site, it is necessary to use some statistical analysis of wind data. To characterize the wind speed behavior, the probability distribution function is used to show the frequency of the wind speeds, which possibly dominate at the Yanco site. The study aims to find the best method for accurate measurement of wind speed data. Four probability distribution functions are investigated, i.e. Gamma, Lognormal, Weibull, and Rayleigh equations.

2.1. Gamma distribution function

The Probability and cumulative of Gamma distribution function are expressed using equations 1 and 2 respectively [10]:

$$f(v) = \frac{v^{\alpha-1}}{\beta^{\xi}\Gamma(\alpha)} exp(-\frac{v}{\beta}) \tag{1}$$

$$F(v) = \int \frac{v^{\alpha-1}}{\beta^{\alpha}\Gamma(\alpha)} exp\left[\frac{-v}{\beta}\right] dv \tag{2}$$

Where Γ is the Gamma function, v is the wind speed, β , α are scale and shape factors respectively

2.2. Lognormal distribution function

The Probability and cumulative of Lognormal distribution function are calculated using equations 3 and 4 respectively [13]:

$$f(v) = \frac{1}{v\,\sigma\sqrt{2\pi}} \exp\left[\frac{(\ln(v)-\mu)^2}{-2\sigma^2}\right] \tag{3}$$

$$F(v) = \frac{1}{2} + \frac{1}{2}\, erf\left(\frac{ln(v)-\mu}{\sqrt{2}\,\sigma}\right) \tag{4}$$

Where $erf(v)$ is the error function related to the normal distribution, μ, σ are the scale and shape factors respectively.

2.3. Weibull distribution function

The Probability and cumulative of Weibull distribution function are expressed using equations 5 and 6 respectively [14]:

$$\boldsymbol{f(v) = \frac{k}{c}\left(\frac{U}{c}\right)^{k-1} . \exp\left[-\left(\frac{U}{c}\right)^{k}\right]} \tag{5}$$

$$F(v) = 1 - \exp\left[-\left(\frac{U}{c}\right)^{k}\right] \tag{6}$$

Where c, k are the scale and shape factors respectively.

2.4. Rayleigh distribution function

The Probability and cumulative of Rayleigh distribution function are determined using equations 7 and 8 respectively[15]:

$$f(v) = \frac{v}{c^2}\exp\left(-\frac{Uv^2}{2\,c}\right) \tag{7}$$

$$F(v) = 1 - \exp\left[-\left(\frac{v}{c}\right)^2\right] \tag{8}$$

Where c is scale factor .

This study used the statistical indicators of root mean square error (RMSE) [16], coefficient of determination (R^2)[16], Bayesian information criterion (BIC) [17], and Akaike information criterion (AIC) [18] to evaluate the accuracy of the investigated probability distribution functions for modeling the frequency of measured wind speeds. The statistical indicators are utilized to determine the differences between the calculated values from probability functions and the measured data.

Some significant descriptive statistics skewness and kurtosis are investigated in this study. The kurtosis and skewness give insight into the shape of the distribution in order to connect those values of kurtosis and skewness according to the heaviness or asymmetry and thickness of the tails of a distribution, respectively. To evaluate wind resources available at the Yanco site, wind power density is used as a powerful tool to indicate the amount of available energy at a specific site [19]. Finally, wind direction is evaluated in order to define the most prevailing direction.

3. Results and Discussion

In this study, hourly wind speeds collected from Yanco agricultural institute station during the period of April 2018 until August 2019. The frequency distribution of wind data is studied by four probability distribution functions: Rayleigh, Weibull, Gamma, and Lognormal. Fig .1 shows the frequency of different wind speeds and used to find the predominant wind speed in the Yanco region. A comparison between calculated and measured data were carried out to determine the function that better predicts wind potential. As hsown in Fig. 1, Weibull distribution has the best fit with measured data followed by Rayleigh, while the least accurate function is Lognormal. Furthermore, it is important to study the cumulative distribution functions compared with measured data as shown in Fig. 2.

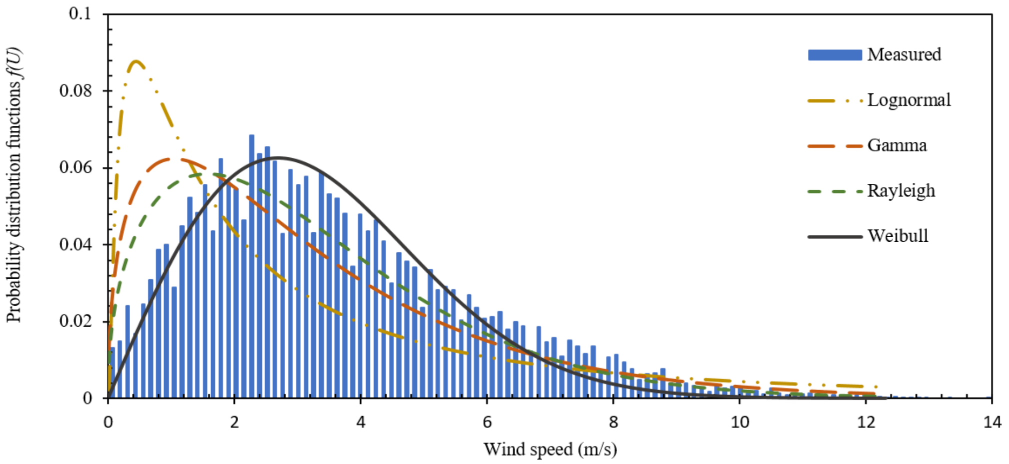

Fig. 1. Probability distribution functions compared with measured histograms.

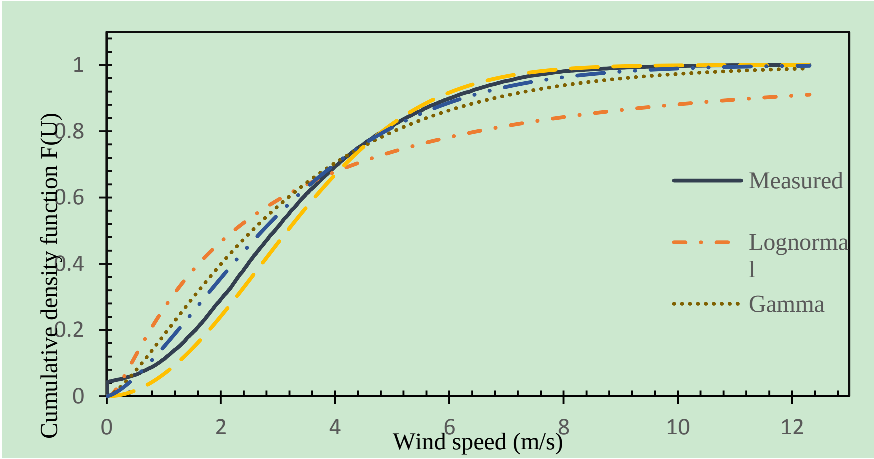

Fig. 2. Cumulative distribution functions compared with the measured curve.

In order to investigate the accuracy of four functions, four test indicators are used, i.e. RMSE, R^2, AIC, and BIC [Table 1]. The coefficient of determination is varied from 0.803537 to 0.992923, which shows the high accuracy of data analysis. The highest value of R^2 is related to Weibull distribution as the most suitable probability function. Rayleigh comes as a second best method with a value of 0.992115, which is near to the Weibull distribution function. The other important indicator that was used is RMSE, in contrast with R^2, this value should be small as possible which varies from a value for Weibull 0.027963 to 0.117126, which is related for the lognormal distribution. AIC and BIC lower values indicate more effectiveness [20].

Table 1. Statistical indicators of four distribution functions.

	R^2	$RMSE$	AIC	BIC	$Rank$
Lognormal	0.803537	0.117126	2.534005	10.43008	4
Gamma	0.971053	0.050675	3.222925	11.119	3
Rayleigh	0.992115	0.029863	-0.540832	7.355238	2
Weibull	0.992923	0.027963	-1.075328	6.820742	1

Fig. 3 shows the skewness from different distribution functions according to the recorded data. It is noticed that the Weibull distribution function gives a skewness value close to the measured value. While Fig.4 represents a comparison between the four functions according to the Kurtosis values. The results show that Kurtosis values of Gamma and Weibull are the closet to the recorded data.

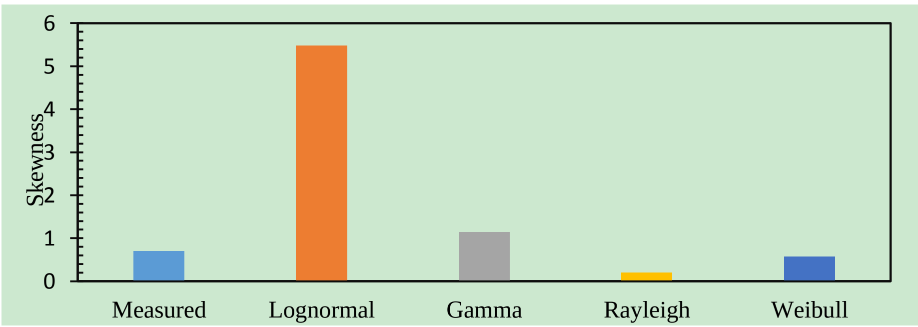

Fig. 3. Skewness calculated with four distribution functions compared with the skewness of measured data.

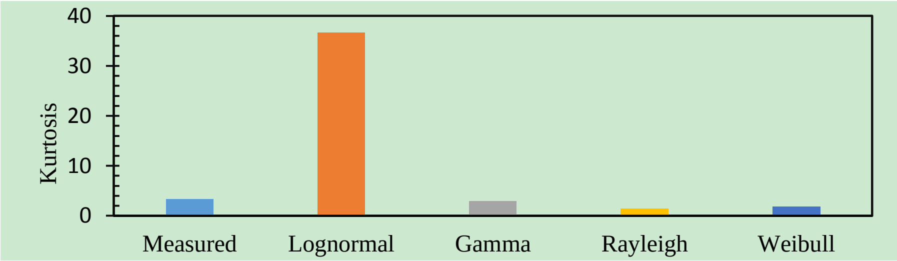

Fig. 4. Kurtosis calculated with four distribution functions compared with the kurtosis of measured data.

Evaluation of wind direction plays significant role in the determination of the type of used wind turbine. A wind rose diagram is used to present the share and direction of predominant wind speed. As shown in Fig.5, the highest frequency of 7% happened in the sector between 0 ° and 30 ° when wind direction is more evenly distributed, but the most prevailing wind direction is between 180 °and 240 °.

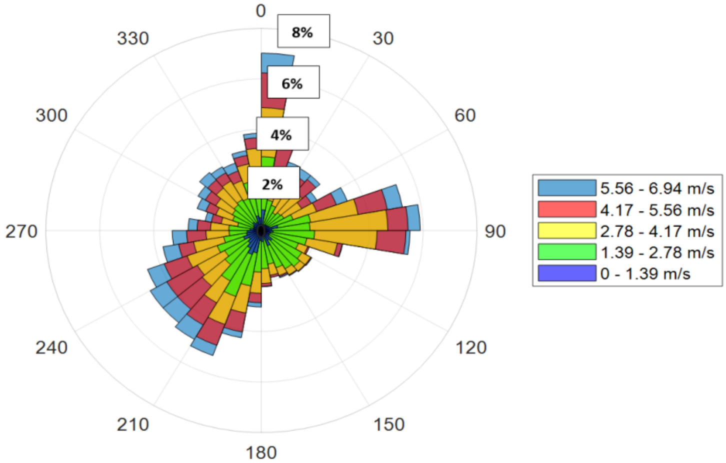

Fig. 5. Wind rose diagrams.

Fig. 6 shows the monthly mean wind speed profile at different elevations in the Yanco region. The actual data was recorded at a height of 10 m and the other remaining data at elevations of 40 m and 50 m are calculated from the power law equation [21]. The lowest average monthly wind speed is measured in December 2018 as 2.191 m/s at 10 m height while the highest average monthly wind speed is in February 2019 at 4.918 m/s at a height of 50 m.

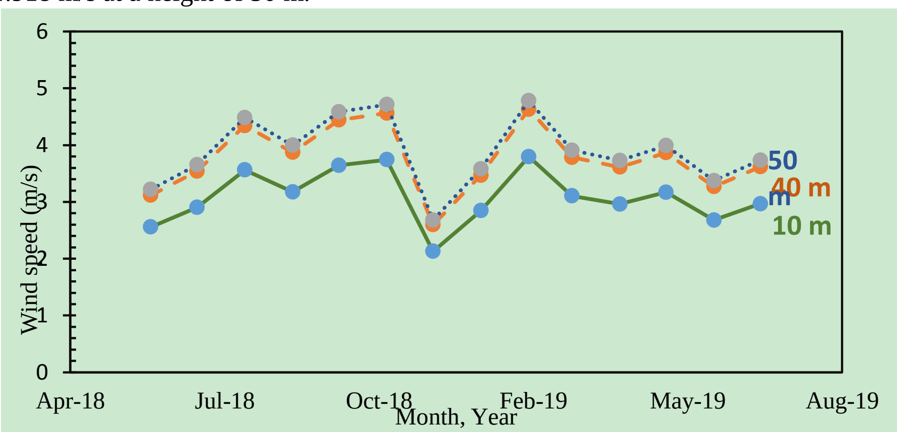

Fig. 6. Monthly average wind speeds for the following heights: 10m, 40m, and 50m.

Wind power density gives a better indication than wind speed when evaluated the wind resource in the specific region. Therefore, the determination of wind power is very essential in wind project assessment. As the Weibull distribution is the most precise function to calculate wind power density. The annual average wind power is 43.404 W/m^2 at an elevation of 10 m, while the annual average wind power at 40 m and 50 m were 78.670 W/m^2 and 86.573 W/m^2 respectively. According to the classification of wind power density, values less than 200 W/m^2 are recorded as class 1, which makes the site a poor wind resource [22].

4. Conclusion

This study investigated the characteristics of wind speed in Yanco agricultural institute, Australia. The study assessed wind speed profile using different probability distribution functions for one site, for future works. The findings of this study can be summarized as the following:

- The highest value of R^2 is related to the most suitable probability function of Weibull distribution. Rayleigh value of 0.992115 is close to the Weibull distribution function.
- The annual average wind power is 43.404 W/m^2 at an elevation of 10 m, while the annual average wind power at 40 m and 50 m are 78.670 W/m^2 and 86.573 W/m^2 respectively.
- The highest frequency of 7% happened in the sector between 0° and 30°.
- The lowest monthly average speed was 2.191 m/s at 10 m in December 2018 while the highest monthly average speed was 4.918 m/s at a 50 m in February 2019.

According to the average wind speed, this site is not suitable to generate enough wind speed for large-scale wind turbines. However, wind speed is suitable for small-scale turbines for small and remote farms, agricultural application, and water pumping. Future studies should extend the statistical assessment of different probability distribution functions of wind energy potential for more weather station.

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Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Author ‘A’ conduct a research of the wind data analysis, Author ‘B’ provides help in data collection and gathering besides giving the recommendation and gaudiness. Author ‘C’ reviewed the data analysis and checked the work comparison against experimental data.

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