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RESEARCH ARTICLE

ASSESSING WIND ENERGY POTENTIAL VIA WEIBULL PARAMETERS AT WEREILU, SOUTH WOLLO, ETHIOPIA

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ABSTRACT

Ethiopian energy sector is highly depend on traditional biomass and has very low modern energy. In this study, wind energy potential of Wereilu, Amhara Region, Ethiopia is analyzed statistically by using the data of wind speed that was measured between 2008 -2017 years. The Weibull distribution method and Rayleigh distribution method were used in this study. Three different methods namely: moment method (MM), empirical method (EM) and Energy Pattern Method (EPM) were used to estimate the Weibull parameters. The results showed that Energy Pattern Method was the most efficient methods for determining the value of shape parameter k and scale parameter c. Four statistical tools namely: the mean percentage error (MPE), mean absolute percentage error (MAPE), root mean square error (RMSE) parameter and Chi square error ($\square^{2}$) were used to precisely rank the distribution methods. The statistical fitting of the wind power density from measured data and wind power density estimated using Weibull and Rayleigh are determined for justifying the performance of the methods. According to the data obtained from Kombolcha Meteorological agency wind energy generation in Wereilu was fair. The result showed that the site has the potential of generating wind power density of 10.45Wm^{-2} at height of 10 m. From statistical tests, Rayleigh model is recommended for this area. Therefore, this paper gives the assessment of wind energy in Wereilu, South Wollo, Ethiopia.

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INTRODUCTION

Energy and environment are the twin major crises in the world (1). Industrial revolution has constantly increased mankind's demand for energy. Most of the energy generated is harnessed from a non-renewable source. Most of these non-renewable sources are fossil fuels (2). These energy sources which have a limited availability, when harnessed results in degradation of the environment. Hence to reduce the negative impact of the fossil fuels, scientists were forced to focus on cleaner energy sources which are easily available and environmental friendly (3). The energy sources which do not exhaust when their energy is exploited are known as renewable energy resources (4). Because of this, both developed and developing country such as Ethiopia becoming increasingly more interested in using pollution free, cost effective and renewable sources of energy (5). Renewable energy resources like wind and solar energy can be considered as essential factors for reducing air pollution and fossil fuel consumption (6). The potential of wind energy of a certain region can be determined before a wind conversion system is installed. The determination of wind energy potential depends on accurately modeling wind speed. Statistical properties of the wind speed are important to predict the output energy of a wind conversion system (7). Akdag and Dinler compared an energy pattern factor method with graphical method and maximum likelihood method and found that energy pattern factor method is more appropriate in terms of comparing wind power and wind speed. Jowder found empirical method more efficient than graphical method to compute the Weibull parameter for determining wind speed and wind power in Bahrain. According to (10) the result obtained using Empirical method shows better agreement with the measured wind power density than the result obtained using Graphical method and Modified maximum likelihood method. Azad et.al, found that the method of moment is the best method than any other methods such graphical method, empirical method and equivalent energy method to determine the Weibull parameters.

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To investigate the feasibility of the wind energy resource at any site, the best method is to calculate the wind power density based on the measured data of the meteorological station. Another method is to calculate the wind power density using frequency distribution functions like Weibull distribution, Rayleigh distribution, chi-squared distribution, generalized normal, log-normal distribution (12) (13). Weibull distribution and the Rayleigh distribution are the probability distribution functions (pdfs) most commonly used in wind speed data analysis especially for studies related to wind energy estimation (14, 15, 16, 17, 18). Researchers have shown that Weibull function fits the wind probability distribution more accurately compared to others (19). In Ethiopia, some studies have been carried on the assessment of wind speed variability and its energy potential using various analytical model tools such as Weibull and Rayleigh distribution parameter methods (20)(21); however none of these literatures has considered Wereilu, South wollo, Ethiopia. Therefore the aim of this paper (i) to assess the wind potential energy from wind speed data through statistical analysis at WoreIlu, South Wollo, Ethiopia.(ii) to find the theoretical model which is closest to the wind power density of measured wind speed. Here the author used: moment method (MM), empirical method (EM) and energy pattern method (EPM) to determine the two parameters of the Weibull distribution (shape parameter k, and scale parameter c) and then to evaluate wind power density. The results show that energy pattern method was the most efficient methods for determining the value of shape parameter k and scale parameter c at Wereilu, South Wollo, Ethiopia. According to the statistical tests, Rayleigh model is recommended for this area. From the result, site has the potential of generating energy with wind power density of 10.45 Wm^{-2} at height of 10 m. Based on this result; the site has fair wind energy potential.

MATERIALS AND METHODS

Site location and data collection: Wereilu is highland distinct previously known as Bete Giorgis in the historic region of Bete Amhara. It is located some 490 Km north of Addis Abeba, 570 Km south east of Bahir Dar and 90 Km south of Dessie. Wereilu town sites some 9000 feet above sea level. In this paper ten years (10) monthly mean speeds wind data measured at a height of 2.5 m for Wereilu, South Wollo, Ethiopia were obtained from the Kombolcha Metrological Agency (KMA). The average wind speed was extrapolated to standard height of 10 m for wind characteristics analysis. The data were statistically analyzed based on Weibull model and Rayleigh model. Parameters such as probability density function, shape factor k, scale factor c, surface roughness (α), and root mean cube wind speed v_{rmc}, average wind speed and wind power densities were then evaluated. In this study, Weibull distribution function and Rayleigh distribution function were implemented to analyze the wind speed data of Wereilu for estimation of wind power potential. For this study the data was analyzed using the latest MATLAB software.

Theoretical Analysis

Frequency Distribution of Wind Speed

Weibull Distribution: The wind speed probability density distributions and their functional forms represent the major aspects in wind related literature. Their use includes a wide range of applications, including identifying the parameters of the distribution functions and analyzing the wind speed data as well as wind energy economics (22-24). The two of the commonly used functions for fitting a measured wind speed probability distribution in a given location over a certain period of time are the Wei bull and Rayleigh distributions. The probability density function of the Weibull distribution is given by (25)(26).

$$f(v) = \left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{k-1} e^{\left(-\left(\frac{v}{c}\right)\right)^{k}} \tag{1}$$

Here, f(v) is the probability of observing wind speed v, c is the Weibull scaling parameter and k is the dimensionless Weibull shape parameter. The corresponding cumulative probability function of the Weibull distribution (24), (26), (27),(28),(29), is given by

$$F(v) = 1 - e^{-\left(\frac{v}{c}\right)^{k}} \tag{2}$$

Wind power is found commonly by formula;

$$P = \frac{1}{2}\rho v^3 \tag{3}$$

Where ρ(kg/m^3) is air density, A

(m^2) is swept area.

Mean power density for Weibull distribution is given by formula;

$$P_W = \rho\Gamma\left(1 + \frac{3}{k}\right) \tag{4}$$

Where $\Gamma$is gamma function. Here the density of the air at sea level, 1 atmosphere pressure and 16:6 ^{o}C is ρ= 1:225Kg/m^3 value.

Rayleigh distribution: The Rayleigh distribution, which is a special case of Weibull distribution with a fixed shape parameter value k=2, is defined by (30-32)

$$f_r = \frac{\pi v}{2\overline{v}} \exp\left[\frac{-\pi}{4}\left(\frac{v}{\overline{v}}\right)^2\right] \tag{5}$$

The Rayleigh cumulative distribution function is given by

$$F(v \leq v_0) = 1 - \exp\left[\frac{-\pi}{4}\left(\frac{v}{\overline{v}}\right)^2\right] \tag{6}$$

The mean value $\overline{v}$ and standard deviation σ of the Weibull distribution can then be computed from;

$$\overline{v} = c\Gamma\left(1 + \frac{1}{k}\right) \tag{7}$$

and

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

The most probable speed of wind can be determined from the shape parameter and scale parameter of Weibull distribution function. The speed of the most probable wind is obtained as (33-36):

$$v_{\mathrm{mp}} = \left(1 - \frac{1}{k}\right)^{\frac{1}{k}} \tag{9}$$

Determination of the maximum speed of wind energy can be calculated from the shape parameter and scale parameter of Weibull distribution function. The wind speed carrying the maximum wind power can be to calculate as

$$v_{\max} = c\left[\frac{k+2}{k}\right]^{\frac{1}{k}} \tag{10}$$

From Rayleigh distribution, power density can be calculated by (37):

$$P_R = \frac{3}{\pi}\rho c^3\left[\frac{\pi}{4}\right]^{\frac{3}{2}} \tag{11}$$

Actual Function: The probability density function of an actual distribution with the mean $\overline{v}$ and standard deviation $\sigma$is defined as;

$$f_a = \frac{1}{\sigma\sqrt{2\pi}} e\left(\frac{v-\overline{v}}{\sigma}\right)^2 \tag{12}$$

And the cumulative distribution function is defined as;

$$F_c = \frac{1}{2}\left[1 + \mathrm{erf}\left(\frac{v-\overline{v}}{\sigma\sqrt{2}}\right)\right] \tag{13}$$

The standard deviation in term of the sampled wind speed datav_i, and the mean wind speed $\overline{v}$ can be defined as

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(v_i - \overline{v})^2} \tag{14}$$

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$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(v_i - \overline{v})^2} \tag{14}$$

Where$\overline{v}$,σ, $f_{a,}F_c$are the mean, standard deviation, pdf and cdf of the actual distribution respectively. The mean wind speed, $\overline{v}$of the site is given by

$$\overline{v} = \frac{1}{N}\sum_{i=1}^{N} v_i \tag{15}$$

Where $v_i$the wind observed and N is is the data point. Regardless of the shape and scale parameters, use of mode or the mean wind speed in the power density equation would always introduce a significant error in the energy estimate. It can alter the result by several folds, therefore making the estimate useless. Therefore, for the assessment of the site power density due to the wind speed, root mean cube (RMC) speed is used. The expression for the RMC speed, $v_{\mathrm{rmc}}$is given in Equation below

$$v_{\mathrm{rmc}} = \sqrt[3]{\frac{1}{N}\sum_{i=1}^{N} v_i} \tag{16}$$

The average wind-power density can be defined as the annual average power per unit area. In other words, it can be regarded as the power passing to a site through an area of 1m^2 perpendicular to the wind as defined in Equation

$$P_W = \frac{1}{2}\rho(v_{\mathrm{rmc}})^3 \tag{17}$$

Where $P_W$is the average wind-power density at the given site and is the oserved air density. The air density is assumed to be constant due to the absence of this from the measured data, and a value of 1.225 kg/m^{3}is used. Average wind-power density is given by (38)(39);

$$\overline{(P_W)} = \frac{1}{N}\sum_{i=1}^{N} P(v_i)\,(v_i)^3 \tag{18}$$

This equation gives the actual or true power in the wind speed if the probabilities P(v) are determined from the actual wind-speed data.

Methods to Estimate Weibull Parameters

Moment Method: Shape parameter k and scale parameter c can be calculated using many methods by previous researches. According to Azad et al. moment method to be the most efficient method in determining the value of k and c to fit the Weibull distribution curves at any altitude. The calculations are based on standard deviation; average wind velocity and gamma function for parameter (40);

$$k = \left[\frac{0.9874}{\sigma\overline{v}}\right]^{1.0983} \tag{19}$$

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(v_i - \overline{v})^2} \tag{20}$$

$$c = \frac{\overline{v}}{\Gamma\left(1+\frac{1}{k}\right)} \tag{21}$$

Where $\Gamma$is gamma function. The mean value $\overline{v}$ and standard deviation σ.

Empirical Method: Empirical Method Shape and scale parameter k and care measured in this method by the following equations (41)(42);

$$k = \left(\frac{\sigma}{\overline{v}}\right)^{-1.086} \tag{22}$$

$$c = \frac{\overline{v}}{\Gamma\left(1+\frac{1}{k}\right)} \tag{23}$$

Energy pattern method: Energy pattern factor $E_{\mathrm{pf,}}$ Energy pattern factor is a ratio of mean of cubic wind speed to cube of mean wind speed (43)(44);

$$E_{\mathrm{pf}} = \frac{\frac{1}{N}\sum_{i=1}^{N} v_i{}^3}{\left(\frac{1}{N}\sum_{i=1}^{N} v_i\right)^3} = \frac{\Gamma\left(1+\frac{3}{k}\right)}{\Gamma\left(1+\frac{1}{k}\right)^3} \tag{24}$$

$$k = 1 + \frac{3.69}{\left(E_{\mathrm{pf}}\right)^2} \tag{25}$$

$$c = \frac{\bar{v}}{\Gamma\left(1+\frac{1}{k}\right)} \tag{26}$$

Wind Speed Vertical Height Extrapolation: Wind speed varies as a function of the height above ground up to an optimum altitude. It is therefore necessary to determine the wind speed at the height of the wind turbines hub in terms of the measured wind speed. The equation for variations in wind speed with hub height is a power law expressed in equation as follows (45-47):

$$v_2 = v_1 \left(\frac{h_2}{h_1}\right)^{\alpha} \tag{27}$$

Where$v_1$is the measured wind speed at a known height $h_1$while v_2 is extrapolated wind speed at practical height h_2. The exponent, α is the surface roughness coefficient or wind shear factor and dependent on height, time of the day, season of the year, nature of the terrain, wind speed and temperature and could be determined by equation (48)(49).

$$\alpha = \left[\frac{0.37-0.088\ln(v_1)}{1-0.088\ln\left(\frac{h_1}{h_o}\right)}\right] \tag{28}$$

Evaluation of Weibull and Rayleigh Distribution: In this paper in order to check how accurately a theoretical probability density function fits with measured data four types of statistical errors are considered as judgment criterion. To evaluate the performance of considered distribution, the mean percentage error (MPE), mean absolute percentage error (MAPE), root mean square error (RMSE) and the chi-square test are performed (50)(51).

Best results are obtained when these values are close to zero (37).

$$\mathrm{MPE} = \frac{1}{N}\sum_{i=1}^{N}(x_{\mathrm{iw}} - y_{\mathrm{iw}})\, x100 \tag{29}$$

$$\mathrm{MAPE} = \frac{1}{N}\sum_{i=1}^{N}\left|\frac{x_{\mathrm{iw}}-y_{\mathrm{iw}}}{y_{\mathrm{iw}}}\right| x100 \tag{30}$$

$$\mathrm{RMSE} = \left[\frac{1}{N}\sum_{i=1}^{N}(y_{\mathrm{iw}} - x_{\mathrm{iw}})^2\right]^{12} \tag{31}$$

$$\chi^2 = \sum_{i=1}^{N}\frac{(y_{\mathrm{iw}}-x_{\mathrm{iw}})^2}{y_{\mathrm{iw}}} \tag{32}$$

Where N is number of observations,$y_{\mathrm{iw}}$is frequency of observation or i^{th} calculated value from measured data , $x$is frequency of Weibull or i^{th}calculated value from the Weibull distribution and same set of formulas can be used when subscript w is replaced by r representing Rayleigh distribution

RESULTS AND DISCUSSION

In this study the wind potential at Wereilu, South Wollo, Ethiopia with the latitude of 3.6° 50′ north and longitude of 7° 48′ is determinedand deep analysis of wind characteristics is presented. The data for this study were collected during 10 years from 2008 to 2017 from Kombolcha meteorological agency. The power density calculated from measured probability density distribution (Actual power density) and those obtained from Weibull and Rayleigh models are presented in table 5 up to table 7 using different parameters estimators such as: moment method, empirical method and energy pattern method. The wind power density calculated from root mean cube speed and predicted by Rayleigh model are close each other than Weibull model. Weibull parameters used to estimate Weibull Power density and Rayleigh power density as shown in table 5 to table 7. For Wereilu, South Wollo, Ethipia, the better power distribution model was Rayleigh and the best Weibull parameters estimator was Energy pattern Method (EPM). As shown in figure 1, the maximum wind speed estimated from data using height extrapolation and measured from NASA at height of 10 m is 4.07 m/s and 3.08 m/s respectively in May month. The minimum value of wind speed both estimated from data and measured from NASA is 2.38 m/s and 1.57 m/s respectively. For moment method Weibull parameters as shown in figure 2, the Rayleigh power density better fit with the actual power density than Weibull power density. The Rayleigh and Actual power density very closer each other at the year of 2012 and 2016. In year of 2010 the two power density far away from each other. As shown in figure 3, the weibull power density result is unfit for both Rayleigh and Actual power density while Rayleigh and Actual power is better fit each other than Weibull power density for empirical method estimator. The Rayleigh and Actual power density overlap each other at the year of 2010. In year of 2009, 2013 and 2015 somewhat better approaches each other than the remaining years. From figure 4, the actual power and Rayleigh power density is closer each other than Weibull power density in the case of Energy pattern Method estimator. These two power density more approaches each other at 2009, 2010, 2013 and 2015. In this figure these two power density is closer each other than the power density due to Weibull estimators of Moment method and Empirical method. Therefore, the best estimator of Weibull parameters and better estimator of wind power density are Energy Pattern Method and Rayleigh distribution function respectively.

Table 1. Monthly mean speed at 2.5 m obtained from Kombolcha meteorological agency for Woreilu, Amhara Region, Ethiopia 2008- 2017)

Month	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
January	2.36	2.4	2.17	2.17	2.66	2.59	2.32	2.53	1.94	2.49
February	3.19	3.04	2.78	2.78	2.88	2.73	2.09	2.08	1.36	2.2
March	3.57	2.83	2.42	2.42	2.72	2.48	2.37	2.64	1.38	2.2
April	4.16	3.27	2.73	2.73	2.41	2.59	3.19	2.61	1.37	3.14
May	3.5	3.52	2.71	xx	Xx	3.06	3.03	3.01	1.74	2.57
June	2.5	3.25	2.71	2.22	2.4	2.14	2.73	2.41	1.9	2.59
July	1.79	1.41	1.61	1.61	1.52	1.37	1.66	4.34	2.73	1.46
August	1.66	1.63	1.4	1.4	1.41	1.38	1.36	1.93	2.58	1.17
September	2.27	2.45	2.06	2.06	1.98	1.88	1.84	2.88	2.59	1.73
October	2.68	2.68	3.13	3.13	2.827	2.22	2.75	2.55	2.38	2.42
November	2.31	Xx	2.5	2.5	2.54	2.65	2.48	2.42	2.41	2.5
December	2.68	2.34	2.91	2.91	2.47	2.38	2.49	2.06	2.6	2.42
Average	2.72	2.64	2.39	2.36	2.35	2.29	2.36	2.62	2.08	2.24

Table 2. The values of surface roughness (α) at 2.5m for Wereilu, Amhara Region, Ethiopia (from 2008-2017)

Month	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
January	0.258	0.278	0.257	0.264	0.255	0.253	0.269	0.269	0.261	0.262
February	0.239	0.243	0.25	0.25	0.247	0.251	0.272	0.272	0.306	0.268
March	0.23	0.248	0.26	0.26	0.251	0.258	0.262	0.254	0.305	0.268
April	0.218	0.237	0.251	0.251	0.261	0.255	0.239	0.255	0.305	0.24
May	0.231	0.231	0.252	xx	Xx	0.242	0.243	0.243	0.286	0.256
June	0.258	0.237	0.267	0.267	0.261	0.27	0.251	0.261	0.279	0.255
July	0.284	0.303	0.292	0.297	0.305	0.305	0.29	0.215	0.251	0.3
August	0.29	0.291	0.303	0.303	0.303	0.304	0.306	0.278	0.255	0.317
September	0.265	0.259	0.273	0.273	0.276	0.28	0.282	0.247	0.255	0.287
October	0.252	0.247	0.24	0.248	0.267	0.267	0.25	0.256	0.262	0.26
November	0.264	Xx	0.258	0.258	0.257	0.253	0.259	0.26	0.261	0.258
December	0.252	0.265	0.246	0.246	0.259	0.262	0.258	0.273	0.255	0.262
Average	0.254	0.257	0.264	0.264	0.265	0.267	0.264	0.256	0.275	0.269

Table 3. Monthly mean wind speed at 10 m using power law equation (height extrapolation) from data at Wereilu, Amhara Region, Ethiopia (2008-2017)

Month	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
January	3.39	3.45	3.15	3.15	3.76	3.69	3.35	3.61	2.85	3.56
February	4.44	4.26	3.93	3.93	4.06	3.87	3.05	3.03	2.08	3.19 8
March	3.91	3.99	3.47	3.47	3.85	3.55	3.41	3.75	2.11	3.19 8
April	5.63	4.54	3.87	3.87	3.46	3.69	4.44	3.72	2.09	4.38
May	4.82	4.85	3.84	xx	Xx	4.28	4.24	4.22	2.59	3.68
June	3.57	4.51	3.21	3.21	3.45	3.11	3.87	3.46	2.8	3.69
July	2.65	2.15	2.41	2.41	2.29	2.09	2.48	5.85	3.87	2.21
August	2.48	2.44	2.13	2.13	2.15	2.1	2.08	2.84	3.67	1.82
September	3.28	3.51	3	3	2.9	2.77	2.72	4.06	3.69	2.58
October	3.8	4.03	4.37	4.37	3.98	3.21	3.89	3.64	3.42	3.47
November	3.33	Xx	3.57	3.57	3.63	3.76	3.55	3.4	3.46	3.57
December	3.8	3.38	4.09	4.09	3.54	3.42	3.56	3	3.7	3.47
Average	3.76	3.74	3.42	3.38	3.37	3.3	3.39	3.72	3.03	3.23

Table 4. Monthly mean wind speed measured at 10 m Wereilu, Amhara Region, Ethiopia (NASA) (2008-2017).

Month	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
January	2.71	2.22	2.29	2.18	2.83	2.38	2.1	2.55	1.98	2.77
February	3.1	2.67	1.83	2.98	3.39	3.01	1.99	2.66	2.52	2.53
March	3.30	2.91	2.67	2.61	2.89	2.23	2.75	3.21	2.63	2.32
April	4.02	3.16	2.51	2.86	2.24	2.37	3.5	3.6	1.85	3.39
May	3.37	3.86	2.42	2.87	3.74	2.84	3.3	3.18	2.49	2.72
June	2.35	2.83	2.33	2.22	2.59	2.06	2.73	2.56	2.29	2.95
July	1.73	1.39	1.79	1.71	1.8	1.75	1.7	1.75	1.6	1.88
August	1.61	1.51	1.56	1.82	1.55	1.64	1.55	1.56	1.56	1.38
September	2.15	2.26	2.01	2.35	2.24	2.1	2.15	2.31	2.04	2.23
October	2.7	2.51	2.86	3.37	3.12	2.36	2.86	3.25	2.59	2.74
November	2.38	2.57	2.23	2.63	2.45	2.63	2.78	3.05	2.65	2.61
December	2.22	1.99	1.97	2.76	2.52	2.12	2.31	2.49	3.18	2.38
Average	2.61	2.49	2.21	2.53	2.61	2.29	2.48	2.68	2.28	2.49
σ	0.67	0.67	0.37	0.47	0.6	0.39	0.58	0.57	0.46	0.5

The performance of three methods including: Moment Method, Empirical Method and Energy Pattern method was used to estimate Weibull shape parameters (k) and scale parameter (c). From these results Weibull distribution functions and Rayleigh distribution function were estimated to compute wind power density at Wereilu, South Wollo, Ethiopia as shown in table 5 to table 7.

Table 5. Weibull parameters (k and c) calculated using Moment Method (MM) and comparison of Weibull power density (WPD), Rayleigh power density (RPD) and Actual power density (APD) (2008-2017)

MM	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
k(-)	4.17	5.22	6.11	5.93	6.22	5.87	5.76	7.74	5.26	5.46
c(m/s)	4.14	4.06	3.68	3.64	3.63	3.56	3.66	3.96	3.29	3.5
WPD(W/m^2)	33.03	2.91	2.67	2.61	2.89	2.23	2.75	3.21	2.63	2.32
RPD(W/m^2)	20.1	18.96	14.12	13.66	13.55	12.78	13.89	17.59	10.09	12.14
APD(W/m^2)	13.16	11.53	7.16	10.89	12.74	7.95	10.89	10.89	8.79	10.52

Table 6. Weibull parameters (k and c) calculated using Empirical Method (EM) and comparison of Weibull density (WPD), Rayleigh power density (RPD) and Actual power density (APD) (2008-2017)

EM	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
k(-)	4.78	5.2	6.07	5.89	6.18	5.84	5.72	7.67	5.23	5.43
c(m/s)	4.12	4.06	3.68	3.64	3.63	3.56	3.66	3.96	3.29	3.5
WPD(W/m^2)	38.42	36.53	27.05	26.19	25.95	24.51	26.64	33.77	19.43	23.35
RPD(W/m^2)	10.37	9.92	7.39	7.15	7.09	6.69	7.27	9.21	5.28	6.36
APD(W/m^2)	13.16	11.53	7.16	10.89	12.74	7.95	10.89	10.89	8.79	10.52

Table 7. Shows estimators of Weibull scale parameters c, shape parameters k, power density P and the model validation parameters MPE, MAPE, RMSE and χ^2 at 10 m height.

EPM	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
K(-)	3.76	3.87	4.03	4.54	4.07	4	3.98	3.85	3.85	3.9
c(m/s)	3.57	3.35	4.11	3.74	3.64	3.71	3.7	3.77	4.13	4.16
WPD(W/m^2)	41.04	39.91	30.12	27.98	28.66	27.15	9.48	39.38	21.32	25.74
RPD(W/m^2)	10.68	10.45	7.95	7.51	7.57	7.15	7.76	10.29	5.57	6.75
APD(W/m^2)	13.16	11.53	7.16	10.89	12.74	7.95	10.89	10.89	8.79	10.52

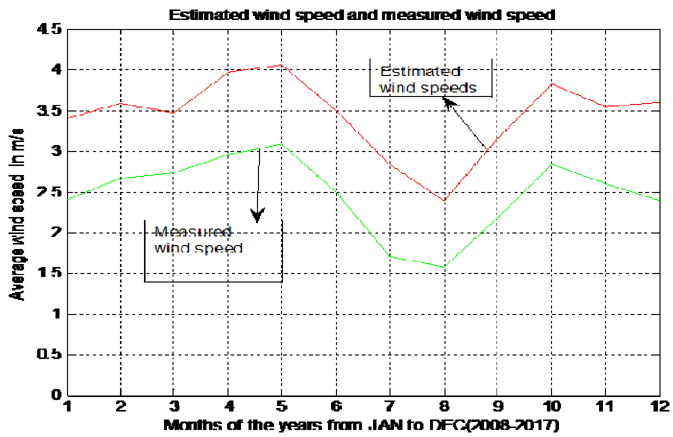

Figure 1. Estimated wind speed using power law equation and Measured wind speed from NASA at height of 10 m from (2008-2017)

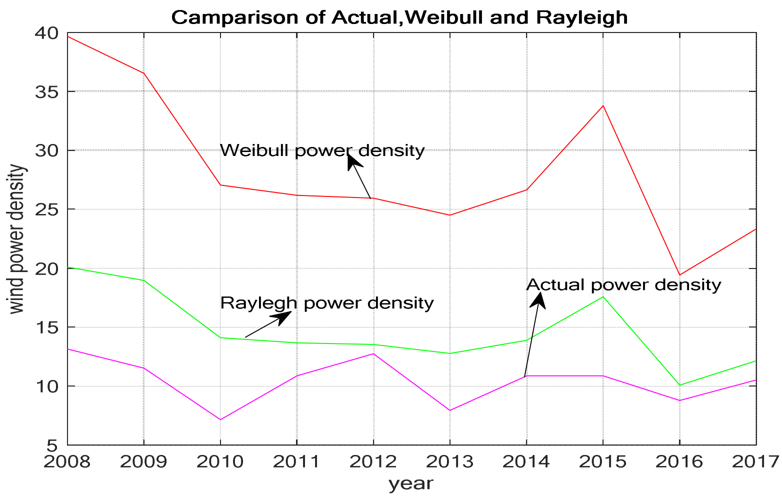

Figure 2. Comparison of wind power of actual with Weibull and Rayleigh of wind power using the Weibull parameters estimated by Moment Method

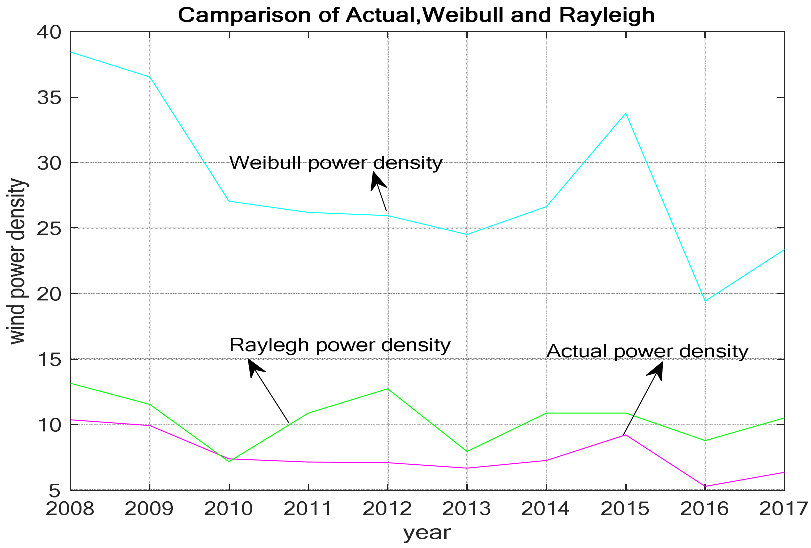

Figure 3. Comparison of wind power of actual with Weibull and Rayleigh of wind power using the Weibull parameters estimated by Empirical Method

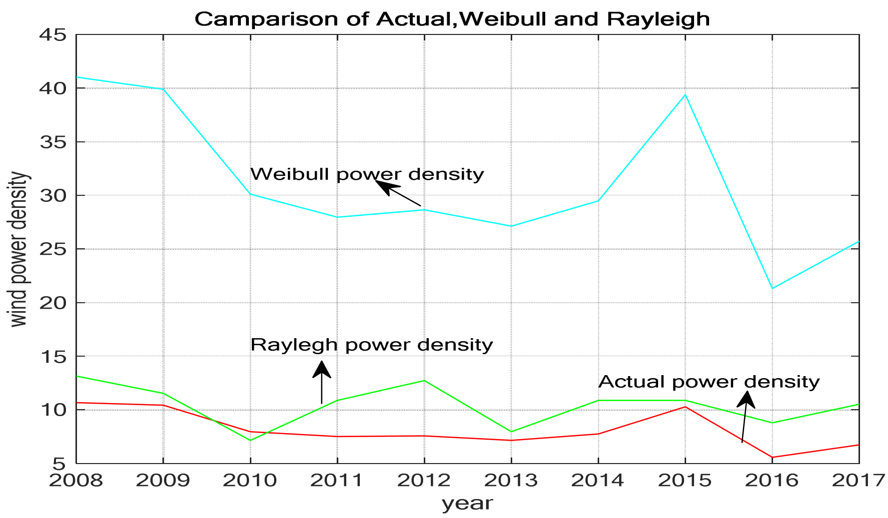

Figure 4. Comparison of wind power of actual with Weibull and Rayleigh of wind power using the Weibull parameters estimated by Energy Pattern Method

Probability Distribution functions	Statistical tests				Weibull parameters Estimators
	MPE	MAPE	RMSE	χ^2	
Weibull	-4.73	0.81	9.58	79.49	Moment method
	17.73	1.74	18.41	327.00	Empirical method
	18.63	1.86	20.56	410.23	Energy pattern method
Rayleigh	4.24	0.43	4.92	24.29	Moment method
	-2.78	0.25	3.22	9.32	Empirical method
	-2.28	0.21	2.85	7.35	Energy pattern method

As shown in figure 2 to figure 4, the wind power density calculated from Weibull function and Raleigh function was compared with wind power density calculated using measured data. As statistical tests showed in table 8, the Energy Pattern Method shows a closer performance while Empirical Method and Moment Method show a weak performance at Wereilu, South Wollo, Ethiopia. According to (52-54), the scale output of wind power classification at a 10 m height was used to categories the wind power as:
Fair (P/A < 100 W/m^2)

Fairly good (100 ≤ P/A < 300 W/m^2)

Good (300 ≤ P/A < 700 W/m^2)

Very good (P/A ≥ 700 W/m^2).

From the result that obtained average power density of Werelu, South Wollo, Ethiopia was approximately 10.45 W/m^2. Therefore, the wind power density output is considered as fair for Wereilu, South Wollo, Ethiopia.

Conclusion

In this paper preliminary calculations were performed to estimate wind energy potential in Wereillu, South Wollo, Ethiopia by utilizing 10 year wind data (2008–2017). Weibull parameters were estimated using the performance methods such as: Moment Method, Empirical Method and Energy Pattern Method. Using the results of performance method, Weibull and Rayleigh distribution were compared with measured value. From the result of the study Rayleigh has good agreement with measured values. In this study mean wind speed ranges from 2.38 m/sec to 4.07 m/sec and average wind power density ranges from 7.16 to 13.16 W/m^2. An interesting finding from this study was to estimate average power density, which is approximately 10.45 W/m^2. The current study initiates other researcher for further study on assessment of wind potential and to find best probability distribution function for future work throughout the Ethiopia.

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