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RESEARCH ARTICLE

WIND ENERGY PROBABILITY DISTRIBUTIONS FOR ELDORET

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Abstract

Weibull and Rayleigh probability distribution functions for a location in Uasin-Gishu county were computed for wind energy estimation. Five years (2004-2008) wind speed data from Eldoret meteorological station was adopted and analyzed. Wind speeds (at 2 m height above the ground) range between 1.3 m/s to 4.0 m/s. Based on these data, it was found that the numerical values of shape and scale parameters for the station considered varied over a wide range. Weibull density distribution function is an analytical function which is found to fit the wind speed curve very well. To assess the wind power potentials, the Weibull two parameters (k and c) were computed in the analysis of wind speed data. The wind speed distributions were represented by Weibull distribution and also by Rayleigh distribution, with a special case of the Weibull distribution for k = 2. The yearly values of k range from 3.0 to 5.21 and the values of c ranged from 3.0 to 4.0. The two distributions also revealed estimated wind power densities ranging between 40. 67 W/m^2 and 80.379 W/m^2 at 20 m height for the location under study. The power density estimates indicate that Eldoret is a good candidate site for small scale exploitation of wind energy.

1. Introduction

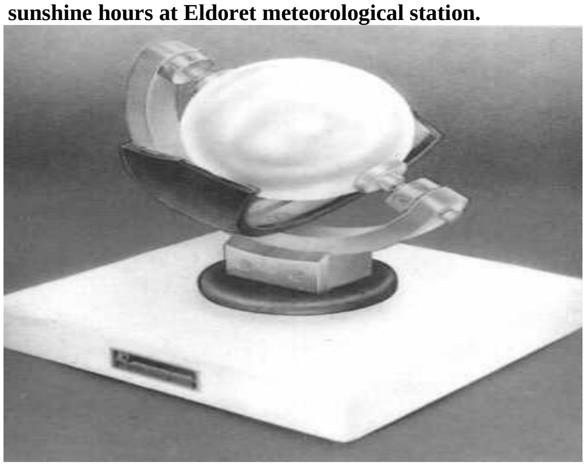
Energy is a vital resource that can transform a developing country in to middle level or developed country. There has been increased growth in wind energy globally majorly due to increased awareness and concern about protecting the environment, depletion of oil and gas reserves and improved technology of wind turbines. Kenya as a developing nation needs to invest in development of green energy as a move to attainment of vision 2030. Sathyajinth Pandey and Kumar (2001) adopted a Rayleigh distribution for defining the distribution of wind velocity in terms of its probability density and cumulative distribution functions. They developed expressions to compute the energy density, energy available in the wind spectra in a time period and the energy received by a wind turbine. A method to identify the most frequent wind speed and velocity that carries maximum amount of energy with it was discussed including the effect of cut-in and cut-out wind speeds on wind turbine performance which was also analysed. Aynur and Balo (2008), investigated wind characteristics and assessment of wind generation potentiality in Uludag-Bursa, Turkey. They analysed wind speed data collected during the period 2000-2006 and obtained speed distribution curves of the area by using the Weibull and Rayleigh probability density functions. This will form the basis for analysis of wind speed distribution curves for Eldoret region. In this study, wind speed data for Eldoret, Kenya, (at 2 m above the ground) over a five year period from 2004 to 2008 were analysed. Based on these data, the wind speeds analysed were processed using MathCAD 2000 and OriginPro statistical software’s. The main results used in the present study can be summarized as follows:

2. Materials and Methods

The data analysed in this study were daily records at Eldoret meteorological station of Kenya Meteorological Department (KMD) at 2 m above the ground level. The station is located at (0.53^{o}N, 35.28^{o}E) and its elevation is 2133 m above sea level in Uasin-Gishu county in Kenya. Wind speeds in this station are captured using a cup-type anemometer while the number of sunshine hours are recorded using Campell-Stoke sunshine recorder. These instruments are shown in figure 1 and 2 respectively.

Fig 1: Cup-type anemometer used to measure wind speeds at Eldoret meteorological station.

Fig 2: Campell-Stokes sunshine recorder used to measure sunshine hours at Eldoret meteorological station.



The Cup Counter Anemometer measures total run of wind passing at the point of observation through mechanical counter of the range 0 to 9999.9 km.

Since wind speeds used in this study were recorded at a height of 2 m above the ground, the wind speeds at higher heights were calculated using the power law. This is done by defining the parameters of the equation in MathCAD at the start of the worksheet. At the start of MathCAD worksheet, variables such as wind speed, air density and wind power are defined. The shape, *k*, and scale, *c*, parameters were calculated and inserted in the worksheet. Wind speed probabilities were calculated to obtain Weibull and Rayleigh distributions respectively by varying the wind speeds at steps of 0.1 between 0 m/s and 8 m/s. The generated values were plotted against wind speeds in OriginPro to depict comparison between Weibull and Rayleigh probability distributions for five years (2004-2008) as shown in figures 3 to 8. The use of MathCAD and its ability to carry units in computations, simplifies the arithmetic of calculating the other values in this study such as Weibull (P_W) and Rayleigh (P_R) wind power densities.

Results and Discussions

The monthly mean wind speed values and the standard deviations calculated for the available data were tabulated as presented in table 1. The highest monthly wind speeds were found to occur in the months of January and December for the whole year as shown in table 1. June to September have little wind, as indicated by the low monthly average values. The yearly probability density and the cumulative distributions derived from the data for Eldoret meteorological station at different heights are presented in Fig 3-8, with Fig 8 giving monthly wind speed cumulative probability distributions.

Fig 3: Weibull density function curves for the year 2004

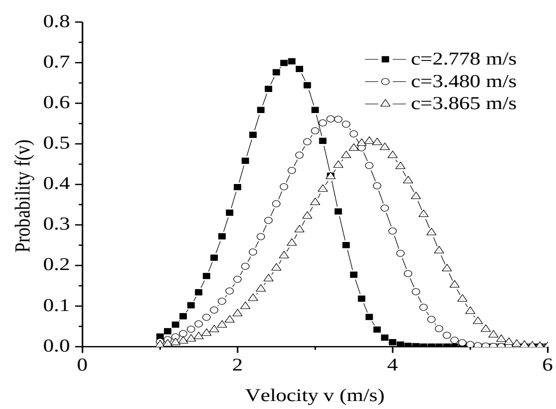


Fig 4: Weibull density function curves for the year 2005

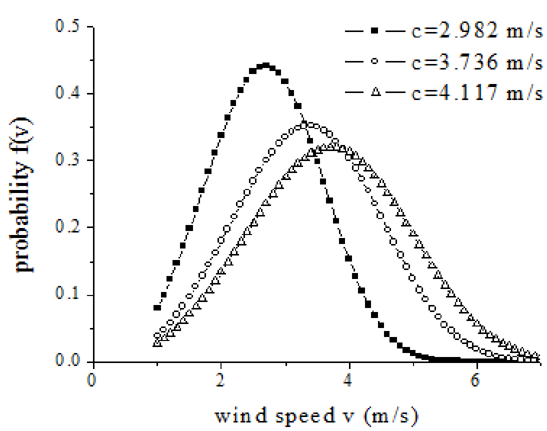


Table 1 Monthly mean wind speeds (m/s) at 2 m and standard deviations in Eldoret, Kenya, 2004–2008

YEAR	2004	2005	2006	2007	2008
JANUARY	2.793	3.065	3.993	2.849	3.574
FEBRUARY	2.788	3.596	3.615	2.469	2.991
MARCH	2.887	3.237	2.674	3.211	2.933
APRIL	2.868	2.894	2.559	2.752	3.324
MAY	2.419	1.853	2.110	1.862	2.330
JUNE	1.892	1.749	1.805	1.345	1.782
JULY	1.739	1.786	1.602	1.406	1.676
AUGUST	1.793	1.615	1.52	1.542	1.626
SEPTEMBER	2.017	1.899	1.937	1.434	1.832
OCTOBER	3.155	2.728	2.858	3.145	2.458
NOVEMBER	3.054	3.818	2.818	3.795	2.680
DECEMBER	3.276	3.916	2.849	3.455	3.170
AVERAGE	2.557	2.679	2.528	2.439	2.531
MAXIMUM	3.276	3.916	3.993	3.795	3.574
MINIMUM	1.739	1.615	1.521	1.345	1.626
STANDARD DEVIATION	0.559	0.867	0.772	0.887	0.685

Fig 5: Weibull density function curves for the year 2006

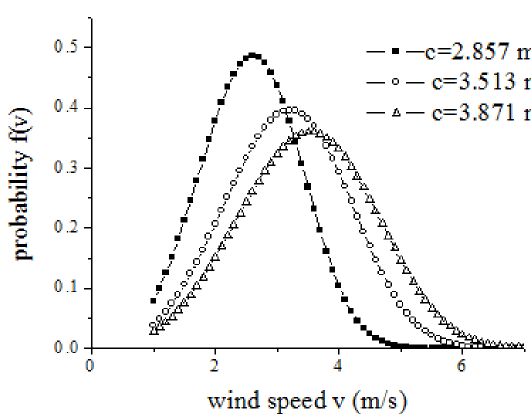


Fig 6: Weibull density function curves for the year 2007

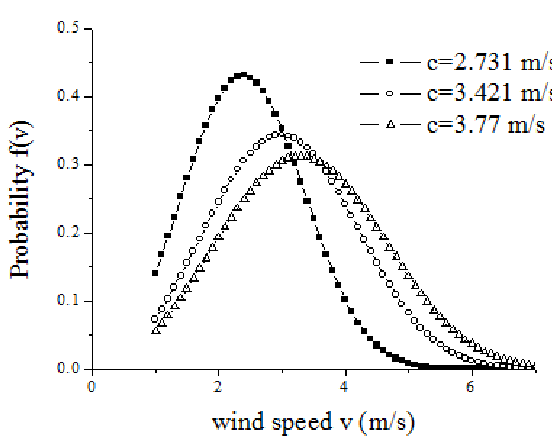


Fig 7: Weibull density function curves for the year 2008

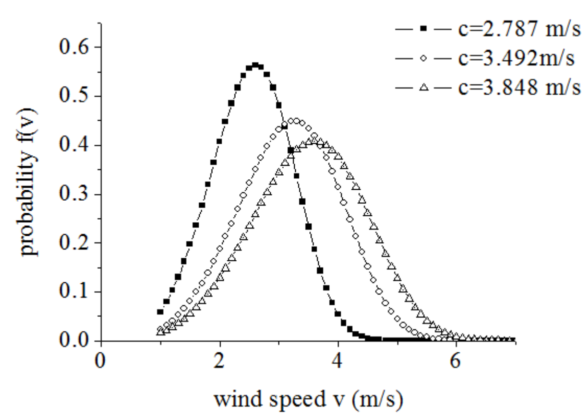
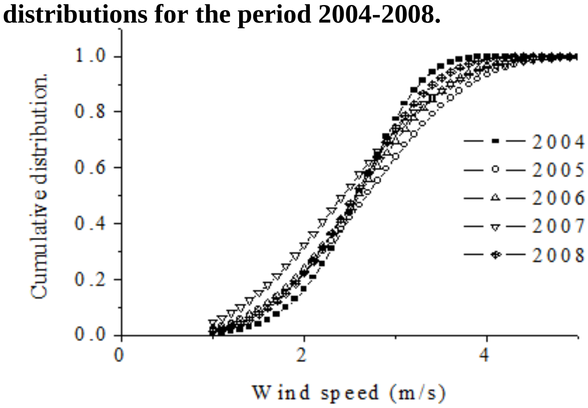


Fig 8: Monthly wind speed cumulative probability distributions for the period 2004-2008.



All the curves (Fig. 3 to Fig. 8) have a similar tendency of the wind speeds for the cumulative density and probability density.

The monthly mean wind speeds are illustrated in Fig. 9. It is also clear from Fig. 9. that the wind speed for the whole year has the lowest value in the month of June and the maximum in the month of January, ranging from 1.969 to 2.702 m/s with an annual average of 2.258 m/s.

Fig 9: Monthly mean wind speeds from the year 2004 to 2008.

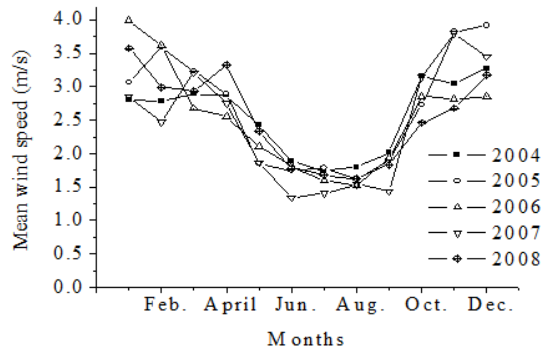
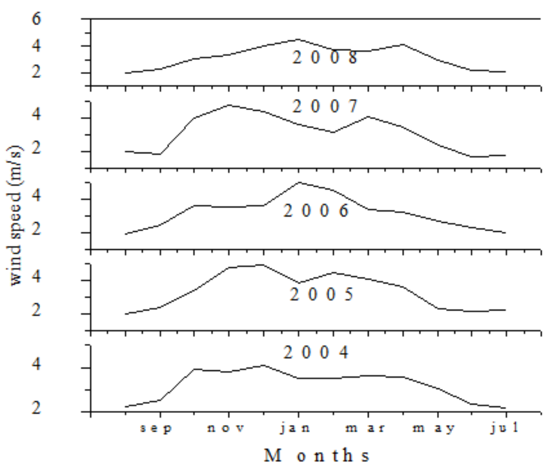


Fig 10: Monthly wind speeds from August to July for the period 2004 to 2008.



The Weibull distribution reduces to Rayleigh distribution when the shape parameter k=2. The comparison between Weibull probability distribution and Rayleigh probability distribution was also carried out and are shown in Fig 11-15.

Fig 11: Comparison between Weibull and Rayleigh probability distributions for 2004.

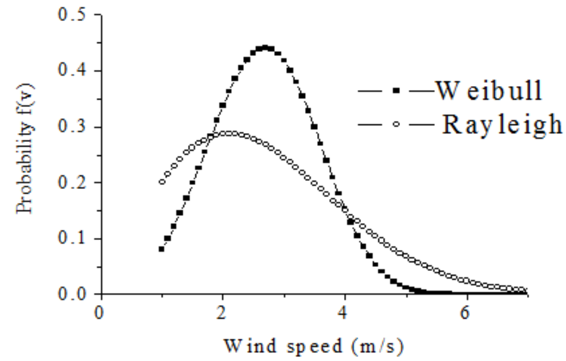


Fig 12: Comparison between Weibull and Rayleigh probability distributions for 2005.

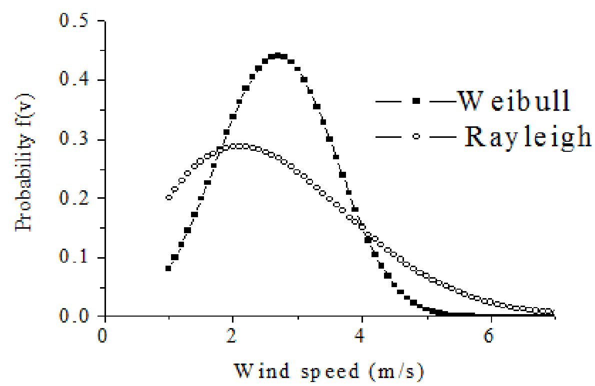


Fig13: Comparison between Weibull and Rayleigh probability distributions for 2006.

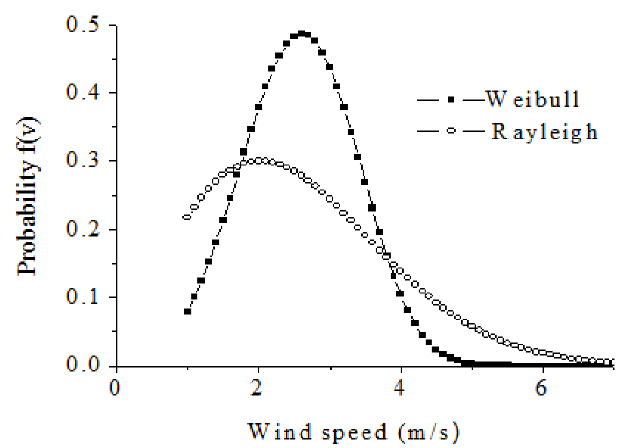


Fig 14: Comparison between Weibull and Rayleigh probability distributions for 2007.

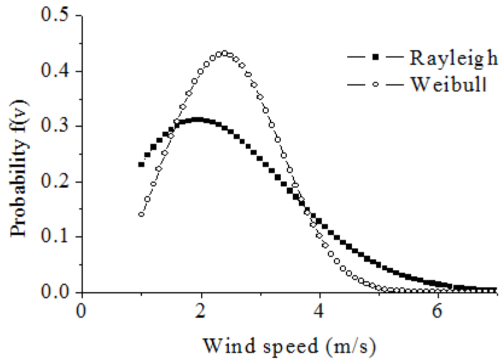


Fig 15: Comparison between Weibull and Rayleigh probability distributions for 2008.

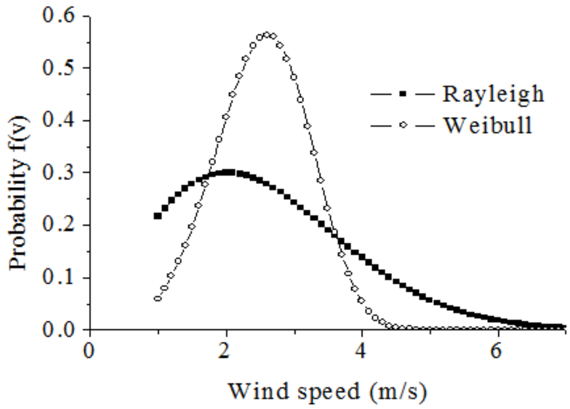


Fig 16: Weibull probabilty density distributions for the period 2004-2008.

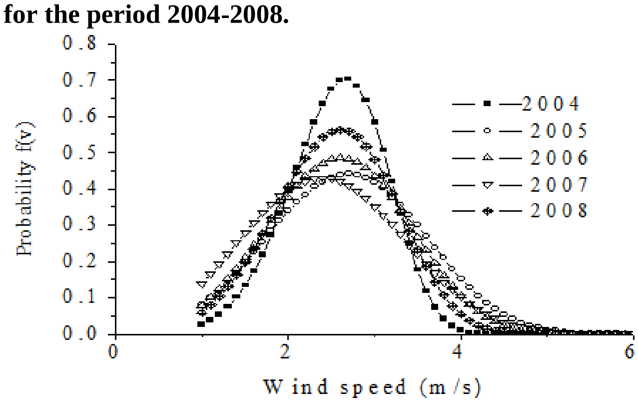
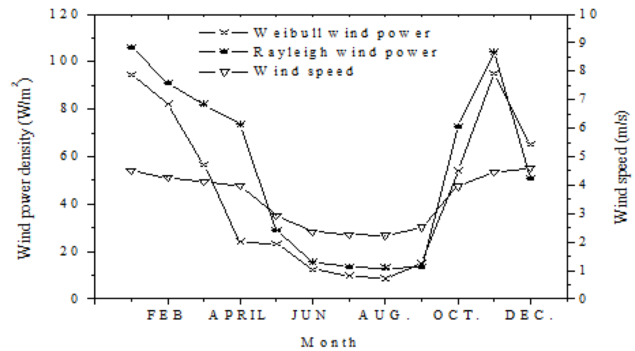


Fig 17: Wind speed, Weibull and Rayleigh wind power densities for the period 2004-2008.



The Weibull density function gets relatively narrower, more peaked and the peak moves in the direction of higher wind speed as shape parameter *k* gets larger. The Weibull parameters calculated analytically for the available data are presented in Table 2.

Table 2: Annual mean wind speed and calculated Weibull parameters.

Year	Annual mean wind speed at 10 m (m/s)	K	c
2004	3.203	5.212	3.481
2005	3.357	3.407	3.736
2006	3.167	3.624	3.513
2007	3.055	3.001	3.421
2008	3.171	4.134	3.492

It can be seen from Table 2 that while the scale parameter varies between 3.056 m/s (2007) and 3.357 m/s (2005), the shape parameter ranges from 3.00 (2007) to 5.21 (2004) for the location analysed. In order to observe the Weibull distribution of Eldoret, the Weibull probability density distributions for each of the five years were analysed. The distributions obtained are illustrated in Fig. 16.

It can be seen that the distribution is similar for a five year period and represents a narrow peak at a wind speed of around 2.7 m/s. Wind power density per unit area of the site was estimated using both Weibull probability density function and Rayleigh density function. The estimated annual wind power densities for the period 2004-2008 are presented in Table 3.

Table.3: Estimated Weibull and Rayleigh annual mean wind power densities (W/m^2) at different heights for the period 2004-2008

	2 m		10 m		20m	
Year	P_W	P_R	P_W	P_R	P_W	P_R
2004	20.689	19.554	40.670	38.443	55.717	51.433
2005	30.544	22.508	60.065	44.250	80.379	59.203
2006	26.106	18.903	48.534	37.162	64.935	49.720
2007	24.947	16.968	49.036	33.358	65.626	44.631
2008	22.882	18.973	45.009	37.299	60.226	49.904

Table 4 shows the annual mean wind speeds and the estimated Weibull and Rayleigh power densities at 2 m height.

Table 4: Annual mean wind speeds and the corresponding Weibull and Rayleigh power density (W/m^2) at 2 m above the ground.

Year	Mean wind speed	P_W	P_R
2004	2.557	20.689	19.554
2005	2.680	30.544	22.508
2006	2.528	26.106	18.903
2007	2.439	24.947	16.968
2008	2.531	22.882	18.973

In order to observe the relationship between wind speed and wind power density, the graph of wind speed (m/s) and wind power density (W/m^2) were plotted on the same axes.

It can be seen from the Fig. 17 that the trend of wind power densities estimated using both Weibull and Rayleigh density functions are almost the same. It is however notable that a small change in wind speed produces a drastic change in wind power density estimated using Rayleigh method due the fact that wind power density is proportional to the cube of mean wind speed.

Conclusion

Wind probability distributions for Eldoret were carried out. Weibull and Rayleigh density distributions were used to describe the distribution over a 5 year period (2004-2008). The values of shape, *k* and scale, *c* parameters were computed for the site and found to range between 3.0 and 5.21 and 3.0 to 4.0 respectively. Average wind power density at the height of 10 m and 20 m were estimated and found to vary from a minimum of 40.67 W/m^2 in 2004 to a maximum of 80.379 W/m^2 in 2005 at 20 m height. The work carried out is just a preliminary study to establish the wind speed distribution for Eldoret. Further detailed study needs to be done before a decision to install suitable small wind turbines is concluded. The results, however, reveal that Eldoret region is a candidate site for wind energy exploitation in small scale.

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