AN INVESTIGATION OF THE UTILITY SCALE WIND ENERGY FOR NORTH-EASTERN KENYA REGION

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Abstract
In the present study, the wind energy potential for Garissa (0°28'S, 39°38'E) and Marsabit (2° 19'N, 37° 58'E), both rural towns in north-eastern Kenya have been statistically analyzed on a 6-year measured hourly time series wind speed data. The probability distribution parameters are derived the time series data and the distributional parameters are identified and fitted annually on the basis of Weibull model. Garissa's average wind speeds were found to range between 2.5 and 3.5 m/s giving power densities of between 74 and 190 W/m^2 at a height of 50 m. The yearly value of Weibull's shape parameter k ranged from 1.26 to 1.38, whilst the values of the scale parameter c ranged between 2.92 and 3.90 m/s. In the case of Marsabit average wind speeds greater than 11 m/s are prevalent. The available power density at a height of 50 m is between 1776 and 2202 W/m^2 which is in the wind class range of 7 and 8. Values of Weibull parameters k and c ranged between 2.5-3.05 and 11.86-12.97 m/s, respectively. From the analysis, the Marsabit site was found suitable for grid connected power generation while the Garissa site was found suitable for non-grid uses such as water pumping and battery charging.

Key words: Wind speed, power law, Weibull parameters, wind class, wind rose, energy potential

Nomenclature

v	wind speed (m/s)
$\bar{v}$	average wind speed (m/s)
c	Weibull scale parameter (m/s)
k	Weibull shape parameter (dimensionless)
$f(v)$	- probability of observing wind speed, v
$F(v)$	cumulative probability distribution function
$f(x)$	Gumbel probability density function
$F(x)$	Gumbel cumulative probability density function
σ^2	Variance
ρ	density of air (kg/m^2)
Γ	gamma function

1.0 Introduction

Energy utilisation has continued to rise globally over the years as technologies expand in the developed countries and as Third World countries experience growth in industrialization and population. Primary energy sources include fossil fuels such as oil, coal, natural gas; and renewable sources such as solar, wind, tidal, geothermal and hydropower. While energy consumption and demand will continue to grow there is fear of depletion of the non renewable sources, with estimates suggesting that the world's oil supply may fail to meet demand by year 2015 (Kumar, 2000).

Most developing nations, Kenya included, rely on fossil fuels for most of their energy; but clean renewable energy is becoming increasingly important as the world faces the threat of global warming and the realization that the fossil fuels will eventually run out or become to expensive to retrieve. International conventions such as The Intergovernmental Panel on Climate Change (IPCC) in its Second Assessment Report (SAR) noted that the average global temperatures are likely to rise between 1.4 and 5.8^{o}c over the current century leading to average sea-level rises of between 0.09 to 0.88m by 2100 (IPCC, 2001). This might cause severe climate change precipitating drought and flooding in most parts of the world. It is therefore becoming increasingly evident that renewable energy technologies have a strategic role to play in the achievement of the goals of sustainable economic development and a good mitigation measure for clean environment and the reduction of the greenhouse gases (GHGs) (Mathur *et al.,* 2002).

In Kenya, the cost of oil based imports has increased by over 1000% in the past three decades. The cost of electricity alone has more than doubled in the past one year rising from Ksh.3.92 in June 2009 to Ksh. 9.0 by August 2011. Generation of electricity has been growing steadily in Kenya. Of the installed capacity of about 1200MW, 79% is hydropower, 16% geothermal, 4% thermal while the rest comes from other sources like fossil fuel, wind and solar. Most people in Kenya live in the rural areas, and only about 10% have access to electricity. Due to unreliability in the rain patterns leading to persistent drought (1999-2002), (2005/6) and more recently year 2008, Kenya cannot continue to rely on hydropower generation for most of its electricity needs. Therefore there is need for using alternative renewable sources such as solar and wind to make country globally competitive and prosperous in line with Kenya's Vision 2030.

Wind energy is world's fastest growing energy source, expanding at annual rates of between 25 to 35% (Shikha *et al.,* 2004). In 2007 alone world wide wind capacity increased by 26% to reach the 100 GW mark (IEA, 2007). Recent interest in wind energy technology has resulted in bigger turbines, larger rotor diameters and reduced costs that are quite competitive with other resources, such as hydro and coal. Currently, Kenya has only 5.5 MW of wind power connected to the grid.

This paper examines the wind energy potential for Garissa (0^o 28'S, 39^o 38'E) and Marsabit (2 ^{o} 19'N, 37^o 58'E) in Kenya with possibilities of feeding the power obtained into the national grid and also for pumping water for domestic use, irrigation and for pasture in the surrounding areas.

The specific objectives include, determining the average wind speeds (diurnal, monthly and annual) for the sites, characterising the various wind parameters (average speed, Weibull shape parameter *k* (dimensionless) and Weibull scale parameter *c* (m/s)), performing Wind rose analysis to determining the available power density and to model the extreme wind speeds to determine the 'return period' for the sites.

2.0 Materials and Methods

The data used in this study consists of averaged time series 6-year wind speeds for the period between 2001 and 2006. The wind speed data was recorded at the standard height of 10m by the Kenya Meteorological Department (KMD). Wind direction and air density were also recorded for the same period.

Wind energy resource is highly variable both in space and time; therefore, to understand the characteristics of the resource various parameters were considered.

2.1 Mean Wind Speeds

Mean wind speed, $\bar{v}$ is the most commonly used indicator of wind production potential (Manwell *et al,* 2002).
The mean wind speed is defined as

$$\bar{v} = \frac{1}{N}\sum_{i=1}^{N} v_i \quad \text{......(1)}$$

where N is the sample size and v_i is the wind speed recorded for the i^{th} observation.
Where the sample size is large, the probability of the observed wind speed being within an interval can be written as

$$P(v_j) = \frac{n_j}{N} \quad \text{...... (2)}$$

where v_j is the median value and n_j is the number of observations in the j^{th} interval.
The mean wind speed can then be calculated as

$$\bar{v} = \sum_{j=1}^{m} P(v_j)v_j \qquad (3)$$

where *m* is the number of intervals, or:

$$\bar{v} = \int_0^\infty v.f(v)dv \qquad (4)$$

where *f (v)* is the non-cumulative probability distribution function.
The variance σ^2 is given by

$$\sigma^2 = \int_0^\infty (v-\bar{v})^2 f(v)dv \qquad (5)$$

2.2 Probability Distribution Function (PDF)

Due to the variability of the wind speed it is found useful to plot the wind speed probability distribution function (the percentage of time that the wind spends at each speed) to understand the character of the variation. One of the commonly used functions for this purpose is the Weibull distribution given by (Seguro and Lambert, 2000; Akpinar and Akpinar, 2004)

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

where $f(v)$ is the probability of observing wind speed *v*, *c* (m/s) is the Weibull scale parameter and *k* is the dimensionless shape factor.

The cumulative probability function of the Weibull distribution is given by

$$F(v) = 1 - \exp\left[-\left(\frac{v}{c}\right)^k\right] \qquad (7)$$

To determine *k* and *c* requires a good fit of equation (7) to the recorded discrete cumulative frequency function (Mikhail and Justus, 1986). By taking the natural logarithm of both sides of equation (7) twice gives

$$\ln\langle -\ln[1-F(v)]\rangle = k\ln(v) - k\ln c \qquad (8)$$

Plotting $\ln\langle -\ln[1-F(v)]\rangle$ against $\ln(v)$ presents a straight line whose gradient is *k* and the y-intercept is $-k\ln c$ from which *c* was calculated.

2.3 Wind Direction

A wind rose is a polar plot that represents the percentage of the time that the wind direction falls within the sector of the compass. Where the wind direction is shown over a period, the value represents the vector sum for the period. The direction shown on the pie graphs in the results section are for standard anemometer height of 10m.

2.4 Wind Speed Variation with Height

As stated before, the standard anemometer height is 10m. However, in order to harvest wind energy, wind speeds at heights greater than 10 m are required for better results. Therefore, equations that predict the wind speeds at one height in terms of the measured speed at another height are required. We applied the power law model (Oludhe and Ogallo, 1990; Lun and Lam, 2000) which takes the form

$$\frac{v_2}{v_1} = \left(\frac{z_2}{z_1}\right)^a \quad \text{.......... (9)}$$

where v_2 is the extrapolated wind speed at height z_2 and v_1 is the measured speed at z_1.

The exponent a depends on such factors as nature of terrain (surface roughness), wind speeds and temperature. For neutral stability the exponent value of $\frac{1}{7}$ has widely been chosen as a good representative of the prevailing conditions (Damarais, 1959). We used the power law to predict the wind speeds at the various heights.

2.5 Wind Power Density

The power in the wind can be computed by using the concept of kinetics. The wind turbine works on the principle of converting kinetic energy of the wind into mechanical energy.

The maximum power (P) available from the wind is given by

$$P = \frac{1}{2}\rho A v^3 \quad \text{.......... (10)}$$

where ρ is the density of air , A is the cross-sectional area swept by the rotor and *v* is the average wind speed. The actual amount would be less since all available energy is not extractable.

To calculate the monthly or annual wind power density per unit area, P_w, of a site based on Weibull probability density function, the following equation as reported by Akpinar and Akpinar (2004) can be used

$$P_w = \frac{1}{2}\rho\, c^3 \left(1 + \frac{3}{k}\right) \quad \text{.......... (11)}$$

The two significant parameters k and c have been shown to be related to the mean value of the wind speed $\bar{v}$ (Mayhoub and Azzam, 1997) as

$$\bar{v} = c\Gamma\left(1 + \frac{1}{k}\right) \quad \text{(12)}$$

where Γ is the gamma function.

The maximum extractable power P_E (W/m^2), by a system working at its optimum efficiency, is limited by the power coefficient called the Betz limit whose value is $\frac{16}{27}$ or 0.593 (John and Antony, 1987) and is therefore given by

$$P_E = 0.593P \quad \text{(13)}$$

This capacity factor makes the maximum extractable power approximately 59.3 % of the theoretical power density.
Equation 11 was used to calculate the power densities.

2.6 Gumbel Distribution

It is necessary to know the return period of extreme winds in a locality. The Gumbel distribution is useful for modeling the probability of extreme wind speeds. The probability distribution function f(x) and the cumulative probability distribution function F(x) of the Gumbel distribution are given respectively by (Stevens and Smulders, 1979)

$$f(x) = \exp\left\langle -\exp\left[-\frac{(x-\mu)}{B}\right]\right\rangle . \exp\left\langle -\exp\left[-\frac{(x-\mu)}{B}\right]\right\rangle . \frac{1}{B} \quad \text{(14)}$$

$$F(x) = \exp\left\langle -\exp\left[-\frac{(x-\mu)}{B}\right]\right\rangle \quad \text{(15)}$$

Where *x* is the extreme value of the wind speed, μ is the mode parameter and B, the scale parameter.
The return period (R) of the extreme winds is the reciprocal of the probability of Exceedence given by

$$x = \mu - B\ln\left[-\ln\left(1 - \frac{1}{R}\right)\right] \quad \text{(16)}$$

3.0 Results and Discussion

In this study, wind speed data for Garissa and Marsabit, both rural towns in north-eastern, Kenya, for the six year period from 2001 to 2006 was analyzed. Based on this data, wind speeds, altitudes, wind directions and densities for the site were processed using statistical software programs to generate distribution curves and Wind Rose plots. Calculations were then made to obtain Weibull distribution parameters in terms of the shape parameter k (dimensionless) and the scale parameter c (m/s), the average (diurnal, monthly, annual) wind speeds and the mean power density. The summary of the results are presented in Tables 1a, 1b, 2a and 2b.

Table1a: Monthly average wind speeds v (m/s) and standard deviation σ (m/s) for Garissa, Kenya 2001-2006

Garissa	**Parameters**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Jan	v	1.690	1.655	1.138	1.219	1.501	2.007
	σ	1.822	1.479	1.398	1.468	1.596	1.811
Feb	v	2.458	2.080	1.624	1.942	2.453	2.132
	σ	2.151	1.811	1.549	1.807	2.151	1.697
Mar	v	2.653	2.596	2.242	1.997	2.655	2.555
	σ	2.130	1.830	1.991	1.809	2.129	2.184
April	v	3.253	2.606	3.156	2.604	3.251	3.119
	σ	2.281	2.155	2.264	2.155	2.284	2.053
May	v	4.246	3.202	2.583	4.674	4.251	3.573
	σ	2.665	2.235	2.057	2.163	2.661	2.346
Jun	v	5.050	4.031	3.209	4.333	5.047	5.725
	σ	3.400	2.550	2.108	2.589	3.403	3.657
Jul	v	5.267	3.782	3.898	5.017	5.273	5.696
	σ	3.189	2.129	2.491	2.773	3.186	3.124
Aug	v	5.895	4.521	3.206	4.157	5.897	4.630
	σ	2.847	2.521	1.831	2.397	2.847	2.910
Sep	v	4.454	3.402	3.691	4.020	4.447	4.769
	σ	2.690	2.202	1.988	2.119	2.690	2.628
Oct	v	4.461	3.122	3.371	3.468	4.460	4.009
	σ	2.948	1.914	2.011	1.918	2.949	2.932
Nov	v	1.751	1.591	1.192	1.900	1.749	1.479
	σ	1.804	1.412	1.281	1.918	1.806	1.334
Dec	v	1.191	1.419	1.444	0.839	1.192	0.872
	σ	1.231	1.352	1.336	1.332	1.231	1.134
All Year	v	3.539	2.839	2.568	3.018	3.522	3.387
	σ	2.925	2.227	2.125	2.491	2.925	2.885

Table 1b: Monthly average wind speeds v (m/s) and standard deviation σ (m/s) for Marsabit, Kenya 2001-2006

Marsabit	Parameters	2001	2002	2003	2004	2005	2006
Jan	v	8.530	9.140	8.240	9.420	10.130	10.850
	σ	4.253	3.071	3.094	4.662	4.773	4.261
Feb	v	12.860	10.590	9.880	10.910	11.640	11.730
	σ	3.993	3.192	3.940	5.708	4.460	4.655
Mar	v	12.630	8.600	10.760	10.870	11.400	10.890
	σ	4.959	3.973	3.542	4.744	4.150	3.665
April	v	9.750	8.640	10.290	9.200	11.480	9.820
	σ	4.583	3.830	4.054	4.423	3.833	3.419
May	v	11.220	9.730	12.250	10.100	9.980	11.100
	σ	4.226	4.856	5.335	4.896	4.180	3.197
Jun	v	11.290	11.350	11.050	13.380	12.510	12.150
	σ	3.807	4.032	4.989	4.310	3.974	3.400
Jul	v	12.080	13.060	11.480	12.590	13.040	12.110
	σ	3.622	3.855	3.775	3.856	4.033	2.260
Aug	v	12.680	14.490	10.890	13.160	12.170	10.840
	σ	4.272	4.131	3.611	3.476	3.710	3.861
Sep	v	12.370	13.930	13.160	12.960	11.790	12.270
	σ	4.313	4.470	4.003	4.223	4.507	3.485
Oct	v	10.920	11.280	10.470	11.640	12.430	9.540
	σ	3.886	4.168	3.432	4.176	3.262	3.669
Nov	v	9.430	9.170	10.340	8.890	9.640	8.460
	σ	3.131	3.425	2.556	4.284	3.682	3.101
Dec	v	10.150	7.440	9.550	8.720	10.400	8.160
	σ	3.303	3.725	3.092	3.920	3.665	3.744
All Year	v	11.150	10.620	10.700	10.990	11.380	10.650
	σ	4.286	4.487	4.038	4.718	4.171	3.837

The monthly average wind speeds, v (m/s) and the standard deviations, σ (m/s) calculated for the available time series data are presented in Table 1a and 1b and the inter-annual monthly variations of the average speeds are presented in Figs. 1a and1b for Garissa and Marsabit respectively. It can be seen from the plots that in the case of Garissa the months of June through October have the highest wind speeds for all the six years, having average wind speeds greater than 4 m/s, except year 2003 whose average speeds were between 3.2 and 3.9 m/s. These high wind speeds may be influenced by the northern hemisphere summer which occurs between June and August. The months of November, December, January and February registered the lowest average wind speed of less than 2.5 m/s corresponding to the northern hemisphere winter season (December-February).

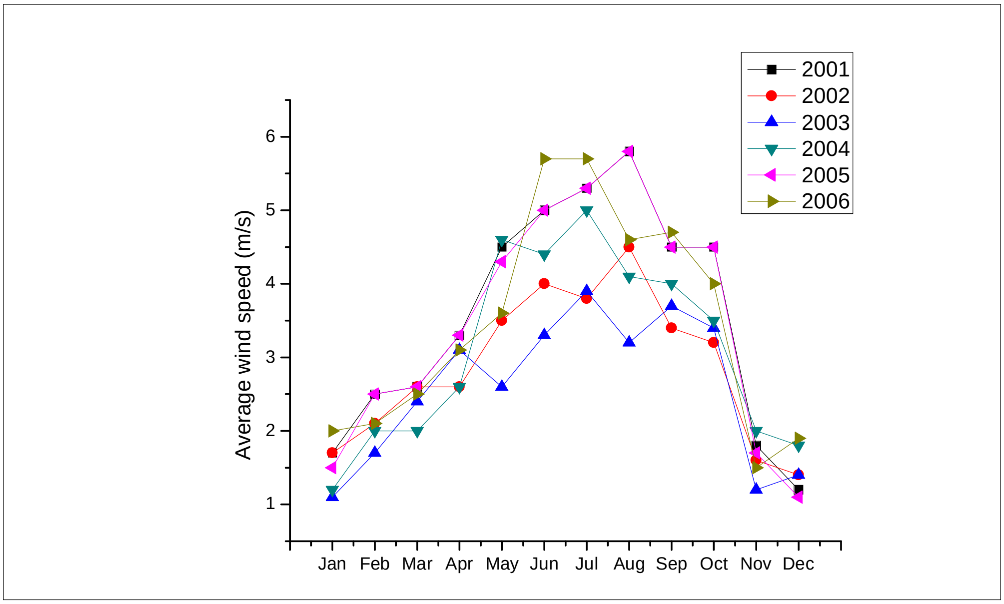

Figure 1a: Inter-annual variability of the monthly average wind speeds, Garissa 2001-2006

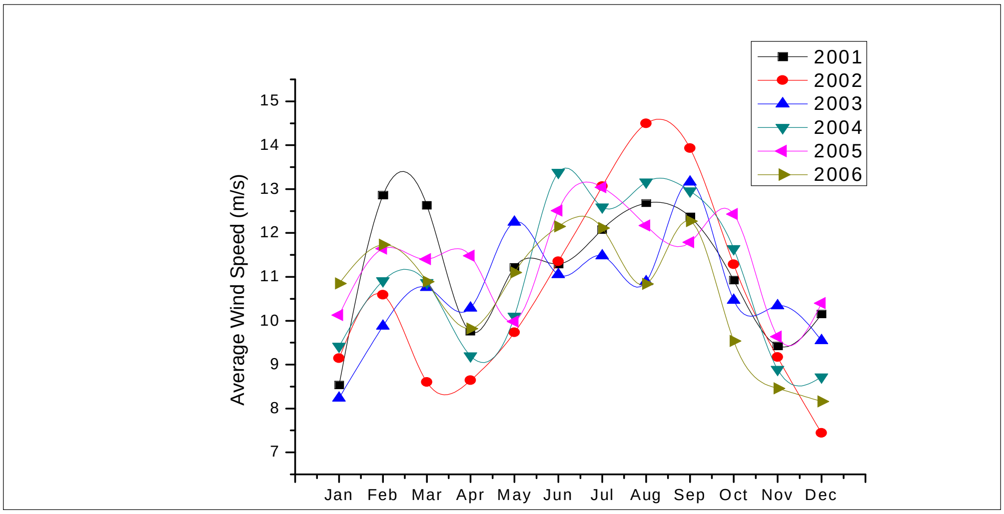

Figure 1b: Inter-annual variability of the monthly average wind speeds, Marsabit 2001-2006

The month to month variation for Marsabit exhibited in Figure 1b may be attributed to channeling effects of wind due the many hills around this area. The inter-annual variability in the wind speeds could be associated with the inter-annual variation in the monsoonal wind characteristics. Figure 2a and 2b illustrates the inter-annual variability of the average wind speed by hour of day. It is clear that for Garissa (Figure 2a) that the peak wind speeds trend is bimodal for all the six years. It depicts high speeds between 11 am and 4 pm, and then between 9 pm and 12 midnight. The early morning hours between 4 am and 8 am depicts the lowest speeds of below 2 m/s. In the case of Marsabit all the years under consideration show a similar profile (Fig. 2b) with the lowest average speed of 7.5 m/s occurring between 15 and 16 hrs (GMT). This corresponds to the sunset hours in Kenya. High wind speeds of above 11 m/s are prevalent during the nighttime hours and peaking to speeds of above 13 m/s during the early morning hours. This enhanced nocturnal resource may be attributed to the reduced vertical mixing of low momentum near-surface air due to the large thermal stability during the night hours (Kamau *et al.*, 2010).

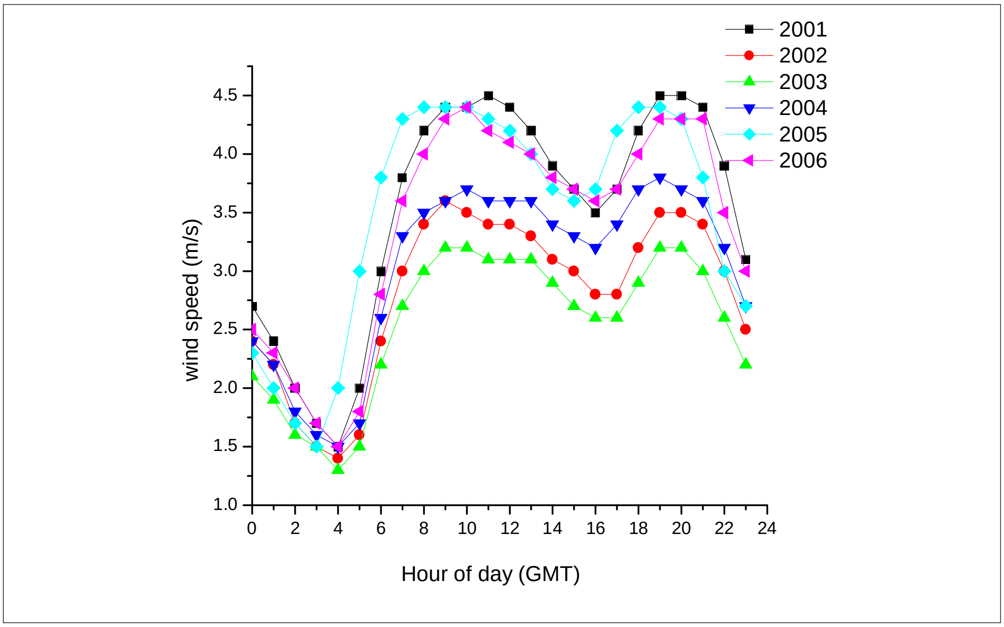

Figure 2a: Inter-annual variability of the average wind speed by hour of day Garissa, Kenya 2001-2006

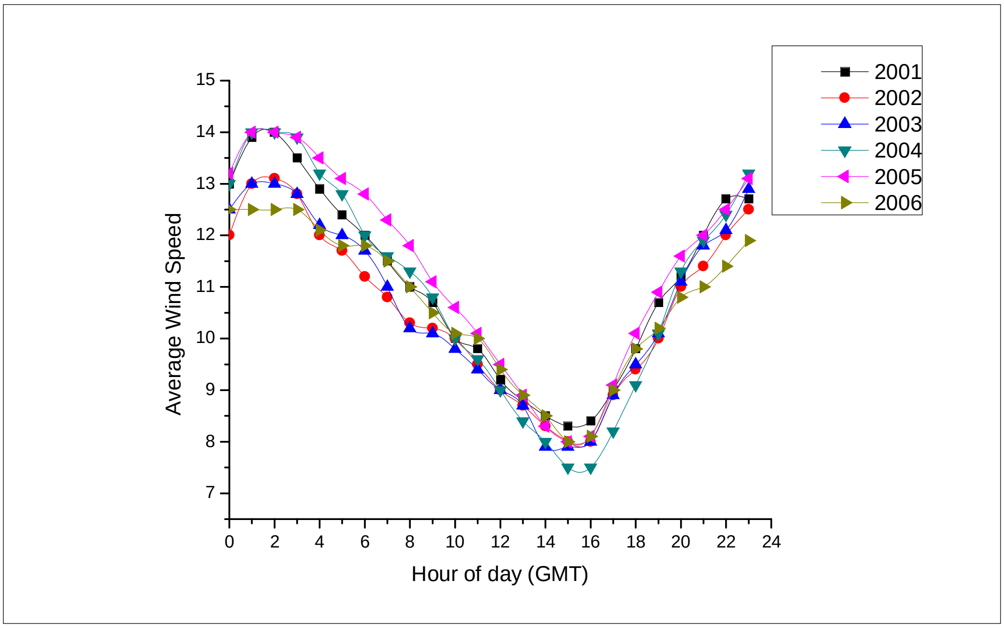

Figure 2b: Inter-annual variability of the average wind speed by hour of day Marsabit, Kenya 2001-2006

Figures 3a and 3b show the probability distribution for the wind speeds for the six year period between 2001and 2006 for Garissa and Marsabit respectively. For Garissa, it can be seen that year 2001 and year 2005 return a similar probability distribution in both shape and scale. Both years have the highest average wind speed of 3.5 m/s. Years 2003 and 2002 had the narrowest distribution owing to their relatively high k values of 1.36 and 1.38 respectively. All the plots for Marsabit show a similar profile of a near normal distribution around the modal value of 11 m/s. The mean annual values of wind speeds range between10.6 and 11.4 m/s whilst the *k* values range between 2.50 and 3.10 showing very small spatial variation.

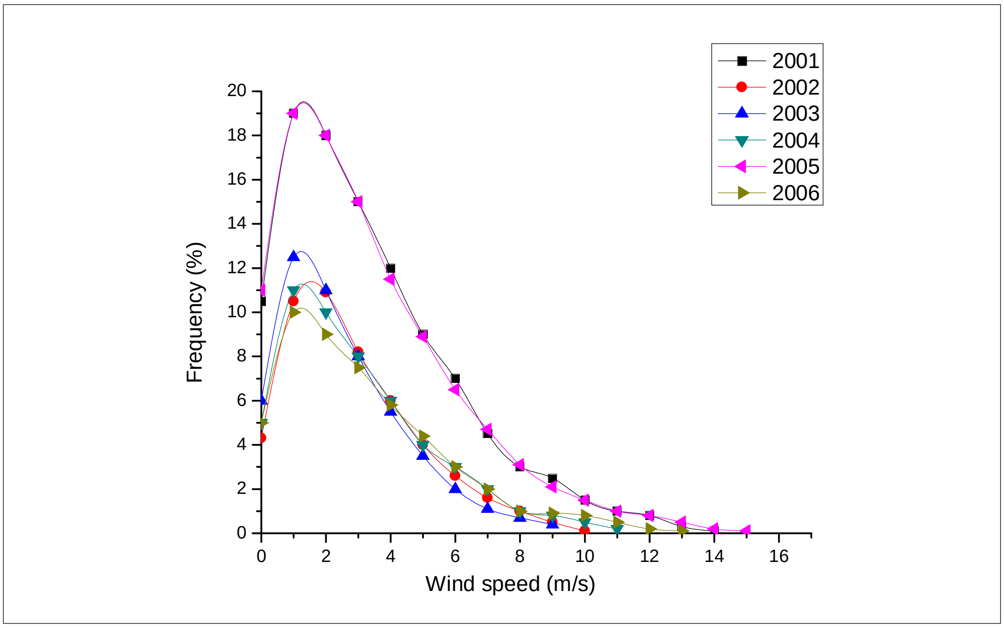

Figure 3a: Probability distribution functions, Garissa 2001-2006

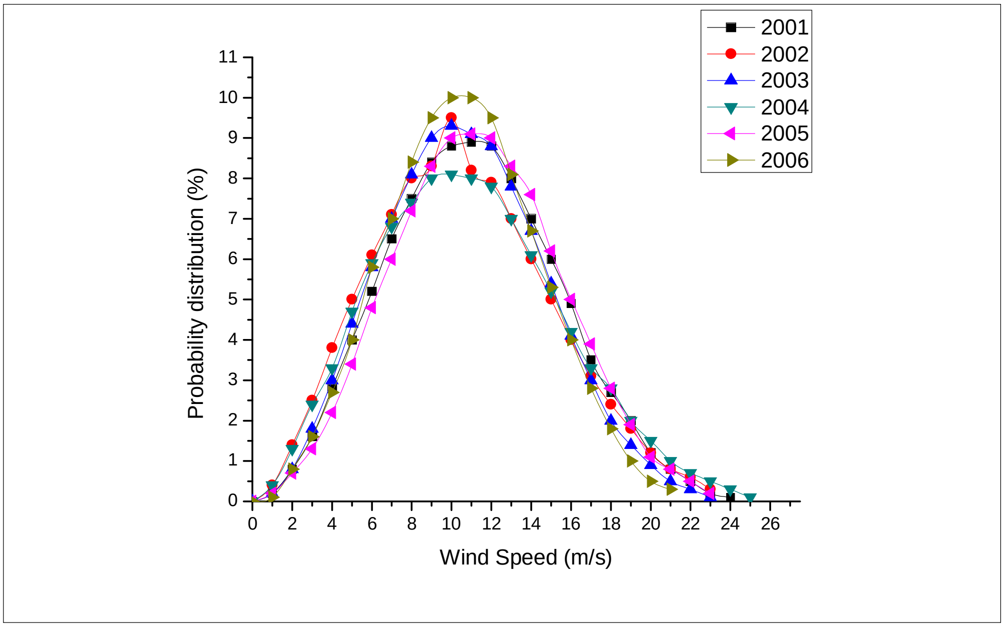

Figure 3b: Probability distribution functions, Marsabit 2001-2006

Table 2a and 2b present the values of Weibull dimensionless shape parameter *k* and the scale parameter *c* (m/s). For Garissa, the monthly values of *k* range between 0.74 and 2.33 both values in year 2004 while the monthly values of *c* ranged between 1.0 and 6.4 m/s. The yearly values of *k* range between 1.27 and 1.39 while the yearly values of *c* range between 2.9 m/s and 3.9 m/s. Clearly the parameter k has a much smaller spatial variation than *c*. The k value for Marsabit ranges from 2.50 to 3.05, while the values of c range between 11.9 and 12.7. In this case the value of k has a higher spatial variation than c. For most wind conditions, values of *k* typically range between 1.5 and 3.0 whilst the values of c are proportional to the wind speed (Akpinar and Akpinar, 2004).

Table 2a: Monthly shape parameter, k (dimensionless) and scale parameter, c (m/s) for Garissa, Kenya 2001-2006

Garissa	**Parameters**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Jan	k	1.133	1.460	0.895	0.742	0.920	1.001
	c	1.979	2.025	1.177	1.124	1.536	2.077
Feb	k	1.186	1.354	1.356	1.281	1.175	1.486
	c	2.654	2.406	1.969	2.272	2.637	2.498
Mar	k	1.433	1.460	1.134	1.351	1.440	1.319
	c	3.036	2.891	2.402	2.367	3.043	2.899
April	k	1.586	1.346	1.156	1.385	1.571	1.768
	c	3.732	2.965	3.301	2.986	3.720	3.630
May	k	1.591	1.431	1.302	2.331	1.586	1.656
	c	4.727	3.544	2.839	5.298	4.726	4.048
Jun	k	1.561	1.573	1.539	1.778	1.555	1.658
	c	5.665	4.487	3.577	4.910	5.656	6.463
Jul	k	1.669	1.823	1.484	1.961	1.678	1.973
	c	5.889	4.254	4.300	5.711	5.901	6.479
Aug	k	2.158	1.863	1.846	1.865	2.165	1.719
	c	6.634	5.093	3.621	4.730	6.640	5.246
Sep	k	1.748	1.695	1.922	2.048	1.759	1.996
	c	5.029	3.887	4.159	4.568	5.030	5.448
Oct	k	1.552	1.811	1.739	1.965	1.548	1.325
	c	4.971	3.578	3.793	3.948	4.967	4.368
Nov	k	1.192	1.485	1.364	1.141	1.183	1.479
	c	2.055	1.967	1.569	2.184	2.050	1.842
Dec	k	0.965	1.415	1.453	0.860	0.974	1.237
	c	1.274	1.791	1.805	1.012	1.281	1.252
All Year	k	1.274	1.386	1.357	1.287	1.270	1.268
	c	3.908	3.203	2.926	3.378	3.888	3.757

Table 2b: Monthly average values of Weibull shape parameter k (dimensionless) and scale parameter c (m/s) for Marsabit, Kenya 2001-2006

Marsabit	Parameters	2001	2002	2003	2004	2005	2006
Jan	k	2.077	3.155	2.896	2.112	2.190	2.783
	c	9.590	10.180	9.240	10.610	11.380	12.180
Feb	k	3.486	3.610	2.708	1.884	2.894	2.694
	c	14.300	11.760	11.110	12.180	13.040	13.080
Mar	k	2.739	2.315	3.390	2.453	3.107	3.364
	c	14.180	9.720	11.970	12.220	12.750	12.080
Apr	k	2.278	2.427	2.741	2.204	3.316	3.184
	c	11.040	9.760	11.550	10.380	12.770	10.930
May	k	2.909	2.063	2.428	2.175	2.520	3.800
	c	12.590	10.940	13.790	11.390	11.180	12.270
Jun	k	3.278	3.038	2.367	3.459	3.416	4.042
	c	12.600	12.700	12.480	14.870	13.900	13.360
Jul	k	3.769	3.610	3.278	3.717	3.572	6.113
	c	13.370	14.470	12.810	13.950	14.420	13.030
Aug	k	3.379	3.768	3.363	4.260	3.708	3.149
	c	14.140	16.030	12.140	14.430	13.460	12.080
Sep	k	3.176	3.392	3.605	3.365	2.909	4.180
	c	13.830	15.520	14.600	14.420	13.250	13.510
Oct	k	3.072	2.866	3.297	3.047	4.229	2.795
	c	12.220	12.670	11.670	13.020	13.610	10.640
Nov	k	3.310	2.902	4.446	2.182	2.805	3.056
	c	10.510	10.290	11.330	10.030	10.770	9.440
Dec	k	3.310	2.114	3.348	2.391	3.098	2.274
	c	11.310	8.400	10.620	9.840	11.540	9.140
All	k	2.817	2.533	2.835	2.502	2.984	3.053
	c	12.510	11.970	12.000	12.360	12.720	11.860

The average power density by direction for Garissa's year 2001 and Marsabit's year 2006 is illustrated in Figure 4a and 4b respectively. Year 2001 returned the highest average power density of 97 W/m^2 at 10 m in the case of Garissa, the mean direction of the wind speed being 165^o with a standard deviation of 70.7^o. Year 2006 returned the lowest power density of 903 W/m^2 in the case of Marsabit, the mean wind speed being between 150^o and 160^o with a standard deviation of 33.5^o.

It is clear from the foregoing and from figs. 4a and 4b that the wind speeds are more dispersed for the Garissa site than the Marsabit site for the years considered.

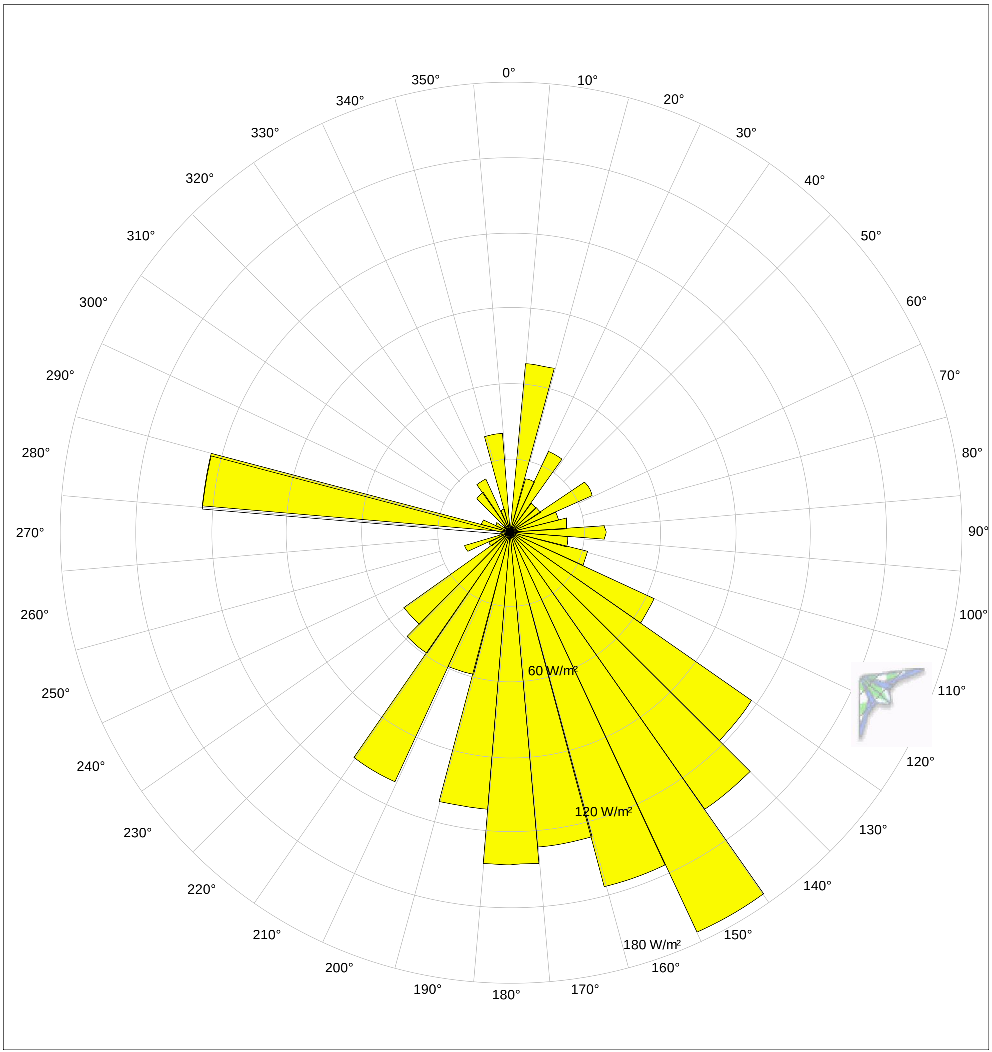

Figure 4a: Average power density by direction, Garissa 2001

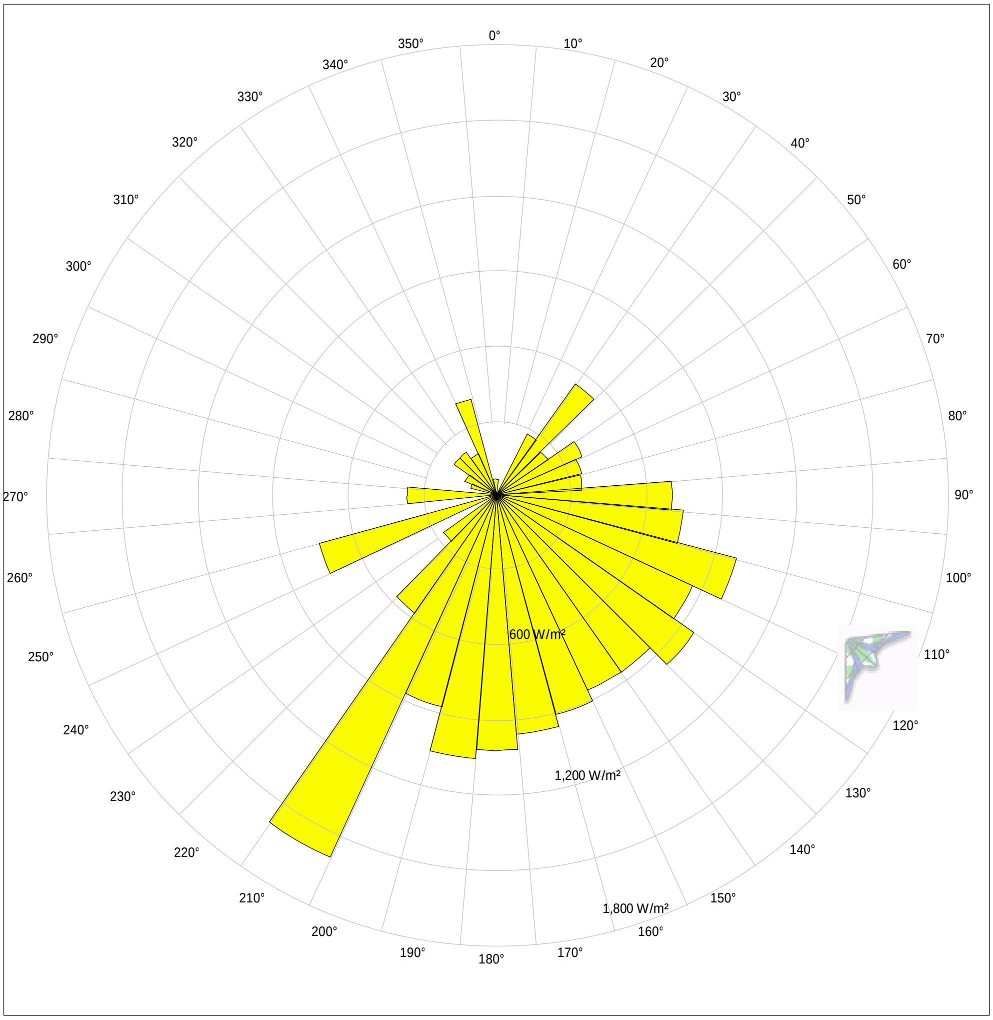

Figure 3b: Probability distribution functions, Marsabit 2001-2006

Table 3 shows a summary of the annual results. Garissa site had a wind class of 1 while the Marsabit site had high power densities with a wind class > 7. Details on wind class can be obtained from reference (Bailey and MacDonald, 1997).

Table 3: Summary of the annual results for Garissa and Marsabit

Garissa **Year**	**Av. Speed (m/s)**	**Weibull,k**	**Weibull, c (m/s)**	**Power density at 10m, W/m^2**	**Power density at 50m W/m^2**	**Wind class**
2001	3.54	1.27	3.90	97	190	1
2002	2.84	1.38	3.20	46	90	1
2003	2.54	1.36	2.92	37	74	1
2004	3.02	1.29	3.38	58	114	1
2005	3.52	1.27	3.89	97	190	1
2006	3.39	1.26	3.75	91	178	1
Marsabit						
2001	11.15	2.81	12.51	1097	2157	8
2002	10.62	2.53	12.97	1021	2007	8
2003	10.70	2.83	12.00	967	1901	7
2004	10.99	2.50	12.36	1119	2199	8
2005	11.38	2.99	12.72	1121	2202	8
2006	10.65	3.05	11.86	903	1776	7

Figures 5a and 5b show respectively the graph of the probability of exceedence plotted against the recorded extreme winds for Garissa and Marsabit in the six years under study. The best Gumbel curve was fitted and the return period calculated for 20, 25 and 50 years period. The extreme wind speeds were found to be 24, 24.5 and 50 m/s respectively for Garissa, and 32, 32.4 and 33.8 respectively in the case of Marsabit.

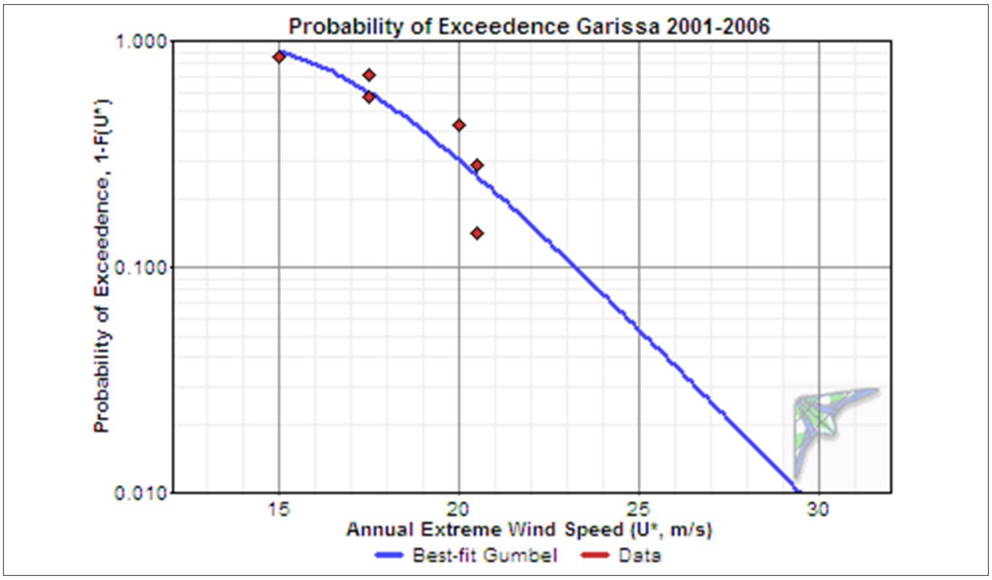

Figure 5a: Best Gumbel fit of the extreme wind speeds, Garissa 2001-2006

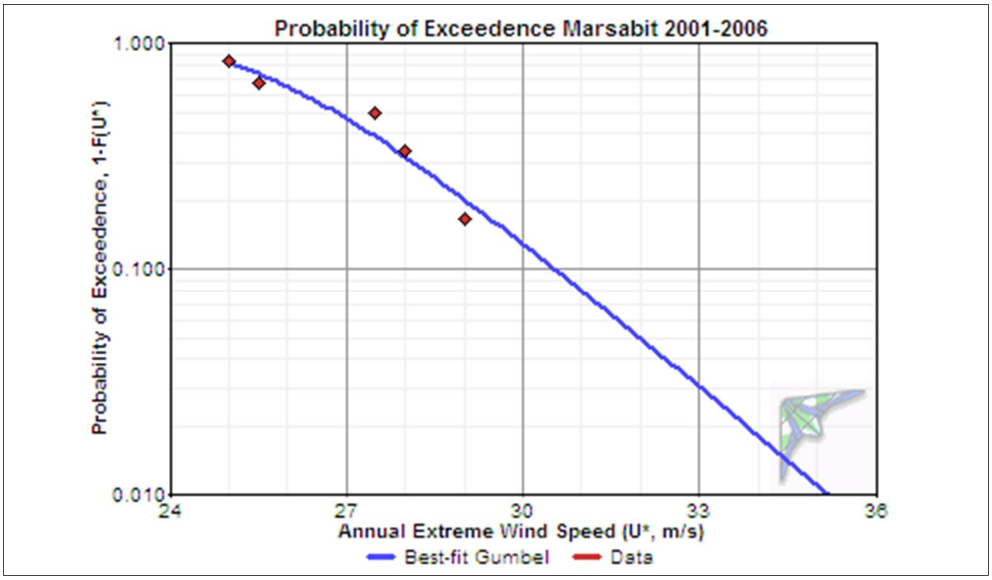

Figure 5b: Best Gumbel fit of the extreme wind speeds, Marsabit 2001-2006

4.0 Conclusions

The following conclusions can be drawn from this study:

(i) The Garissa site had an annual average wind speed of between 2.5 and 3.5 m/s, while that of Marsabit ranged from 10.62-11.38 m/s. The highest monthly wind speed for any year was recorded in the months of June-October. The Garissa site depicted mixed diurnal variation for both day and night hours while the Marsabit site showed enhanced nocturnal speeds.

(i) The Weibull dimensionless shape parameter *k* had a smaller spatial variation ranging between 1.26 and 1.38 than the scale parameter *c* which ranged between 2.92 m/s and 3.90 m/s for Garissa. For Marsabit the yearly values of k and c ranged from 2.05-3.05 and 11.86-12.96 m/s respectively.

(ii) The maximum theoretical power density obtained for the Garissa site was 190 W/m^2 at 50m, corresponding to a wind class of 1. This site was found unsuitable for grid- connected applications. The power in the wind can however be used for non-connected mechanical and electrical applications such as water pumping and battery charging. The high wind speeds in Marsabit throughout the six years gave power densities of between 903-1119 W/m^2 at 10 m. Power law calculation gave available power densities of between 1776-2202 W/m^2 at a height of 50 m with a wind class greater than 7. The maximum theoretical extractable power was found to be between 1053 and 1306 W/m^2

(iii) Since most commercial wind turbines have a claimed cut-off speed > 35 m/s, the sites are suitable for turbine operation since the extreme wind return period of 25 years is 24.5 m/s in the case of Garissa and 32.4 m/s for Marsabit which falls below the cut-off threshold.

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