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**RESEARCH ARTICLE**

# ASSESSMENT OF WIND ENERGY POTENTIAL AT KESSES REGION-KENYA BASED ON WEIBULL PARAMETERS

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***Abstract***

Wind energy potential assessment is an exercise that cannot be under estimated when it comes to designing and setting up a wind power project anywhere in the world. Parametric tools exist that can be used to analyse measured wind speed data in order to derive pertinent wind characteristics necessary for its efficient exploitation for power generation. This paper analyses wind speed characteristics and wind power potential at Kesses region, Kenya using Weibull parameters. A five year (2009-2013) wind speed data measured at a height of 2 m are used, and extrapolated to the standard height of 10 m and practical hub height of 100 m for purposes of characterization and exploitation respectively. The average wind speeds at the two heights were obtained respectively as 3.858 m/s and 6.926 m/s. Values of Weibull distribution functions showed that scale parameter, *c*, range from 2.54 m/s to a maximum of 3.04 m/s in 2010, while shape parameter, *k*, had a peak value of 5.90 in 2012. These results indicate the region to have potential for both small and medium scale wind power systems.



## Introduction:-

Wind energy is becoming a very popular energy resource for electricity generation in developing countries as a result of their quest to bring on board renewable energies in their energy mix. Wind energy is among preferable renewable energy resources being exploited all over the world as a result of many merits such as cleanliness and sustainability. In addition, energy conversion machines and equipment are modular, hence can be sized for stand-alone or grid-connected systems. However, grid-connected applications require regions with high wind speed and available throughout the year to make the systems cost effective. The Global Wind Energy Council (2013) estimated the global wind capacity at 318 GW in 2013 and this value is projected to increase to 600 GW by 2018. The sudden explosion in the global wind energy utilization was linked to the millennium development goals (MDG), where one of its objectives was on promotion of sustainable energy sources.

In Kenya, MDGs on sustainable energy utilization were partially achieved through the expansion of the already developed renewable energy sources mainly the geothermal energy. The country has huge potential of geothermal energy in the Rift Valley basin but not fully exploited due to huge initial cost. The country has been developing this energy resource gradually in phases and as a result has developed infrastructure and expertise in the field, and was made a flagship project under MDG initiative. In addition, the Kenyan government, put in place incentives for the establishment of mini- and micro-hydropower plants by private sector mainly tea sector, both private multinational companies and government owned, the Kenya Tea Development Authority (KTDA). The main incentive was the energy policy of 2012 that introduced Feed-In-Tariffs (FIT), which opened up electricity generation in the country (Kenya, Ministry of energy, 2008). Other small scale stake holders in electricity production are the independent power producers who have been running steam power systems using fossil fuels as prime movers and supplying electricity to the grid. Wind energy is the latest candidate in the grid electricity generation but its contribution is low currently but expected to increase in the near future. The current statistics of electricity generation in Kenya is made up of hydropower at 48%, steam power plants (fossil fuel) at 38%, Geothermal at 12%, biogas at 2% and wind at 0.3%. Thus, it is evident that the contribution of mainstream renewable energies to the national power supply is small. However, the country has targeted to expand the use of the wind energy in electricity generation to 9% by the year 2030 (Government of Kenya, 2014).

Two pilot wind energy projects for grid-connected electricity generation have been established in Kenya. The two projects are located at Ngong Hills (near Nairobi) and Lake Turkana Wind Energy Projects (in North western Kenya) and are projected to produce a total capacity of 300 MW to the national grid when fully operational. More sites have also been identified to set up more wind farms in other parts of the country with huge wind potential. The mapping of wind speed in Kenya was done and reported by WinDForce Management Services Private Limited-Kenya (2013) and their findings are as shown in Figure 1. From this map, it is evident that the average wind speed varies from a low value of about 2.0 m/s to a high value of about 9.5 m/s, with larger fraction of the country having values between 5 m/s to 8 m/s. It is apparent that the huge wind potential is available in arid and semi-arid lands (ASAL) regions of the country, where grid electricity is also not readily available. Thus, the country can invest on wind energy plants for stand-alone generation of electricity for local consumption, which will also spur socio-economic development in these regions.

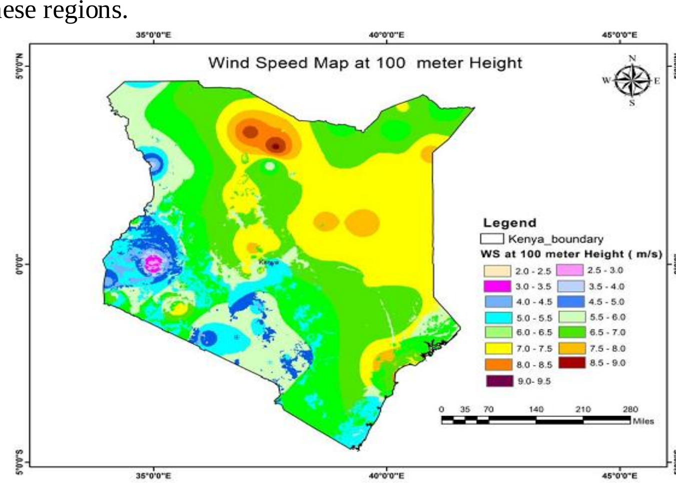


**Figure 1:-** Wind Speed Map of Kenya at 100 m height (WinDForce Management Services Private Limited-Kenya, 2013).

Precise knowledge of wind speed regime is a pre-requisite for the efficient planning and implementation of any wind energy project. In other words, wind resource assessment should be undertaken at the site where the project will be set-up. Various analytical tools have been developed for use in the assessment of wind characteristics and potential, and are reported in many literatures. Celik (2003) proposed Weibull and Rayleigh models as fit for wind analysis and has been used in many analyses done at different parts of the world because of its versatility. Weibull model is used to characterize wind speed data, energy density, power potential, among others (Gupta, 2010). Several researchers have assessed wind energy data at different regions using Weibull distribution and showed to give a better fit curve for the actual data series (Essandoh, 2013 and Jibrin et al, 2014).

In the present paper, Weibull two-parameter model is used to analyze wind speed data measured at a local meteorological station at Moi University Kesses ($0.28333^0$ N and $35.29444^0$ E) over a five-year period (2009-2013) at an average altitude of 1311 m above sea level. Wind speed is measured using a rotating-cup anemometer installed at a height of 2 m on an open field. The average speeds were translated to standard height of 10 m for purposes of determining wind characteristics and also to a practical hub height of 100 m.

## Material and Methods:-

### Average wind speed:-

Among simplest statistical analyses of wind speed data is determination of average value over a specified period, either hourly, daily, monthly or annually, depending on the available data. Equation (1) gives average wind speed, $\overline{\upsilon}$ , regardless of duration (Ahmet, 2015).

$$\overline{\upsilon} = \frac{1}{n}\sum_{i=1}^{N}\upsilon_i \ (m/s) \tag{1}$$

In this work $\upsilon_i$ is the daily wind speed measured at the site. Equation (1) is used to find the average monthly wind speed of measured daily values of the site.

**Effect of height on wind speed:-**

Wind speed varies as a function of altitude, where it increases with increasing height up to an optimum height. For this reason, experimental measurement of wind speed has been accepted internationally to be done at a standard height of 10 m. In addition, an empirical equation referred as Hellmann exponential law or the power law equation correlates wind speed to height is applied in calculation of wind speed at practical heights (Safari, 2010).

$$\upsilon_2 = \left(\frac{h_2}{h_1}\right)^{\alpha} \upsilon_1 \, (m/s) \tag{2}$$

where $\upsilon_1$ is measured speed at a known height $h_1$ while $\upsilon_2$ is extrapolated speed at practical height $h_2$.
The exponent, $\alpha$, in equation (2) is surface roughness coefficient or wind shear factor dependent on height, time of the day, season of the year, nature of the terrain, wind speed and temperature (Akpinar,2005).

$$\alpha = \frac{0.37 - 0.088\,\mathrm{In}(\upsilon_1)}{1 - 0.088\,\mathrm{In}\left(\frac{h_1}{10}\right)} \tag{3}$$

**Weibull parameters:-**

Monthly mean wind speed is calculated as per equation (1) and their standard deviations $\sigma$ can be calculated from available wind speed data.

$$\sigma = \left[\frac{1}{n-1}\sum_{i=1}^{N}(v_i - \bar{v})^2\right]^{0.5} \tag{4}$$

From mean wind speed values and standard deviations, Weibull parameters $k$ and $c$ are calculated using equations (5) and (6) respectively (Choge et al, 2013):

$$k = \left(\frac{\sigma}{\bar{v}}\right)^{-1.086}, \quad (1 \le k \le 10) \tag{5}$$

$$c = \frac{\bar{v}}{\Gamma\left(1 + \frac{1}{k}\right)} \tag{6}$$

where $\Gamma$ is gamma function defined mathematically. Generally x-variable is expressed as:

$$\Gamma(x) = \int_0^{\infty} t^{x-1} \exp(-t)\,dt \tag{7}$$

$k$ parameter is a dimensionless quantity indicating how site wind speed is peaked. The $c$ parameter, on the other hand, has units of wind speed (i.e. m/s) and it shows how windy the site is.

**Wind speed probability distribution:-**

Weibull probability distribution functions have been modeled here for evaluation of wind speed characteristics. Weibull function is a widely applicable probability density function which is characterized by two parameters $k$ and $c$.

$$f(v)=\left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{k-1}e^{-\left(\frac{v}{c}\right)^{k}} \quad (8)$$

where $f(v)$ is the probability of observing particular wind speed $v$ (Akpinar, 2004). Therefore, Weibull model which covers a large range of $k$ $(1 \le k \le 10)$, fits wind speed data very well within its range (Manwell et al, 2002).

Weibull cumulative function is useful in predicting fraction of time when wind speed is equal or lower than speed $v$ by taking the difference of its values and in estimating cut-in wind speed of wind turbines before selection (Bañuelos-Ruedas et al, 2011).

$$F(v)=1-e^{-\left(\frac{v}{c}\right)^{k}} \quad (9)$$

where $F(v)$ is the cumulative distribution function.

**Wind Power density calculation:-**

Wind power density, $P_D$ is the available wind power per unit area swept by the turbine's plates.

$$P_D=\frac{1}{2}\rho c^{3}(1+\frac{3}{k}) \quad (10)$$

where $\rho$ is the air density. It is evident from the expression that wind power density varies directly as the cube of Weibull scale parameter $c$.

## Result and Discussion:-

The available wind speed data are daily averaged wind speeds for all months for each year during the five-year period. A detailed investigation is to analyze and assess region's wind energy potential.

**Monthly wind speed variation:-**

From equation (1), average values obtained were plotted in Figure 2 which show the wind speed monthly variations at height of 2 m. It is observed that there exist two seasons of the year of relatively high speeds in the first and last quarter of the year while midyear experiences low wind speeds. The year 2011 present relatively highest mean wind speeds across all the months.

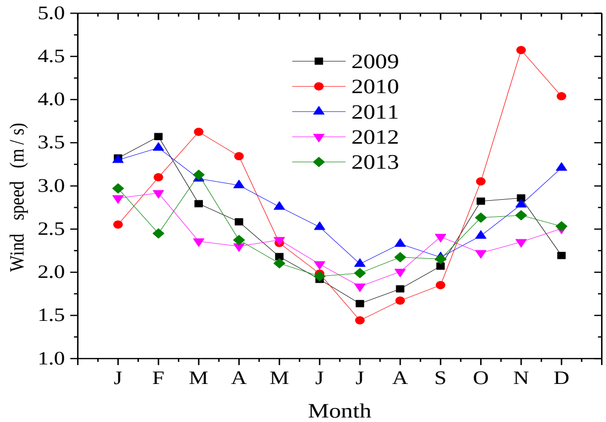


**Figure 2:-** Monthly mean wind speed for the five year period at a height of 2 m.

**Variation of wind speed with height:-**

Table 1 shows yearly average surface roughness coefficient values. From the average value in Table 1, the site is considered as a level 1 ground terrain with occasional buildings and many trees which is a true case for the site, therefore this coefficient is taken as 0.252 in this analysis for calculation of wind velocity at heights of 10 m and 100 m.

**Table 1:-** Calculated average surface roughness coefficient values.

| YEAR | Surface roughness coefficient ($\alpha$) |
|---|---|
| 2009 | 0.249 |
| 2010 | 0.251 |
| 2011 | 0.246 |

| | |
|---|---|
| 2012 | 0.258 |
| 2013 | 0.255 |
| AVERAGE | 0.252 |

Tables 2 and Table 3 show monthly average values of wind speed for the time period 2009-2013 at 10 m and 100 m heights respectively. It is observed that wind speed increases with increase in height with 10 m and 100 m heights having their highest wind speeds of 6.45 m/s and 10.55 m/s respectively.

**Table 2:-** Monthly average values of wind speed (m/s) at 10 m

| MONTH/ YEAR | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2009 | 4.82 | 5.21 | 4.22 | 3.91 | 3.36 | 2.98 | 2.58 | 2.80 | 3.17 | 4.18 | 4.27 | 3.39 |
| 2010 | 3.82 | 4.57 | 5.27 | 4.93 | 3.60 | 3.08 | 2.32 | 2.61 | 2.87 | 4.46 | 6.45 | 5.85 |
| 2011 | 4.79 | 5.05 | 4.59 | 4.47 | 4.15 | 3.82 | 3.24 | 3.53 | 3.34 | 3.66 | 4.15 | 4.72 |
| 2012 | 4.22 | 4.35 | 3.62 | 3.51 | 3.60 | 3.23 | 2.87 | 3.09 | 3.64 | 3.41 | 3.57 | 3.78 |
| 2013 | 4.37 | 3.74 | 4.60 | 3.64 | 3.24 | 3.03 | 3.07 | 3.32 | 3.30 | 3.94 | 4.00 | 3.83 |

**Table 3:-** Monthly average values of wind speed (m/s) at 100 m

| MONTH/ YEAR | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2009 | 8.21 | 8.96 | 7.61 | 7.07 | 6.25 | 5.63 | 4.99 | 5.28 | 5.85 | 7.35 | 7.59 | 6.33 |
| 2010 | 6.83 | 7.97 | 9.00 | 8.62 | 6.70 | 5.80 | 4.58 | 4.94 | 5.38 | 7.70 | 10.55 | 9.97 |
| 2011 | 8.18 | 8.74 | 8.12 | 7.91 | 7.44 | 6.95 | 6.07 | 6.43 | 6.18 | 6.63 | 7.36 | 8.21 |
| 2012 | 7.39 | 7.71 | 6.66 | 6.44 | 6.57 | 6.03 | 5.45 | 5.73 | 6.56 | 6.30 | 6.50 | 6.83 |
| 2013 | 7.60 | 6.85 | 7.99 | 6.73 | 6.05 | 5.69 | 5.73 | 6.11 | 6.11 | 7.02 | 7.18 | 6.95 |

**Weibull parameters and probability distribution:-**

**Table 4:-** Calculated parameters *k* and *c* for the time period 2009-2013 at 2 m.

| Year | | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2009 | $k$ | 3.20 | 2.28 | 6.28 | 3.33 | 3.91 | 5.33 | 3.97 | 5.43 | 4.31 | 3.09 | 2.87 | 4.31 |
| | $c$ | 3.70 | 4.03 | 3.00 | 2.87 | 2.40 | 2.07 | 1.80 | 1.95 | 2.27 | 3.15 | 3.20 | 2.40 |
| 2010 | $k$ | 3.42 | 3.54 | 3.84 | 4.39 | 6.44 | 7.63 | 3.54 | 5.17 | 7.11 | 3.71 | 7.64 | 6.53 |
| | $c$ | 2.83 | 3.44 | 4.00 | 3.66 | 2.51 | 2.11 | 1.60 | 1.81 | 1.97 | 3.38 | 4.86 | 4.33 |
| 2011 | $k$ | 8.48 | 2.81 | 4.01 | 3.67 | 5.00 | 4.30 | 5.78 | 6.83 | 6.12 | 6.01 | 4.90 | 5.83 |
| | $c$ | 3.49 | 3.86 | 3.40 | 3.33 | 3.00 | 2.77 | 2.26 | 2.49 | 2.33 | 2.61 | 3.03 | 3.46 |
| 2012 | $k$ | 5.60 | 7.26 | 6.06 | 9.83 | 6.78 | 5.68 | 5.28 | 4.88 | 4.48 | 6.19 | 4.93 | 3.81 |
| | $c$ | 3.09 | 3.11 | 2.54 | 2.41 | 2.54 | 2.26 | 1.99 | 2.18 | 2.64 | 2.39 | 2.56 | 2.77 |
| 2013 | $k$ | 4.58 | 4.05 | 2.99 | 4.67 | 3.65 | 4.93 | 4.03 | 4.15 | 4.44 | 4.71 | 7.39 | 3.21 |
| | $c$ | 3.25 | 2.70 | 3.50 | 2.59 | 2.33 | 2.12 | 2.19 | 2.39 | 2.36 | 2.87 | 2.83 | 2.82 |

Figure 3 shows Weibull probability density distribution with normal distributions for all the years and centered at wind speed of about 2.823 m/s which corresponds to most probable wind speed. The years 2013 and 2009 have highest and second highest peaks respectively giving highest probabilities of observing high wind speeds but with narrow distribution while 2010 and 2012 have equal peaks and wider distribution with low probabilities of observing high wind speeds. 2011 is intermediate between the two extremes. Weibull probability density function fits winds speed distribution reasonably well in range of 1 m/s to 4 m/s.

Figure 4 show yearly wind speed Weibull cumulative probability distribution for the period 2009-2013. İt is noticeable that frequencies of about 35-50% for a cut-in wind speed of 2.5 m/s; with a cut-in wind speed of 3.0 m/s frequencies of about 65-75% and at a cut-in wind speed of 3.5 m/s, the site has frequencies of about 80-95%.

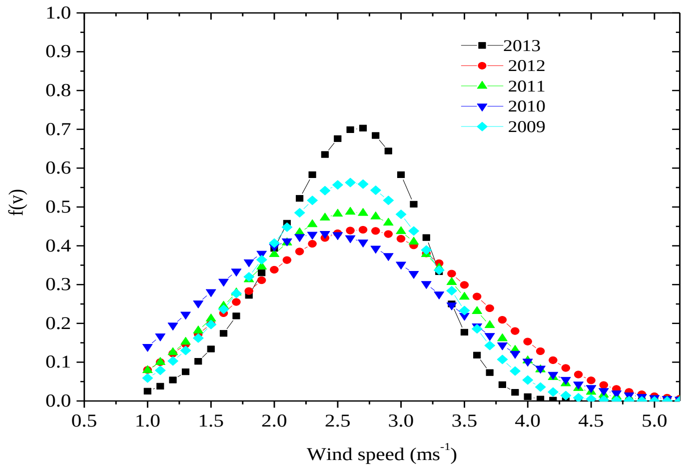


**Figure 3:-** Yearly Weibull probability density distributions

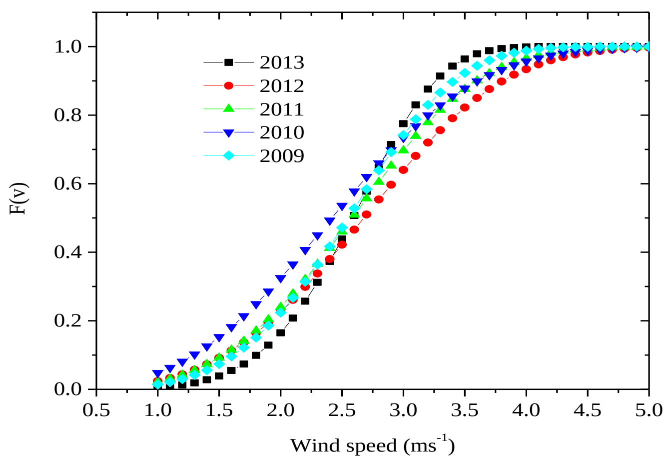


**Figure 4:-** Yearly wind speed Weibull cumulative probability distribution.

From cumulative distribution, the working time period of a wind turbine installed in this particular site can be predicted and used to estimate annual wind energy generation.

Wind turbines have been manufactured by several companies with cut-in wind speeds range of 1.5 - 4.0 m/s but thorough research is needed based on the site data for these turbines as detailed analytical data is not yet available for a particular wind turbine.

**Wind speed power density:-**

Monthly variation of power density has been calculated after taking monthly and yearly averages as depicted in Figure 5 at heights 10 m and 100 m respectively. It is revealed that average power density is around 41.24 W/m$^2$ and 228.91 W/m$^2$ for the two heights respectively. Furthermore, wind power density increase with increase in height and at 100 m power density is considerable enough especially in the early and late months of the year.

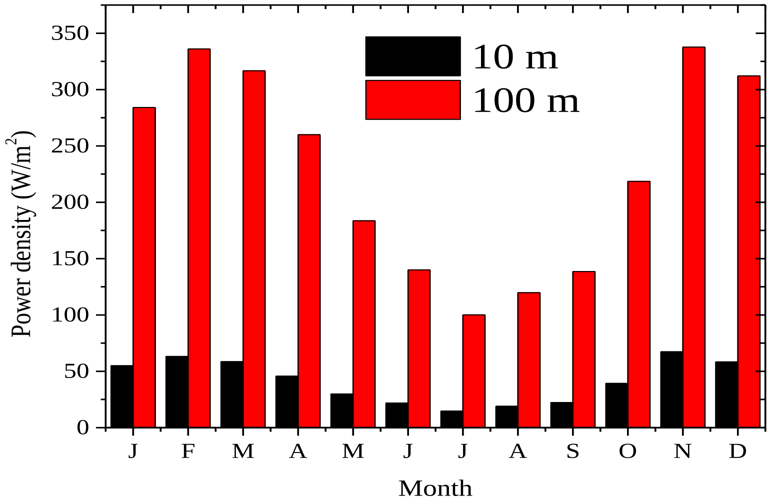


**Figure 5:-** Monthly wind power density variation at heights 10 m and 100 m

Classification of wind power density indicates wind characteristics of the region as relatively good at 100 m elevation according to the below classification of power density (Manwell et al, 2002).

**Table 5:-** Classification of wind power density.

| | |
|---|---|
| Low | $P_D < 100\text{W/m}^2$ |
| Good | $P_D \approx 400\text{W/m}^2$ |
| Great / better | $P_D < 700\text{W/m}^2$ |

## Conclusion:-

The five year period (2009-2013) wind speed data for the region studied were analyzed using Weibull parameter model and reliable results obtained regarding wind speed potential. The region experience significantly medium to high wind speed, highest being 6.45 m/s at 10 m height and 10.55 m/s at 100 m height. Relatively high wind velocity is observed during the whole period of study where average velocity was greater than 5.50 m/s at a height of 100 m. The corresponding power density values on average are 41.24 W/m$^2$ and 228.91 W/m$^2$ at 10 m and 100 m respectively. These results show the region classified under relatively good wind power potential region. Weibull probability density distribution analysis of wind speed gives the most probable wind speed of the region at 2.823 m/s. Weibull cumulative probability analysis of wind speed results show that wind turbines of cut-in wind speeds range of 2.5 m/s to 3.5 m/s are recommended for installation at the region. The region can be considered as a medium wind speed region which is more suitable for wind energy development for both domestic and commercial purposes.

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