Int. J. Pure Appl. Sci. Technol., 20(1) (2014), pp. 36-66

International Journal of Pure and Applied Sciences and Technology
ISSN 2229 - 6107
Available online at **www.ijopaasat.in**

Research Paper

Variation of Wind Speeds at the Shore of Lake Victoria (Kenya)

Kabok P. Aguko[1,*], D.M. Nyaanga[2] and J.O. Onyando[2]

[1] Lake Basin Development Authority, P.O. Box 1516-40100, Kisumu, Kenya
[2] Department of Agricultural and Environmental Engineering, Egerton University, P.O. Box 536-20115, Egerton, Njoro, Nakuru, Kenya

* Corresponding author, e-mail: (kabpaguko@yahoo.com)

(Received 6-11-13; Accepted: 2-12-13)

Abstract: *The Kenyan Lake Victoria shore (LS) covers an area of 5700km^2 with few wind speed recording stations. Kisumu is the only station having continuous 2m and 10m height wind speed records. The other stations (Rusinga, Muhuru, Ahero, Kadenge and Kibos) have the 2m height data. Lack of verified constants for power law equations such as power law index (α) and logarithmic power law (Z_o) that relates wind speed variation with height, location and terrain contribute to difficulty in application of wind energy conversion (WECs) systems. The objective therefore was to determine temporal and spatial wind speeds variation and empirical relationships with height and location within the LS. 2m height data was analyzed to determine consistency (diurnal, monthly, seasonal trends, duration and direction) with location and used to establish direct and indirect relationship in estimating wind speeds at 10m for installation and utilization of the wind energy. It was established that wind speeds (2m) within the LS foremost fitted the three parameter Weibull distribution, Weibull (α) index was averagely 0.4 for the LS, 2 times less the actual (0.8) for Kisumu and was related negatively to the power law index. The predicted Kisumu 10m wind speeds from 2m perfectly related to actual 10m with R^2 above 0.8. The model Weibull distribution parameters (the scale factor and the power law index) were found applicable in estimating wind speeds at 10m from 2m heights. Further, hourly measured wind data for every month was found adequate in estimating the wind speeds at a particular site.*

Keywords: Wind Speeds Consistency, Weibull Distribution, Extrapolation (indirect and Direct), Hourly Wind Speeds, Power Law.

Literature Review

1.1 Introduction

Wind speed records within the LS are inadequate and scanty with only a few stations having continuous records. [21] Characterized the wind speeds in Kenya and concluded that there is wind potential for pumping and electricity generation. This study hence explored the spatial and temporal variation of wind speeds from the 2m wind speeds records available within the LS and extrapolated to the 10m height by direct and indirect methods, which were developed.

In wind energy conversion systems (WECs), the wind speed is critical in determining the extractable power for use. Due to the cubic relationship between velocity and power, a smaller variation in wind speed results in a larger power output, hence, because of this phenomenon knowledge on wind variation in relation to time, altitude and height of measurement above the ground surface is of great importance. [28] and [9] studied the suitability of using power law equation to predict wind speeds at different heights with success. They also noted that during the night time wind profiles measured were far from the derived values from the power law equations.

The quantification of the available wind speed is important for matching the wind pump rotor size and its intended use including water supply and electricity generation among other uses. Proper matching and sizing of the windmill are key in achieving efficient and reliable outputs. The variability of wind speeds strength in relation to location, Height, altitude and duration (time) determines the wind energy exploitation. This is because wind is site specific.

Wind energy on the earth’s surface is due to the incident solar radiation which causes temperature difference between tropics resulting to air motion. The need to evaluate extractable wind power for human use is important. The commonly used wind pumps operate at height of 10m or higher [32]. This height is chosen due to less interference of wind speeds by topographical features and buildings. Lack of enough data is an inherent challenge in extraction and utilization of wind energy within the LS. There is need to understand the trend and profiles at 2m height within the LS from the available data so as to predict the wind speeds for different locations and the 10m heights for installation of wind conversion systems. The objective therefore was to determine temporal and spatial wind speeds variation and empirical relationships with height and location within the Lake Victoria Kenya.

The interest on wind power and the desire for green energy has prompted research on wind potential and use. Many researchers; [6] [3] and [14] show the various methods of wind speed estimation which include: observation, graphical, empirical and statistical formulae.

1.2 Background

The increase in energy demand and the shortages of fossils fuels in the world and the desire for green energy has necessitated utilization of the wind resource. Wind speed is critical since it determines the extractable wind power and the subsequent performance of wind conversion systems. Probability distribution time of wind speed can be determined and used to estimate wind potential. The Weibull function is widely used because of its two flexible parameters namely the shape parameter which describes the width of data distribution and the scale parameter. Wind characterization and operation of a wind conversion system such as water pumping drip irrigation is not an exception and is to be done with respect to the day wind speed spectrum with a chosen wind speed interval. Use of wind machines therefore needs knowledge of wind speed potential at given sites, duration, strength and its variations with time. There is need to develop a wind speed estimation method both at a location and at a higher height where there is no 10 m height wind speed records, especially for the LS.

Most wind turbines including water pumping wind machines operate in such a way that there is an initial velocity (V_{in}) when the rotor starts, design speed (V_r) and the furling speed (V_{out}) where the wind pump rotor is stopped or deflected out of the wind stream by the safety mechanisms [25]. The availability of the rated wind speed (V_r to V_{out}) and any speed between V_{in} to V_r may only be possible for a percent time of a day's wind spectrum; hence the need to analyze the spectrum (temporal variations) and quantify it for operation of a wind turbine.

1.2.1 Wind Speed Variation with Height

The increase of wind speeds with height is mainly ascertained by use of the power law, logarithmic wind power law and Weibull Extrapolation formulae. Power law has been used by various researchers with variations in outputs. [31] assessed the wind characteristics in Taiwan by site pre- determined index (α) and another constant δ based on wind speed at the boundary layer height. The values for these parameters were estimated by Taiwan Central Weather Bureau with regard to the local topographic conditions surrounding the stations. [26] used the power law index to estimate the wind characteristics in the United States. [21], characterized surface wind speeds in Kenya by the Weibull extrapolation formulae from a number of stations, where the LS was represented by the Kisumu station. These prediction equations have been used by other researchers such as [3] and [20] with sufficient accuracy. Wind speeds under adiabatic conditions and for sites with uniform terrain or roughness and with uniform temperature within the first 50-100 m or with linear temperature decreases with height at a rate of 1^o C per 100m; then the logarithmic height law given in equations 1 to 3 has a higher degree of approximation [10, 23, 31].

$$V_B = \frac{u^*}{\eta} \ln \frac{h_B}{Z_0} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$\frac{V_B}{V_A} = \frac{\ln \frac{h_B}{Z_0}}{\ln \frac{h_A}{Z_0}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Hellman's power equation is given as:

$$Z_0 = \exp \frac{h_B^{\alpha} \ln h_A - h_A^{\alpha} \ln h_B}{h_B^{\alpha} - h_A^{\alpha}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

where V_A is the mean wind speed at reference height and V_B is the mean wind speed at height B, u^* is the frictional velocity (equivalent to the ratio of the surface stress to the density, ($\sqrt{\tau/\rho}$); η is the von Karman's constant ≈ 0.4; h_A is the reference height where wind speed V_A is measured, h_B is the height at which the wind speed V_B is measured; Z_o is the surface roughness coefficient [1]; ρ is the air density and τ is the drag per unit of the boundary layer). Typical values of u^* may be obtained from [5]. The values of Z_o are in the order of 0.001 to 100 cm for various descriptions of terrains as reviewed by [4] and in [32]. The use of these values of Z_o has been reported by [1] and [22] among others.

The logarithmic law does not give sufficient accuracy and could be more complicated in some instances for the Lake Shore region due to varied terrain and the proximity to the water body than the power law approximation with the Hellman's shear exponent which offers sufficient approximations for most engineering tasks.

The power law (equation 4) is easy to use. The form of expression for increase of wind speed with height, especially when α is 0.143 also known as the ${}^{1}/{}_{7}{}^{th}$ power law [14] is;

$$\frac{V_B}{V_A} = \left(\frac{Z_B}{Z_A}\right)^{\alpha} \quad \text{(4)}$$

Where α is Hellman's or shear exponent, Z_B and Z_A are mean wind speeds at the respective heights. The (α) index is not the same for different locations, seasons and must be determined for every station.

Like the logarithmic equation, the power law equation has inherent shortfalls in that wind speeds below the reference height are affected by obstacles in the terrain which cause decrease in wind speeds. Whereas wind speeds above the reference height, increases with height due to reduced roughness. [7] noted that the power law offers nearly perfect fit under stable atmospheric conditions with certain surface roughness and good approximation under neutral and unstable conditions in the limit of very smooth surfaces.

As for existing equations (1 to 4) for increase of wind speeds and height, none has the direct application to the situation at the LS. The equations may not be applied directly to determine the wind speed in any particular site except the ${1/7}^{th}$, which has a shortfall in that it underestimates the magnitude of the wind speeds for the LS [22]. The power law (4) and the Hellman power equation (3) though are available for use but the parameter (α) in equation (4) is used when the wind speeds conform to the Weibull distribution or conditions are adiabatic and favours the ${1/7}^{th}$ rule or that (α) can be determined. [11, 12] used the Weibull distribution to represent the wind velocity probability density function. [12] and [16] proposed equations (5 to 8) which allow extrapolation to be made using the scale factor c and the shape factor k.

$$p(v)dv = \left(\frac{k}{c}\right)\left(\frac{k}{c}\right)^{k-1} exp\left[-\left(\left(\frac{v}{c}\right)^{k} dv\right)\right] \quad \text{(5)}$$

Where; $p(v)$ is the probability density function for the Weibull equation.

Other formulae based on the power law are:

$$k_1/k_2 = \left[1 - 0.00881\ln\left(\frac{Z_A}{10}\right)\right] \Big/ \left[1 - 0.00881\ln\left(\frac{Z_B}{10}\right)\right] \quad \text{(6)}$$

And

$$\frac{c_2}{c_1} = \left(\frac{Z_2}{Z_1}\right)^{\alpha} \quad \text{(7)}$$

Where:

$$\alpha = [0.37 - 0.0881\ln(C_1)] \big/ [0.37 - 0.0881\ln(Z_1)] \quad \text{(8)}$$

The subscript 1 and 2 refer to the lower and upper levels (below and above the reference height), α is an index, Z refers to the height in meters and c is velocity in meters per second. [6] cautions on the

use of the above formulae for extrapolation of mean wind speeds due to scatter of data used in its development.
The need for establishment of the variable power law indices α and Z_o which are site specific and are critical in wind speed calculations is often emphasized [26]. Kisumu station is the only one where Z_o and the power law index could be calculated using the available data at two heights and the extrapolation equations could be applied. The rest of the stations at best are estimates because not all the parameters in the extrapolation equations are available within LS unless a statistical distribution that conforms to wind speeds at a location is first determined and applied.

Much research has been carried out, though there exists difficulties in relating the wind profile; the wind speeds power law index (α) and the logarithmic power law Z_o (site specific). The LS case is further complicated by availability of only records at 2 m height while theory has been applied to more than 10 m high [32]. The spatial and temporal variation within the LS is hence analyzed in the context of fitting wind speeds to the Weibull distributions and using the extrapolation parameters.

Wind density functions have been used in wind analysis, such as the Weibull and Rayleigh distributions [1] [19] [23] [26] [31]. In this research, attention was given to the Weibull distributions because the data conformed to the tests of fit at 95% confidence level and ease of determining the distribution parameters. Furthermore, it had been used by [24] in this LS region to characterize the Kisumu wind speeds with success.

1.2.2 Wind Distributions Functions

Many probability distributions have been used to find the best fit for wind data including Beta, Exponential, Negative Exponential, Largest Extreme Value, Smallest Extreme Value, Gamma, Johnson, Log logistic, Lognormal, Normal, Pearson, Uniform distributions and Weibull statistics. The Weibull distribution is emphasized because it has been applied in various locations by authors such as [30] [19] in surface wind speed (10 m and above) analysis and it is characterized by the equations 9 and 10:

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

$$\mathrm{F(v)} = 1 - \mathrm{e}^{-\left(\frac{\mathrm{v}}{\mathrm{c}}\right)^{\mathrm{k}}} \quad \ldots\ldots(10)$$

where: $f(v)$ is the probability density function, $F(v)$ is the cumulative distribution function, *c* is the scale parameter with units equal to wind speed units in m/s, *k* is a dimensionless shape parameter and *v* is the wind speed in m/s . Notably the higher the value of *c* the higher the wind speed, *k* shows the wind stability. The scale and the shape parameters can be estimated by both the method of maximum likelihood and the method of moments available in standard statistical texts.

In their study of the statistical characterization of wind speeds in Kenya, [21] also concluded that the three -parameter Weibull distribution is the best fit distribution for describing the statistical characteristics of the maximum, minimum and mean daily surface (10 m) wind speeds.

1.3 Materials and Methods

1.3.1 Study Area

The area studied is delimited by contour 1200 m a.s.l and a 40 km distance on average from the Lake shoreline and constitutes the lake shore (LS) area as shown in Fig 1 below.

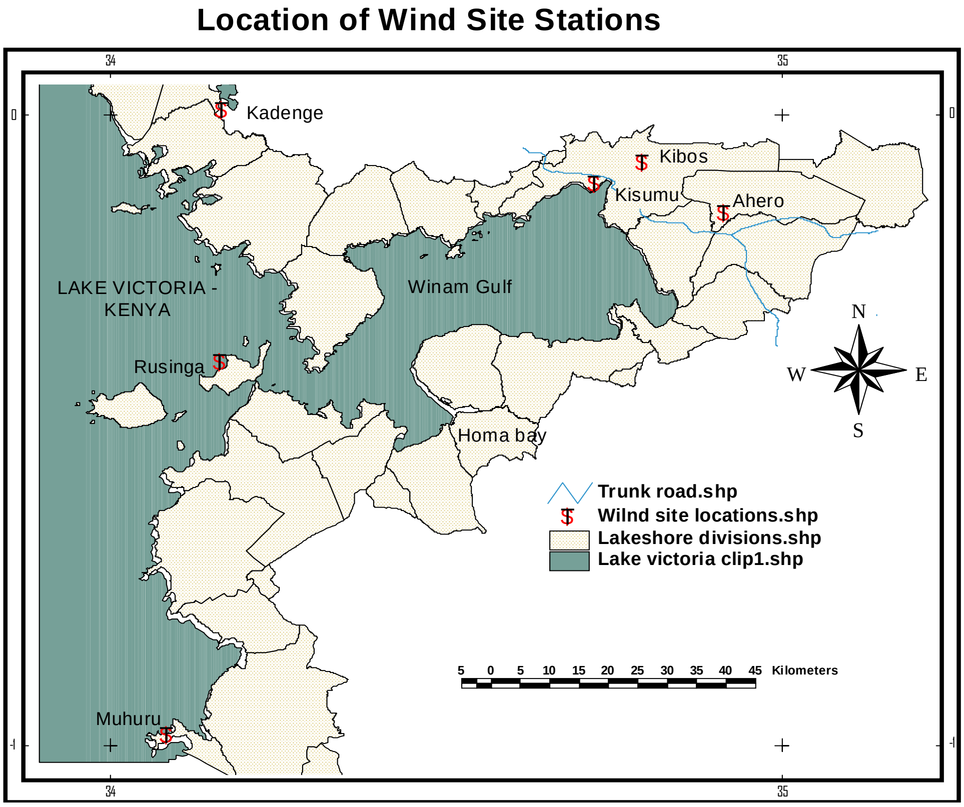

Fig. 1: Map showing Location of wind site stations

It covers an estimated area of 5700 Km^2 from Muhuru Bay in Migori County to Busia County in Kenya excluding the lake water surface area (4113 Km^2). The LS area is characterized by low slopes (<2% near the shore and about 1100 m a.s.l), a rising middle area and a highland zone of contour above 1200 m. Much of the area is within the ecological zone 3 and 4 with distinctive weather indicating limited and poorly distributed rainfall for crop production. Land use in the area is largely rain fed (with minimal irrigation practice) small scale crop production, livestock and settlement (Townships, villages and homes).

The data used were mainly collected for agricultural purposes at the 2 m height by the three cup anemometers, read manually except for the 10 m wind speeds of the Kisumu station that were automatically recorded. The data from 1996 to 2011 for Kadenge, Rusinga, Ahero, Kibos Cotton and Muhuru Bay were used.

The raw wind data was obtained from the Ministry of Water and Irrigation except those of Ahero and Kibos which were from the individual weather stations. The data was hand recorded and later keyed into a computer for the purpose of analysis. The monitoring equipment used in the weather stations included tilting siphon, rain gauge, sunshine recorder, evaporation pan, hygrometer, thermometer, wind vane and cup anemometer.

1.3.2 Temporal and Spatial Wind Trends

The wind speeds were evaluated based on geographical area to show diurnal (hourly) and monthly variation, wind direction and annual averages. These were considered as consistency aspects for projecting the wind speeds to 10m. The 2m height records used were also from the six LS weather stations namely; Kisumu, Kadenge, Muhuru Bay, Rusinga Island, Ahero and Kibos Cotton. The Limited records at 10 m height for Kisumu and 2m height for Kadenge were used for projecting diurnal variations. Uniformity and consistency of data was checked by fitting the data to Weibull distribution formula. Missing data was extrapolated and verified for conformity.

The data from all stations records from 1996 to 2011 were arranged by year, month and day including annual averages. The data below 1996 was excluded in the analysis due to lack of consistency and non-availability from some of the stations. The five variations examined for temporal and spatial characteristics of wind speeds within the LS were; annual/monthly; daily/hourly, wind direction, location and heights. The (α) index and profile values were calculated for the LS 2m data. The relationship of alpha, location and wind speeds from calculations were then amplified by relevant respective graphs. It was the basis of projecting wind speeds of Kisumu 2m data to 10m.

A statistical distribution (Weibull) that would result to best fit of data was examined and determined, mainly to obtain location (ε), scale (c) and shape (k) factors which enabled extrapolation of the wind speeds beyond the 2 m height. Selection of a suitable statistical distribution for the stations that fitted the available wind speeds was then carried out by use of the distribution analyzer by [30] and the Minitab statistical software [17] from the 2m height data. Equation 8 was used to determine (α), while the scale factor (c) was determined from the distribution that fitted the wind speeds data to Weibull model. This was subsequently substituted in equation 4 with the stations known heights and wind speeds, as it was noted that equation 4 and 7 are related.

The general test of fit of the data to the statistical distributions was carried out for all the stations and the parameters determined for three scenarios; Case, i) all daily data for every month put together as one data set for all the years; Case, ii) daily average of a particular month (Jan, to Dec) for all years; Case iii) a month's data randomly selected (Jan, to Dec) for one site of the six stations. Minitab statistical software [17] was used to analyze the data for Weibull, Gamma and log normal distribution which are frequently used in wind analysis. The years for Kisumu were from 2006 to 2011. This procedure was used to determine the descriptive statistics and the pre-requisite statistical p (confidence level) values for test of conformity for each of the statistical distributions. The procedure was repeated for Kisumu data only for the daily averages, case (ii). In case (i), the data was also tested for normal distribution. Result tables were generated to show conformity of the data to Weibull distribution.

1.3.2.1 Temporal Wind Variation

In order to analyze the hourly wind speed changes for Kisumu station as a specific example, data was first divided into four seasonal groups of Dec-March (dry period), April-July (wet season) and August- November(Moderate rains). The alpha values were regressed against the annual wind speed for each quarter. The daily wind speeds from each of the stations as described were analyzed by use of distribution analyzer [30]. The Taylor analyzer shows test of fit of data to a statistical distribution and gives the parameters thereof. This was to determine the viable distribution for the data category and the variability of the Weibull parameters and the statistical P values for conformity. The out of range values identified, were removed without loss of generality from the calculations for two situations; i) in determining the scale factor for extrapolation of the LS stations wind speeds and ii) when confirming that average of the winds speeds for the years available also followed the Weibull distribution.

1.3.2.2 Wind Spatial Relation

(a) Relationship between the 2m and 10m wind speeds

The approach in determining the relationship between the 2m and 10 m heights was twofold, direct and indirect. The indirect approach was established for both the LS stations that had no 10m wind speeds, while the direct approach was applied for Kisumu and Rusinga that had limited 10m data.

The direct relationship was by determining wind speed law index (α) from the Kisumu and Rusinga actual data available by use of equation 4. The 2m and 10m wind speeds for the years available for Kisumu was divided into two sets. The first set (2 and 10 m) was used to determine the wind speed law index (α). The (α) obtained with the first set of 2m wind speeds was used to predict the 10m wind speeds with the second 2m set of data. The actual 10m wind speeds for the second set and the predicted were then regressed and compared. The limited data for 2 and 10 m wind speed available at Rusinga was used to determine wind speed law index (α). The resulting (α) for Rusinga was then compared to those of Kisumu. This was for the purpose of determining the universality of the wind speed law index (α) for the LS. The indirect relationship was applied to the LS stations that had only 2m height data, by first determining their conformity to Weibull distribution (Section 1.4.1.1). Secondly, use was made of the resulting parameters (location factor: ε; c; k) in extrapolation to the 10m wind speeds. The wind speed law index (α) for each month for each station was then determined by use of equations 4 and 8. Furthermore, linear, quadratic and cubic relationships were determined by the Minitab software [17] including the projected data.

(b) Relationship of wind speed and location

After determination of (α) as in section (a), analysis was done by plotting average wind speed against the wind speed law index (α) on annual quarters defined as dry, wet and moderate wet. The law index (α) is location specific and should be determined. Also ratios of wind speeds for the 2m- and predicted 10m-height were determined with respect to the locations so as to verify whether there could be validity for use of ratios in projecting wind speed with height. It be noted that wind speed magnitude was a factor that was determined directly or indirectly in sections 1.2 and 1.3 above for the wind speed relationships.

1.4 Results and Discussions

1.4.1 Geographical Area and Characteristics Coverage

The geographical characteristics of the Kenyan LS (Fig1) has meteorological stations that lie within the altitude and distance range of 1100 to 1300 m (a.s.l) and 2-40 km distance in a straight line from the Lake shore. Kisumu, Rusinga and Muhuru Bay are close to the Lake (<5 km), while the rest of the stations are further inland. The Kenyan gulf is 6% of water surface, 17% of shoreline length and 21.5 % of the catchment of Lake Victoria. The other details are as in Table 1 that gives distance from the Lake, longitude, latitude and duration of the data available.

Table 1: Geophysical Characteristics of Kenyan LS Weather Stations

Location	Altitude (m)	Data Duration (height)	Latitude (Deg)	Longitude (Deg)	Distance from lake (km)
Kisumu*	1146	2006-2011 (10m) & 1996-2011 (2m)	00° 06’S	34° 45’E	2.04
Kadenge	1340	1996-2011 (2 m)	00° 02’N	34° 28’E	18.66
Rusinga	1240	1996-2011 (2 m)	00° 30’S	34° 15’E	0.1

Muhuru	1120	1996-2011 (2 m)	00° 10’S	34° 55’E	0.2
Kibos Cotton	1280	1996-2011 (2 m)	00° 04’S	34° 49’E	7.02
Ahero	1120	1996-2011 (2 m)	00°09’ S	34° 56’E	16.53

Wind distribution is dependent on temporal, spatial and breezes in the lake shore regions that also influences duration and strength (magnitude) of the wind speed as from observations and as the results show or imply in the presented subsequent subsections.

1.4.2 Temporal and Spatial Distribution

1.4.2.1 Temporal Wind Distribution

The average monthly and annual wind speed distribution for the stations along the Lake Victoria shore is as presented in Table 2 and Fig.2 below. The minimum and maximum average mean monthly wind speeds at 2 m height are as underlined; 1.15 and 1.63 m/sec for Kadenge, 1.12 and 1.72 m/sec for Kisumu, 2.23 and 3.02 m/sec for Rusinga.

Table 2: 10 Year Average Monthly Wind Speed (m/s) at the Six Stations in LS

Month	Ahero	Muhuru	Rusinga	Kibos	Kadenge	Kisumu	Avg
Jan	0.91	2.53	2.87	1.04	1.5	1.57	1.74
Feb	0.97	2.63	3.02	1.15	1.61	1.7	1.77
March	0.96	2.71	2.98	1.13	1.63	1.72	1.86
April	0.86	2.33	2.55	0.82	1.37	1.38	1.55
May	0.72	2.25	2.23	0.71	1.16	1.12	1.37
June	0.7	2.29	2.27	0.68	1.15	1.12	1.37
July	0.72	2.47	2.4	0.7	1.24	1.27	1.47
Aug	0.76	2.71	2.55	0.76	1.35	1.44	1.6
Sept	0.83	2.84	2.6	0.84	1.41	1.46	1.66
Oct	0.78	2.78	2.59	0.88	1.38	1.38	1.63
Nov	0.77	2.55	2.54	0.88	1.34	1.38	1.58
Dec	0.85	2.48	2.75	0.96	1.45	1.49	1.66
Average	**0.82**	**2.55**	**2.61**	**0.88**	**1.38**	**1.42**	**1.61**

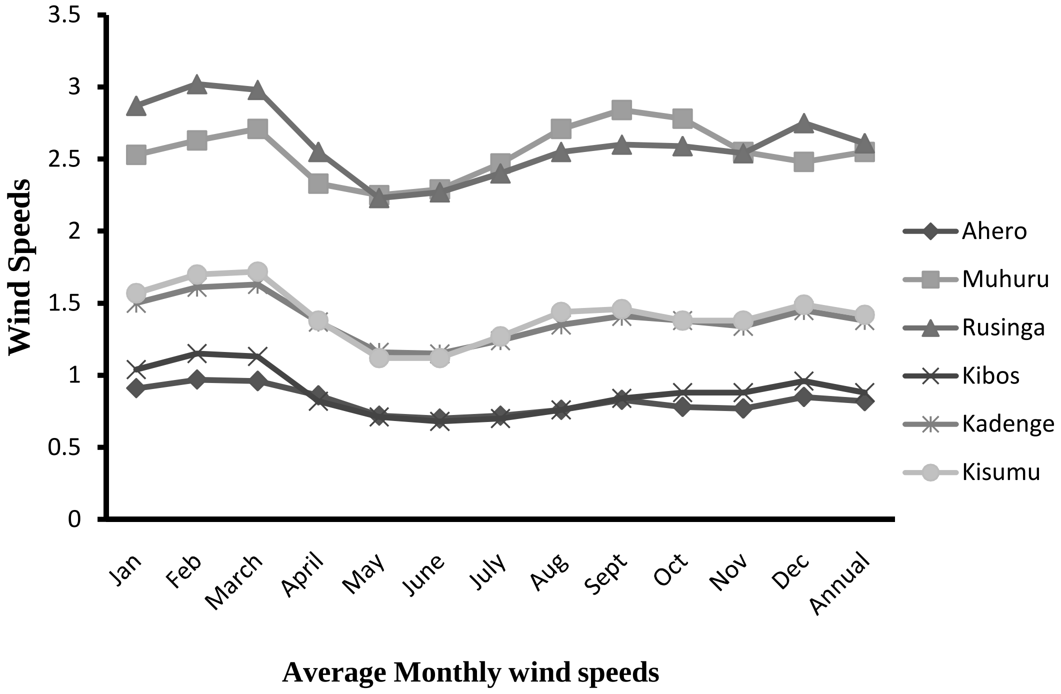

Fig. 2: The LS (1996-2011) Average Monthly Wind Speed Variations

It is evident that the mean monthly wind speeds differ for Muhuru and Rusinga compared to Kadenge and Kisumu and for Kibos cotton and Ahero. Muhuru and Rusinga are close to the lake shore and are more exposed to higher average mean wind speed; followed by Kadenge and Kisumu, while Kibos and Ahero have low average mean wind speeds. This is attributed to distance from the lake, frictional factors from the land and fetch distance (distance before the wind reaches a station with uniform surface). The stations close to the lake have high wind speeds due to longer fetch distance on the water side and low frictional roughness due to the uniform water surface and effects of temperature on both land and water surfaces that cause breezes. Note that, the further the stations inland the lower the wind speeds due to the increase in surface roughness caused by vegetation and built up areas. Fig 1 and Fig 2 above also shows the effects of spatial locations of the stations with respect to the water body.

1.4.2.2 Effect of Seasons on Wind Speeds

All the stations as in Table 1 had low average monthly wind speeds between April and July. The maximum monthly mean wind speeds occur in the month of Feb to March. Another peak though slightly lower occurs between September and October (Table.2 and Fig.2). This supports the observation that maximum wind speeds are in the dry and moderately dry periods/ months, while the low wind speeds are in the wet periods. In the year therefore, there are two peaks (high and moderate) and one low wind speeds period. The season of December to march temperatures are always higher than any other season and correspond to high wind speeds.

1.4.2.3 Daily and Hourly Wind Speeds

The daily and hourly wind speeds within the LS is best represented by data available at Kisumu for six years (2006 to 2011) and Kadenge station (December 2004 and January 2005). The data is presented in Table A6 especially for Kisumu and shown in Fig. 2 and 3.

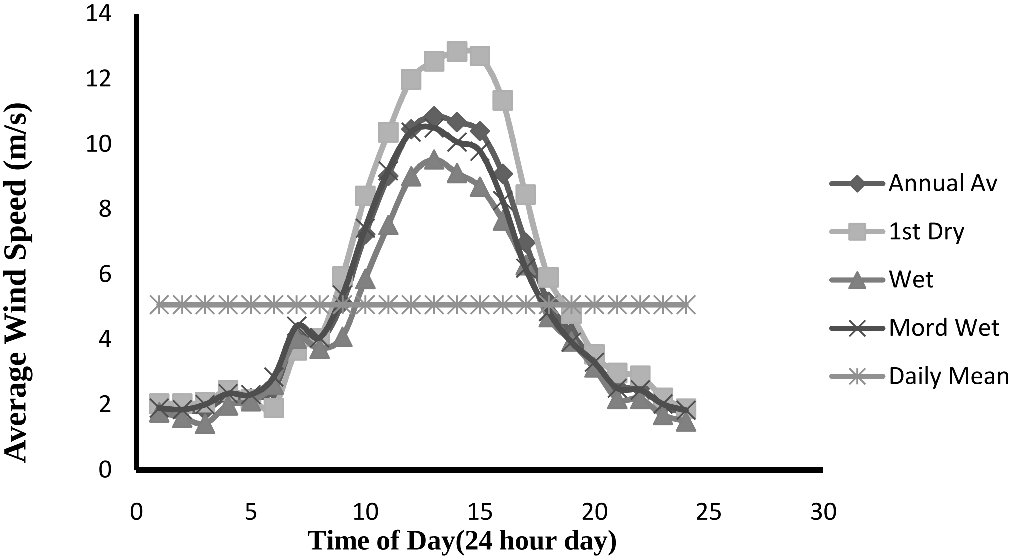

Fig. 3: Hourly 10m Height Wind speed at - Kisumu Airport (2006-2011)

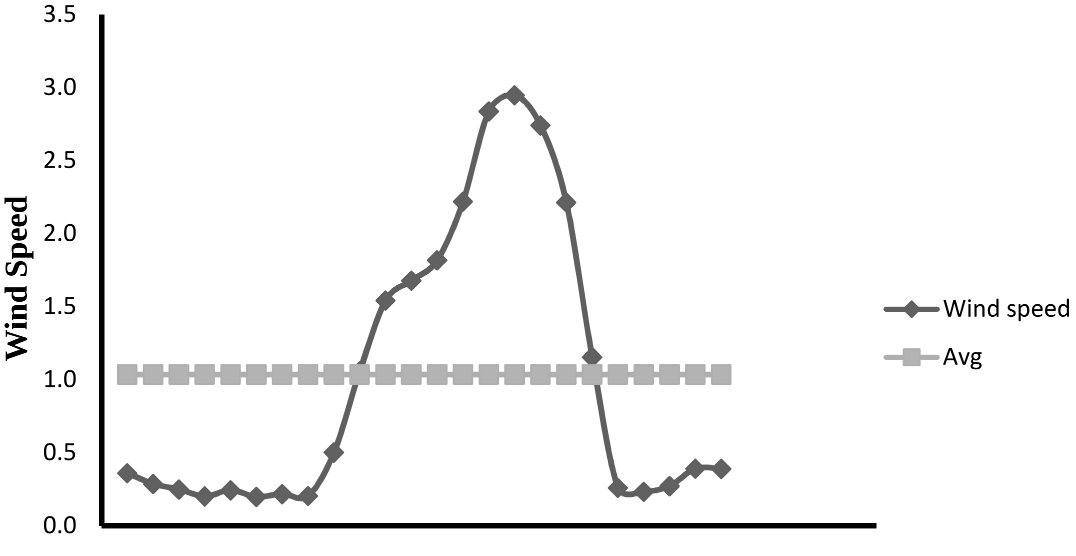

Fig. 4: 10 year hourly2m height Wind Variation at Kadenge

The hourly variation of wind speeds and its bell shape was confirmed and as reported by [26]. The average mean wind speed is 5.07 m/sec at 10m height for Kisumu and while it is 1.00m/sec for Kadenge at 2m height (Table A6). The breezes are common between 09 to 21 hours (Fig. 3 and 4). The land breeze starts from 09 to 18 hours and the sea breeze ends by 00hrs the rest is calm period between 01 08 hours.

The Kisumu 10m height (Fig. 3) shows the diurnal wind speed variation (temporal) depicted for the seasons (long rains, short rains and the dry periods) increasing from a minimum of 2m/sec at 0830 to a maximum 5.8 m/s at about 1530 hours and then reduce to 2m/sec at about 2330 hours. At Kadenge (2m height), it starts at about the same time and drops to 1m/s by 2100 hours three hours ahead of

Kisumu. This is attributed to height of measurement where Kadenge and Kisumu respectively had 2m and 10m measurement heights. Apart from altitude differences as in Table 1, Kadenge was also close to Yala swamp, within 2.5 km.

The seasonal (dry, moderate and rain) and annual variations follow a similar trend (Fig 3). The annual average being lower compared to the dry season and higher than both the short rains and for the long rains. This is due to low temperatures during the rain seasons. Seasons and annual average variations converge to a low wind speed of about 2 m/s for Kisumu. It is therefore observed that wind speeds within the LS show constancy in temporal variation (within the hour, with the days and within the months). The threshold wind speed (2m/s) for a wind pump is available from 0930to 1130 hours for Kisumu. The hourly variation is important for analysis of the site specific performance of a wind energy conversion (WEC) machinery or equipment for water pumping in terms of duration of water supply. The hourly daily wind measurements give a more clear indication of the wind speed for use in irrigation than the monthly graph. The Fig 3 and 4 above demonstrates that hourly wind speed measurements or shorter time step is key to estimation of the duration and the strength of average wind speeds than Fig 5 below which masks the details.

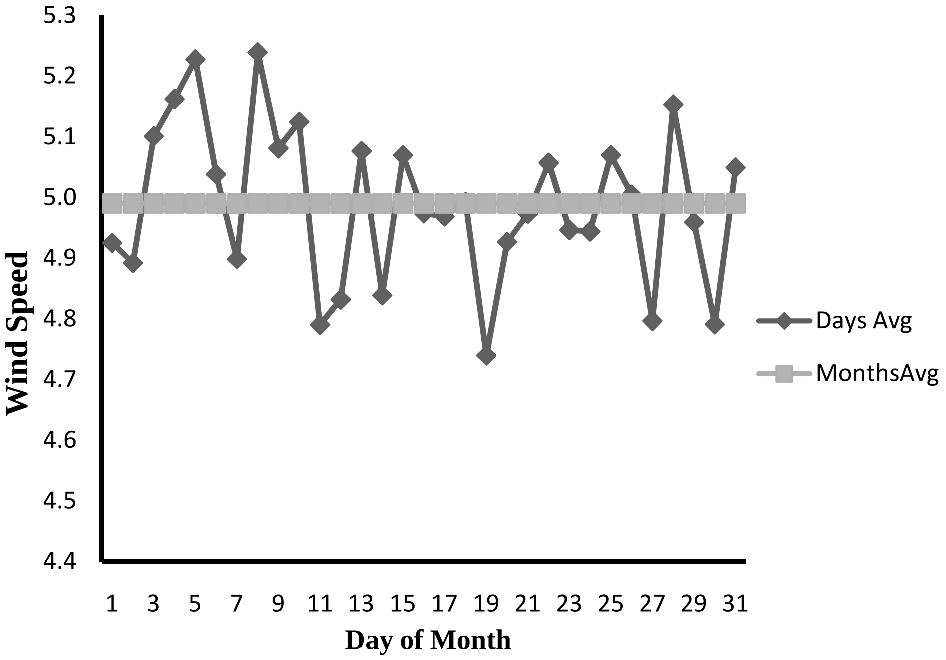

Fig. 5: Annual Daily (Average 10m) Wind Speeds- Kisumu

1.4.2.4 Temporal Wind Direction

Wind direction of the three category sites (Muhuru and Rusinga, Kibos and Ahero, and Kadenge and Kisumu) within the LS is best illustrated by use of data from Kisumu of the years 2006 to 2011, since this was the only available representative data. The direction is significant as one considers installation of wind energy converters, types, discharge and orientation.

The general wind direction is mainly northerly most of the day, (3/4) orientation ,with only westerly direction ¼ of the day as illustrated in Fig 6, derived by dividing into categories the wind speed strength (0-2, 2-4, 4-6.) and time designated into quarters (07:00-12:00, 13:00-18:00, 19:00-24:00 and 01.00-06:00). The time based quarter diagrams in Fig 6 show that at any one quarter, the wind speeds of the LS are always in one major direction. From Fig 6 it can be seen that a smaller magnitude blows in other directions. Frequency tables were developed and used to construct the quarter diagrams which show that wind speeds are in the range of 2-4 m/s which is within the usable portion. It can also be seen that that change of direction is only in one quarter within the span of 24hrs.

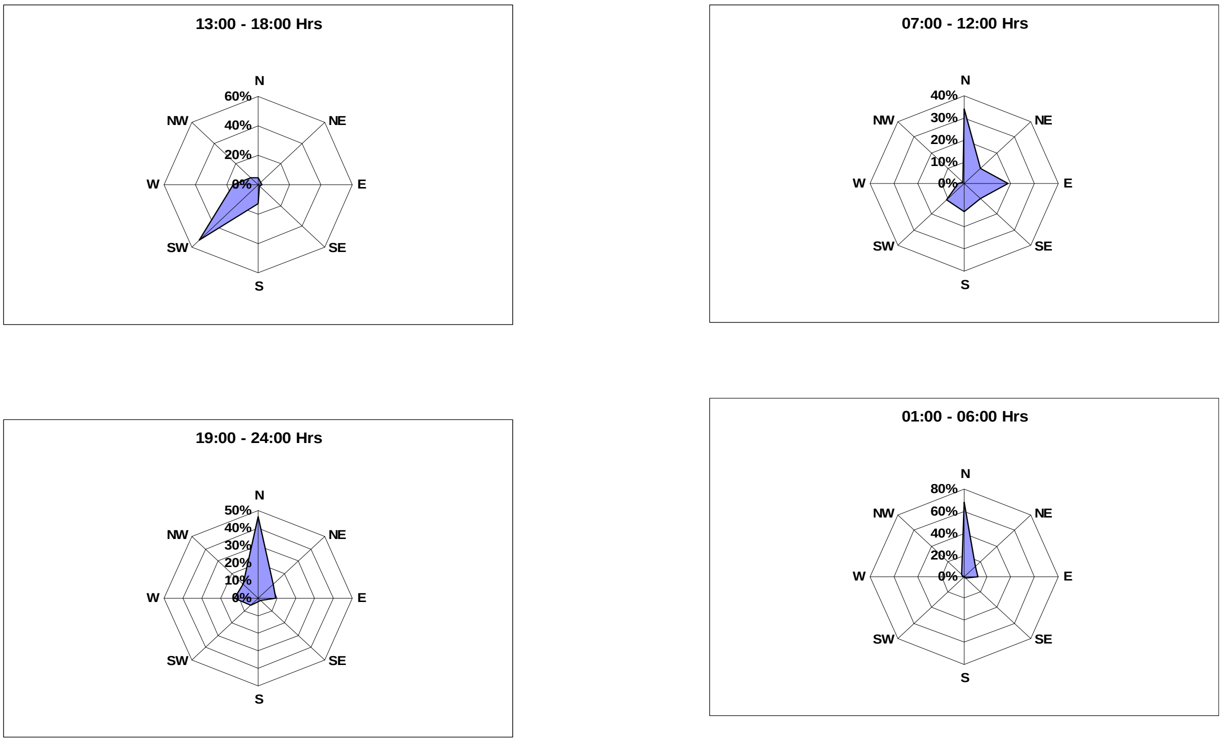

Fig. 6: Kisumu Wind Direction at different times of day

1.4.3 Spatial Variation

Proximity to water body influences wind speeds, due to the nature of the water surface which is horizontal, uniform and homogeneous, as within the LS. This is attributed to physical processes associated with the waves, surface currents, and heat transfer in the water body; and reference to Table 1, 2 and Fig 1 show that wind speed increases with decrease in proximity to the Lake Shore line.

It also be noted that, friction between the ground surface slows the wind speed (geotropic wind) to zero as can been deduced from Table, 1, 2 and Fig. 1, whereas the speed of the wind above the ground is retarded by the resistance due to the earth surface often known as the boundary effect. The instantaneous wind speed increase with elevation is largely affected by the roughness of the surface normally represented by height $Z_{0.}$

1.4.3.1 Probability Density Distribution in the LS

The probability density function as discussed in section 1.3.2 (the indirect method in this case) is an indicator to the role of estimating the power of the wind within the LS. Daily wind speeds taken for a particular month (January) for a number of years together did not fit the Weibull distribution in most cases for all the stations. This though failed in very few cases for a particular calendar month tested independently for all the years and other months. Very few grouped data points from similar months fitted the Weibull distribution. Table A7, A8 and A10 shows the Weibull parameters for the LS stations. Table A7 shows Location, scale and the shape parameters. Tables A8 and A10 respectively show the P –values for the LS and Kisumu station. Kisumu has been represented by the years 2001 and 2011. Tables 4 and A9 respectively show i) increase of wind speeds from 2 m to 10 m by use of the calculated alpha. ii) The % increase of wind speeds for the stations. These are also consistent.

Tables A.8 and A.10 show that to use the Weibull equation, either monthly daily averages for a number of years or a particular year data will give similar results (data used supports Case ii and Case iii).This is emphasized by Tables A10 and A11 in the case of Kisumu which showed negligible inconsistency in only the positions marked red (darkened) for the large number of years considered. Fig.B11 illustrates the performance of the three parameter Weibull distributions of average wind speeds per LS station for the months of the year. It is clear that the range (start and end) of wind speed potential can be easily identified for each station for each month by use of the 3 parameter Weibull distribution. The determined Weibull parameters (after test of fit for the data for distribution) were used in the extrapolation of wind speeds from 2m to 10m for the LS, especially the scale factor c. The Weibull parameters were derived from each station's data hence reflected the conditions of the particular station. The logarithmic power law, the ordinary $1/7^{th}$ power law extrapolation methods registered lower magnitudes of the wind speeds. The basic approach was therefore to use Weibull for extrapolation within the LS, the scale factor and equations 4, 7 and 8.

1.4.3.2 Wind Relationship with Height

Foremost, the wind speed law indexes (α) determined from the first set of 2m and 10m height data are as in Table 5 below and in Table A12 for the LS and Kisumu respectively. The predicted 10m wind speeds from the second 2m and 10m data set by use of the (α) as determined compared well with actual 10m wind speeds (Table.3). Start zero values were used as is usual with wind speeds. A line scatter without zero values fluctuated bound horizontally with negative R^2 values. The annual scatter diagram showed a good relationship ($predicted = 1.1Actual$) of predicted 10m wind speeds from 2m wind speeds and actual 10m wind speeds of Kisumu, with R^2 of 0.84. Seasonal R^2ranged from 0.54 to 0.7. A plot of the predicted compared to actual on daily basis is as in Fig.7 below. Working with limited data from Rusinga 10m wind speeds gave wind speed law index (α) which varied from 0.1 to 0.5 with an average of 0.2. This is due to inadequate 10m wind speed data, but reinforces the fact that the law index (α) varies temporally and spatially (Table.4).

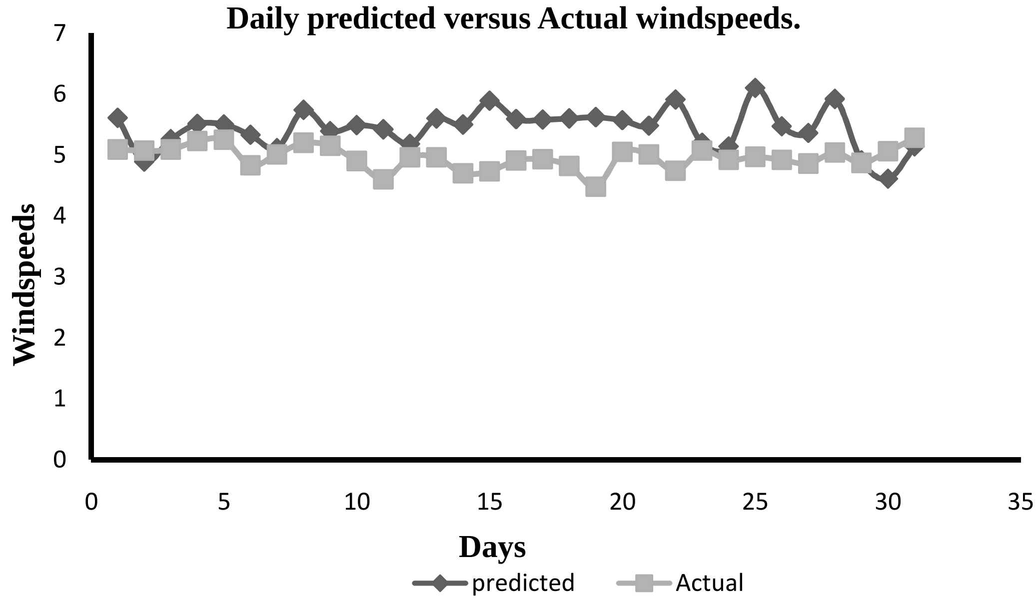

Fig. 7: Annual Actual Wind Speeds Compared to (α) Generated Wind Speeds, Kisumu

Additionally, the Weibull parameters were used to extrapolate data at the 2m for each of the LS stations to higher heights as shown in Table.4 below, also in Fig.B12 and Table A19 (% increase of wind speeds). Fig.B13 correspondingly show wind power distribution for a horizontal axis turbine of

6.1 m diameter based at Rusinga. The aim was to find a suitable procedure of estimating wind speeds at 10m height for water pumping wind mill or electricity generation for the LS.

Table 3: Average Seasonal 10m Actual Vs Predicted Wind Speeds (2009-2011) – Kisumu

	Dec-Mar		**Apr-July**		**Aug –Nov**		**Annual**	
Day	**Pred**	**Actual**	**Pred**	**Actual**	**Pred**	**Actual**	**Pred**	**Actual**
1	5.95	6.39	4.66	4.33	6.2	4.57	5.61	5.09
2	5.38	5.67	4.43	4.52	4.89	5.02	4.89	5.07
3	5.75	5.99	4.85	4.57	5.18	4.7	5.26	5.09
4	5.83	5.51	5.67	4.8	5.06	5.4	5.51	5.23
5	6.44	5.71	5.18	4.61	4.84	5.42	5.5	5.25
6	5.97	6	4.23	4.17	5.83	4.34	5.33	4.83
7	6.17	6.09	4.04	3.97	5.08	4.98	5.11	5.01
8	6.28	5.88	5.51	5.17	5.47	4.55	5.74	5.2
9	6.4	5.88	4.91	4.56	4.89	5.01	5.39	5.15
10	5.81	5.51	5.1	4.33	5.54	4.85	5.49	4.9
11	5.86	5.04	4.7	4.01	5.7	4.74	5.42	4.6
12	5.33	5.5	4.84	4.3	5.42	5.09	5.18	4.96
13	6.58	5.23	4.9	4.7	5.33	4.96	5.6	4.96
14	7.06	5.25	5.02	4.32	4.51	4.53	5.5	4.7
15	6.86	5.9	5.69	4.17	5.19	4.11	5.89	4.73
16	6.16	5.39	5	4.06	5.6	5.27	5.59	4.91
17	6.05	5.6	4.77	4.14	5.92	5.05	5.58	4.93
18	6.83	4.98	4.27	4.4	5.77	5.09	5.6	4.82
19	6.46	4.74	5.04	4.3	5.36	4.4	5.62	4.48
20	6.86	5.09	4.92	5.02	4.95	5.03	5.57	5.05
21	6.26	5.52	5.55	4.43	4.66	5.09	5.48	5.01
22	6.88	5.29	5.48	4	5.37	4.94	5.91	4.74
23	5.92	5.24	4.65	4.2	5.06	5.77	5.2	5.07
24	5.87	5.7	4.33	3.71	5.22	5.35	5.14	4.92
25	6.38	5.66	6.97	4.14	5.16	5.1	6.1	4.97
26	5.98	5.97	5.36	4.05	5.12	4.74	5.47	4.92
27	5.85	5.84	4.83	3.94	5.4	4.79	5.36	4.86
28	6.67	5.77	5.37	3.94	5.72	5.41	5.92	5.04
29	5.07	6.09	4.44	3.89	5.23	4.63	4.91	4.87
30	4.72	5.99	4.45	4.06	4.72	5.13	4.61	5.06
31	5.69	6.66	4.69	3.99	5.03	5.18	5.14	5.28
Avg	6.11	5.65	4.96	4.28	5.27	4.94	5.44	4.96

Table 4: 2m and the Extrapolated α Based 10m Wind Speeds for LS Stations

	Ahero		**Muhuru**		**Rusinga**		**Kibos**		**Kadenge**		**Kisumu**		**Kisumu**		**Ksm -Ob**
	2m	**10m**	**2m**	**10m**	**2m**	**10m**	**2m**	**10m**	**2m**	**10m**	**2m**	**10m**	**2m**	**10m**	**10m**
Jan	0.9	1.8	2.3	4.2	2.9	5.1	0.9	1.7	1.6	3.1	2	3.3	1.5	2.8	5.70
Feb	1	1.9	2.2	3.7	2.8	4.7	0.9	1.8	1.3	2.4	2.1	3.5	1.7	3.2	6.30
Mar	2.6	5	2.8	5.2	3.1	5	1	1.9	1.6	3.1	2	3.5	1.8	3.3	5.90
Apr	0.8	1.6	2.1	3.7	2.2	3.9	0.8	1.6	1.2	2.3	1.2	2	1.6	2.5	4.90
May	0.7	1.3	2.3	4.4	2.2	4.1	0.6	1.3	1.1	2.2	0.6	1.1	1.1	2.3	4.20
Jun	0.7	1.6	2.2	4.1	2.1	3.5	0.6	1.2	1	2.2	0.5	1	1.1	2.1	4.30
Jul	0.7	1.6	2.4	4.4	2.2	3.8	0.7	1.4	1.2	2.5	0.8	1.5	1.5	3	4.20
Aug	0.7	1.5	2.7	5.3	2.6	4.4	0.3	0.7	1.2	2.5	1	1.9	1.5	2.9	4.20
Sept	1.4	2.8	2.9	4.9	2.5	4.8	0.5	0.9	1.4	2.8	1.3	2.6	1.4	2.8	5.20
Oct	0.9	1.7	2.8	4.7	2.7	4.9	0.8	1.8	1.3	2.3	1.2	2.3	1.4	2.7	5.00
Nov	0.7	1.4	2.6	4.7	2.7	4.6	0.8	1.6	1.2	2.4	1.1	2.2	1.5	3	4.60
Dec	0.9	1.8	2.7	5	2.8	4.6	0.7	1.4	1.3	2.6	1.5	2.7	1.6	3	5.30
	1.0	2.0	2.5	4.5	2.6	4.5	0.7	1.4	1.3	2.5	1.3	2.3	1.5	2.8	5.70

Also, one year of data of particular month on an hourly basis was noted (as in section 1.5.3.1) as adequate to predict wind speed with height for a particular station within the LS, *with 95% confidence level which is sufficiently accurate especially where there is lack of data.* This means one year record of data (Table A10) is a good estimate or precursor to many years, which is useful for the trend and confirmation. This is observed in Table.A10 by noting that the single years for Kisumu met the confidence level requirement just as average of LS station by months (case ii and iii).

Table 4 further shows the monthly wind speeds as at 2m and the projected wind speeds to 10 m height from the Weibull α determination. The ratio of V_{10} to V_2 is derived from Table 4 as shown in Fig 8; being Rusinga; 1.74, Muhuru; 1.81, Kisumu; 1.88, Kadenge; 1.98, Kibos; 1.99 and Ahero at the highest ratio of 2.03. From Table 4 it is indicative that multiplying actual 2m wind speeds by 4 and the Weibull generated 10m by 2 results into approximate actual 10m wind speeds. But for Kisumu the ratio of observed data at 2m and 10 m is higher, being 3.8, though the pattern is consistent with the alpha generated wind speeds at 10 m. This difference in ratio for Kisumu may be attributed to the anemometer types, the 2m being mechanical while the 10m is digital type. It was observed that these ratios also vary with distance and speed from Lake Shore (Fig 8). Muhuru and Rusinga with higher wind speeds are nearest to the Lake water while Kadenge and Kisumu, Kibos and Ahero with lower wind speeds are furthest.

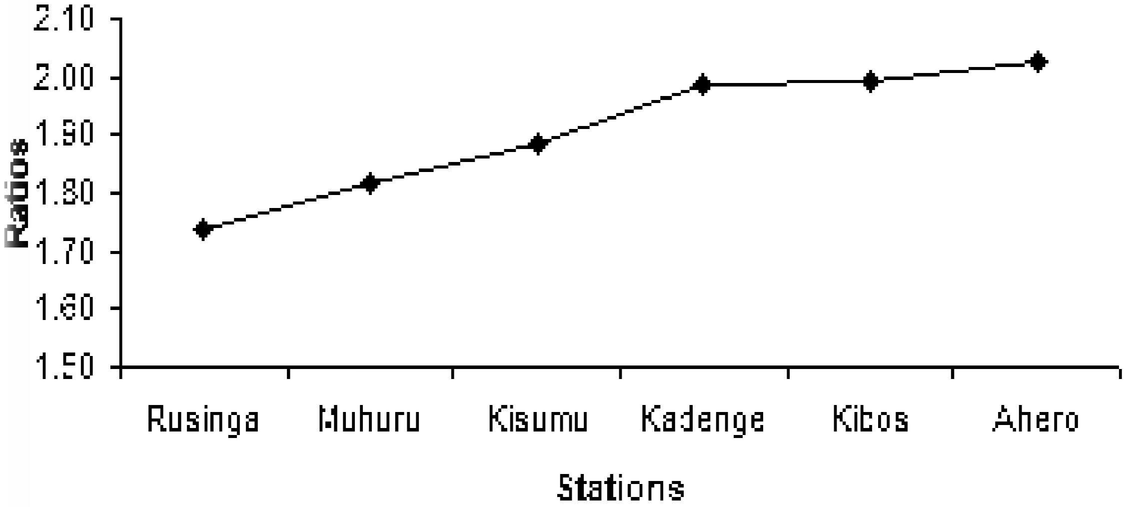

Fig. 8: LS Ratio of Wind Speeds at 2m to 10 m Projection

The two approaches show that the determined alpha is consistent with the location of the site and hence can be used in estimating wind speed from 2m to 10m within the LS. That within a certain radius a ratio can be used. Most notable is that relationship of 2m and 10m vary with location (Refer to Table 1 for distance relationships)

Further, simple regression equations were developed based on actual data available from the stations Kisumu and Rusinga. The wind speeds of 2 m and 10 m were found to obey linear and quadratic relationship for both the stations. Fig. 9 below shows that the monthly averages for Kisumu also fit a cubic relationship for data of 2m and 10m for the record period 2006 to 2011. The graphs 1 to 2 in Fig B14 are for Rusinga, followed by graph 3 to 4 in Fig 9 for Kisumu. Graphs 5 to 6 as in Fig B14 are for Kisumu with actual 2 m wind speeds regressed against the calculated alpha derived 10 m wind speeds. A look at Fig B14 shows that the linear graphs tend to start at the origin and progress at an angle for all the two stations. This is correct as zero wind means no wind and no rotation. The regressions may not be conclusive because of the nature of the data available but taken as a way forward.

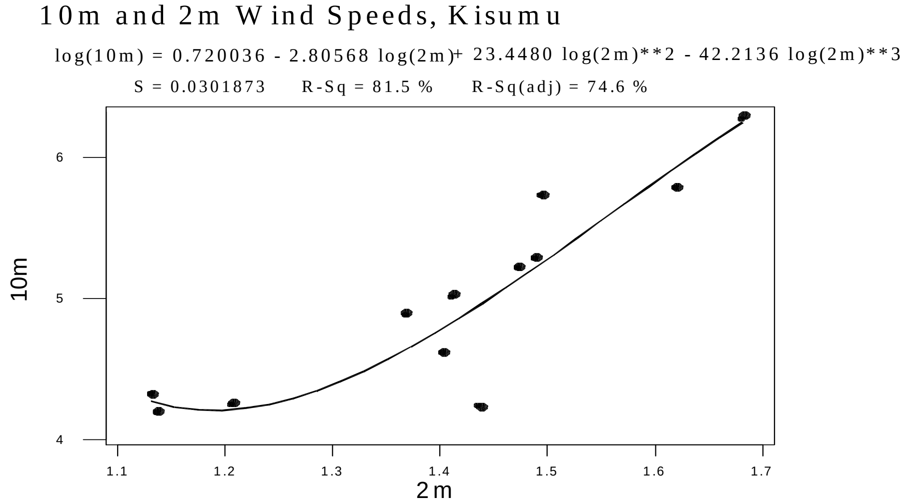

Fig. 9: Monthly Relationship between 2m and 10m Wind Speeds-Kisumu

Table 5: Values of the determined alpha index (α) for the LS Stations/locations

MONTH	Ahero 95	Muhuru 95	Rusinga 95	Kibos 95	Kadenge 95	Kisumu 96	Kisumu 04	LS avg	Kisumu 06-08	
									Actual	**Predicted**
January	0.44	0.37	0.35	0.40	0.43	0.33	0.38	**0.39**	**0.76**	**0.35**
February	0.38	0.31	0.34	0.43	0.38	0.32	0.40	**0.37**	**0.84**	**0.36**
March	0.40	0.39	0.29	0.42	0.39	0.33	0.36	**0.37**	**0.85**	**0.35**
April	0.45	0.35	0.34	0.44	0.43	0.33	0.30	**0.38**	**0.82**	**0.32**
May	0.42	0.41	0.39	0.42	0.42	0.39	0.43	**0.41**	**0.85**	**0.41**
June	0.51	0.38	0.32	0.43	0.48	0.42	0.42	**0.42**	**0.85**	**0.42**
July	0.48	0.38	0.33	0.44	0.47	0.38	0.41	**0.41**	**0.87**	**0.4**
August	0.45	0.41	0.31	0.52	0.44	0.39	0.39	**0.42**	**0.79**	**0.39**
September	0.42	0.34	0.41	0.37	0.45	0.44	0.41	**0.41**	**0.81**	**0.42**
October	0.44	0.33	0.38	0.47	0.34	0.41	0.38	**0.39**	**0.81**	**0.39**
November	0.44	0.38	0.33	0.41	0.42	0.41	0.43	**0.40**	**0.82**	**0.42**
December	0.43	0.39	0.31	0.38	0.43	0.36	0.39	**0.39**	**0.76**	**0.38**
Average	0.44	0.37	0.34	0.43	0.42	0.37	0.39	**0.40**	**0.82**	**0.38**

1.4.3.3 Wind Speed Variation with Location

The different sites within the Lake Shore show variation of wind speeds with location. A common factor (α) though changes with site represents attributes of the stations from the water line. The variation could be due to topography that increases frictional resistance to the flow of wind. The result shown in the Fig10 is a negative linear relation of wind speed and wind speed law index (alpha) based on location. The Fig 10 is a plot of average wind speed from a location based on; average of daily data from December to March denoted as quarter one (Q1) or the dry period of the year. Table 5 and A12 further illustrate the variation of the wind speed law index by LS stations and month of the year for both direct and indirect as is determined. The Law index allows use of equation 4, and ratios may be used within a radius of a data capture station because of the consistencies observed.

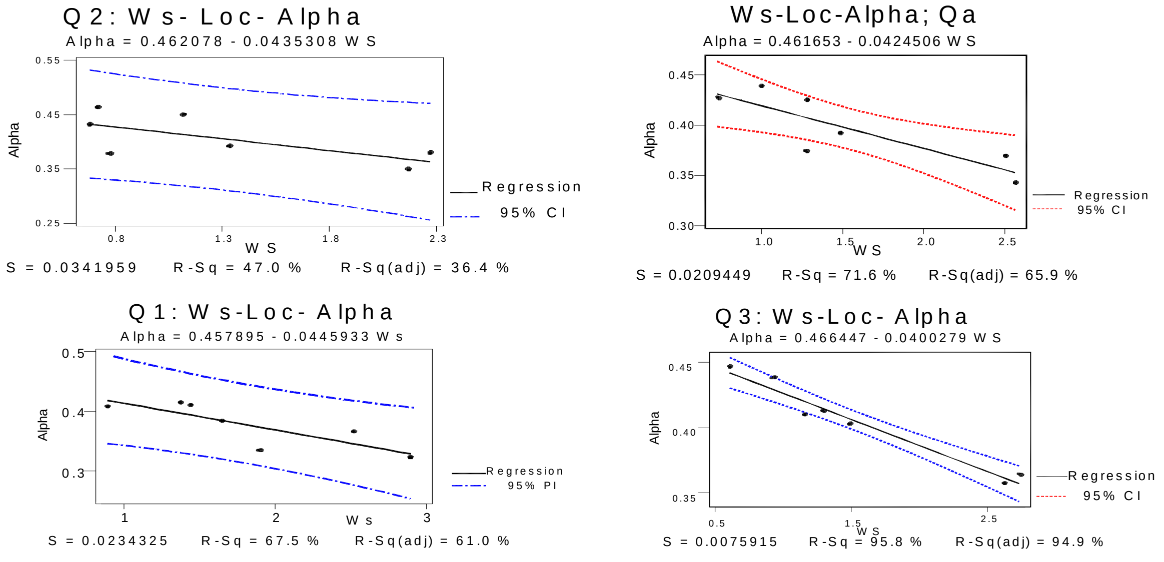

Fig. 10: Wind Speed Location Alpha Index Relationship for LS

Note that above the regression line from right to left (or upwards) are stations Rusinga, Kadenge, and Kibos. Likewise below the regression line or equal to, from right to left are Muhuru, Kisumu (03), Kisumu (04) and Ahero.

The wind speed – alpha index relationship showed high correlation respectively for Q3, Annual (Q_A), Q1 and Q2 being least and moderate. This indicates there was variation of strength of relationship of wind speed – alpha index with seasons, when monthly wind speeds and alpha index was regressed and compared (annual, dry, wet, short rain periods). From Fig 8 (Kadenge & Kisumu); (Kibos & Ahero) and (Rusinga & Muhuru) had different average wind speeds at different sections of the graph, similar to variation with height of the station as in section 1.4.2. Kisumu was represented by two years 1996 and 2004 (Fig10) which were also close together in the regression graph area, confirming the wind speeds were of the particular location. The other stations were represented by the year 1995. The regression relationships obtained were as below for Q1, Q2, Q3 and QA (equations 11 to 14). It is clear that alpha is a function of wind speed strength and the characteristics of the area. The power law index (α**)** as a relationship estimate therefore can be used to estimate the wind speeds potential from 2m to 10m for the LS case as it is location specific, wind speed dependent and period dependent. The equations 11 to 14 can therefore be used for a location but time period must be taken into account. This above discussion supports section 1.4.3.2

$\alpha = 0.46 - 0.045\ \mathrm{WS}$……………Dec to March ……..………………………………………...(11)

$\alpha = 0.46 - 0.044\ \mathrm{WS}$…………… April to July ………………………………………..........(12)

$\alpha = 0.47 - 0.040\ \mathrm{WS}$…………….August to Nov...…...…………………………………………..(13)

$\alpha = 0.46 - 0.042\mathrm{WS}$ …………….Annual winds speed……………………………………...(14)

1.5 Conclusion and Recommendation

1.5.1 Conclusions

The wind resource is variable within the LS by site, time; height of measurement and by distance from the shore line.

- Through observation and analyses of data from anywhere within the LS, the wind characteristics were **consistent** (daily, monthly, seasonal and direction and Weibull derived alphas) and this constitute the calm, land breeze, and sea breeze sessions within the 24 hour period. This can be attributed to temperature change on land and lake water surfaces. These imply that the wind speeds do vary within the LS with comparable similarity. But wind directions constructed from frequencies show that the predominant wind speeds are in the range of 2-4 m/s at 2 to 10mheight, which is consistent according the wind direction charts.
- In the study of wind characteristics in the LS, the three parameter Weibull distribution gave a good account of wind speeds at 2m and that the location (ε) parameter is a necessity only to show on a linear scale the duration (start and the end) of wind speeds and strength (magnitudes) for a given site (Fig B11). It was found that without the location parameter (that is by use of scale and shape parameters only) the point of start of wind speeds is not identifiable. And this does not give adequate details on duration and strength of the wind speeds.
- Monthly data gave reasonable estimate for wind speed prediction for the 2m to 10m. In future, the hourly data or shorter time step is found to be better for determining the wind speed strength and duration compared to daily records. The wind speed strength and duration is important for water pumping design systems.

- That α in the power law index could be determined from equation 4 and the Weibull distribution (equation 5) and directly used with equation 8, proposed by Justus and Mikhail [12]. This gave a good account of the wind patterns as is in Fig. B12 and thus a method for estimating wind speeds from 2 m to 10 m. But this avoided the route of random generation of wind speeds by the Weibull parameters from known height to the unknown which gave none responsive results, which could also be explored.
- Predicted and actual wind speeds by use of (α) index for Kisumu station gave good relationships for dry, wet, moderate and annual data R^2 = (0.54, 0.66, 0.66, 0.83) respectively.
- Equation 4 in section 1.2.1 for wind speeds alpha relationship at the LS is for now proposed to be.$\frac{V_B}{V_A} = \left(\frac{Z_B}{Z_A}\right)^{0.8}$. Should alpha be Weibull based, it should then be multiplied by 2 for projecting actual wind speeds to 10 m or multiply the 2m wind speeds by 4 (Table 4).
- A relationship ratio of wind speeds at a location for two heights showed linearity towards the inland from near the lake shore. The ratio relationship can be used as a method in the same respect for estimating wind speeds at 10m from 2m at the LS but within a reasonable distance.
- It is observable from the three site categories, that wind speeds decreased as one moves inland. Wind speeds are highest at the shore (Muhuru and Rusinga), moderate for Kisumu and Kadenge and lowest inland for Kibos and Ahero.
- A Known (α) value at a location will allow for estimation of wind speed at higher height. That the developed equations 11 to 14 have similar magnitudes and further shows that the (α) index has a negative relation with location. It is higher for low wind speeds and similar in trend with the ratio relationship. These equations are therefore variable with wind speeds strength; period and location, hence α is location based and a method for estimating wind speeds for two heights at a location. For Kisumu station, the Weibull determined alpha (α) was half the actual (Average of 0.4 and 0.8).
- The linear, quadratic and cubic relationship of 2m and 10m wind speeds was established. Just like α index, on their own, the equations may not be universally applied but they can be used within a radius or locality and for comparisons of site wind speed behavior.
- It can therefore be deduced from above, that Kisumu data for now can be used to represent the whole of LS even with variations.

And:

The approaches and equations developed are reasonable and usable within the limits of data. But there is need within the LS to improve on data capture in terms of equipment, intensity and extent.

At present the work is limited to 10m and further research should be for use of the equations and methods beyond 10m, taking into account the location, direction, diurnal and the seasonal variation.

Appendix

Table A6: Data for Diurnal Wind Speed Variation Kisumu and Kadenge

	KISUMU					KADENGE	
Time/day	**Annual Av**	**1st Dry**	**Wet**	**Moderately Wet**	**Daily Mean**	**Annual**	**Daily mean**
3am	1.9	2.03	1.76	1.9	5.07	0.25	1.01
4am	1.83	2.04	1.6	1.85	5.07	0.2	1.01
5am	1.83	2.08	1.42	2.01	5.07	0.24	1.01
6am	2.25	2.44	1.98	2.34	5.07	0.2	1.01
7am	2.2	2.18	2.11	2.31	5.07	0.22	1.01
8am	2.45	1.9	2.62	2.85	5.07	0.21	1.01

9am	4.04	3.67	4.02	4.41	5.07	0.5	1.01
10am	3.94	4.04	3.72	4.05	5.07	1.04	1.01
11am	5.12	5.93	4.08	5.36	5.07	1.54	1.01
12am	7.23	8.41	5.86	7.42	5.07	1.68	1.01
1pm	9.02	10.36	7.51	9.18	5.07	1.82	1.01
2pm	10.45	11.98	9.01	10.37	5.07	2.22	1.01
3pm	10.85	12.54	9.52	10.49	5.07	2.84	1.01
4pm	10.67	12.83	9.11	10.06	5.07	2.95	1.01
5pm	10.39	12.7	8.69	9.78	5.07	2.74	1.01
6pm	9.09	11.34	7.66	8.27	5.07	2.21	1.01
7pm	6.97	8.45	6.28	6.19	5.07	1.16	1.01
8pm	5.15	5.91	4.68	4.86	5.07	0.26	1.01
9pm	4.21	4.78	3.94	3.92	5.07	0.23	1.01
10pm	3.33	3.55	3.14	3.3	5.07	0.27	1.01
11pm	2.55	2.98	2.18	2.51	5.07	0.39	1.01
12pm	2.51	2.89	2.18	2.45	5.07	0.39	1.01
1am	1.97	2.22	1.68	2.02	5.07	0.36	1.01
2am	1.73	1.88	1.48	1.83	5.07	0.29	1.01
	5.07	**5.8**	**4.43**	**4.99**	**5.07**	**1.01**	**1.01**

Table A7: Location, Scale & Shape Parameters for LS Stations (Average: 1996-2011)

	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec
Ahero												
Є	0.543	0.266	0.321	0.437	0.17	0.549	0.534	0.413	0.945	0.49	0.348	0.49
C	0.386	0.029	0.651	0.374	0.947	0.163	0.235	0.36	0.517	0.41	0.382	0.437
K	2.638	3,645	4.014	2.216	3.602	1.642	2.063	2.063	2.713	2.29	2.129	2.934
Muhuru												
Є	-565	0.366	0.428	0.924	1.747	-2.85	1.604	2.264	1.535	1.338	1.724	1.73
C	3.409	2.053	2.445	1.337	0.561	5.18	0.933	0.613	1.465	1.584	0.933	0.77
K	10.3	4.169	6.271	3.776	1.161	15.66	2.349	1.444	3.731	3.776	1.862	2.638
Rusinga												
Є	1.746	1.39	0.641	0.966	1.499	0.315	0.799	0.765	1.923	1.871	1.224	0.835
C	1.341	1.53	2.696	1.412	0.77	1.906	1.581	2.613	0.613	0.93	1.639	2.112
K	2.994	1.774	4.634	2.453	2.542	5.192	3.292	1.244	1.244	1.762	2.848	4.634
Kibos												
Є	0.314	-0.526	0.513	0.314	0.139	0.151	0.321	0.487		0.583		-7.908
C	0.667	1.614	0.521	0.423	0.545	0.471	0.404	0.196		0.27		9.262
K	3.645	6.836	0.987	3.088	5.192	4.331	4.334	1.51		1.751		11.98

Kadenge												
Є	1.166	0.533	0.976	0.762	0.628	0.32	0.994	0.895	1.06	-0.04	0.753	0.891
C	0.446	0.342	0.759	0.462	0.492	0.244	0.272	0.357	0.351	1.463	0.525	0.432
K	1.546	2.271	1.915	1.836	3.561	1.537	1.349	1.751	1.786	5.873	1.774	2.002
Kisumu -94												
Є	0.306	0.41	0.583	0.384	-0.13	0.058	-0.23	-0.24	0.904	0.676	0.587	-0.408
C	4.786	1.838	1.622	1.703	0.782	0.539	0.921	0.78	0.429	0.611	0.606	1.651
K	5,270	4.45	3.121	4.277	3.442	2.29	3.442	4.634	2.163	2.017	2.112	9.185
Kisumu-03												
Є	0.754	1.03	99.52	-0.663	0.723	0.605	-0.57	0.854	0.926	0.618	1.109	-15.98
C	0.868	0.705	97.23	2.402	0-477	0.524	2.077	0.78	0.567	0.913	0.444	17.6
K	3.52	1.211	198	5.78	2.129	2.163	8.101	2.29	3.096	4.064	1.612	93.16

Table A8: Descriptive Statistics of LS Stations/ P-Value for Fit of Weibull Distribution

	Jan	**Feb**	**March**	**April**	**May**	**June**	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Ahero												
N	31	28	30	30	31	30	31	31	30	31	30	31
Mean speed	0.886	1.013	0.911	0.768	0.663	0.695	0.743	0.733	1.405	0.853	0.686	0.924
SD	0.14	228	0.165	-0.158	0.152	0.091	0.106	0.137	0.183	0.168	0.167	0.161
Skewness	0.3	-0.01	-0.09	0.5	0	0.92	0.59	0.36	0.27	-0.46	0.55	0.19
Kurtosis	-83	0.91	-0.17	-0.89	0.9	1.34	1.61	0.29	-0.66	-0.77	-0.30	-0.25
P-value	0.607	0.404	0.979	0.4429	0.3478	0.28	0.442	6503	0.873	0.758	0.95765	0.98
Muhuru												
Mean	2.682	2.242	2.702	2.132	2.279	2.151	2.431	2.82	2.857	2.769	2.553	2.414
SD	0.38	0.504	0.423	0.357	0.46	0.418	0.374	0.391	0.395	0.423	.0.462	0.279
Skewness	-0.65	-0.12	-0.4	-0.4	1.6	-0.78	0.43	1.14	-0.03	-0.04	0.73	0.3
Kurtosis	93	-0.63	0.76	0.15	3.33	1.48	-0.23	2.5	-0.5	-0.85	0.18	-0.66
P-value	0.176	0.802	0.587	0.7888	0.4143	0.747	0.907	0.202	0.926	0.551	0.653	0.8
Rusinga												
Mean	2.944	2.75	3.105	2.218	2.182	2.068	2.217	2.624	2.494	2.699	2.684	2.766
SD	0.436	0.793	0.605	0.545	0.288	0.388	0.474	0.52	0.462	0.485	0.556	0.474
Skewness	0.17	0.8	-20	0.38	0.34	-0.28	0.08	-0.09	1.44	0.81	0.22	-1.2
Kurtosis	-0.38	1.86	1.25	0.3	0.47	-0.51	0.48	0.32	2.95	0.58		0.13
P-value	0.967	0.281.8	0.308	0.4679	0.6791	0.75	0.574	0.751	0.183	0.879	0.158	0.913
Kibos												
Mean	0.917	0.982	0.975	0.692	0.641	0.583	0.689	0.663	0.789	0.797	0.797	0.967
SD	0.184	0.259	0.243	0.134	0.111	0.102	0.096	0.119	0.148	0.126	0.126	0.19
Skewness	-0.01	-0.45	0.64	0.14	-0.28	-0.23	-0.15	1.06	-0.58	-0.2	-0.2	-0.71
Kurtosis	3.72	0.27	1.71	0.99	0.35	0.82	-0.75	2.33	2	0.22	0.22	2.8
p-value	0.014	0.898	0.118	0.2564	0.7983	0.491	0.645	0.049	0.696	0.849	0.849	0.066
Kadenge												

Mean	1.567	1.284	1.649	1.173	1.071	1.04	1.194	1.239	1.373	1.315	1.22	1.274
SD	0.265	0.348	0.366	0.232	0.138	0.146	0.187	0.203	0.181	0.268	0.272	0.2
Skewness	1.02	0.47	0.69	0.75	0.01	1.03	1.27	0.82	0.79	-0.36	0.8	0.63
Kurtosis	1.51	0.16	0.44	1.18	-0.11	1.19	3.32	0.38	0.6	0.14	0.31	-0.08
p-value	0.191	0.906	0.537	0.2932	0.0043	0.779	0.218	0.801	0.7	0.997	0.903	0.976
Kisumu-94												
Mean	1.951	2.086	2.034	1.165	0.571	0.535	-0.596	1.00	1.284	1.218	1.123	1.517
SD	0.359	0.427	0.509	0.409	0.226	0.04	0.266	0.175	0.185	0.281	1.267	0.204
Skewness	-0.29	-0.17	0.13	-0.14	0.04	-0.02	0.04	-0.2	0.53	0.62	0.56	-0.6
Kurtosis	-0.38	0.23	-0.22	-1.12	0.13	-0.15	-0.02	-0.28	-0.03	1.13	-0.26	0.62
p-value	0.313	0.684	0.987	0.1292	0.8378	0.919	0.92	0.993	0.766	0.524	0.937	0.997
Kisumu-03												
Mean	1.535	1.692	2.006	1.561	1.146	1.069	1.384	1.545	1.432	1.446	1.507	1.522
SD	0.246	0.549	0.634	0.446	1.209	0.226	0.287	0.32	0.181	0.229	0.253	0.227
Skewness	0.02	1.5	-1.17	-35	0.55	53	-0.54	0.46	0.15	-0.1	0.95	-1.08
Kurtosis	-0.26	2.78	0.52	2.16	0.99	0.01	1.11	0	-0.98	0.151	1.09	1.89
p-value	0.976	0.315	0.899	363	0.5153	0.907	0.925	0.827	0.255		0.683	0.389

Table A9: % Increase of Wind Speeds with Height and Location

	Ahero-10m	**Muhuru-10m**	**Rusinga-10m**	**Kibos-10m**	**Kadenge-10m**	**Kisumu-10m**	**Kisumu-10m**
	10 m	**10 m**	**10 m**	**10 m**	**10 m**	**10 m**	**10 m**
January	104	81	75	91	101	69	85
February	86	66	72	99	85	68	89
March	91	87	60	97	88	71	80
April	105	75	74	102	100	70	63
May	95	95	87	96	98	87	99
June	127	83	67	99	116	96	97
July	117	83	71	103	113	83	95
August	106	93	66	132	104	87	87
September	97	73	93	83	107	101	95
October	103	71	83	113	73	93	83
November	104	83	71	95	96	93	101
December	98	87	65	85	101	78	88
Mean	**103**	**81**	**74**	**99**	**98**	**83**	**88**

Table A10: P-Values for Fit of Weibull Distribution for (2m) Kisumu Station

Month	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
Jan	0.86	0.87	0.24	0.73	0.49	0.31	0.98	0.29
Feb	0.90	0.87	0.58	0.88	0.88	0.69	0.91	0.60
Mar	0.94	0.70	0.78	0.05	0.40	1.00	0.98	0.60

Apr	0.05	0.66			0.96	0.13	0.25	0.62
May	0.50	0.76	1.00	0.95	0.99	0.84	0.73	0.77
Jun	0.37	0.51	0.91	0.11	0.98	0.92		0.88
Jul	0.57	0.99	0.70	0.97	0.61	0.92	0.42	0.16
Aug	0.42		0.32	0.80	0.96	0.99	0.94	0.56
Sep	0.20	0.96	0.96	0.78	0.44	0.66	0.50	0.99
Oct	0.77	0.97		0.96	0.63	0.52	0.98	0.35
Nov	0.61	0.92	0.22	0.65	0.91	0.91	0.97	0.33
Dec	0.91	0.82	0.80	0.03	0.04	0.89	0.98	0.30
Month	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
Jan	0.40	0.97	0.94	0.97	0.82	0.85	0.98	0.97
Feb	0.99	0.84	0.80	0.85	0.27	0.78	0.31	0.76
Mar	0.68	0.46	0.85	0.09	0.65	0.96	0.90	0.59
Apr	0.86	0.86	0.93	0.48	0.34		0.04	0.85
May	0.09	0.48	0.94	0.79	0.83		0.48	0.89
Jun	1.00	0.69	0.91	0.97	0.87	0.85	0.95	0.98
Jul	0.99	0.40	0.80	0.47	0.98	0.03	0.93	0.77
Aug	0.77	0.37	0.79	0.98	0.78	0.08	0.81	0.52
Sep	0.92	0.38	0.97	0.07	0.89	0.84	0.27	0.70
Oct	0.53	0.64	0.22	0.98	0.98	0.22	0.15	0.52
Nov	0.94	0.83	0.75	0.99	0.79	0.35	0.72	0.21
Dec		0.71	0.47	0.84	0.47	0.37	0.49	0.76

Table A11: Descriptive Statistics of Kisumu Station

Par	SN	Month	Parameter	1995	1996	1997	1998	1999	2000	2001	2003	2004	2005	2006	2007	2008	2009	2010	2011
1	1	Jan	N	31	31	30	31	29	31	31	31	31	27	31	31	31	31	31	31
2	1	Jan	Mean	1.6813	1.4607	1.318	1.81	1.36	1.9511	1.429	1.728	1.524	1.064	1.656	1.472	1.6	1.7855	1.535	1.6813
3	1	Jan	SD	0.3461	0.275	0.294	0.229	0.39	0.3588	0.257	0.292	0.232	0.178	0.275	0.172	0.4	0.4071	0.246	0.3461
4	1	Jan	Skewness	-0.078	0.7112	-0.52	0.277	0.38	-0.291	-0.458	0.213	-0.17	-0.19	0.216	-0.033	-0.39	-0.269	0.022	-0.0776
5	1	Jan	Kurtosis	-0.424	0.1679	1.784	0.316	0.99	-0.879	-0.014	0.795	-0.88	-0.18	-0.28	-0.149	-0.21	0.2528	-0.26	-0.424
Par	**SN**	**Month**	**Parameter**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
1	2	Feb	N	28	28	28	28	28	28	28	28	28	28	28	28	27	28	28	28
2	2	Feb	Mean	1.6398	1.4654	1.585	1.951	1.41	2.0861	1.453	1.681	1.976	1.215	1.918	1.845	1.61	2.052	1.692	1.8161
3	2	Feb	SD	0.2181	0.2624	0.39	0.203	0.29	0.4266	0.323	0.209	0.249	0.252	0.386	0.209	0.24	0.3569	0.549	0.3209
4	2	Feb	Skewness	-0.887	0.1188	-0.51	0.429	-0.26	-0.166	-0.429	-0.26	-0.65	0.378	1.045	0.767	-0.13	0.593	1.499	-0.2791
5	2	Feb	Kurtosis	1.5499	-0.6006	1.194	-0.28	0.28	0.2303	-0.347	-0.58	-0.08	0.012	0.659	0.333	-1.05	-0.427	2.785	0.3438
Par	**SN**	**Month**	**Parameter**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
1	3	Mar	N	31	31	31	31	31	31	31	30	31	31	31	31	31	21	31	31
2	3	Mar	Mean	1.6803	1.6353	1.28	1.948	1.61	2.0336	1.521	1.471	1.989	1.369	1.731	1.715	1.89	1.754	2.006	1.8089
3	3	Mar	SD	0.3892	0.2609	0.224	0.474	0.25	0.5094	0.293	0.293	0.338	0.269	0.377	0.245	0.4	0.3023	0.634	0.2817
4	3	Mar	Skewness	0.2152	-0.4212	-0.88	-0.06	0.71	0.1342	-0.08	-0.36	-1.16	0.541	0.507	-0.32	0.14	0.0133	-1.17	-0.0918
5	3	Mar	Kurtosis	0.0042	-0.6487	1.106	-1.28	1.36	-0.218	-0.234	0.643	2.648	0.189	-0.63	2.016	0.24	-0.334	0.524	0.3046
Par	**SN**	**Month**	**Parameter**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
1	4	Apr	N	30	30			30	30	27	30	30	29	30	30	30		30	30
2	4	Apr	Mean	1.2463	1.2086			1.49	1.1649	1.424	1.342	1.478	1.117	1.222	1.455	1.46		1.561	1.5273
3	4	Apr	SD	0.4081	0.31			0.26	0.409	0.289	0.189	0.337	0.303	0.336	0.287	0.28		0.446	0.2967
4	4	Apr	Skewness	0.9771	0.2594			0.49	-0.141	-0.448	0.374	0.217	-0.13	0.185	0.055	0.54		-0.35	0.8911
5	4	Apr	Kurtosis	3.5213	0.3352			-0.45	-1.122	0.693	0.678	-0.1	-0.59	-0.61	0.57	1.31		3.157	0.287
Par	**SN**	**Month**	**Parameter**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
1	5	May	N	31	31	30	31	31	31	31	31	30	30	31	31	31		31	31
2	5	May	Mean	1.0955	1.0134	1.288	1.201	1.16	0.5709	1.181	1.249	1.042	0.958	1.024	1.285	1.24		1.146	1.262
3	5	May	SD	0.1943	0.2264	0.201	0.183	0.21	0.2261	0.229	0.205	0.237	0.168	0.193	0.201	0.13		0.209	0.1927
4	5	May	Skewness	0.0424	0.3708	-0.41	0.247	0.11	0.0428	0.552	-0.21	-0.5	0.845	0.011	0.038	-0.11		0.553	0.2047
5	5	May	Kurtosis	0.3978	0.4006	-0.06	-0.28	-0.32	0.1288	0.269	-0.59	2.946	0.431	-0.1	0.211	-0.61		0.986	-0.6885

Par	SN	Month	Parameter	1995	1996	1997	1998	1999	2000	2001	2003	2004	2005	2006	2007	2008	2009	2010	2011
1	6	Jun	N	28	26	27	28	28	28		28	28	28	27	28	28	17	28	28
2	6	Jun	Mean	1.2045	1.0374	1.307	1.19	1.04	0.5316		1.128	1.085	0.945	1.085	1.372	1.28	1.257	1.057	1.2753
3	6	Jun	SD	0.2476	0.1908	0.238	0.299	0.16	0.2282		0.236	0.137	0.183	0.184	0.172	0.15	0.2779	0.229	0.2129
4	6	Jun	Skewness	0.4887	-0.0382	0.455	1.181	0	0.4986		0.459	-0.43	0.628	0.415	0.245	0.47	-0.452	0.684	0.5219
5	6	Jun	Kurtosis	-0.759	0.5514	-0.55	3.102	-0.49	-0.29		-0.29	0.481	0.299	0.451	-0.425	-0.39	0.8	0.203	-0.1046
Par	**SN**	**Month**	**Parameter**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
1	7	Jul	N	31	31	31	31	31	30	30	31	31	31	31	31	31	31	31	31
2	7	Jul	Mean	1.2885	1.1762	1.577	1.12	1.29	0.5961	1.167	1.096	1.237	0.931	1.266	1.516	1.47	1.4937	1.384	1.5766
3	7	Jul	SD	0.2872	0.1963	0.258	0.242	0.23	0.2656	0.265	0.225	0.204	0.243	0.187	0.313	0.23	0.285	0.287	0.2737
4	7	Jul	Skewness	0.5532	-0.3657	0.861	0.092	0.22	0.042	-0.105	-0.44	0.249	0.684	-0.05	0.416	0.2	0.3916	-0.54	0.796
5	7	Jul	Kurtosis	-0.583	-0.1622	0.856	-0.18	0.54	-0.021	0.858	1.826	-0.42	1.685	-0.61	0.473	-0.05	2.992	1.109	0.4103
Par	**SN**	**Month**	**Parameter**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
1	8	Aug	N	31		31	30	31	31	31	31	31	31	31	31	31	31	31	31
2	8	Aug	Mean	1.3023		1.616	1.514	1.48	0.9999	1.369	1.631	1.432	1.213	1.373	1.624	1.44	1.5058	1.545	1.5721
3	8	Aug	SD	0.2209		0.224	0.273	0.26	0.1752	0.279	0.282	0.287	0.176	0.208	0.226	0.35	0.2248	0.32	0.2494
4	8	Aug	Skewness	0.7134		0.005	1.001	-0.4	-0.199	0.461	0.047	0.694	0.755	-0.26	0.409	0.01	-0.439	0.456	-0.9443
5	8	Aug	Kurtosis	1.5242		-1.01	0.346	-0.27	-0.278	0.061	0.518	-0.34	1.571	-0.56	-0.099	0.03	-0.858	7E-04	2.8362
Par	**SN**	**Month**	**Parameter**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
1	9	Sep	N	30	30	29	30	30	30	28	30	30	30	30	30	30	30	30	30
2	9	Sep	Mean	1.3164	1.3642	1.584	1.606	1.47	1.2835	1.364	1.606	1.532	1.419	1.311	1.583	1.43	1.514	1.432	1.5041
3	9	Sep	SD	0.2351	0.2	0.246	0.287	0.25	0.1847	0.223	0.196	0.223	0.248	0.26	0.34	0.24	0.1679	0.181	0.2405
4	9	Sep	Skewness	0.2503	0.3313	0.707	-0.24	0.31	0.5289	1.287	0.262	-0.24	1.071	0.443	0.123	0.44	0.0764	0.149	-1.1056
5	9	Sep	Kurtosis	1.249	0.2676	-0.23	0.404	0.72	-0.031	1.817	-0.59	-0.32	2.157	-0.21	2.023	-0	0.0487	-0.98	0.478
Par	**SN**	**Month**	**Parameter**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
1	10	Oct	N	31	31		31	31	31	31	31	31	31	31	30	31	31	31	31
2	10	Oct	Mean	1.2343	1.194		1.423	1.46	1.2182	1.284	1.498	1.354	1.426	1.29	1.607	1.42	1.5292	1.446	1.336
3	10	Oct	SD	0.2478	0.2207		0.368	0.26	0.2815	0.257	0.208	0.227	0.307	0.253	0.204	0.22	0.2016	0.229	0.2054
4	10	Oct	Skewness	0.6348	-0.0764		-0.14	0.68	0.6235	-0.117	0.612	0.281	0.185	-1	-0.144	0	-0.667	-0.1	0.4991
5	10	Oct	Kurtosis	0.4053	-0.4593		-0.45	0.72	1.1284	-0.379	1.244	0.7	0.332	4.096	-0.164	-0.42	2.4643	-1.1	0.4797
Par	**SN**	**Month**	**Parameter**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
1	11	Nov	N	29	29	29	28	28	29	29	29	29	29	29	29	29	29	29	28
2	11	Nov	Mean	1.2009	1.3482	1.6	1.224	1.42	1.1343	1.239	1.353	1.161	1.457	1.273	1.597	1.39	1.5214	1.504	1.3491
3	11	Nov	SD	0.2224	0.2208	0.26	0.157	0.2	0.2653	0.227	0.232	0.193	0.188	0.23	0.296	0.2	0.2641	0.257	0.2128
4	11	Nov	Skewness	0.0755	-0.9976	0.536	-0.73	0.45	0.5274	0.106	1.045	0.117	0.561	0.248	-0.135	0.71	-0.066	0.978	-0.258
5	11	Nov	Kurtosis	0.5538	1.8832	1.855	1.091	-0.21	-0.234	-0.2	1.812	-0.56	-0.03	-0.56	-0.223	0.28	-0.968	1.04	-1.0448
Par	**SN**	**Month**	**Parameter**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
1	12	Dec	N	30	30	29	30	29	30	30	30		30	30	30	30	30	30	30
2	12	Dec	Mean	1.4337	1.3257	1.704	1.728	1.6	1.0932	1.508	1.348		1.759	1.294	1.704	1.62	1.3797	1.521	1.5803
3	12	Dec	SD	0.1691	0.3588	0.232	0.334	0.36	0.3244	0.299	0.169		0.249	0.265	0.225	0.29	0.2736	0.23	0.264
4	12	Dec	Skewness	0.9061	-0.5573	0.245	0.132	0.02	-1.702	-0.158	0.59		0.034	1.213	0.18	-0.01	-0.015	-1.05	0.3268
5	12	Dec	Kurtosis	0.3286	-0.441	0.161	-1.43	-1.34	3.2548	-0.349	0.695		-0.72	1.879	-0.003	0.72	-0.945	1.724	-0.6922

Table A12: Seasonal Alphas for 1996-2011 10m WS, Kisumu

Date	Q1(Dec-March)	Q2(Apr-July	Q3(Aug-Nov	(Annual)
1	0.78	0.83	0.79	0.80
2	0.74	0.79	0.77	0.76
3	0.80	0.83	0.79	0.81
4	0.80	0.87	0.81	0.82
5	0.84	0.86	0.74	0.82
6	0.80	0.80	0.87	0.82
7	0.81	0.73	0.77	0.78
8	0.82	0.89	0.84	0.85
9	0.82	0.84	0.79	0.81
10	0.79	0.89	0.85	0.84
11	0.79	0.83	0.85	0.82
12	0.73	0.82	0.81	0.78
13	0.86	0.82	0.82	0.84
14	0.89	0.85	0.73	0.82
15	0.87	0.92	0.78	0.86

16	0.82	0.86	0.81	0.83
17	0.81	0.84	0.86	0.83
18	0.85	0.76	0.83	0.82
19	0.84	0.86	0.82	0.84
20	0.85	0.81	0.75	0.81
21	0.83	0.90	0.73	0.82
22	0.87	0.92	0.84	0.88
23	0.78	0.82	0.77	0.79
24	0.84	0.78	0.79	0.81
25	0.84	0.93	0.79	0.85
26	0.78	0.87	0.78	0.81
27	0.80	0.85	0.80	0.81
28	0.85	0.91	0.85	0.87
29	0.74	0.82	0.82	0.79
30	0.72	0.79	0.75	0.75
31	0.81	0.80	0.77	0.80
Avg α	**0.81**	**0.84**	**0.80**	**0.82**

Table A13: Alpha Index for Different Conditions

Location	**A**
Unstable air above open water surface:	0.06
Neutral air above open water surface:	0.10
Unstable air above flat open coast:	0.11
Neutral air above flat open coast:	0.16
Stable air above open water surface:	0.27
Unstable air above human inhabited areas:	0.27
Neutral air above human inhabited areas:	0.34
Stable air above flat open coast:	0.40
Stable air above human inhabited areas:	0.60

Source: Kaltschmitt *et al.* (2007)

Appendix B: Figures

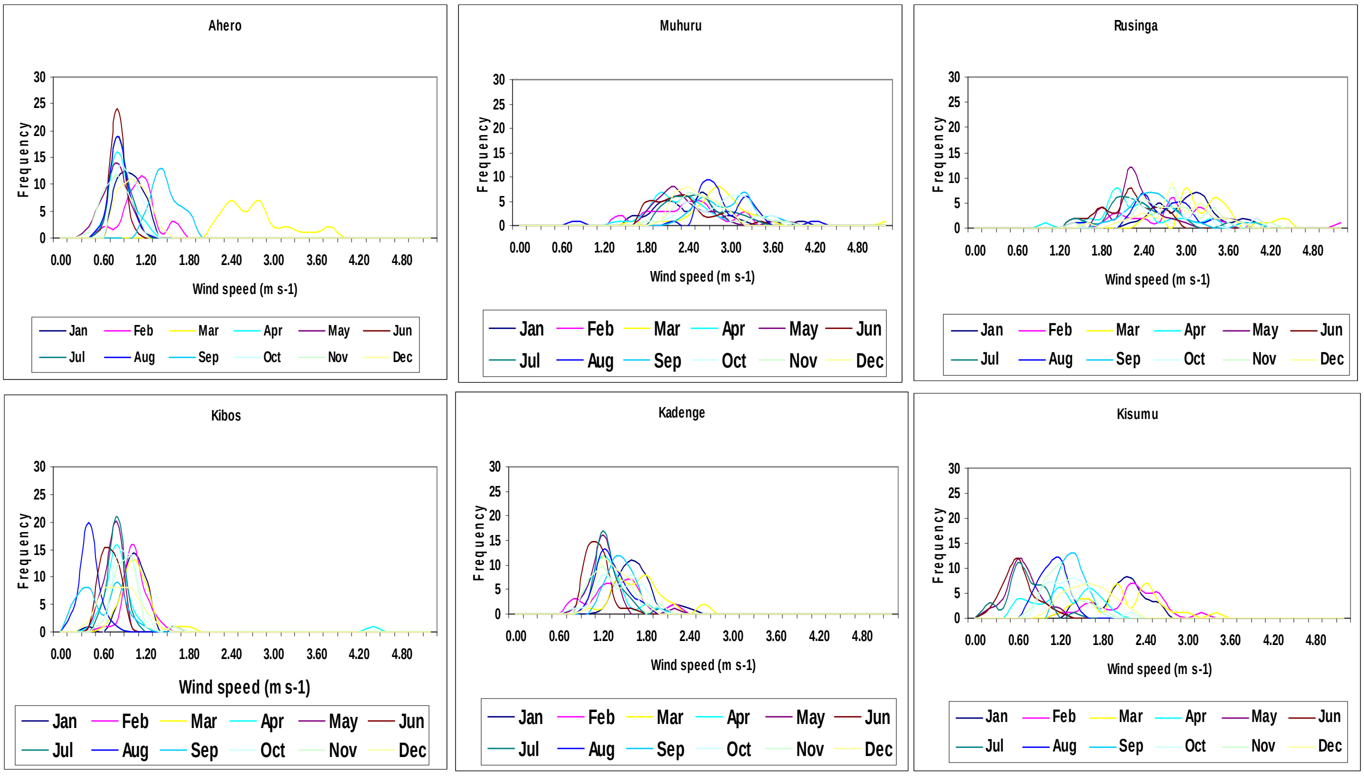

Fig. B11: Weibull Distribution for the LS Stations

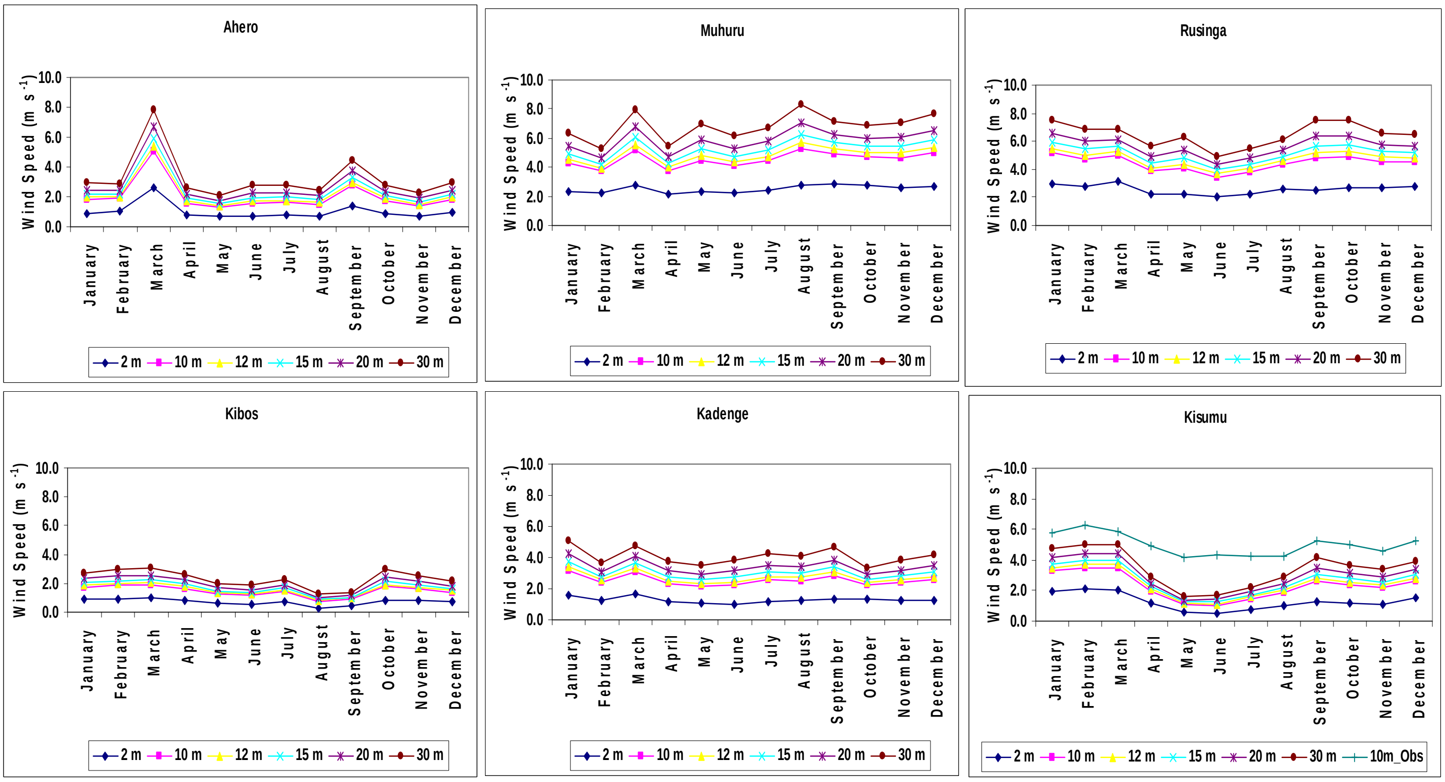

Fig. B12: LS Wind Speed Height Increase based on Weibull Parameters of Table 3a

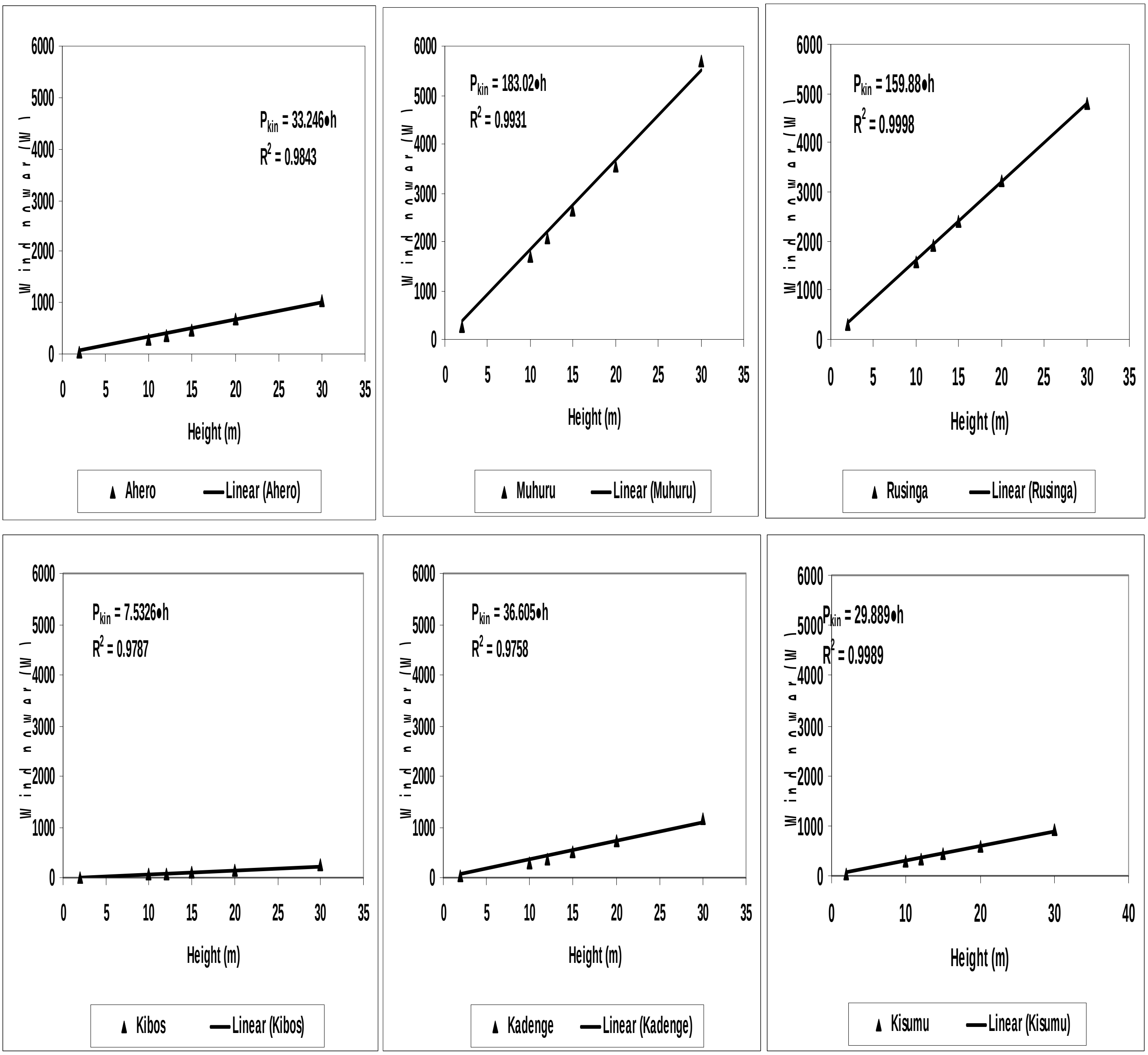

Fig. B13: LS Stations Wind Energy Power Variation with Height

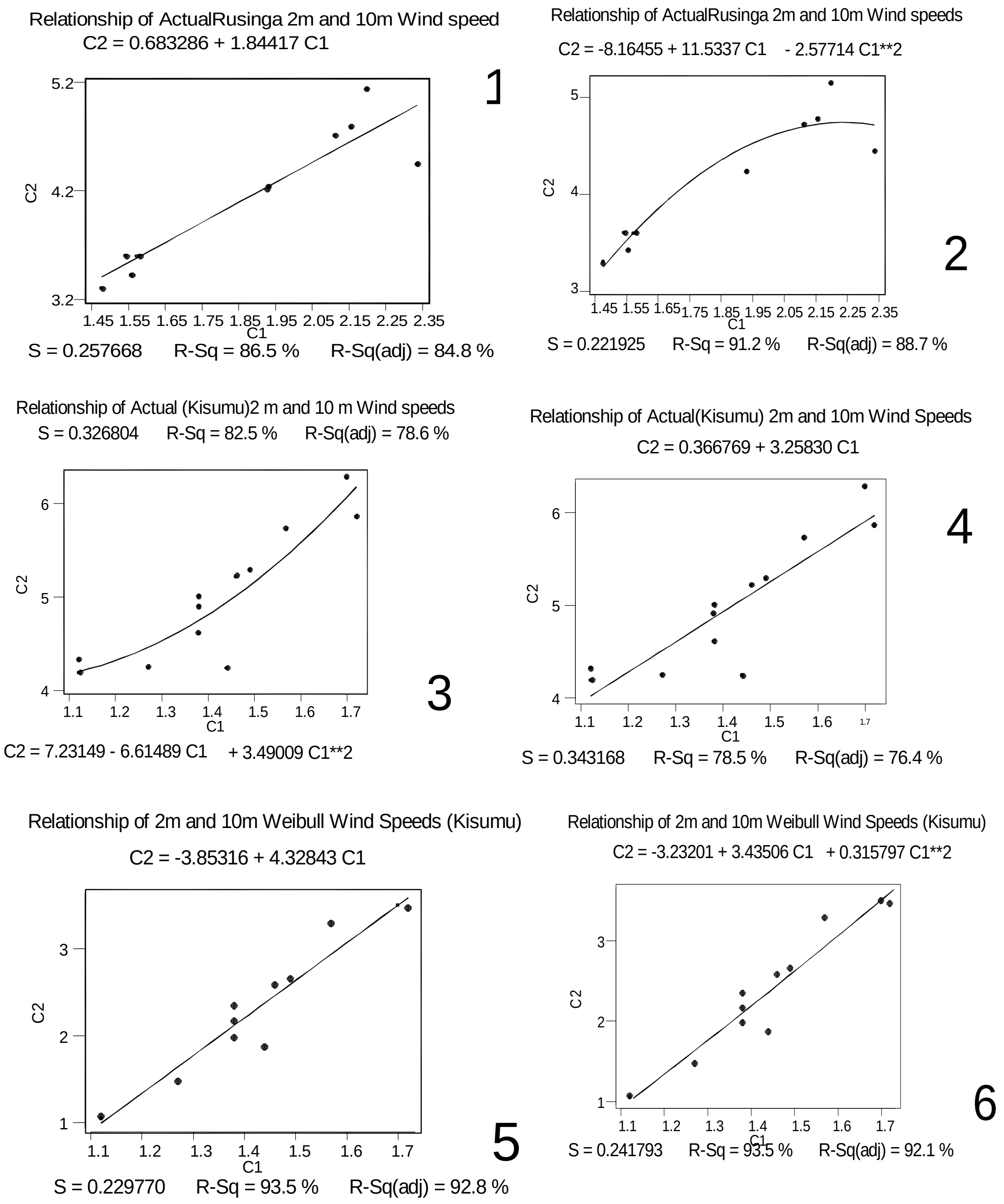

Fig. B14: Relationship of 2 m and 10 m Wind Speeds for LS Stations- Kisumu and Rusinga

References

[1] A.M. Asmail and M.E. Ali, Assessment of the Wind Energy Potential on the Coast of Tripoli, (2010), http://www.ontario-sea.org/Storage/27/1865, Accessed on 8th August (2013).

[2] R. Bansal, T.S. Bati and D.P. Kothari, On some of the design aspects of wind energy conversion systems, *Energy Conversion and Management*, 43(16) (2002), 2175-2187.

[3] A.N. Celik, A statistical analysis of wind power density based on the Weibull and Rayleigh models at the southern region of Turkey, *Renewable Energy*, 29(2003), 593-604.

[4] A.G. Davenport, C.S.B. Grimmond, T.R. Oke and J. Wieringa, Estimating the roughness of cities and sheltered country, *Proceedings 12th Conference on Applied Climatology*, Asheville, NC, American Meteorological Society, Boston, (2000), 96-99.

[5] E.L. Deacon, Vertical diffusion in the lowest layers of the atmospheric, *Quarterly Journal of the Royal Meteorological Society*, 75(1949), K9-103.

[6] J.C. Doran and M.G. Verholek, A note on the vertical extraction formula for Weibull velocity distribution parameters, *Journal of Applied Meteorology*, 17(I3) (1978), 410-412.

[7] S. Emeis and M. Turk, Comparison of logarithmic wind profiles and power law wind profiles and their applicability for offshore wind profiles, *Wind Energy: Proceeding of the Euromech Colloquium*, (2007).

[8] P. Gipe, Wind Power for Home and Business: Renewable Energy for the 1990's and Beyond, Chatsea Green Publishing Company, White Rivers Junction, Vermont, 1993.

[9] E. Holt and J. Wang, Trends of Wind Speed at Wind Turbine Height of 80 m over the Contiguous United States using the North American Regional Reanalysis (NARR), Department of Earth and Atmospheric Sciences, University of Nebraska Lincoln Revised, 2011.

[10] S.A. Hsu, E.A. Meindl and D.B. Gilhousen, Determining Power Law Wind Profile Exponent under Near Neutral Stability Condition at Sea, Coastal Studies Institute, Louisiana State University, Baton Rouge, Louisiana, 1993.

[11] C.G. Justus, W.R. Hargraves and A. Yalcin, Nationwide assessment of potential output from wind power generators, *Journal of Applied Meteorology*, 15(1976a), 673-678.

[12] C.G. Justus, W.R. Hargraves and A. Mikhail, Reference Wind Speeds Distributions and Height Profiles for Wind Turbine Design and Performance Evaluations, ERDAORO/5108.76/4, (1976b).

[13] M. Kaltschmitt, A.W. Wolfgang and Streicher, Renewable Energy: Technology, Economics and Environment, Springer, 2007.

[14] J.N. Kamau, J.N. Mutuku and D.W. Wekesa, Microcontroller-Based data logging instrumentation system for wind speed and direction measurements data logging system, *Jomo Kenyatta University of Agriculture and Technology JAGST*, 14(1) (2012), 176.

[15] P. Kostas and D. Despina, Statistical simulation of wind speed in Athens, Greece based on Weibull and Arma models, *International Journal of Energy and Environment*, 3(4) (2009), 151-158**.**

[16] J.H. McIntyre, W.D. Lubitz and W.H. Stiver, Wind Energy Resource Assessment Using Wind Atlas and Meteorological Data for the City of Guelph, Canada School of Engineering, University of Guelph, Guelph, Ontario, N1G 2W1, Canada, 2004.

[17] Minitab Statistical Software Features – Minitab, Software for statistics: Process improvement, six sigma, Quality-Minitab, N.p., n.d., (2011), Web: <http://www.minitab.com/en-US/products/minitab/features/, Accessed on 13th August (2013).

[18] R.K. Meyer, D. David and Krueger, A Minitab Guide to Statistics (3rd ed.), Upper Saddle River, NJ: Prentice-Hall Publishing, 2004.

[19] H. Nfaoui, H. Essiarab and A.A.M.A. Sayigh, Stochastic Markov chain model for simulating wind speed time series at Tangiers, Morocco, *Renewable Energy*, 29(2004), 1407-1418.

[20] Z.O. Olaofe and K.A. Folly, Wind energy analysis on the basis of Rayleigh distribution for darling city, South Africa, *International Conference on Renewable Energy, Generation and Application*, (2012).

[21] C. Oludhe and L. Ogallo, Statistical characteristics of the surface winds over Kenya, *Journal of Applied Statistics*, 16(1989), 331-334.

[22] C. Oludhe and L. Ogallo, Vertical variation of wind power, *Discovery and Innovations*, 2(1990), 73-79.

[23] R. Pallabazzer, Provisional estimation of the energy output of wind generators, *Renewable Energy*, 29(2004), 413-420.

[24] H.A. Panofsky, An alternative derivation of the adiabatic wind profile, *Quart J. Rmeteorsoc*, 87(371) (1961), 109-110.

[25] C.B. Ramesh, Y.D. Zhao, K.S. Ram and S.S. Jitendra, Wind Energy Resources: Theory, Design and Applications, Handbook of Renewable Energy Technology, World Scientific Publishing Co. Pvt. Ltd., 2011.

[26] M.L. Ray, A.L. Rogers and J.G. McGowan, Analysis of wind shear models and trends in different terrains, University of Massachusetts, Department of Mechanical and Industrial Engineering, Renewable Energy Research Laboratory, (2006).

[27] S. Rehman, T.O. Halawani and T. Hlsain, Weibull parameters for wind speed distribution in Saudi Arabia meteorology, standards & materials division, Research Institute, King Fahd University of Petroleum & Minerals, Dhahran-31261, Saudi Arabia, (1994).

[28] D. Sisterson, B.B. Hicks, R.L. Coulter and M.L. Wesely, Difficulties in using power laws for wind energy assessment, *Solar Energy*, 31(1983), 201-204.

[29] B.A. Stout, Handbook of Energy for World Agriculture, Elsevier Applied Science, 1990.

[30] Taylor Enterprises, Inc. Distribution analyzer, www.Variation.comr.scale, A simple way to estimate wind speeds, (2006 and 2007), Accessed on 8th August (2013).

[31] C. Tsang-Jung, W. Yu-Ting, H. Hsu, C. Chia-Ren and L. Chun-Min, Assessment of wind characteristics and wind turbine characteristics in Taiwan, *Renewable Energy*, 28(2003), 851-871.

[32] WMO, Initial guidance to obtain representative meteorological observations at urban sites, World meteorological organization instruments and observing methods, *Report No. 81*, (2006), Wmo/td-no. 1250.

[33] V. Yilmaz and H.E. Celik, A statistical approach to estimate the wind speed distribution: The case of gelibolu region, *Doğuş Üniversitesi Dergisi*, 9(1) (2008), 122-132, Department of Statistics, Science and Literature Faculty, Eskişehir Osmangazi University.