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# Statistical Analysis of Wind Speed Distribution for Some Selected Cities in Northern Nigeria

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## ABSTRACT
In this study, statistical analysis of wind speed distribution for some selected cities in northern Nigeria has been carried out. Wind speed data for four study locations which include Damaturu, Gausa, Katsina and Nguru were analyzed with a ten year (2012 – 2021) daily wind speed data sourced from the National Aeronautics and Space Administration metrological website. The wind speed data was prepared from daily to monthly values and Weibullness was used to determine the Weibull two parameters. For each study location, wind speed statistics and characteristics were determined. It was observed that January and September were the best and worst months, respectively of the harvest of wind energy, while, more wind energy is expected to be harness in the dry season period than in the rain season period in the study locations. Validation of Weibullness gave a percentage error range of - 0.52 – 0.38 % for the study locations. Hence, Weibullnessis adjudge to be highly accurate and proficient in the determination of the Weibull two parameters.

## I. Introduction

Globally, the supply of energy is essential for economic development, social growth, and political stability of any nation [1]. To achieve a near eradication of poverty in all its forms and dimensions which include extreme poverty, constant supply of electricity is a necessary component. Most countries still depend mainly on fossil fuels for generation of electricity. The use of fossil fuel is responsible for 73 % of human-caused greenhouse gas that is rapidly warming the earth [2]. Conversely, generation of electricity from a non-conventional energy source such as wind energy is a driving force to earth decarbonization, green economy and energy revolution.

Wind energy is free, clean, and inexhaustible renewable energy source. However, its availability and intensity vary seasonally and from one geographical location to another. Presently, wind energy utilization has gained prominence in countries like China and the United State of America, the world's two largest wind energy market [3]. This further contribute to already vast existing energy capacities in these countries as to meet the energy demand for both domestic and industrial needs. For countries, such as Nigeria at a complex crossroad of deep energy crisis, there is need to diversify into alternative energy sources as to meet the dire electricity supply shortage.

Prior to installation of wind turbine, there is need for a holistic audit of the wind statistics and characteristics of the location for optimal performance of wind turbine. The Weibull distribution is a continuous probability distribution that adequately describes observed irregular phenomena conditions such as the constant variation in atmospheric uncertainties. This type of distribution can reasonably describe wind speed data collected at any location around the world if the time period is not too short [4]. Hence, so many researchers have used the Weibull distribution to statistically analysis wind speed data of their various study locations [5-9].

The two-parameters of Weibull distribution; shape $(k)$ and scale $(c)$ are important in the model of wind regime and frequency distribution for the correct estimation of energy demand of wind energy devices. Their values differ from one site to another and for a particular site, these values changes with height [10]. The value of $k$ parameter reflects the amount of wind speed variation [11]. High value of $k$ parameter indicates that the wind speed values are close to the mean wind speed while low values shows more deviation from the mean wind speed and its values ranges from 0 to 4 [10]. For a particular location, when there is low fluctuation in wind speed, the value of $k$ is large [11]. The wind speed in most study locations across the world have Weibull distribution with $k = 2$ which is specifically known as Rayleigh distribution [12]. The scale parameter $(c)$ is the weighted average wind speed and represents cumulative wind speed frequency. It values depends

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on average wind speed. When the average wind speed is high, the value of $c$ is large [13].

Several methods have been suggested for the estimation of the Weibull parameters, though, few hybrid systems that combine different procedure also exist [14-15]. The use of a particular method depends on available wind statistics and intricacy of data analysis to be carried out [4]. Among the methods, the maximum likelihood method gives more theoretical result [16]. However, due to the intrinsic constraints imposed on the parameters and the tedious iteration associated with the likelihood method, reasonably fast iterative procedures require the use of digital computer [17]. Hence, considering, the complexity in the determination of the two parameter of Weibull distribution, the aim of this study is to use a computer programming package to evaluate the two parameters of Weibull distribution from the wind speed data of the study locations and consequently, the statistical and characteristic parameters required for installation of wind energy conversion systems.

## II. Material

Four study locations in northern part of Nigeria is analysed in this study. These study locations include; Damaturu, Gusua, Katisna and Nguru as listed in Table 1 with their geographic properties. The study locations are selected based on the work of Ref [18] that reported that these study locations are characterized with high level of wind speed in Nigeria. For each study location, daily wind speed data for a period of ten years (2012 – 2021) measured at a height of 10 m is sourced from National Aeronautics and Space Administration (NASA) metrological website [19].

**Table 1 study locations**

| *Study locations* | *Latitude ($^O$N)* | *Longitude ($^O$E)* | *Elevation (m)* |
|---|---|---|---|
| *Damaturu* | 11.75 | 11.97 | 402.61 |
| *Gusau* | 12.17 | 6.68 | 381.62 |
| *Katisna* | 12.97 | 7.63 | 474.54 |
| *Nguru* | 12.88 | 10.46 | 345.61 |

## III. Methodology

### A. Wind Energy Characteristic Parameters

Wind variation are characterized by two functions in the Weibull distribution; The probability density function and the cumulative distribution function. The probability density function indicates the fraction of time or probability during which the wind speed is at a given value. It is given as [20-22]

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

Where $f(v)$ is the probability of observing wind, $v$ is the mean wind speed and, $k$ is the shape factor (dimensionless) and $c$ is the scale parameters (m/s)

The cumulative distribution function designates the fraction of time or probability that the wind speed is equal or lower than the mean wind speed. Thus, the cumulative distribution function is an integral of the probability density function. It is given as [20-22]

$$F(v) = 1 - \exp\left[-\left(\frac{v}{c}\right)^{k}\right] \quad (2)$$

By knowing the values of $k$ and $c$, the most probable wind which denotes the most frequent wind speed can be determined from [20-21]

$$V_{mp} = c\left(\frac{k-1}{k}\right)^{1/k} \quad (3)$$

While, the maximum energy of the wind is determined from [20-21]

$$V_{max}E = c\left(\frac{k+2}{k}\right)^{1/k} \quad (4)$$

Power is derived from wind by making use of the force it exerts on an object. Wind turbine blades are designed to move in response to the force of the wind and extract a substantial portion of the available energy. The instantaneous wind energy that flows through the wind turbine blades swept area is related with third power of the wind speed according to the relation

$$P_a = \frac{1}{2}\rho A v^3 \quad (5)$$

Where $\rho$ = is the air density of the study locations which is a function of the altitude (air pressure) and temperature, it is taken as 1.225 kg/m$^3$ in this study. $A$ = the area of the turbine blades.

Another important parameter for characterization of wind property is the mean wind power density. The wind energy of a study location on Weibull density function is obtain from Equation (5) as

$$\frac{P_a}{A} = \frac{1}{2}\rho v^3 = \frac{1}{2}\rho\int_0^\infty v^3\, \rho(v)dv \quad (6)$$

After integration for the Weibull density function of Equation (6), the mean wind power density can be written as [20-21]

$$\frac{P_a}{A} = \frac{1}{2}\rho c^3 \Gamma\left(1 + \frac{3}{k}\right) \quad (7)$$

The mean wind density over a given period of time (T) is the product of the mean wind power density and the period of time. It is given as [21]

$$\frac{E}{A} = \frac{1}{2}\rho c^3 \Gamma\left(1 + \frac{1}{3}\right) T \quad (8)$$

Where $T$ is 8640 hours for a year.

Among the wind energy characteristic parameters, the mean wind speed is an important parameter

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estimated from the wind speed data. The values of the monthly mean wind speed calculated from the daily values of wind speed data can be obtained from

$$v_{md} = \frac{1}{N}\left[\sum_{i=1}^{N} v_i\right] (9)$$

Where $v_{md}$ is the monthly mean wind speed and $v_i$ is the daily wind speed

However, in terms of Weibull two-parameter, the monthly mean wind speed is given as [20-22]

$$v_p = c\Gamma(1 + 1/k) \qquad (10)$$

Where $v_p$ is the monthly mean wind speed calculated from the monthly values of $c$ and $k$ parameters and $\Gamma$ is gamma function

**B. Wind Speed Data Preparation**

In this study, an R statistical contributed package called Weibullness which was developed by Ref [23-26] is used to determine the two parameter of Weibull distribution. For each study location, the daily wind speed data is prepared into monthly wind speed data. Hence, resulting to different number of data points for each month (i.e. considering the number of days in each month). Subsequently, the months are grouped into three as to form a uniform data frame for each group that is acceptable by R programming software as shown in Table 2.

**Table 2 Monthly Data Frame Formation**

| *Group* | *Months* | *Number of data points* |
|---|---|---|
| *A* | Jan, Mar, May, July, Aug, Oct, Dec | 310 |
| *B* | Feb | 283 |
| *C* | April, June, Sept, Nov | 300 |

**C. R Statistical Programming Code**

The Following R statistical programming codes are used in this study

To install the contributed packages that are not included with the typical R installation as to make the package (e.g. Weilbullness) loadable into R. Such packages are installed from CRANE with the use of the following code input into RStudio console:

**R> install.packages('weibullness')** # double or single quotes can be used

To check if the contributed package is installed, input:

**R> installed.packages( )** # this code will list out all the contributed installed packages

To load a package and gain access to the routine code, input:

**R> library('weibullness')**

To confirm if Weibullness package has been loaded for use, input:

**R> search( )** # this will display all the loaded and available to use packages

To read and access the arranged wind speed data saved in Excel CSV spreadsheet file into R, input:

**R>studylocationA< −**read.csv(file.choose( ), header = TRUE)# This code will assign studylocationA to the file that contain wind speed data for group A.

To check if the number of variable loaded into R is correct, input:

**R>length(studylocationA)** # Expected output is seven months with 310 data points for group A

To see all the properties of studylocationA, input:

**R> str(studylocationA)** # "data.frame": 310 obs. of 7 variables is result for group A data. This result can be interpreted as the data type is a data frame with 310 observations and 7 variables.

To access a single variable (i.e. data for each month) in studylocationA, e.g. for January, input:

**R> StudyLocationJan< −studylocationA$JAN** # This code will access the numerical values of the wind speed data for only January in studylocationA and assign it the name StudyLocationJan

To determine the scale and shape factors for each month, input:

**R> weibull.np(x, n, a)** # where x is a numeric vector of observations (e.g. StudyLocationJan), n is the number of data point for each group (e.g. 310 for January in group A as given in Table 1) and a is the offset fraction to be used, typically in (0,1). In this study offset fraction of 0 is used.

## IV. Results and Discussion

**A. Wind Speed Statistical Parameters**

The four study locations are located in the northern part of Nigeria. This part of Nigeria is characterized with high level of solar radiation intensity throughout the year compare to the southern part [27-28]. Climatic conditions in the northern part of Nigeria is mostly influenced by the Sahara Desert. During the months (April-September) of rain season in Nigeria, the northern part experience relatively few days of rainfall that are usually characterized with heavy down pour. While, during the months (October-December and January-March) of dry season, dry harmattan dust laden wind from the

Sahara Desert blow into Nigeria from the northern part.

The mean of the wind speed represents the value where most of the wind speed data aggregates. The spread of the wind speed data and distance of individual wind speed from the mean is indicated by the standard deviation, while, the range value of the wind speed signifies a measure of how the wind speed data is dispersed. Since, the mean and range values are sensitive to outliers. Exclusion of outliers in the wind speed data is essential, hence, the inter quartile range that is less sensitive to outlier values is a more appropriate statistical measure to quote. This is necessary because outlier wind speed values if not removed, the mean value will influence the values of the characteristic parameters since they depend on the mean value. Naturally, bulk of the outlier wind speed will concentrate around the minimum and maximum values if a wind speed data is arranged in ascending or descending order. Tables 3, 4, 5 and 6 presents the monthly wind speed statistics for Damaturu, Gausa, Katsina and Nguru, respectively.

In Table 3 for Damaturu, the mean monthly wind speed ranges from 2.45 – 4.77 m/s and an annual mean wind speed of 3.82 m/s. The minimum monthly mean wind speed occurred in September (0.97 m/s) which also correspond to the month of maximum-minimum monthly wind speed with a value of 4.21 m/s. Hence, this reveal that in September, wind energy harvest in Damaturu will be low. This may be attributed to September-October being the months of transition from rain to dry season. While, the maximum monthly wind speed occurred in April (8.16 m/s) and the minimum-maximum monthly wind speed is seen to have been recorded in January (2.28 m/s). This also may be attributed to January being one of the months during which the harmattan wind from the Sahara Desert is relatively high and March-April are months of transition from dry to rain season. For this study location, the monthly median wind speed ranges from 2.37 m/s in September to 4.8 m/s in January. This indicate that more days with wind speed range values of 2.37 m/s and 4.8 m/s are likely to occur from September through January. This has further confirmed early observations of September and January being the possible months of the harvest of worst and highest wind energy source. The monthly mean standard deviation ranges from 0.56 (September) – 1.24 (April) for the study location. This further indicate that September is the worst month of the harvest of wind energy in Damaturu. Finally, the monthly wind speed inter-quartile range value for Damaturu ranges from 0.72 in September to 1.84 in April.

**Table 3 monthly wind statistics for Damaturu**

| | *Mean* | *Min* | *Max* | *Median* | *SD* | *IQR* |
|---|---|---|---|---|---|---|
| *JAN* | 4.67 | 2.28 | 7.13 | 4.69 | 0.90 | 1.12 |
| *FEB* | 4.77 | 1.80 | 7.44 | 4.80 | 0.99 | 1.18 |
| *MAR* | 4.55 | 1.66 | 7.55 | 4.63 | 1.15 | 1.15 |
| *APR* | 3.98 | 1.72 | 8.16 | 3.78 | 1.24 | 1.84 |
| *MAY* | 3.82 | 1.54 | 6.87 | 3.69 | 1.03 | 1.47 |
| *JUN* | 4.15 | 1.80 | 7.52 | 4.08 | 1.02 | 1.47 |
| *JUL* | 3.51 | 1.51 | 5.91 | 3.48 | 0.85 | 1.11 |
| *AUG* | 2.73 | 1.21 | 5.08 | 2.66 | 0.76 | 1.10 |
| *SEP* | 2.45 | 0.97 | 4.21 | 2.37 | 0.56 | 0.72 |
| *OCT* | 2.73 | 1.06 | 5.2 | 2.55 | 0.75 | 0.85 |
| *NOV* | 3.93 | 1.20 | 5.91 | 3.99 | 0.80 | 0.97 |
| *DEC* | 4.54 | 1.62 | 6.75 | 4.59 | 0.77 | 0.91 |

Table 4 presents the monthly mean statistics for Gausa study location. The monthly mean wind speed ranges from 2.20 – 5.08 m/s as recorded in September and January. The monthly minimum wind speed values ranges from 0.75 – 1.98 m/s in which the minimum-maximum value occurred in May. While, the monthly maximum wind speed value ranges from 4.29 in September to 8.62 m/s in January. A range of 2.12 – 5.12 is estimated for the median, which occurred in September and January. This shows that large number of days will have wind speed within this range in these months. The monthly standard deviation ranges from 0.61 (September) – 1.29 (January). While, the monthly inter-quartile range value ranges from 0.78 – 1.94. From the forgoing, there will be more harvest of wind energy in January, while, September will record the lowest.

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**Table 4 monthly mean wind statistics for Gausa**

| | *Mean* | *Min* | *Max* | *Median* | *SD* | *IQR* |
|---|---|---|---|---|---|---|
| *JAN* | 5.08 | 0.75 | 8.62 | 5.12 | 1.28 | 1.58 |
| *FEB* | 4.89 | 1.69 | 8.34 | 5.02 | 1.29 | 1.79 |
| *MAR* | 4.16 | 1.18 | 7.31 | 4.06 | 1.29 | 1.94 |
| *APR* | 3.68 | 1.38 | 6.52 | 3.57 | 1.04 | 1.43 |
| *MAY* | 3.51 | 1.98 | 6.80 | 3.33 | 0.90 | 1.22 |
| *JUN* | 3.41 | 1.38 | 5.73 | 3.34 | 0.90 | 1.30 |
| *JUL* | 2.86 | 1.38 | 5.21 | 2.89 | 0.76 | 1.02 |
| *AUG* | 2.57 | 0.99 | 4.77 | 2.47 | 0.81 | 1.16 |
| *SEP* | 2.19 | 0.83 | 4.29 | 2.12 | 0.61 | 0.78 |
| *OCT* | 2.64 | 1.30 | 5.05 | 2.40 | 0.83 | 1.26 |
| *NOV* | 3.77 | 1.17 | 5.96 | 3.91 | 0.87 | 1.16 |
| *DEC* | 4.84 | 1.74 | 7.12 | 4.85 | 0.97 | 1.25 |

The monthly wind statistics for Katsina is presented in Table 5. Monthly mean wind speed in Katsina vary from 2.256 m/s (September) to 5.034 m/s (January) and the monthly minimum wind speed ranges from 1.05 m/s (August) to 2 m/s (December). While, the monthly maximum wind speed range from 4.6 m/s in September to 8.6 m/s in January. Monthly median and standard deviation wind speed is seen to follow similar pattern with a range of 2.155 m/s in September to 5.075 m/s in January and 0.547 m/s in September and 1.2766 m/s in January, respectively. A range of 0.6775 (September) to 2.04 (March) is recorded for the inter quartile range for the study location. From observations, January and September are seen to be the months with the highest and lowest harvest of wind energy in this study location.

**Table 5 monthly wind statistics for Katsina**

| | *Mean* | *Min* | *Max* | *Median* | *SD* | *IQR* |
|---|---|---|---|---|---|---|
| *JAN* | 5.03 | 1.30 | 8.60 | 5.08 | 1.22 | 1.56 |
| *FEB* | 4.83 | 1.76 | 7.94 | 4.95 | 1.22 | 1.64 |
| *MAR* | 4.32 | 1.23 | 7.32 | 4.42 | 1.28 | 2.04 |
| *APR* | 3.74 | 1.41 | 6.73 | 3.63 | 1.21 | 1.84 |
| *MAY* | 3.52 | 1.69 | 7.98 | 3.35 | 1.02 | 1.32 |
| *JUN* | 3.54 | 1.51 | 6.16 | 3.43 | 0.88 | 1.06 |
| *JUL* | 3.14 | 1.30 | 6.47 | 3.15 | 0.87 | 1.31 |
| *AUG* | 2.60 | 1.05 | 4.80 | 2.55 | 0.78 | 1.08 |
| *SEP* | 2.26 | 1.24 | 4.60 | 2.16 | 0.55 | 0.68 |
| *OCT* | 2.69 | 1.33 | 5.19 | 2.49 | 0.88 | 1.38 |
| *NOV* | 3.81 | 1.12 | 5.95 | 3.90 | 0.86 | 1.11 |
| *DEC* | 4.788 | 2.00 | 7.06 | 4.88 | 0.97 | 1.23 |

The monthly wind statistic for Nguru is shown in Table 6. In this study location, monthly mean wind speed range from 2.31 m/s (September) to 4.84 m/s (January). It is observed that the monthly minimum wind speed for Nguru range from 0.95 m/s (August) to 1.91 m/s (February). This is the lowest among the study locations. A range of 4.46 m/s (September) to 7.95 m/s (March) is estimated as the monthly maximum wind speed for Nugru. The monthly median wind speed range from 2.22 m/s (September) to 4.90 m/s (January). A range of 0.55 (September) to 1.26 (March) is calculated as the monthly standard deviation. The inter-quartile range value range from 0.68 in September to 1.84 in April. It is also observed that January and September are seen to be the months with the highest and lowest harvest of wind energy in this study location.

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**Table 6 monthly wind statistics for Nguru**

| | *Mean* | *Min* | *Max* | *Median* | *SD* | *IQR* |
|---|---|---|---|---|---|---|
| *JAN* | 4.84 | 1.75 | 7.43 | 4.90 | 1.00 | 1.25 |
| *FEB* | 4.80 | 1.91 | 7.69 | 4.85 | 1.22 | 1.64 |
| *MAR* | 4.54 | 1.44 | 7.95 | 4.68 | 1.26 | 1.72 |
| *APR* | 4.00 | 1.12 | 7.35 | 3.93 | 1.21 | 1.84 |
| *MAY* | 3.45 | 1.26 | 6.09 | 3.32 | 0.93 | 1.17 |
| *JUN* | 3.50 | 1.47 | 5.90 | 3.41 | 0.88 | 1.06 |
| *JUL* | 3.22 | 1.27 | 6.16 | 3.18 | 0.86 | 1.19 |
| *AUG* | 2.52 | 0.95 | 5.05 | 2.43 | 0.77 | 1.03 |
| *SEP* | 2.31 | 1.16 | 4.46 | 2.22 | 0.55 | 0.68 |
| *OCT* | 2.75 | 1.27 | 5.23 | 2.45 | 0.90 | 1.38 |
| *NOV* | 3.99 | 1.15 | 5.86 | 4.06 | 0.86 | 1.11 |
| *DEC* | 4.73 | 1.48 | 6.89 | 4.75 | 0.85 | 1.13 |

The monthly mean wind speed for the study locations are presented in Figure 1. It is observed that the curves of the four study locations followed the same curve pattern with a depression from August to September. However, the wind speed curve for Damaturu is seen to slightly increase between the months of May and June of the rain season period. Hence, the likely possibility of harvest of more wind energy in Damaturu compare to other study locations. A steady increase is observed from October to December and January, before a steep decrease in May and a slight abruptly increase between May and June for all the study location. The steady increase period may be attributed to it being part of dry season period in Nigeria that is usually characterized with dry dusty wind from the Sahara Desert.

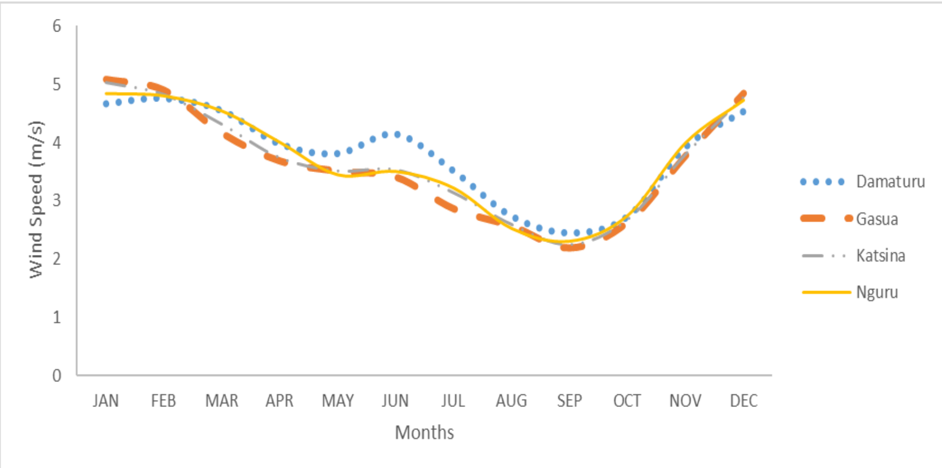


**Figure 1 monthly mean wind for the study locations**

## B. Wind Speed Characteristic Parameters

The wind speed characteristics for each month is presented in Tables 7 – 10 for the study locations. Weibull shape $(k)$ and scale $(c)$ are estimated with the use of Weibullness a contributed package in R statistical software. The characteristic parameters which include; most probable wind speed $(v_{mp})$, wind speed carrying maximum energy $(v_{max,E})$, mean wind power density $(P/A)$, and mean wind energy density $(E/A)$ are a function of the two parameters of Weibull.

The wind speed data for Damaturu reveals that the yearly $k$ and $c$ values are 5.01 and 4.16 m/s respectively, and the monthly values ranges from 3.87 – 5.01 and 2.65 – 4.16 m/s, respectively. In this study location, values of yearly most probable wind speed and wind carrying maximum energy are estimated at 3.97 m/s and 4.22 m/s, respectively. A yearly mean wind power density of 43.96 w/m$^2$ is estimated for the study location, where, the months of dry and rain season contributes 63.09 % and 36.91 % of a total mean wind power density of 527.55 W/m$^2$. This reveal the harvest more wind energy during the dry season period in the study location. It is expected

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because during the months of dry season dry and dusty harmattan wind flows into Nigeria from the Sahara Desert. An estimated yearly mean wind energy density of 379.84 KWh/m$^2$ is obtained, while, yearly a wind turbine installed in this location will harness 455.81 KWh/m$^2$ of wind energy.

**Table 7 wind speed characteristic parameters for Damaturu**

| | $k$ | $c$ $(m/s)$ | $v_{mp}$ $(m/s)$ | $v_{max,E}$ $(m/s)$ | $P/A$ $(W/m^2)$ | $E/A$ $(Wh/m^2)$ |
|---|---|---|---|---|---|---|
| *JAN* | 6.07 | 5.03 | 4.89 | 5.00 | 69.15 | 597455.23 |
| *FEB* | 5.44 | 5.17 | 4.98 | 5.08 | 75.11 | 648987.98 |
| *MAR* | 4.49 | 4.99 | 4.72 | 4.87 | 68.59 | 592648.44 |
| *APR* | 3.87 | 4.39 | 4.06 | 4.33 | 47.93 | 414096.35 |
| *MAY* | 4.45 | 4.18 | 3.95 | 4.19 | 40.41 | 349143.04 |
| *JUN* | 4.86 | 4.52 | 4.31 | 4.50 | 50.76 | 438533.92 |
| *JUL* | 5.00 | 3.82 | 3.65 | 3.92 | 30.49 | 263388.72 |
| *AUG* | 4.30 | 3.00 | 2.82 | 3.24 | 14.99 | 129525.32 |
| *SEP* | 5.33 | 2.65 | 2.55 | 3.02 | 10.17 | 87835.23 |
| *OCT* | 4.55 | 2.99 | 2.83 | 3.24 | 14.70 | 127027.20 |
| *NOV* | 5.38 | 4.27 | 4.11 | 4.30 | 42.30 | 365432.56 |
| *DEC* | 6.53 | 4.88 | 4.76 | 4.87 | 62.96 | 543983.05 |
| *Yearly* | 5.02 | 4.16 | 3.97 | 4.21 | 43.96 | 379838.09 |

The wind speed characteristics parameters forGausa is presented in Table 8. The monthly $k$ and $c$ values ranges from 3.64 – 5.53 and 2.40 – 3.99 m/s, respectively. While, the yearly values are 4.36 and 3.99 m/s, respectively. The values of most probable wind speed and wind carrying maximum energy are estimated at 3.75 m/s and 4.05 m/s, respectively. The yearly mean wind power density obtained for this study location is 42.28 W/m$^2$. A total of 507.34 W/m$^2$ of mean wind power density is estimated in this study location, where the months of dry season contributes 73.58 % and months of rain season contributes 26.42 % of the wind power density. It is observed that more wind energy will be harnessed in this study location during the dry season compared to Damaturu. An estimated yearly mean wind energy density of 365.29 KWh/m$^2$ is obtained, while, yearly a wind turbine installed in this location will harness 438.34 KWh/m$^2$ of wind energy

**Table 8 wind speed characteristic parameters for Gausa**

| | $k$ | $c$ $(m/s)$ | $v_{mp}$ $(m/s)$ | $v_{max,E}$ $(m/s)$ | $P/A$ $(W/m^2)$ | $E/A$ $(Wh/m^2)$ |
|---|---|---|---|---|---|---|
| *JAN* | 4.03 | 5.62 | 5.24 | 5.36 | 99.78 | 862064.96 |
| *FEB* | 4.27 | 5.38 | 5.05 | 5.19 | 86.52 | 747520.88 |
| *MAR* | 3.64 | 4.61 | 4.22 | 4.50 | 56.10 | 484689.04 |
| *APR* | 4.21 | 4.04 | 3.79 | 4.07 | 36.91 | 318868.74 |
| *MAY* | 4.78 | 3.83 | 3.65 | 3.92 | 30.84 | 266464.45 |
| *JUN* | 4.44 | 3.73 | 3.52 | 3.82 | 28.79 | 248755.68 |
| *JUL* | 4.50 | 3.13 | 2.96 | 3.35 | 17.022 | 147071.64 |
| *AUG* | 3.82 | 2.83 | 2.61 | 3.10 | 12.82 | 110798.55 |
| *SEP* | 4.48 | 2.40 | 2.27 | 2.82 | 7.66 | 66162.21 |
| *OCT* | 3.85 | 2.91 | 2.69 | 3.15 | 14.02 | 121121.21 |
| *NOV* | 4.79 | 4.12 | 3.93 | 4.15 | 38.47 | 332376.82 |
| *DEC* | 5.53 | 5.24 | 5.06 | 5.15 | 78.42 | 677527.64 |
| *Yearly* | 4.36 | 3.99 | 3.75 | 4.05 | 42.28 | 365285.15 |

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Table 9 presents the wind speed characteristic parameter for Katsina. The yearly value of $k$ and $c$ are 4.44 and 4.044 m/s, respectively. The $k$ and $c$ values for this study location ranges from 3.60 – 5.57 and 2.45 – 5.51, respectively. The values of most probable wind speed and wind carrying maximum energy are estimated at 3.81 m/s and 4.10 m/s, respectively. In this study location, the yearly mean power density is 42.90 W/m$^2$. A total 514.80 W/m2 of mean power density is estimated in Katsina, where the dry and rain seasons contributes 71.14 % and 28.86 %, respectively. An estimated yearly mean wind energy density of 370.66 KWh/m$^2$ is obtained, while, yearly a wind turbine installed in this location will harness 444.79 KWh/m$^2$ of wind energy.

**Table 9 wind speed characteristic parameters for Katsina**

| | $k$ | $c$ $(m/s)$ | $v_{mp}$ $(m/s)$ | $v_{max,E}$ $(m/s)$ | $P/A$ $(W/m^2)$ | $E/A$ $(Wh/m^2)$ |
|---|---|---|---|---|---|---|
| *JAN* | 4.60 | 5.51 | 5.23 | 5.33 | 92.31 | 797571.28 |
| *FEB* | 4.52 | 5.29 | 5.00 | 5.13 | 81.68 | 705712.05 |
| *MAR* | 3.83 | 4.77 | 4.41 | 4.65 | 61.74 | 533457.03 |
| *APR* | 3.60 | 4.15 | 3.79 | 4.12 | 41.14 | 355432.23 |
| *MAY* | 4.34 | 3.86 | 3.63 | 3.92 | 31.98 | 276303.63 |
| *JUN* | 4.88 | 3.86 | 3.68 | 3.94 | 31.42 | 271430.26 |
| *JUL* | 4.34 | 3.45 | 3.25 | 3.59 | 22.73 | 196390.95 |
| *AUG* | 3.98 | 2.87 | 2.66 | 3.13 | 13.25 | 114468.11 |
| *SEP* | 5.13 | 2.45 | 2.35 | 2.88 | 8.05 | 69583.36 |
| *OCT* | 3.71 | 2.98 | 2.74 | 3.20 | 15.11 | 130505.74 |
| *NOV* | 4.78 | 4.16 | 3.96 | 4.19 | 39.66 | 342694.24 |
| *DEC* | 5.57 | 5.18 | 5.00 | 5.10 | 75.74 | 654359.08 |
| *Yearly* | 4.44 | 4.04 | 3.81 | 4.10 | 42.90 | 370658.99 |

For Nguru, the wind speed characteristic parameter is presented in Table 10. The monthly values of $k$ and $c$ ranges from 3.45 – 6.072 and 2.495 – 5.242 m/s, respectively. While, the yearly mean values are 4.6576 and 4.0688 m/s. The values of most probable wind speed and wind carrying maximum energy are estimated at 3.848 m/s and 4.126 m/s, respectively. A total 517.43 W/m$^2$ of mean power density is estimated in this study location, where the dry and rain seasons contributes 69.82 % and 30.18 %, respectively. An estimated yearly mean wind energy density of 372.658 KWh/m$^2$ is obtained, while, yearly a wind turbine installed in this location will harness 447.791 KWh/m$^2$ of wind energy. This reveal that a slight more wind energy is likely to be harnessed in Nguru compared to Katsina. However, during the dry season, slightly more wind energy will be harvested in Katsina compared to Nguru

**Table 10 wind speed characteristic parameters for Nguru**

| | $k$ | $c$ $(m/s)$ | $v_{mp}$ $(m/s)$ | $v_{max,E}$ $(m/s)$ | $P/A$ $(W/m^2)$ | $E/A$ $(Wh/m^2)$ |
|---|---|---|---|---|---|---|
| *JAN* | 5.49 | 5.24 | 5.05 | 5.15 | 78.40 | 677366.86 |
| *FEB* | 5.15 | 5.22 | 5.00 | 5.11 | 77.55 | 670015.60 |
| *MAR* | 3.95 | 5.01 | 4.66 | 4.85 | 71.12 | 614484.10 |
| *APR* | 3.45 | 4.45 | 4.03 | 4.35 | 51.23 | 442617.88 |
| *MAY* | 4.49 | 3.77 | 3.57 | 3.86 | 29.68 | 256430.99 |
| *JUN* | 4.85 | 3.82 | 3.64 | 3.91 | 30.56 | 264033.11 |
| *JUL* | 4.49 | 3.52 | 3.33 | 3.65 | 24.14 | 208599.17 |
| *AUG* | 3.97 | 2.78 | 2.58 | 3.07 | 12.11 | 104669.00 |
| *SEP* | 5.58 | 2.50 | 2.41 | 2.92 | 8.45 | 72991.47 |
| *OCT* | 3.72 | 3.05 | 2.80 | 3.25 | 16.14 | 139434.48 |
| *NOV* | 4.69 | 4.38 | 4.16 | 4.36 | 46.19 | 399060.35 |
| *DEC* | 6.07 | 5.10 | 4.95 | 5.04 | 71.86 | 620900.30 |
| *Yearly* | 4.66 | 4.07 | 3.85 | 4.13 | 43.12 | 372550.28 |

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### C. Validation of Weibullness

To validate the R programming contributed package called Weibullness used in this study to determine the values of $k$ and $c$ as given in Tables 7 - 10. The percentage error of the monthly mean wind speed estimated from Equation 9 and monthly mean wind speed estimated from the Weibull parameters of Equation 10 are calculated from

$$\%\, error = \frac{v_p - v_{md}}{v_{md}}\, x\, 100 \qquad (11)$$

Figure 2 presents the percentage error of the monthly mean wind speed for each study location. It is observed that different degree of percentage error exists in each month and study location, either positive or negative. The values of the percentage error in all the study location ranges from -0.52 to 0.38 %. The variation that resulted to percentage error may be attributed to computer approximation method and the value of offset fraction used in the Weibull.np code to determine the shape and scale parameter. Hence, considering the range of the percentage error estimated, it is adjudged that the Weibullness R contributed package performed excellently well in the determination of the two parameters of Weibull.

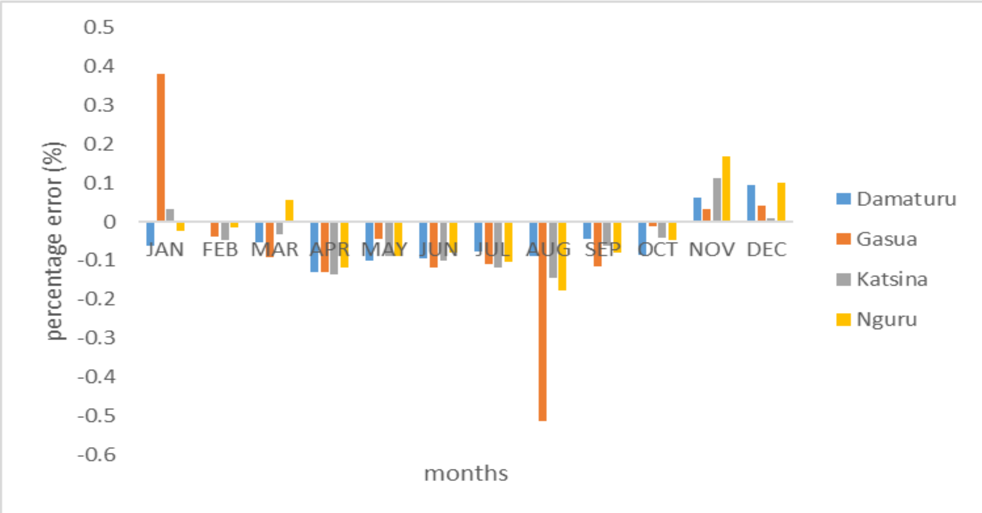


Figure 2 percentage error

## V. Conclusion:

Statistical and characteristic parameters of wind speed data for four study location in Nigeria has been carried out. The effect of outliers in wind speed data require special attention. Such values are most likely to have effect on the mean wind speed. It is shown that Weibullness package in R statistical programme is an excellent resource in the estimation of the two parameters of Weibull.

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