International Research Journal of Pure and Applied Physics, 11 (2),1-23, 2024
ISSN 2055-009X(Print)
ISSN 2055-0103(Online)
Website: https://www.eajournals.org/
Publication of the European Centre for Research Training and Development -UK

# Goodness of Fit Test for Wind Energy Potential Using Five Distribution Functions for Some Selected in Nigeria

**P.J. Manga[1], A. A. Bello[2], F.W. Burari[3], A. Tijjani[4]**
[1] Department of Physics, University of Maiduguri, Borno State – Nigeria
[2]Department of Mechanical Engineering, Abubakar Tafawa Balewa University, Bauchi, Bauchi State – Nigeria
[3&42]Department of Physics, Abubakar Tafawa Balewa University, Bauchi, Bauchi State – Nigeria
Corresponding author mail; 2016peterjohn@gmail.com

doi: : https://doi.org/10.37745/irjpap.13vol11n2123 Published November 26, 2024

**Citation**: Manga P.J., Bello A.A., Burari F.W., Tijjani A. (2024) Goodness of Fit Test for Wind Energy Potential Using Five Distribution Functions for Some Selected in Nigeria, *International Research Journal of Pure and Applied Physics*, 11 (2),1-23

**Abstract**: *This study focused on goodness of fit test of wind energy potentials for Katsina, Sokoto, Bauchi, Maiduguri, Abuja, Jos, Abeokuta, Lagos, Enugu, Owerri, Calabar and Benin City respectively. Twenty Years (2000-2020) average wind speed data obtained from National Aeronautics and Space Administration (NASA), website using a Renewable Energy Online Software REXSCREEN were analysed. The wind speed data for the selected stations was fitted with five distribution functions such as (normal, Weibull, Rayleigh, lognormal and Gamma Function) with fixed shape parameter (K), but different scale parameters (C). The results of goodness of fit test based on Kolmogorov-Smirnov and Anderson – Darling; shows that all the probability distribution functions are accepted at maximum difference, $D_n$ less than their critical values, $D_n^{0.05}$ (= 0.0853 and 0.0855). While in the AD tests, all the distribution functions hold except lognormal distribution function which is satisfactory for Jos and Abuja with an observed significant level (OSL) ranging from (0.7497 - 0.7497). Therefore, in computing wind power density of the selected cities, the power density empirical model based on normal distribution can be used for Katsina, Sokoto, Bauchi, Maiduguri, Abeokuta, Lagos, Enugu, Owerri, Calabar and Benin city respectively, while in Jos and Abuja, power density based on lognormal can be used for the purpose of surface wind electrification.*

**Keywords:** Goodness of fit test; A-D test; K-S Test; Wind Power Potential; Normal Distribution; Weibull Distribution; Rayleigh Distribution; Log-Normal Distribution; Gamma Distribution.

## INTRODUCTION

Due to high-cost fossil fuel, its health hazard and related greenhouse gases cases made renewable energy resources more attractive as a source of alternative energy to meeting the energy demand of our country Nigeria Ramirez, P., and Carta, J. A. (2OO5). On the other hand, for the past decade fossil fuel is finite and recorded as the world source of energy its consumption which is on an increased daily. Gupta, A. K., (1997) and thus, wind energy which is a clean source of energy, available throughout all seasons are of great interest in this work. Moreover, wind power provides power generation by converting kinetic energy of the wind through rotating shaft near load centres and lower transmission losses on lines passing through remote areas Gupta, A. K., (1997) North – East and North – West of Nigeria, has an enormous wind energy potential in terms of wind power generations (Ucar and Balo 2009, Genç *et, al.,* 2012a, 2012b), due to its geographical features and semi-arid region with enormous sun (solar radiation for 4-5hours daily (Jowder 2009).

Statistical analysis of wind speed is plays important role for structures, designing, and power generators and helps investors to have enough knowledge on characteristics of wind speed, wind generation, wind directions are important of any given location for perfect installation of wind farms (Ozgener 2010) and (Genç and Gökçek 2009, Genç 2011). Wind analysis also provides valuable information for researchers in this field (Eskin *et, al.*, 2008). In assessing the effects and the effect of regional wind on structure is achieved whenever analysis of basic wind speed data were properly done (Lagomarsino *et, al.*, 1999, Quan *et, al.*, 2017). Also, basic wind characteristics measured at the field are important component of wind turbine constructions (Zidong *et, al.*, 2017). This assessment reduces the Damage caused by extreme wind events to the wind turbine component in any potential site (Elshaer *et, al.*, 2019).

The forces induced by the wind are of great impact of the aerodynamic performance of the small or large scale wind turbine / wind farm (Ke et al. 2019). It is difficult to predict wind pattern of a place without the measured wind speed data of such location, due to nonlinear and fluctuation characteristics (Ye *et, al.*, 2019). So, many researchers predict that the main wind data is generally considered to be Weibull probability distribution satisfactory (Harris *et, al.*, 2006). However, this may fit into different probability distributions among the five probability distribution functions such as Weibull, Rayleigh, normal, gamma, lognormal, logistic according to the variability of wind speeds in different regions. In Nigeria, many studies were carryout on aerodynamic analysis, wind characteristics, cost analysis estimation and evaluation of wind potential for different locations across the country. Bajic and Peros (2005). It was reported by Asiegbu and Iwuoha (2007) studied the wind resource availability in Umudike, South-East, Nigeria using 10 years (1994–2003) of wind speed data. They found that the economic viability of the site required a hub height of 65 m above the ground with an annual mean wind speed of 5.36 m/s.

Fadare (2008) carried out a statistical analysis of wind energy potential in Ibadan, using a Weibull distribution function on 10 years (1995–2004) of daily wind speed data. The outcome showed that the city experienced an average wind speed and power density of 2.947 m/s and 15.484 W/m2. Ogbonnaya *et, al.* (2009), on the other hand, worked on the prospects of wind energy in Nigeria. Four years' wind data from six cities (Enugu, Jos, Ikeja, Abuja, Warri, and Calabar) cutting across the different geopolitical zones of the federation were employed. The outcome showed that the annual wind speed at 10 m height for the cities varied from 2.3 to 3.4 m/s for sites along the coastal areas and 3.0–3.9 m/s for high land areas and semi-arid regions. Also, Ngala *et, al*. (2007) did a statistical analysis of the wind energy potential in Maiduguri (Borno State). It employed the Weibull distribution with 10 years (1995–2004) of wind data. Further reports on the various assessment studies both by researchers and government agencies are profiled in (Ajayi, 2009).

In the present research, wind data such as speeds of the two selected stations were investigated by using statistical analysis for four different locations (Katsina, Sokoto, Bauchi and Maiduguri). The wind speed time series were analysed annually. Furthermore, to check among the five distributions functions which one is bet fit for electrification in the selected cities (Normal, Weibull, Rayleigh, Gamma and lognormal distribution functions).

## MATERIALS AND METHODS

Wind speed measurements have great importance in analysing the wind potential of a given region. The other important parameters are speed distribution, meteorological statistics and topographical data (Ajayi, 2009). Time series of wind speed is more suitable for statistical analysis Ngala *et, al*. (2007). The time series of wind speed are analysed annually based on five probability density functions, namely Weibullx Rayleigh, Normal, Log`-Normal and Gamma distributions were selected for the estimation of wind speed in Katsina, Sokoto, Bauchi, Maiduguri, Abuja, Jos, Abeokuta, Lagos, Enugu, Owerri, Calabar and Benin city respectively.

**Table 1: Geographical data for the locations in Nigeria.**

| Locations | State | LAT (N) | LONGITUDE (E) | ALTITUDE (M) | ALTITUDE (FT) |
|---|---|---|---|---|---|
| KATSINA | KATSINA | $12^{0}59'7$ | $7^{0}37'1$ | 513 | 1683 |
| SOKOTO | SOKOTO | $13^{0}3'5$ | $5^{0}13'45$ | 272 | 895 |
| BAUCHI | BAUCHI | $10^{0}18'57$ | $9^{0}50'39$ | 615 | 2020 |
| MAIDUGURI | BORNO | $11^{0}50'47$ | $13^{0}9'37$ | 299 | 984 |
| ABUJA | ABUJA | $9^{0}15'0$ | $6^{0}55'60$ | 246 | 810 |
| JOS | PLATEAU | $9^{0}55'0$ | $8^{0}54'$ | 1217 | 3996 |
| ABEOKUTA | OGUN | $7^{0}9'0$ | $3^{0}21'0$ | 66 | 219 |
| LAGOS | LAGOS | $6^{0}27'11$ | $3^{0}23'45$ | 34 | 114 |
| ENUGU | ENUGU | $6^{0}26'25$ | $7^{0}29'39$ | 247 | 813 |
| OWERRI | IMO | $5^{0}28'60$ | $7^{0}1'60$ | 158 | 521 |
| CALABAR | CROSSRIVER | $4^{0}34'27$ | $6^{0}58'33$ | 380 | 1249 |
| BENIN CITY | EDO | $6^{0}20'21$ | $5^{0}37'2$ | 122 | 400 |

**Goodness-of-fit Test**

When a model of a random phenomenon has display to be of a particular probability distribution, is determined perhaps on the basis of available data plotted on a given probability paper, or through visual inspection of the shape of the histogram, the validity of the specified or assumed distribution model may be verified or disproved statistically by goodness-of-fit tests (Chang & Tu, 2007). In this study we used two goodness of fit test. The Kolmogorov-Smirnov (or K-S Test), and the Anderson-Darling (or A-D Test) methods; this two methods may be used to validate a specified or assumed probability distribution model. When two (or more) distributions appear to be credible models, the same test may be used also to distinguish the relative high quality between (or among) the assumed distribution models (Chang and Tu, 2007).

**Kolmogorov-Smirnov (K-S) Test for Goodness-of-Fit**

Kolmogorov-Smirnov (K-S test) is another widely used goodness-of-fit test. The basic of K-S Test is to compare the maximum difference between experimental cumulative frequencies with that of the CDF of an assumed theoretical distribution. If the maximum discrepancy is large than the normal

ISSN 2055-009X(Print)
ISSN 2055-0103(Online)


expected for a given sample size, the proposed model will not be accepted for the modelling of the underlying population. On the other hand, if the discrepancy is less than a critical value, the proposed model will be accepted at significance level α (Aidan and Ododo, 2010).

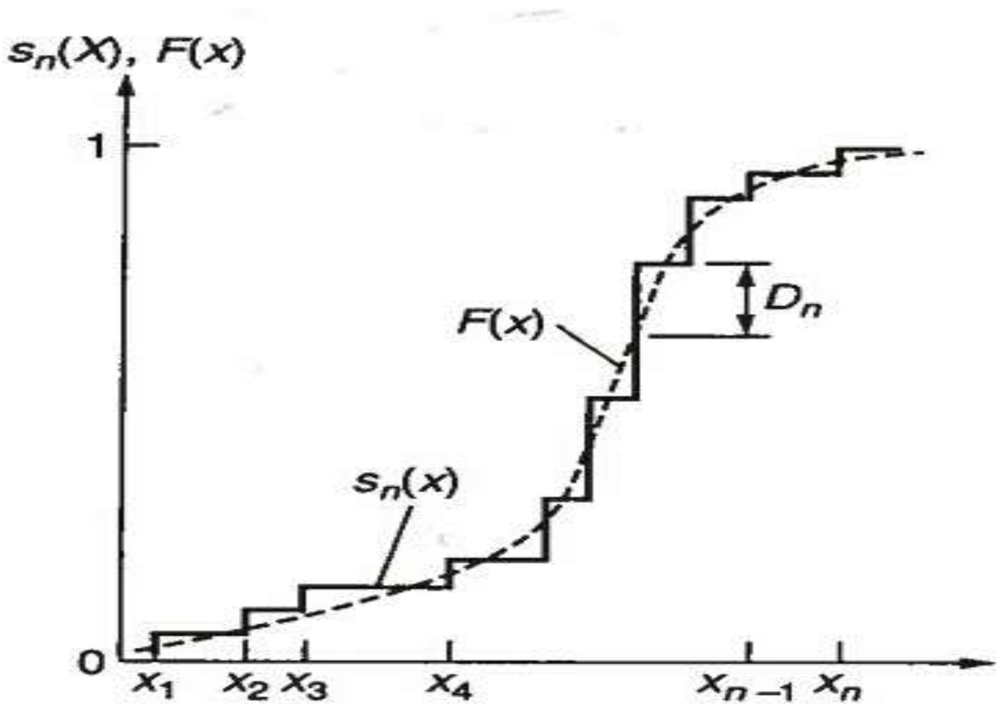



Figure 2 Empirical Cumulative Frequency versus Theoretical CDF. (Chand and Tu, 2007)

The set of the observed data is rearranged, for a given sample of size (n). From this ordered set of sample data, a step by step experimental cumulative frequency function is developed as given by equation (2.53) (Aidan and Ododo, 2010) as:

$$S_n(x) = \begin{cases} 0 & x \geq x_n \\ \frac{K}{n} & x_K \leq x < x_{k+1} \\ 1 & x \geq x_n \end{cases} \quad \ldots (2.1)$$

Where $x_1, x_2, \ldots, x_n$the observed ordered set of the data of a given sample size (n). it was also shown in figure 1 which is a step-function plot of $S_n$ with an assumed theoretical CDF $F_X(x)$ . In the K-S test, the maximum difference between $S_n(x)$ and $F_X(x)$ over the entire observed data.

$$D_n = max\left|F_x - S_{n(x)}\right| \qquad \ldots (2.2)$$

Theoretically, in K-S test $D_n$ the compares the observed maximum difference at significance level α as in equation (2.2) and equation (2.3) at critical value$D_n^{\alpha}$:

$$P(D_n \le D_n^{\alpha}) = 1 - \alpha \qquad \ldots (2.3)$$

In this case if the observed data is less than the critical value $D_n^{\alpha}$ , the proposed theoretical distribution is acceptable at the specified significance level α; otherwise, the assumed theoretical distribution would be rejected.

**Anderson-Darling (A-D) Test for Goodness-of-Fit**

In (1954) Anderson-Darling (A-D) introduced (A-D) goodness-of-fit test in other to place more weight or discriminating power at the tails of distribution. This can be important when the tails of a selected theoretical distribution are of practical significance. Below steps are required when applying A-D method as follows:

i. Arrange the observed data in an increasing order: $x_1, x_2 \ldots\ldots..x_i, \ldots\ldots..x_n$, with $x_n$ as the largest value.
ii. Evaluate the proposed distribution $F_X(x_i)$ at $x_i$, for $i = 1.2, \ldots.n$.
iii. A-D statistics is done by the given equation

$$A = -\sum_{i=1}^{n}\left[\left(\frac{(2i-1)}{n}\right)\{\ln F_X(x_i) + \ln[1 - F_X(x_{n+1-i})]\}\right] - n \qquad \ldots (2.4)$$

i. Firstly compute the adjusted test statistic $A^*$ which will account the effect of the sample size n. this adjustment is done based on the selected form of distribution.
ii. Select a significance level α under a determined critical value $C_\alpha$ for the appropriate distribution type.
iii. For a given distribution, compare $A^*$ with the appropriate critical value $C_\alpha$. In the case that $A^*$ is less than $C_\alpha$, the proposed distribution is acceptable at the significance level $\alpha$, if $n > 7$.

For normal distribution, the critical value $C_\alpha$ is given by equation (2.5), (Chang and Tu, 2007) as:

$$C_\alpha = a_\alpha\left(1 + \frac{0.75}{n} + \frac{2.25}{n^2}\right) \quad \dots (2.5)$$

And the adjusted A-D statistic for normal distribution of a sample size n is given by (Chang and Tu, 2007) as:

$$A^* = A\left(\frac{0.75}{1+\frac{0.75}{n}+\frac{2.25}{n^2}}\right) \quad \dots (2.6)$$

In the case of gamma distribution, the critical value of $C_\alpha$ depends on the parameter k as given by equation (2.59) (Chang and Tu, 2007) as:

$$A^* = A^2\left(1.0 + \frac{0.6}{n}\right), \qquad For\ k = 1 \quad \dots (2.7)$$

$$A^* = A^2 + \frac{\left(0.2+\frac{0.3}{K}\right)}{n} \;, \qquad For\ k \geq 2 \quad \dots (2.8)$$

For the extremal distributions, of Gumbel and Weibull types, the adjusted A-D statistic is given by equation (2.61) (Chang and Tu, 2007) as:

$$A^* = A\left(1.0 + 0.2/\sqrt{n}\right) \quad \dots (2.9)$$

**Distribution Functions**

Five different distribution functions used in this research are: Weibull, *f(v)*, Rayleigh, *R(v)*, normal, *n(f)*, gamma, *g(v)*, lognormal, *l(v)* and their probability density function (PDF) express for the $i^{th}$ wind speed, $v_i$ are given by (Aidan, 2010):

$$f(v) = \left(\frac{k}{c}\right)\left(\frac{v_i}{c}\right)^{k-1} e^{\left[-\left(\frac{v_i}{c}\right)^k\right]} \qquad v \geq 0\,; k, c\ > 0 \quad \dots (2.10)$$

$$R(v) = \frac{2}{c^2} v_i e^{\left[-\left(\frac{v_i}{c}\right)^2\right]} \qquad v\ \geq 0, c > 0 \quad \dots (2.11)$$

$$n(v) = \frac{1}{\sigma\sqrt{2\pi}} e^{\left[-\frac{1}{2}\left(\frac{v_i - \mu}{\sigma}\right)^2\right]} \qquad 0 \leq v \leq \infty \qquad \ldots (2.12)$$

$$g(v) = \frac{v_i^{\alpha-\beta}}{\beta^{\alpha}\Gamma(\alpha)} e^{\left[\frac{v_i}{\beta}\right]} \qquad \alpha, \beta, v > 0 \qquad \ldots (2.13)$$

$$l(v) = \frac{1}{\sigma\sqrt{2\pi v_i}} e^{\left[\frac{[\ln(v_i - \mu)]^2}{2}\right]} \qquad 0 \leq v \leq \infty \qquad \ldots (2.14)$$

Where k, c, σ, μ, α, β and are the distribution function parameters.

A widely accepted empirical relation for the values of $k$ and $c$ are given by equation (2.15) and (3.7) Luna and Church (1974), Garcia *et al.* 1998).

$$k = \left(\frac{\sigma}{\bar{v}}\right)^{-1.086} \qquad \ldots (2.15)$$

$$c = \bar{v}\frac{k^{2.6674}}{0.184 + 0.816k^{2.73859}} \qquad \ldots (2.16)$$

Where $\sigma$ is the standard deviation and $\bar{v}$ is annual mean wind speed for the selected site.

## RESULTS AND DISCUSSIONS

### Kolmogorov- Smirnov and Anderson Darling Goodness of Fit Test

It is clear that from Table (2-4) that the wind speed distributions shows that Katsina, Sokoto, Bauchi, Maiduguri, Abuja, Abeokuta, Lagos, Enugu, Owerri, Calabar and Benin City are fitted by normal distribution functions at 5% significant level while Jos is well fitted by lognormal distribution function at 5% significance level. The selected stations have shown that, all the accepted probability distribution functions have their values less than the KS test, similarly both values of their maximum difference, $D_n$ less than their critical values, $D_n^{0.05}$ (= 0.0853 and 0.0855). The AD tests, though distribution specific, lognormal and distribution function are satisfactory for Jos and Abuja, while normal, Weibull and Rayleigh distribution function only can be satisfactory for Katsina, Sokoto, Bauchi, Maiduguri, Abuja, Abeokuta, Lagos, Enugu, Owerri, Calabar and Benin City. This shows that AD $<$ CV in the case of distributions function for both stations were accepted at observed significant level (OSL) (0.7497 and 0.7497). With the favourable KS and AD test result together in table **(2-4),** with Figure **(2-4),** the wind speed distributions for Katsina, Sokoto, Bauchi, Maiduguri, Abuja, Abeokuta, Lagos, Enugu, Owerri, Calabar and Benin City can be satisfactory represented by normal distribution function while Lognormal can be satisfactory for Jos.

**Table 2: Goodness-of-Fit Test Results for Sokoto, Katsina, Bauchi and Maiduguri**

| Stations | Distribution function | Kolmogorov-Smirnov test $D_n$ | Decision rule | Anderson-Darling test Test value | CV | Decision rule |
|---|---|---|---|---|---|---|
| Sokoto | Weibull | 0.0617 | Accept | $2.689 \times 10^{-17}$ | 0.7497 | Reject |
| | Rayleigh | 0.2000 | Accept | $8.332 \times 10^{-12}$ | 0.7498 | Reject |
| | Normal | 0.0688 | Accept | 0.0037 | 0.7497 | Accept |
| | Gamma | 0.9998 | Reject | $1.945 \times 10^{-5}$ | 0.7497 | Reject |
| | Lognormal | 0.0986 | Reject | $3.138 \times 10^{-43}$ | 0.7497 | Reject |
| | CV | 0.0855 | | | | |
| Katsina | Weibull | 0.0499 | Accept | 0.0058 | 0.7498 | Accept |
| | Rayleigh | 0.2455 | Reject | $3.103 \times 10^{-11}$ | 0.7498 | Reject |
| | Normal | 0.0629 | Accept | 0.0047 | 0.7498 | Accept |
| | Gamma | 0.9997 | Reject | $2.4922 \times 10^{-93}$ | 0.7498 | Reject |
| | Lognormal | 0.0897 | Reject | $7.0972 \times 10^{-5}$ | 0.7498 | Reject |
| | CV | 0.0853 | | | | |
| Bauchi | Weibull | 0.0739 | Accept | 0.00018 | 0.7497 | Accept |
| | Rayleigh | 0.2721 | Accept | $5.0571 \times 10^{-13}$ | 0.7497 | Reject |
| | Normal | 0.0637 | Accept | $2.1506 \times 10^{-26}$ | 0.7497 | Reject |
| | Gamma | 1.000 | Reject | --- | --- | --- |
| | Lognormal | 0.0685 | Accept | 0.00306 | 0.749 | Accept |
| | CV | 0.0855 | | | | |

International Research Journal of Pure and Applied Physics, 11 (2),1-23, 2024
ISSN 2055-009X(Print)
ISSN 2055-0103(Online)
Website: https://www.eajournals.org/
Publication of the European Centre for Research Training and Development -UK

| | | | | | | |
|---|---|---|---|---|---|---|
| Maiduguri | Weibull | 0.0699 | Accept | 0.00331 | 0.749 | Accept |
| | Rayleigh | 0.2205 | Reject | $1.101 \times 10^{-12}$ | 0.749 | Reject |
| | Normal | 0.0752 | Accept | 0.00063 | 0.749 | Accept |
| | Gamma | 0.8233 | Reject | --- | --- | --- |
| | Lognormal | 0.1137 | Reject | $5.6739 \times 10^{-75}$ | 0.749 | Reject |
| | CV | 0.0855 | | | | |

**Table 3: Goodness-of-Fit Test Results for Plateau, Abuja, Lagos and Abeokuta**

| | | | | | | |
|---|---|---|---|---|---|---|
| Plateau | Weibull | 0.1458 | Reject | $3.9071 \times 10^{-8}$ | 0.7498 | Reject |
| | Rayleigh | 0.2737 | Reject | $1.878 \times 10^{-11}$ | 0.7498 | Reject |
| | Normal | 0.1531 | Reject | $4.174 \times 10^{-8}$ | 0.7498 | Reject |
| | Gamma | 0.9998 | Reject | $8.778 \times 10^{-106}$ | 0.7498 | Reject |
| | Lognormal | 0.0045 | Accept | 0.0037 | 0.7498 | Accept |
| | CV | 0.0853 | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| Abuja | Weibull | 0.0482 | Accept | 0.00916 | 0.749 | Accept |
| | Rayleigh | 0.3115 | Reject | $1.7536 \times 10^{-16}$ | 0.749 | Reject |
| | Normal | 0.0357 | Accept | 0.12224 | 0.749 | Reject |
| | Gamma | 0.9872 | Reject | 0.00031 | 0.749 | Accept |
| | Lognormal | 0.0665 | Accept | 0.0134 | 0.749 | Accept |
| | CV | 0.0855 | | | | |
| Lagos | Weibull | 0.0655 | Accept | 0.00233 | 0.749 | Accept |
| | Rayleigh | 0.2810 | Reject | 7.090 x 10-15 | 0.749 | Reject |
| | Normal | 0.0581 | Accept | 0.00901 | 0.749 | Reject |
| | Gamma | 1.0000 | Reject | --- | --- | --- |
| | Lognormal | 0.0614 | Accept | 0.00107 | 0.749 | Accept |
| | CV | 0.0855 | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| Abeokuta | Weibull | 0.0024 | Accept | 0.0589 | 0.749 | Accept |
| | Rayleigh | $8.37\text{x } 10^{-16}$ | Reject | 0.7438 | 0.749 | Accept |
| | Normal | 0.0326 | Accept | 0.0479 | 0.749 | Accept |
| | Gamma | --- | --- | 1.000 | 0.749 | Reject |
| | Lognormal | 0.0052 | Accept | 0.0521 | 0.749 | Accept |
| | CV | 0.0855 | | | | |

**Table 4: Goodness-of-Fit Test Results for Owerri, Benin City, Enugu and Cross River**

| | | | | | | |
|---|---|---|---|---|---|---|
| Owerri | Weibull | 0.0889 | Accept | $4.087 \text{ x } 10^{-5}$ | 0.7498 | Reject |
| | Rayleigh | 0.3239 | Reject | $9.904 \text{ x } 10^{-17}$ | 0.7498 | Reject |
| | Normal | 0.0632 | Accept | 0.0037 | 0.7498 | Accept |
| | Gamma | 1.0000 | Reject | --- | --- | --- |
| | Lognormal | 0.0489 | Accept | 0.0264 | 0.7498 | Accept |
| | CV | 0.0853 | | | | |
| Benin City | Weibull | 0.0901 | Reject | 0.0012 | 0.7498 | Accept |
| | Rayleigh | 0.3378 | Reject | $1.224 \text{ x } 10^{-17}$ | 0.7498 | Reject |
| | Normal | 0.0661 | Accept | 0.0044 | 0.7498 | Accept |
| | Gamma | 0.9800 | Reject | 1.000 | 0.7498 | Reject |
| | Lognormal | 0.0499 | Accept | 0.0489 | 0.7498 | Accept |
| | CV | 0.0853 | | | | |
| Enugu | Weibull | 0.0437 | Accept | $4.087 \text{ x } 10^{-5}$ | 0.7498 | Accept |
| | Rayleigh | 0.2786 | Reject | $9.904 \text{ x } 10^{-17}$ | 0.7498 | Reject |
| | Normal | 0.0619 | Accept | 0.0037 | 0.7498 | Accept |
| | Gamma | 1.0000 | Reject | --- | --- | --- |
| | Lognormal | 0.0944 | Reject | 0.0264 | 0.7498 | Accept |

ISSN 2055-009X(Print)
ISSN 2055-0103(Online)
Website: https://www.eajournals.org/
Publication of the European Centre for Research Training and Development -UK

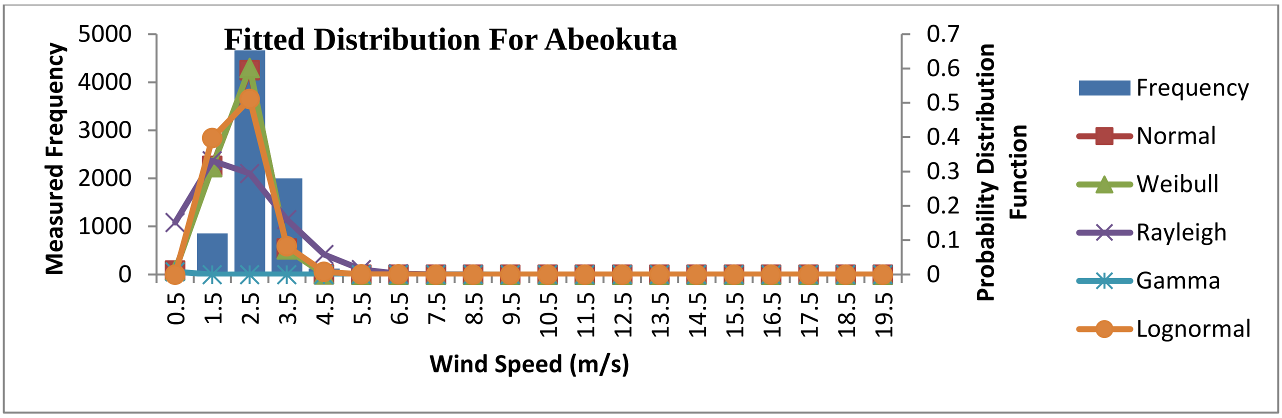
| | | | | | | |
|---|---|---|---|---|---|---|
| | CV | 0.0853 | | | | |
| Cross-River | Weibull | 0.0593 | Accept | 5.1902 x $10^{-8}$ | 0.7498 | Reject |
| | Rayleigh | 0.3198 | Reject | 3.3520 x $10^{-17}$ | 0.7498 | Reject |
| | Normal | 0.0419 | Accept | 7.8265 x $10^{-6}$ | 0.7498 | Reject |
| | Gamma | --- | --- | --- | --- | --- |
| | Lognormal | 0.0835 | Reject | 0.00025 | 0.7498 | Accept |
| | CV | 0.0853 | | | | |

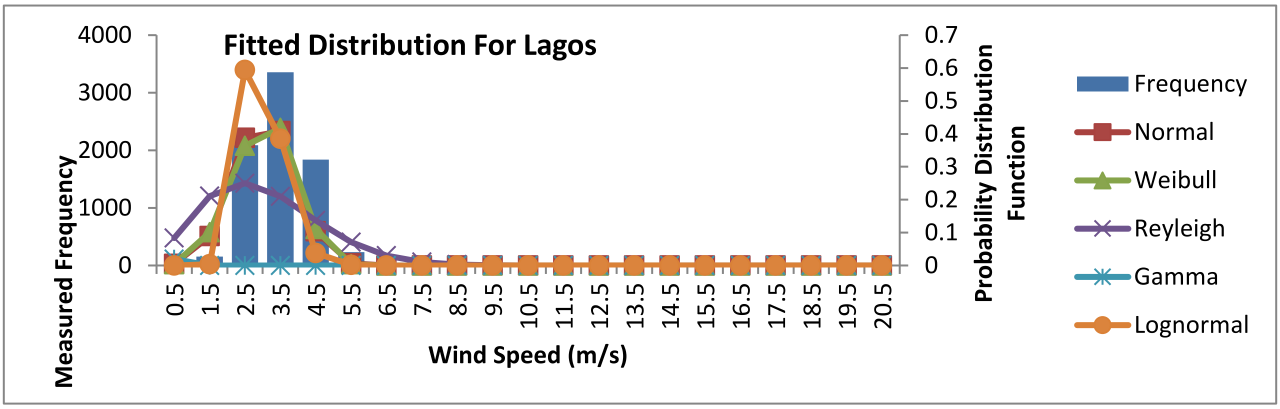
**Wind Speed Data and Frequency Distribution Analysis**

The sample estimated parameters of the distribution functions are presented in Table 2. Figure **(2-4)** shows the fitted probability distribution functions (PDF) onto the constructed frequency diagram of the observed wind speed data for Katsina, Sokoto, Bauchi, Maiduguri, Abuja, Jos, Abeokuta, Lagos, Enugu, Owerri, Calabar and Benin City respectively. It was also shown from Figure **(2-4)** only on the plots of probability distribution functions it could be seen that normal distribution function is the most fitted function onto the constructed data histograms across the above mentioned state. These are validated by the statistical goodness-of-fit test results in Table (2-4).

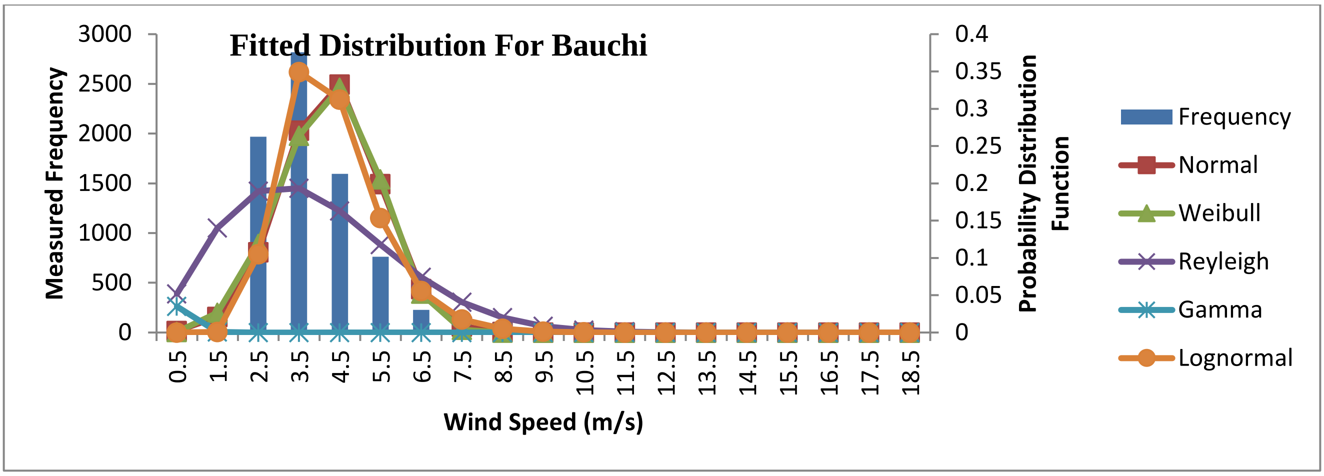
**Table 5** Estimated parameters for the five distribution functions across six geopolitical zones

| Stations | Weibull | | Normal | | Lognormal | | Gamma | | Rayleigh | |
|---|---|---|---|---|---|---|---|---|---|---|
| | K | C | μ | σ | μ | σ | α | β | K | C |
| Abuja | 7.1977 | 2.2242 | 2.0908 | 0.3396 | 0.7245 | 0.1613 | 0.0263 | 0.0552 | 2 | 2.3592 |
| Plateau | 1.9945 | 3.5653 | 3.1599 | 1.6733 | 1.0269 | 0.4971 | 0.2804 | 0.8861 | 2 | 3.5655 |
| Abeokuta | 4.0982 | 2.4647 | 2.2342 | 0.6095 | 0.7679 | 0.2679 | 0.0744 | 0.1663 | 2 | 2.5210 |
| Bauchi | 4.0590 | 4.6707 | 4.2858 | 1.1797 | 1.4187 | 0.2702 | 0.0757 | 0.3247 | 2 | 4.3563 |
| Maiduguri | 4.7009 | 3.9629 | 3.6221 | 0.8710 | 1.2589 | 0.2370 | 0.0578 | 0.2094 | 2 | 4.0871 |
| Katsina | 4.1191 | 3.5796 | 3.2457 | 0.8814 | 1.1417 | 0.2667 | 0.0737 | 0.2394 | 2 | 3.6624 |
| Sokoto | 2.5435 | 3.8445 | 3.4113 | 1.4441 | 1.1446 | 0.1648 | 0.1791 | 0.6113 | 2 | 3.8492 |
| Lagos | 4.0397 | 0.8394 | 3.0363 | 0.8394 | 0.1919 | 1.0738 | 0.2321 | 0.0764 | 2 | 3.4261 |
| Cross-River | 4.9935 | 1.9489 | 1.7881 | 0.4067 | 0.5559 | 0.2245 | 0.0517 | 0.0925 | 2 | 2.0176 |
| Owerri | 4.4398 | 2.4883 | 2.2664 | 0.5744 | 0.7870 | 0.2495 | 0.0642 | 0.1455 | 2 | 2.5573 |
| Enugu | 3.7469 | 2.9603 | 2.6698 | 0.7911 | 0.9399 | 0.2901 | 0.0878 | 0.2344 | 2 | 3.0126 |
| Edo | 3.9095 | 2.5055 | 2.2983 | 0.6549 | 0.7931 | 0.2794 | 0.0811 | 0.1866 | 2 | 2.3362 |


Fitted Distribution For Abeokuta
Measured Frequency
5000
4000
3000
2000
1000
0
Probability Distribution Function
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.5 1.5 2.5 3.5 4.5 5.5 6.5 7.5 8.5 9.5 10.5 11.5 12.5 13.5 14.5 15.5 16.5 17.5 18.5 19.5
Wind Speed (m/s)
Frequency
Normal
Weibull
Rayleigh
Gamma
Lognormal


Fitted Distribution For Lagos
Measured Frequency
4000
3000
2000
1000
0
Probability Distribution Function
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.5 1.5 2.5 3.5 4.5 5.5 6.5 7.5 8.5 9.5 10.5 11.5 12.5 13.5 14.5 15.5 16.5 17.5 18.5 19.5 20.5
Wind Speed (m/s)
Frequency
Normal
Weibull
Reyleigh
Gamma
Lognormal

ISSN 2055-009X(Print)
ISSN 2055-0103(Online)
Website: https://www.eajournals.org/
Publication of the European Centre for Research Training and Development -UK



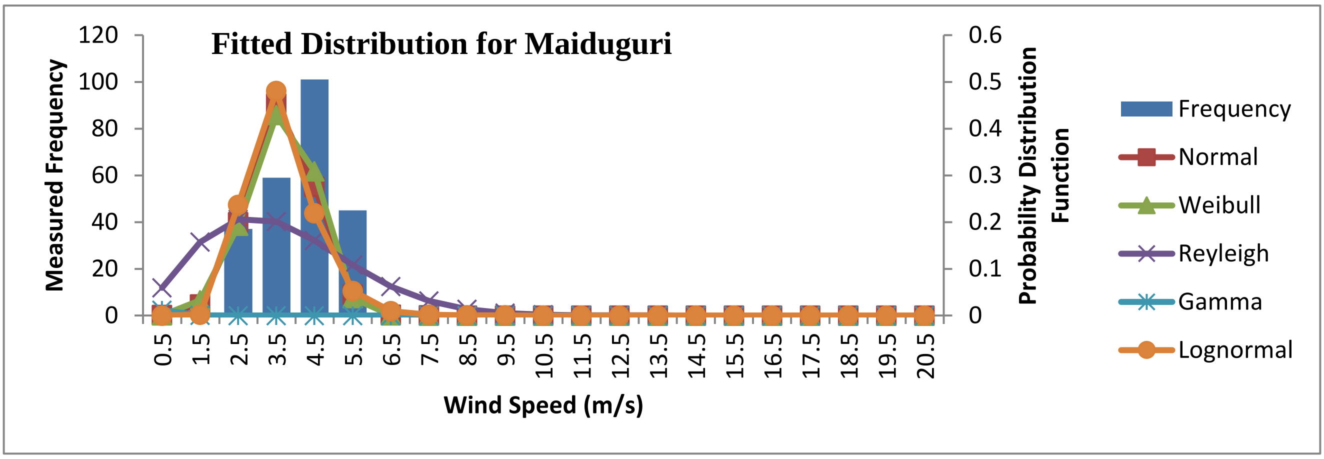
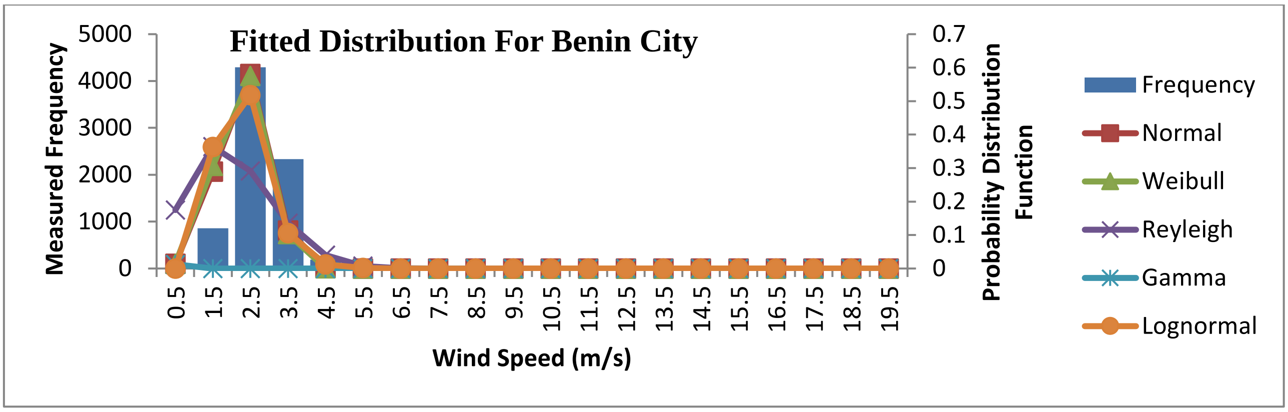
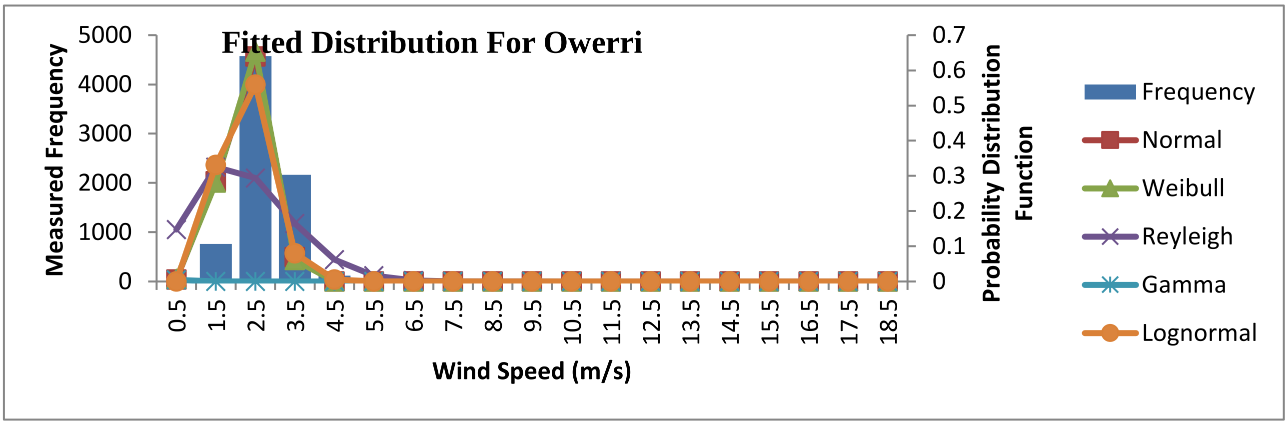



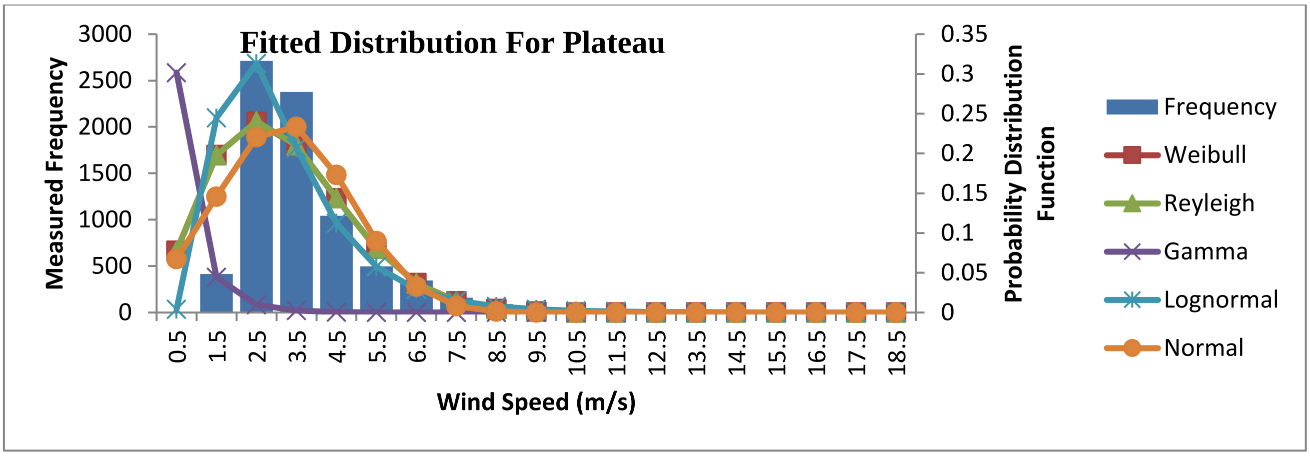

**Figure 2:** fitting of probability density function for Abeokuta, Lagos, Bauchi and Maiduguri.

International Research Journal of Pure and Applied Physics, 11 (2),1-23, 2024
ISSN 2055-009X(Print)
ISSN 2055-0103(Online)
Website: https://www.eajournals.org/
Publication of the European Centre for Research Training and Development -UK



ISSN 2055-009X(Print)
ISSN 2055-0103(Online)
Website: https://www.eajournals.org/
Publication of the European Centre for Research Training and Development -UK



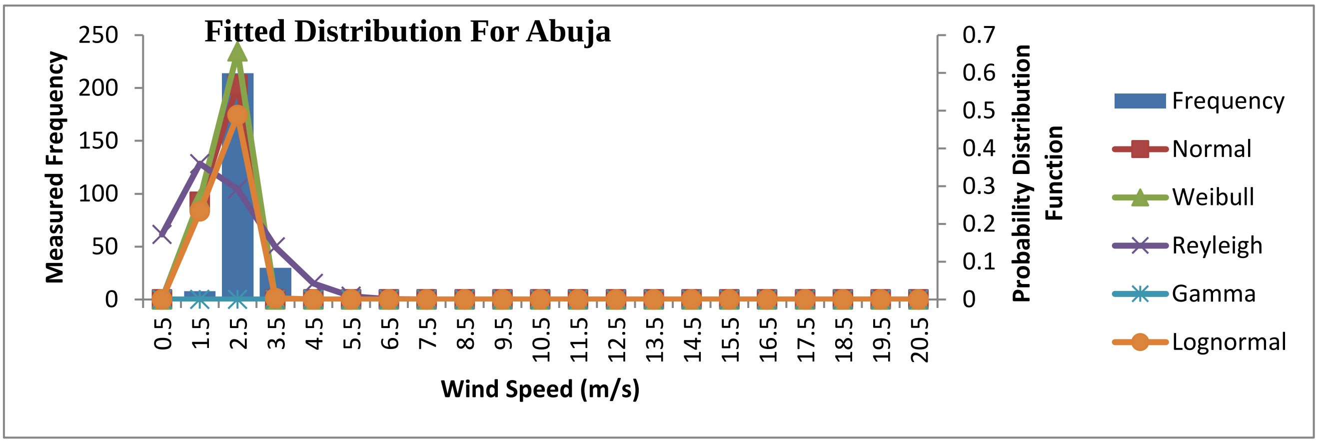




**Figure 3**: Fitting of probability density function for Benin, Owerri, Plateau and Abuja.

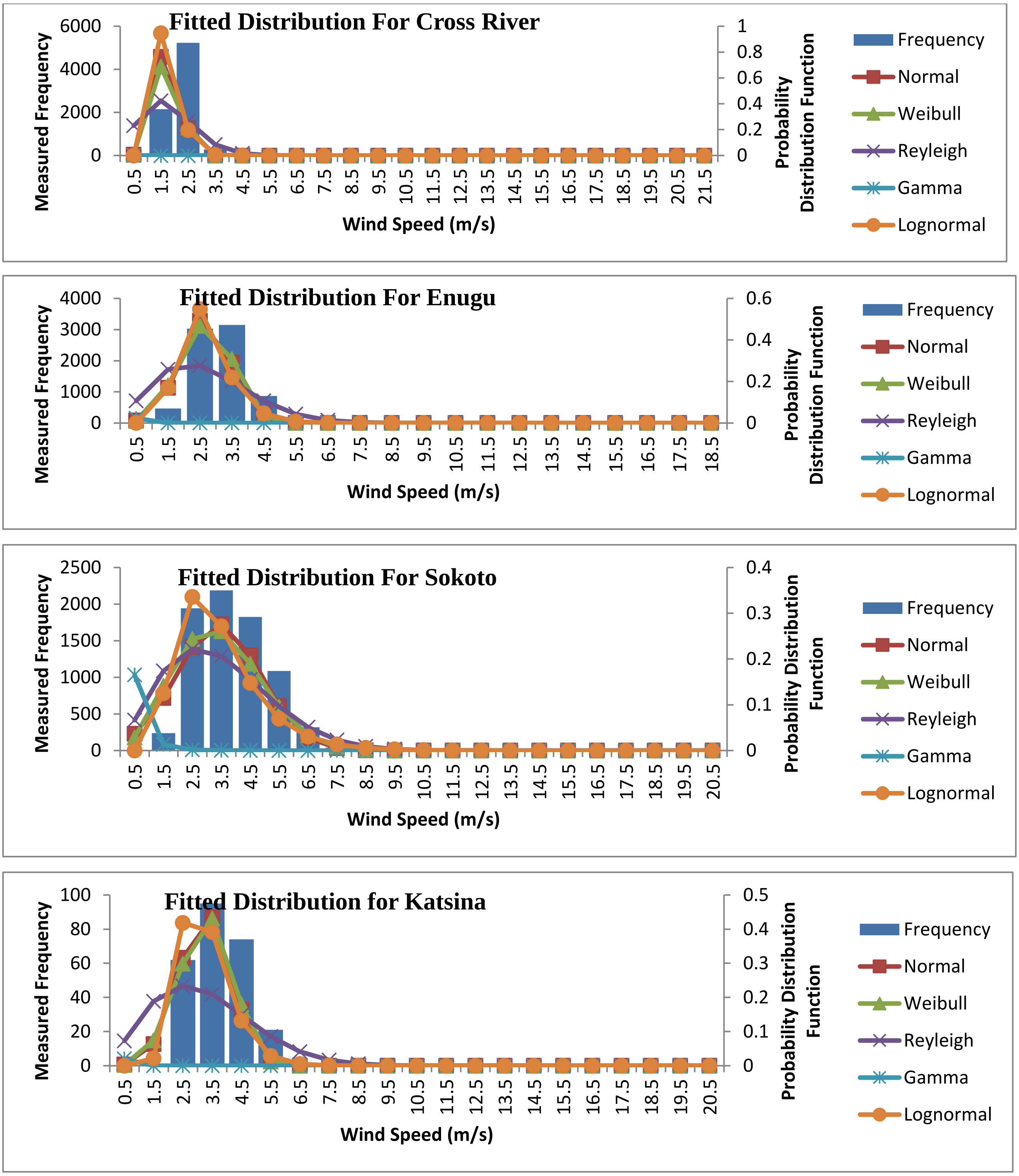



Figure 4: Fitted probability density function for Cross-river, Enugu, Sokoto and Katsina.

## CONCLUSION

The wind speed data for the twelve stations has been fitted to five distribution functions (normal, Weibull, Rayleigh, lognormal and Gamma) with fixed shape parameter, k but different scale parameters, c. The goodness-of-fit at the 5% significance level has been determined by using Kolmogorov and Anderson-Darling tests. Normal distribution function is found to give the best fit for all the selected cities for surface wind electrification.

## REFERENCES

Adekoya, L.O. & Adewale, A. (1992). Wind energy potential of Nigeria. *Renewable Energy*, *2*(6), 35–39.

Agbetuyi, A. F., Akinbulire T. O., Abdulkareem A., & Awosope C. O. (2012). Wind Energy Potential in Nigeria. *International Electrical Engineering Journal (IEEJ)*, 3(1), 595-601 ISSN 2078-2365

Aidan J. & Ododo J. C. (2010). Wind speed distributions and power densities of some cities in Northern Nigeria, *Journal of engineering and applied sciences*, *5*(6), 420-426

Aidan J. (2011). Turbine Selection and Estimates of Unit Cost of Wind Generated Electricity in Kano, Nigeria, *Journal of Engineering and Applied Sciences 6* (4): 227-230

Aidan J. (2015). Wind Energy. A lecture outline presented in a classroom lecture at Moddibbo Adama University of technology Yola, Adamawa State, Nigeria.

Ajayi, O.O., Fagbenle, R.O., Katende, J., & Okeniyi, J.O. (2011) Availability of wind energy resource potential for power generation of Jos, Nigeria. *Front. Energy 5(2)*, 376–385.

Ajayi, O.O. (2009) Assessment of utilization of wind energy resources in Nigeria. *Energy Policy* , *3*(10), 720–723.

Akaike, H. (2011). Akaike's information criterion. In: *International Encyclopedia of Statistical Science*. Berlin, Heidelberg: 25-25. https:/doi.org/10.1007/978-3-642-04898-2_110

Akdağ, S. A., & Dinler, A. A. (2009). New method to estimate Weibull parameters for wind energy applications. Energy Conversion Management 50, 1761–1766.

Akpinar S. & Akpinar E. K. (2009). Estimation of wind energy potential using finite mixture distribution models. *Energy Conversion and Management 50*(4): 877-884

Alberto, L-G. (2008). *Probability, statistics, and random processes for electrical engineering*. Upper Saddle River, NJ: Pearson/Prentice Hall

American Wind Energy Association (AWEA) (2013). 10 Steps in Building a Wind Farm. Wind Energy Fact Sheet (2013). http://www.awea.org

Ashden Publication (2013). Case Study: Cabeólica wind farm. Document last updated May 2013. Available online at www.ashden.org/finalists/cabeolica13.

Asiegbu, A.D. Iwuoha, G.S. (2007). Studies of wind resources in Umudike, South East Nigeria—An assessment of economic viability. *Journal of. Engineering and Applied Science, 2*,(3) 1539–1541.

Bailey, B. H., McDonald, S. L., Bernadett, D.W. Markus, M. J., & Elsholz, K.V. (1997). *Wind Resource Assessment Handbook*. Subcontract No. TAT-5-15283- 01. National Renewable Energy Laboratory.

Bajic, A. and Peros, B. (2005), “Meteorological basis for wind loads calculation in Croatia”, Wind Struct., 8(6), 389-406. https://doi.org/10.12989/was.2005.8.6.389.

Brower, M. C., Bernadett, D. W., & Elsholz, K.V. (2012). *Wind Resource Assessment:* A Practical Guide to Developing a Wind Project, John Wiley & Sons, Inc., Hoboken, NJ, USA. doi: 10.1002/978111824986

Chang, T.J., Tu, Y.L. (2007). Evaluation of monthly capacity factor of WECS using chronological and probabilistic wind speed data: A case study of Taiwan. *Renewable Energy 32*, 1999-2000

Chang, T.P., Ko, H., Liu, F., Chen, P., Chang, Y., Liang, Y., Jang, H., Lin, T., Chen, Y. (2012). Fractal dimension of wind speed time series. *Applied Energy*, *93*, 742–749.

Chang, T. P. (2011). Estimation of Wind Energy Potential Using Different Probability Density Functions. *Applied Energy*, *88*(5), 1848-1856

Clean Development Mechanism (CDM) and Baseline-Assessments for wind Energy Projects (2014). The webpage was last modified on 29 August, at 13:45. Retrieved from https://energypedia.info/index.php?title=Clean_Development_Mechanism_(CDM) BaselineAssessments_for_Wind_Energy_Projects&oldid=83438 on 12/12/2014

Dawde O. Y. (2003). Wind Resource Data Analysis: The case of MYDERHU project site, Tigray regional state, Ethiopia. Master of Science Thesis KTH School of Industrial Engineering and Management Energy Technology EGI 2013 051MSC EKV953 Division of Heat & Power SE 100 44 STOCKHOLM. 2013-06-18

Drobinski P. & Coulais C. (2012). Is the Weibull distribution really suited for wind statistic modelling and wind power evaluation. *Journal of Physics: Conference Series* 753 *3*(7), 5-8.

ECN-UNDP (Energy Commission of Nigeria-United Nations Development of Nigeria). Renewable energy master plan: Final draft report, 2005. Available online: http://www.iceednigeria.org/ REMP%20Final%20Report.pdf (accessed on 17 June 2007).

ECOWAS Observatory for Renewable Energy and energy Efficiency (2013). Katsin Wind Farm Project. Available online at http://www.ecowrex.org/project/katsina-wind-farm-project

Edafienene L. E., Sholademi M. O., Olayanju J. O, Ediang A.O., Oyegbule G. A., & Dogbey J. K. (2010). Effects of Wind on Nigeria Ports and Harbours. The 1st International Applied Geological Congress, Department of Geology, Islamic Azad University – Mashad Branch, Iran, 26-28 April, 2010

Elshaer, A., Bitsuamlak, G. and Abdallah, H. (2019), “Variation in wind load and flow of a low-rise building during progressive damage scenario”, Wind Struct., 28(6), 389-404. https://doi.org/10.12989/was.2019.28.6.389.

Enibe, S. O. (1987). A Method of Assessing the Wind Energy Potential in a Nigerian Location, *Nigerian Journal of Solar Energy 6*(4/5), 14-20.

Eskin, N., Artar, H. and Tolun, S. (2008), “Wind energy potential of Gokceada Island in Turkey”, Renew. Sustain. Energy Rev., 12(3), 839-851. https://doi.org/10.1016/j.rser.2006.05.016.

Fadare, D.A. (2010). The application of artificial neural networks to mapping of wind speed profile for energy application in Nigeria. *Applied Energy,87*, 934–942.

Fadare, D.A. (2008). Statistical analysis of wind energy potential in Ibadan, Nigeria, based on Weibull distribution function. *Journal of Science and Technology, 9*,110–19.

Fagbenle, R.O. & Karayiannis, T.G. (1994) On the wind energy resources of Nigeria. *International Journal of Energy Resource, 18,* 493–508.

Fagbenle, R.O., Fasade, A.O., Amuludun, A.K., & Lala, P.O. (1980) Wind energy potential of Nigeria. In Proceedings of 12th Biennial Conference of West Africa Science Association, University of Ife, Osogbo, Nigeria.

Fagbenle, R.O.; Katende, J., Ajayi, O. & Okeniyi, J.O. (2011). Assessment of wind energy potential of two sites in North East, Nigeria. *Renewable Energy, 36,* 1277–1283.

Fawzan, M. A. (2000). *Methods for Estimating the Parameters of Weibull Distribution:* Al-Yaseen Press Cairo University.

Fluid-Dynamic Analysis. A thesis submitted in partial fulfilment of the requirements of Edinburgh Napier University, for the award of Doctor of Philosophy. February, 2012

Folorunsho R. & Awosika L. (2015). The Ocean Data and Information Network for Africa. Nigerian Institute for Oceanography and Marine Research (NIOMR)

Genç, M.S. (2011), "Economic viability of water pumping systems supplied by wind energy conversion and diesel generator systems in North Central Anatolia, Turkey", J. Energy Eng., 137(1), 21-35. https://doi.org/10.1061/(ASCE)EY.1943-7897.0000033.

Genç, M.S. and Gökçek, M. (2009), "Evaluation of wind characteristics and energy potential in Kayseri, Turkey", J. Energy Eng., 135(2), 33-43. https://doi.org/10.1061/(ASCE)0733-9402(2009)135:2(33)

Global Environment Facility (GEF) (2012). United Nation Industrial Development Organization (UNIDO), ECOWAS Centre for Renewable Energy and Energy Efficiency (ECREEE). Promoting Market Based Development of Small to Medium Scale Renewable Energy Systems in Cape Verde.

Gupta, A. K. (1997). Power Generation from Renewables in India, *Ministry of Non-Conventional Energy Sources*, New Delhi, India.

Gupta, B. K. (1986). Weibull Parameters for Annual and Monthly Wind Speed Distribution for five Locations in India. *Solar Energy, 37*(13), 469-477

Harris, R.I. (2006), "Errors in GEV analysis of wind epoch maxima from Weibull parents", Wind Struct., 9(3), 179-191. https://doi.org/10.12989/was.2006.9.3.179.

Hemami, A. (2012). *Wind Turbine Technology*, 1st Edition Information center.https://doi.org/10.21236/ADA374109

International Finance Corporation (IFC) (2011). The World Bank Group. GHG Accounting Guidance Note for Grid Connected Wind, Solar, Run-of River Hydro, Small Hydro (<10 MW) and Geothermal Generation Investment Projects IFC Climate Business Group. September, 2011

International Renewable Energy Agency (2015). Global Atlas. http://geocatalog.webservice-energy.org/geonetwork/srv/eng/main.home

International Renewable Energy Agency (IRENA) (2013). Renewable Energy Technologies: Cost Analysis Series. http://www.irena.org/DocumentDownloads/Publications/RE_Technologies_Cost Analysis-SOLAR_PV.pdf.

Irshad W. (2012). Wind Resource Assessment: Statistical and Computational

Jensson, P. (2006). *Profitability Assesment Model*, Reykjavik University.

Jowder, F.A.L. (2009), "Wind power analysis and site matching of wind turbine generators in Kingdom of Bahrain", Appl. Energy, 86(4), 538-545. https://doi.org/10.1016/j.apenergy.2008.08.006.

Ke, S.T., Wang, X.H. and Ge, Y.J. (2019), "Wind load and windinduced effect of the large wind turbine tower-blade system considering blade yaw and interference". Wind Struct., 28(2) Energy, 86(10), 1864- 1872 https://doi.org/10.1016/j.apenergy.2008.12.016.

Kiss P. & Janosi I.M. (2008). Comprehensive empirical analysis of ERA-40 surface wind speed distribution over Europe. *Energy Conversion and Management 49*(8): 2142-2151.

Kost C., Mayer J. N., Thomsen J., Hartmann N., Senkpiel N., Philipps S., Nold S., Lude S., Saad N., & Schleg T. (2013). Levelized cost of electricity renewable energy technologies. Fraunhofer Institute for Solar Energy Systems ISE. November, 2013

Lagomarsino, S., Piccardo, G. and Solari, G. (1999), "Probabilistic analysis of ltalian extreme winds: Reference velocity and return criterion", Wind Struct., 2(1), 51-68. https://doi.org/10.12989/was.1999.2.1.051.

Lahmeyer (International) Consultants. (2005) Report on Nigeria Wind Power Mapping Projects; Federal Ministry Science Technology: Abuja, Nigeria, 37–51.

Lange, M., Wilkinson, M., & Vandeft, T. (2010). Wind Turbine Reliability Analysis.

Leadership Newspaper (2014). Work Resumes on Katsina 10MW Wind Farm. Available online at http://leadership.ng/news/391965/work-resumes-katsina-10mw-wind- farm

Ledec G. C., Rapp K. W. & Aiello R. G. (2011). Greening the Wind: Environmental and Social Considerations for Wind Power Development. World Bank Studies.December 2011.

Lu, W., & Tsai, T. R. (2009). Interval Censored Sampling Plans for the Gamma Life Model. *European Journal of Operational Research*, 192(1), 116-124

Meteotest, (2015). The Swiss Wind Power Data Website. http://wind-data.ch/tools/index.php

Mosetlhe, T. C., Yusuff, A. A. & Hamam, Y. (2017). Assessment of small signal stability of power systems with wind energy conversion unit. Proceedings of IEEE. Africon, Cape Town, South Africa.: 1089-1094

Mukasa, A. D., Mutambatsere E., Arvanitis, Y., & Triki., T. (2013). Development of Wind Energy in Africa. Working Paper Series No 170 African Development Bank,Tunis, Tunisia. Available online at http:/www.afdb.org/

Mukund, R. P. (1999). *Wind and Solar Power Systems:* CRC Press LLC. United States of America.

Ngala, G.M., Alkali, B., Aji, M.A. (2007). Viability of wind energy as a power generation source in maiduguri, Borno state, Nigeria. *Renewable Energy, 32,* 2242–2246.

Nogay, S. H., Akinci, T. C. and Eidukluciute, M. (2012). Application of artificial neural nertworks for short term wind speed forecasting in Mardin, Turkey. *Journal of Energy of Southern Africa 23*(4). 2-7.

Ogbonnaya, I.O., Chikuni, E., & Govender, P. (2009). Prospect of wind energy in Nigeria. Available online: http://active.cput.ac.za/energy/web/due/papers/2007/023O_Okoro.pdf (accessed on 16 July 2009).

Ojosu, J.O.; Salawu, R.I. An evaluation of wind energy potential as a power generation source in Nigeria. Sol. Wind Technology. 1990, 7, 663–673.

Osei E. Y. (2010). Technical and Financial Assessment of a 50 MW Wind Power Plant in Ghana. A thesis submitted to the School of Graduate Studies, Kwame Nkrumah University of Science and Technology, Ghana, in partial fulfillment of the requirements for the Degree of Master Of Science in Mechanical Engineering. October, 2010.

Ozgener, L. (2010), "Investigation of wind energy potential of Muradiye in Manisa", Renew. Sustain. Energy Rev., 14(9), 3232-3236. https://doi.org/10.1016/j.rser.2010.06.004.

Papoulis, P. (2017). *Probability, Random Variables, and Stochastic Processes*, 4th Edition

Quan, Y., Hou, F. and Gu, M. (2017), "Effects of vertical ribs protruding from facades on the wind loads of super high-rise buildings", Wind Struct., 24(2), 145-169. https://doi.org/10.12989/was.2017.24.2.145.

Ramirez, P., & Carta, J. A. (2OO5). Influence of the Data Sampling Interval in the Estimation of the Parameters of the Weibull Wind Speed Probability Density Distribution. *Energy Conversion and Management*, *46*(15-16), 2419-2438

Reliasoft, RBDs and Analytical System Reliability. [Online]. Available: http//reliawiki.com/index.php/RBDs_and_Analytical_System_Reliability. [Accessed:10-January-2019].

Safari, B. and Gasore, J. (2010). A Statistical Investigation of Wind Characteristies and Wind Energy Potential Based on the Weibull and Rayleigh Models in Rwanda. *Renewable Energy*, 35(12), 2874-2880.

Sathyajith M., Geetha S & Chee M. (2011). Analysis of Wind Regimes and Performance of Wind Turbines, Faculty of Science, University of Brunei Darussalam, Jalan Tungku Link, Gadong, BE1410 Negra, Brunei Darussalam.

Sathyajith, M. (2006). *Wind Energy: Fundamentals, Resource Analysis and Economics:* Springer-Verlag New York.

Saucier, R. 2000. Computer Generation of Statistical distributions. Defense Technical

Shamilov, A., Kantar, Y.M., Usta, I. (2008). Use of MinMaxEnt distributions defined on basis of MaxEnt method in wind power study. *Energy Conversion Management. 49,* 660–677.

Spanier, J. & Oldham, K. B., (1987). The Gamma Function, Γ(x) and The Incomplete Gamma $\gamma(v, x)$ and Related Functions, *In An Atlas of Functions, Hemisphere,* Washinton, DC, 43(45), 411-443

Stevens, M. J., & Smulders P. T. (1979). "The estimation of the parameters of the Weibull wind speed distribution for wind energy utilization purposes." *Wind Engineering*, *3*(2), 132-45.

Tavner, P., Feng, Y., Korogiannos, A., & Qiu, Y. (2011). *The correlation between wind turbine turbulence and pitch failure,* Durham University, UK.

The Wind Power and UK Wind Speed Database programs (2015). Wind statistics and the Weibull distribution. http://www.wind-power-program.com/wind_statistics.htm

Ucar, A. and Balo, F. (2009), "Evaluation of wind energy potential and electricity generation at six locations in Turkey", Appl.

Vanguard Newspaper (2015). Katsina 10 MW Wind Farm Achieves 98 % completion -FG. Available online at http://www.vanguardngr.com/2015/05/katsina-10mw-wind-farm-attains-98-completion-fg/

Vestas-American Wind Technology, Inc. Key Aspects in Developing a Wind Power Project.https://www1.eere.energy.gov/tribalenergy/guide/pdfs/developingwindpower. Pdf

Vilar (ED) (2012). Renewable Energy in Western Africa: Situation, Experiences and Tendencies. ECOWAS Centre for Renewable Energy and Energy Efficiency (ECREEE).

Vogiatzis, N., Kotti, K., Spanomitsios, S., and Stoukides, M. North Aegean Greece. *Renewable Energy*, 29(7), 1193-1208.

Weibull, W. (1951). A Statistical Distribution Function of Wide Applicability. *J. Appl.Mech-Trans*, ASME, *18*(3), 293-297

Wide Energy The Facts: (2009) . A Guide to the Technology, Economics and Future of Wind Power: *European Wind Energy Association (EWEA).* Earthscan Publications Ltd.

Ye, X.W., Ding, Y. and Wan, H.P. (2019), “Machine learning approaches for wind speed forecasting using long-term monitoring data: a comparative study”, Smart Struct. Syst., 24(6), 733-744. https://doi.org/10.12989/.2019.24.6.733.

Zhou Y., & Smith S. J. (2013) Spatial and temporal patterns of global onshore wind speed distribution. Environ. Res. Lett. 8 034029.

Zidong, X., Hao, W., Teng, W., Tianyou, T. and Jianxiao, M. (2017), “Wind characteristics at Sutong Bridge site using 8-year field measurement data”, Wind Struct., 25(2), 195-214. https://doi.org/10.12989/was.2017.25.2.195.