

**VALIDATION OF ENERGY COMMISSION OF NIGERIA
WIS-SOFTWARE FOR WIND ENERGY POTENTIAL OF
NIGERIA**

BY

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FULFILMENT OF THE REQUIREMENTS FOR THE AWARD
OF M.ENG.ENERGY ENGINEERING.**

MAY, 2015.

DECLARATION

I hereby declare that this work is the product of my research efforts undertaken under the supervision of Dr. M.T. Jimoh, and has not been presented anywhere for the award of a degree or certificate. All sources have been dully acknowledged.

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CERTIFICATION

This is to certify that the research work for this dissertation and the subsequent write-up by Muritala Akanni Omirinde, (SPS/11/MGY/00026), were carried out under my supervision.

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NOMENCLATURE

Symbols	Description
P	Total power, W/m ²
A	Area, m ²
Pe	Practically extractable power, W/m ²
k	Dimensionless shape parameter
c	Scale parameter (m/s)
$f(v)$	Weibull probability density function
$F(v)$	Cumulative distribution function
C	Constant
L	Likelihood function
V_i	Random sample of wind speed central to bin i
n	Number of sample or bin
$f(v_i)$	Weibull frequency for wind speed ranging within bin i
$f(v \geq 0)$	Probability for wind speed ≥ 0
W_{vi}	Observed frequency of the wind speed
Vm^3	Mean of the cubic wind speed, m/s
h_o	Reference height, m
k_h	Weibull shape factor at desired height
c_h	Weibull scale factor at desired height, m/s
v_h	Wind speed at desired height, m/s
P_h	Power at desired height, W/m ²
N	Total number of observations

$y_{i,m}$	i -th calculated value from measured data
$x_{i,w}$	i -th calculated value from the Weibull distribution
R^2	Analysis of variance
Γ	Gamma function
σ	Standard deviation of wind speed, m/s
ρ	Air density, kg/m ³
θ	Unknown parameter for maximum likelihood function
η	law coefficient
χ^2	Chi-square error

ABSTRACT

This work aimed to generally validate Wind Information System (WIS) software developed by Energy Commission of Nigeria (ECN) by assessing the wind energy potential in Kano, Lagos, Jos, Enugu, Ilorin and Lokoja. The wind data obtained from NIMET, Oshodi, Lagos for the selected sites in this work were analysed using Microsoft Office Excell 2007 and Mathematical Model Weibull probability distribution function to process the data. The estimated result was then compared with the result generated by the WIS software. The experimental shows that, the maximum and minimum wind speed of the selected sites occurred at 10m and 50m with values of 5.451m/s and 3.663m/s respectively. The Coefficient of variation (COV) and standard deviation at these heights vary between 47.2% and 54.0% and, 2.573 and 1.979, respectively. On the other hand, WIS generated the same wind speed of 5.194m/s, COV of 13.9% and standard deviation of 0.724 from 10-50m. Therefore, the calculated mean wind speeds have shown wind characteristics than the WIS from 20-50m. Also, the Weibull parameters, average power, total energy production and energy total specific in the study sites exhibit high variability with the height, while the ones generated by the WIS show no variability with the height. The high wind variability in experimental results translates to high wind power variability. However, wind power generated by the WIS for the sites exhibits the same pattern of intermittency. Hence, the software needs to be improved.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of the Study

Energy and environment are the twin major crises in the world (Baños, *et al.*, 2011). Because of this, both developed and developing countries are becoming increasingly more interested in using pollution free, cost effective and renewable sources of energy (Cruz-Peragon, *et al.*, 2012). As a renewable and alternative energy, wind is the most common and fastest-growing source of energy in the world (Acker, *et al.*, 2007).

The quest to reduce environmental impacts of conventional energy resources and, more importantly, to meet the growing energy demand of the global population had motivated considerable research attention in a wide range of environmental and engineering application of renewable form of energy. It is recognized that wind energy, as a renewable energy source, has stood out as the most valuable and promising choice. Due to its many advantages, wind energy has also become the fastest growing renewable source of energy in both developed and developing countries (Global Wind Energy Council, 2012).

Wind energy has served mankind well for many centuries by propelling ships and driving wind turbines to grind grain and pump water. Wind power has many benefits that make it an attractive source of power for both utility-scale and small, distributed power generation applications. The beneficial characteristics of wind

power include clean and inexhaustible fuel, local economic development, modular and scalable technology, reduce reliance on imported fuels (Gary, 2001).

The increasing energy demand, the rapidly depleting fossil fuel reserves and the environmental problems associated with the use of fossil fuel have necessitated the development of alternative energy sources like wind energy for electricity generation in Nigeria. It is reported that the electricity production in Nigeria as of the end of 2010 is less than 4,000 MW due to fluctuations in the availability and maintenance of production sources, leading to a short fall in supply (Fagbenle, *et al.*, 2011). However, analyses of available wind data for selected cities have confirmed a high prospect of wind energy resources in Nigeria. Several studies on renewable sources of energy have also been performed. Worthy of mention here from these studies, however, is that the effective utilization of wind energy at a typical location requires sound knowledge of the wind characteristics and accurate wind data analysis. For example, the choice of wind turbine design must be based on the average wind velocity at a selected wind turbine installation site (Marcius-Kaitis, 2008). Prior studies have also shown that the wind flow patterns are influenced by terrains, vegetation and water bodies.

Weibull distribution (Weibull , 1951) has many applications in engineering and plays an important role in reliability and maintainability analysis. Because of useful applications, its parameters need to be evaluated precisely and efficiently (Rockette *et al.*, 1974).

Weibull has been recognized as an appropriate model in reliability studies and life testing problems such as time to failure or life length of a component or product. Over the years, estimation of the shape and scale parameters for a Weibull distribution function has been approached through maximum likelihood method (MLM), linear method, and several versions of regression analysis. In recent years, Weibull distribution has been one of the most commonly used, accepted, recommended distribution to determine wind energy potential and it is also used as a reference distribution for commercial wind energy software such as Wind Atlas Analysis and Application Program (WAsP). The two-parameter Weibull distribution function is commonly used to fit the wind speed frequency distribution. Weibull distribution can be used to model the wind speed distribution at a particular site and hence, it can help in wind resource assessment of a site. By calculating the two parameters (shape and scale) for Weibull distribution the wind speed frequency curve for a site can be made (Prasad *et al.*, 2009) and the key to perform wind turbine and wind farm energy calculation.

1.1.1 Wind Information System (WIS) Software

Wind Information System (WIS) software is an application software developed in 2010 by the Energy Commission of Nigeria (ECN) to estimate the wind speed at various heights above sea level. The captured data was put together and packaged into the application software that is graphically activated by a click of the desired location on the map of Nigeria. The package is capable of calculating the

expected energy output for a number of wind turbines, at height range of 10-80m.

This makes it friendly and versatile.

Information of the chosen area include the following

- Increase of average wind speed with height
- Probability of annual mean wind speed
- Weibull distribution on selected point and power curve of selected wind converter
- Table of specific converter data
- Distribution of wind direction and wind speed
- Weibull for measurement site
- Daily wind speed pattern.

1.2 Statement of the Problem

Although several studies have been carried out to investigate the characteristics and pattern of wind speed across Nigeria, less has been done examining the wind energy density in the areas such as Kano, Lagos, Jos, Enugu, Ilorin and Lokoja. However, the Energy Commission of Nigeria developed software to this effect to cover all part of Nigeria and it is now left to validate the Energy Commission of Nigeria WIS software for the particular case of the mentioned states. The focus of this study is therefore, to validate the Energy Commission of Nigeria WIS software.

1.3 Significance of the Research

The results of this work would be useful to examine the existing WIS software by Energy Commission of Nigeria there by paving the way for updating the software.

1.4 Aim and Objectives of the Study

The aim of the study is to generally validate Wind Information System (WIS) software by Energy Commission of Nigeria by assessing the wind energy potential in the areas of Kano, Lagos, Jos, Enugu, Ilorin and Lokoja.

The objectives are as follows;

1. To acquire wind energy data of these areas
2. To estimate the probability that the wind speed of the area is such that it can support a wind farm for wind turbine of various sizes using Weibull Probability distribution.
3. To estimate the power density at standard wind turbine hub-height
4. To compare the results of this work with those given by the Energy Commission of Nigeria WIS- software for wind potential.

1.5 Methodology

1. A thorough review of literature relating to standard procedures for the assessment of wind energy potential.
2. Collection of wind speed data for the specific areas from the NIMET or any other recognized weather station.

3. Analysis of wind data to predict the wind energy density of the said areas, using Weibull distribution analysis and MS-Excell for computations.
4. Running of the Energy Commission of Nigeria Wind Information System (WIS) software to obtain the wind energy potential for comparison with the one from this work.

1.6 Scope and Limitation of the Study

The study will be limited to assessing the general wind energy potential of these areas; Kano, Lagos, Jos, Enugu, Ilorin and Lokoja.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Wind Data Assessment

In literature, several distributions were applied to calculate the wind speed distribution. Justus *et al.*, (1978) applied the Weibull and Lognormal distribution to wind speed data from more than a hundred stations of the USA and concluded that Weibull Distribution rendered the best fit. Corotis *et al.*, (1978) preferred the Rayleigh distribution a special case of Weibull. Hennessey (1978) found that the energy output calculated by Rayleigh distribution is within 10% of the output based on the Weibull distribution. On the whole, Weibull gave a good fit based on the shape and scale parameters. In recent years, the Weibull distribution has been one of the most widely used and recommended tool to determine the potential of wind energy. Moreover, it is used as a benchmark to estimate the wind energy commercially.

The extent to which wind can be exploited as a source of energy depends on the probability density of occurrence of different speeds at the site. To optimize the design of a wind energy conversion device, data on speed range over which the device must operate to maximize energy extraction is required, which requires the knowledge of the frequency distribution of the wind speed. Among the probability density functions that have been proposed for wind speed frequency distributions of most locations, the Weibull function has been the most acceptable distribution and forms the basis for commercial wind energy applications and

software (Seyit and Ali, 2009), such as the Wind Atlas Analysis and Application Program (WAsP) and the recently developed Nigerian Wind Information System (WIS) software.

The wind speed data of 8 cities in Northern Nigeria have been fitted to four distribution functions (normal, Weibull, Rayleigh and gamma). The goodness-of-fit at the 5% significance level has been determined by using Chi-square, Kolmogorov-Smirnov and Anderson-Darling tests. For four cities (Bida, Minna, Yelwa and Yola) which have the lowest altitudes (<260m) the gamma distribution was found to give the best fit while other cities (Gusau, Kaduna, Maiduguri and Zaria) either the Weibull or normal distribution gives the best fit. By considering the predicted wind speed variation at various heights above the ground, it was seen that the potential for utility-scale wind generation at a height of about 80m was very satisfactory, especially for Gusau, Kaduna, Maiduguri and Zaria (Aidan *et al.*, 2010). The work of Mahyoub and Albuhaire (2006) showed that the Weibull distribution estimated power density is better than the Rayleigh distribution.

Twenty one years' data obtained from Nigerian Meteorological agency (NIMET) were statistically analyzed using the Weibull and Rayleigh distribution functions. The results of the study showed that Uyo has a mean wind speed of 3.17m/s with a maximum value of 3.67m/s in April, while the corresponding mean wind power density is approximately 19.91 W/m² for the whole year, thereby making the

selected site to fall under class 1 of the international system of wind classification (Olayinka *et al.*, 2011).

In recent times, numerous studies have been carried out to assess the wind speed characteristics and associated wind energy potentials in different parts of the world with similar studies carried out on the assessment of wind characteristics in some locations in Nigeria (Fadare, 2008).

Wind data from 10 coastal meteorological stations along the Mediterranean Sea in Egypt have been used for statistical analysis to determine the wind characteristics. It was found that three stations show annual mean wind speed greater than 5.0 (Ahmed, *et al.*, 2005).

The wind speed characteristics and energy potential in three selected locations in the southeastern part of Nigeria were investigated using wind speed data that span between 24 and 37 years and measured at a height of 10 m. It was shown that the annual mean wind speed at a height of 10 m for Enugu, Owerri and Onitsha were 5.42, 3.36 and 3.59 m/s, respectively, while the annual mean power densities were 96.98, 23.23 and 28.34 W/m², respectively (Oyedepo *et al.*, 2012).

The technologies for harnessing wind energy have, over the years, been tried in the northern parts of the country, mainly for water pumping from open wells in many secondary schools of old Sokoto and Kano States as well as in Kastina, Bauchi and Plateau States. Other areas of “potential application” of wind energy conversion systems in Nigeria are in Green electricity (which is the type of

electricity produced from renewable source that is environmentally friendly and non-polluting) production for the rural community and for integration into the national grid system. In 1998, a 5-kW wind electricity conversion system for village electrification was installed at Sayyan Gidan Gada, in Sokoto State (Mutlu, 2010).

Using assessed power densities of three northern cities of Sokoto, Kano and Gusau, the wind-electricity potential and the capacity factors of these cities were estimated using three model wind turbines. The three cities showed reasonable wind energy utilization potential, with Kano having the highest potential and capacity factor (Adamu and Abdullahi, 2010).

A preliminary evaluation of Lagos's wind energy resource was undertaken to determine the suitability of the city for wind energy development. The mean wind speed, the Weibull distribution, annual energy and annual capacity factor were calculated for the site. The annual energy and annual capacity factor calculation were based on specification of wind turbine known as Vestas V42-600. This study indicated that the annual energy and capacity factor for the site were 512.11MWh and 9.7%, respectively (Sanusi and Abisoye, 2011).

A model that can be employed to carry out a pre-assessment study of a potential site for wind farm was developed by Oluseyi, O, *et al.* It made use of 21years (1987-2007) monthly mean wind speeds from 11 stations spread across the South-West geopolitical zone of Nigeria. The data were assessed from the

nation's meteorological department, Oshodi Lagos. These were then statistically analyzed to develop a model that could predict the likelihood of a site's capacity for wind farm development (Oluseyi, *et al.*, 2012).

According to the report of Lahmeyer (International) Consultants (Report on Nigeria Wind Power Mapping Projects, 2005), wind energy reserve in Nigeria at 10m (or 40m) height based on data analyzed for ten wind stations cutting across North West, North East, North Central, South East and South West geopolitical zones shows that some sites have wind regime between 1.0 and 5.1m/s (1.0 and 6.3m/s) depending on the particular stations, and still confirms that Nigeria falls into the moderate wind regime.

The wind speed regimes of Yelwa, Sokoto, Kano, Kaduna, and Gusau in Northwestern Nigeria were assessed for their wind energy potential at heights of between 30m and 80m using the *ReliaSoftWeibull++ 7* software the *Wind Power Calculator*. Only three stations (Sokoto, Kano, and Gusau) showed very reasonable potential at these heights. The least values of annual energy output obtained at these heights for these three stations are, respectively: Kano: 4979 MW h at 28% capacity factor (cf), 1413 MW h at 16% cf and 1093 MW h at 21% cf; Sokoto: 3260 MW h at 19% cf, 917 MW h, at 10% cf and 680 MW h at 13% cf; and Gausau: 1895 MW h, at 11% cf, 545 MW h at 6% cf, and 347 MW h at 7% cf (Adamu *et al*, 2010).

Computing the power output of a wind turbine generator (WTG) is one of the most important issues which could affect the scheduling of the grid incorporated with wind farm and finding a proper method to model and convert wind energy to electricity is most significant and challengeable. Potential assessment of the wind power for installing wind turbine generators and estimating wind turbine generators output have been carried out by many studies (Mehdi and Arman, 2012).

Different models used to describe the performance of wind turbine generator by previous researchers. In wind energy engineering, wind speed distribution is modeled by the Weibull distribution and commonly used in practical studies related to the wind energy modeling (Bogman and Saleme, 1996).

Fadare (2010) modeled wind speed profile in Nigeria using artificial neural network consisting of 3-layered, feed-forward, back-propagation network with different configurations, designed using the Neural Toolbox for MATLAB. Carta and Mentado (2007) developed a bivariate probability model for wind power density and wind turbine energy output estimation.

Wind turbines power curves were modeled with seven power curve model and energy output results were compared with Wind Atlas Analysis and Application Program (WASP) results (Akdag and Uler, 2010). Different studies assumed that wind power curve has a linear, quadratic or cubic relationship with wind speed. Most of previous studies showed and proved the fact, which is really vital to

determine the accurate value of wind turbines energy output (Joselin *et al.*, 2010). The use of the manufacturer's power curve is the easiest approach to find the power output of wind turbine generator at the specific wind speed. However, for a specific wind turbine generator, a model should be developed according to its power output performance curve, which is given by the manufacturer (Gregor, 2003).

Wind Atlas Analysis and Application Program (WAsP) has become the industry standard for wind resource assessment and siting of wind turbines and wind farms (WAsP, WAsP, 2012). Due to some of the simplifications made in the numerical models used within WAsP, the program can produce somewhat inaccurate results when used outside its recommended operational envelope (Bowen & Mortensen, 2004). When a site has complex, rugged terrain or very complex atmospheric conditions, the accuracy of WAsP can be unreliable (Mortensen, Bowen, & Antoniou, 2006).

2.2 Wind Information System (WIS) Software Developed by Energy Commission of Nigeria

In the year 2003, the Federal Ministry of Science and Technology constituted an Inter-ministerial Team with members drawn from the Federal Ministry of Power, Energy Commission of Nigeria and its energy research centres, and the Nigerian Metrological Agency to work on a project that produced the onshore wind resource map of Nigeria. Layhmeyer International was consulted on the project.

The software produced provides information on sites which can generally be considered as potential wind farms. Thus, the product of the project can serve as a useful decision making tool for prospective wind farm developers as well as for communities who would like to determine most suitable sites for small scale wind energy generation. It is in this regard that the Commission has been engaged in executing renewable energy pilot projects to demonstrate the feasibility of renewable energy technologies. It is also to be noted that on the basis of the information obtained from the WIS software, the Federal Government has commenced the development of a 10MW wind farm in Katsina State (George *et al.*, 2014).

In this work, the WIS software will be validated by comparing the results of this work with those given by the Energy Commission of Nigeria WIS software for wind potential. The wind energy data acquired for each site will be analysed to estimate the probability that the wind speed of each site can support a wind farm and to estimate the power density at standard wind turbine hub height.

CHAPTER THREE

3.0 MATERIALS AND METHODS.

3.1 Introduction

The wind data used in this study was obtained from the Nigerian Meteorological Agency, Oshodi, Lagos. The monthly wind speed data for the period 2006-2010 was obtained from the Nigerian Meteorological Agency (NIMET) and used in this study to validate the Energy Commission of Nigeria Wind Information System software.

A thorough review of literature relating to standard procedures for the assessment of wind energy potential of a particular area was conducted.

The wind data obtained from NIMET for the areas of Kano, Lagos, Jos, Enugu, Ilorin and Lokoja were converted from Knot to m/s (1 Knot = 0.514 m/s). All the graphs, tables and data in this work were analyzed by applying Microsoft Office Excel 2007. In order to process the data the mathematical model Weibull Probability Distribution Function was used. Probability Distribution Function is the most applicable strategy to the work and calculation of wind statistics at a specific location. After the calculation of the components of this function using four different methods which include method of moments, standard deviation method, maximum likelihood method and power density method, some parameters relating to the calculation of wind energy were then estimated.

The software developed by the Energy Commission of Nigeria was then used to obtain the wind energy potential at the locations of study and the results were compared with the ones from this work.

3.2 Analysis of Wind Data

Several mathematical models such as normal and lognormal have been used for wind data analysis. Previous studies have also shown that statistical methods such as the Weibull and Rayleigh distribution models can equally be used (Akpinar, and Akpinar, 2005). According to Akdag, *et al.* (2010), the two-parameter Weibull probability distribution function is the most appropriate, accepted and recommended distribution function for wind speed data analysis. This is because it gives a better fit for measured monthly probability density distributions than other statistical functions (Akpinar and Akpinar, 2005). In addition, the Weibull parameters at known height can be used to estimate wind parameters at another height (Justus *et al.*, 1978).

Therefore, the two-parameter Weibull probability density function was used in this study. In Weibull distribution, the variation in wind velocity is characterized by two parameter functions: the probability density function and the cumulative distribution. The probability density function $f(V)$ indicates the probability of the wind at a given velocity V , while the corresponding cumulative distribution function of the velocity, V , gives the probability that the wind velocity is equal to

or lower than V , or within a given wind speed range (Akpinar and Akpinar, 2005):

3.3 Weibull Probability Density Function

The Weibull probability density function is a two-parameter function characterized by a dimensionless shape parameter (k) and scale parameter (c in m/s). These two parameters determine the wind speed for optimum performance of a wind conversion system as well as the speed range over which the device is likely to operate as given in equation (3.1):

$$f(v) = \frac{dF(v)}{dv} = \left(\frac{k}{c}\right) \left(\frac{v}{c}\right)^{k-1} \exp\left[-\left(\frac{v}{c}\right)^k\right] \dots\dots\dots (3.1)$$

Where $f(V)$ = the probability of observing wind speed (V);

k = dimensionless Weibull parameter; and

c = the Weibull scale parameter (in meter per second).

The scale factor could be related to the mean wind speed through the shape factor, which determines the uniformity of the wind speed in a given site.

3.4 Cumulative Distribution Function or Weibull Function

The cumulative distribution $F(v)$ is the integral of the probability density function, and it is expressed as (Mathew, 2002):

$$F(v) = \int_0^v f(v)dv \dots\dots\dots (3.2)$$

or
$$F(v) = 1 - e^{-\left(\frac{v}{c}\right)^k} \dots\dots\dots (3.3)$$

All these distributions are used to determine the probability of occurrence. The nature of the occurrence affects the shape of the probability curve, and in the case

of the wind regime, the cumulative curve probability nature mostly fits to the Weibull function (Mathew, 2002). There are several methods for determining k and c from the wind data. Some of the common methods are graphical method, moment method, maximum likelihood method, energy pattern factor method and the standard deviation method (Mathew, 2006). Four of these methods are used in this study:

- (1) Method of Moments (MOM)
- (2) Standard Deviation Method (STDM)
- (3) Maximum Likelihood Method (MLM)
- (4) Power Density Method (PDM)

3.4.1 Method of Moments (MOM)

The method of moments is considered as an alternative to maximum likelihood method. The first two moments of the Weibull density function are utilized to calculate the parameters ‘k’ and ‘c’. The calculations are based on standard deviation, average wind velocity and gamma function for parameter (1+1/k). This method is suggested by Justus *et al* (1978). The two moments of the distribution are given in equations (3.4) and (3.5) which help in calculating shape and scale parameters.

$$\bar{v} = c\Gamma\left(1 + \frac{1}{k}\right) \dots\dots\dots (3.4)$$

$$\sigma = c \left[\Gamma\left(1 + \frac{2}{k}\right) - \Gamma^2\left(1 + \frac{1}{k}\right) \right]^{1/2} \dots\dots\dots (3.5)$$

$$\frac{\sigma}{\bar{v}} = \sqrt{\frac{\Gamma(1+\frac{2}{k})}{[\Gamma(1+\frac{1}{k})]^2}} - 1 \quad \dots\dots\dots (3.6)$$

After some calculation we can find:

$$k = \left(\frac{0.9874}{\frac{\sigma}{\bar{v}}}\right)^{1.0983} \quad \dots\dots\dots (3.7)$$

3.4.2 Standard Deviation Method (STDM)

The monthly and annual values of Weibull parameters are calculated using standard deviation method. This method is useful where only the mean wind speed and standard deviation are available. In addition, it gives better results than graphical method and has relatively simple expressions when compared with other methods (Jowder, 2009). Moreover, it is unlike most of the other methods that may require more detailed wind data (which, in some cases, are not readily available) for the determination of the Weibull distribution shape and scale parameters. The shape and scale factors are thus given by (Ouammi, *et al.*, 2010):

In the STDM, the Weibull factors can be obtained as follows:

$$k = \left(\frac{\sigma}{\bar{v}}\right)^{-1.086} \quad \dots\dots\dots (3.8)$$

and:

$$c = \frac{\bar{v}}{\Gamma(1+\frac{1}{k})} \quad \dots\dots\dots (3.9)$$

where \bar{v} and σ are mean wind speed and standard deviation of wind speed for any specified periods of time respectively, and $\Gamma(x)$ is the gamma function, which is defined as (Ouammi *et al.*, 2010):

$$\Gamma(x) = \int_t^\infty t^{x-1} e^{-t} dt. \dots\dots\dots (3.10)$$

In addition to the mean wind speed, the other two significant wind speeds for wind energy estimation are the most probable wind speed (VF) and the wind speed carrying maximum energy (VE). They can be expressed respectively as (Bagiorgas *et al.*, 2007):

$$V_F = c \left(\frac{k-1}{k} \right)^{\frac{1}{k}} \dots\dots\dots (3.11)$$

$$V_E = c \left(\frac{k+1}{k} \right)^{\frac{1}{k}} \dots\dots\dots (3.12)$$

The most probable wind speed corresponds to the peak of the probability density function, while the wind speed carrying maximum energy can be used to estimate the wind turbine design or rated wind speed. Previous studies have shown that wind turbine system operates most efficiently at its rated wind speed. Therefore, it is required that the rated wind speed and the wind speed carrying maximum energy should be as close as possible (Mathew *et al.*, 2002).

3.4.3 Maximum Likelihood Method (MLM)

Maximum likelihood method was suggested by Steven *et al* (1979). it adopts an iterative procedure for determination of parameters, k and c. these parameters are found by the equations

$$k = \left(\frac{\sum_{i=1}^n v_i^k \ln v_i}{\sum_{i=1}^n v_i^k} - \frac{1}{n} \sum_{l=1}^n \ln v_i \right)^{-1} \dots\dots\dots (3.13)$$

$$c = \left(\frac{1}{n} \sum_{i=1}^n v_i^k \right)^{1/k} \dots\dots\dots (3.14)$$

3.4.4 Power Density Method (PDM)

To obtain the shape factor and scale factor through this method, firstly the energy pattern factor is computed. The energy pattern factor usage is for turbine aerodynamic design. The energy pattern factor is related to the averaged data of wind speed and is defined as a ratio between mean of cubic wind speed to cube of mean wind speed. The energy pattern factor E_{pf} is expressed as (Akdag and Dinler, 2009):

$$E_{pf} = \frac{\text{Total amount of power available in the wind}}{\text{Power calculated by cubing the mean wind speed}}$$

$$\text{or } E_{pf} = \frac{\frac{1}{n} \sum_{i=1}^n v_i^3}{\left(\frac{1}{n} \sum_{i=1}^n v_i\right)^3} = \frac{\bar{v}^3}{(\bar{v})^3} = \frac{\Gamma\left(1+\frac{3}{k}\right)}{\Gamma^3\left(1+\frac{1}{k}\right)} \dots \dots \dots (3.15)$$

Once the energy pattern factor is calculated by using the above equation, the Weibull shape factor and scale factor can be estimated from the following formulas (Costa *et al.*, 2012):

$$k = 1 + \frac{3.69}{E_{pf}} \dots \dots \dots (3.16)$$

$$c = \frac{\bar{v}}{\Gamma\left(1+\frac{1}{k}\right)} \dots \dots \dots (3.17)$$

Where E_{pf} is the energy pattern factor; and Γ is the gamma function.

3.5 Extrapolation of Wind Speed at Different Hub Height

In most cases, the available wind data are measured at a height different from the wind turbine hub height. It is noted that it is the wind speed at the hub height that is of interest for wind power application; therefore, the available wind speeds are

adjusted to the wind turbine hub height using the following power law expression, e.g., (Akpinar and Akpinar, 2005):

$$\frac{V}{V_0} = \left(\frac{h}{h_0}\right)^\alpha \dots\dots\dots (3.18)$$

Where V is the wind speed at the hub height,

V_0 is wind speed at the original height (h_0) and

α is the surface roughness coefficient and is assumed to be 0.143 (or 1/7)

in most cases. The surface roughness coefficient α can be determined from

the following expression (Ucar and Balo, 2009):

$$\alpha = [0.37 - 0.088 \ln(V_0)] / [1 - 0.088 \ln\left(\frac{h_0}{10}\right)] \dots\dots\dots (3.19)$$

Alternatively, the Weibull probability density function can be used to obtain the extrapolated values of wind speed at different heights. Since the boundary layer development and the effect of the ground are non-linear with respect to wind speed, the scale factor c and form factor k of the Weibull distribution will change as a function of height by the following expressions (Justus *et al.*, 1978):

$$c(h) = c_0 \left(\frac{h}{h_0}\right)^n \dots\dots\dots (3.20)$$

$$k(h) = k_0 \left[1 - 0.088 \ln\left(\frac{h_0}{10}\right)\right] / \left[1 - 0.088 \ln\left(\frac{h}{10}\right)\right] \dots\dots\dots (3.21)$$

Where c_0 and k_0 are the scale factor and shape parameter, respectively, at the measurement height h_0 . The exponent n is defined as (Justus *et al.*, 1978):

$$n = [0.37 - 0.088 \ln(c_0)] / \left[1 - 0.088 \ln\left(\frac{h_0}{10}\right)\right] \dots\dots\dots (3.22)$$

3.6 Mean Wind Power Density and Energy Density

The mean wind power density can be estimated by using the following equation:

$$P_D = \frac{P(v)}{A} = \frac{1}{2} \rho \bar{v}^3 \dots\dots\dots (3.21)$$

Where $P(v)$ = the wind power (in Watts),

P_D = the wind power density (Watts per square meter),

ρ = the air density at the site (assumed to be 1.225 kg/m³ in this study) and

A = the swept area of the rotor blades (in square meter).

Both the mean wind speed and power density are generally used to classify the wind energy resource (e.g., Pacific Northwest Laboratory (PNL) wind power classification scheme (Ilinca *et al.*, 2003).

However, the wind power density (wind power per unit area) based on the Weibull probability density function can be calculated using the following equation (Celik, 2004):

$$P_D = \frac{P(v)}{A} = \frac{1}{2} \rho c^3 \Gamma(1 + \frac{3}{k}) \dots\dots\dots (3.22)$$

The mean energy density (E_D) over a period of time T is the product of the mean power density and the time T, and it is expressed as (Celik, 2004):

$$E_D = \frac{1}{2} \rho c^3 \Gamma(1 + \frac{3}{k}) T \dots\dots\dots (3.23)$$

Where k , c , P_D and E_D are shape factor, scale factor, wind power density and energy density at the desired height, respectively. The h_0 is the reference height. ρ is the air density and for standard conditions (*i.e.*, at sea level with temperature of 15 °C and pressure of 1 atmosphere) and is equal to 1.225 kg/m³ and v is the wind

speed (m/s). In this work, the Weibull distribution model was used to find wind speed and wind power at a height of 20-50m.

3.7 Wind Turbine Energy Output and Capacity Factor

A wind energy conversion system can operate at its maximum efficiency only if it is designed for a particular site because the rated power and cut-in and cut-off wind speeds must be defined based on the site wind characteristics (Akpinar and Akpinar, 2005). It is essential that these parameters are selected so that energy output from the conversion system is maximized. The performance of a wind turbine installed in a given site can be examined by the amount of mean power output over a period of time ($P_{e,ave}$) and the conversion efficiency or capacity factor of the turbine. The capacity factor C_f is defined as the ratio of the mean power output to the rated electrical power (P_{eR}) of the wind turbine, (Balouktsis *et al.*, 2002).

The mean power output $P_{e,ave}$ and capacity factor C_f of a wind turbine can be estimated using the following expressions based on Weibull distribution function (Akpinar and Akpinar, 2005):

$$P_{e,ave} = P_{eR} \left[\frac{e^{-\left(\frac{V_c}{c}\right)^k} - e^{-\left(\frac{V_r}{c}\right)^k}}{\left(\frac{V_r}{c}\right)^k - \left(\frac{V_c}{c}\right)^k} e^{-\left(\frac{V_f}{c}\right)^k} \right] \dots \dots \dots (3.24)$$

$$C_f = \frac{P_{e,ave}}{P_{eR}} \dots \dots \dots (3.25)$$

Where V_c , V_r and V_f are the cut-in wind speed, rated wind speed and cut-off wind speed, respectively. For an investment in wind power to be cost effective, it is suggested that the capacity factor should be greater than 0.25 (Mathew, 2006).

3.8 Statistical Error Analysis

(a) Root mean square error (RMSE) is expressed as (Mohammadi *et al.*, 2013):

$$RMSE = \left[\frac{1}{N} \sum_{i=1}^N (y_{i,m} - x_{i,w})^2 \right]^{1/2} \dots\dots\dots (3.26)$$

(b) Chi-square error is expressed as (Costa *et al.*, 2012):

$$X^2 = \frac{\sum_{i=1}^N (y_{i,m} - x_{i,w})^2}{N-n} \dots\dots\dots (3.27)$$

(c) Analysis of variance or efficiency of the method is expressed as (Justus *et al.*, 1976):

$$R^2 = \frac{\sum_{i=1}^N (y_{i,m} - z_{i,\bar{v}})^2 - \sum_{i=1}^N (y_{i,m} - x_{i,w})^2}{\sum_{i=1}^N (y_{i,m} - z_{i,\bar{v}})^2} \dots\dots\dots (3.28)$$

Where N is the number of observations; $y_{i,m}$ is the frequency of observation or i^{th} calculated value from measured data; $x_{i,w}$ is the frequency of Weibull or i^{th} calculated value from the Weibull distribution; $z_{i,\bar{v}}$ is the mean of i^{th} calculated values from measured data. Best results are obtained when these values are close to zero. R^2 determines the linear relationship between the calculated values from the Weibull distribution and the calculated values from measured data. The ideal value of R^2 is equal to 1 (Justus *et al.*, 1978).

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Mean Monthly Wind Speeds for Different Seasons of the Year

Table 1 shows the estimated monthly and annual mean wind speed (m/s) at a height of 10m of the meteorological stations.

The monthly variation of wind speeds of the year for each of the selected stations shown in Figure 4.1 exhibits a similar trend. The gradual increase in the mean wind speed value from January to April could be linked to the general rise in solar radiation associated with dry season. The decreasing trend noticed in some of the stations from May to September is due to the drop in temperature during the rainy season. However, the sudden rise from October to November could be attributed to thermal convection resulting from low temperature, causing the upper air momentum to be transferred to lower layers.

The wind speed has a maximum value of 8.1m/s at Jos in November, and a minimum value of 0.8 m/s at Lokoja in December. From Figure 4.1, it can be seen that high wind speeds occur in dry season in all the locations. During dry season, the wind speed level at two stations (Kano and Jos) reaches high values of 6.1 and 8.1 m/s respectively. While, Lokoja has the lowest value of 0.8m/s of mean wind speed which was recorded in December. In wet season, the wind speed level at Kano and Jos reaches high values of 6.1 and 7.3m/s respectively; while Lokoja has the lowest value of 1.3m/s mean wind speed in August and September.

Figure 4.2 illustrates the annual mean wind speeds for all the stations. The wind speeds decrease from Jos to Lokoja. In general, it can be taken that, Jos and Kano are the windiest stations with annual mean wind speeds greater than 5.7m/s.

Table 4.1: Estimated Monthly and Annual Mean Wind Speed (m/s) at a height 10m

Month /station	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual mean
Kano	6.1	5.9	6.1	6.0	5.7	5.9	6.1	5.0	4.6	4.6	5.9	6.0	5.7
Lagos	1.6	1.6	1.7	1.6	1.7	1.7	1.8	1.9	1.8	1.6	1.6	1.7	1.7
Jos	7.2	7.4	7.4	7.3	6.6	6.2	6.4	6.1	6.0	6.6	8.1	7.5	6.9
Enugu	4.3	3.6	4.1	4.1	3.4	3.4	3.8	4.1	3.3	2.8	2.8	3.5	3.6
Ilorin	3.0	3.4	3.5	3.8	3.3	3.2	3.7	3.8	3.2	2.7	3.0	2.7	3.2
Lokoja	1.0	1.4	1.9	2.2	1.8	1.9	1.7	1.3	1.3	1.3	1.2	0.8	1.5

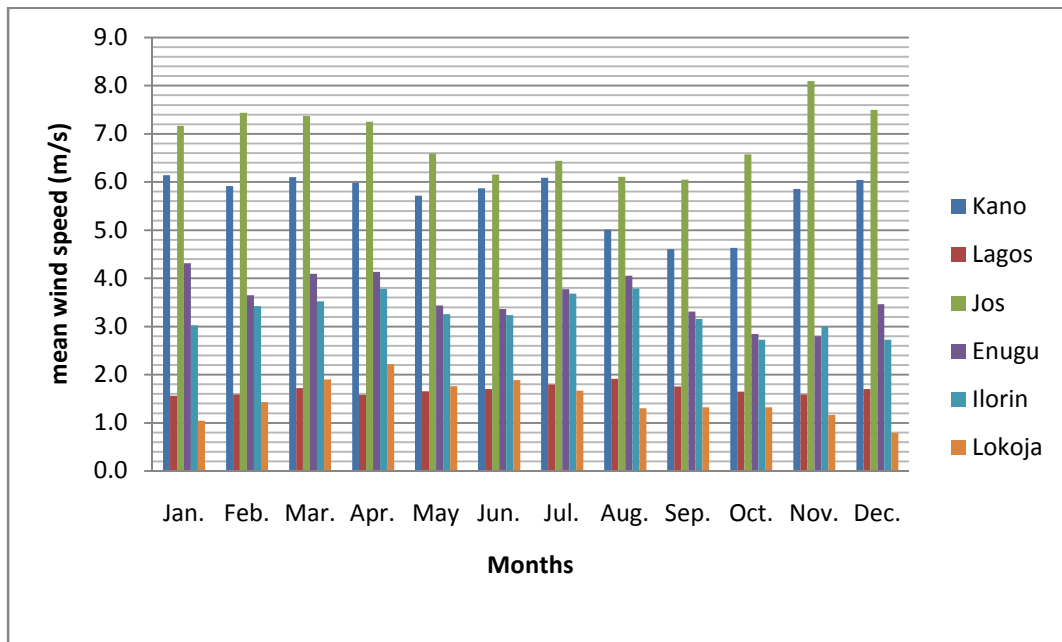


Figure 4.1: Variation of Mean Wind Speed of the Year

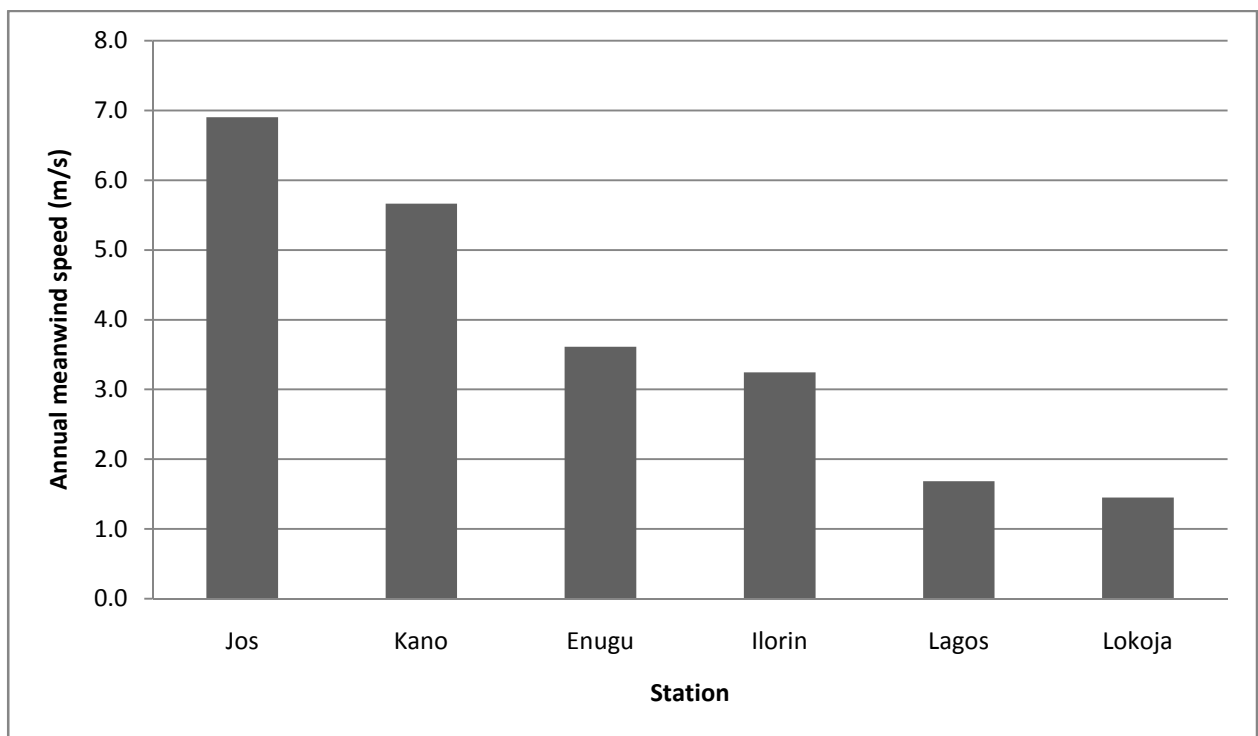


Figure 4.2: Annual Mean Wind Speed for Selected Stations

4.2 Frequency Distribution and Cumulative Frequency Distribution for the Selected Sites

It is important to know the number of hours per month or per year during which the given wind speeds occurred, i.e the frequency distribution of the wind speeds. When the percentage frequency distribution (F%) is plotted against the wind speed, the frequency distribution emerges as a curve. The top of this curve being the most frequent wind speed. This frequency distribution is also used to identify the most suitable site for the wind turbine (Anani *et al*, 1998).

From Figures 4.3, 4.4, 4.5, 4.6 4.7 and 4.8, Jos has 7m/s as the most frequent wind speed with frequency percentage of 43.8%, Kano has the most frequent wind speed of 6m/s with the frequency percentage of 38.3%, Enugu has 3m/s as the most frequent wind speed with frequency percentage of 57.1%, Ilorin has 3m/s as the most frequent wind speed with frequency percentage of 51.8%, Lagos has 2m/s as the most frequent wind speed with frequency of 86.4% and Lokoja has 2m/s as the most frequent wind speed with frequency of 55% respectively. From Figures 4.3-4.8, all the stations have most frequent wind speed of 2-3 m/s except Kano and Jos with a higher value above 5m/s.

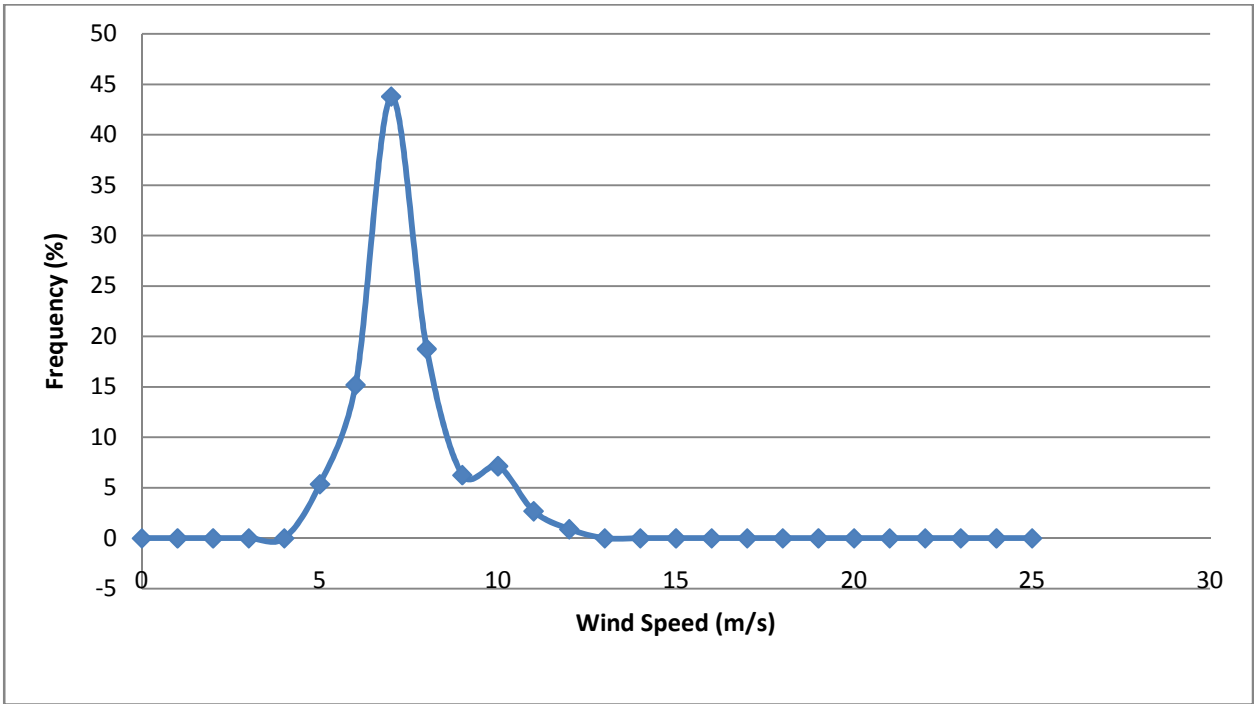


Figure 4.3: Wind Speed Frequency Distribution Throughout the Year For Jos

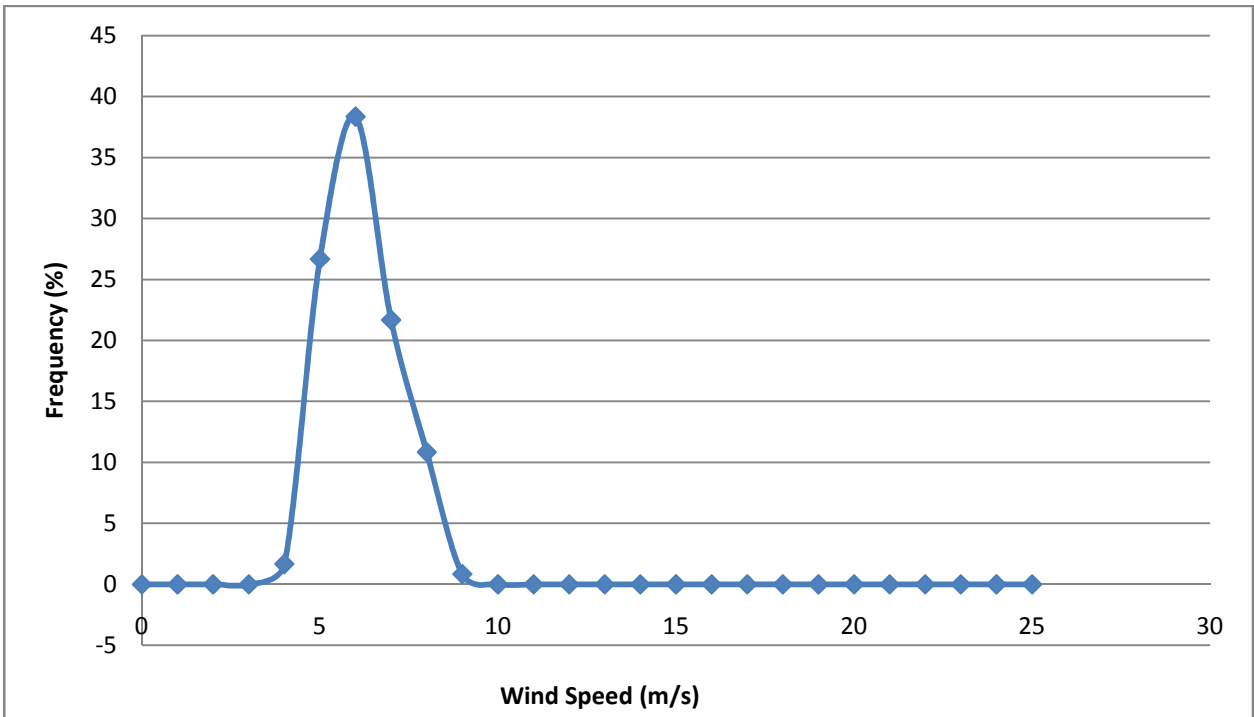


Figure 4.4: Wind Speed Frequency Distribution Throughout The Year For Kano

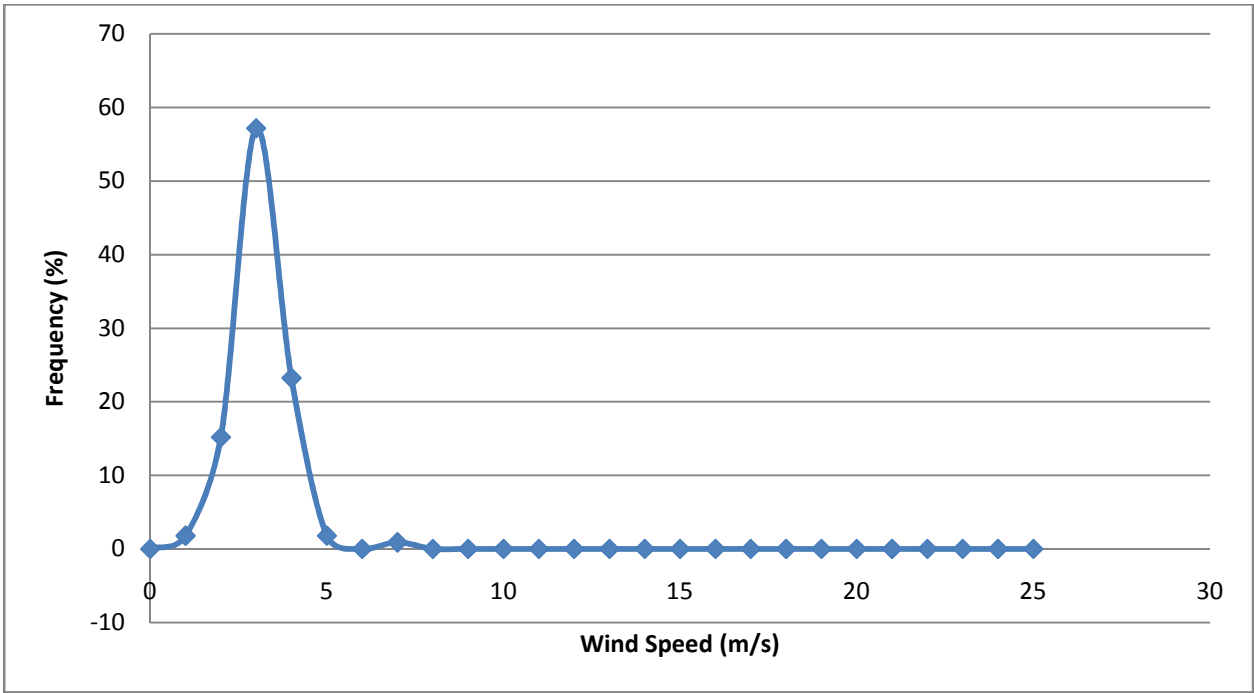


Figure 4.5: Wind Speed Frequency Distribution Throughout The Year For Enugu

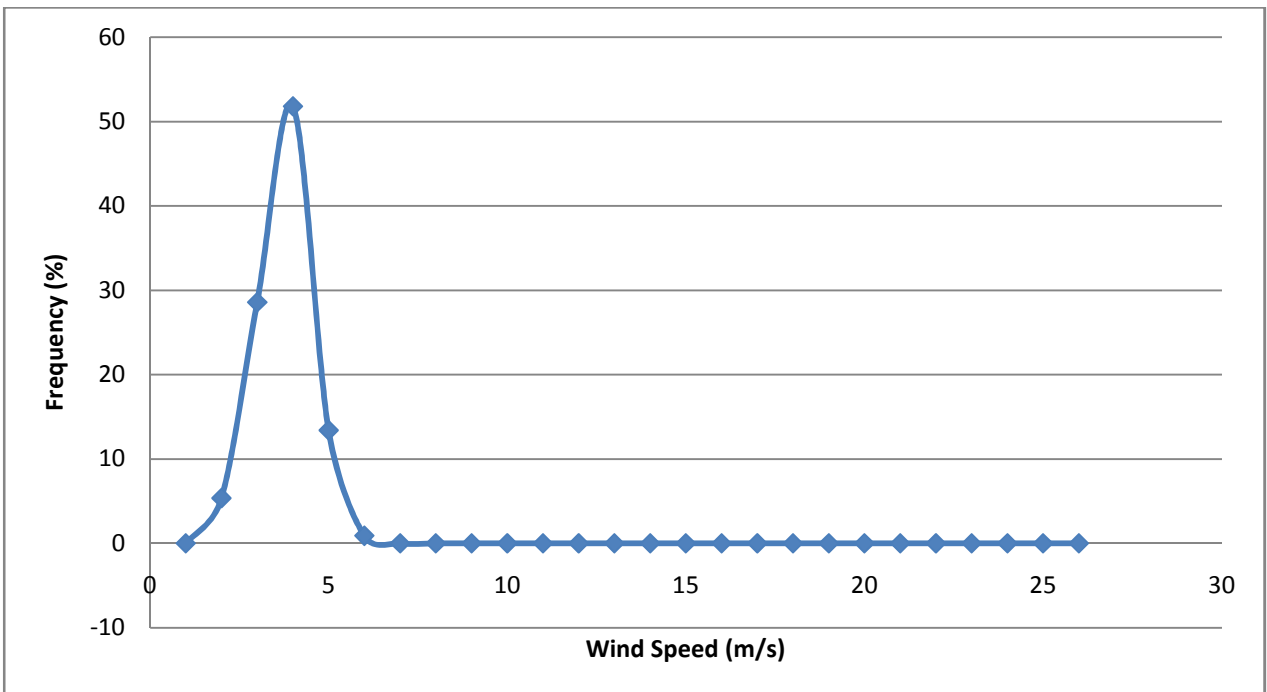


Figure 4.6: Wind Speed Frequency Distribution Throughout The Year For Ilorin

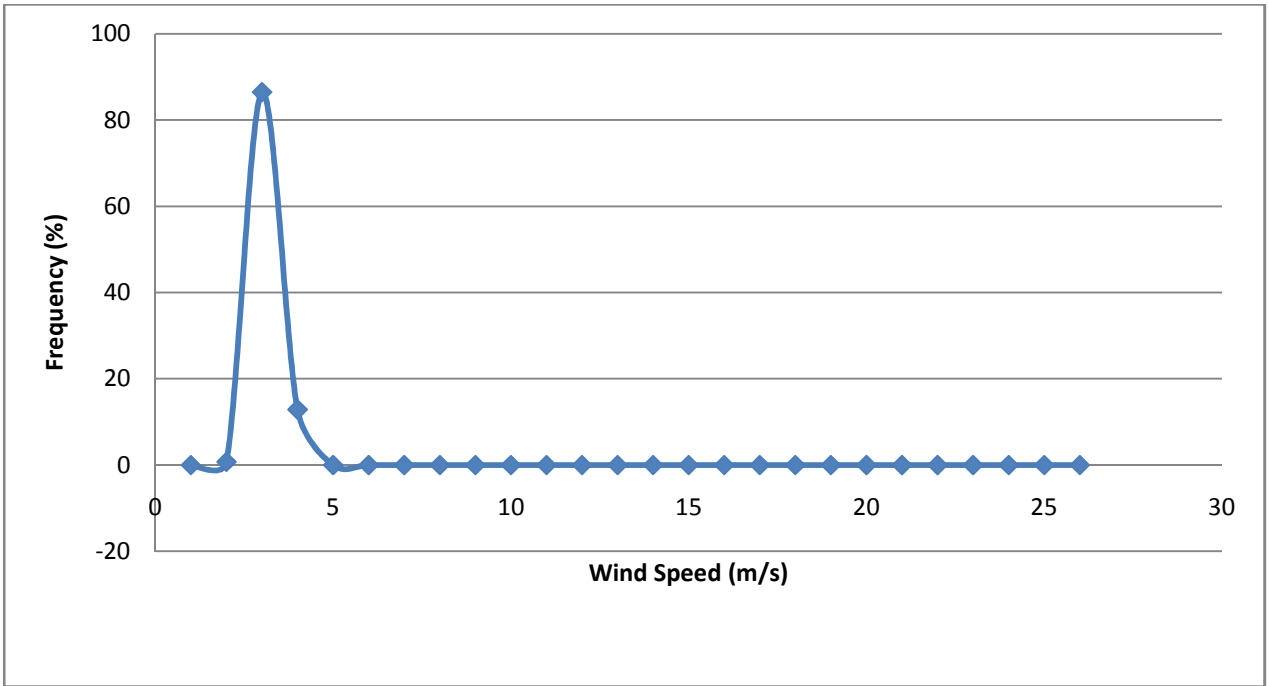


Figure 4.7: Wind Speed Frequency Distribution Throughout The Year For Lagos

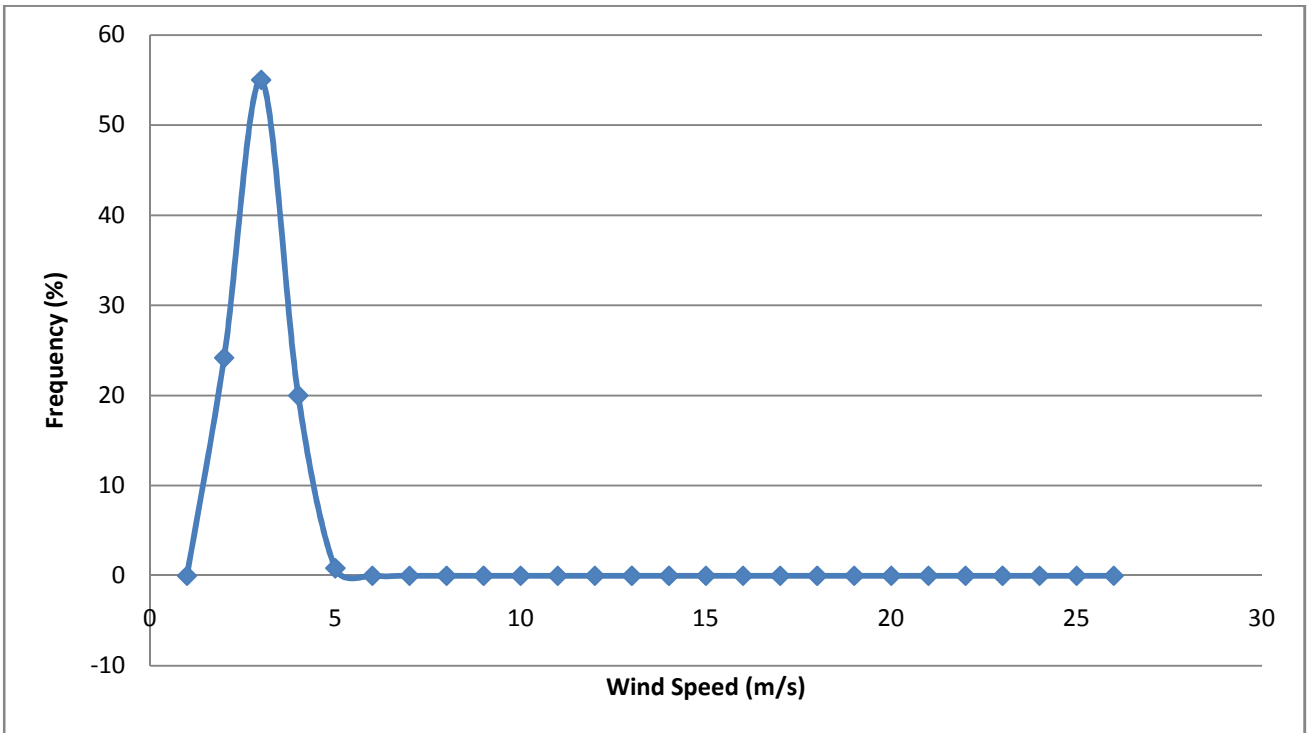


Figure 4.8: Wind Speed Frequency Distribution Throughout The For Lokoja

4.3 Weibull Distribution

The Weibull distribution shows its usefulness when the wind data of one reference station are being used to predict the wind regime in the surroundings of that station. The idea is that only annual or monthly average wind speeds are sufficient to predict the complete frequency distribution of the year or the month. The annual values of the monthly average wind speeds for the stations under study are estimated to predict the complete annual mean frequency distribution of the year for all stations.

4.3.1 Estimation of Weibull Parameters by Four Methods at Different Stations

To determine Weibull frequency distribution and Weibull cumulative distribution, it is necessary to determine first the scale parameter (c) and shape parameter (k). Using Microsoft Excel 2007 and gamma function calculator, the Weibull parameters were estimated using four methods with the actual time series data for five (5) years.

Table 4.8: Estimated Weibull Parameters with Actual Data at 10m Height

Stations	Enugu		Ilorin		Jos		Kano		Lokoja		Lagos	
Method	K (-)	c (m/s)	K (-)	c (m/s)	K (-)	c (m/s)	K (-)	c (m/s)	K (-)	c (m/s)	K (-)	c (m/s)
MLM	4.409	3.933	5.050	3.546	3.799	6.944	5.951	6.091	2.692	1.671	7.134	1.803
MOM	5.302	3.931	5.223	3.545	3.815	6.943	6.582	6.075	2.662	1.670	8.860	1.798
STD	5.276	3.932	5.199	3.546	3.811	6.943	6.534	6.077	2.670	1.670	8.766	1.799
PDF	4.214	3.984	4.230	3.589	3.940	6.930	4.367	6.218	3.453	1.651	4.493	1.864

4.3.2 Statistical Error Analysis of the Estimated Weibull Parameters

In statistical analysis, data from six wind monitoring stations were used to determine the best method of the weibull distribution. The most important results of this study, based on monthly mean and annual figures, are presented.

From the Tables 4.9 – 4.14, the most important statistical test gives a chi-square error of X^2 to be very close to zero, in Jos and Kano and the measure of the efficiency of the method (R^2) is approximately equal to 1, indicating the best fit between the measured and observed data. For Jos station, (see Table 4.12), PDM method shows a better performance than the others. The common factor was that the MLM gave the better performance at every site. MLM method showed better performance than others in terms of ranking. Therefore, it can be said that the MLM is the most efficient method for wind data assessment of the considered locations.

Table 4.9: Weibull Distribution Analysis For Kano

Methods	k(-)	c(m/s)	RMSE	R^2	X^2
MLM	5.951	6.091	0.08902	0.99974	0.01189
MOM	6.582	6.075	0.08995	0.99973	0.01214
STD	6.534	6.077	0.08999	0.99973	0.01215
PDM	4.367	6.218	0.11301	0.99958	0.01916

Table 4.10: Weibull distribution analysis for Enugu

Methods	k(-)	c(m/s)	RMSE	R^2	X^2
MLM	4.409	3.933	0.12615	0.99876	0.02785
MOM	5.302	3.931	0.13298	0.99862	0.03095
STD	5.276	3.932	0.13294	0.99862	0.03093
PDM	4.214	3.984	0.13460	0.99859	0.03171

Table 4.11: Weibull Distribution Analysis For Ilorin

Methods	k(-)	c(m/s)	RMSE	R ²	X ²
MLM	5.050	3.546	0.13999	0.99772	0.03266
MOM	5.223	3.545	0.14193	0.99766	0.03357
STD	5.199	3.546	0.14189	0.99766	0.03356
PDM	4.230	3.589	0.14214	0.99765	0.03367

Table 4.12: Weibull Distribution Analysis For Jos

Methods	k(-)	c(m/s)	RMSE	R ²	X ²
MLM	3.799	6.944	0.09385	0.99984	0.01174
MOM	3.815	6.943	0.09337	0.99984	0.01162
STD	3.811	6.943	0.09349	0.99984	0.01165
PDM	3.940	6.930	0.08973	0.99985	0.01074

Table 4.13: Weibull Distribution Analysis For Lokoja

Methods	k(-)	c(m/s)	RMSE	R ²	X ²
MLM	2.692	1.671	0.15809	0.98565	0.04998
MOM	2.662	1.670	0.15700	0.98584	0.04930
STD	2.670	1.670	0.15931	0.98542	0.05076
PDM	3.453	1.651	0.17126	0.98315	0.05866

Table 4.14: Weibull Distribution Analysis For Lagos

Methods	k(-)	c(m/s)	RMSE	R ²	X ²
MLM	7.134	1.803	0.27883	0.87564	0.23324
MOM	8.860	1.798	0.30122	0.85487	0.27220
STD	8.766	1.799	0.30065	0.85541	0.27118
PDM	4.493	1.864	0.27634	0.87785	0.22910

4.3.4 Weibull Probability Density Distributions for the Selected Sites

The Weibull distribution gives a good match with the measurement data as shown in Figures 4.9-4.20 in comparison with weibull probability distributions figures.

This is also mentioned by Vogiatzis *et al.* (2004). This distribution is characterized

by two parameters: the shape parameter k (dimensionless) and scale parameter c (m/s). Tables 4.8 give the estimates of the parameters c and k for the four methods. In this study, the annual Weibull functions and its two parameters are derived from the available data and are shown in Figures 4.9-4.20 which show the frequency distribution throughout the year in the selected sites. In Figure 4.9, Lagos has the most 'peaked' Weibull wind distribution with the shape factor of 7.134 and its most frequent wind speed is 2m/s. Figure 4.11 shows that Lokoja has the lowest shape factor of 2.692, scale factor of 1.671m/s and its most frequent wind speed to be 2m/s. Figure 4.13 shows that Jos is the most 'windy' place with the largest scale factor of 6.944m/s and its most frequent wind speed is 7m/s;

The annual values of the monthly average wind speeds for the stations under study were estimated using the Weibull probability density distribution in order to predict the complete annual mean weibull probability density function and the cumulative distribution function of the year for all the stations, as shown in Figures 4.21 and 4.22

It can be observed from Figure 4.21 that:

- (1) All the probability densities have the same trend and have pronounced peaks, which are located in the neighbourhood of the mean wind speed.
- (2) In all the stations, the peak probability densities are shifted towards the higher values of mean wind speed. For example, Jos has mean wind speed of 8m/s and

peak probability density value of 0.20, while Lagos has mean wind speed of 4m/s and peak probability of 0.92.

(3) In general, all the stations have peak probability densities

(4) For the investigated stations in this study, no probability densities occurred for a mean wind speed of 12 m/s which is the cut out speed.

One important characteristic which is noted from figure 4.21 is that: there are no frequencies for mean wind speed of zero speed (calm winds). This is discussed by Vogiatzis *et al.* (2004) as follows: wind speed frequencies based directly on measurements and those computed through Weibull distribution formula (theoretical), the comparison indicates a good agreement except for the range of wind stillness. Where the mathematical formula of Weibull distribution imposes zero probability, while the frequency computed directly through the measurements attains significant values.

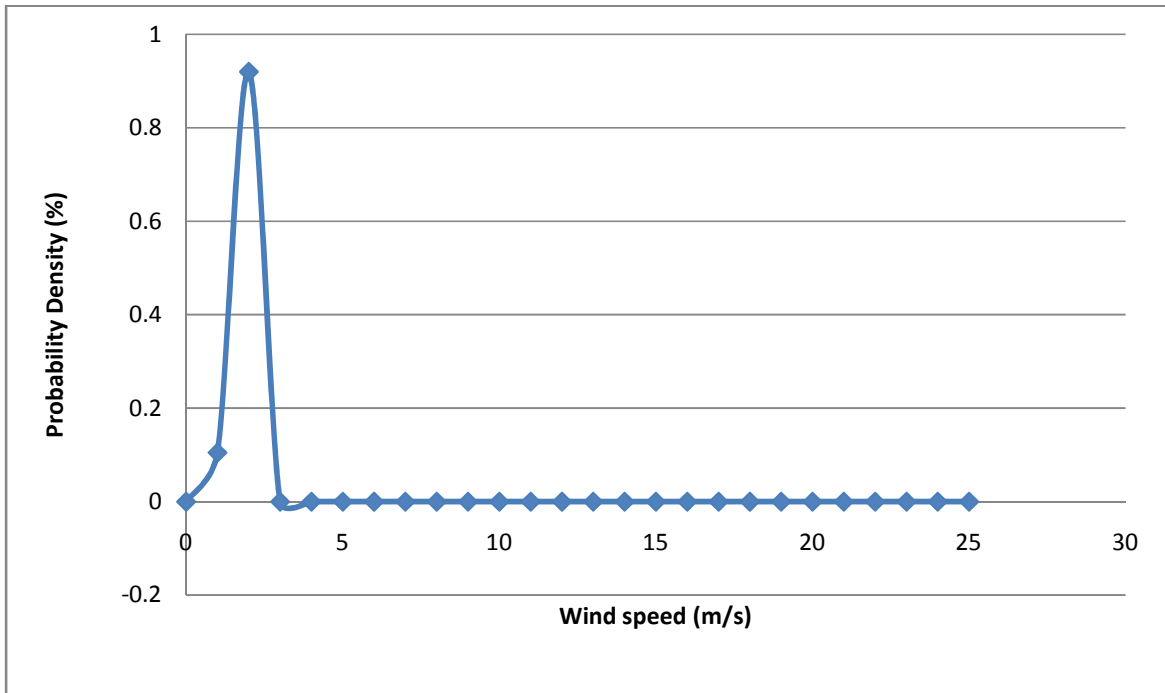


Figure 4.9 Weibull Probability Density Distribution of Lagos

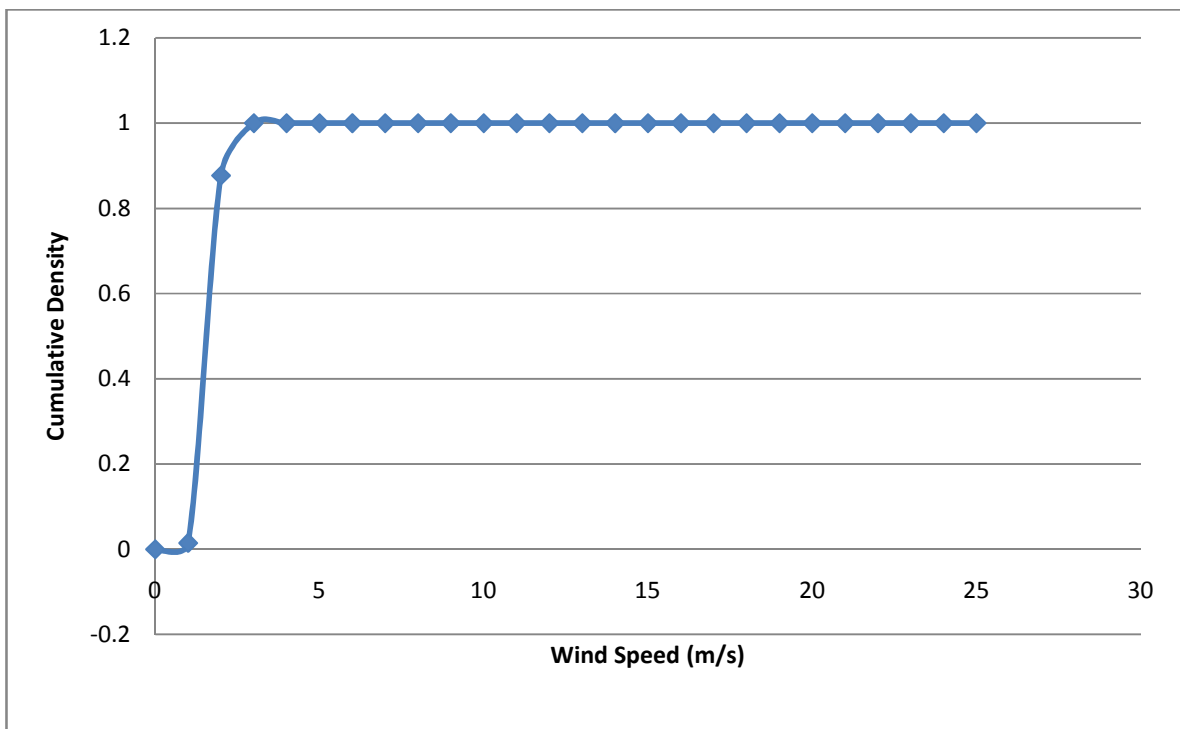


Figure 4.10 Weibull Cumulative Distribution of Lagos

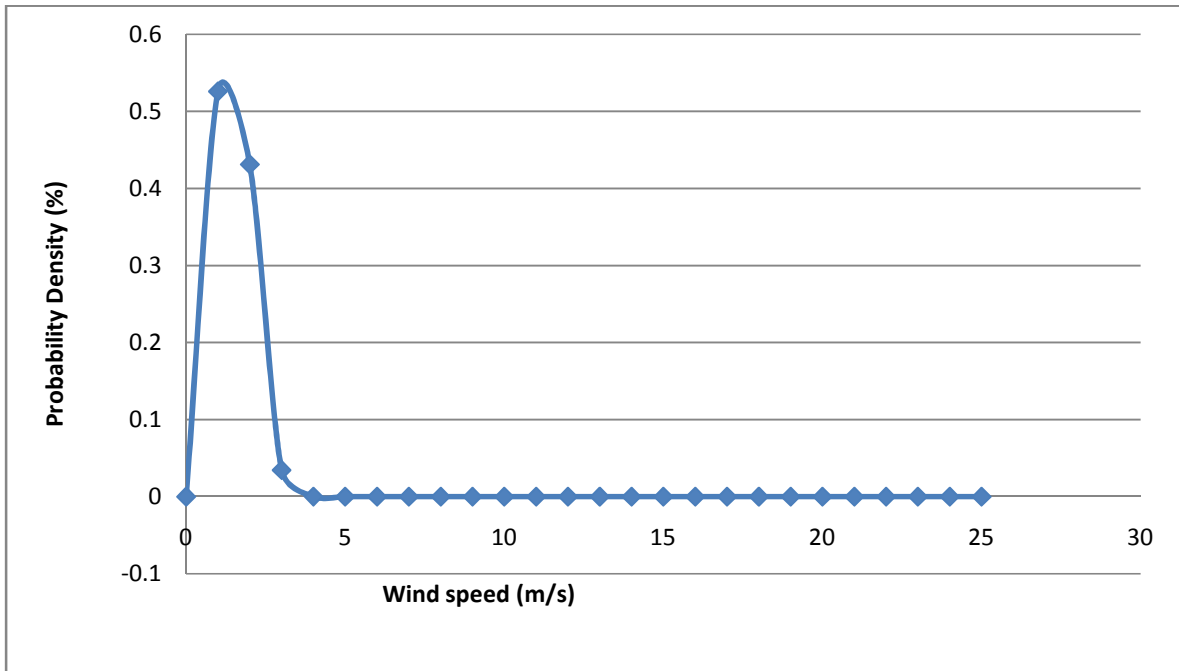


Figure 4.11 Weibull Probability Density Distribution of Lokoja

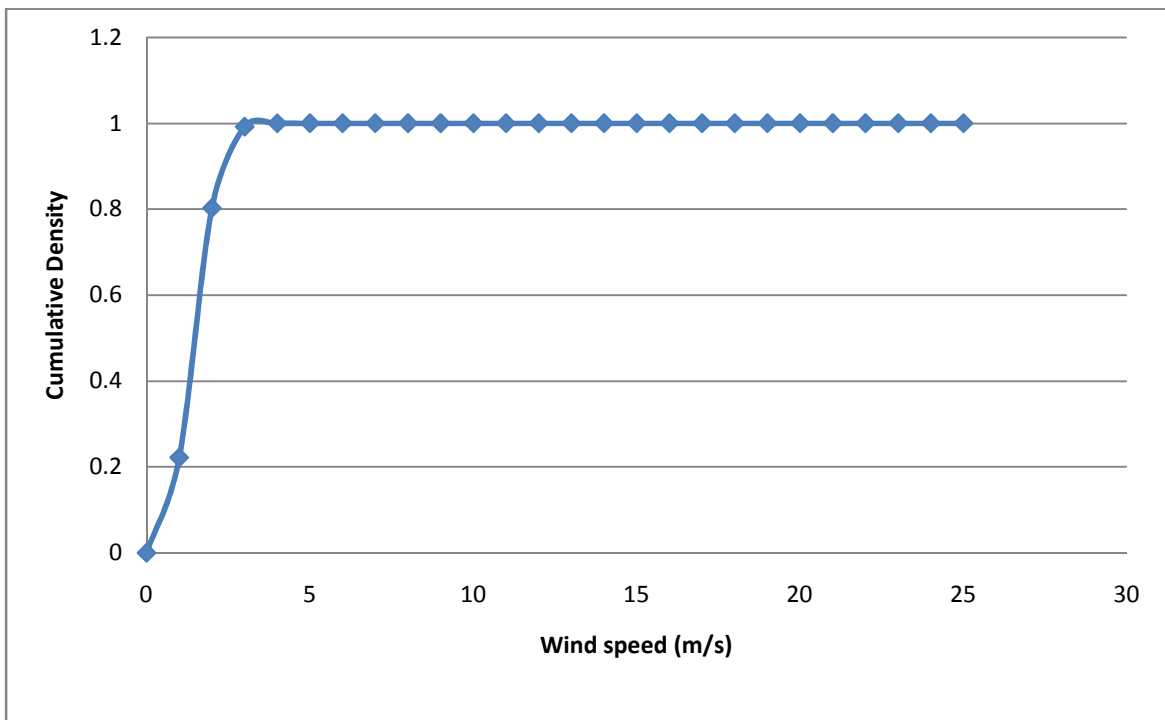


Figure 4.12 Weibull Cumulative Distribution of Lokoja

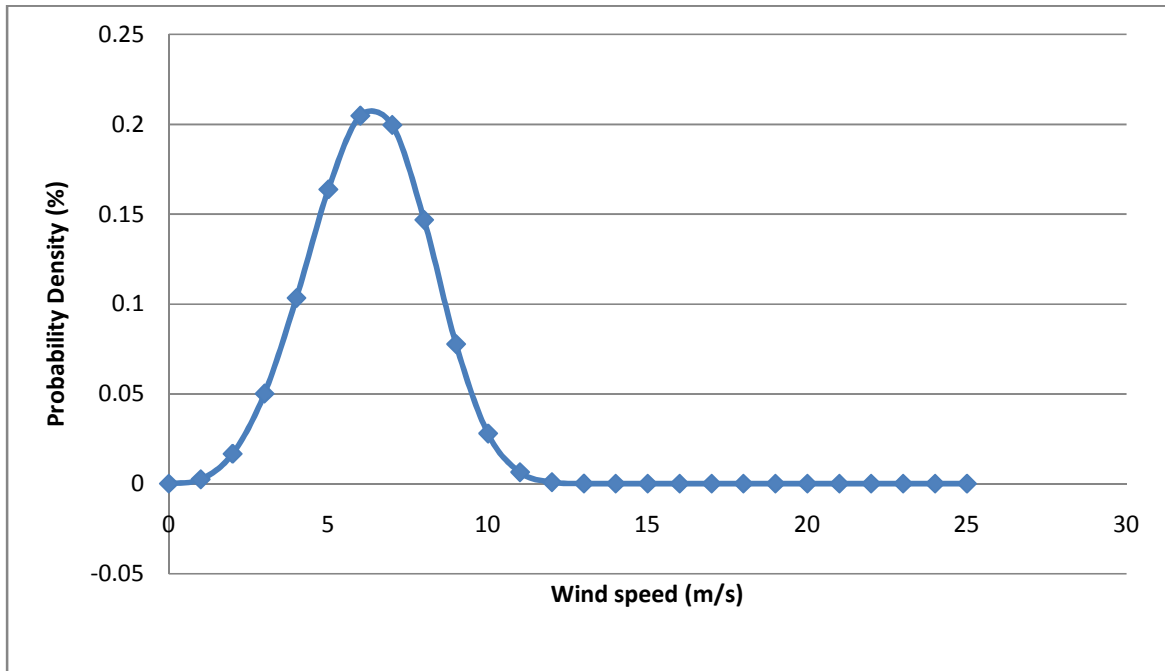


Figure 4.13 Weibull Probability Density Distribution of Jos

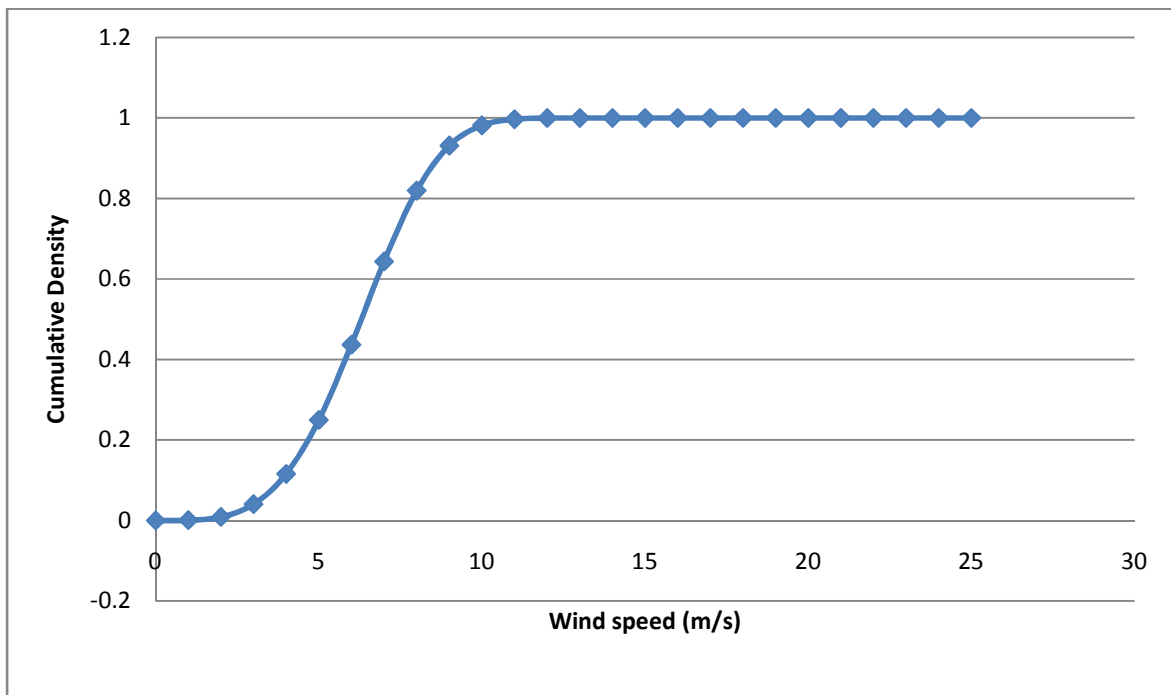


Figure 4.14 Weibull Cumulative Distribution of Jos

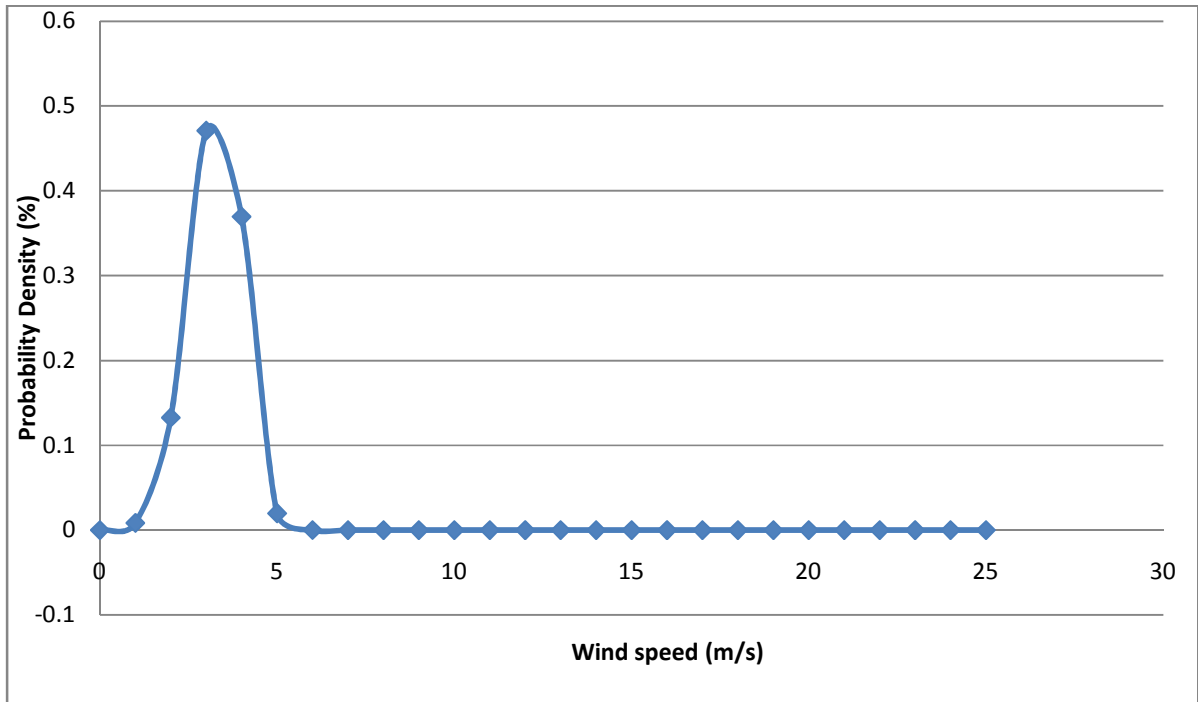


Figure 4.15 Weibull Probability Density Distribution of Ilorin

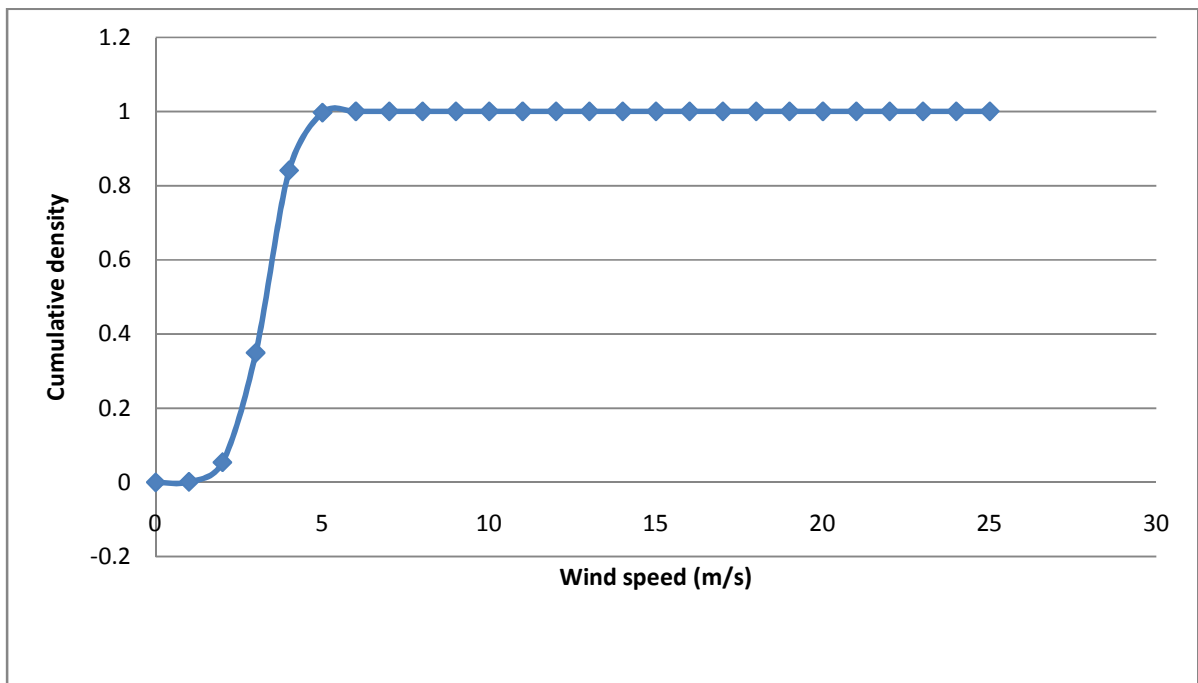


Figure 4.16 Weibull Cumulative Distribution of Ilorin

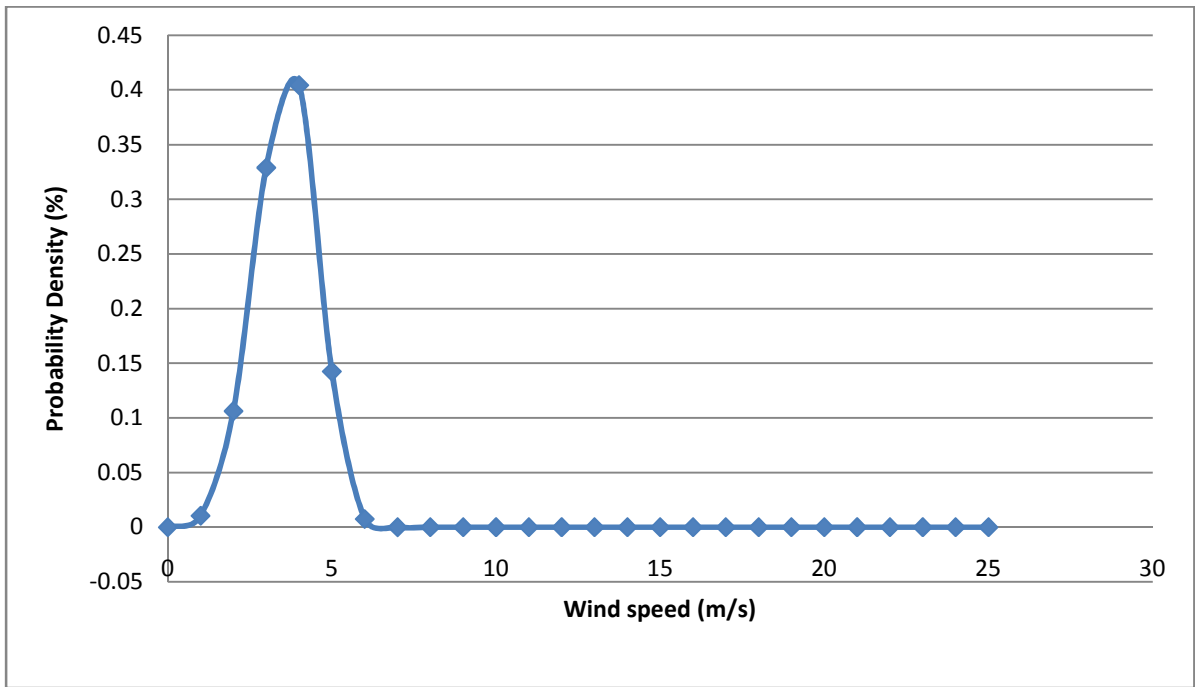


Figure 4.17 Weibull Probability Density Distribution of Enugu

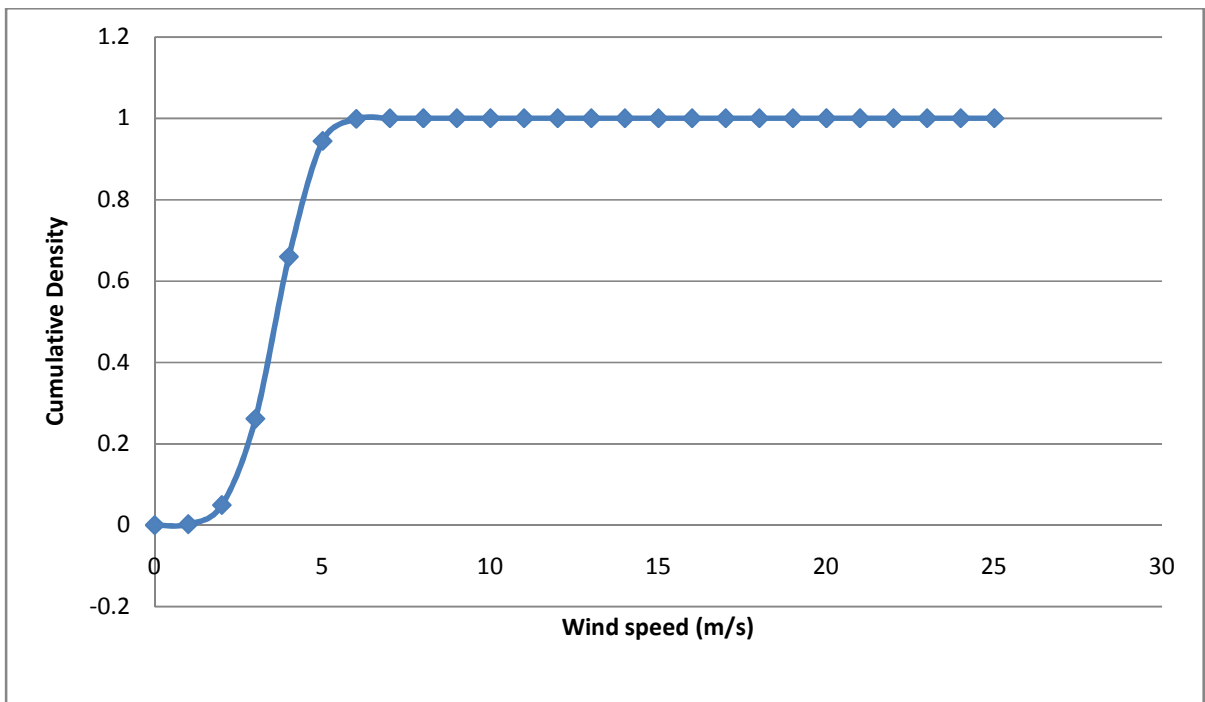


Figure 4.18 Weibull Cumulative Distribution of Enugu

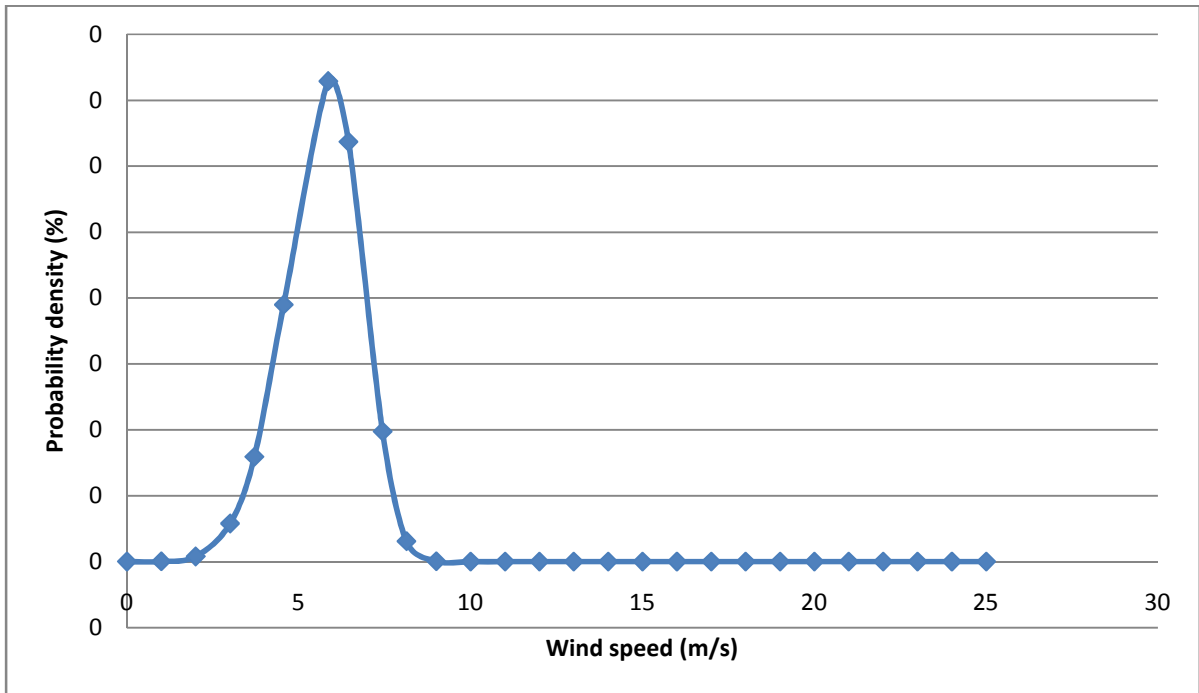


Figure 4.19 Weibull Probability Density Distribution of Kano

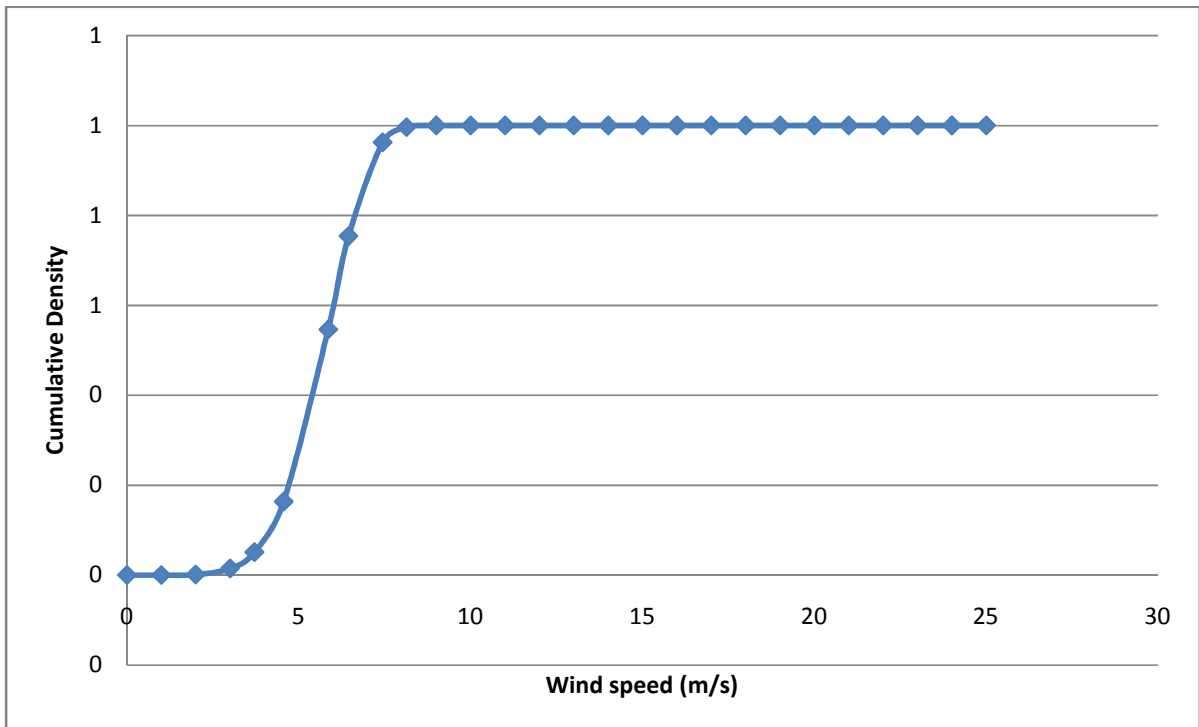


Figure 4.20 Weibull Cumulative Distribution of Kano

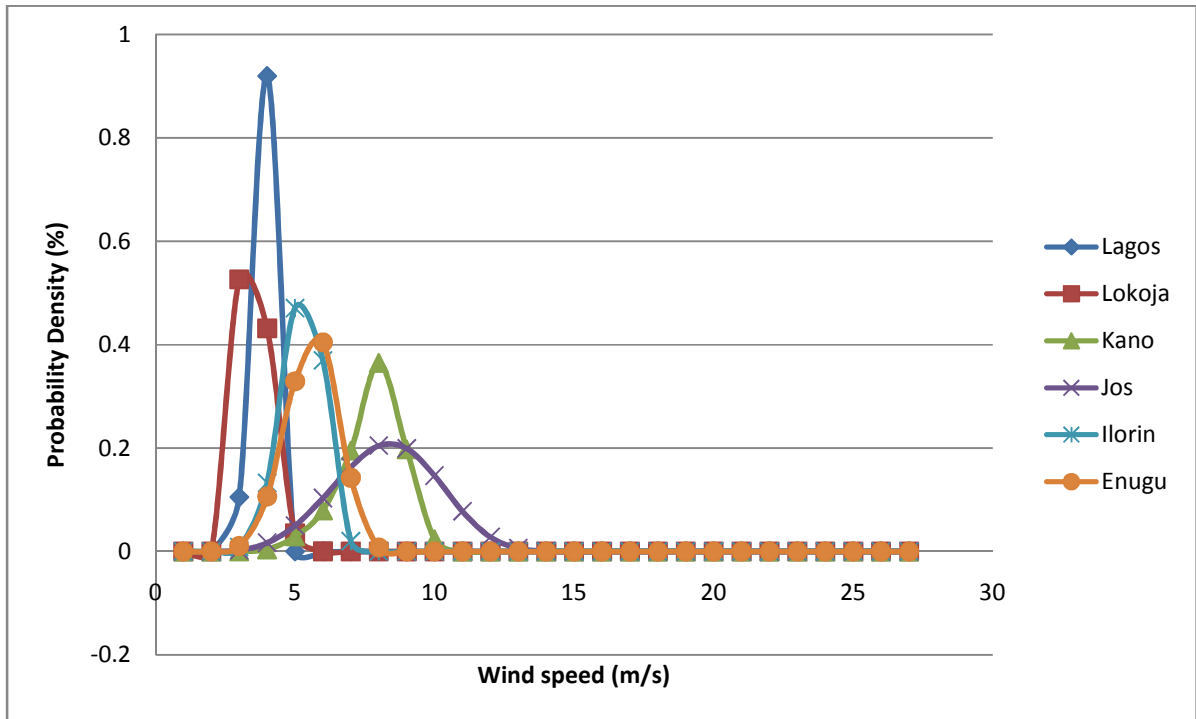


Figure 4.21 Weibull Probability Density Distribution of Selected Stations

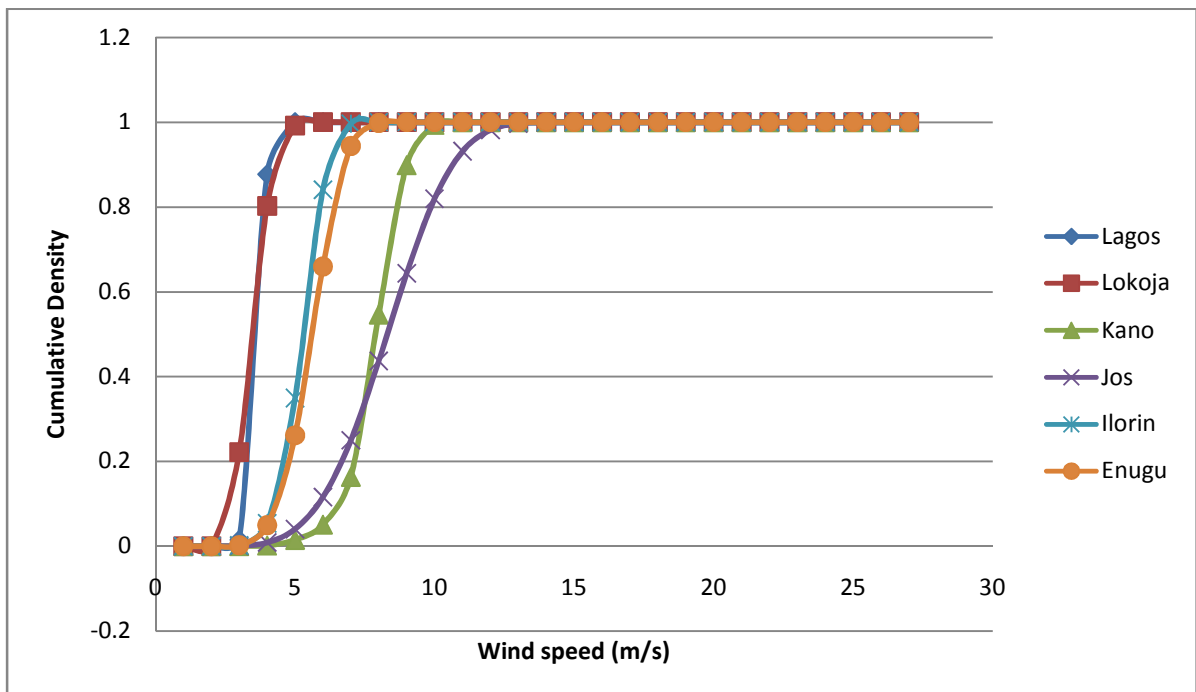


Figure 4.22 Weibull Cumulative Distribution of Selected Stations

4.4 Probability Estimation

In general, wind turbines are designed with a cut-in wind speed, or the wind speed at which it begins to produce power, and a cut-out speed, or the wind speed at which the turbine will be shut down to prevent the drive train from being damaged. For most of the turbines, the range of cut-in and cut-out speed is 3 to 25m/s. As in the concerning locations, wind speed more than 12 m/s is very rare; the cut-out speed is chosen as 12m/s reducing the cost of the system. Using equation (3.3), the probability that at any time the wind speed at a site is greater than 3.0 m/s for each of the stations was obtained and the results are given in Table 4.21.

Table 4.21: Probability that $v > 3.0$ m/s

Station	k (-)	c (m/s)	p ($v > 3$)
Enugu	4.409	3.933	0.74
Ilorin	5.050	3.546	0.65
Jos	3.799	6.944	0.96
Kano	5.951	6.091	0.99
Lokoja	2.692	1.671	0.01
Lagos	7.134	1.803	0.00

It is clearly seen from Table 4.21 that at the height of 10 m above ground level, only four stations have significant probability distribution that the wind speed is greater than 3.0 m/s. These stations, in order of decreasing probability distributions, are Kano, Jos, Enugu, and Ilorin. The probability that the wind speed would be greater than this value is virtually nonexistent for Lokoja and Lagos.

4.5 Extrapolation of Annual Mean Wind Speed and Weibull Parameters with Heights

An obvious calculation is that the Weibull distribution function and its two parameters are quite different for different places at different heights, so it is important to choose a suitable site with good wind field for wind turbine.

Annual mean wind speed and Weibull parameters were estimated based on the four methods (i.e MLM, MOM, STD and PDM) with the actual time series data for all the years at 10m, 20m, 30m, 40m and 50m. The variation in the values for all the sites analyses are given in Tables 4.22-4.27.

Table 4.22: Estimated Mean Velocity (m/s), Weibull Parameters, k (-) and c (m/s) at 10m, 20m, 30m, 40m and 50m using Four different Methods For Enugu

Station	Enugu			
Height (m)	Methods	V (m/s)	k (-)	c (m/s)
10	MLM	3.622	4.409	3.933
	MOM	3.622	5.302	3.931
	STD	3.622	5.276	3.932
	PDM	3.622	4.214	3.984
Height (m)	Methods	V (m/s)	k (-)	c (m/s)
20	MLM	4.327	4.696	4.728
	MOM	4.327	5.647	4.727
	STD	4.327	5.619	4.728
	PDM	4.327	4.487	4.786
Height (m)	Methods	V (m/s)	k (-)	c (m/s)
30	MLM	4.802	4.881	5.327
	MOM	4.802	5.870	5.325
	STD	4.802	5.841	5.327
	PDM	4.802	4.665	5.389
Height (m)	Methods	V (m/s)	k (-)	c (m/s)
40	MLM	5.170	5.022	5.831
	MOM	5.170	6.039	5.830
	STD	5.170	6.009	5.831
	PDM	5.170	4.799	5.897
Height (m)	Methods	V (m/s)	k (-)	c (m/s)
50	MLM	5.475	5.137	6.278
	MOM	5.475	6.177	6.277
	STD	5.475	6.147	6.278
	PDM	5.475	4.909	6.347

Table 4.23: Estimated Mean Velocity (m/s), Weibull Parameters, k (-) and c (m/s) at 10m, 20m, 30m, 40m and 50m using Four different Methods For Ilorin

Height (m)	Methods	V (m/s)	k (-)	c (m/s)
10	MLM	3.263	5.050	3.546
	MOM	3.263	5.223	3.545
	STD	3.263	5.199	3.546
	PDM	3.263	4.230	3.589
Height (m)	Methods	V (m/s)	k (-)	c (m/s)
20	MLM	3.924	5.378	4.291
	MOM	3.924	5.563	4.291
	STD	3.924	5.536	4.292
	PDM	3.924	4.505	4.340
Height (m)	Methods	V (m/s)	k (-)	c (m/s)
30	MLM	4.370	5.591	4.856
	MOM	4.370	5.782	4.855
	STD	4.370	5.755	4.857
	PDM	4.370	4.683	4.909
Height (m)	Methods	V (m/s)	k (-)	c (m/s)
40	MLM	4.718	5.752	5.334
	MOM	4.718	5.949	5.333
	STD	4.718	5.921	5.334
	PDM	4.718	4.818	5.389
Height (m)	Methods	V (m/s)	k (-)	c (m/s)
50	MLM	5.006	5.884	5.758
	MOM	5.006	6.085	5.757
	STD	5.006	6.056	5.759
	PDM	5.006	4.928	5.816

Table 4.24: Estimated Mean Velocity (m/s), Weibull Parameters, k (-) and c (m/s) at 10m, 20m, 30m, 40m and 50m using Four different Methods For Jos

Height (m)	Methods	V (m/s)	k (-)	c (m/s)
10	MLM	6.276	3.799	6.944
	MOM	6.276	3.815	6.943
	STD	6.276	3.811	6.943
	PDM	6.276	3.940	6.930
Height (m)	Methods	V (m/s)	k (-)	c (m/s)
20	MLM	7.251	4.046	8.046
	MOM	7.251	4.063	8.044
	STD	7.251	4.058	8.045
	PDM	7.251	4.195	8.031
Height (m)	Methods	V (m/s)	k (-)	c (m/s)
30	MLM	7.891	4.206	8.850
	MOM	7.891	4.224	8.849
	STD	7.891	4.218	8.850
	PDM	7.891	4.361	8.835
Height (m)	Methods	V (m/s)	k (-)	c (m/s)
40	MLM	8.378	4.327	9.514
	MOM	8.378	4.345	9.513
	STD	8.378	4.340	9.514
	PDM	8.378	4.487	9.498
Height (m)	Methods	V (m/s)	k (-)	c (m/s)
50	MLM	8.777	4.426	10.093
	MOM	8.777	4.445	10.092
	STD	8.777	4.439	10.092
	PDM	8.777	4.590	10.077

Table 4.25: Estimated Mean Velocity (m/s), Weibull Parameters, k (-) and c (m/s) at 10m, 20m, 30m, 40m and 50m using Four different Methods For Kano

Height (m)	Methods	V (m/s)	k (-)	c (m/s)
10	MLM	5.664	5.951	6.091
	MOM	5.664	6.582	6.075
	STD	5.664	6.534	6.077
	PDM	5.664	4.367	6.218
Height (m)	Methods	V (m/s)	k (-)	c (m/s)
20	MLM	6.585	6.338	7.118
	MOM	6.585	7.010	7.100
	STD	6.585	6.958	7.103
	PDM	6.585	4.651	7.256
Height (m)	Methods	V (m/s)	k (-)	c (m/s)
30	MLM	7.192	6.588	7.873
	MOM	7.192	7.287	7.854
	STD	7.192	7.233	7.857
	PDM	7.192	4.834	8.019
Height (m)	Methods	V (m/s)	k (-)	c (m/s)
40	MLM	7.656	6.778	8.500
	MOM	7.656	7.497	8.480
	STD	7.656	7.442	8.483
	PDM	7.656	4.974	8.651
Height (m)	Methods	V (m/s)	k (-)	c (m/s)
50	MLM	8.037	6.933	9.048
	MOM	8.037	7.668	9.027
	STD	8.037	7.612	9.030
	PDM	8.037	5.088	9.204

Table 4.26: Estimated Mean Velocity (m/s), Weibull Parameters, k (-) and c (m/s) at 10m, 20m, 30m, 40m and 50m using Four different Methods For Lokoja

Height (m)	Methods	V (m/s)	k (-)	c (m/s)
10	MLM	1.484	2.692	1.671
	MOM	1.484	2.662	1.670
	STD	1.484	2.670	1.670
	PDM	1.484	3.453	1.651
Height (m)	Methods	V (m/s)	k (-)	c (m/s)
20	MLM	1.873	2.866	2.124
	MOM	1.873	2.835	2.123
	STD	1.873	2.843	2.122
	PDM	1.873	3.677	2.100
Height (m)	Methods	V (m/s)	k (-)	c (m/s)
30	MLM	2.145	2.980	2.481
	MOM	2.145	2.947	2.479
	STD	2.145	2.956	2.479
	PDM	2.145	3.822	2.454
Height (m)	Methods	V (m/s)	k (-)	c (m/s)
40	MLM	2.363	3.066	2.791
	MOM	2.363	3.032	2.789
	STD	2.363	3.041	2.789
	PDM	2.363	3.933	2.762
Height (m)	Methods	V (m/s)	k (-)	c (m/s)
50	MLM	2.546	3.136	3.073
	MOM	2.546	3.102	3.071
	STD	2.546	3.110	3.071
	PDM	2.546	4.023	3.042

Table 4.27: Estimated Mean Velocity (m/s), Weibull Parameters, k (-) and c (m/s) at 10m, 20m, 30m, 40m and 50m using Four different Methods For Lagos

Height (m)	Methods	V (m/s)	k (-)	c (m/s)
10	MLM	1.701	7.134	1.803
	MOM	1.701	8.860	1.798
	STD	1.701	8.766	1.799
	PDM	1.701	4.493	1.864
Height (m)	Methods	V (m/s)	k (-)	c (m/s)
20	MLM	2.128	7.597	2.280
	MOM	2.128	9.435	2.274
	STD	2.128	9.335	2.275
	PDM	2.128	4.785	2.353
Height (m)	Methods	V (m/s)	k (-)	c (m/s)
30	MLM	2.426	7.897	2.655
	MOM	2.426	9.808	2.648
	STD	2.426	9.704	2.649
	PDM	2.426	4.974	2.735
Height (m)	Methods	V (m/s)	k (-)	c (m/s)
40	MLM	2.663	8.125	2.980
	MOM	2.663	10.091	2.972
	STD	2.663	9.984	2.973
	PDM	2.663	5.117	3.066
Height (m)	Methods	V (m/s)	k (-)	c (m/s)
50	MLM	2.862	8.311	3.274
	MOM	2.862	10.321	3.266
	STD	2.862	10.212	3.267
	PDM	2.862	5.234	3.366

4.6 Comparison of Estimated and WIS Weibull Parameters

Weibull distribution function is the most widely used function for modeling wind speed around the globe. The scale factor (c) of the Weibull distribution is related to the average wind speed at different heights and is calculated using the maximum likelihood method. Similarly, the Weibull parameter (k) is the dimensionless shape factor of the Weibull distribution. This factor reflects the breadth of the distribution. The variation of both scale and shape parameters with heights for the calculated and the WIS is shown in Tables 4.28-4.33. Since the wind speed increases with height, the scale parameter too follows the same trend. The shape parameter also increases with height. This implies that as height increases, the shape of the distribution tends to be peaked which implies less variation in the wind speed.

From Table 4.28, the WIS generated shape parameter of 2.147 for Enugu at 10m height, while the calculated shape parameters at the same height using the four methods are as follow: the value of 4.409 (i.e 51.3% rise) using MLM, 5.302 (i.e 59.5% rise) using MOM, 5.276 (i.e 59.3% rise) using STD and 4.214 (i.e 49.1% rise) using PDM. Also, the scale parameter generated by the WIS for Enugu is 5.079m/s, while the calculated scale parameters are 3.546m/s (30.2% less) using MLM, 3.545m/s (30.2% less) using MOM, 3.546m/s (30.2% less) using STD and

3.589m/s (29.3%less) using PDM when compared with the result generated by the WIS.

From Table 4.29, the WIS generated shape parameter of 2.866 for Ilorin at 10m height, while the calculated shape parameters the same height using the four methods are as follow: the value of 5.050 (i.e 43.2% rise) using MLM, 5.223 (i.e 45.1% rise) using MOM, 5.199 (i.e 44.9% rise) using STD and 4.230 (i.e 32.2% rise) using PDM. Also, the scale parameter generated by the WIS for Ilorin is 5.250m/s, while the calculated scale parameters are 3.54m/s (32.5% less) using MLM, 3.545m/s (32.8% less) using MOM, 3.546m/s (32.5% less) using STD and 3.589m/s (31.6% less) using PDM when compared with the result generated by the WIS.

From Table 4.30, the WIS generated shape parameter of 2.623 for Jos at 10m height, while the calculated shape parameters at the same height using the four methods are as follow: the value of 3.799 (i.e 30.9% rise) using MLM, 3.815 (i.e 31.2% rise) using MOM, 3.811 (i.e 31.2% rise) using STD and 3.940 (i.e 33.4% rise) using PDM. Also, the scale parameter generated by the WIS for Jos is 5.820m/s, while the calculated scale parameters are 6.944m/s (16.2% less) using MLM, 6.943m/s (16.2% less) using MOM, 6.943m/s (16.2% less) using STD and 6.93m/s (16.0% less) using PDM when compared with the result generated by the WIS.

From Table 4.31, the WIS generated shape parameter of 2.459 for Kano at 10m height, while the calculated shape parameters at the same height using the four methods are as follow: the value of 5.951 (i.e 58.7% rise) using MLM, 6.582 (i.e 62.6% rise) using MOM, 6.534 (i.e 62.4% rise) using STD and 4.367 (i.e 29% rise) using PDM. Also, the scale parameter generated by the WIS for Kano is 4.580m/s, while the calculated scale parameters are 6.091m/s (24.8% less) using MLM, 6.075m/s (24.6% less) using MOM, 6.075m/s (24.6% less) using STD and 6.218m/s (26.4% less) using PDM when compared with the result generated by the WIS.

From Table 4.32, the WIS generated shape parameter of 2.147 for Lokoja at 10m height, while the calculated shape parameters at the same height using the four methods are as follow: the value of 2.692 (i.e 20.2% rise) using MLM, 2.662 (i.e 19.5% rise) using MOM, 2.67 (i.e 19.4% rise) using STD and 3.453 (i.e 37.8% rise) using PDM. Also, the scale parameter generated by the WIS for Lokoja is 5.079m/s, while the calculated scale parameters are 1.671m/s (67.1% less) using MLM, 1.670m/s (67.1% less) using MOM, 1.670m/s (67.5% less) using STD and 1.651m/s (67.6% less) using PDM when compared with the result generated by the WIS.

From Table 4.33, the WIS generated shape parameter of 2.866 for Lagos at 10m height, while the calculated shape parameters at the same height using the four

methods are as follow: the value of 7.134 (i.e 59.8% rise) using MLM, 8.860 (i.e 67.7% rise) using MOM, 8.766 (i.e 67.3% rise) using STD and 4.493 (i.e 36.2% rise) using PDM. Also, the scale parameter generated by the WIS for Lagos is 5.250m/s, while the calculated scale parameters are 1.803m/s (65.7% less) using MLM, 1.798m/s (65.8% less) using MOM, 1.799m/s (65.7% less) using STD and 1.864m/s (64.5% less) using PDM when compared with the result generated by the WIS.

Table 4.28: Estimated Weibull Parameters, k (-) and c (m/s) at 10m for Enugu

WIS Values			Experimental Values		
Height (m)	k (-)	c (m/s)	Methods	k (-)	c (m/s)
10	2.147	5.079	MLM	4.409	3.933
			MOM	5.302	3.931
			STD	5.276	3.932
			PDM	4.214	3.984

Table 4.29: Estimated Weibull Parameters, k (-) and c (m/s) at 10m for Ilorin

WIS Values			Experimental Values		
Height (m)	k (-)	c (m/s)	Methods	k (-)	c (m/s)
10	2.866	5.250	MLM	5.050	3.546
			MOM	5.223	3.545
			STD	5.199	3.546
			PDM	4.230	3.589

Table 4.30: Estimated Weibull Parameters, k (-) and c (m/s) at 10m for Jos

WIS Values			Experimental Values		
Height (m)	k (-)	c (m/s)	Methods	k (-)	c (m/s)
10	2.623	5.820	MLM	3.799	6.944
			MOM	3.815	6.943
			STD	3.811	6.943
			PDM	3.940	6.930

Table 4.31: Estimated Weibull Parameters, k (-) and c (m/s) at 10m for Kano

WIS Values			Experimental Values		
Height (m)	k (-)	c (m/s)	Methods	k (-)	c (m/s)
10	2.459	4.580	MLM	5.951	6.091
			MOM	6.582	6.075
			STD	6.534	6.077
			PDM	4.367	6.218

Table 4.32: Estimated Weibull Parameters, k (-) and c (m/s) at 10m for Lokoja

WIS Values			Experimental Values		
Height (m)	k (-)	c (m/s)	Methods	k (-)	c (m/s)
10	2.147	5.079	MLM	2.692	1.671
			MOM	2.662	1.670
			STD	2.670	1.670
			PDM	3.453	1.651

Table 4.33: Estimated Weibull Parameters, k (-) and c (m/s) at 10m for Lagos

WIS Values			Experimental Values		
Height (m)	k (-)	c (m/s)	Methods	k (-)	c (m/s)
10	2.866	5.250	MLM	7.134	1.803
			MOM	8.860	1.798
			STD	8.766	1.799
			PDM	4.493	1.864

4.7 Comparison between Estimated and WIS Wind Speed

The variation of wind speed with height at the selected sites is presented in Table 4.34. The mean wind speed generated by the WIS for all the selected sites is greater than the calculated mean wind speed at 10m height and remains the same as the height increases. The calculated mean wind speed of 3.668m/s at 10m with standard deviation of 1.979 and coefficient of variation (COV) of 54.0%, while WIS generated mean wind speed of 5.194m/s at the same height with standard deviation and COV of 0.724 and 13.9% respectively. The important issue which has been clearly shown in Table 4.40 is that turbulence is comparatively decreasing from 54.0% at 10m to 47.2% at 50m, while WIS maintained the same COV of 13.9% from 10-50m. Therefore, at the higher level the wind velocity stream is more uniform, i.e., the COV is lower. The COV is lower when the wind speeds become maximum. The calculated COV/ turbulence with the altitude is at its minimum during higher windy periods. It is also clear that from 20-50m, the calculated mean wind speed at the sites show better result than those generated by the WIS.

Table 4.34: Comparison of Estimated and WIS Wind Speed at 10m, 20m, 30m, 40m and 50m.

	h =10m		h =20m		h =30m		h =40m		h (50m)	
	Exp.	WIS	Exp.	WIS	Exp.	WIS	Exp.	WIS	Exp.	WIS
Stations	V(m/s)	V(m/s)	V(m/s)	V(m/s)	V(m/s)	V(m/s)	V(m/s)	V(m/s)	V(m/s)	V(m/s)
Enugu	3.622	4.711	4.327	4.711	4.802	4.711	5.17	4.711	5.475	4.711
Ilorin	3.263	5.201	3.924	5.201	4.37	5.201	4.718	5.201	5.006	5.201
Jos	6.276	6.075	7.251	6.075	7.891	6.075	8.378	6.075	8.777	6.075
Kano	5.664	6.051	6.585	6.051	7.192	6.051	7.656	6.051	8.037	6.051
Lokoja	1.484	4.765	1.873	4.765	2.145	4.765	2.363	4.765	2.546	4.765
Lagos	1.701	4.363	2.128	4.363	2.426	4.363	2.663	4.363	2.862	4.363
MEAN	3.668	5.194	4.348	5.194	4.804	5.194	5.158	5.194	5.451	5.194
STDEV	1.979	0.724	2.221	0.724	2.373	0.724	2.484	0.724	2.573	0.724
COV(%)	54.0	13.9	51.1	13.9	49.4	13.9	48.1	13.9	47.2	13.9

4.8 Weibull Probability Density Distributions for the Selected Sites at Different Heights

The estimated mean velocity (m/s), Weibull parameters, k (-) and c (expressed in m/s) at 10m, 20m, 30m, 40m and 50m for each of the stations (see Tables 4.22-4.27) were used to predict the complete annual mean weibull probability density function and the cumulative distribution function of the year for all the stations at different heights using the Maximum Likelihood method (MLM), and the results are presented as shown in Figures 4.23 to 4.34. It is observed that the most frequent wind speed for each station increases with the increase in height. It can be seen from the Figures that as the height increases, the Weibull function fit becomes increasingly better and the wind speed fluctuation also becomes less due to decrease in wind turbulence at higher altitudes.

The probability density frequency and cumulative density curves of wind speed from 10m to 50 m height for the Weibull density function are shown in Figures 4.23-4.34. Figure 4.23 indicated that 4m/s and 6m/s wind speeds prevail in Enugu at 10m and 50m height with probabilities of 0.404 and 0.307 respectively. Figure 4.25 indicated that 3m/s and 6m/s wind speeds prevail in Enugu at 10m and 50m height with probabilities of 0.470 and 0.349 respectively. Figure 4.27 indicated that 6m/s and 11m/s wind speeds prevail in Enugu at 10m and 50m height with probabilities of 0.204 and 0.136 respectively. Figure 4.29 indicated that 6m/s and

9m/s wind speeds prevail in Enugu at 10m and 50m height with probabilities of 0.363 and 0.283 respectively. Figure 4.31 indicated that 1m/s and 3m/s wind speeds prevail in Enugu at 10m and 50m height with probabilities of 0.526 and 0.383 respectively. Figure 4.33 indicated that 2m/s and 3m/s wind speeds prevail in Enugu at 10m and 50m height with probabilities of 0.919 and 0.826 respectively.

Figures 4.24, 4.26, 4.28, 4.30, 4.32 and 4.34 give the cumulative distribution function of the wind speeds. The curves represent the time fraction or probability that the wind speed is smaller than or equal to a given wind speed. From the Figures 4.24, 4.26, 4.28, 4.30, 4.32 and 4.34, 40% of the wind speeds recorded will be below the wind speed 3 m/s. cut-in wind speeds greater than or equal to 3m/s have frequencies greater than 60% for all the locations at 50m.

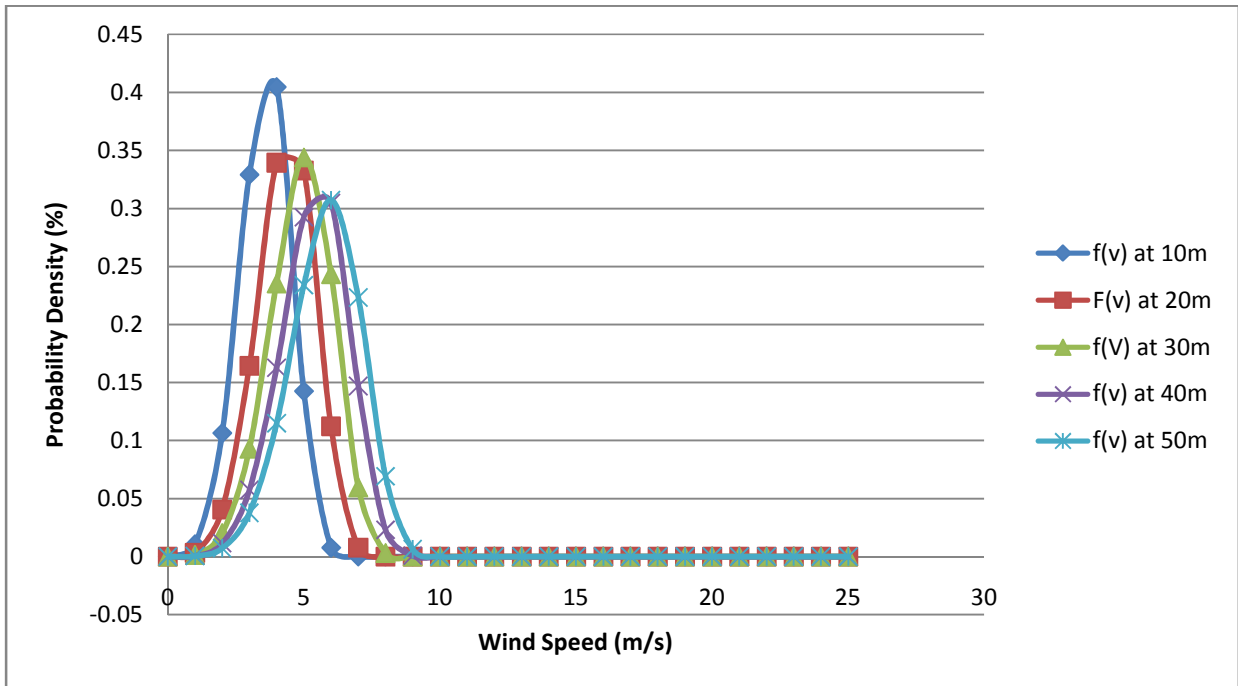


Figure 4.23 Weibull Probability Density Distribution of Enugu

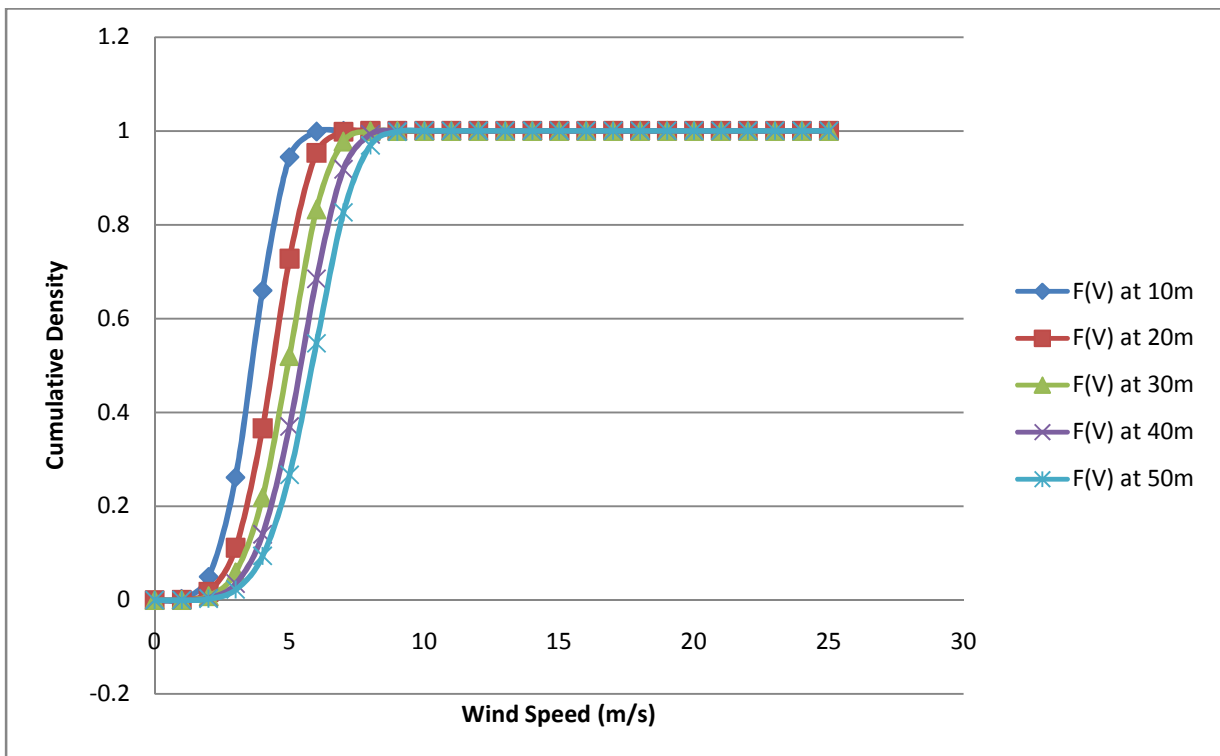


Figure 4.24 Weibull Cumulative Distribution of Enugu

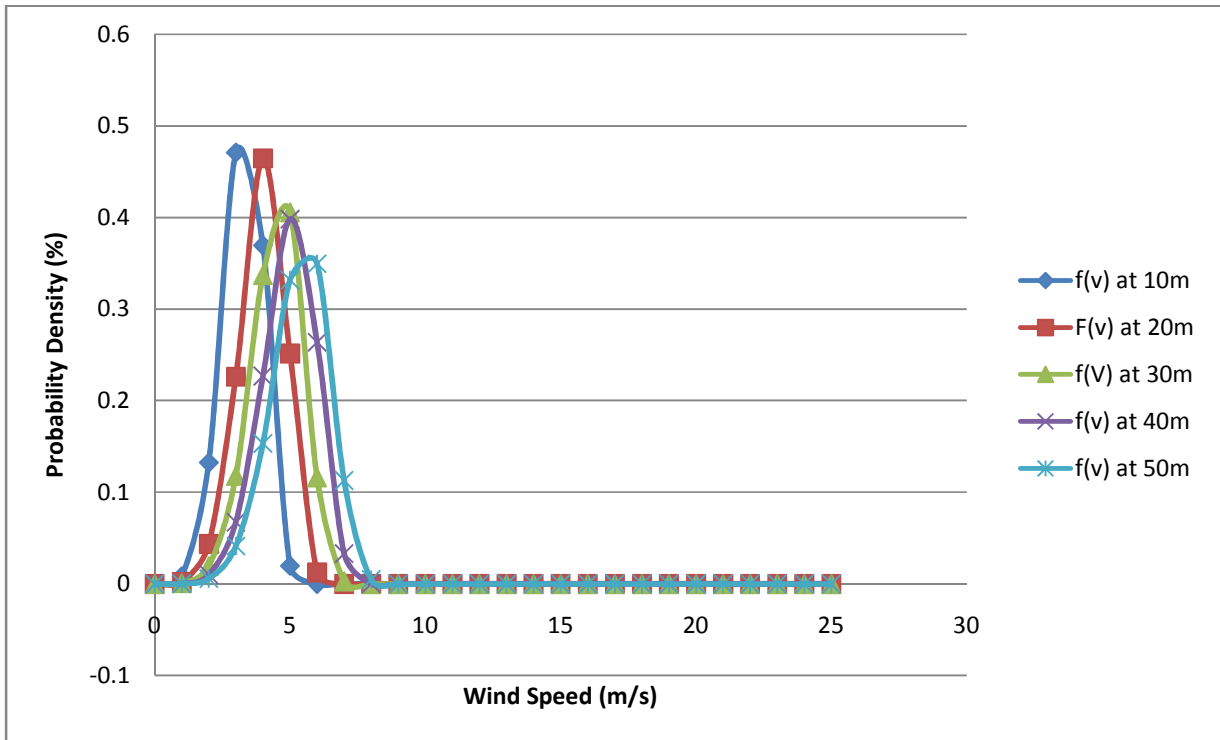


Figure 4.25 Weibull Probability Density Distribution of Ilorin

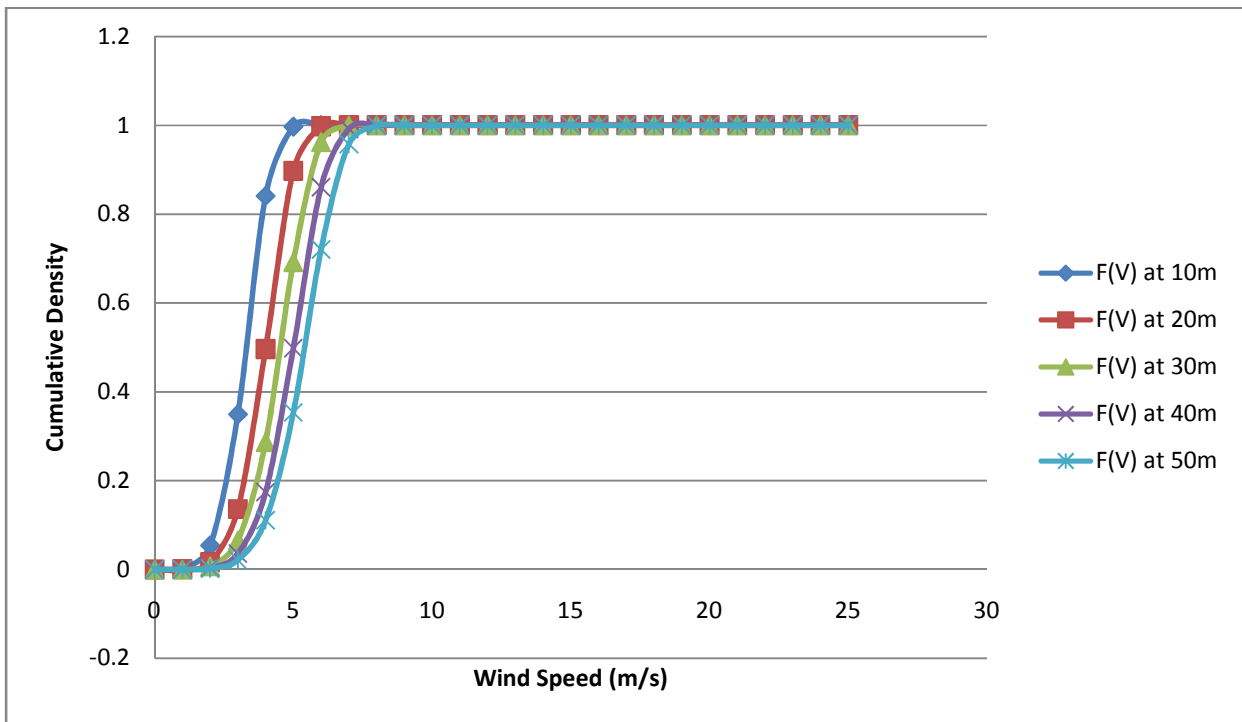


Figure 4.26 Weibull Cumulative Distribution of Ilorin

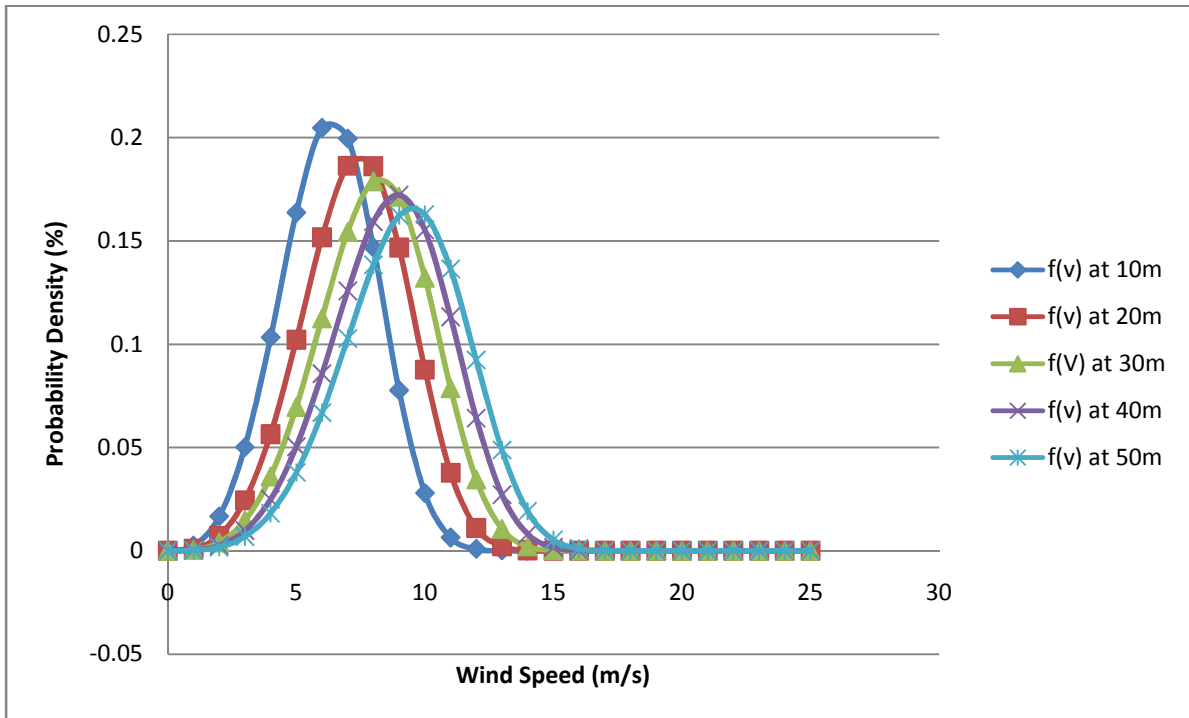


Figure 4.27 Weibull Probability Density Distribution of Jos

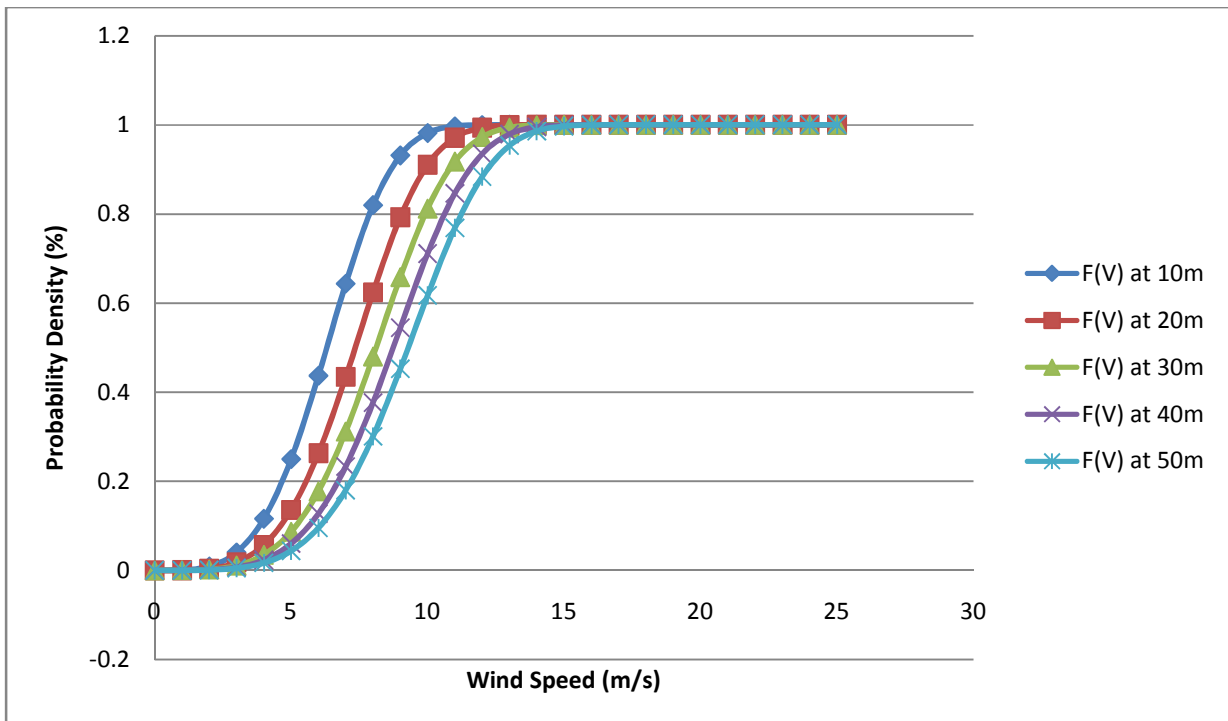


Figure 4.28 Weibull Cumulative Distribution of Jos

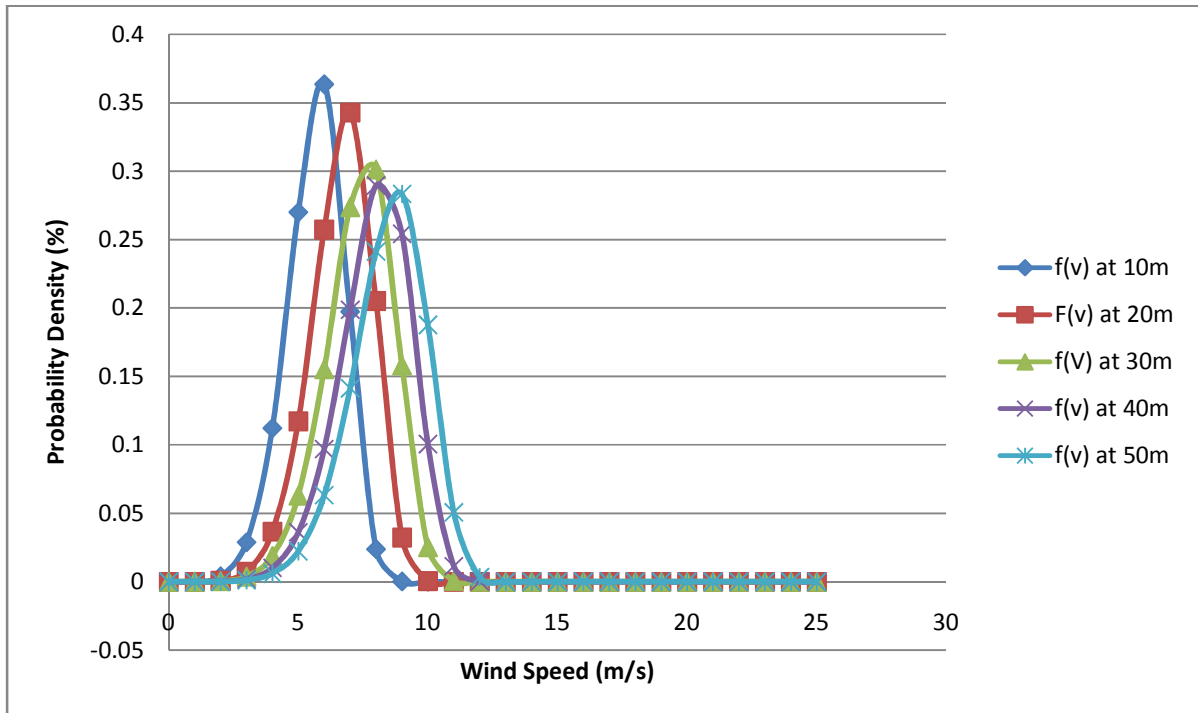


Figure 4.29 Weibull Probability Density Distribution of Kano

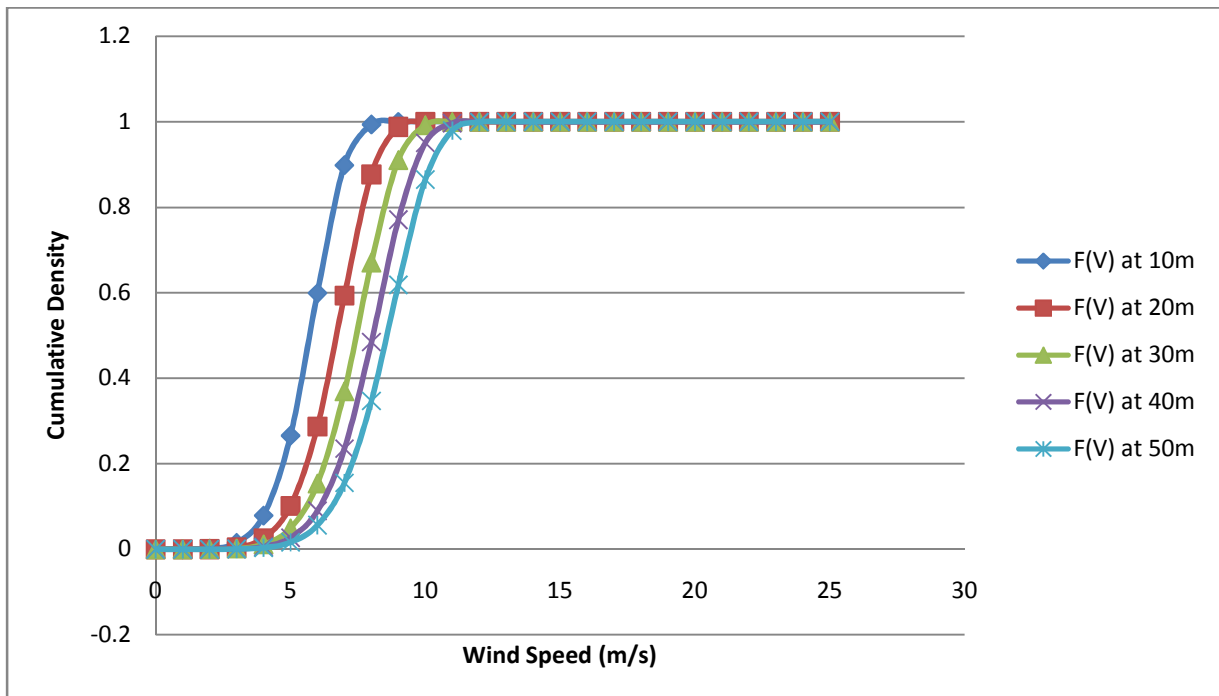


Figure 4.30 Weibull Cumulative Distribution of Kano

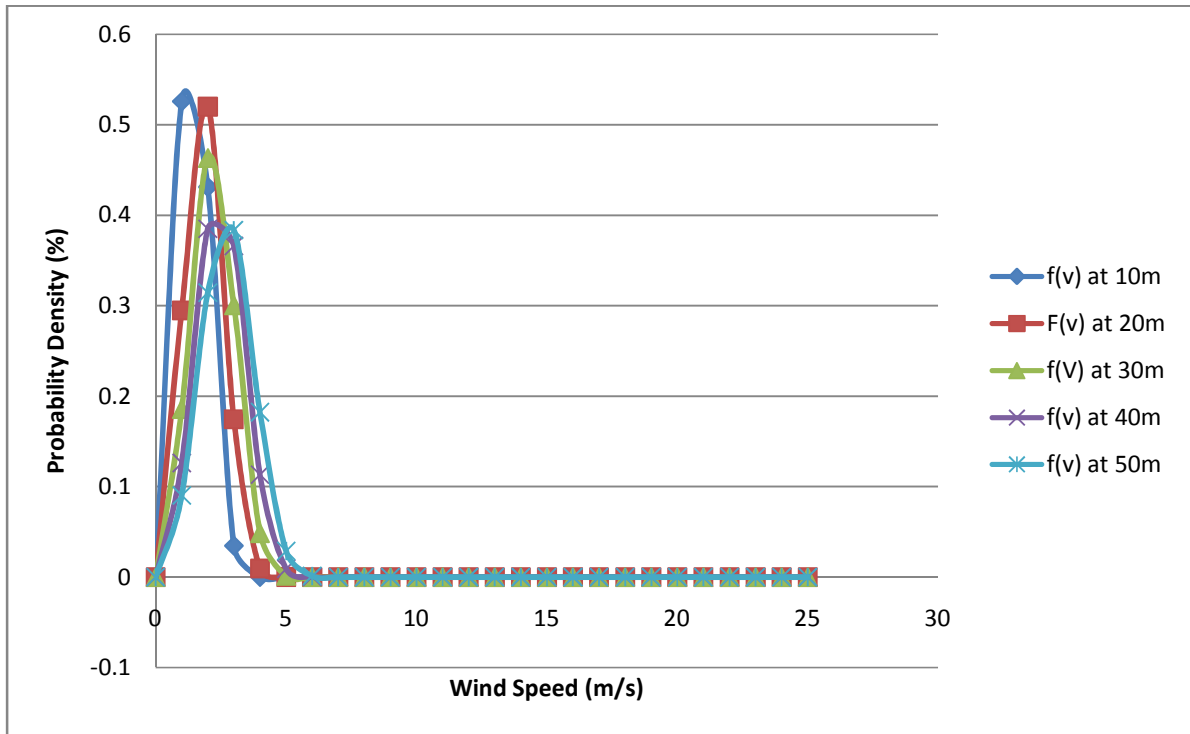


Figure 4.31 Weibull Probability Density Distribution of Lokoja

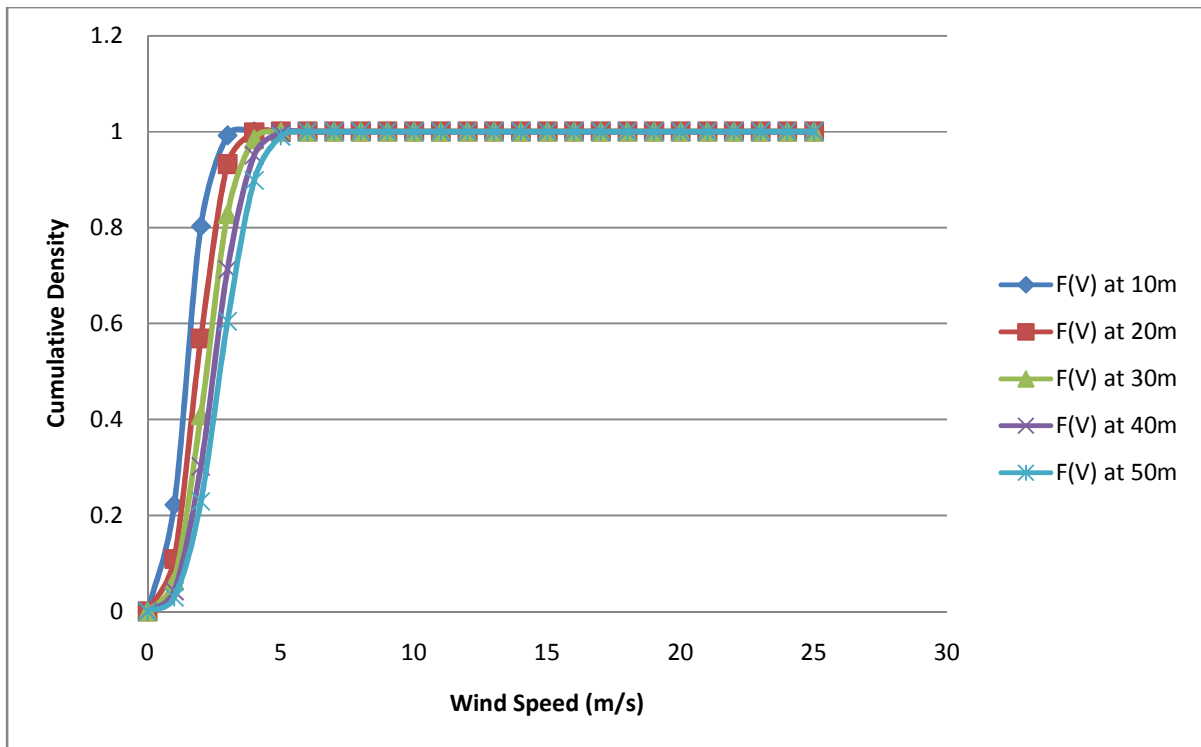


Figure 4.32 Weibull Cumulative Distribution of Lokoja

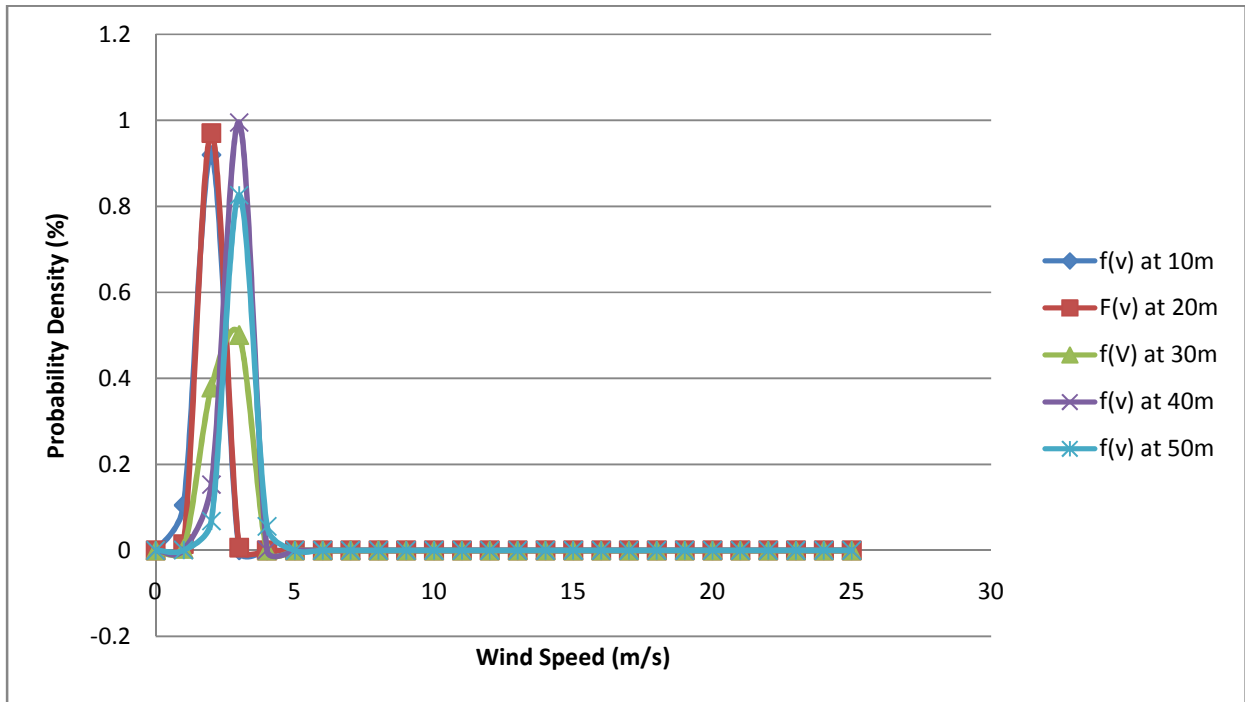


Figure 4.33 Weibull Probability Density Distribution of Lagos

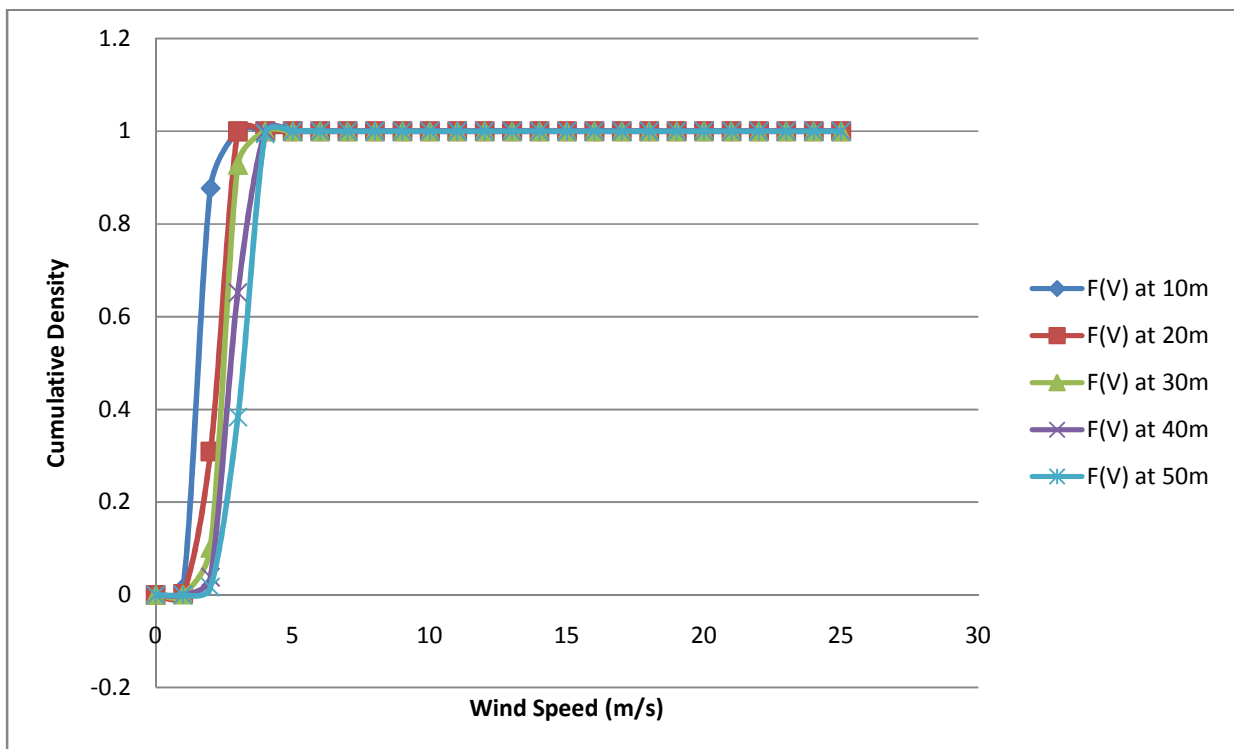


Figure 4.34 Weibull Cumulative Distribution of Lagos

4.9 Comparison between the Estimated and WIS Weibull Probability

Density and Cumulative Density Distribution

From equations (3.2) and (3.3), it is evident that Weibull parameters k (-) and c (m/s) are the factors that determine the nature of the wind spectra within a given region. Effect of the Weibull parameters on the Weibull probability density and cumulative density distribution of wind velocity are estimated using the wind data from each station and those using Wind Information System (WIS) for comparison.

Therefore, the Weibull probability density and cumulative density distributions obtained from the Wind Information System (WIS) software were drawn and superimposed with the plots of the experimental Weibull probability density and cumulative density distributions as shown in Figures 4.35-4.46.

Figure 4.35 shows that, Enugu has its most frequent wins speed at 4m/s for both experimental and that generated by the WIS but different occurrences and different shape factors. The most frequent wind speed of 4m/s occurs at the probability of 0.40 for the experimental result and 0.17 for that generated by the WIS. The lower shape factor of 2.147 generated by the WIS indicated a relatively wide distribution of wind speed around the average of 4.71m/s, while the higher shape factor of

4.409 for the experimental indicated a relatively narrow distribution of wind speed around the average wind speed of 3.622m/s.

Figure 4.37 shows the most frequent wind speed of Ilorin for the experimental result to be 3m/s at the probability of 0.47 with the shape factor of 5.05, while the most frequent wind speed generated by the WIS is 5m/s at the probability of 0.21 with a shape factor of 2.866. The lower shape factor of 2.866 generated by the WIS indicated a relatively wide distribution of wind speed around the average wind speed of 5.201m/s, while the higher shape factor of 5.050 for the experimental indicated a relatively narrow distribution of wind speed around the average wind speed of 3.263m/s.

Figure 4.39 shows that, Jos has its most frequent wind speed at 6m/s at the probability of 0.36 with a shape factor of 5.951, while the most frequent wind speed generated by the WIS is 4m/s at the probability of 0.22 with a shape factor of 2.459. The lower shape factor of 2.459 generated by the WIS indicated a relatively wide distribution of wind speed around the average wind speed of 6.05m/s, while the higher shape factor of 5.591 for the experimental indicated a relatively narrow distribution of wind speed around the average wind speed of 5.664m/s.

Figure 4.41 shows that, Kano has its most frequent wind speed at 6m/s at the probability of 0.21 with a shape factor of 3.940, while the most frequent wind

speed generated by the WIS is 5m/s at the probability of 0.18 with a shape factor of 2.623. The lower shape factor of 2.623 generated by the WIS indicated a relatively wide distribution of wind speed around the average wind speed of 6.075m/s, while the higher shape factor of 3.940 for the experimental indicated a relatively narrow distribution of wind speed around the average wind speed of 6.276m/s.

Figure 4.43 shows that, Lokoja has its most frequent wind speed at 1m/s at the probability of 0.52 with a shape factor of 2.662, while the most frequent wind speed generated by the WIS is 4m/s at the probability of 0.18 with a shape factor of 2.147. The lower shape factor of 2.147 generated by the WIS indicated a relatively wide distribution of wind speed around the average wind speed of 4.765m/s, while the higher shape factor of 2.662 for the experimental indicated a relatively narrow distribution of wind speed around the average wind speed of 1.484m/s.

Figure 4.45 shows that, Lokoja has its most frequent wind speed at 2m/s at the probability of 0.78 with a shape factor of 4.493, while the most frequent velocity generated by the WIS is 5m/s at the probability of 0.209 with a shape factor of 2.866. The lower shape factor of 2.866 generated by the WIS indicated a relatively wide distribution of wind speed around the average wind speed of 4.363m/s, while the higher shape factor of 4.493 for the experimental indicated a relatively narrow distribution of wind speed around the average wind speed of 1.70m/s.

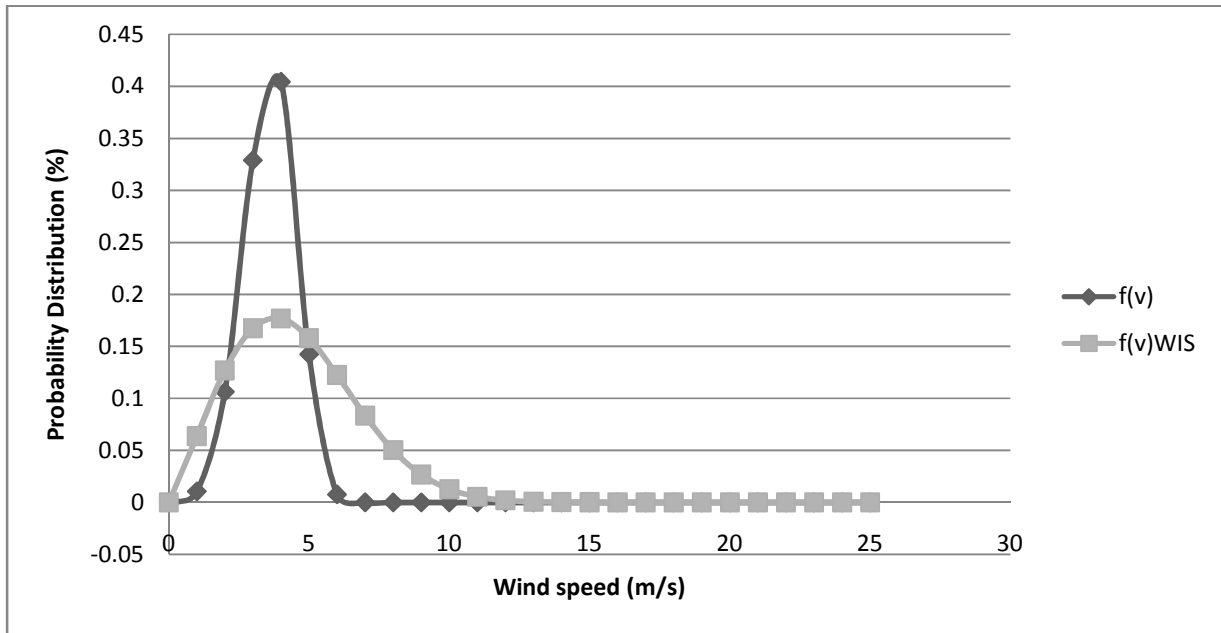


Figure 4.35 Graphical Comparison of Weibull Probability Density Distribution of Enugu

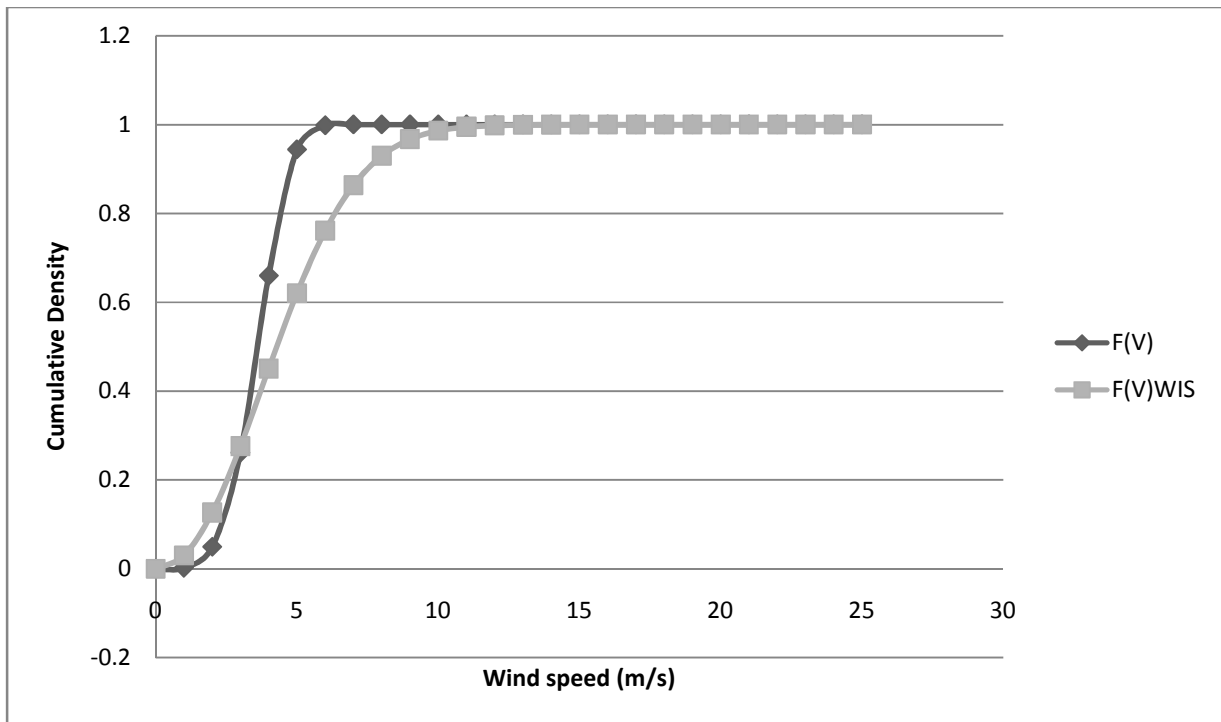


Figure 4.36 Graphical Comparison of Weibull Cumulative Distribution of Enugu

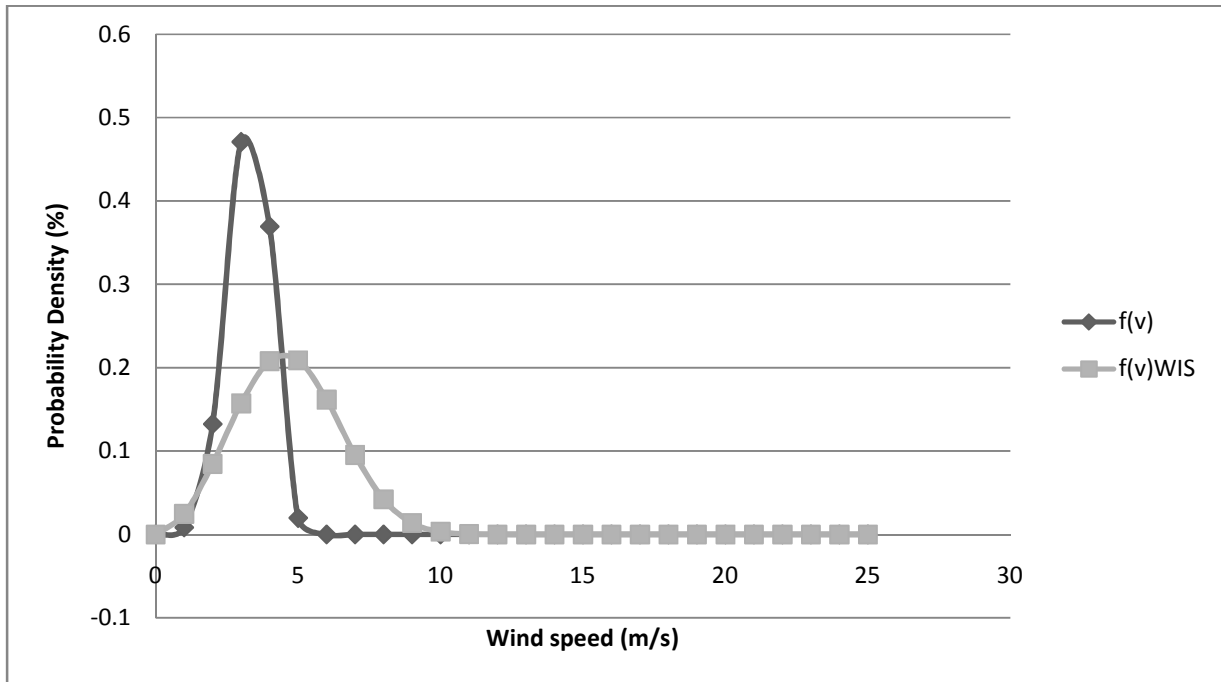


Figure 4.37 Graphical Comparison of Weibull Probability Density Distribution of Ilorin

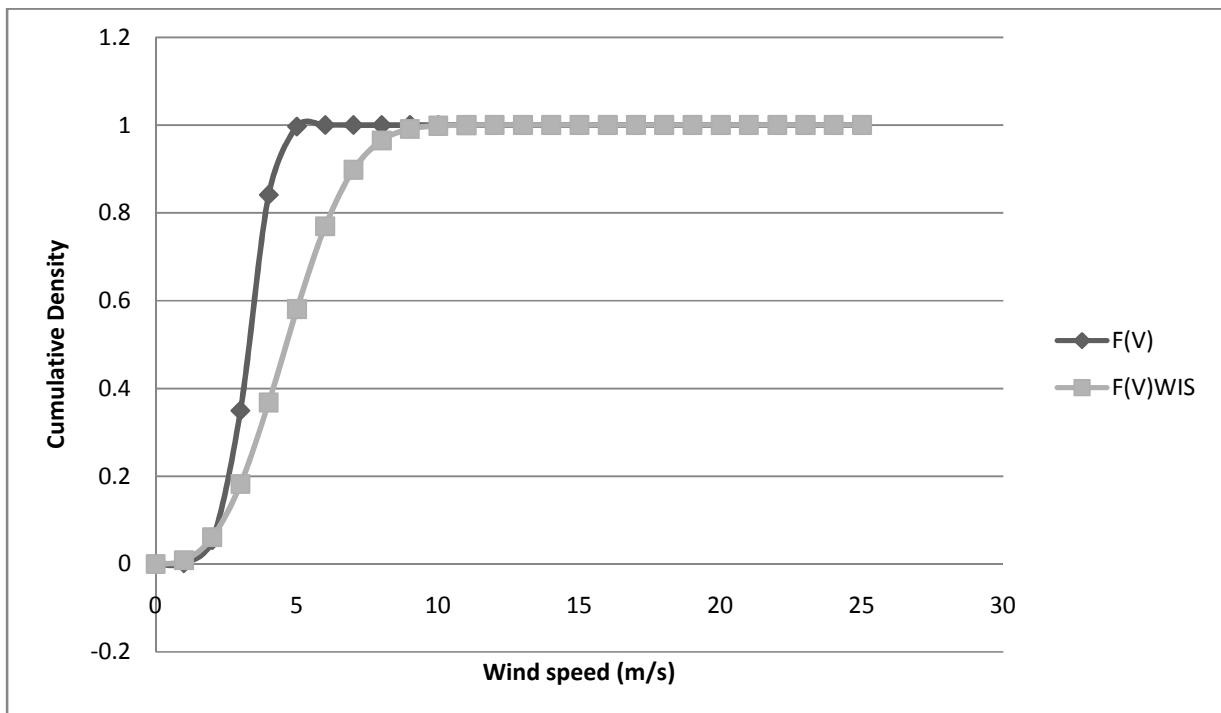


Figure 4.38 Graphical Comparison of Weibull Cumulative Distribution of Ilorin

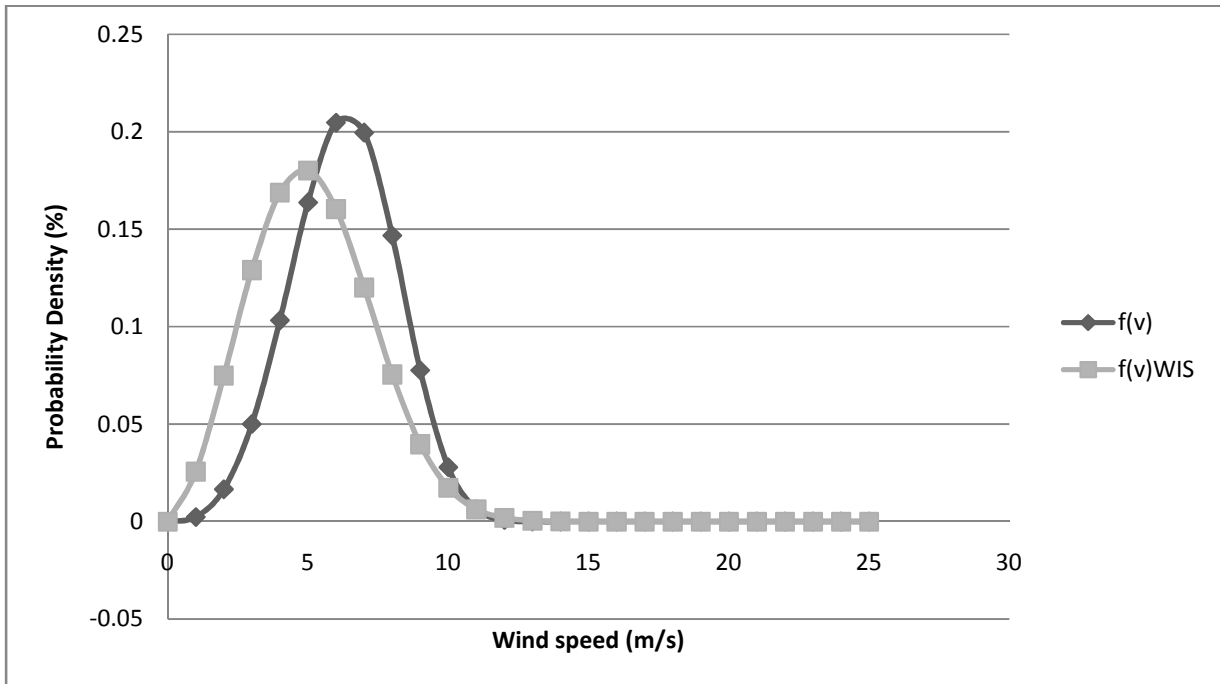


Figure 4.39 Graphical Comparison of Weibull Probability Density Distribution of Jos

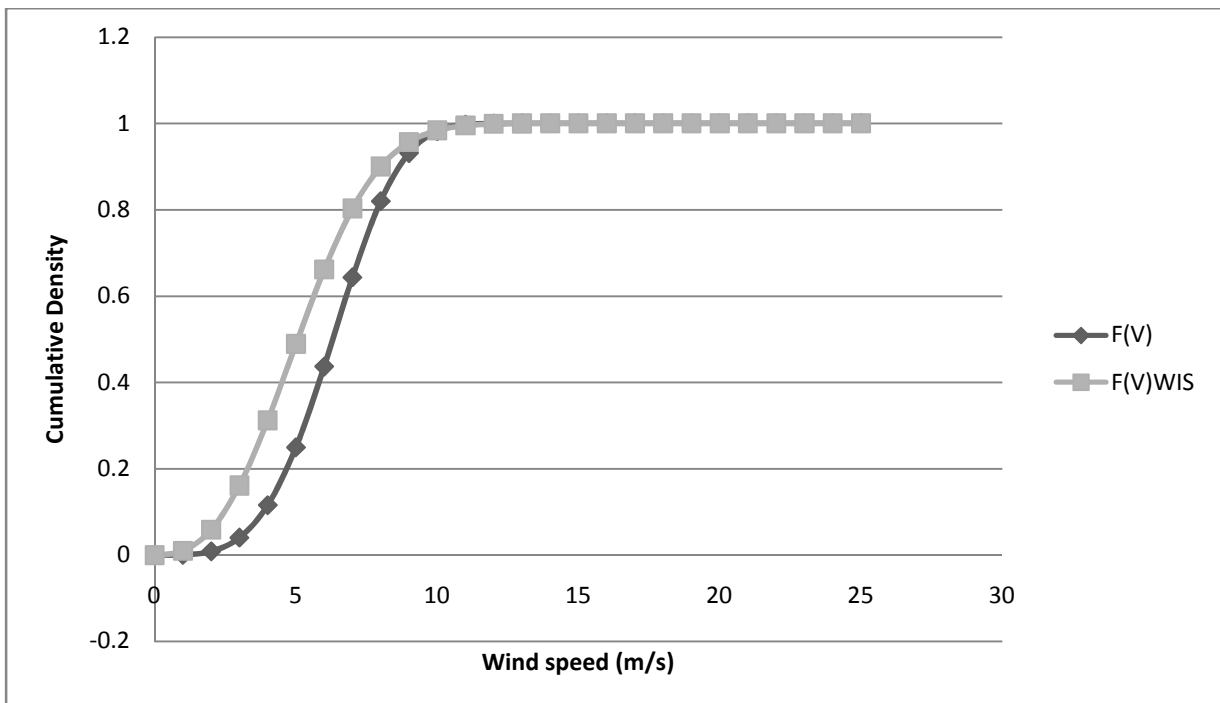


Figure 4.40 Graphical Comparison of Weibull Cumulative Distribution of Jos

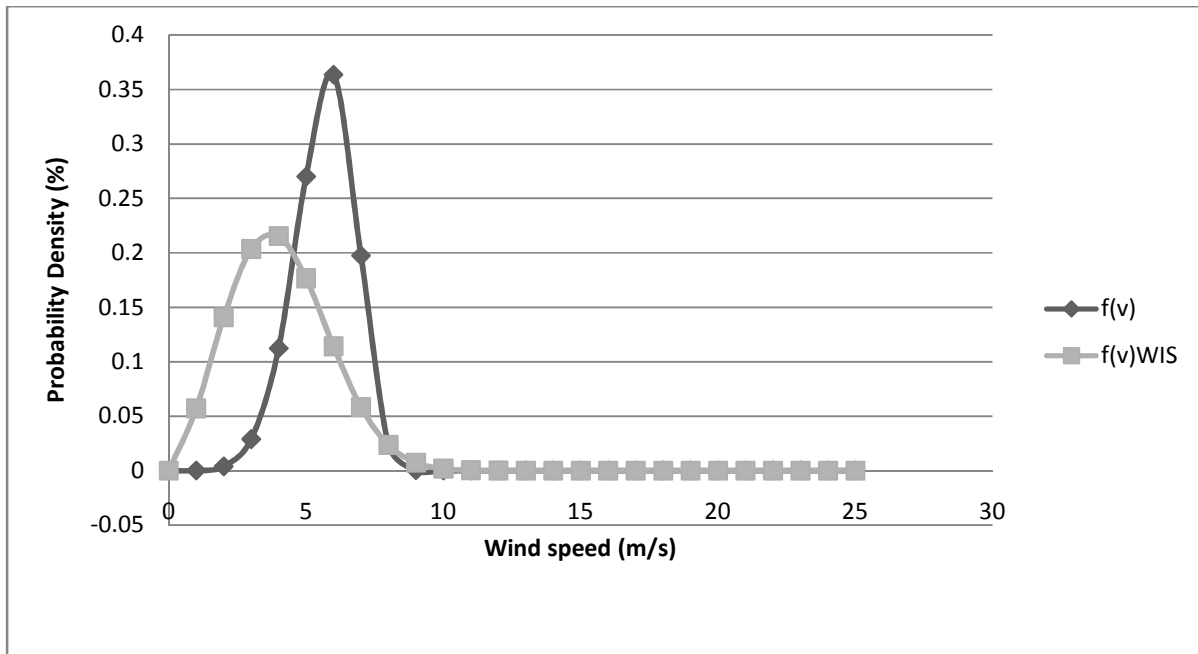


Figure 4.41 Graphical Comparison of Weibull Probability Density Distribution of Kano

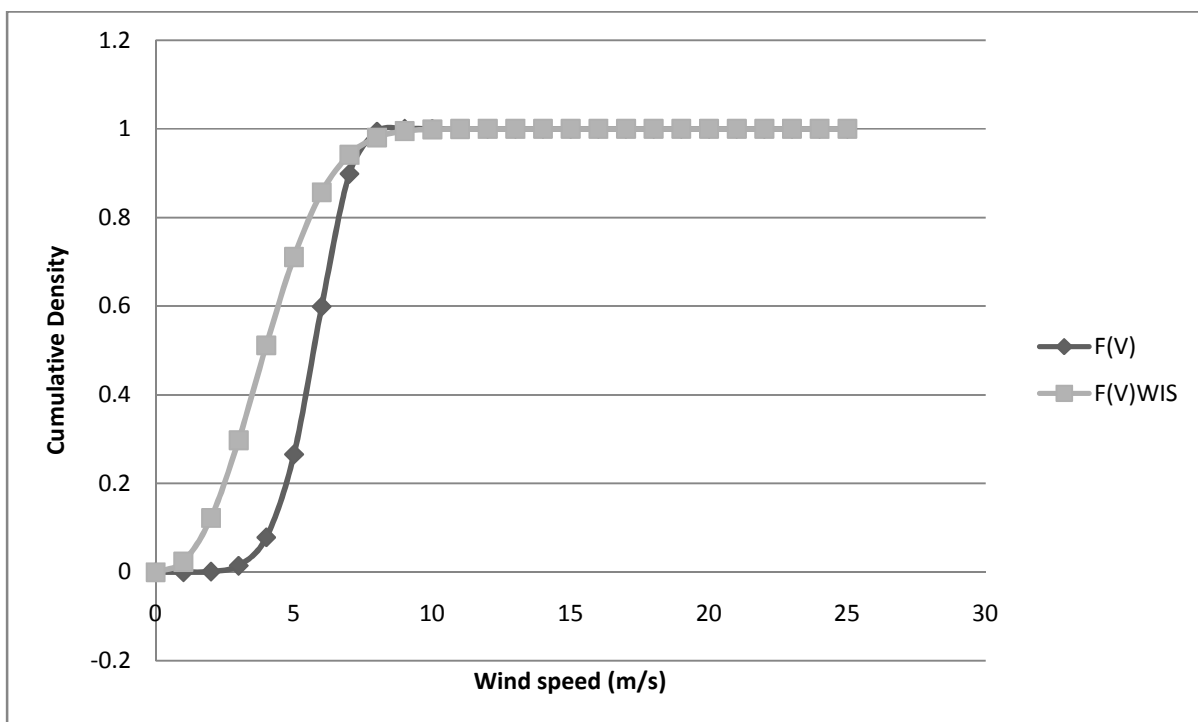


Figure 4.42 Graphical Comparison of Weibull Cumulative Distribution of Kano

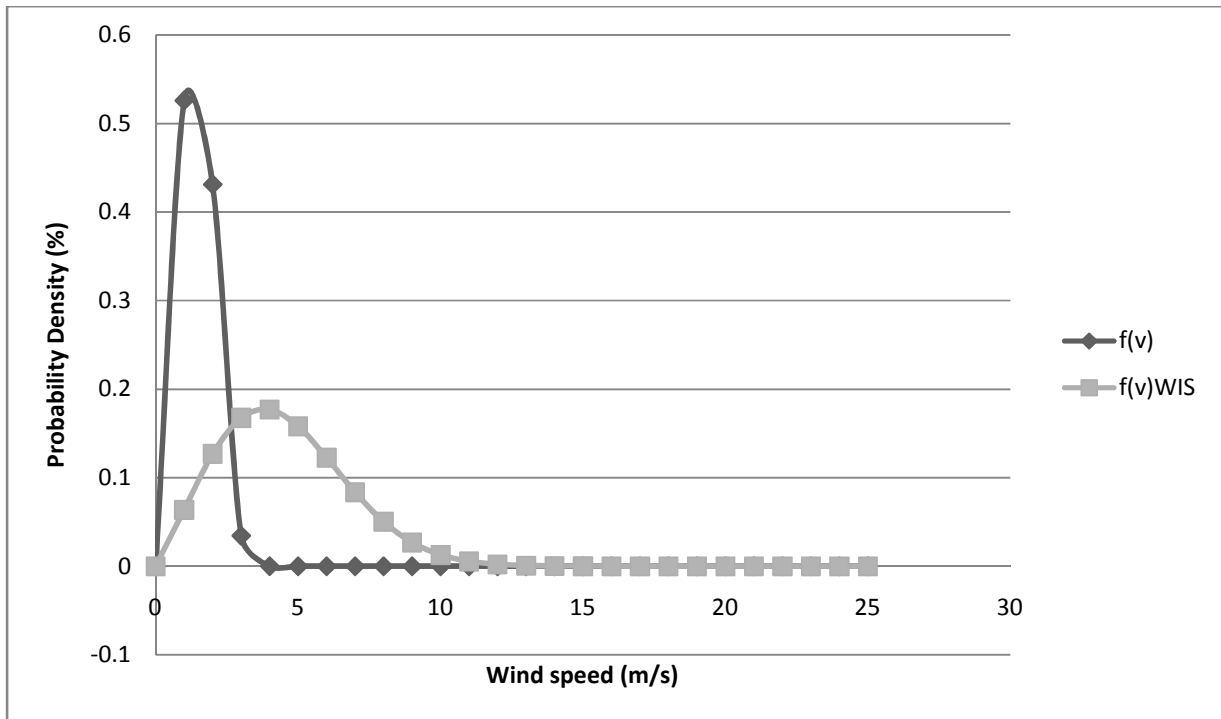


Figure 4.43 Graphical Comparison of Weibull Probability Density Distribution of Lokoja

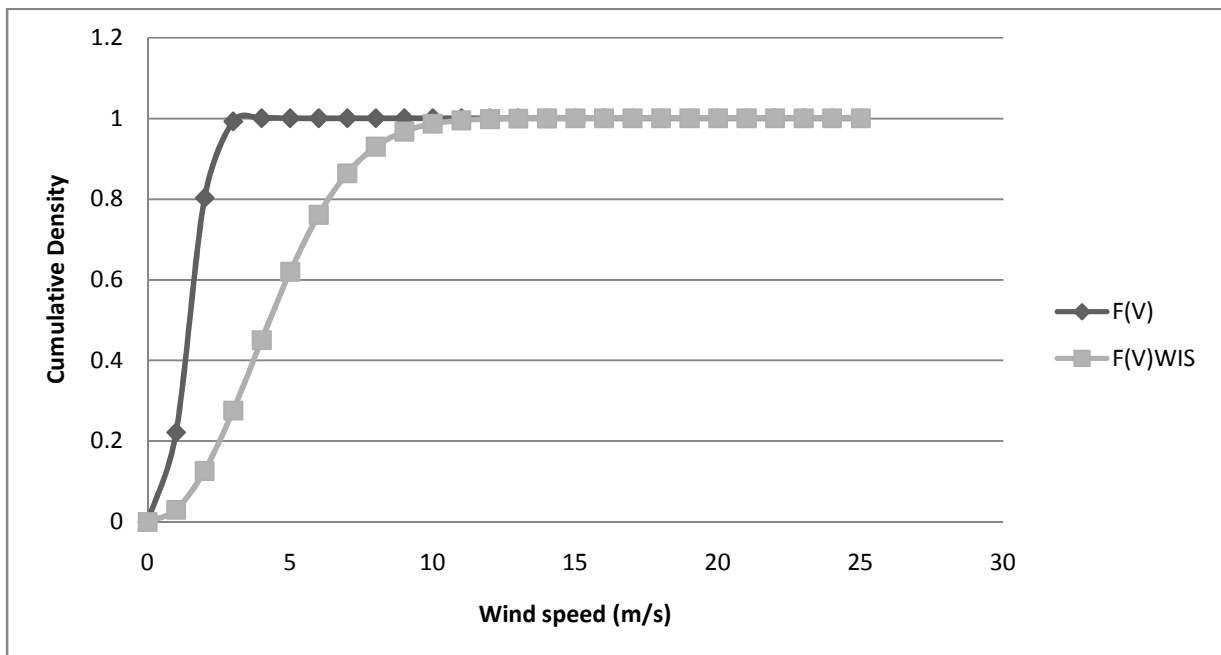


Figure 4.44 Graphical Comparison of Weibull Cumulative Distribution of Lokoja

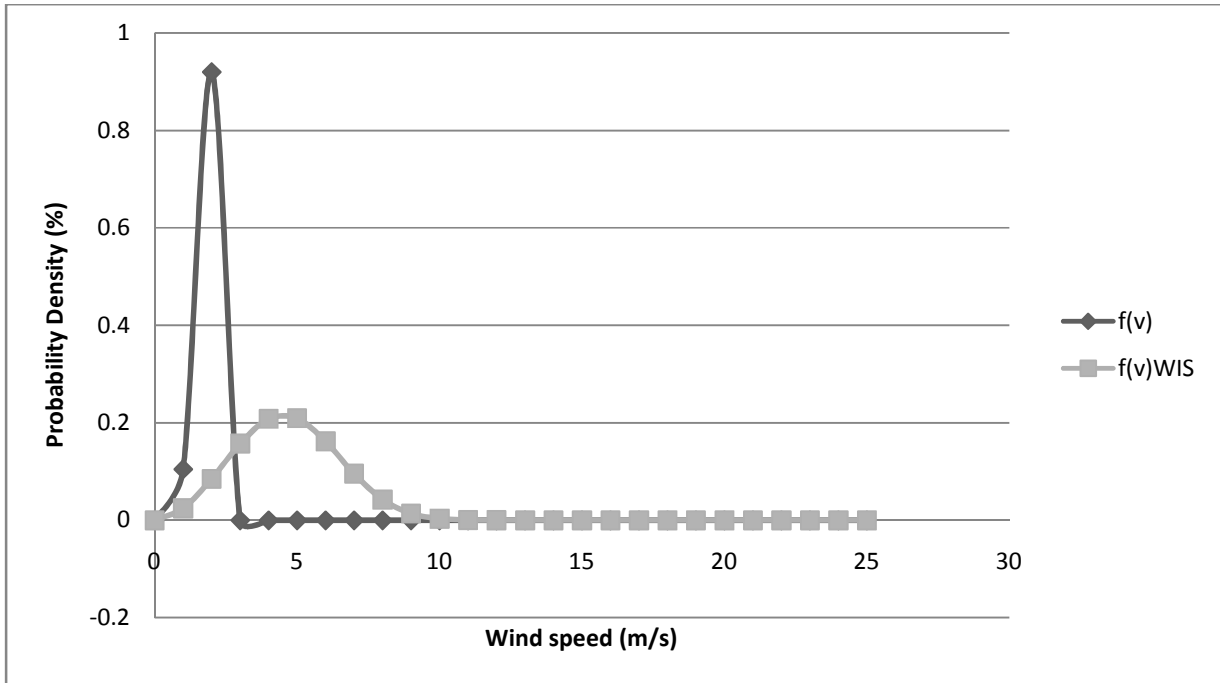


Figure 4.45 Graphical Comparison of Weibull Probability Density Distribution of Lagos

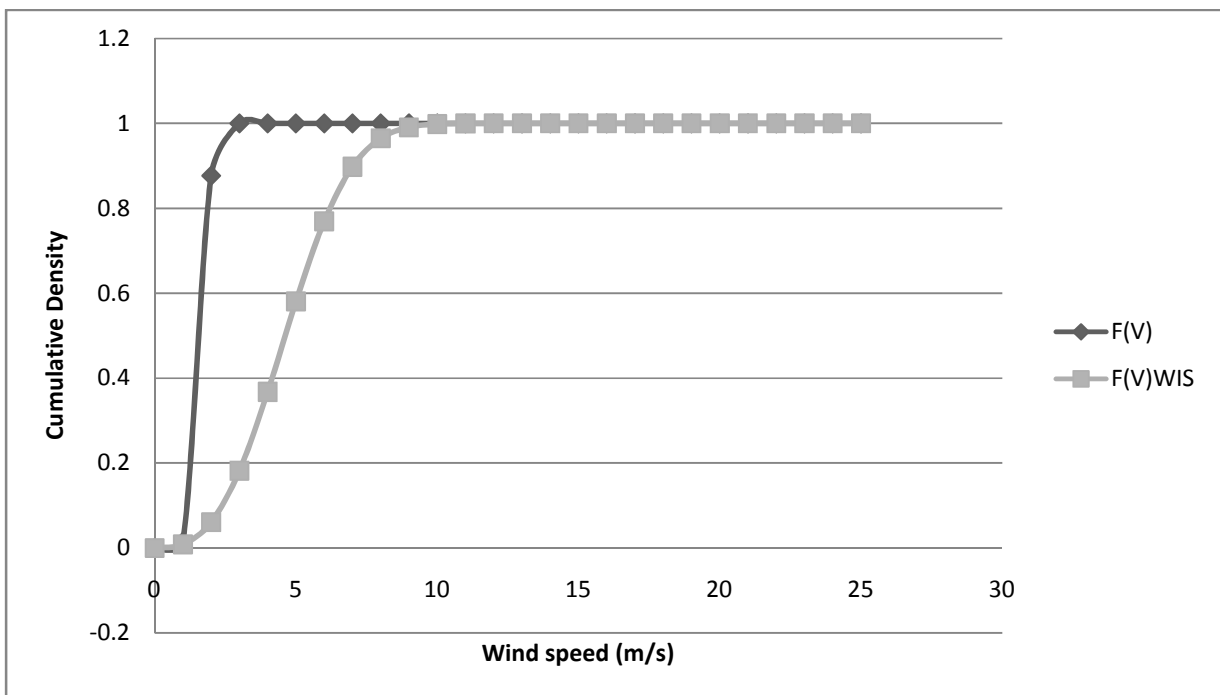


Figure 4.46 Graphical Comparison of Weibull Cumulative Distribution of Lagos

4.10 Wind power Estimation

4.10.1 Extrapolation of wind power with height

The vertical extrapolation of annual mean wind power density and energy density were calculated as shown in Tables 4.53-4.58, using equations (3.41) and (3.42), and the results for all the stations considered are plotted as shown in Figure 4.47 at different heights based on the measured wind speed at the measurement height (10m). The values of the roughness factor (α) for each station were calculated using equation (3.35).

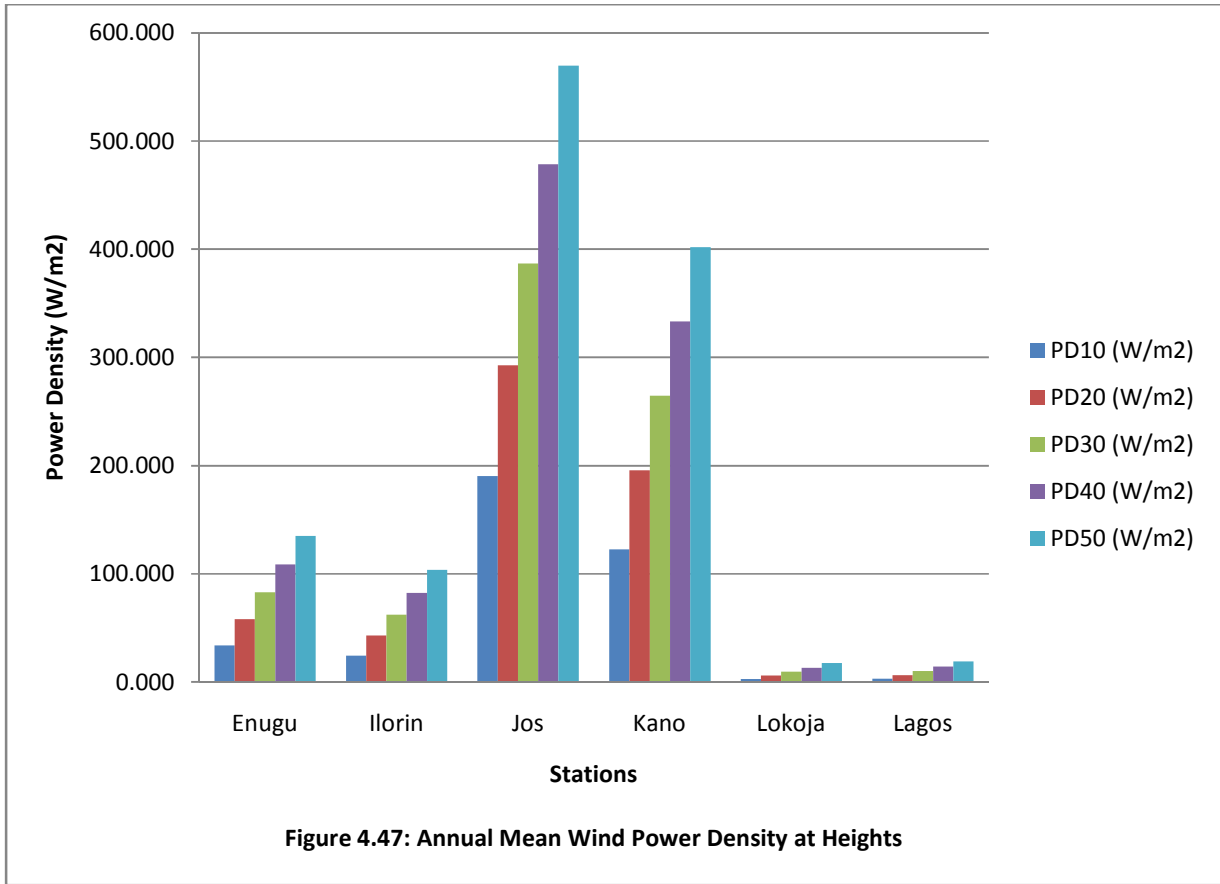
Since the effect of height on air density at the elevations under consideration is negligible, the power density of the wind above the ground level will be mainly affected by the increase in wind speed with height (Khogali *et al.*, 1991).

Annual mean wind speed (in m/s), the Weibull shape factor (-), scale factor (in m/s), power density (in W/m^2) and energy density ($W/year m^2$) at 10m, 20m, 30m, 40m and 50m were as well tabulated (see Tables 4.53-4.58).

Kano and Jos have shown greater wind power densities than others (see Figure 4.47). The values of the wind power densities obtained from these sites show that a medium or larger size wind turbines installed especially at heights of 30 and 50m above the ground could generate sufficiently high wind power if not for electricity, at least for water pumping.

Based on Figure 4.47, a classification into two different groups can be done. Group A which contains Kano and Jos, has annual mean specific wind power in the range from 265 to 402 W/m² and from 387 to 570 W/m² at heights of 30 m and 50 m above the ground level respectively. It has annual mean specific wind power in the range from 402 to 570 W/m² at a height 50 m. This group A is ideal for electricity generation using large wind turbines.

Group B, which contains the stations Ilorin and Enugu, has annual mean specific wind power between 62–104 and 82–135 W/m² at the heights of 30 and 50 m, respectively. This group B is suitable for special wind turbines because it has only annual mean wind speed between 3.3 and 3.6 m/s at a height of 10 m, (see Tables 4.47-4.48). A special wind conversion system, with simple technology, is suitable for the stations of group B. Applications might be: lighting of small areas, irrigation, water pumping and desalination plants in rural areas.



4.11 Wind Energy Yield Analysis

For energy yield estimation, a wind turbine of 660kW rated power with rotor diameter of 47m from Vestas was chosen. For energy yield estimation, five hub heights of 10m, 20m, 30m, 40m and 50m were considered and then compared with the WIS energy yield estimation.

Average power (kW), total energy production (MWh/y) and energy total specific (kW/y^{m²}) for all the stations were calculated at 10m, 20m, 30m, 40m and 50m for comparison with that of WIS software as shown in Tables 4.53-4.58.

Figures 4.48-4.65 have been prepared for illustration of the relationship between the average power, total energy production and energy total specific obtained experimentally and those generated from the WIS for the selected stations.

A comparison between the experimental results of average power from 10m-50m in Enugu was made with the ones obtained from the WIS. The results are depicted in Figure 4.48. As shown in the figure, the average power varies from 34.513kW to 138.383kW in Enugu, while WIS generated 77.036kW throughout the heights of 10m-50m. Again, a comparison was made with the observed total energy production in Figure 4.49, it can be seen that the total energy production for the experimental results in Enugu at 10-50m are in the range of 302.335-1212.236MWh/y with the capacity factor of 25.23-20.97%, while WIS generated

value of 616.285MWh/y with the capacity factor of 10.66%. Furthermore, the energy total specific at 10-50m are in the range 174.263-698.719kW/ym² and remained 355.22kW/ym² for the experimental result and that generated by the WIS respectively in Figure 4.50.

From Figure 4.51, the average power varies from 24.951kW to 106.123kW in Ilorin, while WIS generated 85.553kW throughout the heights of 10m-50m. Again, a comparison was made with the observed total energy production in Figure 4.52, it can be seen that the total energy production for the experimental results in Ilorin at 10-50m are in the range of 218.573-929.638MWh/y with the capacity factor of 3.78-16.08%, while WIS generated values of 684.427 with the capacity factor of 11.84%. Furthermore, the energy total specific at 10-50m are in the range 125.985-535.833kW/ym² and remained 684.427kW/ym² for the experimental result and that generated by the WIS respectively in Figure 4.53.

From Figure 4.54, the average power varies from 194.949kW to 583.183kW in Jos, while WIS generated 130.725kW throughout the heights of 10m-50m. Again, a comparison was made with the observed total energy production in Figure 4.55, it can be seen that the total energy production for the experimental results in Jos at 10-50m are in the range of 1707.754-5108.683MWh/y with the capacity factor of 29.54-88.37%, while WIS generated values of 1045.803 MWh/y with the capacity factor of 18.09%. Furthermore, the energy total specific at 10-50m are in the range

984.330-2944.588kW/ym² and remained 602.79kW/ym² for the experimental result and that generated by the WIS respectively in Figure 4.56.

From Figure 4.57, the average power varies from 125.604kW to 411.385kW in Kano, while WIS generated 143.159kW throughout the heights of 10m-50m. Again, a comparison was made with the observed total energy production in Figure 4.58, it can be seen that the total energy production for the experimental results in Kano at 10-50m are in the range of 1100.295MWh/y with the capacity factor of 19.03-62.33%, while WIS generated values of 1145.275MWh/y with the capacity factor of 19.81%. Furthermore, the energy total specific at 10-50m are in the range 634.198-2077.149kW/ym² and remained 660.12kW/ym² for the experimental result and that generated by the WIS respectively in Figure 4.59.

From Figure 4.60, the average power varies from 3.085kW to 17.875kW in Lokoja, while WIS generated 80.512kW throughout the heights of 10m-50m. Again, a comparison was made with the observed total energy production in Figure 4.61, it can be seen that the total energy production for the experimental results in Lokoja at 10-50m are in the range of 27.028-156.584MWh/y with the capacity factor of 0.47-2.71%, while WIS generated values of 644.099MWh/y with the capacity factor of 11.14%. Furthermore, the energy total specific at 10-50m are in the range 15.579-90.253kW/ym² and remained 371.25kW/ym² for the experimental result and that generated by the WIS respectively in Figure 4.62.

From Figure 4.63, the average power varies from 3.258kW to 19.583kW in Lagos, while WIS generated 46.205kW throughout the heights of 10m-50m. Again, a comparison was made with the observed total energy production in Figure 4.64, it can be seen that the total energy production for the experimental results in Lagos at 10-50m are in the range of 28.536-171.544Wh/y with the capacity factor of 0.49-2.97%, while WIS generated values of 369.639MWh/y with the capacity factor of 6.39%. Furthermore, the energy total specific at 10-50m are in the range 16.448-98.876kW/ym² and remained 213.06kW/ym² for the experimental result and that generated by the WIS respectively in Figure 4.65.

In summary, the experimental results indicated that the average power ranges from 17.9kW (Lokoja) to a maximum of 583.2kW (Jos) while the WIS generated range from 46.2kW (Lagos) to a maximum of 143kW (Kano). In case of experiment, the accumulated annual wind energy in the considered stations ranges from 156.6MWh/y (Lokoja) to a maximum of 5108.7MWh/y (Jos) per year, which is the energy that can be extracted by the chosen model wind turbine (Vesta 47/Stall).

From Figures 4.48-4.65, it can clearly be seen that the average power, total energy production and energy total specific increase with height in the experimental values, while the values generated from WIS remained the same as the height increases. It is known that power in the wind is proportional to the cube of wind speed, so even the modest increase in wind speed will cause significant increase in

the wind power. In order to get higher wind speeds, the wind turbines should be mounted on a taller tower.

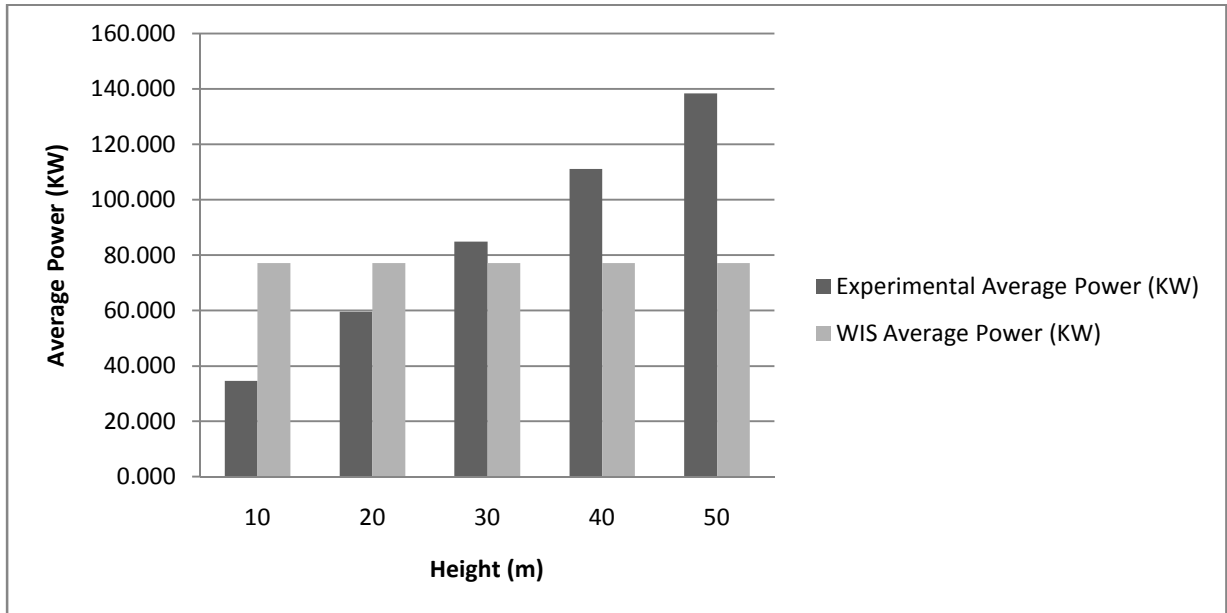


Figure 4.48: Graphical Comparison of Experimental and WIS Average Power of Enugu

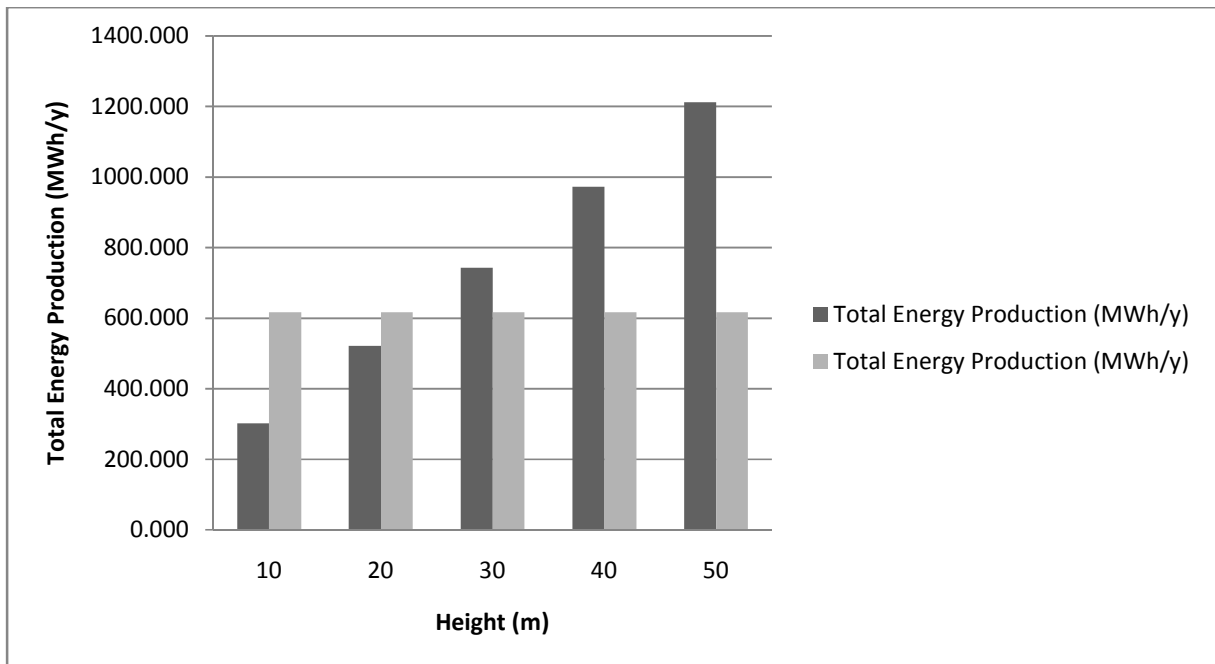


Figure 4.49: Graphical Comparison of Experimental and WIS Total Energy Production of Enugu

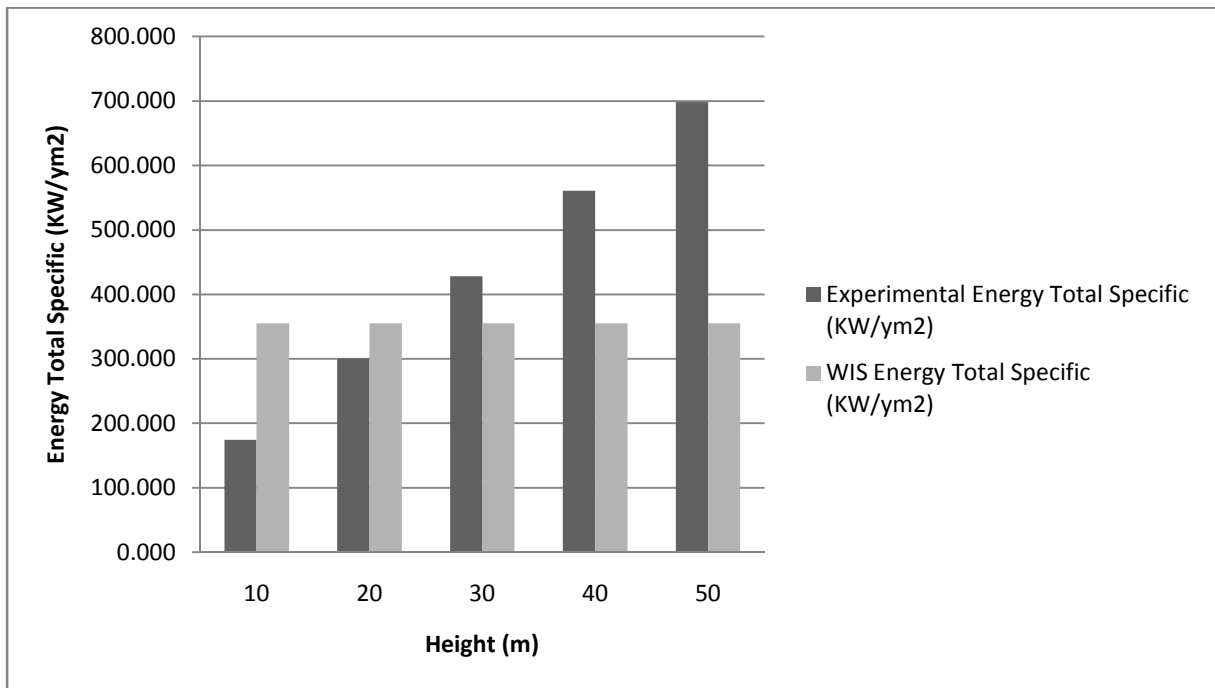


Figure 4.50: Graphical Comparison of Experimental and WIS Energy Total Specific of Enugu

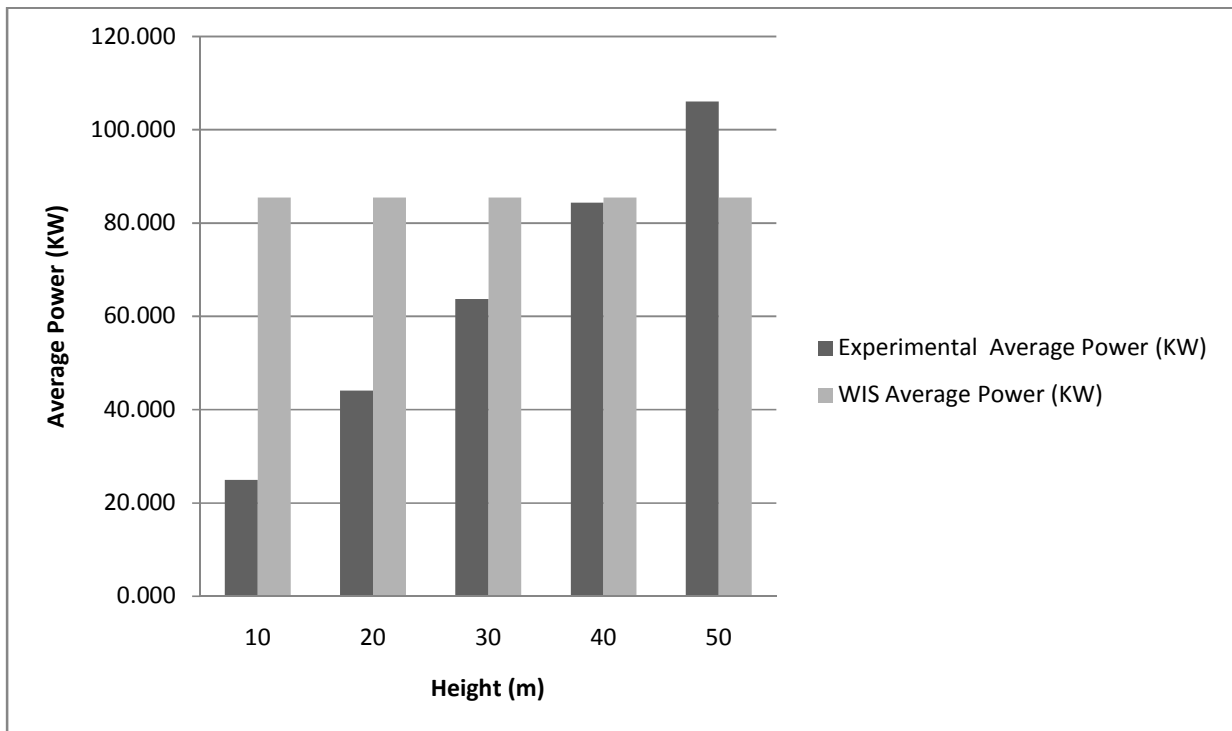


Figure 4.51: Graphical Comparison of Experimental and WIS Average Power of Ilorin

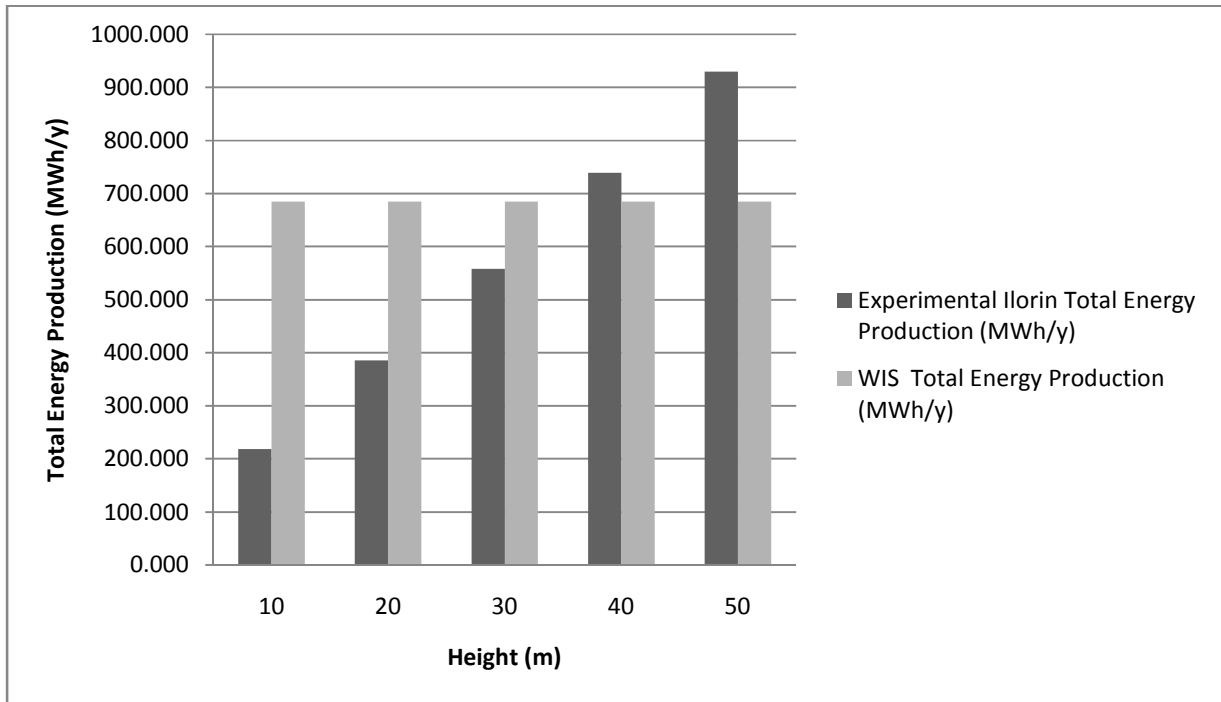


Figure 4.52: Graphical Comparison of Experimental and WIS Total Energy Production of Ilorin

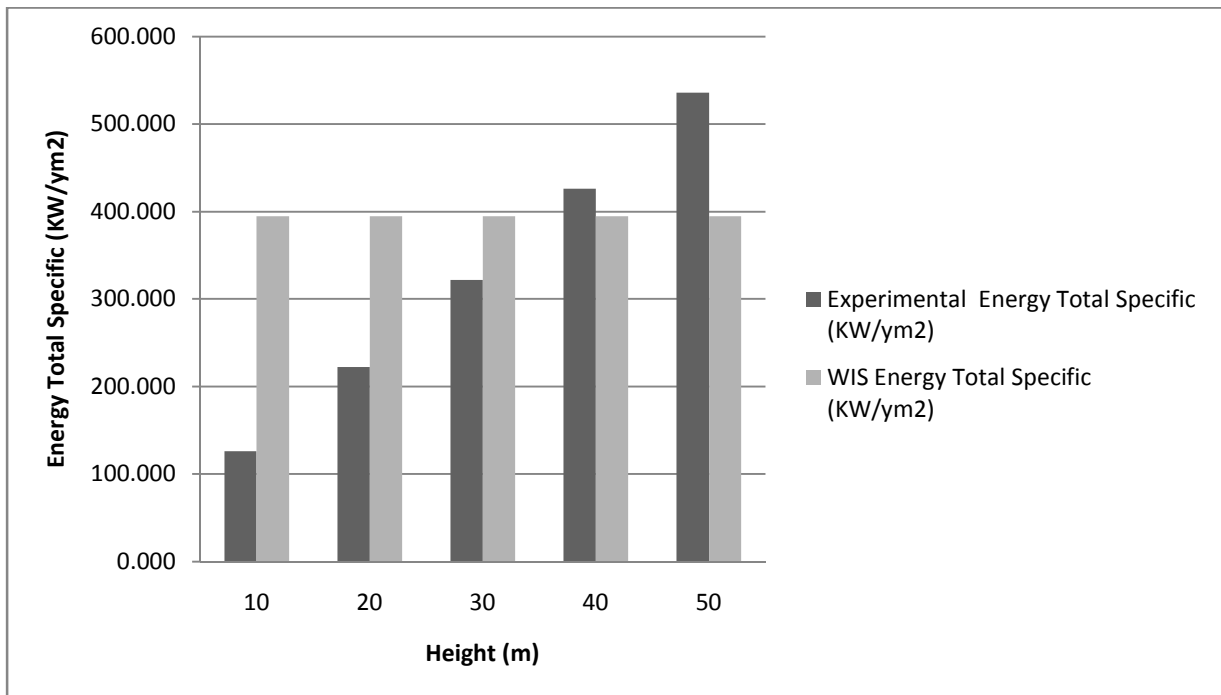


Figure 4.53: Graphical Comparison of Experimental and WIS Energy Total Specific of Ilorin

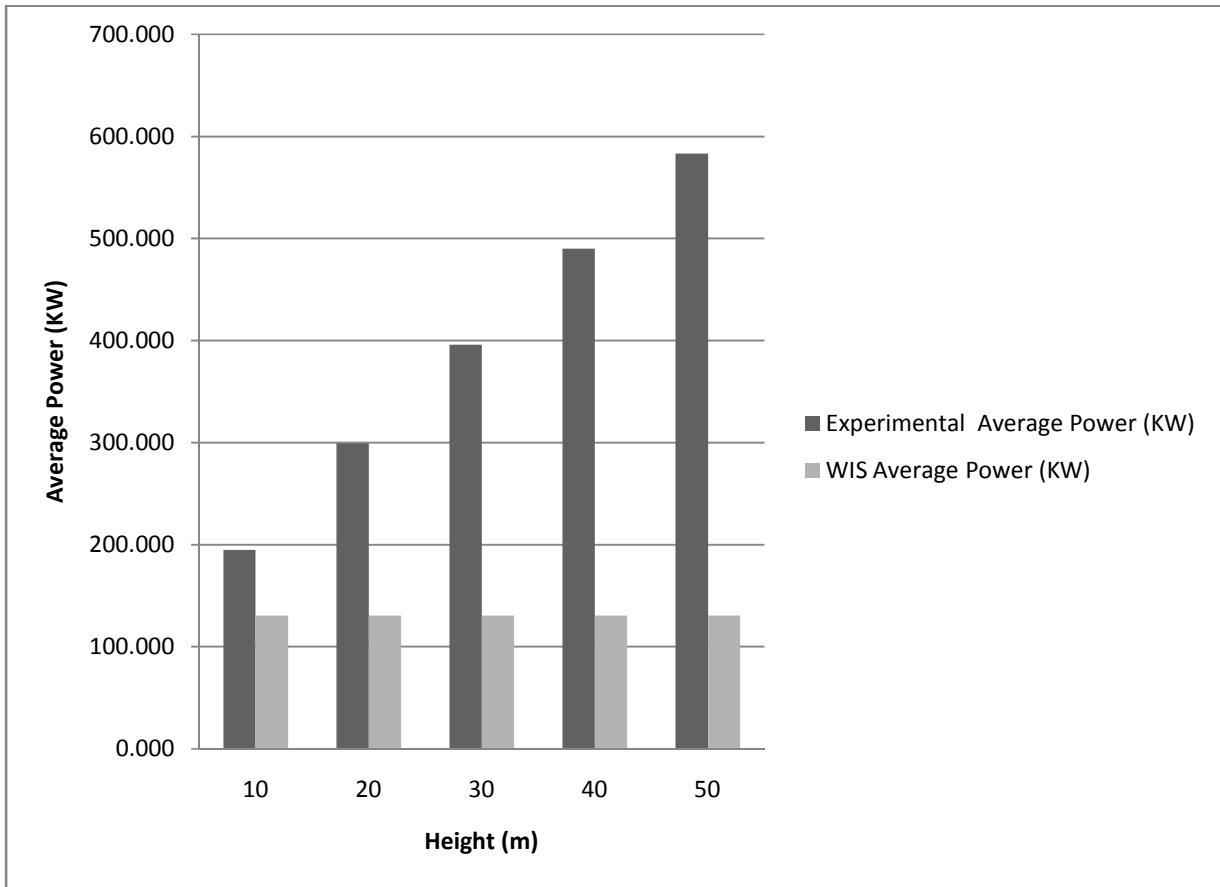


Figure 4.54: Graphical Comparison of Experimental and WIS Average Power of Jos

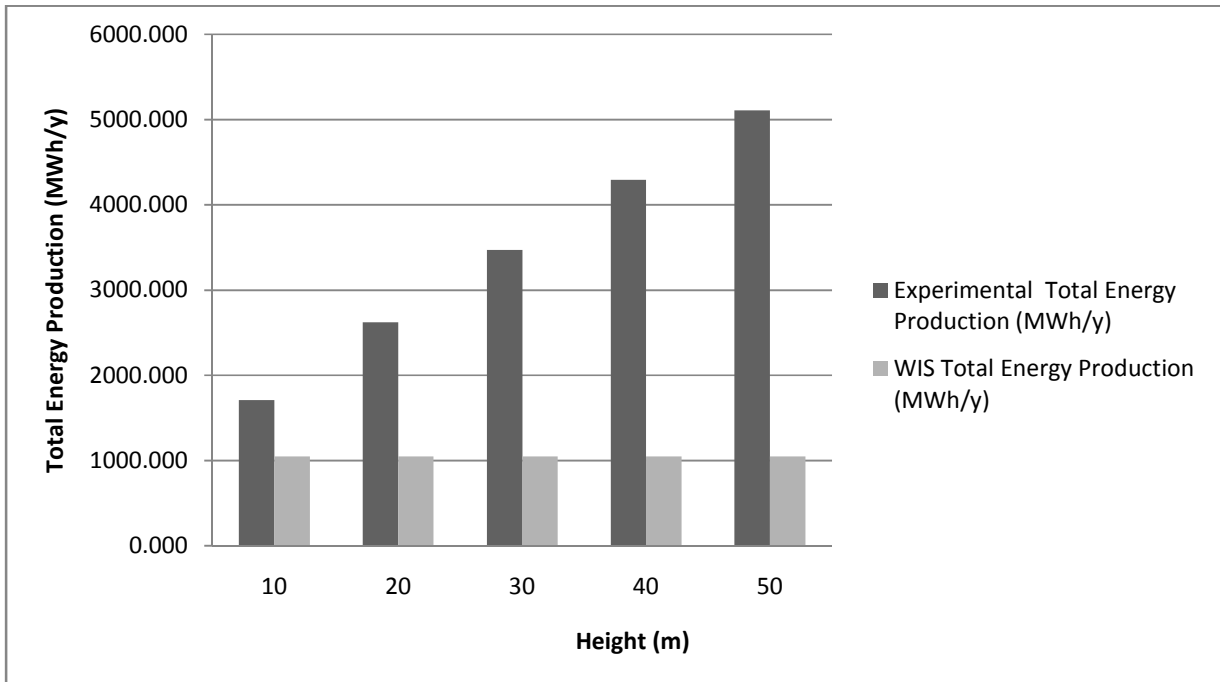


Figure 4.55: Graphical Comparison of Experimental and WIS Total Energy Production of Jos

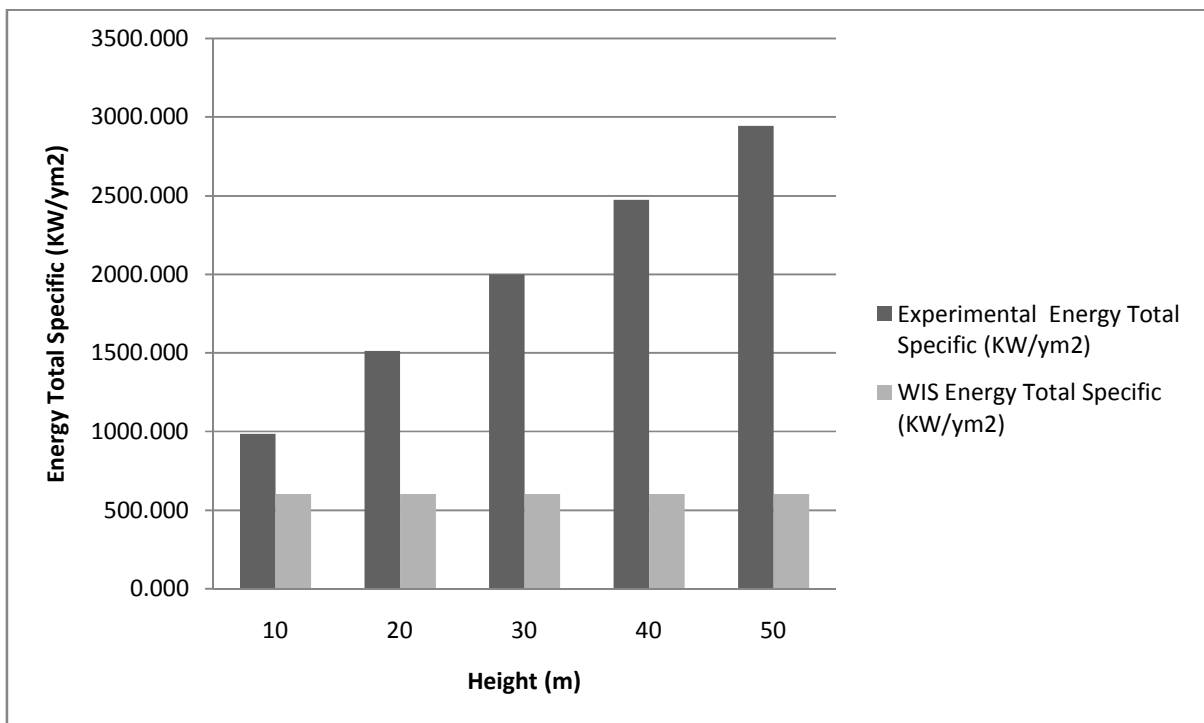


Figure 4.56: Graphical Comparison of Experimental and WIS Energy Total Specific of Jos

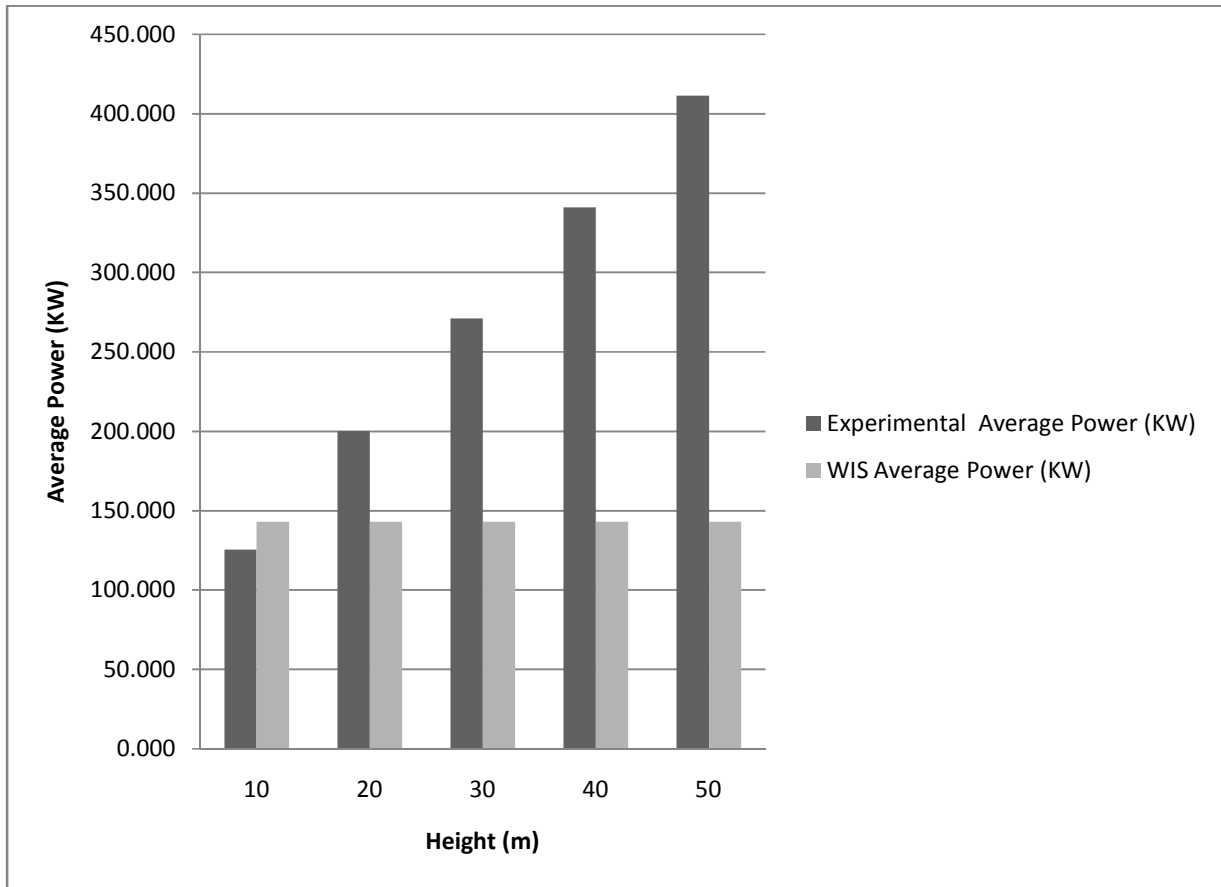


Figure 4.57: Graphical Comparison of Experimental and WIS Average Power of Kano

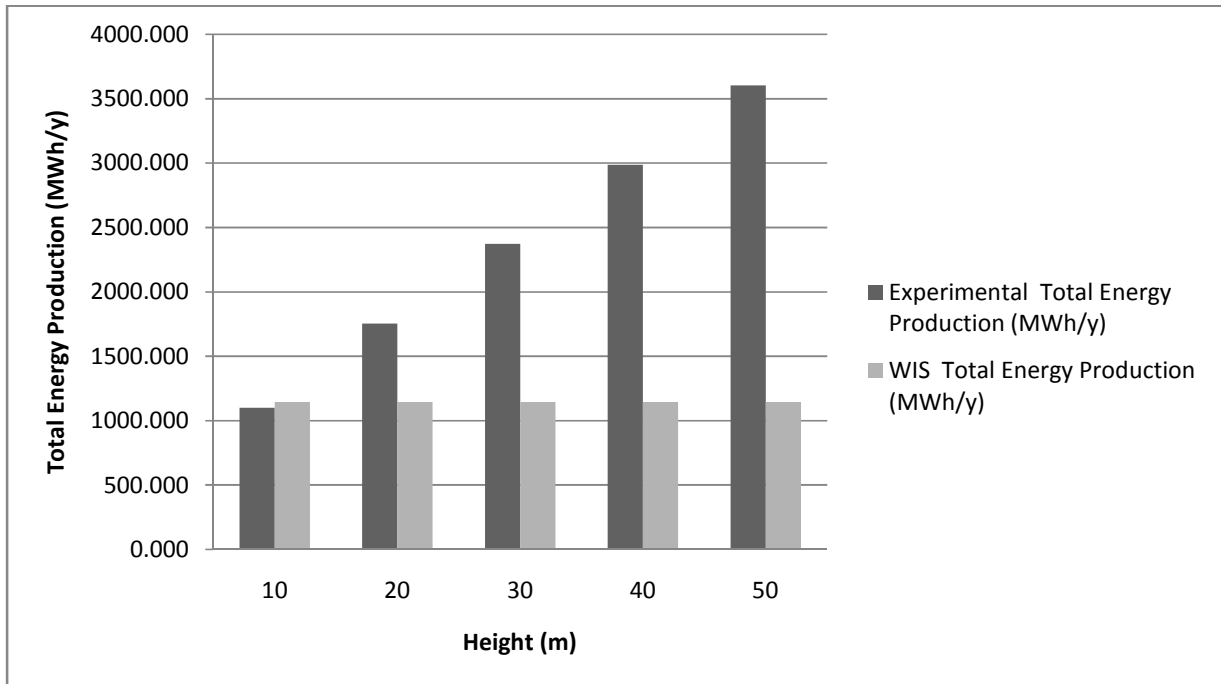


Figure 4.58: Graphical Comparison of Experimental and WIS Total Energy Production of Kano

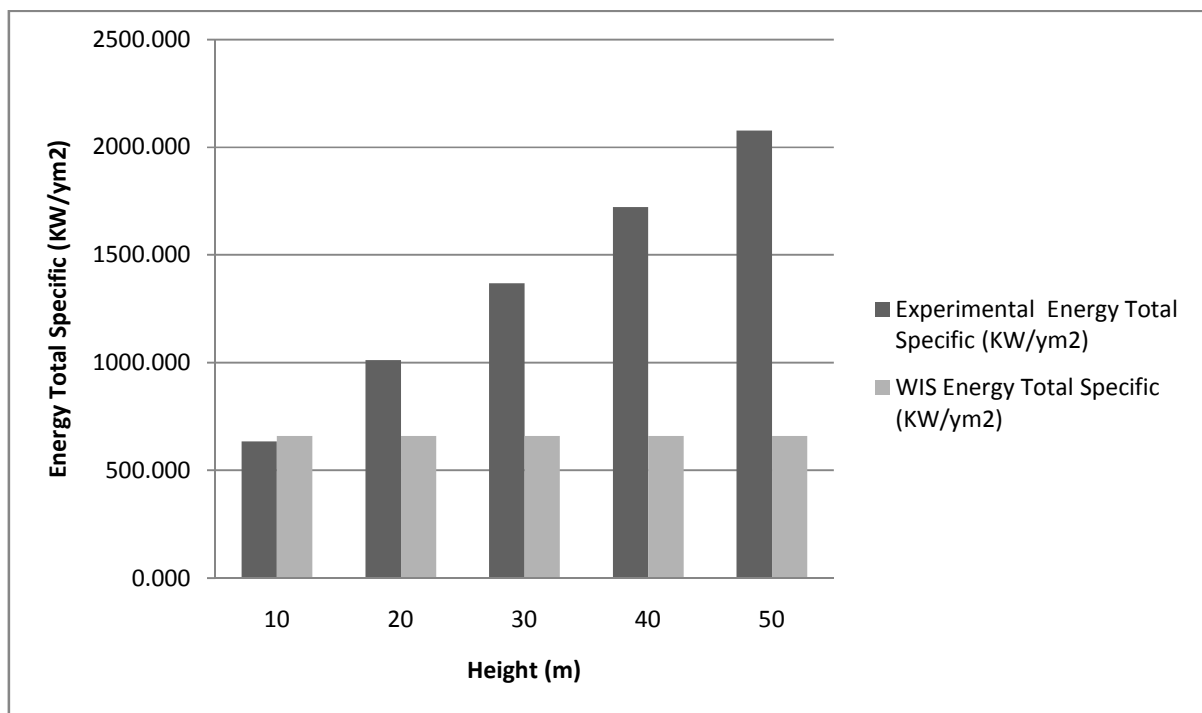


Figure 4.59: Graphical Comparison of Experimental and WIS Energy Total Specific of Kano

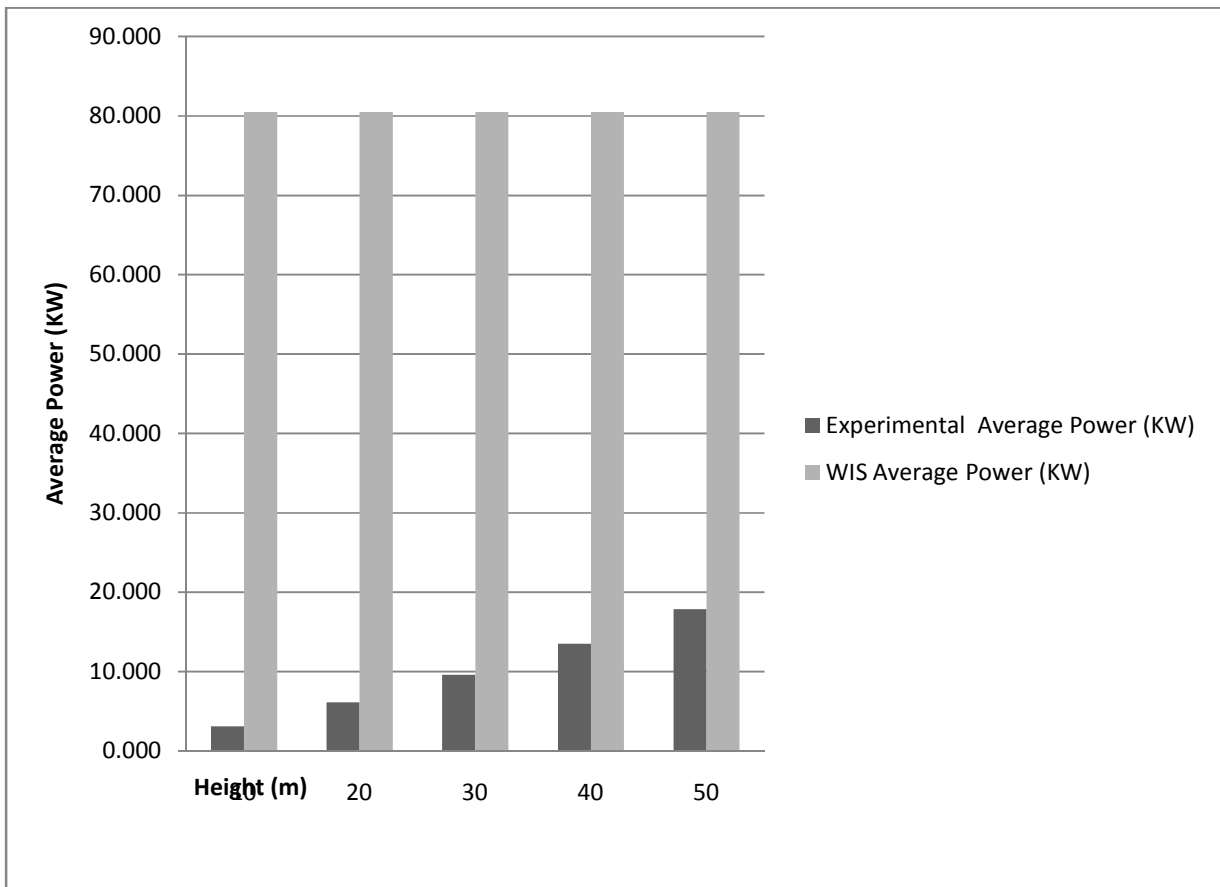


Figure 4.60: Graphical Comparison of Experimental and WIS Average Power of Lokoja

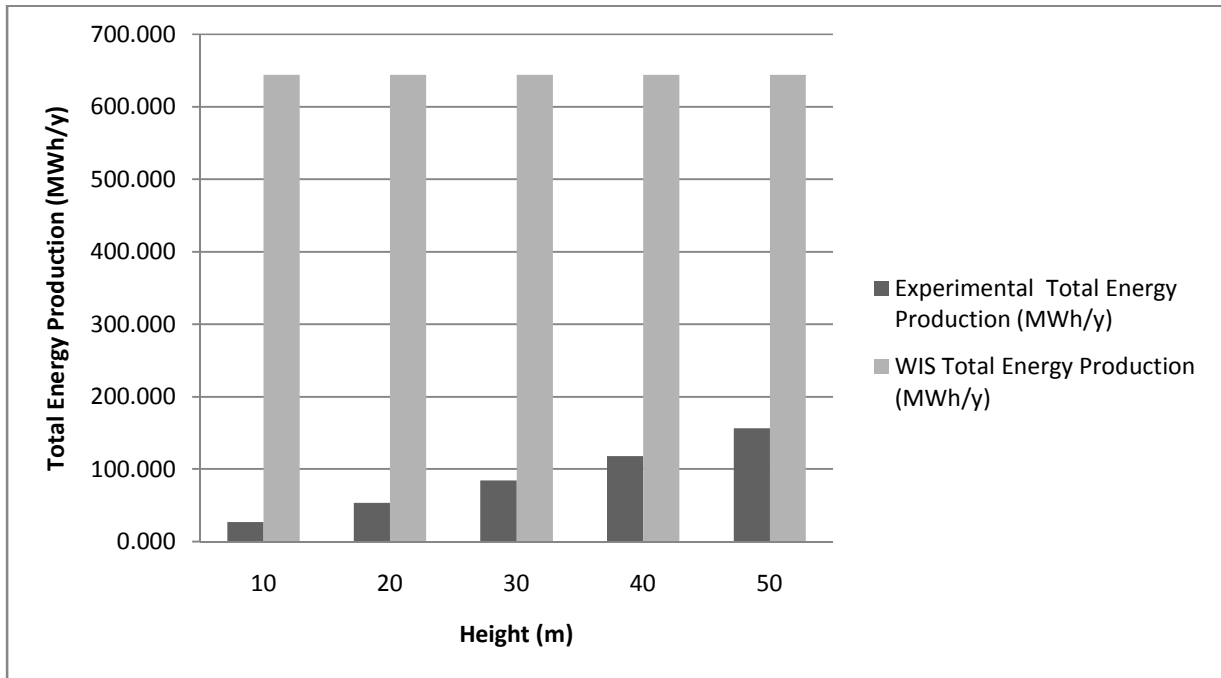


Figure 4.61: Graphical Comparison of Experimental and WIS Total Energy Production of Lokoja

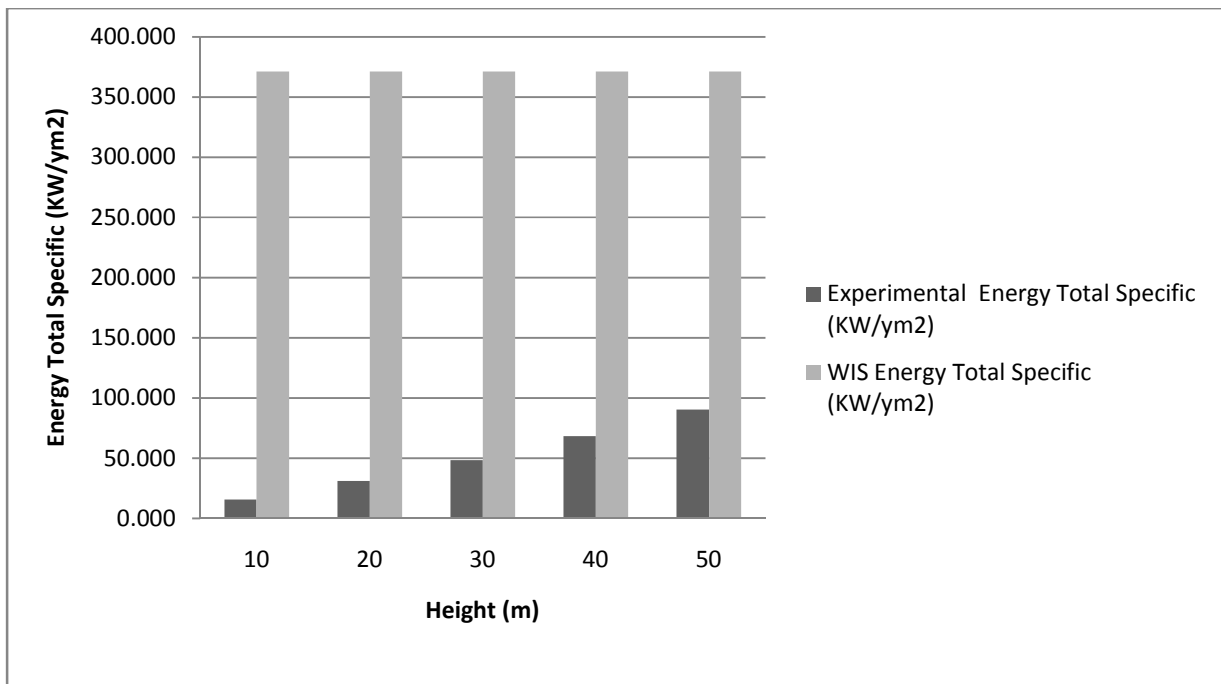


Figure 4.62: Graphical Comparison of Experimental and WIS Energy Total Specific of Lokoja

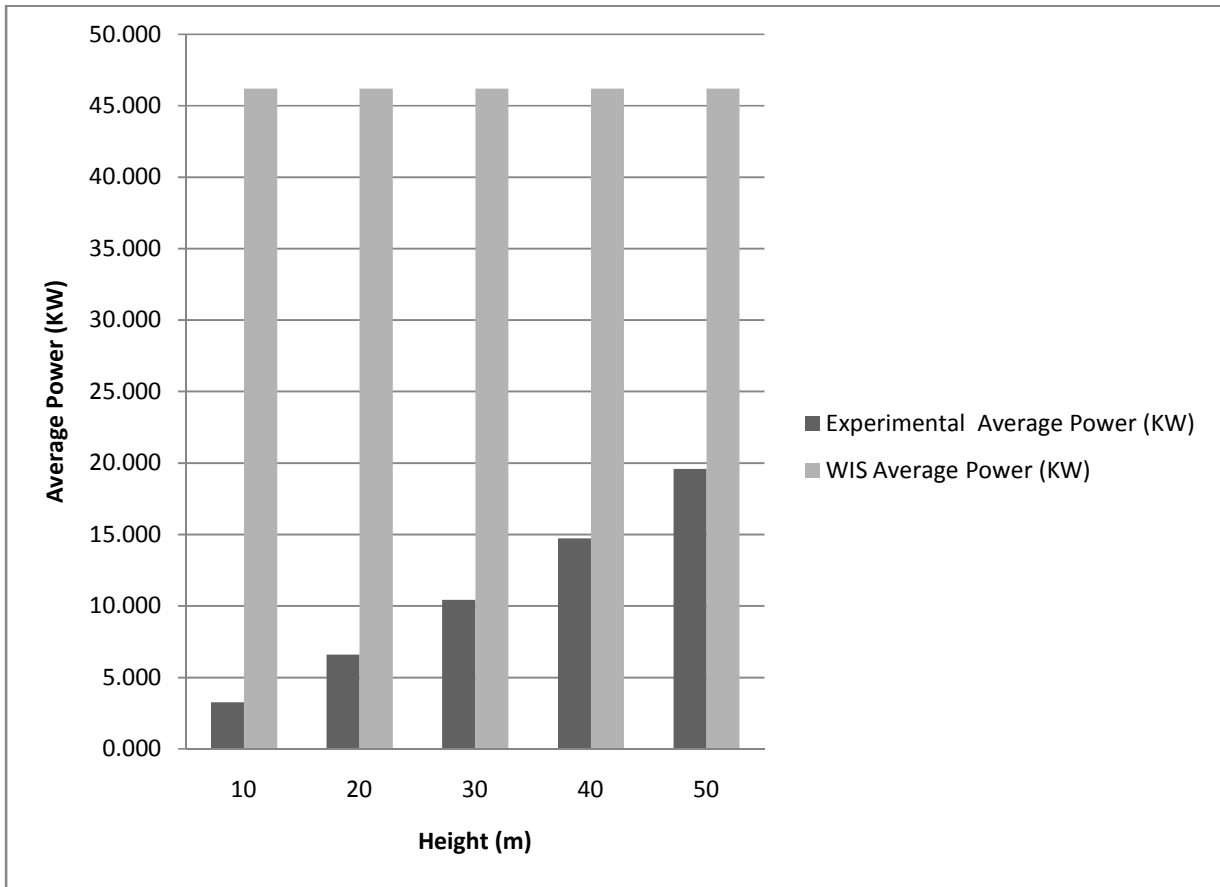


Figure 4.63: Graphical Comparison of Experimental and WIS Average Power of Lagos

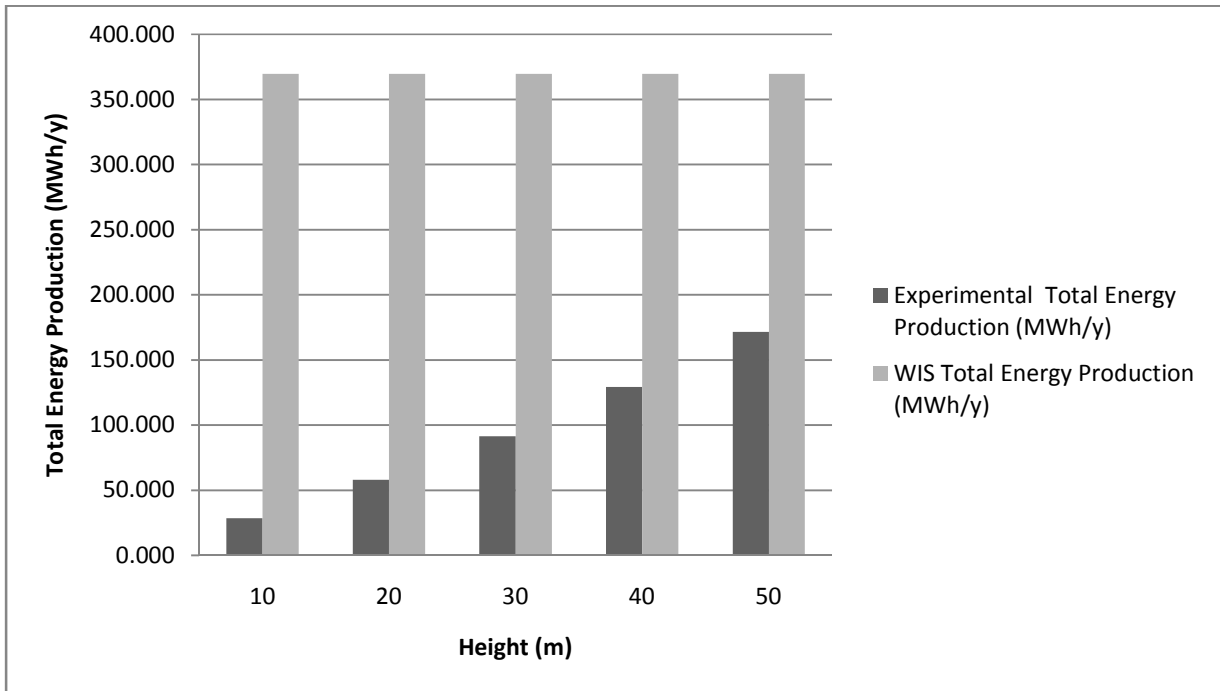


Figure 4.64: Graphical Comparison of Experimental and WIS Total Energy Production of Lagos

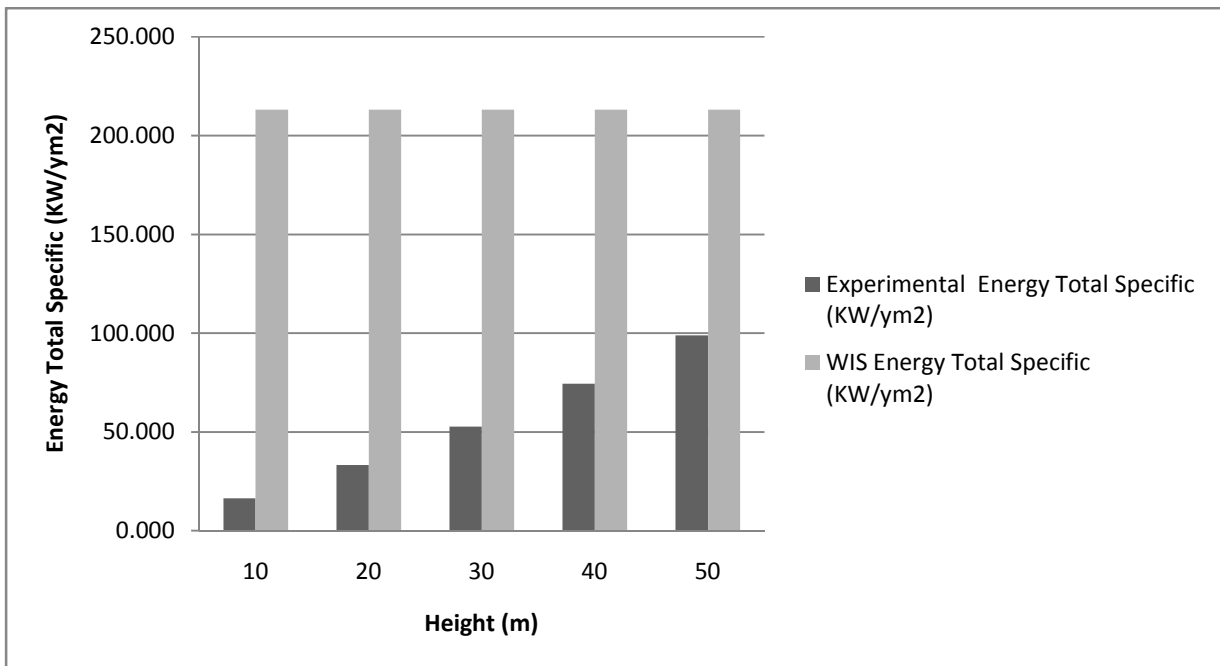


Figure 4.65: Graphical Comparison of Experimental and WIS Energy Total Specific of Lagos

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Of the six sites assessed, only four (Enugu, Ilorin, Kano, and Jos) have wind speed regimes with some appreciable potential for wind energy application. At 10 m height, the mean annual wind speeds for these stations are 3.6, 3.2, 5.7 and 6.9 m/s, respectively. Lokoja and Lagos have very low annual mean wind speeds of less than 2.5 m/s. The wind data for all these places were fitted with Weibull distribution using Microsoft Excell 2007. Also, using the Weibull cumulative density function, the probability that the wind speed would be greater than 3 m/s (being a typical value of cut-in speed of many wind turbines) was estimated to be 0.74, 0.65, 0.99 and 0.96 for Enugu, Ilorin, Kano, and Jos, respectively. Lokoja and Lagos have 0.01, and 0.00, respectively, which rules them out of any major wind energy applications, (American Wind Energy Association, 1998).

The wind speed regimes for these sites were also extrapolated at various heights above 10m (from 20m to 50m), using equation (3.36) to calculate the surface roughness coefficient of each station. Even at these heights, the wind speeds for Lokoja and Lagos were still too low for any reasonable economic of wind energy utilization. On the other hand, Enugu, Ilorin, Kano, and Jos show wind speed

regimes that can be economically fitted with wind turbines at many of these heights, (American Wind Energy Association, 1998).

The estimated mean wind speed, Coefficient of Variation (COV) and standard deviation for the selected sites were compared with the result generated by the WIS software as clearly presented in Table 4.34. The estimated result shows that, the maximum and minimum wind speed of the selected sites occurred at 10m and 50m with values of 5.451m/s and 3.663m/s respectively. The Coefficient of variation (COV) and standard deviation at these heights vary between 47.2% and 54.0% and, 2.573 and 1.979, respectively. On the other hand, WIS generated the same wind speed of 5.194m/s, COV of 13.9% and standard deviation of 0.724 from 10-50m.

Hence, the estimated turbulence is comparatively decreasing from 54.0% at 10m to 47.2% at 50m, while WIS maintained the same COV of 13.9% from 10-50m.

Furthermore, energy density and total energy intensity per unit area were analyzed. From the statistical data and calculations, one can conclude that the wind energy potential in the sites at 30-50m is quite promising, because the chances of having wind speeds less than 3 m/s are small (see Tables 4.53-4.58). Since the wind speed range for electricity generation is (5–6) m/s (Adekoya, *et al.*, 1992), the following sites are suitable for electric wind applications: Kano and Jos. Investigation of available wind power density at the heights of 30–50m indicates that, there are four

stations which have good wind power densities. Group A, which includes the two contiguous stations: Kano and Jos have high wind power density ranging from 265–387W/m² and 402–570 W/m² at the heights of 30–50 m, respectively. So wind farms can be installed in these regions to supply a reasonable amount of energy using a number of wind turbines, like Vestas V47 turbine, with rated capacity of 660kW in the Wind Information System Software. Group B, included the following stations: Ilorin and Enugu have moderate wind power densities ranging from 62–82 W/m² to 104–135 W/m² at the heights of 30–50 m above ground level. The two foreseen applications of these stations are water pumping for storage and electricity generation using small wind machines with installed capacities of less than 100 kW.

From tables 4.47-4.58, it is seen that velocity, Weibull parameters, average power, total energy production and energy total specific vary with the heights for the experimental data but remained the same as the height increases from 10m to 50m in the case of wind information system (WIS) software which really contradicts the general concept of the relationship between them. According to Patel, M. R, (1999) Wind speed increases with height above ground level due to the frictional drag of the ground, vegetation and buildings. As such, any plans to harness the wind must take this variation into account. Because wind energy development depends sensitively on the nature of the wind resource, any detailed evaluation of wind

energy requires a series of wind assessment studies. Therefore, there is need for this software to be upgraded to be free from errors as discovered by the experimental results which are used to validate it.

5.2 Recommendation

This work should be extended to other parts of the country to determine the wind energy of different locations in order to detect the proper fields for the establishment of wind farms.

The Energy commission of Nigeria should continue to create awareness and training on the use of the existing on-shore Wind Information System (WIS) software and the utilization of wind energy at the states and local government levels.

The existing Wind Information system has addressed only on-shore wind data, but not the off-shore (where there may be a more promising wind regime). Hence, effort should be made by the Energy commission of Nigeria in collaboration with other relevant government agencies to produce a Nigerian off-shore WIS since there is an existing proposal.

REFERENCES

- Abramowitz, M. and Stegun, I. A., eds. (1965). *Handbook of Mathematical Functions*. New York, NY: Dover.
- Acker, T. L., Williams, S. K., Duque, E. P., Brummels, G. and Buechler, J. (2007) Wind resource assessment in the state of Arizona: Inventory, capacity factor, and cost. *Renew. Energy*, 32, pp 1453–1466.
- Adamu A. A. and Abdullahi I: Wind-Electricity Generation Potential for Selected Regions in Northwestern, Nigeria. *Journal of Engineering and Applied Sciences*.
- Adamu A. A. and Abdullahi I: Wind Energy Potential of Northwestern Nigeria. *Journal of Engineering and Applied Sciences*.
- Adaramola, M., Paul, S., Oyedepo, S. (2011). Assessment of electricity generation and energy cost of wind energy conversion systems in north-central Nigeria. *Energy Convers. Manag.*, 52, 3363–3368.
- Adekoya L. O, Adewale A. A. (1992). Wind Energy Potential of Nigeria. *Renewable Energy*: 2(1): 35-9.
- Ahmed M. M and Sultan. A. (2008). Data Driven Parameter Estimation for the Three Parameter Weibull Population from Censored Samples. *Mathematical and Computational Applications*, Vol. 13, No. 2, pp. 129-136.
- Ahmed Shata A. S. (2000). Site Potential of Egypt for Wind Energy Application. MSc Thesis Submitted to Physics Department, Faculty of Science, Zagazig University, Egypt.
- Aidan J. and 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.
- Akdag S. A, Ali D (2009). A New Method to Estimate Weibull Parameters for Wind Energy Applications. *Energy Convers. Manag.* 50:1761-1766.
- Akdag, S. A, Bagiorgas, H. S. and Mihalakakou, G. (2010). Use of two-component Weibull mixtures in the analysis of wind speed in the Eastern Mediterranean. *Applied Energy* 87, 2566– 2573.

- Akdag, S. A, Dinler, A. (2009). A New Method to Estimate Weibull Parameters for Wind Energy Applications. *Energy Conversion and Management* 50, 1761–1766.
- Akhmatov, V. (2007). Influence of wind direction on intense power fluctuations in large offshore wind farms in the North Sea. *Wind Eng.* 31, 59–64.
- Akpinar, E. K. and Akpinar, S. (2005). An assessment on seasonal analysis of wind energy characteristics and wind turbine characteristics. *Energy Conversion and Management* 46, 1848–67.
- Akpinar, E. and Akpinar, S. (2004). Statistical Analysis of Wind Energy Potential on the Basis of the Weibull and Rayleigh Distributions for Agin-Elazig, Turkey. *Proc. Inst. Mech. Eng. Part A J. Power Energy*, 218, 557–565.
- American Wind Energy Association, (1998). Basic Principles of Wind Resource Evaluation. <http://www.awea.org>. Accessed February, 2008.
- Anani A, Zuamot S, Abu-Allan F, Jibril Z. (1998). Evaluation of Wind Energy as a Power Generation Source in a Selected Site in Jordan. *Solar and Wind Technology*; 5(1):67-74.
- Azad, A. (2013). Statistical Weibull distribution analysis for wind power of the two dimensional ridge areas. *Int. J. Adv. Renew. Energy Res.* 1, 8–14.
- Bagiorgas, H. S, Assimakopoulos, M. N. Theoharopoulos, D, Matthopoulos, D. and Mihalakakou, G.K (2007) Electricity generation using wind energy conversion systems in the area of Western Greece. *Energy Conversion and Management* 48, 1640–1655
- Balouktsis, A, Chassapis, D. and Karapantsios, T. D. (2002). A nomogram method for estimating the energy produced by wind turbine generators. *Solar Energy* 72, 251–259.
- Baños, R., Manzano-Agugliaro, F., Montoya, F. G., Gil, C., Alcayde, A.; Gómez, J. (2011). Optimization methods applied to renewable and sustainable energy: A review. *Renew. Sustain. Energy Rev.* 15, 1753–1766.

- Belu, R. and Koracin, D. (2009). Wind characteristics and wind energy potential in western Nevada. *Renew. Energy*, 34, 2246–2251.
- Bogdan, S. B. and Salameh, Z. M. (1996) “Methodology for optimally sizing the combination of a battery bank and PV array in wind/PV hybrid system,” *IEEE Transactions on Energy Conv.* 11(2), pp. 367-375.
- Bowen, A. J. and Mortensen, N. G. (2004). WASP prediction errors due to site orography. Roskilde, Denmark: Risø National Laboratory.
- Carta, J. A. and Mentado D. (2007). “A continuous Bivariate Model for Wind Power Density and Wind Turbine Energy Output Estimations”. *Journal of Energy Conversion and Management*. 48(2); pp 420-432.
- Celik, A. N. (2004). A statistical analysis of wind power density based on the Weibull and Rayleigh models at the southern region of Turkey. *Renew. Energy* 29, 593 – 604.
- Costa Rocha, P. A., de Sousa, R. C., de Andrade, C. F. and da Silva, M. E. V. (2012). Comparison of seven numerical methods for determining Weibull parameters for wind energy generation in the northeast region of Brazil. *Appl. Energy*, 89, 395–400.
- Cruz-Peragon, F., Palomar, J. M., Casanova, P. J., Dorado, M. P. and Manzano Agugliaro, F. (2012). Characterization of solar flat plate collectors. *Renew. Sustain. Energy Rev.* 16, 1709–1720.
- Fadare, D.A, (2008). A Statistical analysis of wind energy potential in Ibadan, Nigeria, based on Weibull distribution function. *Pacific J. Sci. Technol.* 9:110-119.
- Fagbenle, R. O., Katende, J., Ajayi, O. O. Okeniyi, J. O. (2011). Assessment of wind energy potential of two sites in North-East, Nigeria. *Renew. Energy* 36, 1277 – 1293.
- Gary L. Johnson, “Wind Energy Systems”. November 21, 2001.
- Global Wind Energy Council: Global wind report: annual market updates 2011. <http://www.gwec.net/> (2011). Accessed 30 April 2012.

- Gregor Giebel, (2003) “The State of The Art in Short-Term Prediction of Wind Power, A Literature Overview,” Riso National Laboratory.
- Guure, C. B. and Ibrahim, N. A. (2012). Bayesian analysis of the survival function and failure rate of Weibull distribution with censored data. *Math. Probl. Eng*, doi:10.1155/2012/329489.
- Hernandez-Escobedo, Q., Manzano-Agugliaro, F., Gazquez-Parra, J. A. and Zapata-Sierra, A. (2011). Is the wind a periodical phenomenon? The case of Mexico. *Renew. Sustain. Energy Rev.* 15,721–728.
- Hernández-Escobedo, Q., Manzano-Agugliaro, F. and Zapata-Sierra, A. (2010) The Wind Power of Mexico. *Renew. Sustain. Energy Rev.*, 14, 2830–2840.
- Ilinca, A, McCarthy, E, Chaumel, J. L. and Retiveau, J. L. (2003). Wind potential assessment of Quebec Province. *Renew. Energy* 28, 1881 – 1897.
- Joselin Herbert, G. M. Iniyar, Ranko Goic, S. (2010) “Performance, reliability and failure analysis of wind farm in a developing country,” *Renewable Energy*, 35(12), pp. 2739-2751.
- Jowder, FAL. (2009). Wind power analysis and site matching of wind turbine generators in Kingdom of Bahrain. *Applied Energy* 86, 538–545.
- Justus, C. G, Hargraves, W. R, Mikhail, A, Graber, D. (1978). Methods for estimating wind speed frequency distributions. *J. Appl. Meteorol.* 17, 350–353.
- Khogali, A. Albar, O. F. and Yousif, B. (1991). Wind and Solar Energy Potential in Makkah (Saudi Arabia)-Comparison with Red Sea Coastal Sites. *Renewable Energy* 1(3): 435-40.
- Lehmeyer (International) Consultant, (2005) Report on Nigeria wind power mapping projects, Federal Ministry of Science and Technology, Pp. 37-51, (Unpublished).
- Mahyoub, H. and Albuhairi, H. (2006). “Assessment and Analysis of Wind power density in Taiz-Republic of Yemen”. 10(2006): pp 12-21.

- Marcus-Kaitis, M., Katnals, V. and Karaliauskas, A. (2008). Wind power usage and prediction prospects in Lithuania. *Renew. Sustain. Energy Rev.* 12, 265–277.
- Mathew, S. (2006). *Wind Energy: Fundamentals, Resource Analysis and Economics*. Springer, Heidelberg.
- Mathew, S., Pandey, K. P. and Kumar, A. V. (2002). Analysis of wind regimes for energy estimation. *Renew. Energy* 25, 381–399.
- Mehdi Kazemi and Arman Goudarzi, (2012) “A Novel Method for Estimating Wind Turbines Power Output based on Least Square Approximation”, *International Journal of Engineering and Advanced Technology (IJEAT)*, Volume 2, Issue-1.
- Mohammadi, K.; Mostafaeipour, A. Using different methods for comprehensive study of wind turbine utilization in Zarrineh, Iran. *Energy Convers. Manag.* 2013, 65, 463–470.
- Mortensen, N., Bowen, A. J., and Antoniou, I. (2006). Improving WASP predictions in (too) complex terrain. 2006 European Wind Energy Conference and Exhibition. Athens: Riso National Laboratory, University of Canterbury.
- Mutlu, O. S. (2010) “Evaluating the impacts of wind farms on power system operation” *Journal of Naval Science and Engineering*, Vol 6, No 2, Pp.166-185.
- Ohunakin, O. S. (2010). Energy Utilization and Renewable Energy Sources in Nigeria. *J. Eng. Applied Sci.*, 5: 171-177.
- Olayinka S. O. (2011). Wind characteristics and Wind energy potential Assessment in Uyo. . *Journal of Engineering and Applied Sciences* 6(2): 141-146,
- Oluseyi, O. A., Fagbenle, R. O. and Katende J. (2012). Analytical Predictive Model for Wind Energy Potential Estimation: A Model for Pre-Assessment study. *Journal of Applied Sciences*; 12(5): 450-458.
- Ouammi, A, Dagdougui, H, Sacile, R, and Mimet, A. (2010). Monthly and seasonal assessment of wind energy characteristics at four monitored locations in Liguria region (Italy). *Renew. Sustain. Energy Rev.*14, 1959–1968.

- Oyedepo, S. O., Adaramola, M. S. and Paul, S. S. (2012). Analysis of wind speed data and wind energy potential in three selected locations in south-east Nigeria. *Int. J. Energy Environ. Eng.* 3, doi: 10.1186/2251-6832-3-7.
- Patel, M. R. (1999). Wind and Solar Power Systems. CRC Press LLC. ISBN: 0-8493-1605-7.
- Prasad R. D., Bansal R. C. and Sauturaga M. (2009). Wind Modelling Based on Wind Input Data Conditions Using Weibull Distribution. *Inter. J. Glob. Energy* 32(3): 227-240.
- Rockette H., Antle Ch. and Klimko L. A. (1974), Maximum likelihood estimation with the Weibull model, *J. Amer. Statist. Assoc.* 69, No. 345, 246–249.
- Sanusi, Y. K and Abisoye, S. G. (2011). Estimation of Wind Energy Potential in Southwestern Nigeria. *The pacific Journal of science and Technology* Vol. 12, Number 2,
- Soper, D. S. (2015). Gamma Function Calculator [Software]. Available from <http://www.danielsoper.com/statcalc>.
- Stevens MJM, Smulders PT. The estimation of the parameters of the Weibull wind speed distribution for wind energy utilization purposes. *Wind Eng* 1979; 3: 132-45.
- Ucar, A. and Balo, F. (2009). Evaluation of Wind Energy Potential and Electricity Generation at six locations in Turkey. *Applied Energy* 86, 1864–1872.
- Vincent, C. L., Giebel, G. Pinson, P. and Madsen, H. (2010). Resolving Non Stationary Spectral Information in Wind Speed Time Series Using The Hilbert-Huang transform. *J. Appl. Meteorol. Climatol.* 49, 253–267.
- Vogiatzis N, Kotti K, Spanomitsios S, Stoukides M. (2004). Analysis of Wind Potential and Characteristics in North Aegean, Greece. *Renewable Energy* 29:1193–208.
- Yilmaz V, Aras H, Celik H. E. (2005). Statistical Analysis of Wind Speed Data. *Eng, and Arch. Fac. Eskisehir Osmangazi University.* 98(2):1-10.

WASP—The Wind Atlas Analysis and Application Program. Available online:
<http://www.wasp.dk> (accessed on 15 March 2014).

Weibull, W. (1951). A Statistical Distribution Function of Wide Applicability. *J. Applied Mech.*, 18: 253-253.

APPENDIX

Table 4.2: Wind Speed Frequency Distribution For Jos

Wind Speed (m/s)	Frequency (%)	Cumulative Frequency (%)
0-1	0	0
1-2	0	0
2-3	0	0
3-4	0	0
4-5	0	0
5-6	5.357	5.357
6-7	15.179	20.536
7-8	43.750	64.286
8-8	18.750	83.036
9-10	6.250	89.286
10-11	7.143	96.429
11-12	2.679	99.107
12-13	0.893	100
13-14	0	100
14-15	0	100
15-16	0	100
16-17	0	100
17-18	0	100
18-19	0	100
19-20	0	100
20-21	0	100
21-22	0	100
22-23	0	100
23-24	0	100
24-25	0	100
25-26	0	100

Table 4.3: Wind Speed Frequency Distribution For Kano

Wind Speed (m/s)	Frequency (%)	Cumulative Frequency (%)
0-1	0	0
1-2	0	0
2-3	0	0
3-4	0	0
4-5	1.667	1.667
5-6	26.667	28.333
6-7	38.333	66.667
7-8	21.667	88.333
8-9	10.833	99.167
9-10	0.833	100
10-11	0	100
11-12	0	100
12-13	0	100
13-14	0	100
14-15	0	100
15-16	0	100
16-17	0	100
17-18	0	100
18-19	0	100
19-20	0	100
20-21	0	100
21-22	0	100
22-23	0	100
23-24	0	100
24-25	0	100
25-26	0	100

Table 4.4: Wind Speed Frequency Distribution For Enugu

Wind Speed (m/s)	Frequency (%)	Cumulative Frequency (%)
0-1	0	0
1-2	1.786	1.786
2-3	15.179	16.964
3-4	57.143	74.107
4-5	23.214	97.321
5-6	1.786	99.107
6-7	0.000	99.107
7-8	0.893	100
8-9	0	100
9-10	0	100
10-11	0	100
11-12	0	100
12-13	0	100
13-14	0	100
14-15	0	100
15-16	0	100
16-17	0	100
17-18	0	100
18-19	0	100
19-20	0	100
20-21	0	100
21-22	0	100
22-23	0	100
23-24	0	100
24-25	0	100
25-26	0	100

Table 4.5: Wind Speed Frequency Distribution For Ilorin

Wind Speed (m/s)	Frequency (%)	Cumulative Frequency (%)
0-1	5.357	5.357
1-2	28.571	33.929
2-3	51.786	85.714
3-4	13.393	99.107
4-5	0.893	100
5-6	0	100
6-7	0	100
7-8	0	100
8-8	0	100
9-10	0	100
10-11	0	100
11-12	0	100
12-13	0	100
13-14	0	100
14-15	0	100
15-16	0	100
16-17	0	100
17-18	0	100
18-19	0	100
19-20	0	100
20-21	0	100
21-22	0	100
22-23	0	100
23-24	0	100
24-25	0	100
25-26	0	100

Table 4.6: Wind Speed Frequency Distribution For Lagos

Wind Speed (m/s)	Frequency (%)	Cumulative Frequency (%)
0-1	0.714	0.714
1-2	86.429	87.143
2-3	12.857	100
3-4	0	100
4-5	0	100
5-6	0	100
6-7	0	100
7-8	0	100
8-8	0	100
9-10	0	100
10-11	0	100
11-12	0	100
12-13	0	100
13-14	0	100
14-15	0	100
15-16	0	100
16-17	0	100
17-18	0	100
18-19	0	100
19-20	0	100
20-21	0	100
21-22	0	100
22-23	0	100
23-24	0	100
24-25	0	100
25-26	0	100

Table 4.7: Wind Speed Frequency Distribution For Lokoja

Wind Speed (m/s)	Frequency (%)	Cumulative Frequency (%)
0-1	24.167	24.167
1-2	55	79.167
2-3	20.0	99.167
3-4	0.833	100
4-5	0	100
5-6	0	100
6-7	0	100
7-8	0	100
8-8	0	100
9-10	0	100
10-11	0	100
11-12	0	100
12-13	0	100
13-14	0	100
14-15	0	100
15-16	0	100
16-17	0	100
17-18	0	100
18-19	0	100
19-20	0	100
20-21	0	100
21-22	0	100
22-23	0	100
23-24	0	100
24-25	0	100
25-26	0	100

Table 4.15: Weibull Probability Density Distribution For Lagos

Wind Speed (m/s)	Weibull Probability Density Function $f(v)$	Cumulative Distribution Function $F(V)$
0	0	0
1	0.104853	0.014808
2	0.919478	0.876983
3	3.44E-15	1
4	7.9E-126	1
5	0	1
6	0	1
7	0	1
8	0	1
9	0	1
10	0	1
11	0	1
12	0	1
13	0	1
14	0	1
15	0	1
16	0	1
17	0	1
18	0	1
19	0	1
20	0	1
21	0	1
22	0	1
23	0	1
24	0	1
25	0	1

Table 4.16: Weibull Probability Density Distribution Lokoja

Wind speed (m/s)	Weibull Probability Density Function $f(v)$	Cumulative Distribution Function $F(V)$
0	0	0
1	0.52577	0.222011
2	0.431149	0.802548
3	0.03455	0.992032
4	0.000198	0.999972
5	5.14E-08	1
6	3.84E-13	1
7	5.28E-20	1
8	8.66E-29	1
9	1.11E-39	1
10	7.53E-53	1
11	1.8E-68	1
12	1.04E-86	1
13	1E-107	1
14	1.1E-131	1
15	1.1E-158	1
16	5.6E-189	1
17	1.2E-222	1
18	8E-260	1
19	1.1E-300	1
20	0	1
21	0	1
22	0	1
23	0	1
24	0	1
25	0	1

Table 4.17: Weibull Probability Density Distribution for Jos

Wind Speed (m/s)	Weibull Probability Density Function f(v)	Cumulative Distribution Function F(V)
0	0	0
1	0.002411	0.000635
2	0.016639	0.008799
3	0.050113	0.0404
4	0.103309	0.115748
5	0.16372	0.249602
6	0.204715	0.436739
7	0.19956	0.643344
8	0.146733	0.819538
9	0.077635	0.931334
10	0.027897	0.981628
11	0.006368	0.996788
12	0.000857	0.999661
13	6.27E-05	0.99998
14	2.28E-06	0.999999
15	3.75E-08	1
16	2.52E-10	1
17	6.24E-13	1
18	5.06E-16	1
19	1.2E-19	1
20	7.29E-24	1
21	1E-28	1
22	2.73E-34	1
23	1.28E-40	1
24	8.86E-48	1
25	7.85E-56	1

Table 4.18: Weibull Probability Density Distribution For Ilorin

Wind Speed (m/s)	Weibull Probability Density Function f(v)	Cumulative Distribution Function F(V)
0	0	0
1	0.008441	0.001673
2	0.132493	0.053955
3	0.470745	0.349371
4	0.369357	0.840782
5	0.019737	0.996554
6	7.85E-06	0.999999
7	7.59E-13	1
8	1.41E-25	1
9	7.42E-47	1
10	2.47E-80	1
11	1.3E-130	1
12	2.7E-203	1
13	3.3E-305	1
14	0	1
15	0	1
16	0	1
17	0	1
18	0	1
19	0	1
20	0	1
21	0	1
22	0	1
23	0	1
24	0	1
25	0	1

Table 4.19: Weibull Probability Density Distribution for Enugu

Wind Speed (m/s)	Weibull Probability Density Function $f(v)$	Cumulative Distribution Function $F(V)$
0	0	0
1	0.010499	0.002384
2	0.106265	0.049447
3	0.32893	0.261425
4	0.404344	0.659493
5	0.142418	0.94395
6	0.007569	0.9984
7	2.43E-05	0.999997
8	1.45E-09	1
9	3.7E-16	1
10	7.01E-26	1
11	1.26E-39	1
12	2.02E-58	1
13	1.94E-83	1
14	5.4E-116	1
15	1.5E-157	1
16	9.3E-210	1
17	2.3E-274	1
18	0	1
19	0	1
20	0	1
21	0	1
22	0	1
23	0	1
24	0	1
25	0	1

Table 4.20: Weibull Probability Density Distribution for Kano

Wind Speed (m/s)	Weibull Probability Density Function $f(v)$	Cumulative Distribution Function $F(V)$
0	0	0
1	0	0
2	0.00393	0.00132
3	0.02887	0.01466
4	0.07950	0.05086
5	0.19487	0.16347
6	0.36445	0.54619
6	0.31841	0.75406
7	0.09869	0.96241
8	0.01541	0.99623
9	0	1
10	0	1
11	0	1
12	0	1
13	0	1
14	0	1
15	0	1
16	0	1
17	0	1
18	0	1
19	0	1
20	0	1
21	0	1
22	0	1
23	0	1
24	0	1
25	0	1

Table 4.35: Weibull Probability Density Distribution for Enugu at 10m, 20m, 30m, 40m and 50m.

V(m/s)	f(v) ₁₀	F(v) ₂₀	f(V) ₃₀	f(v) ₄₀	f(v) ₅₀	F(V) ₁₀	F(V) ₂₀	F(V) ₃₀	F(V) ₄₀	F(V) ₅₀
0	0	0	0	0	0	0	0	0	0	0
1	0.010499	0.003185	0.001388	0.000717	0.00041	0.002384	0.000679	0.000284	0.000143	7.97E-05
2	0.106265	0.040589	0.020286	0.011589	0.007185	0.049447	0.01744	0.008347	0.004626	0.002801
3	0.32893	0.164282	0.092878	0.057394	0.037703	0.261425	0.111399	0.058852	0.034902	0.022268
4	0.404344	0.339318	0.235435	0.162694	0.114856	0.659493	0.366202	0.218857	0.139856	0.093997
5	0.142418	0.33272	0.343927	0.29236	0.23391	0.94395	0.727578	0.520027	0.369994	0.266993
6	0.007569	0.112192	0.243413	0.304606	0.307164	0.9984	0.953176	0.832586	0.684718	0.547252
7	2.43E-05	0.007671	0.05959	0.14693	0.223238	0.999997	0.998189	0.977468	0.918189	0.826102
8	1.45E-09	5.1E-05	0.003066	0.022996	0.069162	1	0.999993	0.99931	0.992516	0.968991
9	3.7E-16	1.27E-08	1.7E-05	0.000712	0.006272	1	1	0.999998	0.999856	0.998273
10	7.01E-26	3.64E-14	4.27E-09	2.28E-06	0.000101	1	1	1	1	0.999982
11	1.26E-39	2.82E-22	1.69E-14	3.33E-10	1.5E-07	1	1	1	1	1
12	2.02E-58	1.07E-33	2.88E-22	8.08E-16	9.27E-12	1	1	1	1	1
13	1.94E-83	2.72E-49	4.58E-33	9.74E-24	8.96E-18	1	1	1	1	1
14	5.4E-116	4.62E-70	1.13E-47	1.38E-34	4.18E-26	1	1	1	1	1
15	1.5E-157	3.8E-97	5.44E-67	4.3E-49	2.37E-37	1	1	1	1	1
16	9.3E-210	7.8E-132	4.75E-92	4.21E-68	3.26E-52	1	1	1	1	1
17	2.3E-274	1.5E-175	5.1E-124	1.41E-92	1.69E-71	1	1	1	1	1
18	0	6.3E-230	3.2E-164	1.3E-123	3.94E-96	1	1	1	1	1
19	0	1E-296	4.2E-214	1.9E-162	3.7E-127	1	1	1	1	1
20	0	0	2.5E-275	1.8E-210	9.4E-166	1	1	1	1	1
21	0	0	0	3.3E-269	3.1E-213	1	1	1	1	1
22	0	0	0	0	4.4E-271	1	1	1	1	1
23	0	0	0	0	0	1	1	1	1	1
24	0	0	0	0	0	1	1	1	1	1
25	0	0	0	0	0	1	1	1	1	1

Table 4.36: Weibull Probability Density Distribution table for Ilorin at 10m, 20m,30m, 40m and 50m.

V(m/s)	f(v) ₁₀	F(v) ₂₀	f(V) ₃₀	f(v) ₄₀	f(v) ₅₀	F(V) ₁₀	F(V) ₂₀	F(V) ₃₀	F(V) ₄₀	F(V) ₅₀
0	0	0	0	0	0	0	0	0	0	0
1	0.008441	0.002131	0.000814	0.000378	0.000198	0.001673	0.000396	0.000146	6.58E-05	3.36E-05
2	0.132493	0.043599	0.019475	0.010157	0.005829	0.053955	0.016348	0.006991	0.003538	0.001983
3	0.470745	0.226044	0.117914	0.067489	0.041412	0.349371	0.135757	0.065461	0.03585	0.021344
4	0.369357	0.464355	0.337053	0.226907	0.153383	0.840782	0.496139	0.286925	0.17387	0.11063
5	0.019737	0.25141	0.405601	0.39803	0.33169	0.996554	0.8973	0.691949	0.498119	0.353262
6	7.85E-06	0.012603	0.116347	0.263697	0.349454	0.999999	0.997683	0.961739	0.860196	0.720317
7	7.59E-13	9.81E-06	0.002722	0.033102	0.11301	1	0.999999	0.999559	0.991564	0.957398
8	1.41E-25	8E-12	9.5E-07	0.000251	0.005012	1	1	1	0.999966	0.999016
9	7.42E-47	1.52E-22	4.12E-13	2.04E-08	8.78E-06	1	1	1	1	0.999999
10	2.47E-80	4.01E-40	7.12E-24	1.57E-15	1.01E-10	1	1	1	1	1
11	1.3E-130	1.82E-67	4.94E-41	4.07E-27	6.29E-19	1	1	1	1	1
12	2.7E-203	3E-108	3.57E-67	4.53E-45	7.75E-32	1	1	1	1	1
13	3.3E-305	4.8E-167	1.4E-105	7.86E-72	2.52E-51	1	1	1	1	1
14	0	2E-249	2.7E-160	1.8E-110	8.99E-80	1	1	1	1	1
15	0	0	2.8E-236	9.1E-165	3.7E-120	1	1	1	1	1
16	0	0	0	2.4E-239	4E-176	1	1	1	1	1
17	0	0	0	0	4.1E-252	1	1	1	1	1
18	0	0	0	0	0	1	1	1	1	1
19	0	0	0	0	0	1	1	1	1	1
20	0	0	0	0	0	1	1	1	1	1
21	0	0	0	0	0	1	1	1	1	1
22	0	0	0	0	0	1	1	1	1	1
23	0	0	0	0	0	1	1	1	1	1
24	0	0	0	0	0	1	1	1	1	1
25	0	0	0	0	0	1	1	1	1	1

Table 4.37: Weibull Probability Density Distribution table for Jos at 10m, 20m, 30m, 40m and 50m.

V(m/s)	f(v) ₁₀	F(v) ₂₀	f(V) ₃₀	f(v) ₄₀	f(v) ₅₀	F(V) ₁₀	F(V) ₂₀	F(V) ₃₀	F(V) ₄₀	F(V) ₅₀
0	0	0	0	0	0	0	0	0	0	0
1	0.002411	0.000877	0.000438	0.000253	0.000159	0.000635	0.000217	0.000104	5.84E-05	3.6E-05
2	0.016639	0.007218	0.00403	0.002534	0.001711	0.008799	0.003574	0.001918	0.001172	0.000773
3	0.050113	0.024453	0.014658	0.009711	0.006836	0.0404	0.0183	0.010511	0.006755	0.004644
4	0.103309	0.056394	0.035962	0.024868	0.018099	0.115748	0.057435	0.034814	0.023261	0.016494
5	0.16372	0.102035	0.069596	0.050285	0.0378	0.249602	0.135756	0.086597	0.059939	0.04367
6	0.204715	0.151635	0.112483	0.085632	0.066789	0.436739	0.26294	0.177175	0.127197	0.095226
7	0.19956	0.18621	0.154328	0.125699	0.102694	0.643344	0.43404	0.311293	0.232848	0.17961
8	0.146733	0.186005	0.17878	0.159308	0.138338	0.819538	0.623587	0.480019	0.376485	0.300581
9	0.077635	0.146648	0.171483	0.172209	0.162164	0.931334	0.792698	0.658104	0.544507	0.452351
10	0.027897	0.087576	0.132135	0.155251	0.162689	0.981628	0.910188	0.812071	0.710782	0.617052
11	0.006368	0.037668	0.078652	0.11317	0.136274	0.996788	0.971104	0.917591	0.846465	0.768589
12	0.000857	0.011005	0.0345	0.064182	0.092316	0.999661	0.993523	0.972651	0.934812	0.883645
13	6.27E-05	0.002044	0.010559	0.027056	0.048663	0.99998	0.999057	0.993524	0.978945	0.953375
14	2.28E-06	0.000224	0.00212	0.008044	0.019082	0.999999	0.999918	0.998975	0.995108	0.985817
15	3.75E-08	1.34E-05	0.000261	0.00159	0.005288	1	0.999996	0.999899	0.999231	0.996897
16	2.52E-10	3.99E-07	1.82E-05	0.000196	0.000977	1	1	0.999994	0.999924	0.99954
17	6.24E-13	5.41E-09	6.63E-07	1.39E-05	0.000113	1	1	1	0.999996	0.999957
18	5.06E-16	3.01E-11	1.16E-08	5.3E-07	7.61E-06	1	1	1	1	0.999998
19	1.2E-19	6.15E-14	8.75E-11	9.91E-09	2.77E-07	1	1	1	1	1
20	7.29E-24	4.14E-17	2.59E-13	8.28E-11	5E-09	1	1	1	1	1
21	1E-28	8.09E-21	2.69E-16	2.8E-13	4.09E-11	1	1	1	1	1
22	2.73E-34	4.05E-25	8.68E-20	3.43E-16	1.37E-13	1	1	1	1	1
23	1.28E-40	4.54E-30	7.71E-24	1.37E-19	1.71E-16	1	1	1	1	1
24	8.86E-48	9.87E-36	1.65E-28	1.57E-23	7.06E-20	1	1	1	1	1
25	7.85E-56	3.6E-42	7.44E-34	4.52E-28	8.57E-24	1	1	1	1	1

Table 4.38: Weibull Probability Density Distribution table for Kano at 10m, 20m, 30m, 40m and 50m.

V(m/s)	f(v) ₁₀	F(v) ₂₀	f(V) ₃₀	f(v) ₄₀	f(v) ₅₀	F(V) ₁₀	F(V) ₂₀	F(V) ₃₀	F(V) ₄₀	F(V) ₅₀
0	0	0	0	0	0	0	0	0	0	0
1	0.000127	1.69E-05	8.22E-06	3.4E-06	1.62E-06	2.14E-05	3.96E-06	1.25E-06	5.02E-07	2.33E-07
2	0.003933	0.000794	0.000395	0.000187	9.89E-05	0.001323	0.00032	0.00012	5.51E-05	2.85E-05
3	0.028888	0.00754	0.003805	0.001941	0.001096	0.014671	0.004177	0.001734	0.000859	0.000474
4	0.11224	0.036588	0.018805	0.010176	0.006021	0.078617	0.025586	0.011484	0.006024	0.00348
5	0.269981	0.117231	0.062952	0.036161	0.022337	0.265783	0.10113	0.048998	0.027044	0.016242
6	0.363457	0.257246	0.155156	0.096981	0.063203	0.599209	0.287227	0.153791	0.090029	0.056314
7	0.197347	0.342659	0.27363	0.198607	0.141193	0.898552	0.593215	0.369369	0.235252	0.155294
8	0.023783	0.205156	0.301209	0.289466	0.241098	0.993688	0.877141	0.67083	0.48472	0.346841
9	0.000248	0.032206	0.158054	0.254286	0.2832	0.999963	0.988005	0.910563	0.770803	0.618557
10	5.69E-08	0.00056	0.02535	0.100642	0.187573	1	0.99982	0.992038	0.950651	0.864784
11	4.21E-14	2.97E-07	0.000633	0.011365	0.050714	1	1	0.999883	0.996787	0.979232
12	7.64E-24	7.6E-13	9.3E-07	0.000186	0.003436	1	1	1	0.999968	0.99916
13	1.17E-38	7.28E-22	2.08E-11	1.71E-07	2.89E-05	1	1	1	1	0.999996
14	2.01E-60	8.43E-36	1.14E-18	2.35E-12	1.13E-08	1	1	1	1	1
15	1.74E-91	1.29E-56	1.38E-29	8.36E-20	5.47E-14	1	1	1	1	1
16	9.5E-135	7.72E-87	1.65E-45	7.72E-31	5.62E-22	1	1	1	1	1
17	9.7E-194	1.1E-129	3.75E-68	9.54E-47	1.25E-33	1	1	1	1	1
18	1E-272	4.1E-189	1.2E-99	3.72E-69	3.24E-50	1	1	1	1	1
19	0	4.3E-270	1.1E-142	4.2E-100	2.46E-73	1	1	1	1	1
20	0	0	1.8E-200	4.4E-142	5.6E-105	1	1	1	1	1
21	0	0	6.7E-277	3.6E-198	1.4E-147	1	1	1	1	1
22	0	0	0	4.8E-272	3.8E-204	1	1	1	1	1
23	0	0	0	0	3E-278	1	1	1	1	1
24	0	0	0	0	0	1	1	1	1	1
25	0	0	0	0	0	1	1	1	1	1

Table 4.39: Weibull Probability Density Distribution table for Lokoja at 10m, 20m, 30m, 40m and 50m.

V(m/s)	f(v) ₁₀	F(v) ₂₀	f(V) ₃₀	f(v) ₄₀	f(v) ₅₀	F(V) ₁₀	F(V) ₂₀	F(V) ₃₀	F(V) ₄₀	F(V) ₅₀
0	0	0	0	0	0	0	0	0	0	0
1	0.52577	0.294791	0.185895	0.126242	0.09006	0.222011	0.10903	0.064508	0.042073	0.029147
2	0.431149	0.51982	0.463211	0.385009	0.314375	0.802548	0.568998	0.409105	0.302298	0.228976
3	0.03455	0.174408	0.300611	0.366168	0.383492	0.992032	0.932141	0.828179	0.712872	0.60441
4	0.000198	0.009513	0.048703	0.113382	0.182226	0.999972	0.997836	0.984251	0.95093	0.898321
5	5.14E-08	5.92E-05	0.001503	0.009311	0.028949	1	0.999991	0.999688	0.997459	0.989971
6	3.84E-13	2.84E-08	6.37E-06	0.000155	0.001227	1	1	0.999999	0.999971	0.999712
7	5.28E-20	7.03E-13	2.61E-09	3.85E-07	1.07E-05	1	1	1	1	0.999998
8	8.66E-29	5.99E-19	7.29E-14	1.05E-10	1.48E-08	1	1	1	1	1
9	1.11E-39	1.18E-26	9.63E-20	2.29E-15	2.39E-12	1	1	1	1	1
10	7.53E-53	3.62E-36	4.19E-27	2.85E-21	3.41E-17	1	1	1	1	1
11	1.8E-68	1.17E-47	4.16E-36	1.46E-28	3.16E-23	1	1	1	1	1
12	1.04E-86	2.71E-61	6.59E-47	2.2E-37	1.41E-30	1	1	1	1	1
13	1E-107	3.06E-77	1.15E-59	6.98E-48	2.2E-39	1	1	1	1	1
14	1.1E-131	1.15E-95	1.54E-74	3.3E-60	8.79E-50	1	1	1	1	1
15	1.1E-158	9.9E-117	1.1E-91	1.65E-74	6.56E-62	1	1	1	1	1
16	5.6E-189	1.4E-140	2.9E-111	6.19E-91	6.6E-76	1	1	1	1	1
17	1.2E-222	2E-167	2E-133	1.2E-109	6.47E-92	1	1	1	1	1
18	8E-260	2.3E-197	2.4E-158	9.2E-131	4.5E-110	1	1	1	1	1
19	1.1E-300	1.4E-230	3.6E-186	1.8E-154	1.5E-130	1	1	1	1	1
20	0	2.9E-267	4.7E-217	6.6E-181	1.9E-153	1	1	1	1	1
21	0	1.6E-307	3.7E-251	3.1E-210	6.2E-179	1	1	1	1	1
22	0	0	1.2E-288	1.4E-242	3.7E-207	1	1	1	1	1
23	0	0	0	3.9E-278	2.8E-238	1	1	1	1	1
24	0	0	0	0	2E-272	1	1	1	1	1
25	0	0	0	0	0	1	1	1	1	1

Table 4.40: Weibull Probability Density Distribution table for Lagos at 10m, 20m,30m, 40m and 50m.

V(m/s)	f(v) ₁₀	F(v) ₂₀	f(V) ₃₀	f(v) ₄₀	f(v) ₅₀	F(V) ₁₀	F(V) ₂₀	F(V) ₃₀	F(V) ₄₀	F(V) ₅₀
0	0	0	0	0	0	0	0	0	0	0
1	0.104853	0.014474	0.003535	0.00114	0.000435	0.014808	0.001907	0.000448	0.00014	5.24E-05
2	0.919478	0.970074	0.378848	0.152984	0.067989	0.876983	0.308967	0.101256	0.038405	0.016498
3	3.44E-15	0.006541	0.500812	0.994843	0.826074	1	0.999679	0.927499	0.652104	0.383474
4	7.9E-126	1.14E-29	4.46E-10	0.000397	0.055719	1	1	1	0.999982	0.994924
5	0	3E-167	9.89E-63	8.63E-28	1.23E-13	1	1	1	1	1
6	0	0	1.8E-269	3.9E-126	4.16E-65	1	1	1	1	1
7	0	0	0	0	4.1E-238	1	1	1	1	1
8	0	0	0	0	0	1	1	1	1	1
9	0	0	0	0	0	1	1	1	1	1
10	0	0	0	0	0	1	1	1	1	1
11	0	0	0	0	0	1	1	1	1	1
12	0	0	0	0	0	1	1	1	1	1
13	0	0	0	0	0	1	1	1	1	1
14	0	0	0	0	0	1	1	1	1	1
15	0	0	0	0	0	1	1	1	1	1
16	0	0	0	0	0	1	1	1	1	1
17	0	0	0	0	0	1	1	1	1	1
18	0	0	0	0	0	1	1	1	1	1
19	0	0	0	0	0	1	1	1	1	1
20	0	0	0	0	0	1	1	1	1	1
21	0	0	0	0	0	1	1	1	1	1
22	0	0	0	0	0	1	1	1	1	1
23	0	0	0	0	0	1	1	1	1	1
24	0	0	0	0	0	1	1	1	1	1
25	0	0	0	0	0	1	1	1	1	1

Table 4.41: Comparison of Experimental and WIS
PDF and CDF for Enugu

V(m/s)	f(v)	F(V)	f(v)WIS	F(V)WIS
0	0	0	0	0
1	0.010499	0.002384	0.063572	0.030066
2	0.106265	0.049447	0.126791	0.126467
3	0.32893	0.261425	0.16732	0.275957
4	0.404344	0.659493	0.176609	0.450556
5	0.142418	0.94395	0.157879	0.619741
6	0.007569	0.9984	0.122449	0.76073
7	2.43E-05	0.999997	0.083383	0.863472
8	1.45E-09	1	0.050174	0.929514
9	3.7E-16	1	0.026774	0.96714
10	7.01E-26	1	0.012696	0.986191
11	1.26E-39	1	0.005356	0.994778
12	2.02E-58	1	0.002011	0.998226
13	1.94E-83	1	0.000672	0.999459
14	5.4E-116	1	0.0002	0.999852
15	1.5E-157	1	5.29E-05	0.999964
16	9.3E-210	1	1.25E-05	0.999992
17	2.3E-274	1	2.61E-06	0.999998
18	0	1	4.86E-07	1
19	0	1	8.03E-08	1
20	0	1	1.18E-08	1
21	0	1	1.53E-09	1
22	0	1	1.77E-10	1
23	0	1	1.81E-11	1
24	0	1	1.64E-12	1
25	0	1	1.32E-13	1

Table 4.42: Comparison of Experimental and WIS
PDF and CDF for Ilorin

V(m/s)	f(v)	F(V)	f(v)WIS	F(V)WIS
0	0	0	0	0
1	0.008441	0.001673	0.024522	0.008593
2	0.132493	0.053955	0.084664	0.06098
3	0.470745	0.349371	0.157131	0.182185
4	0.369357	0.840782	0.207746	0.367894
5	0.019737	0.996554	0.208909	0.580841
6	7.85E-06	0.999999	0.16164	0.769208
7	7.59E-13	1	0.095443	0.897791
8	1.41E-25	1	0.042281	0.964708
9	7.42E-47	1	0.013754	0.990784
10	2.47E-80	1	0.003208	0.998234
11	1.3E-130	1	0.000523	0.999759
12	2.7E-203	1	5.82E-05	0.999977
13	3.3E-305	1	4.29E-06	0.999999
14	0	1	2.05E-07	1
15	0	1	6.14E-09	1
16	0	1	1.13E-10	1
17	0	1	1.24E-12	1
18	0	1	7.87E-15	1
19	0	1	2.84E-17	1
20	0	1	5.63E-20	1
21	0	1	5.99E-23	1
22	0	1	3.34E-26	1
23	0	1	9.46E-30	1
24	0	1	1.33E-33	1
25	0	1	9.04E-38	1

Table 4.43: Comparison of Experimental and WIS
PDF and CDF for Jos

V(m/s)	f(v)	F(V)	f(v)WIS	F(V)WIS
0	0	0	0	0
1	0.002411	0.000635	0.025593	0.009805
2	0.016639	0.008799	0.074923	0.058897
3	0.050113	0.0404	0.128947	0.16124
4	0.103309	0.115748	0.168712	0.311987
5	0.16372	0.249602	0.179983	0.489026
6	0.204715	0.436739	0.160298	0.66148
7	0.19956	0.643344	0.119997	0.80268
8	0.146733	0.819538	0.075452	0.900104
9	0.077635	0.931334	0.039677	0.956609
10	0.027897	0.981628	0.01734	0.984017
11	0.006368	0.996788	0.006252	0.995063
12	0.000857	0.999661	0.001845	0.998735
13	6.27E-05	0.99998	0.000442	0.999734
14	2.28E-06	0.999999	8.52E-05	0.999954
15	3.75E-08	1	1.31E-05	0.999994
16	2.52E-10	1	1.6E-06	0.999999
17	6.24E-13	1	1.53E-07	1
18	5.06E-16	1	1.14E-08	1
19	1.2E-19	1	6.53E-10	1
20	7.29E-24	1	2.87E-11	1
21	1E-28	1	9.58E-13	1
22	2.73E-34	1	2.41E-14	1
23	1.28E-40	1	4.53E-16	1
24	8.86E-48	1	6.32E-18	1
25	7.85E-56	1	6.48E-20	1

Table 4.44: Comparison of Experimental and WIS
PDF and CDF for Kano

V(m/s)	f(v)	f(v)WIS	F(V)	F(V)WIS
0	0	0	0	0
1	0.000127	0.056937	2.14E-05	0.023431
2	0.003933	0.140694	0.001323	0.122226
3	0.028888	0.203406	0.014671	0.29765
4	0.11224	0.215176	0.078617	0.511687
5	0.269981	0.176449	0.265783	0.710845
6	0.363457	0.114106	0.599209	0.856684
7	0.197347	0.05836	0.898552	0.941463
8	0.023783	0.023532	0.993688	0.980575
9	0.000248	0.007435	0.999963	0.994832
10	5.69E-08	0.001827	1	0.998911
11	4.21E-14	0.000346	1	0.99982
12	7.64E-24	5.03E-05	1	0.999977
13	1.17E-38	5.53E-06	1	0.999998
14	2.01E-60	4.58E-07	1	1
15	1.74E-91	2.83E-08	1	1
16	9.5E-135	1.29E-09	1	1
17	9.7E-194	4.33E-11	1	1
18	1E-272	1.06E-12	1	1
19	0	1.87E-14	1	1
20	0	2.36E-16	1	1
21	0	2.12E-18	1	1
22	0	1.35E-20	1	1
23	0	6.03E-23	1	1
24	0	1.87E-25	1	1
25	0	4.03E-28	1	1

Table 4.45: Comparison of Experimental and WIS
PDF and CDF for Lokoja

V(m/s)	f(v)	F(V)	f(v) _{WIS}	F(V) _{WIS}
0	0	0	0	0
1	0.52577	0.222011	0.063572	0.030066
2	0.431149	0.802548	0.126791	0.126467
3	0.03455	0.992032	0.16732	0.275957
4	0.000198	0.999972	0.176609	0.450556
5	5.14E-08	1	0.157879	0.619741
6	3.84E-13	1	0.122449	0.76073
7	5.28E-20	1	0.083383	0.863472
8	8.66E-29	1	0.050174	0.929514
9	1.11E-39	1	0.026774	0.96714
10	7.53E-53	1	0.012696	0.986191
11	1.8E-68	1	0.005356	0.994778
12	1.04E-86	1	0.002011	0.998226
13	1E-107	1	0.000672	0.999459
14	1.1E-131	1	0.0002	0.999852
15	1.1E-158	1	5.29E-05	0.999964
16	5.6E-189	1	1.25E-05	0.999992
17	1.2E-222	1	2.61E-06	0.999998
18	8E-260	1	4.86E-07	1
19	1.1E-300	1	8.03E-08	1
20	0	1	1.18E-08	1
21	0	1	1.53E-09	1
22	0	1	1.77E-10	1
23	0	1	1.81E-11	1
24	0	1	1.64E-12	1
25	0	1	1.32E-13	1

Table 4.46: Comparison of Experimental and WIS
PDF and CDF for Lagos

V(m/s)	f(v)	F(V)	f(v) _{WIS}	F(V) _{WIS}
0	0	0	0	0
1	0.104853	0.014808	0.024522	0.008593
2	0.919478	0.876983	0.084664	0.06098
3	3.44E-15	1	0.157131	0.182185
4	7.9E-126	1	0.207746	0.367894
5	0	1	0.208909	0.580841
6	0	1	0.16164	0.769208
7	0	1	0.095443	0.897791
8	0	1	0.042281	0.964708
9	0	1	0.013754	0.990784
10	0	1	0.003208	0.998234
11	0	1	0.000523	0.999759
12	0	1	5.82E-05	0.999977
13	0	1	4.29E-06	0.999999
14	0	1	2.05E-07	1
15	0	1	6.14E-09	1
16	0	1	1.13E-10	1
17	0	1	1.24E-12	1
18	0	1	7.87E-15	1
19	0	1	2.84E-17	1
20	0	1	5.63E-20	1
21	0	1	5.99E-23	1
22	0	1	3.34E-26	1
23	0	1	9.46E-30	1
24	0	1	1.33E-33	1
25	0	1	9.04E-38	1

Table 4.47: Estimated Power and Energy Densities at Heights for Enugu

H=10m							
Methods	α_{10}	V_{10} (m/s)	n_{10}	c_{10} (m/s)	k_{10} (-)	PD_{10} (W/m ²)	ED_{10} (W/ym ²)
MLM	0.257	3.622	0.249	3.933	4.409	33.717	295360.537
MOM	0.257	3.622	0.250	3.931	5.302	33.128	290199.213
STD	0.257	3.622	0.250	3.932	5.276	33.165	290523.648
PDM	0.257	3.622	0.248	3.984	4.214	35.283	309077.546
H=20m							
Methods	α_{20}	V_{20} (m/s)	n_{20}	c_{20} (m/s)	k_{20} (-)	PD_{20} (W/m ²)	ED_{20} (W/ym ²)
MLM	0.257	4.327	0.266	4.728	4.696	58.161	509493.625
MOM	0.257	4.327	0.266	4.727	5.647	57.407	502885.989
STD	0.257	4.327	0.266	4.728	5.619	57.462	503371.368
PDM	0.257	4.327	0.264	4.786	4.487	60.623	531057.456
H=30m							
Methods	α_{30}	V_{30} (m/s)	n_{30}	c_{30} (m/s)	k_{30} (-)	PD_{30} (W/m ²)	ED_{30} (W/ym ²)
MLM	0.257	4.802	0.276	5.327	4.881	82.881	726039.154
MOM	0.257	4.802	0.276	5.325	5.870	82.013	718430.086
STD	0.257	4.802	0.276	5.327	5.841	82.084	719059.533
PDM	0.257	4.802	0.275	5.389	4.665	86.180	754940.149
H=40							
Methods	α_{40}	V_{40} (m/s)	n_{40}	c_{40} (m/s)	k_{40} (-)	PD_{40} (W/m ²)	ED_{40} (W/ym ²)
MLM	0.257	5.170	0.284	5.831	5.022	108.489	950359.914
MOM	0.257	5.170	0.284	5.830	6.039	107.536	942015.225
STD	0.257	5.170	0.284	5.831	6.009	107.614	942701.176
PDM	0.257	5.170	0.283	5.897	4.799	112.607	986439.097
H=50m							
Methods	α_{50}	V_{50} (m/s)	n_{50}	c_{50} (m/s)	k_{50} (-)	PD_{50} (W/m ²)	ED_{50} (W/ym ²)
MLM	0.257	5.475	0.291	6.278	5.137	135.191	1184269.964
MOM	0.257	5.475	0.291	6.277	6.177	134.176	1175384.881
STD	0.257	5.475	0.291	6.278	6.147	134.279	1176282.669
PDM	0.257	5.475	0.289	6.347	4.909	140.125	1227491.216

Table 4.48: Estimated Power and Energy Densities at Heights for Ilorin

H=10m							
Methods	α_{10}	V_{10} (m/s)	n_{10}	c_{10} (m/s)	k_{10} (-)	PD_{10} (W/m ²)	ED_{10} (W/ym ²)
MLM	0.266	3.263	0.259	3.546	5.050	24.376	213530.388
MOM	0.266	3.263	0.259	3.545	5.223	24.310	212958.601
STD	0.266	3.263	0.259	3.546	5.199	24.337	213193.801
PDM	0.266	3.263	0.258	3.589	4.230	25.771	225750.195
H=20m							
Methods	α_{20}	V_{20} (m/s)	n_{20}	c_{20} (m/s)	k_{20} (-)	PD_{20} (W/m ²)	ED_{20} (W/ym ²)
MLM	0.266	3.924	0.275	4.291	5.378	43.055	377166.031
MOM	0.266	3.924	0.275	4.291	5.563	42.972	376436.563
STD	0.266	3.924	0.275	4.292	5.536	43.013	376795.751
PDM	0.266	3.924	0.274	4.340	4.505	45.196	395915.917
H=30m							
Methods	α_{30}	V_{30} (m/s)	n_{30}	c_{30} (m/s)	k_{30} (-)	PD_{30} (W/m ²)	ED_{30} (W/ym ²)
MLM	0.266	4.370	0.286	4.856	5.591	62.282	545590.000
MOM	0.266	4.370	0.286	4.855	5.782	62.187	544759.206
STD	0.266	4.370	0.286	4.857	5.755	62.241	545231.051
PDM	0.266	4.370	0.285	4.909	4.683	65.107	570337.563
H=40m							
Methods	α_{40}	V_{40} (m/s)	n_{40}	c_{40} (m/s)	k_{40} (-)	PD_{40} (W/m ²)	ED_{40} (W/ym ²)
MLM	0.266	4.718	0.295	5.334	5.752	82.446	722223.402
MOM	0.266	4.718	0.295	5.333	5.949	82.343	721325.541
STD	0.266	4.718	0.295	5.334	5.921	82.409	721905.365
PDM	0.266	4.718	0.293	5.389	4.818	85.932	752761.030
H=50m							
Methods	α_{50}	V_{50} (m/s)	n_{50}	c_{50} (m/s)	k_{50} (-)	PD_{50} (W/m ²)	ED_{50} (W/ym ²)
MLM	0.266	5.006	0.301	5.758	5.884	103.675	908191.239
MOM	0.266	5.006	0.301	5.757	6.085	103.568	907253.725
STD	0.266	5.006	0.301	5.759	6.056	103.646	907938.940
PDM	0.266	5.006	0.300	5.816	4.928	107.811	944427.686

Table 4.49: Estimated Power and Energy Densities at Heights for Jos

H=10m							
Methods	α_{10}	V_{10} (m/s)	n_{10}	c_{10} (m/s)	k_{10} (-)	PD_{10} (W/m ²)	ED_{10} (W/ym ²)
MLM	0.208	6.276	0.199	6.944	3.799	190.452	1668356.291
MOM	0.208	6.276	0.199	6.943	3.815	190.179	1665968.313
STD	0.208	6.276	0.199	6.943	3.811	190.268	1666749.089
PDM	0.208	6.276	0.200	6.930	3.940	187.909	1646082.641
H=20m							
Methods	α_{20}	V_{20} (m/s)	n_{20}	c_{20} (m/s)	k_{20} (-)	PD_{20} (W/m ²)	ED_{20} (W/ym ²)
MLM	0.208	7.251	0.212	8.046	4.046	292.551	2562748.310
MOM	0.208	7.251	0.212	8.044	4.063	292.190	2559588.098
STD	0.208	7.251	0.212	8.045	4.058	292.310	2560633.772
PDM	0.208	7.251	0.213	8.031	4.195	289.164	2533075.632
H=30m							
Methods	α_{30}	V_{30} (m/s)	n_{30}	c_{30} (m/s)	k_{30} (-)	PD_{30} (W/m ²)	ED_{30} (W/ym ²)
MLM	0.208	7.891	0.221	8.850	4.206	386.916	3389383.070
MOM	0.208	7.891	0.221	8.849	4.224	386.483	3385594.785
STD	0.208	7.891	0.221	8.850	4.218	386.627	3386852.035
PDM	0.208	7.891	0.221	8.835	4.361	382.831	3353597.562
H=40m							
Methods	α_{40}	V_{40} (m/s)	n_{40}	c_{40} (m/s)	k_{40} (-)	PD_{40} (W/m ²)	ED_{40} (W/ym ²)
MLM	0.208	8.378	0.227	9.514	4.327	478.684	4193268.470
MOM	0.208	8.378	0.227	9.513	4.345	478.187	4188915.524
STD	0.208	8.378	0.227	9.514	4.340	478.353	4190369.346
PDM	0.208	8.378	0.227	9.498	4.487	473.973	4152004.844
H=50m							
Methods	α_{50}	V_{50} (m/s)	n_{50}	c_{50} (m/s)	k_{50} (-)	PD_{50} (W/m ²)	ED_{50} (W/ym ²)
MLM	0.208	8.777	0.232	10.093	4.426	569.729	4990826.424
MOM	0.208	8.777	0.232	10.092	4.445	569.173	4985958.429
STD	0.208	8.777	0.232	10.092	4.439	569.360	4987590.816
PDM	0.208	8.777	0.233	10.077	4.590	564.439	4944484.718

Table 4.50: Estimated Power and Energy Densities at Heights for Kano

H=10m							
Methods	α_{10}	V_{10} (m/s)	n_{10}	c_{10} (m/s)	k_{10} (-)	PD_{10} (W/m ²)	ED_{10} (W/ym ²)
MLM	0.217	5.664	0.211	6.091	5.951	122.707	1074911.563
MOM	0.217	5.664	0.211	6.075	6.582	121.609	1065291.149
STD	0.217	5.664	0.211	6.077	6.534	121.750	1066533.754
PDM	0.217	5.664	0.209	6.218	4.367	133.425	1168801.334
H=20m							
Methods	α_{20}	V_{20} (m/s)	n_{20}	c_{20} (m/s)	k_{20} (-)	PD_{20} (W/m ²)	ED_{20} (W/ym ²)
MLM	0.217	6.585	0.225	7.118	6.338	195.636	1713770.854
MOM	0.217	6.585	0.225	7.100	7.010	194.246	1701596.275
STD	0.217	6.585	0.225	7.103	6.958	194.441	1703304.670
PDM	0.217	6.585	0.223	7.256	4.651	210.439	1843448.663
H=30m							
Methods	α_{30}	V_{30} (m/s)	n_{30}	c_{30} (m/s)	k_{30} (-)	PD_{30} (W/m ²)	ED_{30} (W/ym ²)
MLM	0.217	7.192	0.234	7.873	6.588	264.750	2319210.961
MOM	0.217	7.192	0.234	7.854	7.287	263.148	2305178.646
STD	0.217	7.192	0.234	7.857	7.233	263.387	2307272.588
PDM	0.217	7.192	0.232	8.019	4.834	282.991	2479001.271
H=40m							
Methods	α_{40}	V_{40} (m/s)	n_{40}	c_{40} (m/s)	k_{40} (-)	PD_{40} (W/m ²)	ED_{40} (W/ym ²)
MLM	0.217	7.656	0.240	8.500	6.778	333.133	2918241.772
MOM	0.217	7.656	0.241	8.480	7.497	331.362	2902734.755
STD	0.217	7.656	0.241	8.483	7.442	331.641	2905172.239
PDM	0.217	7.656	0.238	8.651	4.974	354.489	3105327.938
H=50m							
Methods	α_{50}	V_{50} (m/s)	n_{50}	c_{50} (m/s)	k_{50} (-)	PD_{50} (W/m ²)	ED_{50} (W/ym ²)
MLM	0.217	8.037	0.246	9.048	6.933	401.894	3520591.936
MOM	0.217	8.037	0.246	9.027	7.668	399.986	3503877.295
STD	0.217	8.037	0.246	9.030	7.612	400.301	3506633.165
PDM	0.217	8.037	0.244	9.204	5.088	426.167	3733223.094

Table4.51: Estimated Power and Energy Densities at Heights for Lokoja

H=10m							
Methods	α_{10}	V_{10} (m/s)	n_{10}	c_{10} (m/s)	k_{10} (-)	PD_{10} (W/m ²)	ED_{10} (W/ym ²)
MLM	0.335	1.484	0.325	1.671	2.692	3.014	26404.406
MOM	0.335	1.484	0.325	1.670	2.662	3.025	26498.276
STD	0.335	1.484	0.325	1.670	2.670	3.019	26449.259
PDM	0.335	1.484	0.326	1.651	3.453	2.623	22973.271
H=20m							
Methods	α_{20}	V_{20} (m/s)	n_{20}	c_{20} (m/s)	k_{20} (-)	PD_{20} (W/m ²)	ED_{20} (W/ym ²)
MLM	0.335	1.873	0.346	2.124	2.866	5.992	52489.648
MOM	0.335	1.873	0.346	2.123	2.835	6.009	52640.261
STD	0.335	1.873	0.346	2.122	2.843	5.999	52555.337
PDM	0.335	1.873	0.347	2.100	3.677	5.307	46491.591
H=30m							
Methods	α_{30}	V_{30} (m/s)	n_{30}	c_{30} (m/s)	k_{30} (-)	PD_{30} (W/m ²)	ED_{30} (W/ym ²)
MLM	0.335	2.145	0.360	2.481	2.980	9.381	82179.141
MOM	0.335	2.145	0.360	2.479	2.947	9.405	82384.572
STD	0.335	2.145	0.360	2.479	2.956	9.391	82262.698
PDM	0.335	2.145	0.361	2.454	3.822	8.394	73534.578
H=40m							
Methods	α_{40}	V_{40} (m/s)	n_{40}	c_{40} (m/s)	k_{40} (-)	PD_{40} (W/m ²)	ED_{40} (W/ym ²)
MLM	0.335	2.363	0.370	2.791	3.066	13.202	115646.891
MOM	0.335	2.363	0.370	2.789	3.032	13.231	115906.611
STD	0.335	2.363	0.370	2.789	3.041	13.213	115746.057
PDM	0.335	2.363	0.371	2.762	3.933	11.898	104222.433
H=50m							
Methods	α_{50}	V_{50} (m/s)	n_{50}	c_{50} (m/s)	k_{50} (-)	PD_{50} (W/m ²)	ED_{50} (W/ym ²)
MLM	0.335	2.546	0.378	3.073	3.136	17.462	152971.149
MOM	0.335	2.546	0.378	3.071	3.102	17.499	153287.049
STD	0.335	2.546	0.378	3.071	3.110	17.476	153085.619
PDM	0.335	2.546	0.380	3.042	4.023	15.824	138616.537

Table 4.52: Estimated Power and Energy Densities at Heights for Lagos

H=10m							
Methods	α_{10}	V_{10} (m/s)	n_{10}	c_{10} (m/s)	k_{10} (-)	PD_{10} (W/m ²)	ED_{10} (W/ym ²)
MLM	0.323	1.701	0.318	1.803	7.134	3.182	27877.567
MOM	0.323	1.701	0.318	1.798	8.860	3.175	27813.219
STD	0.323	1.701	0.318	1.799	8.766	3.178	27841.535
PDM	0.323	1.701	0.315	1.864	4.493	3.583	31386.266
H=20m							
Methods	α_{20}	V_{20} (m/s)	n_{20}	c_{20} (m/s)	k_{20} (-)	PD_{20} (W/m ²)	ED_{20} (W/ym ²)
MLM	0.323	2.128	0.339	2.280	7.597	6.446	56468.804
MOM	0.323	2.128	0.339	2.274	9.435	6.445	56454.580
STD	0.323	2.128	0.339	2.275	9.335	6.450	56503.893
PDM	0.323	2.128	0.336	2.353	4.785	7.152	62652.897
H=30m							
Methods	α_{30}	V_{30} (m/s)	n_{30}	c_{30} (m/s)	k_{30} (-)	PD_{30} (W/m ²)	ED_{30} (W/ym ²)
MLM	0.323	2.426	0.352	2.655	7.897	10.184	89211.709
MOM	0.323	2.426	0.352	2.648	9.808	10.193	89291.761
STD	0.323	2.426	0.352	2.649	9.704	10.201	89361.832
PDM	0.323	2.426	0.349	2.735	4.974	11.202	98130.797
H=40m							
Methods	α_{40}	V_{40} (m/s)	n_{40}	c_{40} (m/s)	k_{40} (-)	PD_{40} (W/m ²)	ED_{40} (W/ym ²)
MLM	0.323	2.663	0.362	2.980	8.125	14.410	126231.508
MOM	0.323	2.663	0.363	2.972	10.091	14.434	126444.713
STD	0.323	2.663	0.363	2.973	9.984	14.445	126535.906
PDM	0.323	2.663	0.359	3.066	5.117	15.753	137996.104
H=50m							
Methods	α_{50}	V_{50} (m/s)	n_{50}	c_{50} (m/s)	k_{50} (-)	PD_{50} (W/m ²)	ED_{50} (W/ym ²)
MLM	0.323	2.862	0.371	3.274	8.311	19.131	167586.269
MOM	0.323	2.862	0.371	3.266	10.321	19.175	167970.077
STD	0.323	2.862	0.371	3.267	10.212	19.188	168082.795
PDM	0.323	2.862	0.367	3.366	5.234	20.813	182321.289

Table 4.53: Estimated Power for Enugu

Height (m)	Experimental Values			WIS Values		
	Average Power (KW)	Total Energy Production (MWh/y)	Energy Total Specific (KW/ym ²)	Average Power (KW)	Total Energy Production (MWh/y)	Energy Total Specific (KW/ym ²)
10	34.513	302.335	174.263	77.036	616.285	355.22
20	59.535	521.525	300.601	77.036	616.285	355.22
30	84.838	743.184	428.363	77.036	616.285	355.22
40	111.050	972.802	560.712	77.036	616.285	355.22
50	138.383	1212.236	698.719	77.036	616.285	355.22

Table 4.54: Estimated Power for Ilorin

Height (m)	Experimental Values			WIS Values		
	Average Power (KW)	Total Energy Production (MWh/y)	Energy Total Specific (KW/ym ²)	Average Power (KW)	Total Energy Production (MWh/y)	Energy Total Specific (KW/ym ²)
10	24.951	218.573	125.983	85.553	684.427	394.49
20	44.072	386.073	222.528	85.553	684.427	394.49
30	63.753	558.474	321.898	85.553	684.427	394.49
40	84.393	739.278	426.112	85.553	684.427	394.49
50	106.123	929.638	535.833	85.553	684.427	394.49

Table 4.55: Estimated Power for Jos

Height (m)	Experimental Values			WIS Values		
	Average Power (KW)	Total Energy Production (MWh/y)	Energy Total Specific (KW/ym ²)	Average Power (KW)	Total Energy Production (MWh/y)	Energy Total Specific (KW/ym ²)
10	194.949	1707.754	984.330	130.725	1045.803	602.79
20	299.460	2623.267	1512.022	130.725	1045.803	602.79
30	396.053	3469.422	1999.736	130.725	1045.803	602.79
40	489.988	4292.291	2474.028	130.725	1045.803	602.79
50	583.183	5108.683	2944.588	130.725	1045.803	602.79

Table 4.56: Estimated Power for Kano

Height (m)	Experimental Values			WIS Values		
	Average Power (KW)	Total Energy Production (MWh/y)	Energy Total Specific (KW/ym ²)	Average Power (KW)	Total Energy Production (MWh/y)	Energy Total Specific (KW/ym ²)
10	125.604	1100.295	634.198	143.159	1145.275	660.12
20	200.256	1754.241	1011.125	143.159	1145.275	660.12
30	271.002	2373.978	1368.334	143.159	1145.275	660.12
40	340.999	2987.155	1721.763	143.159	1145.275	660.12
50	411.385	3603.729	2077.149	143.159	1145.275	660.12

Table 4.57: Estimated Power for Lokoja

Height (m)	Experimental Values			WIS Values		
	Average Power (KW)	Total Energy Production (MWh/y)	Energy Total Specific (KW/ym ²)	Average Power (KW)	Total Energy Production (MWh/y)	Energy Total Specific (KW/ym ²)
10	3.085	27.028	15.579	80.512	644.099	371.25
20	6.133	53.729	30.969	80.512	644.099	371.25
30	9.603	84.120	48.486	80.512	644.099	371.25
40	13.513	118.378	68.232	80.512	644.099	371.25
50	17.875	156.584	90.253	80.512	644.099	371.25

Table 4.58: Estimated Power for Lagos

Height (m)	Experimental Values			WIS Values		
	Average Power (KW)	Total Energy Production (MWh/y)	Energy Total Specific (KW/ym ²)	Average Power (KW)	Total Energy Production (MWh/y)	Energy Total Specific (KW/ym ²)
10	3.258	28.536	16.448	46.205	369.639	213.06
20	6.598	57.802	33.317	46.205	369.639	213.06
30	10.424	91.318	52.635	46.205	369.639	213.06
40	14.750	129.212	74.477	46.205	369.639	213.06
50	19.583	171.544	98.876	46.205	369.639	213.06

Table 4.59: Wind Information System (WIS) Data for the selected stations at heights of 10m, 20m, 30m, 40m and 50m.

Station		Enugu						
Location X (°) Y (°)		Heights (m)	Velocity (m/s)	k (-)	c (m/s)	Average Power (KW)	Total Energy Production (MWh/y)	Energy Total Specific (KW/ym ²)
7.56729	6.45237	10	4.711	2.147	5.079	77.036	616.285	355.22
7.56729	6.45237	20	4.711	2.147	5.079	77.036	616.285	355.22
7.56729	6.45237	30	4.711	2.147	5.079	77.036	616.285	355.22
7.56729	6.45237	40	4.711	2.147	5.079	77.036	616.285	355.22
7.56729	6.45237	50	4.711	2.147	5.079	77.036	616.285	355.22
Station		Ilorin						
Location X (°) Y (°)		Heights (m)	Velocity (m/s)	k (-)	c (m/s)	Average Power (KW)	Total Energy Production (MWh/y)	Energy Total Specific (KW/ym ²)
4.61093	8.55097	10	5.201	2.866	5.250	85.553	684.427	394.49
4.61093	8.55097	20	5.201	2.866	5.250	85.553	684.427	394.49
4.61093	8.55097	30	5.201	2.866	5.250	85.553	684.427	394.49
4.61093	8.55097	40	5.201	2.866	5.250	85.553	684.427	394.49
4.61093	8.55097	50	5.201	2.866	5.250	85.553	684.427	394.49
Station		Jos						
Location X (°) Y (°)		Heights (m)	Velocity (m/s)	k (-)	c (m/s)	Average Power (KW)	Total Energy Production (MWh/y)	Energy Total Specific (KW/ym ²)
8.96636	9.65024	10	6.075	2.623	5.820	130.725	1045.803	602.79
8.96636	9.65024	20	6.075	2.623	5.820	130.725	1045.803	602.79
8.96636	9.65024	30	6.075	2.623	5.820	130.725	1045.803	602.79
8.96636	9.65024	40	6.075	2.623	5.820	130.725	1045.803	602.79
8.96636	9.65024	50	6.075	2.623	5.820	130.725	1045.803	602.79

Station		Kano						
Location X (°) Y (°)		Heights (m)	Velocity (m/s)	k (-)	c (m/s)	Average Power (KW)	Total Energy Production (MWh/y)	Energy Total Specific (KW/ym ²)
8.54997	11.88208	10	6.051	2.459	4.580	143.159	1145.273	660.12
8.54997	11.88208	20	6.051	2.459	4.580	143.159	1145.273	660.12
8.54997	11.88208	30	6.051	2.459	4.580	143.159	1145.273	660.12
8.54997	11.88208	40	6.051	2.459	4.580	143.159	1145.273	660.12
8.54997	11.88208	50	6.051	2.459	4.580	143.159	1145.273	660.12
Station		Lokoja						
Location X (°) Y (°)		Heights (m)	Velocity (m/s)	k (-)	c (m/s)	Average Power (KW)	Total Energy Production (MWh/y)	Energy Total Specific (KW/ym ²)
6.77615	7.86809	10	4.765	2.147	5.079	80.512	644.099	371.25
6.77615	7.86809	20	4.765	2.147	5.079	80.512	644.099	371.25
6.77615	7.86809	30	4.765	2.147	5.079	80.512	644.099	371.25
6.77615	7.86809	40	4.765	2.147	5.079	80.512	644.099	371.25
6.77615	7.86809	50	4.765	2.147	5.079	80.512	644.099	371.25
Station		Lagos						
Location X (°) Y (°)		Heights (m)	Velocity (m/s)	k (-)	c (m/s)	Average Power (KW)	Total Energy Production (MWh/y)	Energy Total Specific (KW/ym ²)
3.45337	6.61060	10	4.363	2.866	5.250	46.205	369.639	213.06
3.45337	6.61060	20	4.363	2.866	5.250	46.205	369.639	213.06
3.45337	6.61060	30	4.363	2.866	5.250	46.205	369.639	213.06
3.45337	6.61060	40	4.363	2.866	5.250	46.205	369.639	213.06
3.45337	6.61060	50	4.363	2.866	5.250	46.205	369.639	213.06

Source: Energy Commission of Nigeria Wind Information System (WIS) software