WIND ENERGY POTENTIAL BASED ON WEIBULL AND RAYLEIGH MODEL

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Abstract: *The wind energy potential in Adamawa State were statistically analysed based on Weibull and Rayleigh* Models *using mean monthly wind speed data. The Rayleigh and Weibull model were used for selected locations and wind speed data at 10m, 25m, 30m, 60m and 80m height above the sea level. Assessment of wind speeds in Adamawa state was carried out in some locations such as Mubi, Michika, Numan, Mayo-Belwa, Guyuk and Yola, According to the assessment record obtained shows that, the results are good enough for wind energy generation in these Areas. Hence, the Weibull model is recommended for the area. The research shows that, the site has the potential of generating energy with power density of 59.96Wm*$^{-2}$*. Despite the sufficient wind speeds to drive the turbine, stability and reliability studies is to be carried out in order to control the connection to grid. Hence, the overall purpose of the power system operation, independent of wind power generation level, is to give sufficient electricity to consumers and continuously to balance production and consumption. Therefore, this paper gives the inner value of wind energy in Adamawa State.*

Keywords: Wind power potential, Energy production, Weibull and Rayleigh distribution, assessment of wind speeds,

1. Introduction:

With ever increasing concern on energy issues, the development of renewable energy sources is becoming more and more attractive. Present world is moving fast towards development of renewable energy. Energy is the lifeline of our society. It is essential to our quality of life and underpins all other elements of our economy in terms of Industrialization. So, renewable energy technology offer a tantalizing promise, that is absence of harmful emissions, very clean and abundant energy gathered from continuously self-renewing resources [18]. The poor state of power supply in Adamawa State and Nigeria at large, coupled with the problem of global warming, encourages strong demand for wind generation [11]. Despite the abundance of energy resources in Nigeria, the country is still in short electric power supply. Only about 40% of Nigerians has access to grid electricity, and even those that are connected to the Utility grid are not getting it enough [3]. So, there is need to harness renewable energy potential such as wind and solar for reliable power supply in this country[20], most especially the study area. Also the concern about global warming and continued apprehensions about nuclear power around the world made wind energy generation demandable [4].

The system operates by converting wind energy into electrical energy using Wind turbine, which is fed into Utility Network [13]. The main advantages of electricity generation from renewable energy sources, in particular wind, is the absence of harmful emissions, clean and its availability [15]. However, Wind speed and direction were collected by using cup anemometers and wind vanes at several heights, ranging from 10m to 80m or even above depends on the location. So, assessment of wind speeds in Adamawa state was carried out in some locations such as Mubi, Michika, Numan, Mayo-Belwa, Guyuk and Yola, which indicated average wind speeds of 3.20 to 4ms^{-1} at 10m height, 4 to 5 ms^{-1} at 25m height and

5 to 6ms^{-1} at 80m height, and the wind energy potential of these areas are; 4.50ms^{-1}, 4.22ms^{-1}, 4.14ms^{-1}, 3.98ms^{-1}, 4.07ms^{-1} and 3.86ms^{-1} with the estimated power of 16.34Wm^{-2}, 16.12Wm^{-2}, 16.03Wm^{-2}, 15.43Wm^{-2}, 15.76Wm^{-2} and 14.45Wm^{-2}.

Here, based on the assessment record obtained shows that, the results are good enough for wind energy generation, since the minimum wind speed required to turn the turbine of a wind machine is 3.0ms^{-1} [24]. In this case wind speeds for energy generation is certainly justifiable in these locations at this range, especially those with the most stable speed conditions. The aim of this paper is to give sufficient electricity to consumers and continuously to balance production and consumption.

This paper is divided into various sections; apart from section one which deals with the introduction. Section two covers Location and data collection, Power in the Wind, Mean and standard deviation of wind speed, Probability Distribution Density of Weibull and Rayleigh**,** wind speed data, wind speed height. Section three is about result and discursion and section four gives the concluded part of the work, whereas section five is recommended some areas to be considered for the development of wind energy.

1.1 Overview of Global Wind Energy

Historically, Nigeria is one of the largest countries in Africa by land mass which is about 923,000 square kilometres, and its only licensed “JBS Wind Power Ltd” which has generation capacity of 100MW, but it has not yet linked to the grid [12]. Hence, some years ago, the technology for harnessing wind energy was conducted in some parts of northern Nigeria particularly places like: Borno, Sokoto, Kano, Katsina, Bauchi and Plateau States [8]. However, wind energy generation was experimented in Sokoto State by the year 1998 in a location call Sayyan Gidan Gada. Also, in Katsina State and similarly in Kano State large wind energy is being piloted of about 30MW [17]. The utilization of wind energy has increased spectacularly in recent years all over the World, with annual increases in installed capacity of around 20% in recent years [15]. Analysts were able to point to some significant potential of wind energy which is the fastest growing technology in the world, rising to 32% on the annually average [1]. At the end of 2009, the total installed capacity was 157,899 MW, which was acquired in Asia by 24.6%. China topped the list with a total installed capacity of 25,104 MW, up to now [22]. India is the second with 10,926 MW, followed by 2,056 MW in Japan and Taiwan were added in the fourth generation of 436 MW. The 39 GW increment in 2010 represented an investment of US$ 65 billion, and it was followed by a 41 GW increase in 2011, 45 GW in 2012, 35 GW in 2013, 51 GW in 2014 with 23 GW of it contributed by China, 63 GW in 2015 with 30.7 GW of it contributed by China and 54 GW in 2016 also with 23 GW of this in China. Total world wind capacity was 486 GW at the end of 2016, with tens of thousands of turbines now installed]22].

2. Location and Data Collection

Adamawa is one of the largest state in Nigeria and occupies about 36,917 square kilometres [8]. It is bordered by the states of Borno to the northwest, Gombe to the west and Taraba to the southwest. Its eastern border forms the national eastern border with Cameroon. Topographically, it is a land crossed by the large river valleys Benue, Gongola and Yedsarem [21]. The valleys of the Cameroon, Mandara and Adamawa mountains form part of the landscape. It is located at an elevation of 300 meters above sea level with the population of 3,737,223. Its coordinates are 9°19'60" N and 12°30'0" E in DMS (Degrees Minutes Seconds) or 9.33333 and 12.5 (in decimal degrees). Its UTM position is TL23 and its Joint Operation Graphics reference is NC33-09. In this paper monthly mean speeds wind data measured were obtained from the

Nigerian Metrological Agency (NIMET). The data were statistically analysed based on Weibull model. Weibull parameters such as probability density function, shape factor K, scale factor C and the gamma function and the evaluation of power densities.

2.1 Power in the Wind

The following formula illustrates factors that are important to the performance of a wind turbine [6]. The formula for how to calculate power is:

$$A = \frac{P}{0.5 \times \rho \times C_P \times V^3 \times N_g \times N_b} \quad (1)$$

Where;

A = Swept area of the rotor, propeller or blades. The rotor swept area, A, is important because the rotor is the part of the turbine that captures the wind energy. So, the size of the rotor determines the level of energy to be capture.

$$\rho = \frac{P}{0.5 \times A \times C_P \times V^3 \times N_g \times N_b} \quad (2)$$

ρ = Air density, lb/ft3=1.2 kg/m^3 (sea level)

A slightly change of air density (ρ) is directly proportional to the air temperature and height.

The ratings for wind turbines are based on standard conditions of 59° F at sea level.

$$C_P = \frac{P}{0.5 \times \rho \times A \times V^3 \times N_g \times N_b} \quad (3)$$

Where;

C_p = Performance coefficient. Typical value is 0.35, while 0.56 is the theoretical max known as the Betz limit.

$$V^3 = \left(\frac{P}{0.5 \times \rho \times A \times C_P \times N_g \times N_b}\right) \quad (4)$$

Where;

V^3= wind speed.

The wind speed (V^3) increases with large increase in power generation. Therefore, wind turbine productivity is based on height of the tower by giving it access to higher wind speeds.

$$N_g = \frac{P}{0.5 \times \rho \times A \times C_P \times V^3 \times N_b} \quad (5)$$

N_g= generator or alternator efficiency. Typical values 50 percent to 80 percent.

$$N_b = \frac{P}{0.5 \times \rho \times A \times C_P \times V^3 \times N_g} \tag{6}$$

Where;

N_b = gear box bearing efficiency.

$$P = 0.5 \times \rho \times A \times C_P \times V^3 \times N_g \times N_b \tag{7}$$

Where;

P=wind power.

2.2 Mean and standard deviation of wind speed

The monthly wind speed data were obtained using equations [2].

$$V_m = \frac{1}{N}\left(\sum_{i=1}^{N} V_i\right) \tag{8}$$

V_m =mean wind speed in ms^{-1}

$$\sigma = \left[\frac{1}{N-1}\sum_{i=1}^{N}(V_i - V_m)^2\right]^{\frac{1}{2}} \tag{9}$$

Where,

σ = standard deviation of the observed data in ms^{-1};

V_i = monthly wind speed in ms^{-1};

N = number of measured monthly wind speed data.

2.3 Probability Distribution Density of Weibull and Rayleigh

Weibull and Rayleigh Probability Distribution of Wind Speed is a method that has great simplicity and flexibility [5]. The Weibull distribution is often used in the field of life data analysis due to its flexibility. The probability density function and cumulative function of the Weibull distribution [18] are determined using equation (12). Weibull parameters computation of the wind speed is described by the Weibull distribution function [20]. The parameters functions **k** and **c** are used for studies. The Weibull distribution probability density function is expressed in equation (10).

$$f_w(v) = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1} exp\left[-\left(\frac{v}{c}\right)^k\right] \tag{10}$$

f_w = Weibull probability density function

v = average wind speed (m/s),

k = shape parameter (dimensionless).

c = scale factor (m/s)

$$F_W(v) = 1 - exp\left(\frac{v}{c}\right)^k \quad (11)$$

F_W = Weibull cumulative distribution function

Hence, k and c are expressed mathematically in these equations;

$$k = \left(\frac{\sigma}{v}\right)^{-0.086} \quad , \quad (1 \leq k \leq 10) \quad (12)$$

$$c = \frac{v}{\Upsilon\left(1+\frac{1}{k}\right)}\frac{m}{s} \quad (13)$$

Where

$\Upsilon_{(x)}$ = Gamma function of x

The mathematical expression of the gamma function thus as

$$\Upsilon_{(x)} = \int_0^\infty t^{x-1}\exp(-t)dt \quad (14)$$

Rayleigh model is a special and simplified case of the Weibull model. The probability density and the cumulative distribution functions of the Rayleigh model [13] are expressed as follows;

$$f_R(v) = \frac{\pi}{2}\frac{v}{v_m^2} exp\left[-\left(\frac{\pi}{4}\right)\left(\frac{v}{v_m^2}\right)^k\right] \quad (15)$$

$$F_R(v) = 1 - exp\left[-\left(\frac{\pi}{4}\right)\left(\frac{v}{v_m}\right)^2\right] \quad (16)$$

f_R = Rayleigh probability density function,

F_R = Rayleigh cumulative distribution function,

2.4 Wind Speed Data

A scatter plot of wind speed data shows the wind speed points which clustered in the same area as seen in figure.1. Here it has several outliers that represent a significant amount of wind speed shear.

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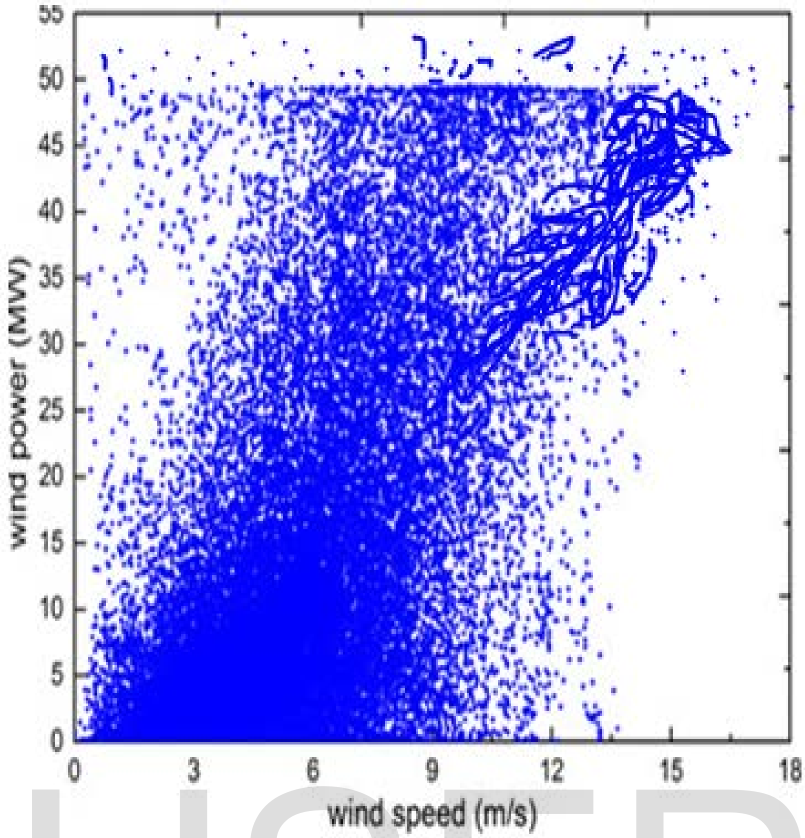

Figure.1 shows the scatter plot of wind speeds of Mubi site for the month of August 2016

In order to separate the wind speed data into more clearly defined stability regimes, R_i is to be determine using equation (17);

$$R_i = \frac{g\left(\frac{\partial_\theta}{\partial_z}\right)}{T_O\left(\frac{\partial_u}{\partial_z}\right)^2} \quad (17)$$

Where

R_i = Gradient Richardson number

g = Gravitational acceleration,

T_o = Surface temperature,

$\frac{\partial_u}{\partial_z}$ And $\frac{\partial_\theta}{\partial_z}$ = Vertical gradients of wind speed and potential temperature.

$$R_i = \frac{g\left[\frac{T_x - T_y}{\Delta_{ZT} + \Gamma_d}\right]\left(\Delta z_u{}^2\right)}{T_{my}\left(u_{im} - u_{rm}\right)^2} \quad (18)$$

Where;

$\mathbf{T}_x$ and $\mathbf{T}_y$ = Temperatures at X and Y,

$\mathbf{u}_i$ and $\mathbf{u}_r$ = Wind speed magnitudes above ground level respectively based on the site location,

$\mathbf{\Delta}_T$ and $\mathbf{\Delta}_u$ = Differences in measurement levels for T and **u**.

$\mathbf{\Gamma_d}$ = Dry adiabatic lapse rate.

Here, the vertical gradient of T_p is by adding $\mathbf{\Gamma_d}$ to the temperature gradient. Where, the value of R_i is observed for average of 15mins of the wind speed.

2.5 Wind Speed Height

Wind speed vertical height is the function of height above ground up to a maximum altitude. Therefore, it is necessary to determine the wind speed at the height of the wind turbines hub. Power law guiding the wind speed height gives an equation for variations in wind speed with hub height [9] as:

$$v_2 = \left(\frac{h_2}{h_1}\right)^{\propto} v_1 \left(\frac{m}{s}\right) \tag{19}$$

Where

v_1 = measured wind speed at a known height h_1

v_2= extrapolated wind speed at practical height h_2.

$\propto$ =surface roughness coefficient and dependent on height, time of the day, season of the year, nature of the terrain, wind speed and temperature is calculated as follows

$$\alpha = \frac{\left[(3.7*10^{-1})-(8.8*10^{-2})\right]}{1-0.088\ln\left(\frac{h_1}{10}\right)} \tag{20}$$

3. Result and Discursion

3.1 Frequency distribution of the wind speed probability

The frequency distribution of wind speed probability is in time series as shown in table.1. Hence, the wind speed data were recorded continuously at a height of 25m using a cup generator anemometer as shown in figure 1.1 and was obtained from Nigeria Metrological Agency (NIMET), Yola. The Table shows the arrangement of Monthly measured frequency distribution series data in Adamawa, they are; Average wind speed (AWS in m/s), Mean wind speed (MWS in m/s), Weibull probability density function (WPDF), Rayleigh probability density function (RPDF), Rayleigh cumulative distribution function (RCDF) and Weibull cumulative distribution function (WCDF)

Figure 1.1 Cup-Anemometer at a height of 25m

The wind speed data was captured by a cup-anemometer at different heights. The cup-anemometer consists of three cups attached to short rods that are connected to a vertical shaft at right angles. When the wind blows, it pushes the cups, which turn the shaft [5]. The number of turns per minute is translated into wind speed by a system of gears similar to the speedometer of an automobile

Table 1: The Monthly measured frequency distribution series data in Adamawa

N	AWS (m/s), (V_n)	MWS (V_{mn}) m/s	f_n	f_{vn}	WPDF($f_{W(vn)}$)	RPDF ($f_{R(vn)}$)	RCDF (F_R)	WCDF (F_W)
1	0 – 0.9	0.53	0	0.000	0.00767	$4.1853*10^{-46}$	1	0.001644421
2	1 – 1.9	1.53	0	0.000	0.03995	$9.1065*10^{-06}$	1	0.003413367
3	2 – 2.9	2.53	3	0.000	0.07942	$1.5790*10^{-2}$	0.9898	0.083681204
4	3 – 3.9	3.53	0	0.000	0.11569	$7.7337*10^{-2}$	0.901	0.181897433
5	4 – 4.9	4.53	0	0.118	0.14019	$1.169* 10^{-2}$	0.751	0.311097877
6	5 – 5.9	5.53	0	0.471	0.14777	0.123934141	0.6042	0.456578874
7	6 – 6.9	6.53	3	0.176	0.13811	0.115345279	0.484	0.600835111
8	7 – 7.9	7.53	0	0.235	0.11547	0.102041674	0.391	0.728438987
9	8 – 8.9	8.53	6	0.000	0.08669	0.088581694	0.3199	0.829723746
10	9 – 9.9	9.53	4	0.000	0.05852	0.076516649	0.2653	0.902043475
11	10 – 10.9	10.53	8	0.000	0.03551	0.066188671	0.2228	0.948517316
12	11 – 11.9	11.53	0	0.000	0.01935	0.057503412	0.1894	0.975379276
13	12 – 12.9	12.53	0	0.000	0.00946	0.050237391	0.1627	0.989326467
14	13 – 13.9	13.53	5	0.000	0.00414	0.044153415	0.1412	0.995820548
15	14 – 14.9	14.53	0	0.000	0.00162	0.039039471	0.1235	0.998526878
16	15 – 15.9	15.53	0	0.000	0.11163	0.01098712	0.1523	0.998687522
17	16 – 16.9	16.53	4	0.000	0.06241	0.02104622	0.5123	0.999875263
18	17 – 17.9	17.53	0	0.000	0.00631	0.08521904	0.2315	0.999975245
19	18 – 18.9	18.53	0	0.000	0.00534	0.066033412	0.3152	0.999987664
20	19 – 19.9	19.53	0	0.000	0.00265	0.054568211	0.6135	0.999998777

3.1 Wind Energy Resources for Mubi

Mubi is one of the twenty-one local government Area of Adamawa state, located in the Northern part of the state has sufficient wind energy for power generation. Based on the data collected used in the calculation of monthly average values for the wind speeds, standard deviation and the Weibull parameters of the Area is shown in table 2. The values of *C* ranged from 4.69 - 6.98ms^{-1} and k =3.53 - 17.08 respectively. The mean wind speed values is between 4.07 – 7.54ms^{-1} while for standard deviation values ranged from 0.45 – 2.83ms^{-1}. Weibull scale parameter 'C' varies between 9.77 ms^{-1} and 11.63 ms^{-1}, thus were found to be generally higher than the shape parameter k which varies between 3.68 and 9.56. The annual power density has 510.93 Wm^{-2} as the minimum value and 869.58 Wm^{-2} as its highest value. Weibull probability density distribution for wind speed data at 10m height for each month.

Table 2: Average monthly values of wind speed, (Weibull and performance parameters)

Month	**Mean wind speed (v_m) m/s**	**Standard Deviation (σ) m/s**	**Scale Factor (c) m/s**	**Shape parameter (k)**	**P (W/m2)**	**RMSE**
Jan	6.34	2.65	6.78	3.53	529.44	0.04
Feb	7.14	2.61	6.63	5.01	510.93	0.02
Mar	6.89	2.56	6.98	4.52	859.52	0.06
Apr	7.54	0.86	6.95	10.78	725.98	0.02
May	6.44	0.77	5.89	10.08	630.74	0.01
Jun	5.67	0.67	5.58	14.05	869.58	0.04
Jul	5.78	0.65	5.79	15.98	665.45	0.03
Aug	5.72	2.83	6.06	3.29	467.53	0.06
Sep	5.69	0.54	5.51	14.86	449.89	0.01
Oct	4.98	0.45	4.69	17.08	508.37	0.02
Nov	4.07	0.89	4.79	7.68	513.09	0.05
Dec	5.65	1.43	5.89	3.78	435.74	0.07

Hence, increasing the height also increases the wind speed. Which is an evident that wind speed is directly proportional to the vertical height. Table 3 shows the calculated values at the height of 25m. The highest mean wind speed was 19.66 ms-1 on December 2014 as compared to 14.40 ms-1 of the same month and year at 10 m height.

Table 3: The average wind speed values measured at 25m height (ms^{-1}).

YEAR	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2012	12.59	12.59	16.81	15.63	13.22	15.04	14.43	13.83	13.83	12.59	14.43	12.59
2013	13.83	11.96	17.40	16.81	15.63	13.22	17.97	11.96	12.59	14.43	13.83	13.22
2014	17.40	13.22	16.90	13.83	13.22	14.43	14.43	15.63	13.83	12.59	14.43	19.66
2015	15.04	11.96	16.81	13.83	16.81	16.81	17.40	18.54	16.23	17.40	13.83	15.04
2016	11.96	11.96	15.04	11.96	14.43	13.83	13.23	12.59	15.63	15.04	15.63	14.43
2017	18.54	16.81	12.59	16.22	13.23	19.11	19.11	17.97	18.54	6.51	10.80	9.81

Table 4; The monthly variations of wind in Mubi Area.

Month	Mean wind speed (10 m)	σ	K	c (m/s)	Power density (W/m^2)	Average energy (kWh/m^2)	Mean wind speed (50 m)
January	4.94	1.70	3.18	5.51	99.12	73.75	8.00
February	5.90	1.82	3.58	6.55	160.17	107.64	9.56
March	6.10	1.80	3.76	6.76	173.70	129.23	9.89
April	5.80	1.53	4.26	6.38	142.85	102.85	9.40
May	5.81	1.63	3.97	6.42	147.02	109.38	9.42
June	6.06	1.87	3.58	6.72	173.21	124.71	9.82
July	5.66	2.04	3.03	6.33	153.17	113.96	9.17
August	4.62	1.33	3.88	5.11	74.52	55.44	7.49
September	4.49	1.06	4.79	4.90	63.80	45.94	7.27
October	4.55	1.35	3.76	5.04	72.01	53.57	7.37
November	5.10	1.59	3.53	5.66	103.82	74.75	8.26
December	4.68	1.50	3.45	5.21	81.45	60.60	7.59

Wind speed measurements in some hilly and coastal areas in Nigeria have shown an excellent wind potential for implementation of wind farms in those areas. Table 5 shows the wind energy density estimate at 25m height from a wind energy Turbine (KWh) of 20m Blade. It can also be seen from the table that Sokoto, Jos and Yola have the annual wind energy from wind turbine (kWh) of 97035.94, 94559.98 and 85284.42 respectively. A number of authors recommended base on the wind speeds that these potential wind farm areas should be injected to the grid (at Distribution level). The Director General of Energy commission of Nigeria in a Paper presented at International Association for Energy Economics

Third quarter 2009 still lamented that these renewable Energy resources most especially wind have not been properly utilized by integrated to the Nigeria grid.

Table 5 Wind speed measurements and data in Nigeria.

Station	*MWS at 10m (m/s)*	*MMWE (kWh)*	*AWE (kWh)*	*AWE from a wind energy Turbine (KWh)*
Sokoto	4.476	16.47	197.68	97,035.94
Jos	4.430	16.05	192.64	94,559.98
Yola	4.259	14.48	173.74	85,284.42
Kaduna	3.605	9.91	188.88	58,355.08
Enugu	3.372	7.83	93.91	46,097.96
Maiduguri	3.486	8.42	101.01	49,583.17
Potiskum	3.636	9.44	113.25	55,591.46
Yelwa	3.360	7.76	93.13	45,714.59
Kano	3.516	8.57	102.86	50,491.28
Warri	2.027	2.02	24.20	11,879.15
Zaria	2.891	5.32	63.88	31,357.02
Ilorin	2.078	1.23	14.73	7,230.57
Makurdi	2.689	4.44	53.27	26,148.85
Lagos	2.671	4.36	52.32	25,682.52
P.H.	2.640	4.17	49.98	24,533.88
Ibadan	2.620	4.15	49.78	24,436.19
Lokoja	2.235	2.60	31.21	15,320.17
Benin City	2.135	2.32	27.86	13,673.78
Nguru	1.824	1.45	17.34	8,511.75
Calabar	1.702	1.12	13.42	6,587.53
Oshogbo	1.625	1.07	12.81	6,288.09
Minna	1.589	1.05	12.60	6,185.01
Total		**134.23**	**1,680.5**	**790,548.39**

3.2 Probability Density Function for Weibull and Rayleigh

Figure.2 shows the probability density function for Weibull and Rayleigh, it can be seen from the graph that Weibull returns the highest value of 0.15 as compared to Rayleigh with highest value of 0.12. It can be seen that the mean reference power values are lower as compared to Weibull and Rayleigh power. The Rayleigh model returns higher values in wind power density than the Weibull model in all the months. However, the average energy and Monthly variation of mean wind power density of the selected locations in the study areas are given as; figure 3, 4, 5, 6 and 7.

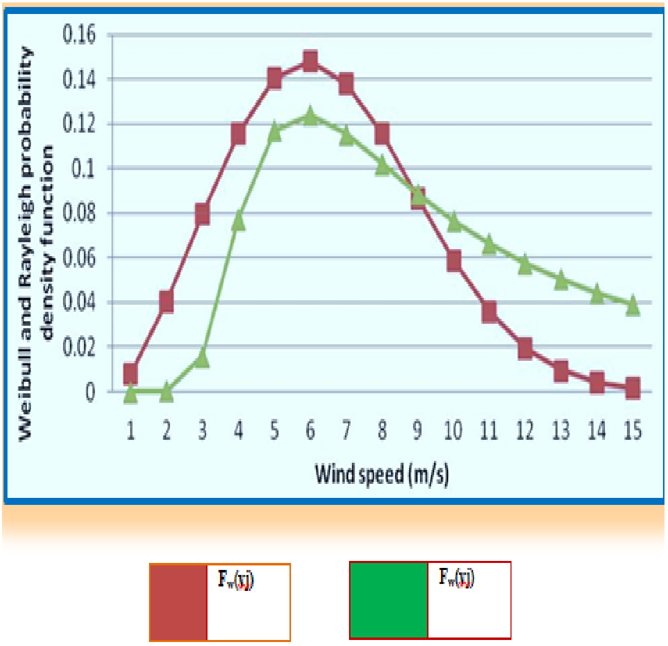

Figure.2 Probability density function of Weibull and Rayleigh

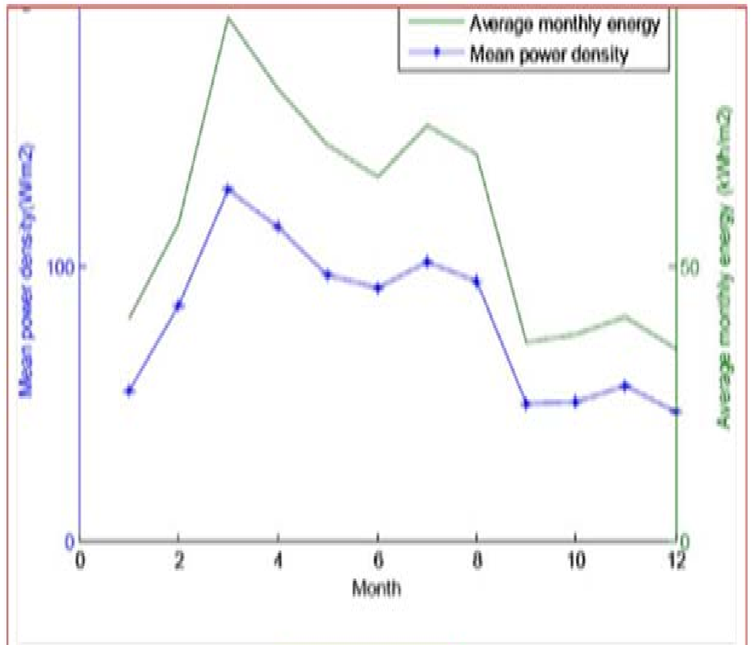

Figure 4 Hong Area

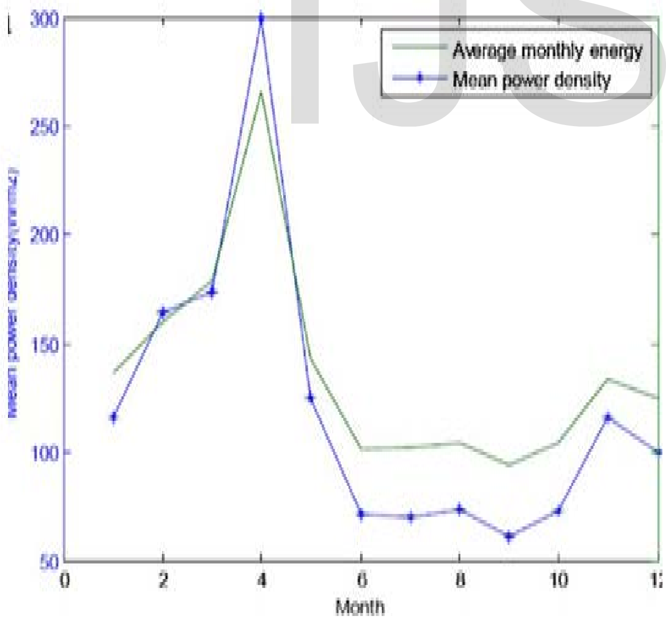

Figure 3 Gombi Area

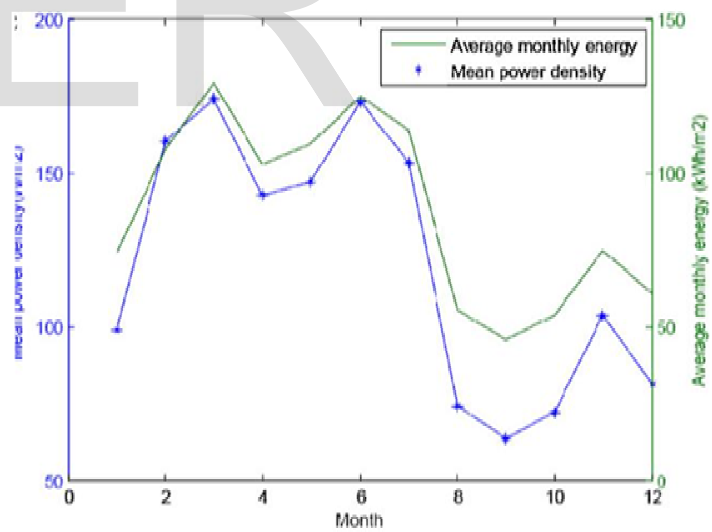

Figure 5 Mubi

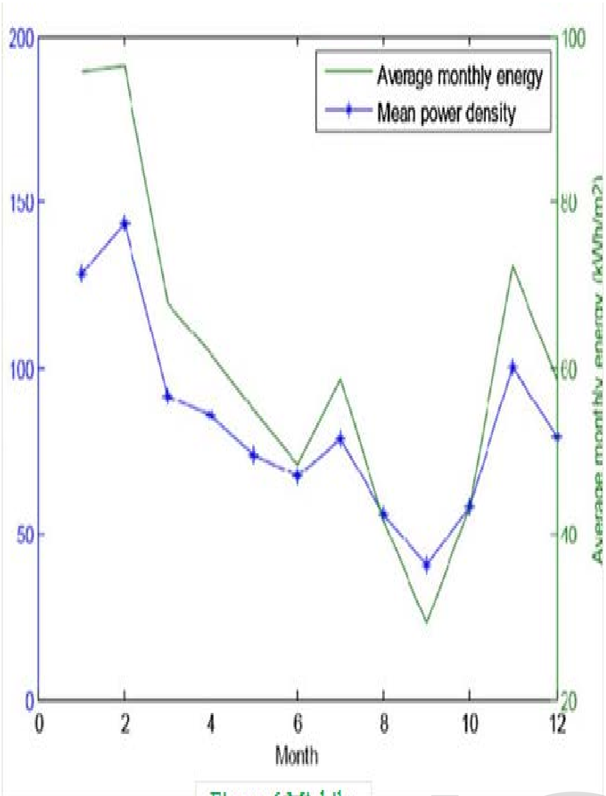

Figure 6 Michika

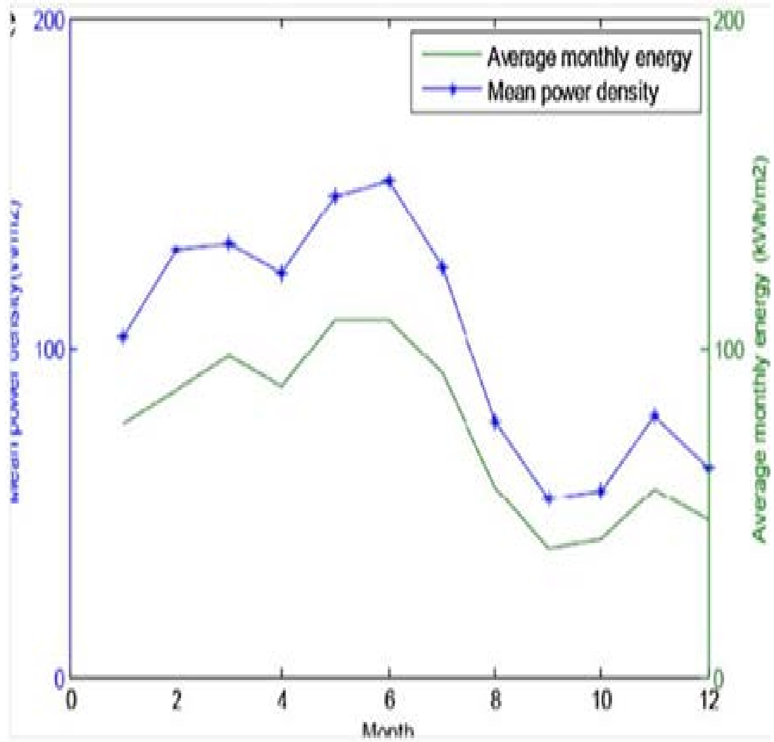

Figure 7 Maiha Area

Figure 3 – 7. The average energy and Monthly variation of mean wind power density for (3) Gombi (4) Hong (5) Mubi (6) Machika and (7) Maiha

4. Conclusion

Due to liberalization and change in lifestyle of consumer, demand for energy has increased. This growth of demand can be effectively tackled by better energy management, which will address the issues of Adamawa State energy problems by using energy mix as solution. In general, Nigeria has huge potential of renewable energy sources especially solar and wind. So, realizing this potential, Government of Nigeria has been actively putting efforts to promote renewable energy. The availability of wind energy potentials and the extent to which wind energy is utilized in the study area have not been encouraging. The state is blessed with abundant energy resources with great potential for energy generation, yet, it received poor attention, which engrossed with high level of energy deficiency. The challenges of wind energy development are: reluctance of government to encourage wind technologies, wind mapping, lack of local manufacturing for wind energy machinery and systems, low financing. Therefore, overcoming these challenges that inflict the growth of wind energy resources will boost the economy of the state and Nigeria at large.

Furthermore, detailed analysis of Weibull and Rayleigh distributions was then carried out. For each selected location the most suitable distribution to describe the wind speed data was identified. The Weibull distribution was found the best option with moderate values of mean wind speeds. The Weibull function fitted well to wind speed data with less skewness.

However, the study area has sufficiently ability to accommodate wind energy generation, which was based on the obtained result from the selected locations of the research Area gives the average wind speeds of 3.20 to $4ms^{-1}$ at 10m height, 4 to 5 ms^{-1} at 25m height and 5 to $6ms^{-1}$ at 80m height, and the wind energy potential of these areas are; $4.5ms^{-1}$, $4.22ms^{-1}$, $4.14ms^{-1}$, $3.98ms^{-1}$, $4.07ms^{-1}$ and $3.86ms^{-1}$ with the estimated power of $16.34Wm^{-2}$, $16.12Wm^{-2}$, $16.03Wm^{-2}$, $15.43Wm^{-2}$, $15.76Wm^{-2}$ and $14.45Wm^{-2}$. This research will create breakthrough for further research in the area of wind power technology, create ways on how to develop wind farms and wind energy technology, encourage wind energy utilization in the research Area and Nigeria at large, as well as reduce the country's dependence on other sources of energy such as Hydro, Thermal and fossil fuels.

5. RECOMMADATIONS

It is recommended that research agencies and individual researchers in the relevant field should carry out more work on the wind energy potentials and utilization in order to explore the maximum potential of wind energy in Adamawa State. The Government of Nigeria through its various agencies should develop more wind farm sites across the country, establish local manufacturing industries for wind energy systems, create enabling environment for investors to widen research activities. The Energy Commission of Nigeria should also carry out offshore mapping.

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