ASSESSMENT OF WIND RESOURCE AND ITS ENERGY POTENTIAL IN THREE STATES OF NORTHWEST NIGERIA

ABSTRACT

The growing need for clean energy to address the environmental issues caused by the usage of fossil fuels results to the need for Nigeria to develop an alternative energy from untapped wind which is in abundance in the region. The aim of this study is to evaluate wind power potential and wind energy resources of three locations (Kaduna, Kano and Katsina) of northwestern part of Nigeria. The Nigerian Meteorological agency (NIMET) provided the wind speed data spanning 25 years (1996-2020). In the analysis, Weibull two-parameter statistical model was used. The distribution of wind speed across Nigeria demonstrates that some areas in the North are equipped to generate wind. Microsoft excel was used in analyzing the wind speed data obtained. In addition, evaluation of the region's wind energy resources shows that Kano recorded the highest potential, with WPD of 443.03 Wm^{-2}at 10m AGL with annual WED of 4.921 $kWhm^{-2}day^{-1}$while Kaduna recorded the lowest potential of 198.43 Wm^{-2} with annual WED of 2.093 $kWhm^{-2}day^{-1}$. As a result, Kaduna is found to be ideal for small scale wind power generation, while Kano and Katsina may be suitable for large scale wind power generation.

Keywords: *Nigeria, Weibull, Wind Speed, Wind Power and Wind Energy*

1. INTRODUCTION

Air under motion is referred to as wind. Pressure differences across regions and heights result to the production of wind and in turn result to the large movement of air masses (Madu, 2018).

Wind energy is the most rapidly expanding source of energy in the world, it can provide industry, commerce, and residences with renewable energy that is environmentally friendly for many more generations to come. The operation of wind turbines results in no fuel use, it doesn't emit any air pollutants, including carbon dioxide, sulfur dioxide, mercury, particles, or any other kind (Alsaad, 2013).

"The Nigerian government has not been able to find permanent solutions that will resolve the problems due to the adaptation of short term, hasty policies and also still undergoing energy projects which are detriment to long term energy policies that will help the nation to achieve sustainable energy and energy efficiency. For example, what the country have done is still usage of the various alternatives that are still within the limits of fossil fuels, which are the only source that currently powers the nation economy" (Kennedy and Hoyt 2008).

In Nigeria, about 40% of the population has access to grid-connected power, while the remaining 60% must rely on locally available energy sources like firewood and solar radiation (Ucar and Balo, 2009). The situation necessitates diversifying the energy supply mix and raising public knowledge of the nation's abundant renewable energy resources in order to promote and develop them. Nigeria offers a lot of potential for renewable energy sources such as wind, sun, biomass, and hydropower. Leveraging the wind's power requires thorough research of both temporal and spatial fluctuations in wind speed values, since wind speeds and directions present severe transitions at most sites. Precise assessment of wind resources is essential and needs to be well understood. The output power generation of any wind energy conversion system (WECS) is directly related to the system's operational parameters, or the wind characteristics of the location

(Ucar and Balo, 2009). Therefore, the ideal locations are typically those where the wind blows most frequently. In certain places throughout the North-western (NW) area of Nigeria, wind energy can be adopted and used to generate electricity using WECS.

2. Study Area

The study areas areKano, Kaduna and Katsina all, located in Northwestern region of Nigeria.The region occupies a land mass of about $214{,}395Km^2$, located within longitude $3°\,45'\,00''\ E$ to longitude $10°\,20'\,00''\ E$ and latitude $9°\,0'\,00''\ N$ to$13°\,49'\,30''\ N$. Based on National census, Northwest Nigeria is the most populated geopolitical zone with 35,786,944 people (Salihu, *et al*., 2018).

Figure 1. Table 1 below shows the coordinates of the three (3) locations and Elevations.

Table 1. Geographical Locations of North-Western States of Nigeria

S/N	Station Name	Lat. (^{o}N)	Long. (^{o}E)	States	Elevation (m)
1	Katsina	13.01	07.41	Katsina	517.6
2	Kaduna	10.36	07.27	Kaduna	645.4
3	Kano	12.03	08.12	Kano	472.5

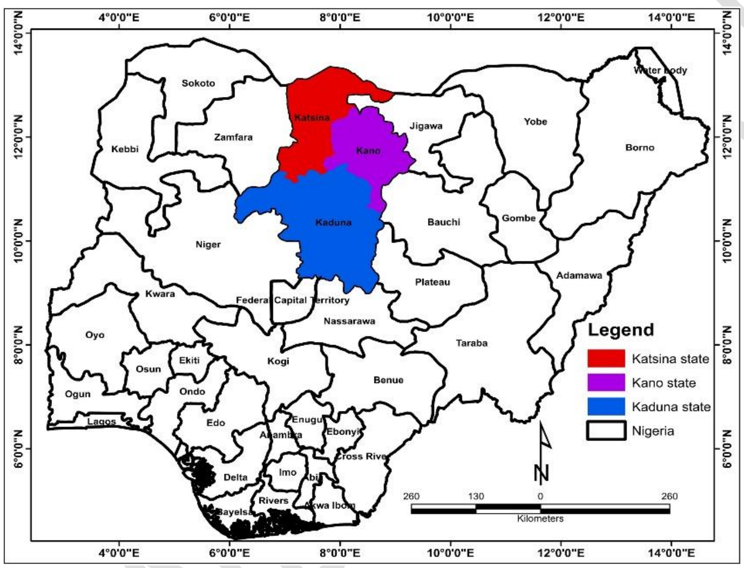

Figure1: Map of Nigeria showing the study locations.

3. Classification of wind power using WPD

A classification of wind power density was developed by the Battelle-Pacific Northwest Laboratory (PNL). A numerical ranking is used in this categorization, with class 1 having the lowest value and class 7 having the highest value. Class 4 and higher locations are considered appropriate for both small- and large-scale generation. Class 1 locations are unsuitable for wind investment, whereas class 2 locations are considered marginal (Ordonez, 2013).

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Table 2. Wind Power Classification

Wind Power Class	WPD at 10m (Wm^{-2})	Resource Potential
1	0-100	Poor
2	100-150	Marginal
3	150-200	Moderate
4	200-250	Good
5	250-300	Excellent
6	300-400	Excellent
7	400-1000	Excellent

4. MATERIALS AND METHOD

The materials employed in this research are; 20years (1996-2020) secondary data of monthly average wind speed for seven locations obtained from Nigeria meteorological agency (NIMET), laptop computer window 10, installed with Microsoft excel and Origin software.

Wind power will be used to measure actual wind resources, to determine the distribution of wind speed for the location, because of its considerable influence on wind potential. "The Weibull probability density function is a mathematical idealization of the distribution of wind speed over time. The function gives the probability of the wind speed being in 1m/s interval centered on a particular speed (v), taking into account both seasonal and annual variations over the period covered by the statistics. The Weibull distribution function is given" (Walker and Jenkins, 1997) by:

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

Where f (v) is the probability density defined as the frequency of occurrence of wind speed (v), c (in unit of m/s) is the scale parameter which is closely related to the modal wind speed for the location, and k is the dimensionless shape parameter which describes the form and width of the distribution. The Weibull distribution is therefore characterized by the two parameters c and k. The cumulative Weibull distribution F (v) which gives the probability of the wind speed exceeding the value v is expressed (Justus,*et al*,. 1978; Walker and Jenkins, 1997) as:

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

On the other hand, the power derivable from the wind is a cubic function of the wind speed, such that, in the Weibull distribution, the power density P(A), of the wind at any speed is given (Walker and Jenkins, 1997) by:

$$P(A) = \frac{1}{2}\rho\int_0^\infty v^3 f(v)dv \qquad (3)$$

Where $\rho$is the density of air. Analysis of equation (3) using equation (1) shows that the power density could be expressed as a gamma function Γ defined in x-variable (Dass, 1998) as:

$$\Gamma(x) = \int_0^\infty x^{n-1}e^{-x}dx \qquad (4)$$

Using equation (4) for v in equation (3), the average wind power density (P_{av}) based on Weibull distribution can be expressed (Ucar and Balo, 2009) in the form:

$$P_{(av)} = \frac{1}{2}\rho\bar{v}^3 \frac{\Gamma(1+{}^3/_k)}{[\Gamma(1+{}^1/_k)]^3} \qquad (5)$$

Where v^3 is the mean of the cube of wind speed distribution. However, "meteorologists have characterized the wind speed distribution patterns for many of the world's wind regimes. In temperate climate (mid-latitudes), a typical shape parameter (k) of 2 offers a good approximation" (Enibe, 1987). For k = 2, equation (1) or (2) reduces to Raleigh wind speed distribution. Hence, "the Raleigh distribution is a special case of the Weibull distribution developed for estimation of wind potential in temperate climate locations. Wind characteristics are essentially location specific and performance of practical wind conversion devices may greatly differ if actual wind conditions at the location differ from those standard speed distributions" (Enibe, 1987**)**.

5. Wind Power Density and Wind Energy Density

Wind power density (WPD) indicates how much energy per unit of time and swept area of the blades is available at the selected area for conversion to electricity by a wind turbine. The mean wind power density was calculated by using the Weibull two parameter methods as expressed by Kamau,*et al.,* (2010):

$$P(v) = \frac{1}{2}\rho c^3 \Gamma\left(1 + \frac{3}{k}\right) \qquad (6)$$

Where, P (v) is the wind power density (Wm^{-2}), v is the Wind speed (ms^{-1}), c is weibull scale parameter (ms^{-2}), k is Weibull shape parameter (dimensionless) and Γ(x) is the gamma function, which is defined as:

$$\Gamma(x) = \int_0^\infty t^{x-1} e^{-t} dt \qquad (7)$$

$$\rho = \rho_o - 1.194 \times 10^{-4} \times H_m \qquad (8)$$

Where the air density $\rho_0$is value at sea level usually taken as $1.225Kgm^{-3}$ and H_m is the site elevation in meters.

The wind energy density (WED) is the product of the mean power density and the time (T) in hours. The daily and annual wind energy density was estimated by multiplying WPD by 24 and 8760 hours respectively. WED is usually expressed in $kWhm^{-2}$ and can be given as:

$$WED = \frac{1}{2}\rho c^3 \Gamma\left(1 + \frac{3}{k}\right) T \qquad (9)$$

The Weibull parameters k and c were calculated using the standard deviation method given by Justus,*et al.,*(1978):

$$k = \left(\frac{\sigma}{v_m}\right)^{-1.086} \qquad (10)$$

$$c = \frac{v_m}{\Gamma\left(1+\frac{1}{k}\right)} \qquad (11)$$

$$\sigma = \left[\left[\frac{1}{N-1}\sum_{i=1}^{N}(v_i - v_m)^2\right]\right]^{\frac{1}{2}} \qquad (12)$$

Where σ is standard deviation, v_m mean wind speed (m/s), $v_i$is observed wind speed (m/s) andN is the number of months in the period of time considered.

6.RESULTS AND DISCUSSION

Kaduna recorded the highest wind speed of $10ms^{-1}$ in February while the lowest was found to be $2.4\ ms^{-1}$ in October. The monthly mean wind speed was found to be $5.682\ ms^{-1}$ as shown in Figure 2. In Kano, the highest wind speed was recorded to be $14.5ms^{-1}$ while the lowest was recorded tobe $2.0\ ms^{-1}$, of which the average monthly wind speed was found to be $8.216\ ms^{-1}$. Katsina recorded the highest wind speed of $12.9ms^{-1}$ and the lowest $2.7ms^{-1}$, the monthly mean wind speed was found to be $7.392\ ms^{-1}$

Similarly, the highest and lowest values of wind speed recorded for Kaduna was found to be 7.975 and 3.9667 ms^{-1}in the year 2010 and 2013 respectively as shown in Figure 3. In Kano, the highest wind speed recorded was found to be 12.292 ms^{-1} in the year 2014 and the minimum was found to be 3.608ms^{-1} in 2004 The highest value of wind speed obtained in Katsina was 8.39 ms^{-1} and 4.808ms^{-1} was the lowest value obtained in the year 1998 and 2010, respectively. The annual mean wind speed recorded during the period of this study is $5.202\ \text{ms}^{-1}$ for Kaduna, $6.95\ \text{ms}^{-1}$for Kano, $6.23\ \text{ms}^{-1}$for Katsina.

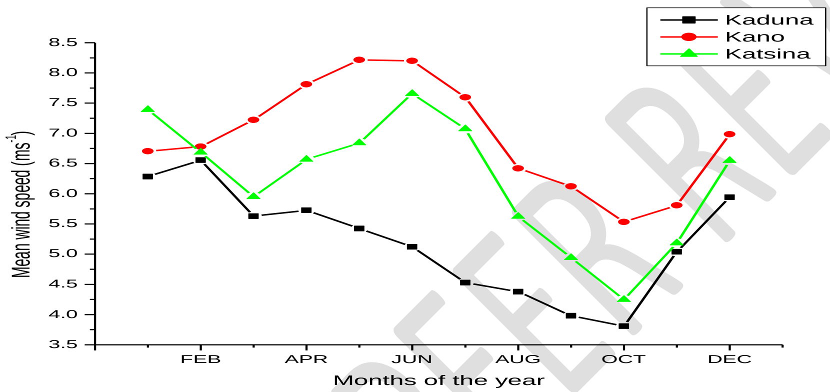

Figure 2. Monthly wind speed of Kaduna, Kano and Katsina

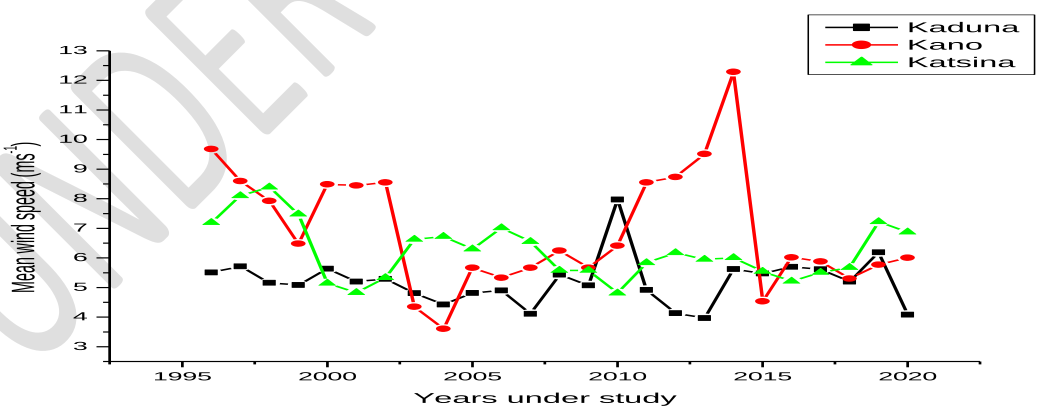

Figure 3. Annual mean Wind Speed over Kaduna, Kano and Katsina

Kaduna recorded the highest and lowest wind power densities of 198.49 and 41.03 Wm^{-2}in the months of February and October respectively. In Kano, the highest and lowest wind power densities are 443.04 and 112.55 Wm^{-2} in the months of June and October, respectively. As for Katsina, the highest was found to be 297.65 Wm^{-2} while the lowest was 53.35 Wm^{-2} in the months of June and October respectively. Kano and Katsina measured highest and lowest wind power densities in the months of June and October respectively.

Figure 4 shows the annual wind power density for Kaduna during the period under investigation. The result shows that the highest annual wind power potential with its peak value was found in February 2005 with 573.9696Wm^{-2}, an annual WED was recorded to be 2.093 kWhm^{-2}day^{-1}. Figure 5 shows the annual wind power density for Kano during the period under investigation. The result shows that the highest annual wind power potential with its peak value was found in February 2014 with 1781.286Wm^{-2}, an annual WED is obtained as 4.921 kWhm^{-2}day^{-1}

Figure 6 shows the annual wind power density for Katsina during the period under investigation. The result shows that the highest annual wind power potential with its peak value was found in January 1998 with 1248.513Wm^{-2}, an annual WED is estimated to be 3.623 kWhm^{-2}day^{-1} (Table 3).

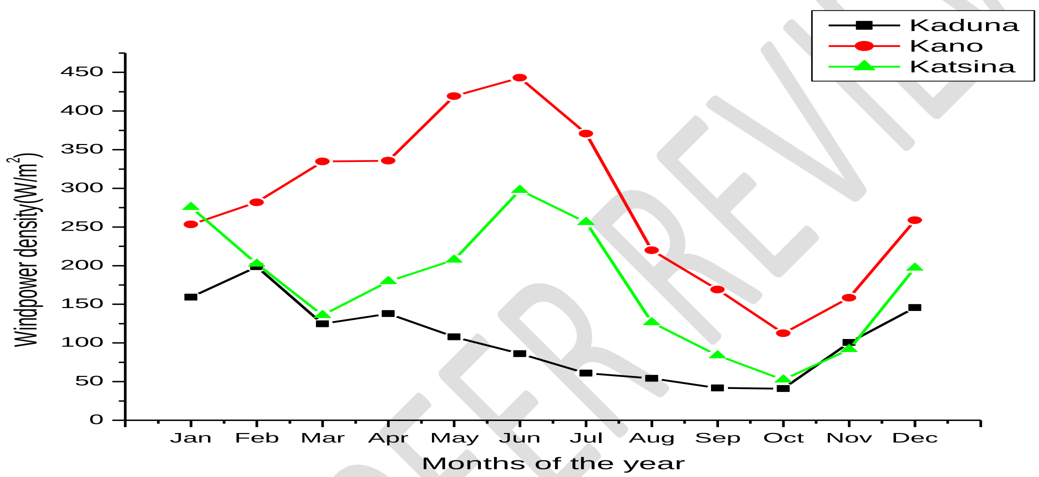

Figure 4. Monthly wind Power for locations under study

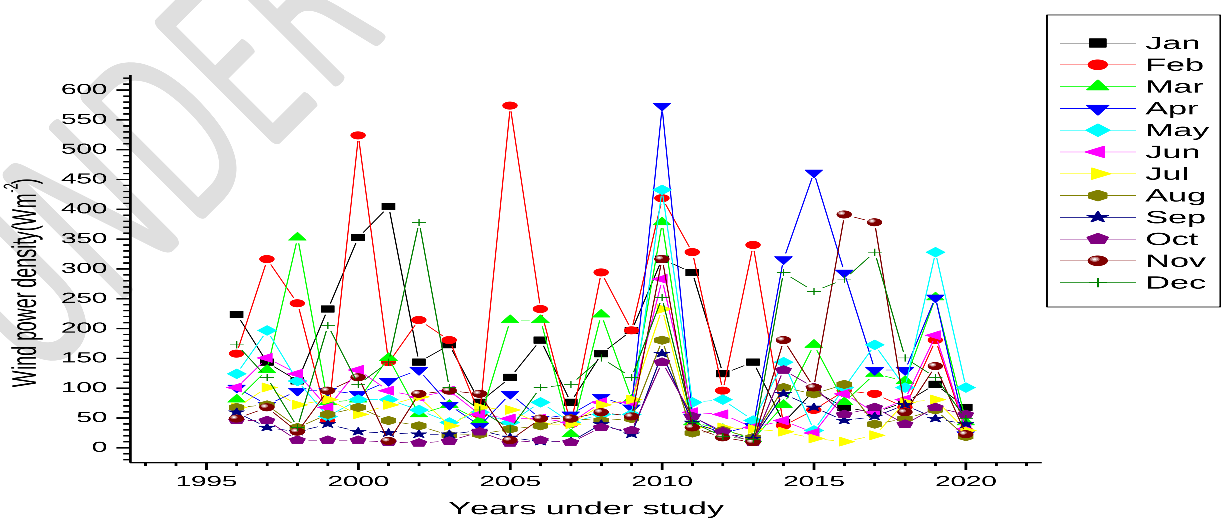

Figure 5. Annual wind Power density for Kaduna

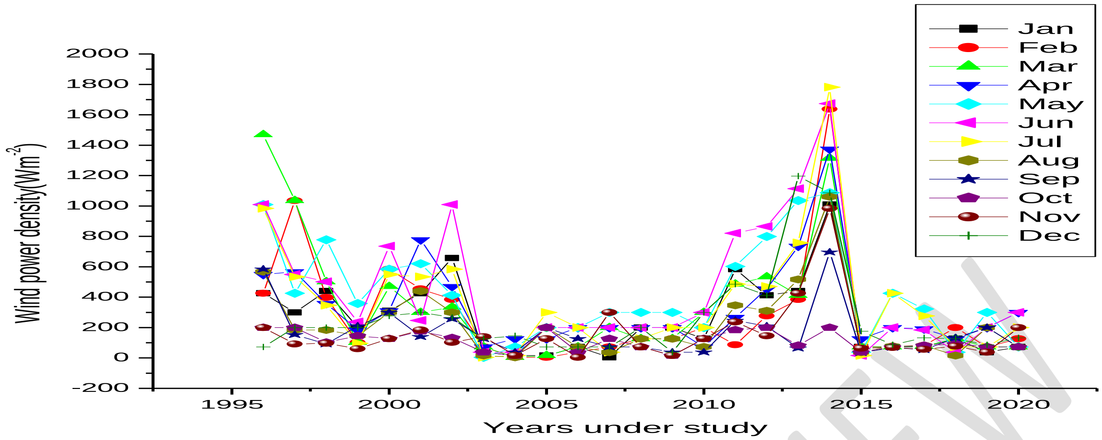

Figure 6. Annual wind Power density for Kano

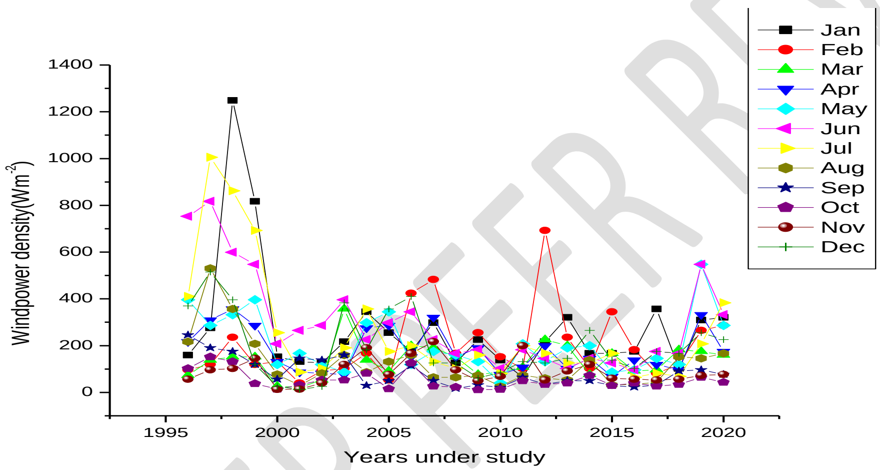

Figure 7. Annual wind Power density for Katsina

Table 3 Wind speed and other parameters in Kaduna

Period	**V_m(ms^{-1})**	**k**	**c (ms^{-1})**	**WPD (Wm^{-2})**	**WED ($kWh/m^2/d$)**
JAN	6.284	5.87	6.78	142.43	3.418
FEB	6.556	4.09	7.23	161.74	3.882
MAR	5.628	4.21	6.20	102.32	2.456
APR	5.728	3.74	6.24	107.87	2.589
MAY	5.424	4.90	5.92	91.59	2.198
JUN	5.12	5.99	5.51	77.04	1.849

JUL	4.528	5.30	4.92	53.29	1.279
AUG	4.38	5.84	4.73	48.23	1.158
SEP	3.98	5.23	4.32	36.19	0.868
OCT	3.808	4.99	4.15	31.69	0.761
NOV	5.04	6.76	5.38	73.48	1.764
DEC	5.944	8.09	6.27	120.54	2.893
Average					**2.093**

Table 4 Wind speed and other parameters in Kano

Period	**V_m(ms^{-1})**	**k**	**c (ms^{-1})**	**WPD (Wm^{-2})**	**WED (kWh/m^2/d)**
JAN	6.704	7.39	7.12	176.05	4.225
FEB	6.78	7.48	7.19	182.10	4.370
MAR	7.224	8.01	7.63	220.27	5.287
APR	7.812	8.72	8.20	278.56	6.685
MAY	8.216	9.21	8.59	324.05	7.777
JUN	8.2	9.19	8.58	322.16	7.732
JUL	7.596	8.46	7.99	256.09	6.146
AUG	6.42	7.05	6.84	154.61	3.711
SEP	6.124	6.70	6.55	134.19	3.221
OCT	5.532	6.00	5.96	98.92	2.374
NOV	5.808	6.32	6.23	114.47	2.747
DEC	6.984	7.72	7.39	199.04	4.777
Average					4.921

Table 5 Wind speed and other parameters in Katsina

Period	**V_m(ms^{-1})**	**k**	**c (ms^{-1})**	**WPD (Wm^{-2})**	**WED (kWh/m^2/d)**
JAN	7.39	5.00	8.06	234.91	5.638
FEB	6.68	4.99	7.29	173.67	4.168
MAR	5.95	6.02	6.41	122.63	2.943
APR	6.57	6.77	7.02	164.79	3.955
MAY	6.84	5.95	7.37	186.12	4.467
JUN	7.66	5.41	8.30	260.99	6.264
JUL	7.07	4.12	7.80	205.71	4.937
AUG	5.62	4.25	6.19	103.46	2.483
SEP	4.94	4.51	5.42	70.11	1.683

OCT	4.25	4.79	4.64	44.58	1.070
NOV	5.18	5.41	5.62	81.02	1.945
DEC	6.55	4.21	7.21	163.29	3.919
Average					3.623

Table 6. Wind Power Density of Locations under Study

Location	WPD (Wm^{-2})	Class	Resource Potential
Kano	443.03	7	Excellent
Katsina	297.65	5	Excellent
Kaduna	198.49	3	Moderate

Kaduna is classified as Class 3 which is considered marginal for the production of wind energy. Kano is classified as Class 7. This shows that wind energy available in Kano is sufficient for the production of environmental friendly, large scale wind energy. However, employing specialized wind turbines with low cutting speeds, water pumps for irrigation purposes, and other low-energy capacity applications that require intermittent power delivery.

8. Summary

Nigeria has a reasonable amount of wind energy resources that can be used to generate electricity. According to studies, some areas in the northern part of the country and more conducive for the production of wind energy since they experience higher wind speed than the other part of the country most especially the southern region. This evaluation of wind energy potential in the chosen locations in Nigeria's northwest shows that:

i. The highest mean wind speed for the locations was recorded in Kano as 12.29 ms^{-1} and lowest mean wind speed was recorded as 7.975 ms^{-1} in Kaduna,

ii. The annual values of wind power density for the seven selected locations is computed as 443.03 Wm^{-2} with wind energy density (WED) of 4.921 $kWhm^{-2}day^{-1}$ in Kano as the highest, while the minimum is computed as 198.43 Wm^{-2} with annual WED of 2.093 $kWhm^{-2}day^{-1}$ in Kaduna.

iii. From the result of this study, Kaduna is ideal for small scale wind power generation, while Kano and Katsina suitable for large scale wind power generation.

9.Conclusion

This research has applied statistical tool of weibull distribution function to analyze wind speed (m/s) collected across seven locations in northwestern geopolitical zone of Nigeria to determine the wind power (W/m^2) and wind energy potential ($KW/m^2/h$) by analyzing shape parameter (k) and scale parameter (c).

The results obtained and presented has shown the variation of wind power across all the locations and the energy potential of each region which has shown that Kanoand Katsina has highest potential while Kaduna has the lowest

Therefore, the locations that shows high potential are suitable for large scale wind power generation are Kano and Katsina, while Kaduna is ideal for small scale generation.

10.Recommendations

It is recommended that:

i. Wind should be properly exploited as it is a very important energy source of enormous potential which will help Nigeria resolve its energy crisis.
ii. Extensive research should be carried out in order to better understand the impact of climate change of the trends in weather condition across Nigeria as it is showing chaotic tendency.

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