WIND RESOURCE ASSESSMENT AND ITS ENERGY POTENTIAL IN NORTHWESTERN NIGERIA

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Abstract: Nigeria has to create an alternative energy source from untapped wind, which is abundant in the region, in order to fulfill the growing need for clean energy to address the environmental challenges produced by the usage of fossil fuels. This study's objective is to assess seven locations in Nigeria's northwest on their potential for wind energy production. The Nigerian Meteorological Agency provided the 25 years of wind speed data (1996-2020) (NiMeT). In this investigation, the wind power density and wind energy density were derived using the Weibull two-parameter statistical model; the scale parameter (c) and shape parameter (k) were generated using the moment model. The acquired wind speed data was examined using Microsoft Excel. Nigeria's wind speed distribution shows that certain northern regions are capable of producing wind. Furthermore, an assessment of the wind energy resources in the area reveals that Kebbi and Dutse have the lowest potential at 86.52 and $7.69\mathrm{Wm}^{-2}$, with WED of 0.998 and $0.712\ \mathrm{kWhm}^{-2}day^{-1}$, while Kano and Sokoto recorded the highest potential at 10m AGL, with WPD of 443.03 and $340.67\ \mathrm{Wm}^{-2}$, respectively, and annual WED of 4.921 and $5.354kWhm^{-2}day^{-1}$. Consequently, Kano, Sokoto, and Katsina are appropriate for large-scale wind power generation, while Gusau and Kaduna are best for small-scale wind power development. But given their poor wind potential, Dutse and Kebbi might not be feasible. It is advised that wind power be properly utilized since it is a significant energy source with enormous potential that will aid Nigeria in resolving its energy crisis. Additionally, since weather patterns throughout Nigeria are becoming more chaotic due to climate change, extensive research should be done to better understand the impact of these trends.

Keywords: Nigeria; Weibull; Wind Speed; Wind Power; Wind Energy

Introduction

Wind energy, the world's energy source that is growing the fastest, can supply ecologically beneficial, renewable energy to homes, businesses, and industries for many more generations to come. Wind turbines don't require fuel to run, and they don't release any particles, carbon dioxide, sulfur dioxide, mercury, or any other type of air pollution (Alsaad, 2013). Nigeria has long struggled with energy issues, which are preventing the country from developing economically. Energy is a fundamental component of economic expansion and is necessary for all human activities in the contemporary world. Nigeria suffers from a chronic electrical scarcity, which is attributed to structural, social, and financial issues. Consequently, there are significant energy losses in the nation's power industry throughout electricity generation and billing, which leads to insufficient income generation (Iwayemi, 2008).

Between 60 and 70 percent of Nigerians do not have access to electricity. The primary energy source in Nigeria is fuel wood, and the people most affected by the energy crisis are women and children. Currently, only 10% of rural houses and 30–40% of the total population have access to electricity. The financing of big power plants and upgrades to the country's energy infrastructure, as well as fuel subsidies from the federal, state, and local governments, are the only sources of finance available to Nigeria's energy sector (Sambo, 2006).

The Nigerian government has been unable to find long-term solutions that will address the problems because of the adoption of hasty, short-term policies and ongoing energy projects that are harmful to long-term energy strategies that will help the nation achieve environmentally friendly energy and energy efficiency. For example, the country still uses a range of alternatives that are still constrained by the use of fossil fuels, which are the only source of energy currently utilized to power the nation's economy (Kennedy and Hoyt, 2008).

Study Area

This study focuses on all the seven states of Nigeria's northwest region which are Kebbi, Sokoto, Gusau, Kano, Kaduna, Katsina, and Dutse Figure 1. The zone occupies a land mass of about $214{,}395 Km^2$ and lies between longitude $12° 10'$ North and latitude $6° 15'$ East Northwest Nigeria is the most populated geopolitical zone with 35,786,944 people (Salihu *et al.*, 2018).

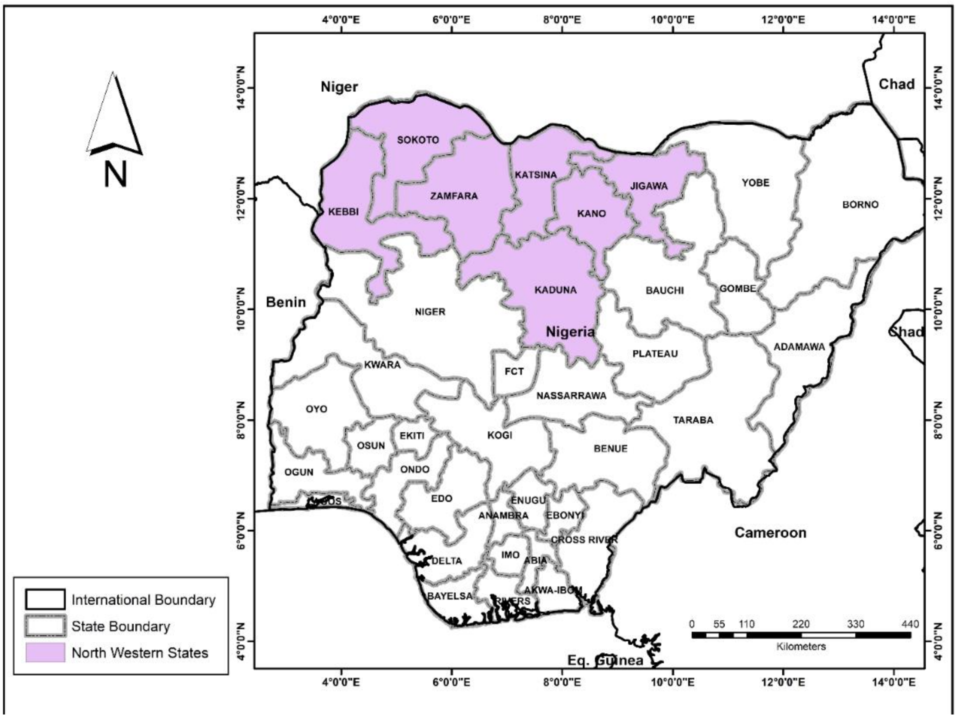

Fig. 1 Map of Nigeria showing the study locations in the Northwestern Zone Wind Power Density and Wind Energy Density

The Weibull two parameter methods were utilized to calculate the mean wind power density as expressed by Kamau *et al.,* (2010):

$$P(v) = \frac{1}{2}\rho c^3 \Gamma\left(1 + \frac{3}{k}\right) \qquad 1.1$$

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:

$$\Gamma(x) = \int_0^\infty t^{x-1} e^{-t} dt \qquad 1.2$$

$$\rho = \rho_o - 1.194 \times 10^{-4} \times H_m \qquad 1.3$$

Where the air density ρ_0 is value at sea level usually taken as $1.225 Kgm^{-3}$ and H_m is the site elevation in meters. The product of the mean power density and the time (T) in hours yields the wind energy density (WED). The daily wind energy density was estimated by multiplying WPD by 24 and the annual wind energy density was estimated by multiplying WPD by 8760 hours. WED is usually expressed in $kWhm^{-2}$ and can be given as:

$$WED = \frac{1}{2}\rho c^3 \Gamma\left(1 + \frac{3}{k}\right) T \qquad 1.4$$

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

$$k = \left(\frac{\sigma}{v_m}\right)^{-1.086} \quad 1.5$$

$$c = \frac{v_m}{\Gamma\left(1+\frac{1}{k}\right)} \quad 1.6$$

$$\sigma = \left[\left[\frac{1}{N-1}\sum_{i=1}^{N}(v_i - v_m)^2\right]\right]^{\frac{1}{2}} \quad 1.7$$

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

Classification of wind power using WPD

A classification of wind power density was developed by the Battelle-Pacific Northwest Laboratory (PNL) as shown in Table 1 below. 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 1. 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

Results and discussion

Wind Speed Variation

Figure 2 shows the monthly mean wind speed values over Gusau, Kaduna, Kano, Katsina, Kebbi, Sokoto and Kebbi. The outcome showed that during the study period, there were monthly variations in the mean wind speed, it is evident that across the majority of Nigeria's northwest, higher wind speeds were observed during the dry season than during the wet one. The Highest value of wind speed was found to be 10.9ms^{-1} in February and the lowest was found to be $1.7\ ms^{-1}$ in October for Gusau, while the monthly mean wind speed was found to be $6.808\ ms^{-1}$. The highest value of wind speed was found to be $6.5\ ms^{-1}$ in the month of February for Dutse and the lowest was found to be $1.7\ ms^{-1}$ in October while the average monthly wind speed was found to be $4.966\ ms^{-1}$. For Kaduna location, the highest wind speed was found to be $10\ ms^{-1}$ in February and the lowest was found to be $2.4\ ms^{-1}$ in October, the monthly mean wind speed was found to be $5.682\ ms^{-1}$ in Kano, the highest wind speed was recorded to be $14.5\ ms^{-1}$ while the lowest was recorded to be $2.0\ ms^{-1}$, of which the average monthly wind speed was found to be $8.216\ ms^{-1}$. Katsina recorded a highest wind speed $12.9\ ms^{-1}$of and the lowest as $2.7\ ms^{-1}$, the monthly mean wind speed was found to be $7.392\ ms^{-1}$. The highest and lowest values of wind speed was recorded as $10.6\ ms^{-1}$ in February and $0\ ms^{-1}$ in August for Kebbi respectively, while the monthly mean wind speed was found to be $4.924\ ms^{-1}$ for Kebbi. In Sokoto, the maximum and minimum wind speed was found to be $13.2\ ms^{-1}$ for the month of April and $0.6\ ms^{-1}$ in January respectively, the monthly mean wind speed was found to be $8.572\ ms^{-1}$.

Figure 3 shows the variation of the annual wind speed over Gusau, Kaduna, Kano, Katsina, Kebbi, Sokoto and Dutse. Over the course of this investigation, it was found that the wind speed value varied from year to year. The highest value of wind speed recorded for Gusau was found to be 7.04 in the 2001 and the lowest wind speed was found to be $4.458\ ms^{-1}$ in the year 2015.

Similarly, the highest record of wind speed obtained for Dutse was found to be $4.0\ ms^{-1}$ in 2019 and the lowest value obtained was $3.2\ ms^{-1}$ in the year 2020. In a similar vein, Kaduna's wind speed record was found to $7.975\ ms^{-1}$ in 2010 and the highest, the lowest values of wind speed recorded for same location was found to be $3.967\ \mathrm{ms}^{-1}$ in the year 2013. In Kano, the highest wind speed ever recorded was $12.292\ \mathrm{ms}^{-1}$ in the year 2014 and the lowest wind speed ever recorded there was $3.608\ \mathrm{ms}^{-1}$in 2004 while in Kebbi, the highest value of wind speed was recorded as $5.825\ \mathrm{ms}^{-1}$ in 2014 and the lowest was found to be $2.333\ \mathrm{ms}^{-1}$ in 2017; this signify high values of wind speed observed in 1996 for Kano and Kebbi. The highest value of wind speed obtained in Katsina was $8.39\ \mathrm{ms}^{-1}$in 1998 and $4.808\ \mathrm{ms}^{-1}$ was the lowest value obtained in the year 2010, respectively. Sokoto experienced the highest value of wind speed as $8.75\ \mathrm{ms}^{-1}$ in 2017 and the lowest as $5.3667\ \mathrm{ms}^{-1}$ in 2014. The annual mean wind speed recorded during the period of this study is 5.56 for Gusau, 3.48 for Dutse, 5.202 for Kaduna, 6.95 for Kano, 6.23 for Katsina, 4.01 for Kebbi, and $7.1\ \mathrm{ms}^{-1}$ for Sokoto.

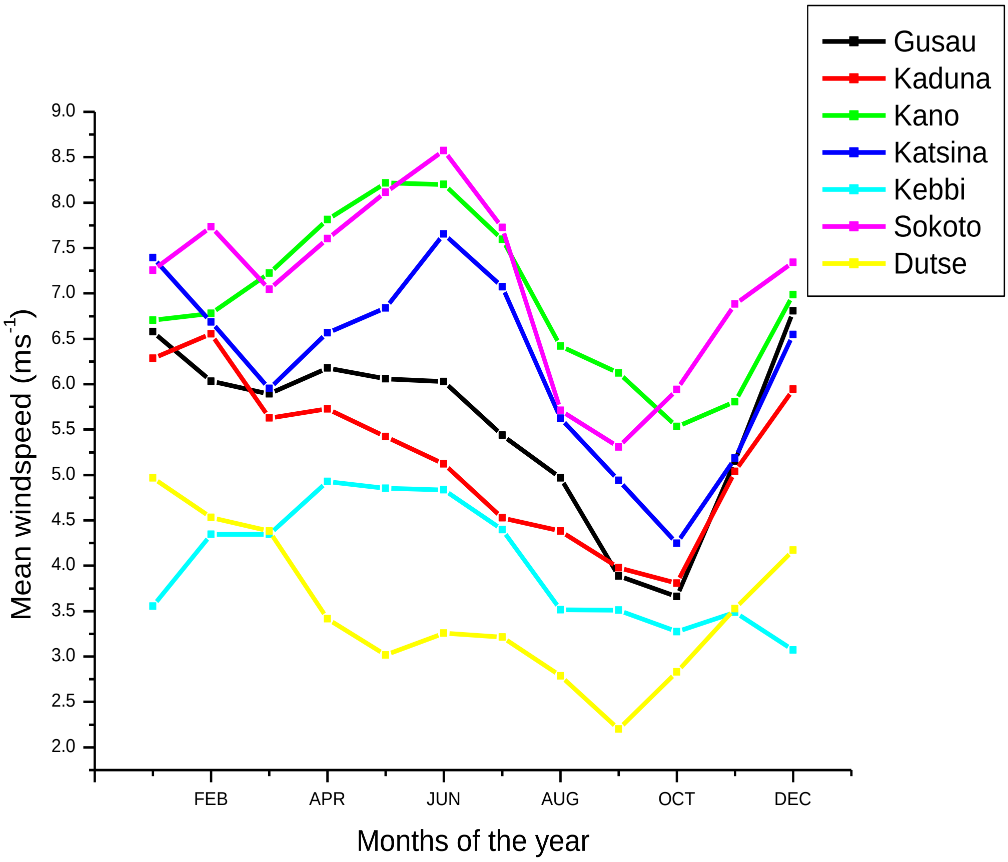

Figure 2. Monthly wind speed of Gusau, Kaduna, Kano, Katsina, Kebbi, Sokoto and Dutse

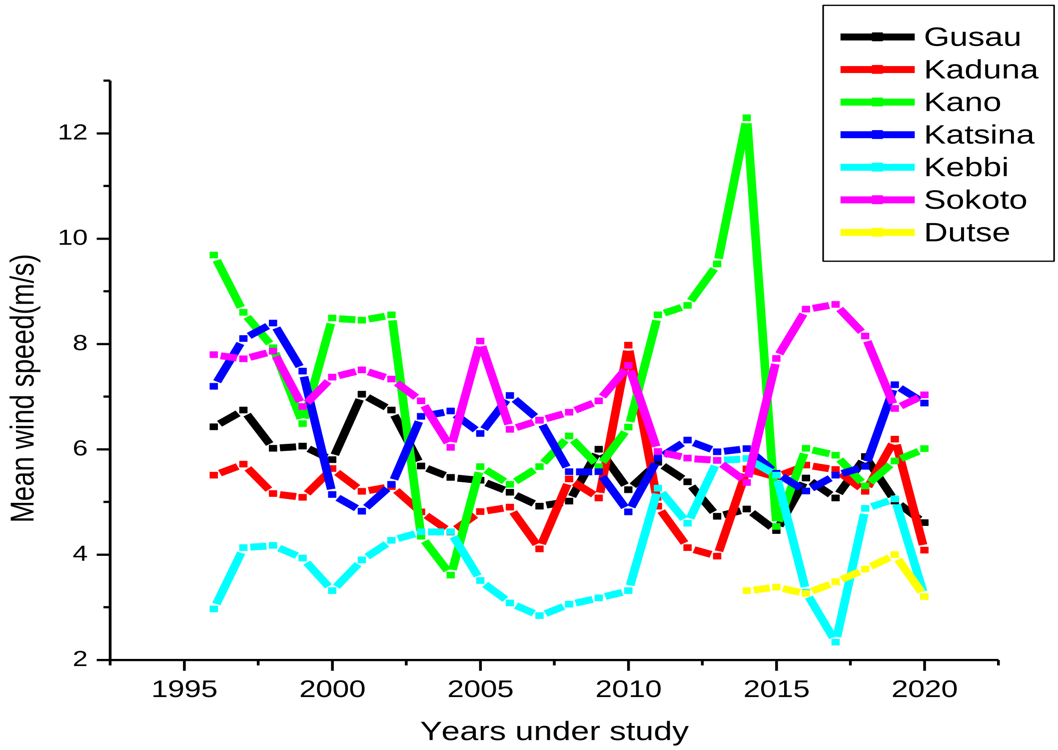

Figure 3. Annual mean Wind Speed over Gusau, Kaduna, Kano, Katsina, Kebbi, Sokoto and Dutse

Wind energy potential

Figure 4 shows that the highest wind power density for Gusau $180.07\ \mathrm{Wm^{-2}}$ in January and the lowest is $30.64\ \mathrm{Wm^{-2}}$ in December. For Kaduna, the highest wind power density is $198.49\ \mathrm{Wm^{-2}}$in February and the lowest is $41.03\ \mathrm{Wm^{-2}}$ October. In Kano, the highest wind power density is $443.04\ \mathrm{Wm^{-2}}$ in June and the lowest wind power density is $112.55\ \mathrm{Wm^{-2}}$ October, respectively. As for Katsina, the highest was found to be 297.65 $\mathrm{Wm^{-2}}$ in June while the lowest was $53.35\ \mathrm{Wm^{-2}}$ in October; by implication, Kano and Katsina measured highest and lowest wind power densities in the months of June and October, respectively. In Kebbi, the highest wind power density was found to be $86.52\ \mathrm{Wm^{-2}}$ in February and the lowest was found to be $31.33\ \mathrm{Wm^{-2}}$ in December. In Sokoto, the highest wind power density was found to be 340.67 in May and the lowest was found to be $9.28\ \mathrm{Wm^{-2}}$ September. While in Dutse, the highest wind power density is 77.69 $\mathrm{Wm^{-2}}$ in January and the lowest wind power density was found to be 6.54 $\mathrm{Wm^{-2}}$ October.

Figure 5 displays Gusau's annual wind power density over the time under investigation. The result shows that the highest annual wind power potential in February with its peak value found as $757.34\ \mathrm{Wm^{-2}}$, an annual wind energy density (WED) is obtained to be$2.608\ \mathrm{kWhm^{-2}}day^{-1}$ (Table 2). When a wind power project is evaluated or constructed to create maximum power, it is crucial to distinguish between the different months and seasons of the year under consideration (Nze-Esiaga and Okogbue, 2014). This is demonstrated by the considerable monthly fluctuation in wind power density reported by Keyhani *et al.*, (2010). Figure 6 displays Kaduna's annual wind power density over the time under investigation. The result shows that the highest annual wind power potential was found in February 2005 as $573.97\ \mathrm{Wm^{-2}}$, an annual WED was recorded to be $2.093\ \mathrm{kWhm^{-2}}day^{-1}$ (Table 3) Figure 7 display Kano's wind power density during the investigation period. The result shows that the highest annual wind power potential was found in February 2014 as $1781.29\ \mathrm{Wm^{-2}}$, an annual WED is obtained as $4.921\ \mathrm{kWhm^{-2}}day^{-1}$ (Table 4).

Figure 8 displays the annual wind power density for Katsina during the investigation period. The result shows that the highest annual wind power potential was found in January 1998 as 1248.513 Wm^{-2}, an annual WED is estimated as 3.623 $kWhm^{-2}day^{-1}$ (Table 5). Figure 9 depict the annual wind power density for Kebbi during the investigation period. The result shows that the highest annual wind power potential was found in February 2014 as 712.148 Wm^{-2}, annual WED is estimated as 0.998 $kWhm^{-2}day^{-1}$ (Table 6). Figure 10 shows the annual wind power density for Sokoto during the investigation period. The result shows that the highest annual wind power potential was found in April 2013 as 1360.563 Wm^{-2}, 5.354 $kWhm^{-2}day^{-1}$ is estimated as the annual WED in this location (Table 7). Figure 11 display the annual wind power density for Dutse during the investigation period. The result shows that the highest annual wind power potential was found in February 2017 and March 2018 as 161.136 Wm^{-2}, an annual WED of 0.712 $kWhm^{-2}day^{-1}$ is obtained in this location (Table).

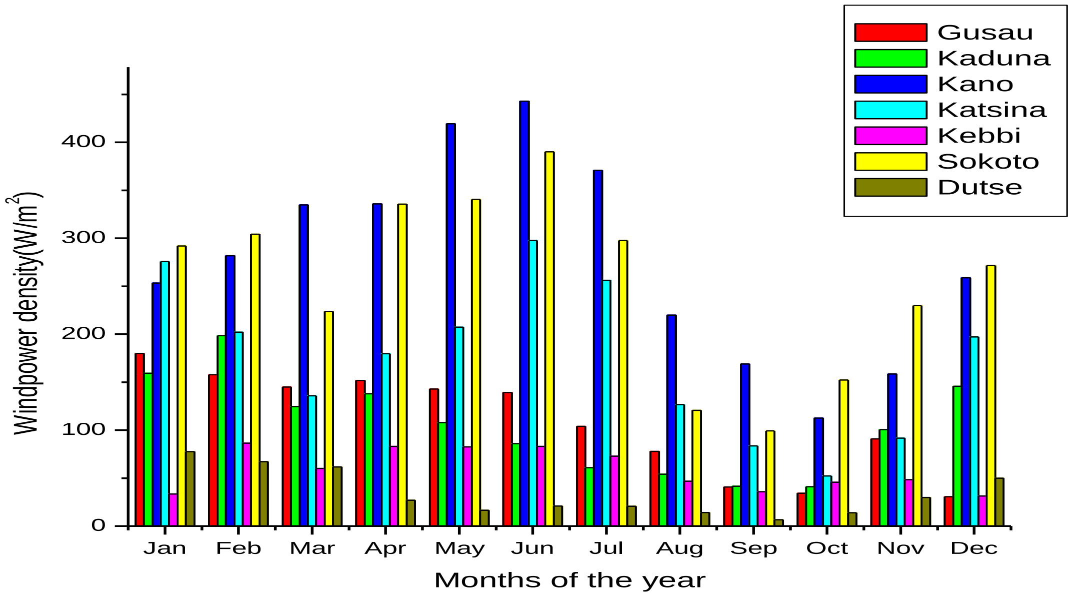

Figure 4. Monthly wind Power for locations under study

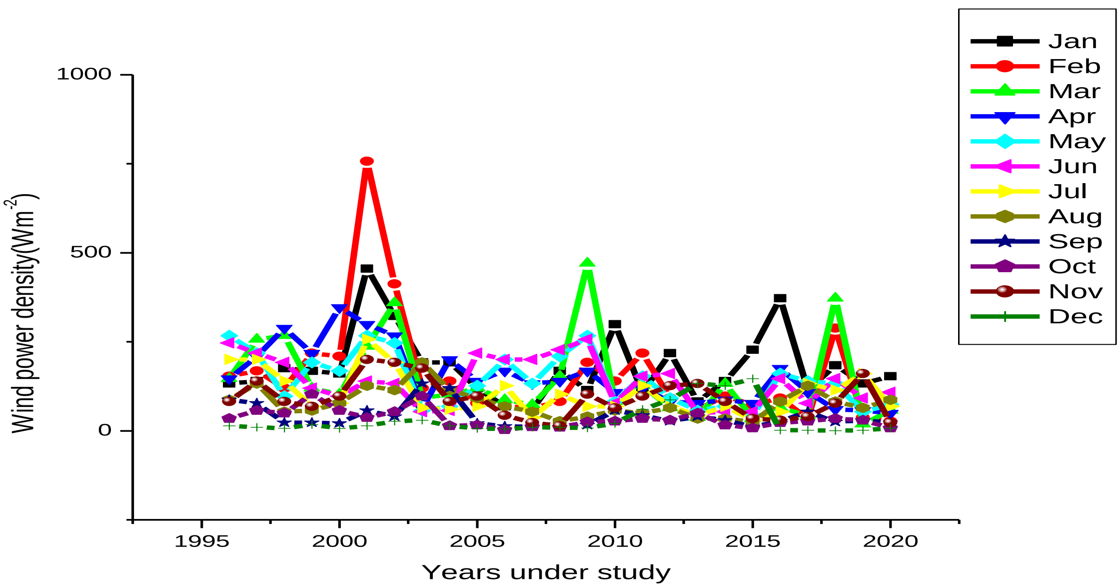

Figure 5. Annual wind Power density for Gusau

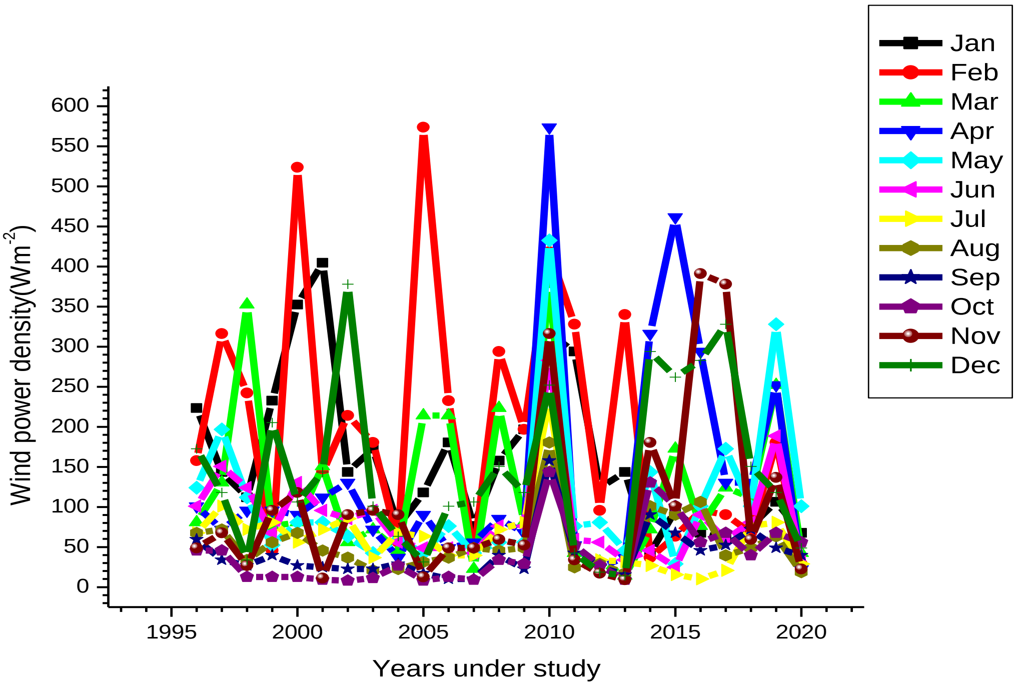

Figure 6. Annual wind Power density for Kaduna

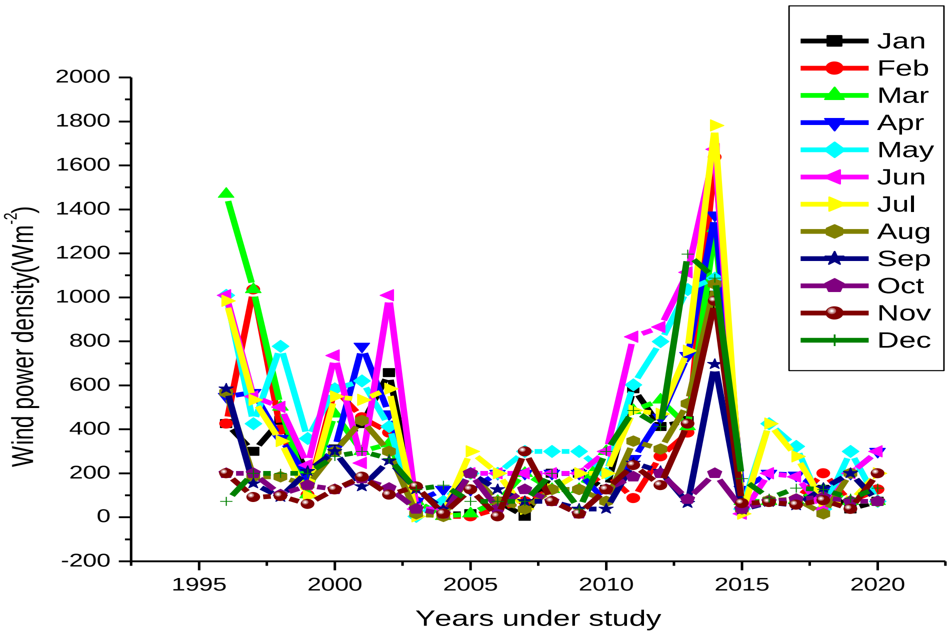

Figure 7. Annual wind Power density for Kano

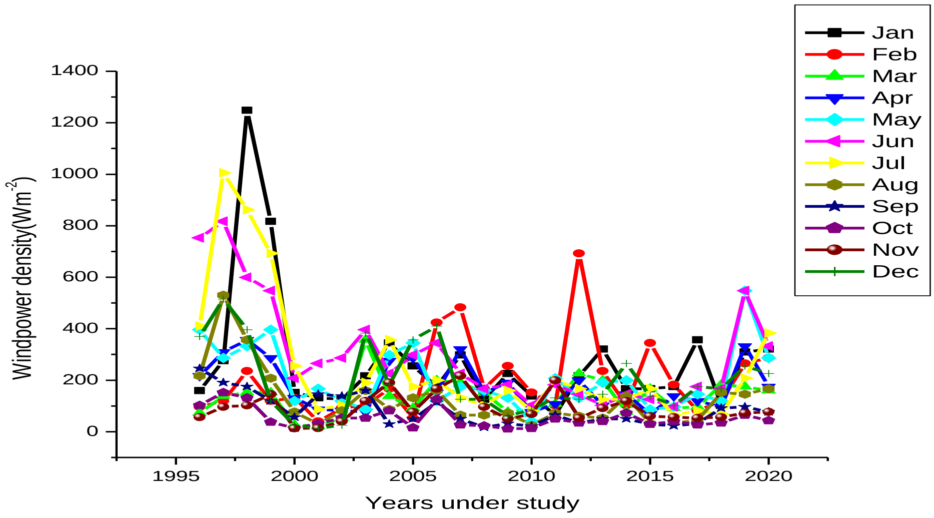

Figure 8. Annual wind Power density for Katsina

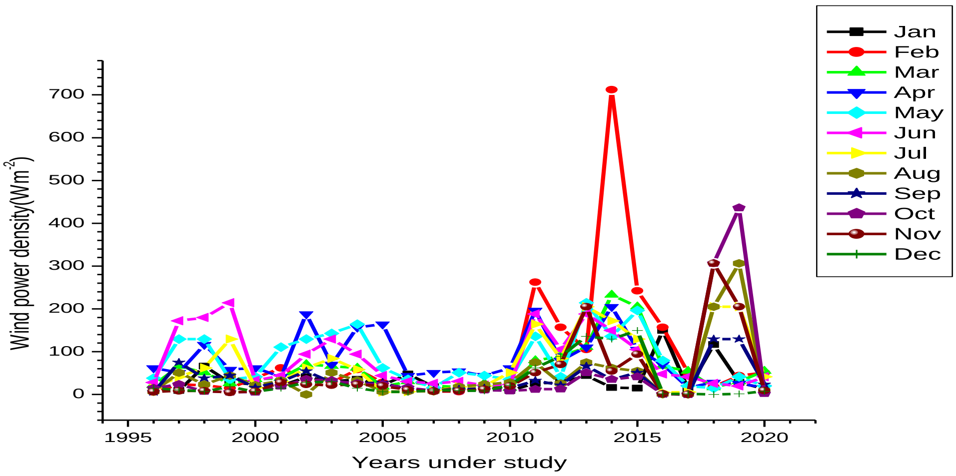

Figure 9. Annual wind Power density for Kebbi

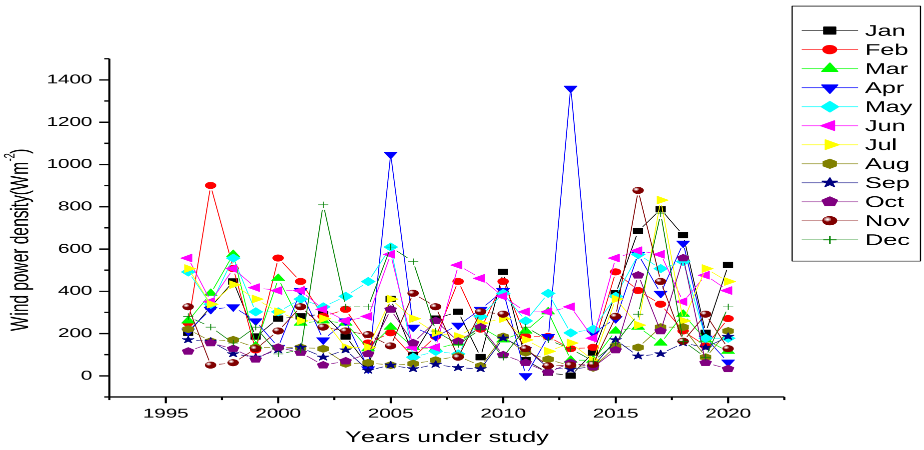

Figure 10. Annual wind Power density for Sokoto

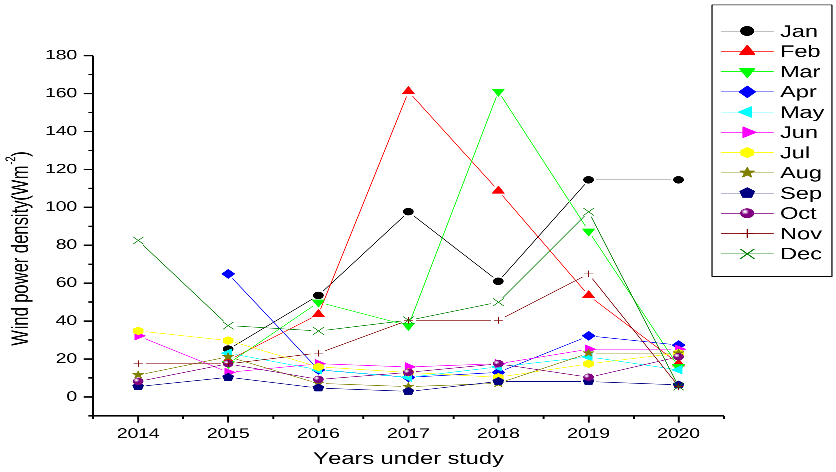

Figure 11. Annual wind Power density for Dutse

Table 2. Wind speed and other parameters in Gusau

Period	V_m (ms^{-1})	k	c (ms^{-1})	WPD (Wm^{-2})	WED (kWh/m²/d)
JAN	6.58	7.24	7.00	166.61	3.999
FEB	6.032	4.25	6.64	128.35	3.080
MAR	5.892	4.30	6.48	119.62	2.871
APR	6.18	6.42	6.63	138.03	3.313
MAY	6.06	6.39	6.50	130.15	3.123
JUN	6.028	6.83	6.44	128.09	3.074
JUL	5.44	6.26	5.84	94.15	2.260
AUG	4.968	6.98	5.30	71.71	1.721
SEP	3.888	4.66	4.26	34.37	0.825
OCT	3.66	4.43	4.02	28.67	0.688
NOV	5.148	5.27	5.59	79.79	1.915
DEC	6.808	2.18	3.47	184.53	4.429
Average	**5.557**	**5.43**	**5.68**	**106.67**	**2.608**

Table 3. Wind speed and other parameters in Kaduna

Period	V_m (ms^{-1})	k	c (ms^{-1})	WPD (Wm^{-2})	WED (kWh/m²/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	**5.417**	**5.41**	**5.64**	**87.20**	**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	**6.950**	**7.69**	**7.36**	**205.04**	**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	**6.23**	**5.12**	**6.78**	**150.94**	**3.623**

Table 6. Wind speed and other parameters in Kebbi

Period	V_m (ms^{-1})	k	c (ms^{-1})	WPD (Wm^{-2})	WED ($kWh/m^2/d$)
JAN	3.56	4.21	3.92	26.89	0.645
FEB	4.35	2.34	4.91	49.15	1.180
MAR	4.35	4.30	4.78	49.15	1.180
APR	4.93	4.93	5.38	71.56	1.717
MAY	4.85	4.30	5.34	68.30	1.639
JUN	4.84	4.14	5.33	67.63	1.623
JUL	4.40	2.88	4.94	50.80	1.219
AUG	3.52	2.38	3.97	25.99	0.624
SEP	3.51	3.01	3.94	25.90	0.622
OCT	3.27	1.94	3.69	20.95	0.503
NOV	3.49	2.10	3.94	25.37	0.609
DEC	3.07	2.43	4.01	17.33	0.416
Average	**4.01**	**3.25**	**4.511**	**41.58**	**0.998**

Table 7. Wind speed and other parameters in Sokoto

Period	V_m (ms^{-1})	k	c (ms^{-1})	WPD (Wm^{-2})	WED (kWh/m^2/d)
JAN	7.256	8.05	7.66	225.99	5.424
FEB	7.732	8.63	8.12	273.45	6.563
MAR	7.044	7.80	7.45	206.75	4.962
APR	7.604	8.47	8.00	260.09	6.242
MAY	8.112	9.09	8.49	315.78	7.579
JUN	8.572	9.65	8.94	372.60	8.942
JUL	7.724	8.62	8.12	272.60	6.542
AUG	5.712	6.21	6.14	110.25	2.646
SEP	5.308	5.73	5.73	88.47	2.123
OCT	5.94	6.48	6.36	123.98	2.976
NOV	6.884	7.60	7.30	192.98	4.632
DEC	7.34	8.15	7.74	233.93	5.614
Average	**7.10**	**7.87**	**7.50**	**223.07**	**5.354**

Table 8. Wind speed and other parameters in Dutse

Period	V_m (ms^{-1})	k	c (ms^{-1})	WPD (Wm^{-2})	WED (kWh/m^2/d)
JAN	4.97	7.00	5.29	71.89	1.725
FEB	4.53	6.34	4.86	54.66	1.312
MAR	4.38	6.11	4.71	49.42	1.186
APR	3.42	4.66	3.74	23.40	0.562
MAY	3.02	4.66	3.74	16.11	0.387
JUN	3.26	11.97	3.30	20.28	0.487
JUL	3.21	8.69	3.38	19.49	0.468
AUG	2.79	6.06	3.00	12.68	0.304
SEP	2.20	9.46	2.30	6.25	0.150
OCT	2.83	10.68	2.93	13.28	0.319
NOV	3.53	4.89	3.85	25.78	0.619
DEC	4.17	4.62	4.57	42.59	1.022
Average	**3.53**	**7.10**	**3.81**	**29.65**	**0.712**

Conclusion

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 are 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 states. This evaluation of wind energy potential in the chosen locations in Nigeria's northwest shows that:

The highest mean wind speed and the lowest were recorded in Sokoto and Kebbi as 8.572 and 4.924 ms^{-1} respectively, while the minimum annual wind speed of 3.48 ms^{-1} is obtained in Dutse, and the maximum annual wind speed value is recorded as 7.102 ms^{-1} in Sokoto. The annual values of wind power density for the seven 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 7.69 Wm^{-2} with 0.712 kWhm^{-2}day^{-1} in Dutse. The Weibull shape parameters, k ranges within 1.938 and 9.648 in Kebbi and Kano respectively, while the scale parameter c, ranges within 2.296 to 9.194 ms^{-1} in Dutse and Kano respectively. From the finding of this research, Gusau and Kano are ideal for small scale wind power generation, while Katsina, Kano and Sokoto are suitable for large scale wind power generation. However, Dutse and Kebbi will not be viable due to their low wind potential.

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