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Wind resources in North-East geopolitical zone, Nigeria: An assessment of the monthly and seasonal characteristics

Olayinka S. Ohunakin

Mechanical Engineering Department, Covenant University, P.M.B. 1023, Ota, Ogun State, Nigeria

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ABSTRACT

This paper evaluates wind speed data of 37 years, 1971–2007 periods measured at 10 m height for five meteorological stations in North-East geo-political zone, Nigeria, namely Bauchi, Nguru, Maiduguri, Yola and Potiskum that have been analyzed statistically to examine the monthly and seasonal variation of the wind characteristics. Wind data at 50 m hub height were obtained by extrapolating the 10 m data using the power law. The results proved Bauchi and Maiduguri to be the best sites among the five locations with monthly mean wind speeds ranging from 3.96 to 7.04 m/s and 4.49 to 6.10 m/s respectively while monthly average power density varies between 61.33–299.88 W/m^2 and 63.80–173.70 W/m^2 in that order, followed by Potiskum recording monthly mean wind speed ranging from 3.92 to 5.68 m/s coupled with an average power density between 53.82 and 150.84 W/m^2 in April and June. A Weibull distribution also gave a better fit than actual data while further investigations revealed higher wind speeds in the morning hours for Nguru, Maiduguri and Potiskum together with equal monthly periods of rainy and wet seasons whereas Bauchi and Yola are windier in the afternoon than morning periods with almost comparable months of rainy and dry seasons. Furthermore, wind availability shows that Maiduguri has wind speed above 4 m/s, 100% of the time in the two seasons while Bauchi, Nguru, Potiskum and Yola have approximately 80 and 100%, 50 and 50%, 75 and 75%, 50 and 50% periods of wind availability above 4 m/s in the dry and rainy seasons respectively.

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1. Introduction

Renewable energy has an increasing role in achieving the goals of sustainable development, energy security and environmental protection [1]. According to Ohunakin [2], renewable energy reserves (solar, wind, hydro, biomass, etc.) are abundant in Nigeria and are sourced from non-fossil and non-nuclear sources in ways that can be replenished while its harvesting, conversion and use occur in a way that avoids negative impact on the viability and rights of local communities and natural ecosystems. Moreover, renewable energy sources constitute about 90% of the energy used by the rural population and since rural loads are characterized by low load factors that have negative impact on plant operating costs thereby making it less cost effective to supply from the grid, renewable energy sources have become the best alternative in spite of the high installation costs [2,3]. However, because of the high costs associated with the energy conversion technologies of the various

E-mail addresses: ohunakin@covenantuniversity.com, ohunakin@yahoo.com

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renewable energy sources, their use is yet to be fully exploited; the low level of socio-economic development reached through over reliance on fossil fuels, has led to increased awareness on the need to consider renewable energy sources in Nigeria [2].

Wind is a natural phenomenon related to the movement of air masses and caused primarily by the differential solar heating of the earth surface which has stood out as a valuable alternative energy source because it is cheap, environmentally friendly, inexhaustible, price stable and readily available in every part of the nation in some amount; its energy conversion system is also available in a wide range of sizes and can fit almost any application where power is needed [3,4]. Wind represents a promising renewable energy source which is able to meet energy demand in the direct, grid connected modes, as well in standalone and remote applications, while its exploitation has witnessed rapid growth in the past two decades resulting in a mature, reliable and efficient technology for electricity production [1]. It was shown in Awogbemi and Ojo [3], that in areas with annual mean wind speed of 3.5–4.0 m/s or greater, wind power systems can usually generate electricity or pump water at costs lower than photovoltaic, diesel or grid extension. However, according to the Battelle-Pacific Northwest Laboratory (PNL), wind power density is numerically classified: Class 4 or greater are considered suitable for most wind turbine applications, Class 3 areas are suitable for wind energy development using taller wind turbine towers, Class 2 zones are considered marginal for wind power development while Class 1 regions are unsuitable [1].

This paper aims at investigating the wind characteristics of North-East (NE) geo-political zone, Nigeria considering long range wind data from five meteorological stations spread across the region (Fig. 1). According to Ouammi et al. [1], accuracy of the analyzed wind resources data is essential because the choice of a wind exploitation site is based on the preliminary investigation of the average wind velocity and potential.

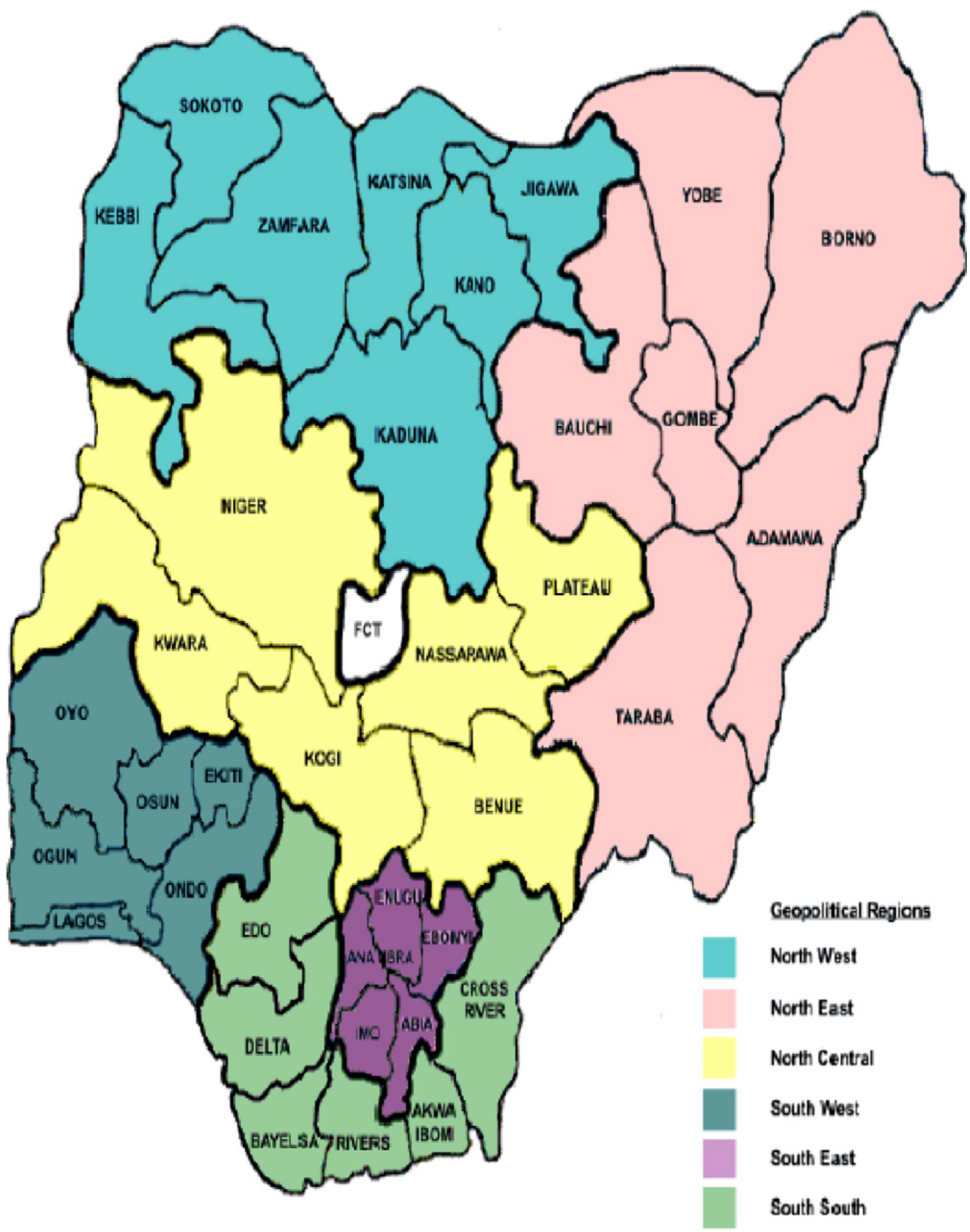

Fig. 1. Map of Nigeria showing the six geo-political zones.

Table 1
Geographical coordinates of North-East region.

Station	Latitude °N	Longitude °E	Elevation (m)
Bauchi	10.17	09.49	609.7
Nguru	12.53	10.28	343.1
Maiduguri	11.51	13.05	353.8
Potiskum	11.42	11.02	186.1
Yola	09.14	12.28	414.8

2. Methodology and materials

2.1. Site description and wind data used in the study

The wind data used in this study were obtained from the Nigerian Meteorological Agency (NIMET), Oshodi, Lagos. The geographical coordinates of the meteorological stations are given in Table 1. A 37-year (1971–2007) monthly wind data together with a synoptical data captured at two respective hours of 9:00 and 15:00 daily were obtained for Bauchi, Nguru, Maiduguri, Potiskum and Yola. The wind speed data were recorded at a height of 10 m by a cup-generator anemometer at the respective stations of NIMET situated at each of the locations considered. The recorded wind speeds were computed as the average of the speed for each month.

2.2. Wind models

In Jowder [5], the probability distribution widely used to describe long-term wind speeds records is a Weibull distribution having probability density function given by:

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

while the corresponding cumulative probability function is given by Jowder [5] as:

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

where $f(v)$ is the probability of observing wind speed (v), k is the dimensionless Weibull shape parameter, c is the Weibull scale parameter (m/s), $F(v)$ is the cumulative probability function of the observing wind speed (v).

The shape factor and scale factor of a Weibull distribution are given as [1]:

$$k = \left(\frac{\sigma}{v_m}\right)^{-1.086} \quad (1 \leq k \leq 10) \quad (3)$$

$$c = \frac{v_m}{\Gamma(1+1/k)} \quad (4)$$

where σ is the standard deviation, v_m is the average wind speed (m/s) and $\Gamma(x)$ is the gamma function of (x)

$$v_m = \frac{1}{n}\sum_{i=1}^{n} v_i \quad (5)$$

$$\sigma^2 = \frac{1}{n-1}\sum_{i=1}^{n}(v_i - v_m)^2 \quad (6)$$

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

k and c are related [1] by:

$$v_m = c\Gamma\left(1 + \frac{1}{k}\right) \quad (8)$$

2.2.1. Extrapolation of wind speed at different hub heights

The wind speed data are captured at height h_0 which is different from hub height. Hence, it is necessary to express wind speed at

Table 2
Monthly variations of wind characteristics for Bauchi location.

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	5.12	1.92	2.90	5.74	116.41	86.61	8.30
February	5.61	2.34	2.59	6.31	164.15	110.31	9.09
March	5.50	2.63	2.23	6.21	173.78	129.29	8.91
April	7.04	2.61	2.94	7.89	299.88	215.92	11.41
May	5.30	1.90	3.05	5.93	125.21	93.16	8.58
June	4.25	1.78	2.57	4.78	71.59	51.55	6.88
July	4.20	1.79	2.53	4.74	70.31	52.31	6.82
August	4.24	1.84	2.47	4.78	73.40	54.61	6.87
September	3.96	1.78	2.38	4.46	61.33	44.16	6.41
October	4.08	2.02	2.15	4.61	73.36	54.58	6.62
November	4.42	2.65	1.74	4.96	116.17	83.65	7.16
December	4.3	2.45	1.84	4.84	100.41	74.71	6.97

Table 3
Monthly variations of wind characteristics for Nguru location.

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	5.04	2.29	2.36	5.70	128.58	95.66	8.19
February	4.99	2.63	2.00	5.63	143.31	96.30	8.08
March	4.54	2.00	2.43	5.12	91.25	67.89	7.36
April	4.14	2.28	1.92	4.67	85.70	61.71	6.71
May	3.95	2.16	1.93	4.45	73.90	54.98	6.40
June	4.07	1.84	2.37	4.60	67.28	48.44	6.60
July	4.32	1.91	2.43	4.88	78.79	58.62	7.01
August	3.53	2.03	1.83	3.97	55.97	41.64	5.72
September	3.18	1.82	1.84	3.58	40.77	29.35	5.16
October	3.51	2.11	1.74	3.93	58.22	43.32	5.68
November	4.29	2.46	1.83	4.83	100.31	72.23	6.95
December	3.86	2.35	1.71	4.32	79.00	58.78	6.25

Table 4
Monthly variations of wind characteristics for Maiduguri location.

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

Table 5
Monthly variations of wind characteristics for Yola location.

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	3.7	1.82	2.16	4.18	54.51	40.56	6.00
February	4.20	2.22	2.00	4.74	85.73	57.61	6.81
March	4.83	2.50	2.05	5.46	127.73	95.03	7.84
April	5	2.04	2.65	5.63	114.50	82.44	8.10
May	4.65	2.02	2.48	5.25	96.84	72.05	7.54
June	4.51	2.07	2.33	5.09	92.15	66.35	7.31
July	4.47	2.32	2.04	5.05	101.64	75.62	7.25
August	4.2	2.42	1.82	4.73	94.55	70.35	6.81
September	3.57	1.80	2.11	4.03	50.06	36.04	5.79
October	3.56	1.81	2.08	4.02	50.33	37.44	5.78
November	3.54	2.04	1.82	3.98	56.61	40.76	5.73
December	3.52	1.74	2.15	3.97	47.03	34.99	5.70

Table 6
Monthly variations of wind characteristics for Potiskum location.

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	4.83	1.97	2.65	5.44	103.39	76.92	7.83
February	5.15	2.19	2.53	5.80	129.34	86.92	8.35
March	5.38	1.92	3.06	6.02	131.14	97.57	8.72
April	5.42	1.63	3.69	6.00	122.33	88.08	8.78
May	5.68	1.83	3.42	6.32	145.76	108.44	9.21
June	5.47	2.25	2.62	6.16	150.84	108.60	8.86
July	5.24	1.95	2.93	5.88	124.08	92.32	8.50
August	4.43	1.74	2.76	4.98	77.48	57.65	7.18
September	3.92	1.55	2.74	4.40	53.82	38.75	6.35
October	3.98	1.56	2.76	4.47	56.23	41.84	6.45
November	4.22	2.05	2.20	4.76	79.53	57.26	6.84
December	3.93	1.89	2.22	4.44	63.70	47.39	6.37

the reference height (h_0) to wind speed at another height (h). The expression usually adopted to describe wind speed variation with different hub heights is the power law given by:

$$\frac{v}{v_0} = \left(\frac{h}{h_0}\right)^n \tag{9}$$

where v is the wind speed at the required height h, is the wind speed at the original height h_0, and n is the surface roughness coefficient which lies in the range 0.05–0.5. A value of 0.3 is used in this paper for extrapolation at various heights.

2.2.2. *Wind power density*

Wind flowing at speed v_m through the blade sweep area has a power that increases as the cube of its velocity and given by [6]:

$$P(v) = \frac{1}{2}\rho A v_m^3 \tag{10}$$

while the power of the wind per unit area is given as [5]:

$$p(v) = \frac{1}{2}\rho v_m^3 \tag{11}$$

Table 7
Whole year wind characteristics for the five sites.

Locations	Average mean speed (m/s)	Average mean power density (W/m^2)	Annual energy (kWh/m^2/year)
Bauchi	4.83	120.50	1050.84
Nguru	4.12	83.59	728.92
Maiduguri	5.31	120.40	1051.83
Yola	4.16	80.97	709.24
Potiskum	4.80	103.14	901.75

The wind power density (wind power per unit area) based on the Weibull probability density function can be calculated as:

$$p(v) = \frac{P(v)}{A} = \frac{1}{2}\rho c^2 \Gamma\left(1 + \frac{3}{k}\right) \quad (12)$$

where $P(v)$ is the wind power (W), $p(v)$ is the wind power density (W/m^2), ρ is the air density at the site (1.21 kg/m^3), A is the sweep area of the rotor blades (m^2)

2.2.3. Estimation of wind energy

The extractible mean daily and monthly energy, together with the annual energy are defined by the relationships (13)–(15) respectively [7].

$$\overline{E_j} = 24 \times 10^{-3}\overline{P_T} \quad (\mathrm{kWh/m^2}) \quad (13)$$

$$\overline{E_j} = 24 \times 10^{-3} d\overline{P_T} \quad (\mathrm{kWh/m^2}) \quad (14)$$

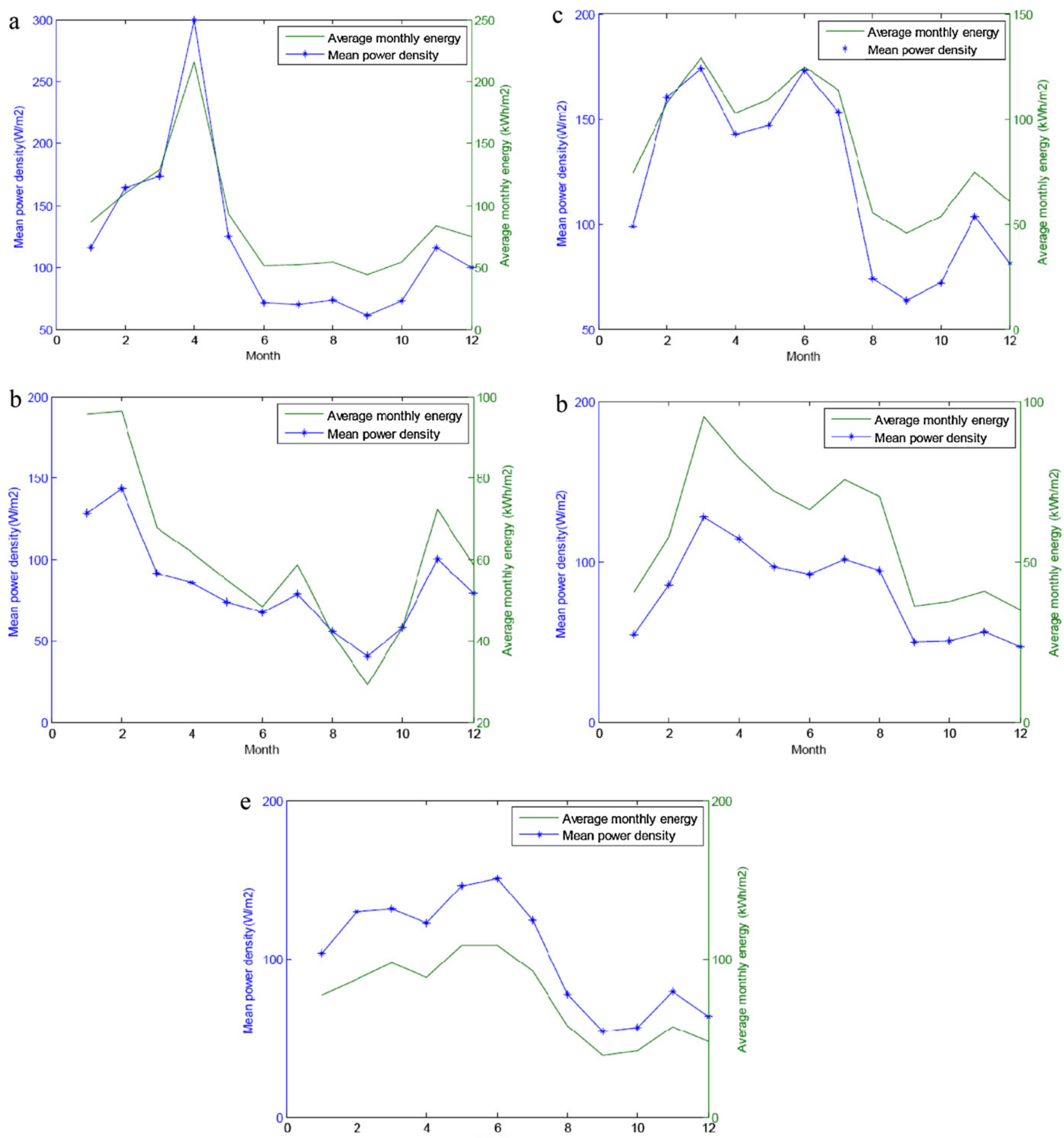

Fig. 2. Monthly variation of mean wind power density and average energy for (a) Bauchi, (b) Nguru, (c) Maiduguri, (d) Yola and (e) Potiskum.

$$\overline{E_a} = \sum_{n=1}^{12} \overline{E_j} \quad (\text{kWh/m}^2/\text{year}) \tag{15}$$

where $\overline{P_T}$ is mean wind power in (W/m^2) and d is the number of days in the month considered.

3. Results and discussion

The Weibull parameters in terms of c and k, mean power density, mean wind speed and wind energy were estimated using the combination of Microsoft Excel (2007) and self developed Matlab programme using Mathwork-Matlab 7.6.0 (R2008a).

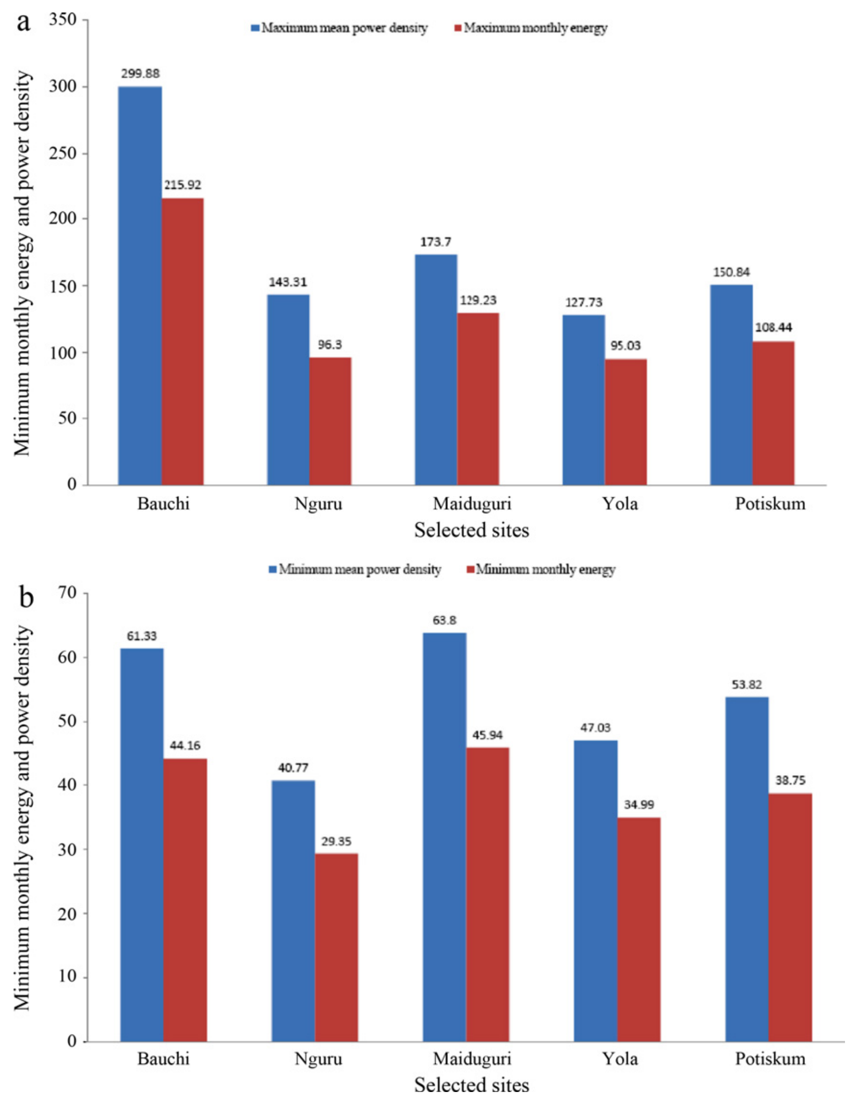

Fig. 3. Comparison of (a) maximum and (b) minimum mean wind power density with energy recorded in each location at 10 m height.

Table 8
Seasonal variation of wind characteristics for the five locations.

Season	Mean wind speed (10 m)	k	c (m/s)	Average power density (W/m^2)	Mean wind speed (50 m)
Bauchi					
Rainy season	4.39	2.6	4.94	80.37	7.11
Dry season	5.16	2.34	5.79	149.17	8.36
Nguru					
Rainy season	3.78	2.12	4.26	60.71	6.13
Dry season	4.29	1.99	4.83	95.03	6.96
Maiduguri					
Rainy season	5.21	3.82	5.77	116.18	8.44
Dry season	5.36	3.69	5.94	122.52	8.69
Yola					
Rainy season	4.16	2.14	4.70	80.93	6.75
Dry season	4.14	2.14	4.66	81.02	6.70
Potiskum					
Rainy season	4.77	2.76	5.36	101.56	7.73
Dry season	4.84	2.82	5.41	103.93	7.82

3.1. Wind speed analysis

The monthly and seasonal variations were taken into consideration in analyzing the wind speed data of five locations in the North-East geo-political zone of Nigeria. Tables 2–6 show the monthly variations of the Weibull (k and c) parameters and the mean monthly wind speed at 10 and 50 m height above ground level.

In Table 2, it can be observed that Bauchi has minimum and maximum values of monthly wind speeds 3.96 and 7.04 m/s in September and April respectively at 10 m height; the monthly values range from 6.41 to 11.41 m/s, same months at 50 m hub height. However, the Weibull shape parameter k varies from 1.74 to 3.05 while the scale parameter c is between 4.46 and 7.89 m/s.

In Nguru (Table 3), the maximum monthly wind speed at 10 m occurs in the month of January with a value of 5.04 m/s while the minimum speed is 3.18 m/s in September. At 50 m hub height, the values range from 5.16 to 8.19 m/s same months for the minimum and maximum wind speeds respectively.

The Weibull shape parameter k varies from 1.71 to 2.43 while the scale parameter c ranged between 3.58 and 5.70 m/s in September and January.

Table 4 depicts the wind characteristics for Maiduguri. Wind results reveal that at 10 m height, the approximate maximum

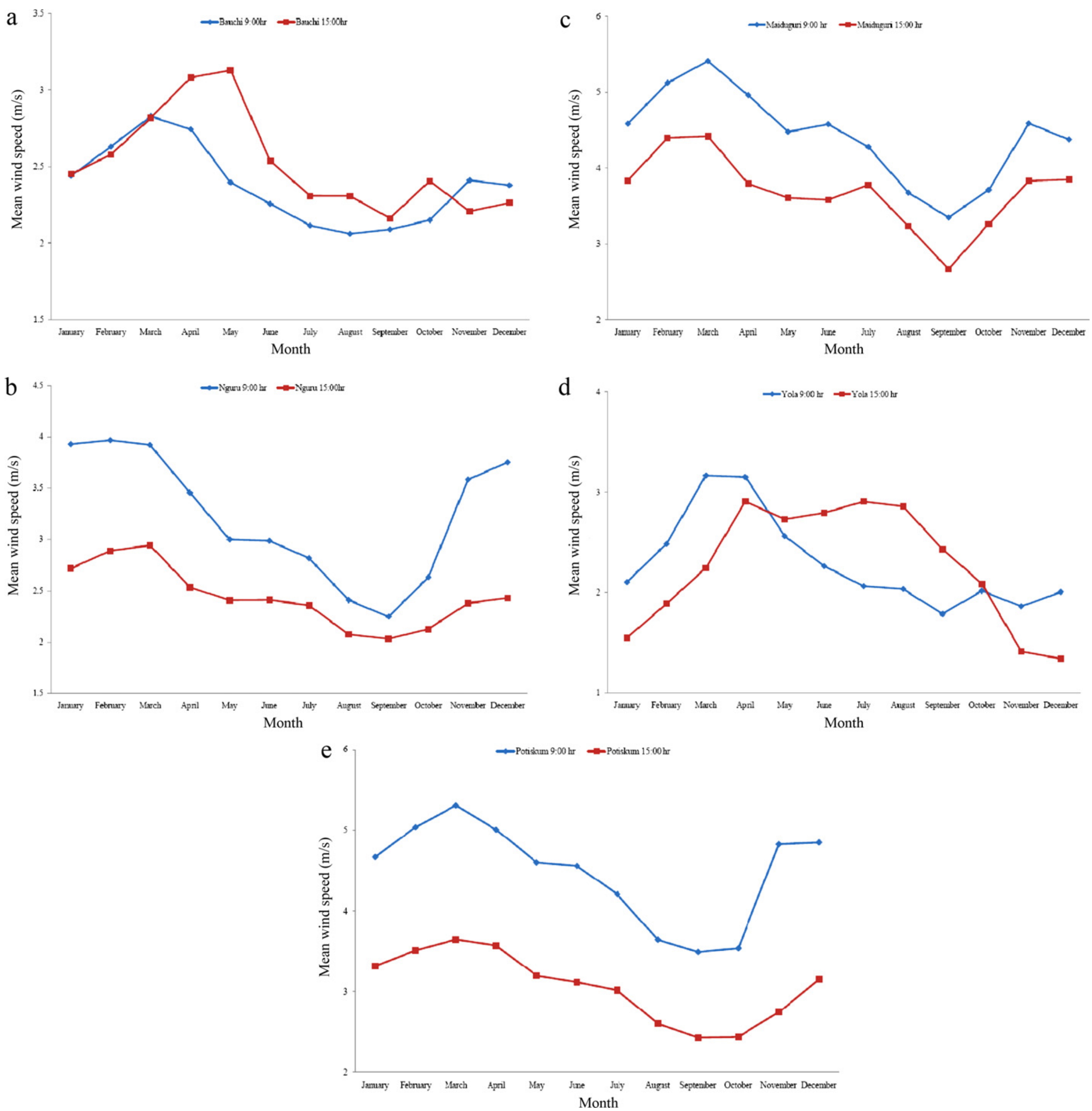

Fig. 4. Monthly mean wind speed captured at two synoptical hours of 9:00 and 15:00 for (a) Bauchi, (b) Nguru, (c) Maiduguri, (d) Yola and (e) Potiskum for the period 1971–2007.

monthly wind speed is 6.10 m/s in March and a value of 4.49 m/s in September as the minimum.

The values range between 7.27 and 9.89 m/s for the minimum and maximum monthly values for the same month at 50 m hub height. The Weibull shape parameter k is between 3.03 and 4.79 while the scale parameter c ranges from 4.90 to 6.76 m/s in September and March.

Wind characteristics in Yola (Table 5), showed an approximate monthly mean wind speed ranging from 3.52 to 5.00 m/s in December and April at 10 m while the mean wind speed range is between 5.70 and 8.10 m/s at 50 m height above ground level.

The Weibull shape parameter is between 1.82 and 2.65 while scale parameter c varies from 3.97 to 5.63 m/s for the months of December and April respectively.

In Potiskum, the approximate monthly minimum and maximum mean wind speed values vary from 3.92 m/s in September to 5.68 m/s in May at 10 m height while at 50 m hub height, the values range between 6.35 and 9.21 m/s same months; the Weibull shape parameter k is between 2.20 and 3.69 while the scale param-

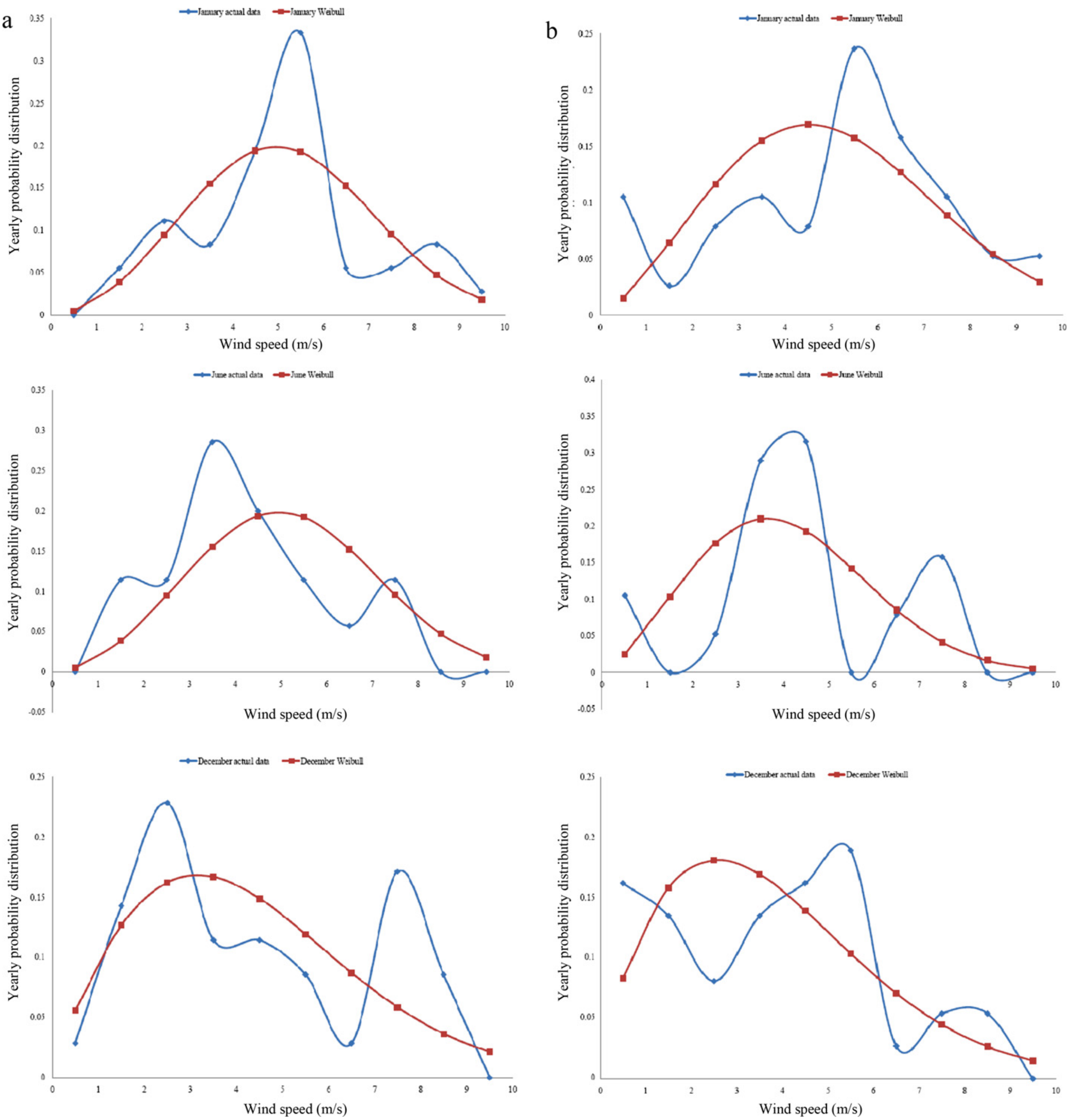

Fig. 5. Weibull approximations of the actual probability distribution of wind speeds for (a) Bauchi, (b) Nguru, (c) Potiskum, (d) Maiduguri and (e) Yola.

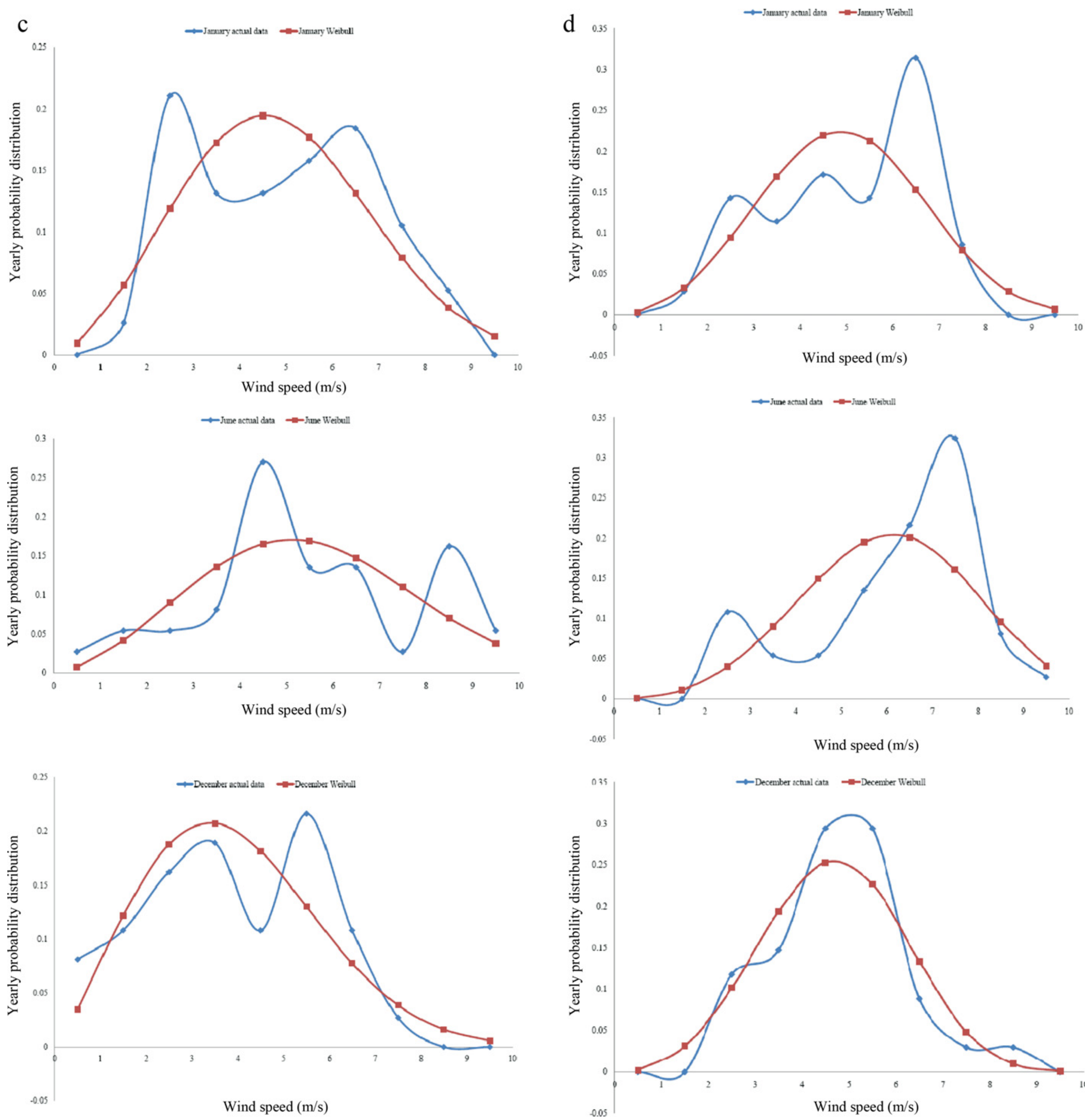

Fig. 5. (*Continued*)

eter *c* ranges from 4.40 in September to 6.32 in May. This is shown in Table 6.

In other words, the maximum monthly wind speed is having the highest value of 7.04 m/s in April at Bauchi and a minimum value of 3.18 m/s in September at Nguru. On the overall, the Weibull *k* parameter ranged 1.71 in Nguru as the minimum in December to 4.79 in September as the maximum in Maiduguri while the scale parameter *c* ranged between 3.58 and 7.89 m/s in September and April respectively, as the minimum in Nguru and maximum value in Bauchi.

The value of the power density is an important parameter that can provide complimentary information regarding the choice of a suitable site as well as an immediate classification of site [1]. The wind power density for the five locations is thus computed and interpreted.

The monthly variation of mean wind power density and average energy is shown in Fig. 2. It was observed that two of the five selected sites (Maiduguri and Yola) displayed similar characteristics with regard to the month of March as having the highest average power density and energy. On the other hand, Bauchi, Nguru, Maiduguri and Potiskum recorded the least power density and energy occurring in September, while Yola has its minimum in December. It can be seen from Fig. 3 that the mean power density has the same rate of variation with the average energy when

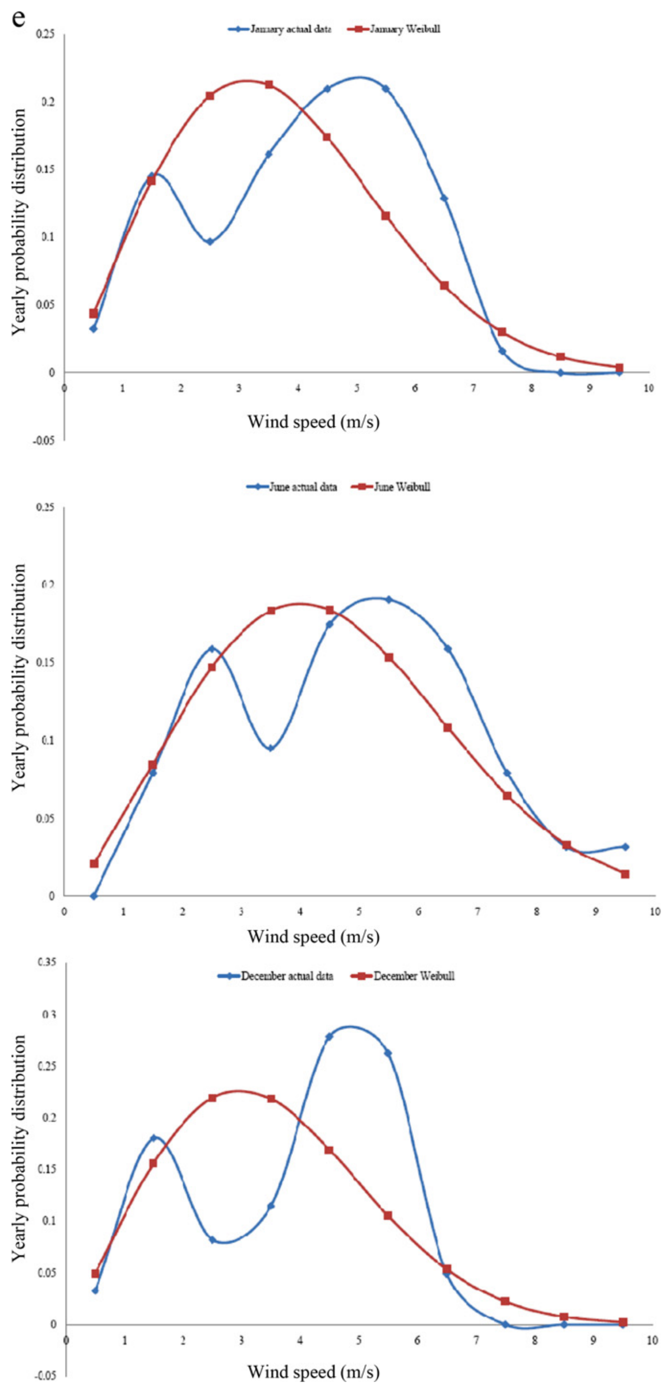

Fig. 5. (*Continued*).

considering the minimum and maximum values of the selected sites at a particular month. From Fig. 3a, Bauchi showed month with the highest power density and energy of 299.88 W/m^2 and 215.92 kWh/m^2 in April, while Nguru in September have the lowest values of 40.77 W/m^2 and 29.35 kWh/m^2 in power density and energy respectively (Fig. 3b).

However, observing Table 7 shows that Maiduguri has the highest wind potential with an average annual wind speed of 5.31 m/s followed by Bauchi and Potiskum with respective mean wind speed of 4.83 and 4.80 m/s and their corresponding mean power density of 120.40, 120.50 and 103.14 W/m^2 with energy 1051.83, 1050.84 and 901.75 kWh/m^2/year in that order for the period of study at 10 m above ground level. Nguru gave the lowest wind characteristics of the five selected locations in the NE geo-political zone as indicated in Table 7. Wind characteristics at 50 m hub height follow similar trend with 10 m as shown in Tables 2–6.

Fig. 4 shows the variation of monthly mean wind speeds of the five sites, taken at two synoptical hours of 9:00 and 15:00 for the whole year under study. It can be observed from trend of the plot that the mornings recorded higher wind speed than afternoon periods in Potiskum, Maiduguri and Nguru; it was also discussed earlier that the three locations have similar periods of dry (October–May) and rainy (June–September) seasons. Furthermore, the graph shows Bauchi and Yola as having windy afternoon periods than morning but with almost equal rainy periods (May–September and May–October) and dry seasons (October–April and November–April) respectively.

Table 8 shows the results obtained for wind characteristics based on the two seasons (rainy and dry) for the sites under consideration. It can be seen that the highest wind speeds, mean power density and average energy for Bauchi, Nguru, Maiduguri and Potiskum lie in the dry season whereas Yola observed a higher wind traits in the rainy period. As depicted in the same table, Maiduguri has the highest seasonal mean wind speed of 5.36 m/s of all the five sites, occurring in the dry season together with a maximum and minimum wind power density of 122.52 and 116.18 W/m^2 respectively. Similar trend follows the values at 50 m height with a maximum (8.69 m/s) and minimum (8.44 m/s) mean wind speeds in the dry and rainy seasons respectively. However, Nguru recorded the least seasonal wind speed and power density of 3.78 m/s and 60.71 W/m^2 in that order, and observed in the rainy season.

The comparison between the actual data and Weibull frequency distributions of wind speed for three selected months used as representative of the rainy and dry seasons in the five locations is shown in Fig. 5.

It can be seen from Fig. 5 that Weibull distributions gave a good fit of the data in all the locations; in Potiskum, Nguru and Maiduguri wind speed extends a wider variation in the rainy season (June) with wind speeds extending beyond 10 m/s, than in the dry season (December and January) where it was less than 10 m/s. Bauchi gave a higher variation in wind speed in December (wind speed extending beyond 10 m/s) than January and June where the possibility of having speeds beyond 10 m/s is not possible. Yola is less windy, the three months selected to represent the dry and rainy season did not show the likelihood of obtaining wind speeds up to 10 m/s. Furthermore, availability of wind speed is computed for the locations. Wind speed is above 4 m/s at approximately 80 and 100%, 50 and 50%, 75 and 75%, 50 and 67% of the time in the dry and rainy periods for Bauchi, Nguru, Potiskum and Yola respectively. However, wind speed is always available above 4 m/s throughout the seasons in Maiduguri allowing wind power plants installed within this range to produce energy 100% of the time in both the dry and rainy seasons.

4. Conclusion

In this study, wind characteristics in five selected locations in NE geo-political region of Nigeria have been evaluated. The following can be drawn from the result of the study:

- The synoptical readings taken at two periods of 9:00 and 15:00 h show higher wind speeds in the morning hours for Nguru, Maiduguri and Potiskum together with equal monthly periods of rainy and wet seasons while Bauchi and Yola are windier in the afternoon than morning periods with almost comparable months of rainy and dry seasons
- The seasonal trend of wind speed shows that the dry periods of the year are windier than the rainy season for Bauchi, Nguru, Maiduguri and Potiskum while Yola has it windy in the rainy season.
- It was observed that mean wind speeds range from 3.96 to 7.04 m/s, 3.18 to 5.04 m/s, 4.49 to 6.10 m/s, 3.52 to 4.83 m/s and 3.93 to 5.68 m/s for Bauchi, Nguru, Maiduguri, Yola and Potiskum respectively.
- The Weibull shape parameter k varies between 1.74 and 3.05, 1.71 and 2.43, 3.03 and 4.79, 1.82 and 2.65, and 2.20 and 3.69 for Bauchi, Nguru, Maiduguri, Yola, and Potiskum respectively while scale parameters c range between 4.46 and 7.89 m/s, 3.58 and 5.70 m/s, 4.90 and 6.76 m/s, 3.97 and 5.63 m/s and 4.40 and 6.32 m/s for Bauchi, Nguru, Maiduguri, Yola and Potiskum in that order.
- The highest extractible annual energy is obtained in Bauchi with 215.92 kWh/m^2/year followed by Maiduguri with 129.23 kWh/m^2/year while Nguru, Yola and Potiskum are having 96.30, 95.03 and 108.44 kWh/m^2/year respectively.
- The power density ranges from 61.33 to 299.88 W/m^2, 40.77 to 143.31 W/m^2, 63.80 to 173.70 W/m^2, 44.03 to 127.73 W/m^2 and 53.82 to 150.84 W/m^2 for Bauchi, Nguru, Maiduguri, Yola and Potiskum respectively.
- Bauchi, Maiduguri and Potiskum fall under Class 2 [8] of the international system of wind classification and as such may be considered marginal for wind power development though higher altitudes will be better preferred for economical wind power generation while Nguru and Yola each placed under Class 1 may only be adequate for non-connected electrical and mechanical applications like battery charging and water pumping.

References

[1] Ouammi A, Dagdougui H, Sacile R, Mimet A. Monthly and seasonal assessment of wind energy characteristics at four monitored locations in Liguria region (Italy). Renewable and Sustainable Energy Reviews 2010;14:1959–68.
[2] Ohunakin OS. Energy utilization and renewable energy sources in Nigeria. Journal of Engineering and Applied Sciences 2010;5:171–7.
[3] Awogbemi O, Ojo AO. Harnessing wind energy to solve Nigeria's energy crises. Journal of Engineering and Applied Sciences 2009;4:197–204.
[4] Akinbami JFK. Renewable energy resources and technologies in Nigeria, present situation, future prospects and policy framework. Mitigation and adaptation strategies for global change, vol. 6. Kluwer Publishers; 2001. p. 155–181.
[5] Jowder FAL. Wind power analysis and site matching of wind turbine generators in kingdom of Bahrain. Applied Energy 2009;86:538–45.
[6] Eskin N, Artar H, Tolun S. Wind energy potential of Gokceada Island in Turkey. Renewable and Sustainable Energy Reviews 2008;12:839–51.
[7] Tchinda R, Kendjio J, Kaptouom E, Njomo D. Estimation of mean wind energy available in far north Cameroon. Energy Conversion & Management 2000;41:1917–29.
[8] American Wind Energy Association (AWEA), Resource. Available from: http://www.awea.org/faq/basicwr.html [accessed 15.08.2010].