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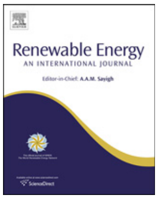

Assessment of wind energy potential of two sites in North-East, Nigeria

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ABSTRACT

The study is used to assess the wind energy potential of Maiduguri and Potiskum, two sites in North-East, Nigeria. 21 years (1987–2007) monthly mean wind data at 10 m height were assessed from the Nigeria Meteorological department and subjected to 2-parameter Weibull and other statistical analyzes. The result showed that average monthly mean wind speed variation for Potiskum ranged from 3.90 to 5.85 m/s, while for Maiduguri, it ranged from 4.35 to 6.33 m/s. Seasonally, data variation between the dry and wet seasons revealed that, the mean wind speed variation for Potiskum ranged from 4.46 (for dry) to 5.16 m/s (for wet), while for Maiduguri it ranged from 5.10 (dry) to 5.59 m/s (wet). The wind power density variation based on the Weibull analysis ranged from 102.54 to 300.15 W/m^2 for Potiskum and it ranged from 114.77 to 360.04 W/m^2 for Maiduguri respectively. Moreover, Maiduguri was found to be the better of the sites in terms of monthly and seasonal variation of mean wind speed, but they both can be suitable for stand alone and medium scale wind power generation.

1. Introduction

The challenge of providing adequate and sufficient amount of energy for the populace is a global issue. The depth of concern may vary from developed to underdeveloped nations but the exercise of providing required energy is a major challenge throughout the world. Therefore, there is a need for concerted efforts to be deployed to seeking ways of adequately meeting the growing energy demand of the global population. The finite nature of the conventional sources of energy has made the sources unsustainable. Moreover, lack of energy in an economy or its inadequacy had been reported to be a source of social and economic poverty [1].

Nigeria is a country whose energy demand exceeds supply from the national utility. Current electricity production within the country is reported to be less than 4000 MW due to fluctuations in the availability and maintenance of production sources. This has culminated into high losses in electricity distribution leading to a shortfall in supply. However, considering the fact that some of the rural areas are not connected to the national grid, suggests a need to develop adequate and sustainable energy system which will be suitable, sustainable, and able to be deployed as stand alone power source [2,3]. One way through this is to develop the available renewable energy resources of which wind energy technology is a major. To begin harvesting wind resources for power production involves therefore, the initial effort of resource assessment to ascertain its potential for power generation. Based on this, the northern part of Nigeria has been identified as a region possessing great potential for wind energy utilization for power generation because of the prevailing wind situation of the place [2]. Therefore, a careful wind resource assessment of this region will be a major leap in the move towards developing sustainable energy and power for the nation. This is the focus of this study. It evaluated and compared the prevailing wind resource potential of two sites, Maiduguri and Potiskum, in North-East Nigeria, as captured by a cup-generator anemometer at 10 m height. The sites, about 142 miles apart, were formerly in old Borno State, but now separated into two different states in August 1991 as a result of the state creation exercise of the federal government. Presently, Maiduguri is the capital city of Borno state while Potiskum is in Yobe state.

2. Materials and methods

Twenty one years (1987–2007) monthly mean wind data for the two sites were assessed from the Nigeria Meteorological department, Oshodi, Lagos State, South-West, Nigeria. Continuous 3 h daily readings over the period considered were used and subjected to various statistical analyses. The data were recorded continuously using cup-generator anemometer at a height of 10 m and presented

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graphically in Figs. 1 and 2. However, Fig. 1 gives the monthly mean wind distribution of the sites across the years considered while Fig. 2 gives the annual contribution of each site's mean wind distribution for each month. The sites' details for the stations considered are as displayed in Table 1 below.

2.1. Mathematical analysis

Various statistical distributions exist for describing and analyzing wind resource data. Some of these include normal and lognormal, Rayleigh and Weibull probability distributions to mention a few [4,5]. However, of the statistical methods, the Weibull distribution has been found to be accurate and adequate in analyzing and interpreting the situation of measured wind speed and in predicting the characteristics of prevailing wind profile over a place [6–8]. Thus, in this study, the Weibull two parameter Probability Density Function (PDF) was employed in carrying out the analyses of wind speed potentials over the sites considered. This is given as [9–13]:

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

Where k is the Weibull shape parameter, c is the scale parameter and $f(v)$ is the probability of observing wind speed v (m/s).

The Weibull Cumulative Density Function (CDF) corresponding to the PDF is given as

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

Where $F(v)$ is the cumulative distribution function of observing wind speed v.

The mean value of the wind speed v_m and standard deviation σ for the Weibull distribution as defined in terms of the Weibull parameter k and c are given as [9,10]:

$$v_m = c\Gamma\left(1+\frac{1}{k}\right) \tag{3}$$

and

$$\sigma = \sqrt{c^2\left\{\Gamma\left(1+\frac{2}{k}\right) - \left[\Gamma\left(1+\frac{1}{k}\right)\right]^2\right\}} \tag{4}$$

Where $\Gamma()$ is the gamma function of $()$.

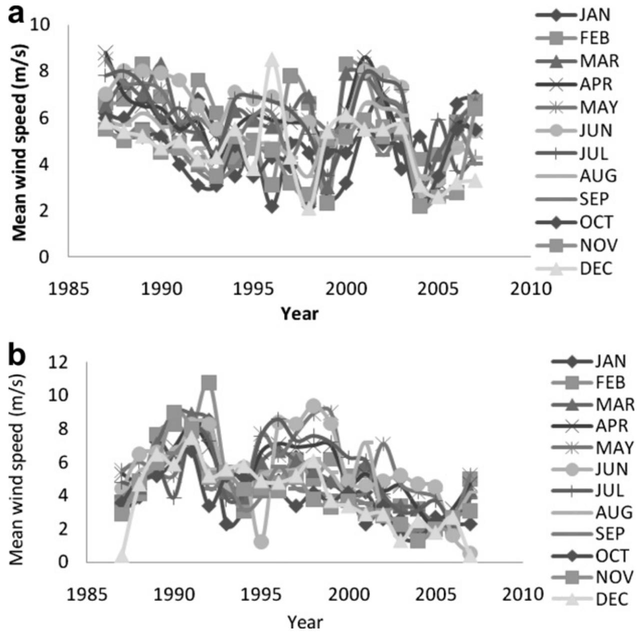

Fig. 1. a) Plot of whole monthly wind speeds for Maiduguri; b) Plot of whole monthly wind speeds for Portiskum.

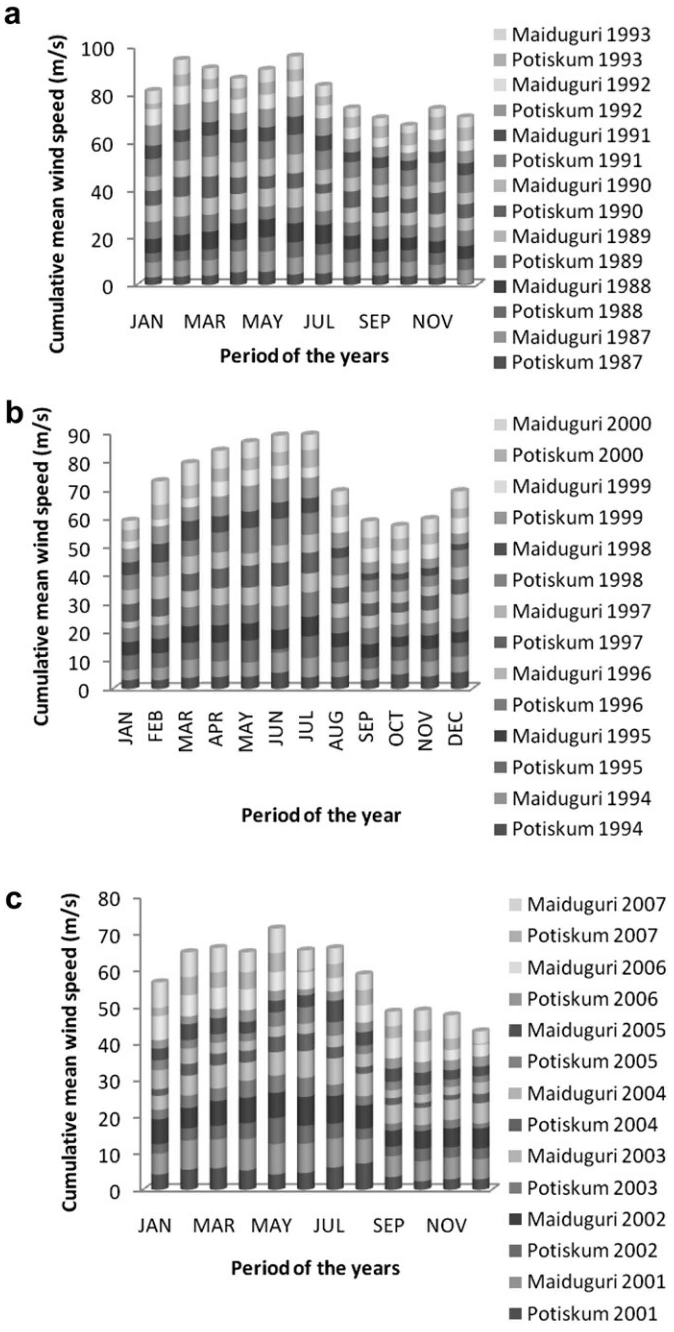

Fig. 2. Plot displaying annual mean wind speed distribution for the two sites combined together.

Table 1
Details of the two stations for which wind data were assessed and analyzed.

Sites	Location	Latitude	Longitude	Air density (kg/m^3)	Elevation (m)
Maiduguri	Borno State	11.51′	13.05′	1.1842	353.8
Potiskum	Yobe State	11.42′	11.02′	1.1771	414.8

Table 2
Some result of Weibull analysis and estimation parameters for the whole 21 years.

Potiskum station							Maiduguri station					
Period	$\sigma_{Actual\ Data}$ (m/s)	k	c (m/s)	R^2	P_{data} (W/m^2)	$\sigma_{Weibull}$ (m/s)	$\sigma_{Actual\ Data}$ (m/s)	k	c (m/s)	R^2	P_{data} (W/m^2)	$\sigma_{Weibull}$ (m/s)
January	1.90	2.48	4.90	0.92	95.78	1.87	1.46	3.37	5.67	0.96	154.02	1.67
February	2.12	2.72	5.77	0.95	159.23	2.04	1.64	3.50	6.63	0.98	248.54	1.89
March	1.93	2.99	5.82	0.96	165.51	1.90	1.41	4.11	6.71	0.94	264.40	1.67
April	1.54	3.46	6.03	0.96	185.85	1.73	1.42	4.04	6.43	0.93	232.19	1.62
May	1.71	3.69	6.48	0.95	235.38	1.76	1.43	4.15	6.61	0.96	255.17	1.63
June	2.41	1.50	6.80	0.86	207.25	4.16	1.50	3.94	7.02	0.95	300.15	1.81
July	1.86	3.06	6.05	0.93	184.38	1.93	1.47	4.12	6.62	0.97	255.78	1.64
August	1.56	2.87	5.37	0.94	125.76	1.81	0.95	5.70	5.36	0.95	145.08	1.01
September	1.37	3.17	4.49	0.97	76.42	1.39	1.03	4.14	4.91	0.95	103.85	1.21
October	1.35	2.87	4.40	0.98	70.08	1.48	1.06	4.02	4.81	0.96	97.31	1.22
November	1.84	2.53	4.70	0.97	85.15	1.76	1.16	3.76	4.97	0.95	106.20	1.33
December	1.98	1.36	4.81	0.90	75.88	3.28	1.40	3.56	5.25	0.96	124.45	1.47
Dry Season	1.94	2.35	5.08	0.97	104.29	2.04	1.53	3.71	5.66	0.98	157.38	1.53
Wet Season	1.87	2.76	5.84	0.98	161.60	2.04	1.47	4.28	6.14	0.99	206.90	1.47
Whole yrs	0.00	2.53	5.46	0.98	130.86	2.05	0.00	3.96	5.90	0.98	181.01	1.51
1987	1.28	1.36	4.84	0.69	61.66	3.30	1.10	6.34	7.16	0.84	350.87	1.23
1988	0.72	7.29	5.25	0.88	141.33	0.80	1.10	5.93	6.94	0.88	316.53	1.26
1989	0.78	8.21	6.55	0.87	279.41	0.90	1.04	6.59	7.06	0.93	340.45	1.17
1990	1.44	4.68	7.30	0.94	351.40	1.63	1.18	5.53	6.64	0.94	274.33	1.28
1991	0.63	12.77	7.99	0.94	535.66	0.73	0.98	5.87	5.75	0.92	179.64	1.05
1992	2.03	3.37	7.59	0.98	371.49	2.23	1.30	4.19	5.79	0.99	172.99	1.41
1993	0.86	4.26	5.17	0.82	119.63	1.24	0.94	4.98	4.84	0.94	104.35	1.02
1994	0.89	4.90	4.63	0.88	90.36	0.99	1.05	5.26	5.70	0.97	172.17	1.15
1995	1.66	2.09	6.24	0.80	170.33	2.78	1.05	5.14	5.72	0.95	172.99	1.17
1996	1.44	4.36	6.55	0.87	249.00	1.55	1.67	3.02	5.93	0.98	172.99	1.91
1997	1.35	4.48	6.62	0.99	259.59	1.53	1.28	4.18	5.60	0.91	156.31	1.37
1998	1.75	3.71	6.76	0.93	267.19	1.83	1.74	2.35	5.11	0.90	104.94	2.05
1999	1.84	3.19	6.29	0.92	208.57	1.94	1.12	3.47	4.81	0.92	94.15	1.38
2000	0.74	6.47	4.78	0.89	104.31	0.80	1.32	4.40	6.30	0.94	224.15	1.48
2001	1.44	3.20	5.09	0.97	110.88	1.57	1.20	5.65	7.54	0.83	400.40	1.43
2002	1.24	3.35	4.16	0.78	60.43	1.23	1.06	6.05	6.72	0.97	289.10	1.20
2003	1.21	2.56	3.44	0.97	33.13	1.28	0.98	6.04	6.13	0.97	219.30	1.10
2004	1.04	2.62	3.06	0.94	23.17	1.11	0.86	3.90	3.39	0.85	34.15	0.88
2005	0.82	3.50	3.02	0.78	23.17	0.86	0.88	4.48	3.99	0.83	56.80	0.92
2006	0.39	6.11	2.74	0.93	19.52	0.49	1.11	4.17	5.43	0.95	141.46	1.33
2007	1.53	1.19	4.15	0.82	43.27	3.31	1.19	4.51	5.98	0.95	192.57	1.37

2.2. *Evaluation of Wind Power Density (WPD)*

The WPD evaluation can be carried out in two forms. One based on available power in the wind as captured by the wind conversion system and estimated directly from the wind speed v (m/s), and the other based on the Weibull two parameter method [14]. These two approaches are given as:

$$p(v) = \frac{1}{2}\rho A v^3 \tag{5}$$

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

Where, $P(v)$ is the wind power (W), $p(v)$ is the wind power density (W/m^2) and ρ is the air density (kg/m^3) at the sites.

To simulate the electrical power output of a model wind turbine require using [10]:

$$P_e = \begin{cases} 0 & (v < v_C) \\ P_{eR}\frac{v^k - v_c^k}{v_R^k - v_c^k} & v_C \le v \le v_R \\ P_{eR} & v_R \le v \le v_F \\ 0 & v > v_F \end{cases} \tag{7}$$

Where P_{eR} is the rated electrical power, v_c is the cut-in wind speed, v_R is the rated wind speed and v_F is the cut-out speed respectively of the model wind turbine.

2.3. *Useful site specific wind speeds*

Basically there are two wind speeds that are of utmost interest to wind resource assessors. These are the maximum energy carrying wind speed (v_{Emax}) and the most probable wind speed (v_{mp}). While the former is described as the wind speed carrying maximum wind energy, the latter represents the modal wind speed for the given wind distribution [10]. They are expressed as:

$$v_{Emax} = c\left(\frac{k+2}{k}\right)^{\frac{1}{k}} \tag{8}$$

$$v_{mp} = c\left(\frac{k-1}{k}\right)^{\frac{1}{k}} \tag{9}$$

3. Results and discussion

Observing Fig. 1 revealed that the range of mean wind speed variation for the whole period considered lie between 10.8 m/s in February 1992 and 0.4 m/s in December 1987 and 2007 respectively for Potiskum, while it was between 8.6 m/s in April 2001 and 2.1 m/s in December 1998 respectively for Maiduguri. Fig. 2a–c, also show that there was increase in the mean wind distribution of the two sites from January to June, with slight dip from August to October across the period considered. Moreover, Figs. 1 and 2 indicate that there were general decline in values of the wind profiles across the years considered with only few exceptions and October appeared to be the month with the least wind supply for the sites. Performing a statistical Weibull analysis on the wind speed data gave Table 2 and the plots of the CDF and PDF for the whole data and seasons (shown in Figs. 3–6) clearly demonstrate that all the wind profiles for these periods follow the same cumulative distribution pattern.

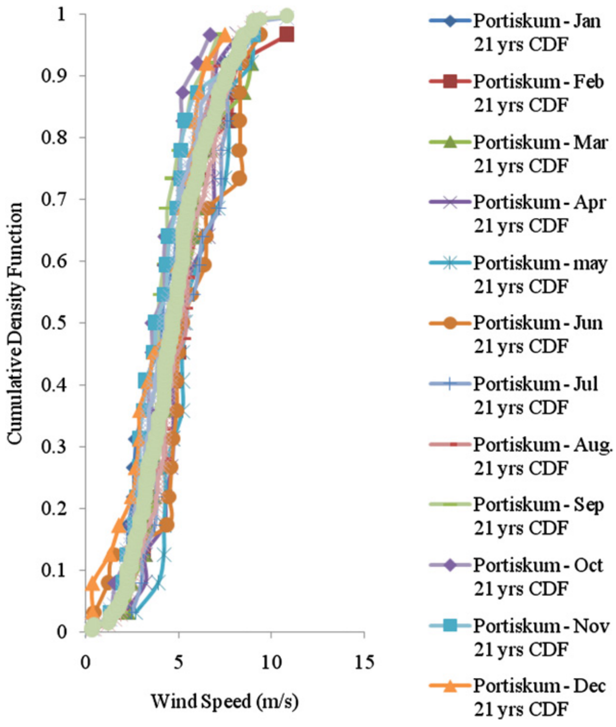

Fig. 3. CDF plots for Portiskum.

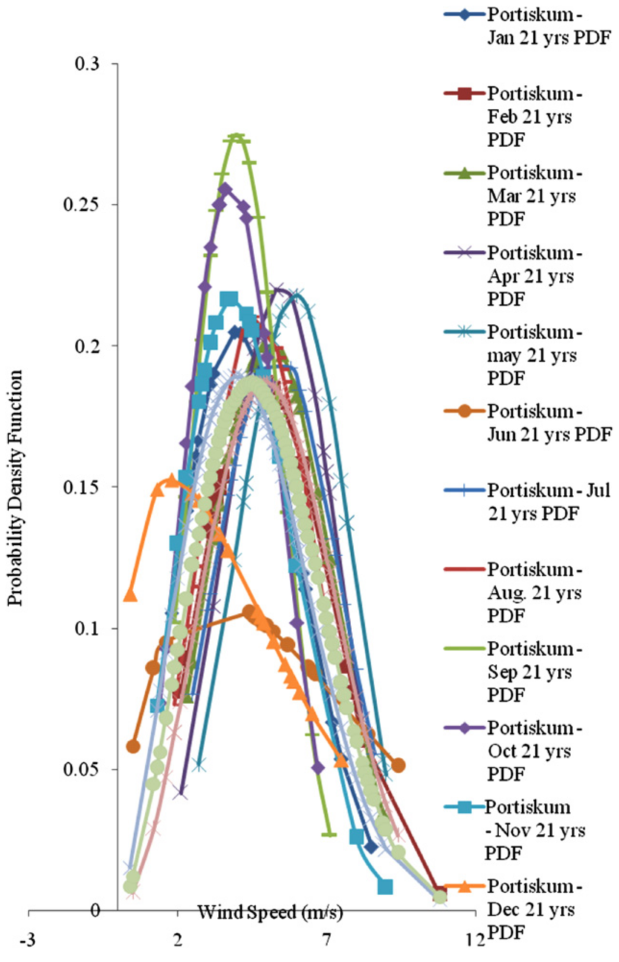

Fig. 4. PDF Plots for Portiskum.

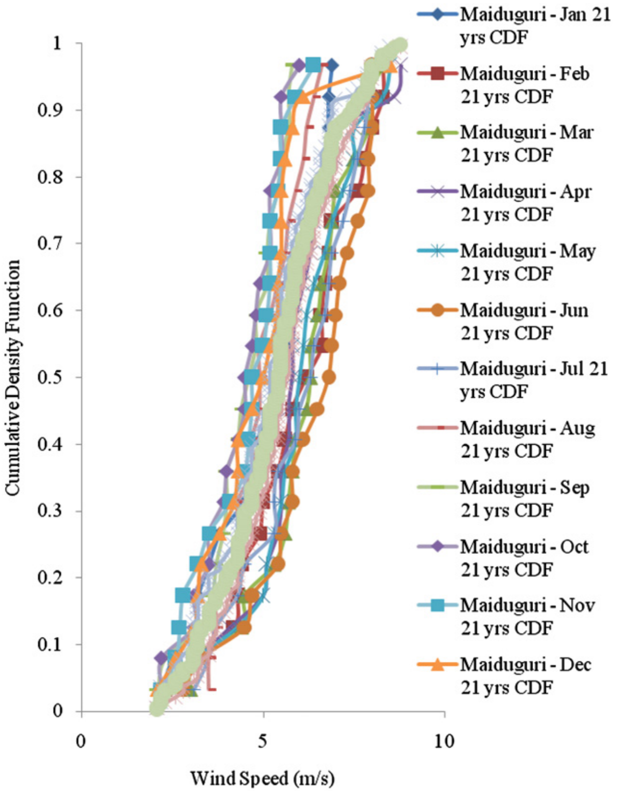

Fig. 5. CDF Plots for Maiduguri.

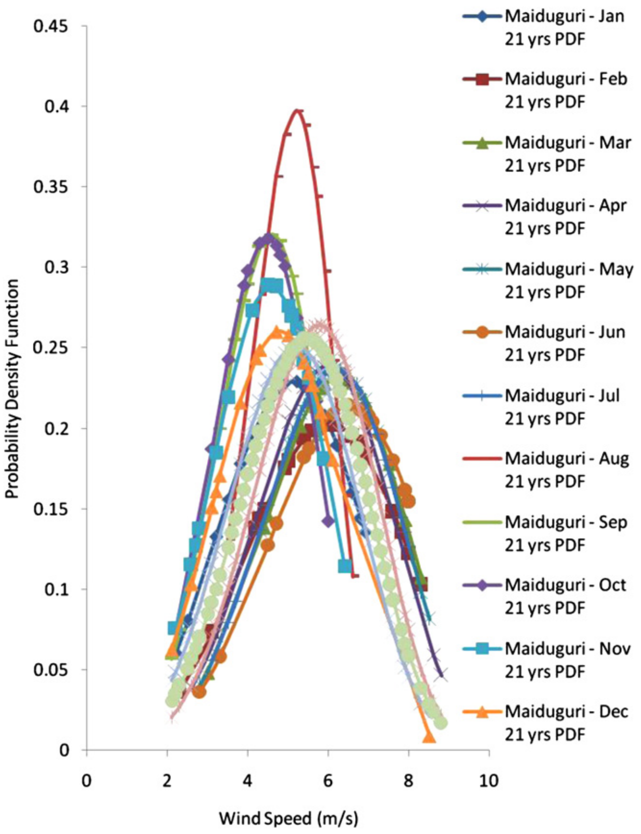

Fig. 6. PDF Plots for Maiduguri.

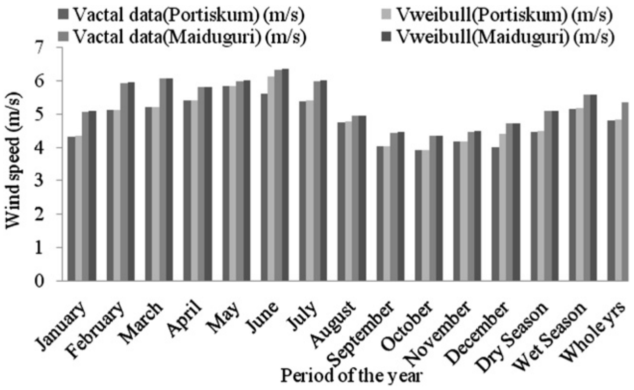

Fig. 7. Plot showing the predictive ability of the Weibull distribution for monthly and seasonal distribution.

However, there were slight deviation in the PDF pattern (Fig. 4) for June and December of Potiskum site. These deviations are a result of the values of *k* for the period of months (shown in Table 2). Furthermore, the monthly mean wind speed variations for Potiskum ranged from 3.90 (in October) to 5.85 m/s (in May) while for Maiduguri, they range from 4.35 (in October) to 6.33 m/s (in June). Seasonally, comparing data variations between dry (March to October) and wet (April to September) seasons revealed that, the mean wind speed variations for Potiskum ranged from 4.46 (dry season) to 5.16 m/s (for wet season) and 4.81 m/s (for whole years' data combination), while for Maiduguri it ranged from 5.10 (dry season) to 5.59 m/s (wet season) and 5.35 m/s (for whole years' data combination). The yearly analysis however, gave mean wind speeds range for Potiskum as 2.55 (in 2006) to 7.69 m/s (in 1991) and for Maiduguri, they are between 3.07 (in 2004) and 6.97 (in 2001). The variation in the values of the Weibull shape and scale parameters as well as the standard deviations of the measured data and Weibull results for both sites analyses are given in Table 2.

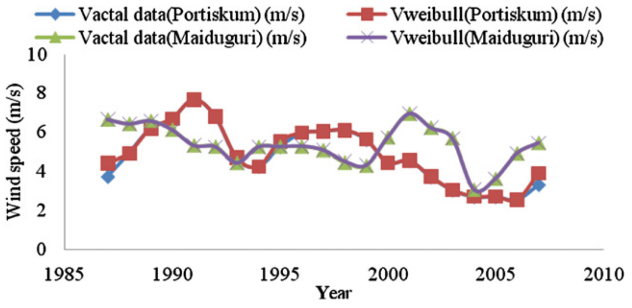

Fig. 8. Plot showing the predictive ability of the Weibull distribution for yearly mean wind speed distribution.

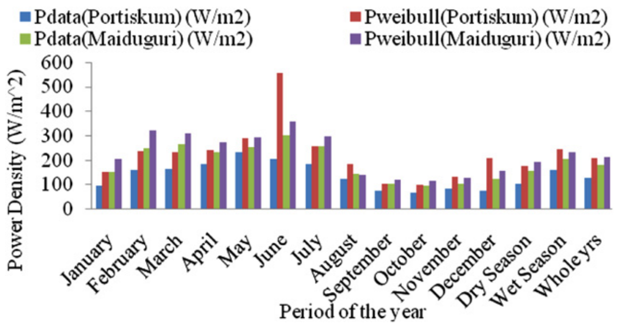

Fig. 9. Plot showing the power density distribution for both measured data and Weibull result for the two stations for particular period of the 21 years considered.

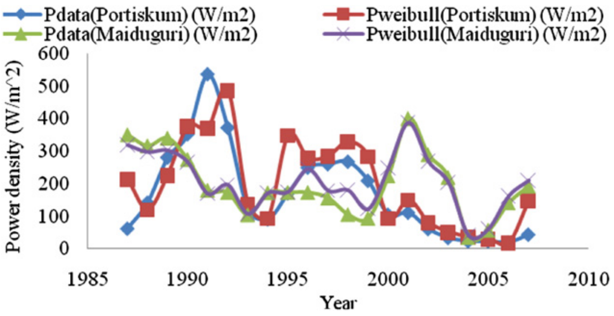

Fig. 10. Plot showing the annual power density distribution for both measured data and Weibull result for the two stations for particular period of the 21 years considered.

Further observing Figs. 3 and 5 revealed that at the Potiskum site, 50% of the data ranged from 3.6 to 5.4 m/s and below, while 80% of the data ranged from little less than 5.4–8.3 m/s, across the period considered. Moreover, the month of February and period of dry season for this site possessed the opportunity for wind harvest of up to 10.8 m/s, while June and the wet season has the prospect for wind speed of 9.4 m/s. At the Maiduguri site, 50% of the data ranged from 4.5 to 6.8 m/s and below, while 80% of the data ranged from little less than 5.5–7.9 m/s. On the other hand, the months of January and August to November have the least maximum mean wind speeds between 5.8 and 7 m/s, while the other months including those of dry and wet seasons have their maximum values from 8.3 m/s and above.

Comparing the Weibull generated results with the actual data to determine the predictive ability of the statistical Weibull distribution on the periodic and yearly mean wind speed data gave Figs. 7 and 8. These showed that Weibull statistical distribution adequately predicts the situation of mean wind speed distributions at the two sites. Table 2 also displays the values of the standard deviations and R^2–values across the period of analysis. Thus, the curve fitting by the Weibull probability distribution to the measured data has provided a quality goodness-of-fit.

The result of analysis of monthly and seasonal variations in power density distribution from both direct data measurement and Weibull distribution for the two sites is given in Fig. 9. This indicates that for every month and period in consideration the Maiduguri station gave higher values of power density harvestable from the wind. However, the yearly analysis (Fig. 10) gave variation in annual power harvestable from the wind to be averagely higher for Potiskum in the period between 1989 and 1993. The reason for this is due to the variation in the measured mean wind speed at the two sites (see Figs. 11 and 12) for this period and years. Annually, Potiskum seem to provide a better wind distribution, while for monthly, seasonal and on the whole years considered, Maiduguri appeared to have a better

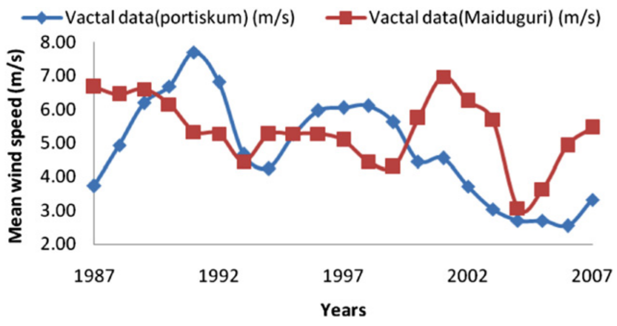

Fig. 11. Plot comparing measured yearly mean wind speed for the two sites.

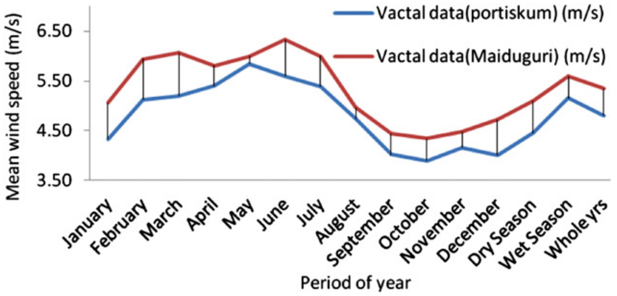

Fig. 12. Plot comparing measured mean wind speed for the two sites based on specific period of the 21 years.

prospect. The values of the power density estimation from the direct data evaluation are given in Table 2, while the corresponding Weibull estimation can be derived from Eq. (6).

Furthermore, the most probable (v_{mp}) and maximum energy carrying wind speeds (v_{Emax}) analyses for the periods gave results (Figs. 13 and 14) similar in distribution to those of power density distribution described above, with Maiduguri possessing a better prospect on monthy and seasonal distribution and Potiskum being the better in terms of annual distribution. The values of v_{mp} and v_{Emax} for Potiskum ranged from 1.80–5.95 m/s (for January to December), 4.01 m/s (dry season), 4.96 m/s (wet season), 4.47 m/s (whole years), 0.87–7.94 m/s (1987–2007) and 5.24–11.94 m/s (for January to December), 6.60 m/s (dry season), 7.12 m/s (wet season), 6.87 m/s (whole years) 2.87–9.54 m/s (1987–2007) respectively. For Maiduguri v_{mp} and v_{Emax} values ranged from 4.48–6.51 m/s (for January to December), 5.20 m/s (dry season), 5.77 m/s (wet season), 5.48 m/s (whole years), 3.14–7.28 m/s (1987–2007) and 5.31–7.79 m/s (for January to December), 6.35 m/s (dry season), 6.72 m/s (wet season), 6.54 m/s (whole years) 3.77–7.95 m/s (1987–2007) respectively. To simulate the electrical power output derivable from a wind turbine model require using Eq. (7) with the wind speed results of the analysis.

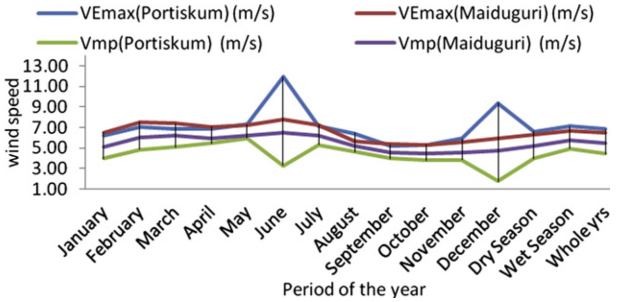

Fig. 13. Plot comparing the most probable and maximum likelihood wind speeds for the two sites based on specific period of the 21 years.

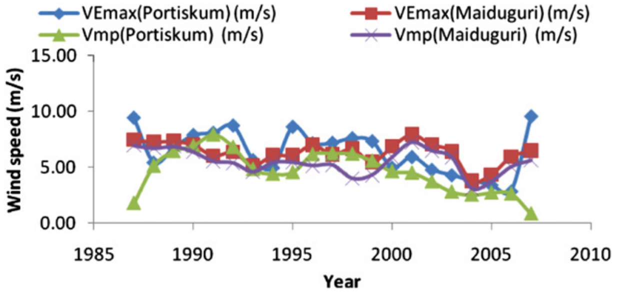

Fig. 14. Plot comparing the yearly most probable and maximum likelihood wind speeds for the two sites based for the 21 years period.

4. Conclusion

The assessment of wind energy potential for power generation of two sites in North-East, Nigeria was carried out. 21 years' continuous 3 h daily mean wind data were assessed from the Nigeria Meteorological department, Oshodi, Nigeria for the two sites and subjected to Weibull two parameter and other statistical analyses. It was discovered that:

1. The Weibull probability distribution adequately predicts the mean wind distribution of the two sites and statistically significant results were obtained.
2. From the cumulative density function of the Weibull statistics, it was observed that 80% of the measured wind data ranged from 5.4 to 8.3 m/s and below, while 50% of data ranged from 3.6 to 5.4 m/s and below for Potiskum site. The month of February and period of dry season for this site also possess the opportunity of a wind harvest of up to 10.8 m/s, while June and the wet season has the prospect of a wind speed of 9.4 m/s. For Maiduguri, 80% of the data were from 5.5 to 7.9 m/s and below while 50% of the data range from 4.5 to 6.8 m/s and below. The months of January and August to November for this site have the least maximum mean wind speed between 5.8 and 7 m/s, while the other months and the periods of dry and wet seasons have their maximum values from 8.3 m/s and above.
3. On direct data analysis, the monthly mean wind speed variation for Potiskum ranged from 3.90 to 5.85 m/s, while for Maiduguri, it ranged from 4.35 to 6.33 m/s. Seasonally, comparing data variation between the dry and wet seasons revealed that, the mean wind speed variation for Potiskum ranged from 4.46 (for dry) to 5.16 m/s (for wet), while for Maiduguri it ranged from 5.10 (dry) to 5.59 m/s (wet).
4. The wind power density variation based on the Weibull analysis ranged from 102.54 to 300.15 W/m^2 for Potiskum site and it ranged from 114.77 to 360.04 W/m^2 for Maiduguri site respectively.
5. Ranking the sites, it was discovered that the Maiduguri site possessed a better wind energy prospect than Potiskum.
6. Seasonally, the wet season, the period from April to September every year, seem to provide a better opportunity for higher wind energy harvest than the dry season from October to march. However, the period for highest wind energy harvest for the sites could be from January to June every year.
7. The findings suggest that the sites could be suitable for power generation for both medium scale power generation and stand alone connection systems.

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