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MODELLING A WIND MAP OF NIGERIA TO ASSESS THE UTILIZATION OF WIND AS AN ALTERNETIVE SOURCE OF ENERGY

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ABSTRACT

This paper deals with the feasibility study and efficient utilization of wind energy in Nigeria. Twenty (20) years hourly wind data at 10 m height were collected for 2 stations in each of the 6 geographical zones of Nigeria. The selected stations were: Abeokuta, Osogbo, Calabar, Port Harcourt, Owerri, Enugu, Sokoto, Kano, Jos, Abuja, Maiduguri and Yola. A wind map of Nigeria was modelled using ArcView© Geographical Iinformation System. The study revealed that Jos, Kano and Sokoto have wind energy potential sufficient to generate electrical power that could be connected to the national grid, while Enugu and Maiduguri have enough wind energy potential that could be used to power irrigation devices and other agricultural activities. The establishment of wind power plants for excellent stations such as Jos, Kano and Sokoto for the generation of electricity which could be integrated with the present national grid is recommended.

Keywords: Wind map, Wind energy, ArcView, Wind speed, Nigeria.

INTRODUCTION

Nigeria is a developing country located between longitude 3^0 and 14^0 East of Greenwich and latitude 4^0 and 14^0 North of the equator, in West Africa on the Gulf of Guinea and has a total area of 923,768 km^2 (356,669 sq miles) ,making it the world's 32^{nd} largest country [Wikipedia, 2017]. As in the other parts of West Africa, the climate of the area is determined by the interplay of three major airstreams: the tropical maritime (Tm) air mass, the tropical continental (Tc) air mass, and the equatorial easterlies [Omotosho, 1998]. The Tm air mass originates from the St. Helena anticyclone located off the coast of Namibia and in its trajectory, picks up moisture from the South Atlantic Ocean, crosses the equator, and enters south western Nigeria. The Tc air mass originates from the Libyan anticyclone north of the tropic of Cancer. It picks up little moisture along its path and thus very dry.

Energy development in Nigeria has over the years been through many challenging stages. The regular power outages have contributed in no small measure to the ever present poverty crises in the nation, with many businesses relying on the use of diesel and petrol generators to run their machines, contributing to the emission of greenhouse gases and air pollutants, thus creating global warming concerns and also increasing cost of production. The erratic nature of power supply has caused the economy to nosedive, and unless alternative means of power supply is provided for her growing population, the nation stand a risk of remaining underdeveloped.

The way out of this, lies in the use of renewable sources of energy for power generation, as they contain enormous largely untapped and sustained opportunity for meeting the country energy needs. These forms of energy are environmentally friendly as they do not contribute harmful and toxic emission to it, they do not also create the concern of eventual resource depletion as those of non renewable sources. An example of renewable sources of energy is the wind energy; which is one of the cleanest and most environmentally friendly sources of energy, capable of generating a high amount of electricity. Currently wind energy is one of the fastest developing renewable energy source technologies across the globe. It is an alternative clean energy source compared to fossil fuel, which pollute the layer of the atmosphere. It has the advantage of being suitable to be used locally in both urban and rural areas. The inconsistence in power supply is mainly due to the nation's dependence on hydropower which is seasonally dependent. Windmills were first used in Nigeria as early as the mid 1960s in the northern regions of Sokoto and Garo, over 20 homes and schools used windmills to pump water [Akinbami, 2001]. The following decades saw the prices of fossil fuels drop and therefore with cheap energy, wind power was not an appealing alternative. Investment in windmills ceased and the infrastructure deteriorated, making the existing infrastructures obsolete.

Adegoke and Anjorin [1996] investigated the prospects of wind energy utilization in Nigeria by analyzing available wind data for Akure, Bauchi and Port Harcourt. They observed that the average wind speed measured at 10 m height above the ground for Bauchi is 4.78 m/s, Port Harcourt is 2.56 m/s and that for Akure is 0.76 m/s. It was concluded that Bauchi favors the installation of wind turbines more than Port Harcourt and Akure and that the variation of annual mean wind speed is much lower for Port Harcourt than for Bauchi. This implies that wind turbines installed in Port Harcourt functions more regularly over several years.

A study by Ogbonnaya *et al* , [2007] shown that the annual wind mean speed at a height of 10 m ranges between 2.3-3.4 m/s for sites along the coastal areas and 3.0-3.9 m/s for high land areas and semi arid regions. It was also discovered that the wind turbine can generate a monthly average wind power as high as 50.1 W/m^2. Similarly, after analysis of wind potential of Jos by Awogbemi and Ojo [2009], it was discovered that the maximum power intensity, which could be extracted from the wind in the area was found to be 14.23 W/m^2. The amount of energy density available in the wind has also been estimated to be 1126 kWh/yr, this result suggest that Jos is an ideal location for installation of wind turbine.

MATERIAL AND METHOD

In this study, the wind potential of Nigeria was assessed by analysing the hourly wind data at 10 m height for a period of 1996 – 2015 (20 years), for twelve stations spread across the six regions of the country, these wind data were obtained from the Nigeria Meteorological Agency, Oshodi., Lagos. The twelve (12) stations and their locations are as listed in Table 1, with 2 stations from each of the six geographical zones in Nigeria. In getting a perfect impression about the wind regime of a place, wind speed recording over a long period of time is essential, since wind speed on a particular day of a month varies from year to year and this is more so, in the present world, when the global weather trends are fast changing due to the degradation of the biosphere.

Table 1: Twelve (12) locations used for the study

S/NO	TOWN	REGION	LATITUDE (^{0}N)	LONGITUDE (^{0}E)	ALTITUDE (m)
01	SOKOTO	NORTH WEST	13.02	5.25	350.8
02	KANO	NORTH WEST	11.50	8.50	472.5
03	ABUJA	NORTH CENTRAL	9.00	10.00	344.0
04	JOS	NORTH CENTRAL	9.87	8.90	586.0
05	YOLA	NORTH EAST	9.91	11.93	186.1
06	MAIDUGURI	NORTH EAST	11.85	13.08	353.8
07	OSOGBO	SOUTH WEST	7.77	4.57	305.0
08	ABEOKUTA	SOUTH WEST	7.15	3.33	104.0
09	OWERRI	SOUTH EAST	5.48	7.02	91.0
10	ENUGU	SOUTH EAST	6.47	7.55	141.8
11	PORT HARCOURT	SOUTH SOUTH	4.75	7.00	19.5
12	CALABAR	SOUTH SOUTH	4.97	8.35	61.9

MEAN WIND SPEED

Mean Wind Speed (MWS) is the most commonly used indicator of wind production potential. A mean annual wind speed (MAWS) of about 3 m/s at 10 meters height is considered economically viable for a utility-scale wind farm (Grubb and Meyer, 1993). The mean wind speed is defined as:

$$MWS = \frac{1}{n}\sum_{i=1}^{n} v_i \qquad (1)$$

where n is the sample size, and v_i is the wind speed recorded for the ith observation. Where the sample size is large, it is useful to group the wind speed data into intervals to create a histogram of the wind speed distribution. The probability of the observed wind speed being within an interval can be written as:

$$p(v_j) = \frac{n_j}{n}$$

where v_j is the median value and n_j is the number of observations in the j^{th} interval.

Wind Power Density

Wind power density is the amount of wind power available per unit of area perpendicular to the wind flow, (Celik, 2003). This is given by equation (3)

$$WPD = \frac{1}{2}\rho v^2 \qquad (3)$$

where ρ is the air density (kg/m^3) and v wind speed (m/s).

The geographical parameters which include latitude, longitude, elevation and wind speed were used as input to develop the contour wind map for the country. The wind map was obtained using the Geographical Information System (GIS) software ArcView® 3.2.

2.3 Weibull Distribution Function

Weibull density function is widely accepted for evaluating local wind load probabilities and is considered as a standard approach (Lu *et al..*, 2002; Seguro *et al..*, 2000; Persaud *et al..*, 1999; Musgrove, 1988). It has a great flexibility and simplicity.

However, the main limitation of the Weibull density function is its inability to accurately calculate the probabilities of observing zero or very low wind velocities (Weisser, 2001). Nevertheless, this statistical method is found to fit a wide collection of recorded wind data (Lun *et al..*, 2000; Dorvlo, 2002). The Weibull wind velocity probability density function can be represented as:

$$f_{Weibull}(v) = \frac{k}{A}\left(\frac{v}{A}\right)^{k-1} \cdot \exp\left[-\left(\frac{v}{A}\right)^k\right]$$

where $f(v)$ is the probability of observing wind velocity v; A is the Weibull scale parameter and k is the dimensionless Weibull shape parameter. Basically, the scale parameter, A, indicates how 'windy' a wind site under consideration is, whereas the shape parameter, k, indicates how peaked the wind distribution is (that is, if the wind speeds tend to be very close to a certain value, the distribution will have a high k value and be very peaked). The average wind speed (v*)* and variance of wind velocity are represented as;

$$\bar{v} = \frac{1}{n}\sum_{i=1}^{n} v_i$$

$$\sigma^2 = \frac{1}{n-1}\sum_{i=}^{n}(v_i - \bar{v})^2$$

Based on the values of mean, v and variance, the following equations can be used to calculate the Weibull parameters A and k:

$$k = \left(\frac{\sigma}{\bar{v}}\right)^{-1.086} \qquad (1 \le k \le 10)$$

$$A = \frac{\bar{v}}{\gamma\left(1+\frac{1}{k}\right)}$$

Wind speed variation with height

Wind speed generally changes with height, which requires an equation that predicts the wind speed at one height in terms of the measured speed at another height. Under normal conditions, a wind speed is greater at higher distance above ground. This is largely because the effect of surface features and turbulence diminishes as the height increases. The variability depends on distance from the ground and roughness of the terrain. The analysis of wind speed with height for this thesis was done on the site roughness class of a fallow field. The most common expression accepted to describe the vertical variation of wind speed is expressed by a power law (Ramrez and Carta, 2005; Perez *et al..*, 2004)

$$V/_{V_0} = \left\{\frac{h}{h_0}\right\}^{\propto}$$

where v is the wind speed at the required height h, v_0 is wind speed at the reference height h_0, and α is the surface roughness coefficient. The value of the exponent α varies from less than 0.10 over the tops of steep hills to over 0.25 in shaded areas.

2.5 Average Wind Energy Content

The average wind energy content (EC) was calculated using the following equation:

$$EC = WPD \times \frac{8760}{yr} \div \frac{1000W}{KW}$$

where EC is the average wind energy content (kWh/m^2/yr) and WPD is the wind power density (W/m^2)

RESULTS AND DISCUSSION

Figure 1 shows the wind map using the annual mean wind speed from the data over the period of twenty years, it can be seen that most of the Northern region has a higher wind regime than the southern region. Figures 2-5 showed the monthly wind maps for January, April, July and October respectively. The monthly mean wind speed varied decreasingly from the savannah region in the north to the coastal region in the south. Two distinct wind belts are recognizable from the various maps, the high wind belt in the north and the low wind belt in the south, similar trend in wind speed variation in Nigeria was reported by Iloeje [2001].

As noticed from the Table 2, the highest mean wind speed of 9.8 m/s was observed in Jos while the lowest of 1.7 m/s was in Yola. At other sites the mean wind speed ranges from 2.7 m/s to 9.1 m/s (Table 2). In January, the wind map (Figure 2) shows that the variation for the country is 1.6-10.5 m/s, April has a variation of 2.7-10.2 m/s as shown in Figure 3. Figure 4 shows that July wind speed across Nigeria ranges from 2.1-10 m/s, while October has a range of 1.5-8.1 m/s as shown in Figure 5.

The estimation of the mean wind speed over a site is not a final step to assess the available wind potential in the considered site. Moreover, the value of the power density is an important parameter that can provide complementary information regarding the choice of suitable site, as well as an immediate classification of the site. For this main reason, the wind power density available at 10 m and a hub height of 70 m for the twelve (12) stations has been computed as shown in Tables 3 and 4. Table 3 shows that Jos has a wind power density of 647 W/m^2 and a mean energy content of 5670 kWh/m²/yr being the highest of all the twelve sites used in this study, while Yola has a wind power density of 5 W/m^2 with a mean energy content of 44 kWh/m²/yr at 10 m height.

The Weibull parameters as shown in Table 3 revealed that the scale parameter, k, varies between 0.882 (Owerri) and 6.310 (Enugu) at 10 m while the shape parameter, c, varies between 2.007 m/s (Yola) and 10.673 m/s (Jos). The scale parameter shows that owerri has an exponential distribution (for $k \leq 1$), meaning that on most days there was very low wind speed (Rehman *et al.* 1994), Yola had a Rayleigh distribution, $1 > k \leq 2$, this shows that on most days, wind speed was lesser than the mean wind speed and that very high winds occurred only on few days, implying that wind turbines installed in Yola may function less regularly over several years (Rehman *et al.* 1994). The remaining stations had scale parameters greater than 3, which imply a Gaussian distribution, where variation in the wind speed is low, wind turbines installed in these stations might therefore function more regularly (Rehman *et al.* 1994). The shape parameter, c, depends on the mean wind speed of the station, and varies as the mean wind for the various stations varies; it also increased with heights for all the stations.

The mean power density for the stations increases with increase in the hub height, implying that power produced depends largely on the amount of wind available at the station. Using the wind power classification, Jos and Kano are in Class 7, Sokoto is in class 4, Enugu and Maiduguri are in class 2, while the remaining stations are in class of 1 which implies that they are poor sites for wind energy conversion system. The wind speed at 70m, which is the hub height for Acciona 70/1500 class I turbine, was obtained using the Power law as shown in Table 4. The mean wind speed at this height varies from 12.9 m/s at Jos to 2.3 m/s at Yola. The mean power density obtainable at this hub height is 1466 W/m^2 in Jos, followed by Kano with 1254 W/m^2 with the least mean power density obtained in Yola (11 W/m^2). The Weibull scale parameters also follow the pattern of the value obtained at the 10 m heights.

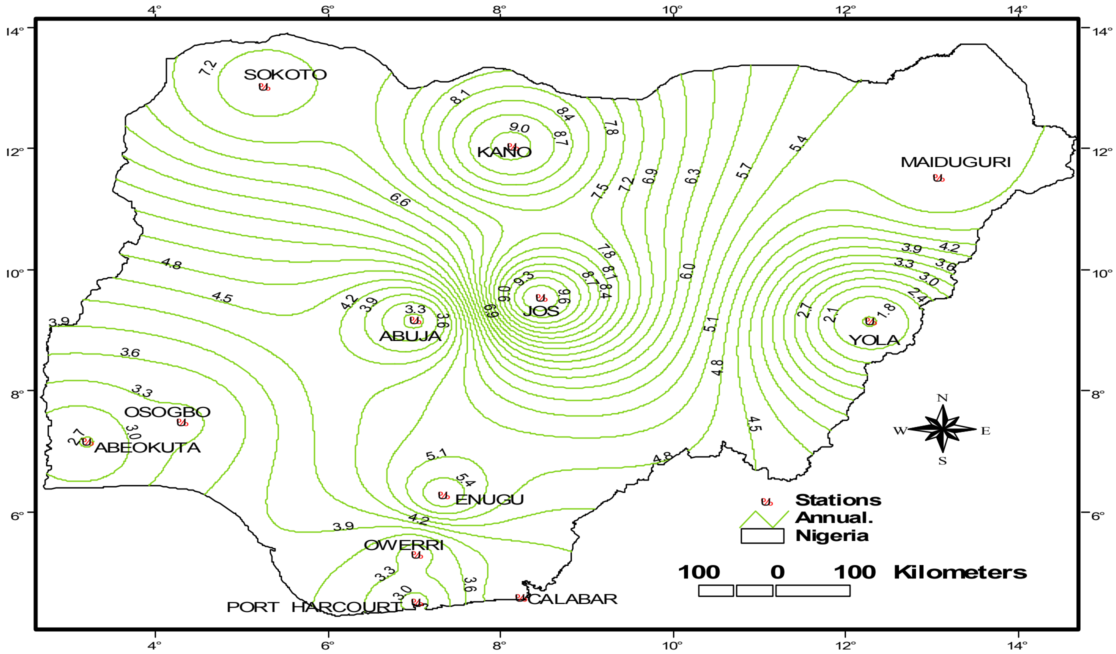

Figure 1: Wind Map using the Mean of the Annual Means

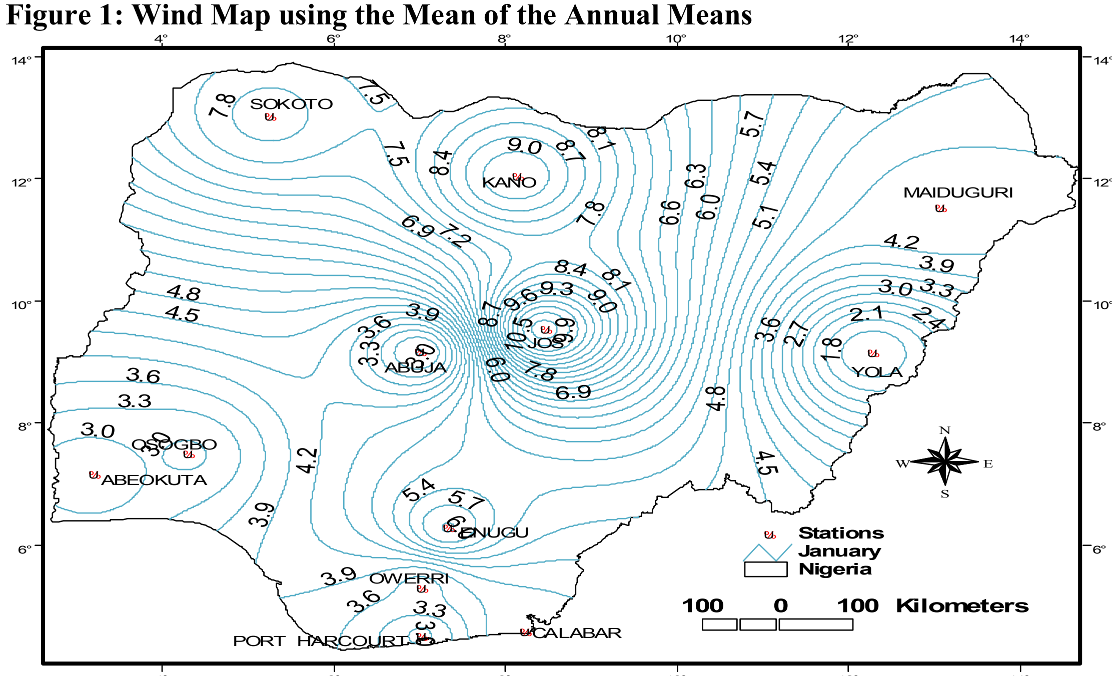

Figure 2: Wind Map of Monthly Mean Wind Speed for the Month of January

Table 2: Mean of Monthly Average for the Twelve Stations

	Abeokuta	Abuja	Calabar	Enugu	Jos	Kano	Maiduguri	Osogbo	Owerri	Port Harc	Sokoto	Yola
January	2.7448	2.6868	4.0923	6.0242	10.649	9.25	4.3887	2.9529	3.4871	2.9474	7.9232	1.56
February	3.0049	3.1774	4.3989	5.9166	10.595	10.29	5.7286	3.3933	3.4739	3.1696	8.2753	1.6615
March	3.0248	3.3855	4.3558	6.4974	10.195	9.82	6.1219	4.2545	3.5945	3.4329	7.7713	1.98
April	2.952	4.015	4.5723	6.107	10.628	9.79	5.985	4.3627	3.6633	3.4133	7.3463	2.51
May	2.7232	3.7739	4.4326	5.2519	10.183	10.53	5.9203	3.5216	3.279	3.1248	8.4787	2.4158
June	2.554	3.5043	4.1923	5.3207	9.35	10.46	6.431	3.315	3.3443	3.06	8.951	2.21
July	2.5974	3.3142	3.9165	5.9384	9.705	9.39	6.0481	3.831	2.901	2.9371	8.0848	1.85
August	2.6523	3.281	4.0019	5.9471	9.153	8.63	4.9787	3.7235	3.1829	3.4826	6.049	1.61
September	2.4553	3.1623	4.1523	5.2007	7.947	8.01	4.316	2.9837	3.263	2.9527	5.8267	1.57
October	2.5742	3.0874	4.0435	4.5426	8.398	7.16	4.131	2.3706	2.8365	2.4361	5.259	1.48
November	2.493	2.8003	3.5933	4.651	10.002	7.37	4.5523	2.1423	2.5237	2.2063	6.6887	1.0977
December	2.544	2.7502	3.7126	5.5401	11.127	8.524	5.078	2.2545	2.9226	2.1358	7.4048	1.51
Mean	**2.693325**	**3.244858**	**4.122025**	**5.578142**	**9.827667**	**9.102**	**5.306633**	**3.2588**	**3.205983**	**2.94155**	**7.338233**	**1.787917**

Table 3

	Abeokuta	Abuja	Calabar	Enugu	Jos	Kano	Maiduguri	Osogbo	Owerri	Port Harcout	Sokoto	Yola
Mean wind speed (m/s)	2.692	3.244	4.120	5.578	9.825	9.095	5.303	3.258	3.204	2.940	7.333	1.788
Min wind speed (m/s)	0.800	0.100	2.100	3.100	1.600	1.000	1.100	0.500	1.100	0.400	1.800	0.100
Max wind speed (m/s)	4.800	7.200	6.200	8.700	16.900	18.900	9.900	7.300	10.800	5.800	13.400	3.900
Weibull k	4.221	3.148	6.297	6.310	5.030	3.736	3.574	3.194	0.882	3.621	4.356	2.813
Weibull *A* (m/s)	2.963	3.627	4.415	5.978	10.673	10.068	5.891	3.641	3.185	3.265	8.045	2.007
Mean power density (W/m²)	14	29	46	114	647	554	114	28	26	20	279	5
Mean energy content (kWh/m²/yr)	126	251	404	998	5,670	4,853	998	245	229	175	2,446	44
Wind power class	1	1	1	2	7	7	2	1	1	1	4	1

Table 4

	Abeokuta	Abuja	Calabar	Enugu	Jos	Kano	Maiduguri	Osogbo	Owerri	Port Harcout	Sokoto	Yola
Mean wind speed (m/s)	3.535	4.260	5.410	7.325	12.902	11.944	6.964	4.279	4.207	3.861	9.629	2.348
Min wind speed (m/s)	1.051	0.131	2.758	4.071	2.101	1.313	1.444	0.657	1.444	0.525	2.364	0.131
Max wind speed (m/s)	6.303	9.455	8.142	11.424	22.192	24.818	13.000	9.586	14.182	7.616	17.596	5.121
Weibull k	4.223	3.150	6.289	6.318	5.032	3.738	3.573	3.190	0.883	3.617	4.356	2.801
Weibull A (m/s)	3.891	4.763	5.797	7.850	14.016	13.221	7.736	4.780	4.184	4.287	10.564	2.634
Mean power density (W/m^2)	32	65	105	258	1466	1254	258	63	59	45	632	11
Mean Energy Content ($kWh/m^2/yr$)	284	568	916	2261	12840	10988	2259	555	518	396	5539	99
Wind Power Class	1	1	1	2	7	7	2	1	1	1	4	1

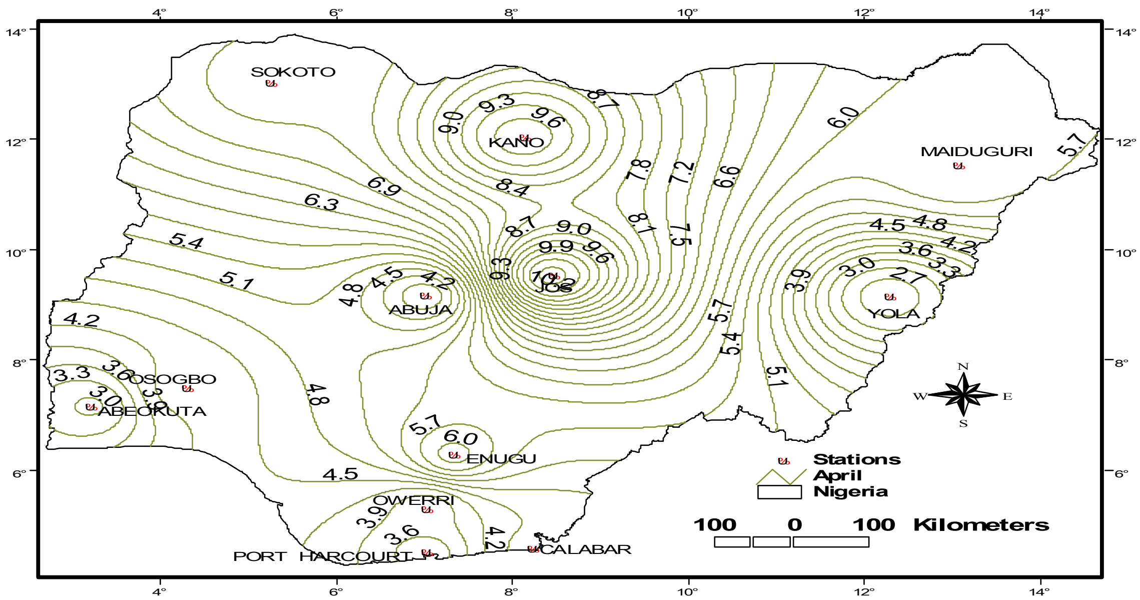

Figure 3: Wind Map of Monthly Mean Wind Speed for the Month of April

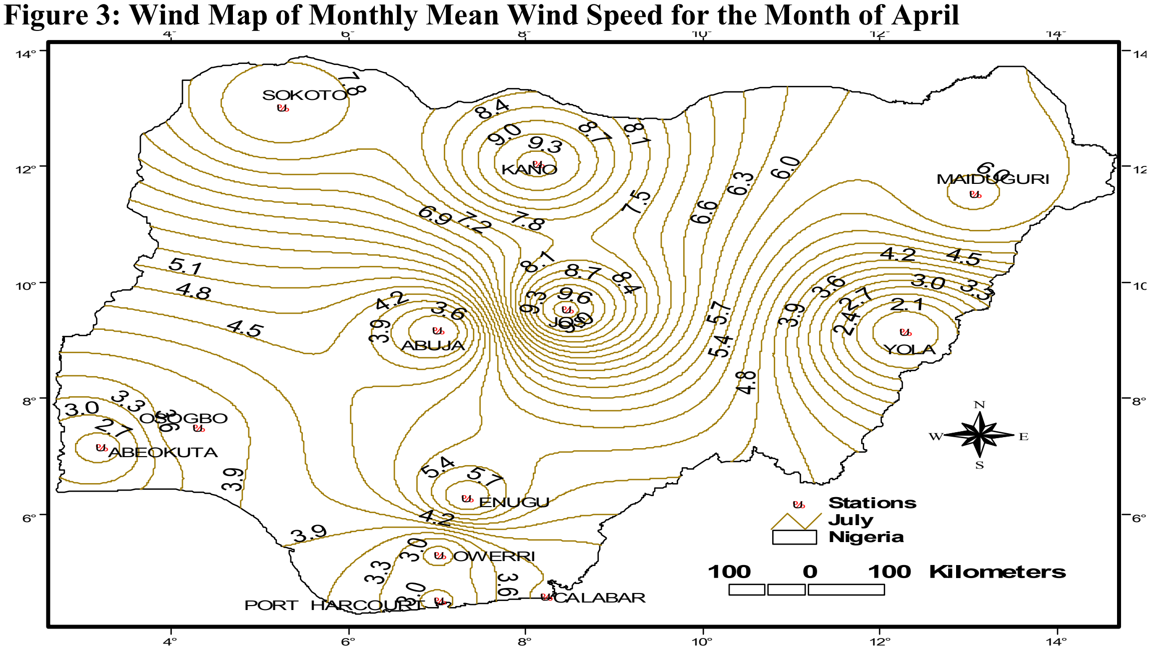

Figure 4: Wind Map of Monthly Mean Wind Speed for the Month of July

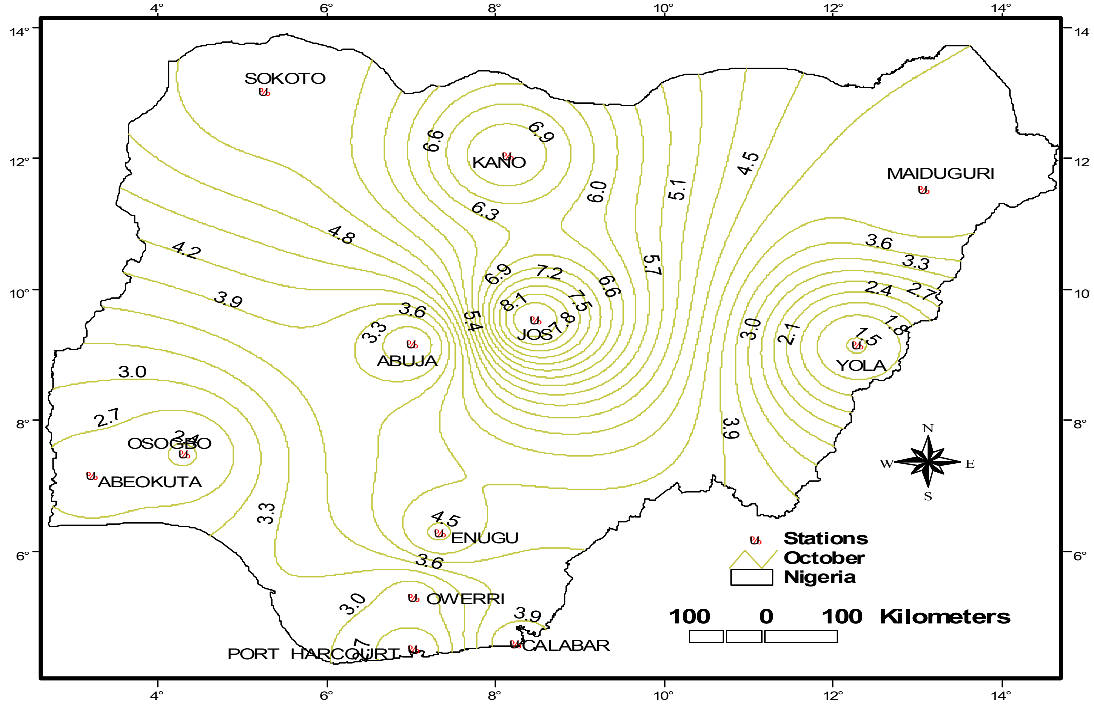

Figure 5: Wind Map of Monthly Mean Wind Speed for the Month of October

Variations occur in wind speed for the twelve stations across the country; with Jos (9.82 m/s) having the highest mean wind speed and Yola (1.78 m/s) having the least mean wind speed at 10 m height. The Northern part of Nigeria has higher wind regime and probabilities of reoccurrence of these winds than the southern part of the country system this is in line with the work of Muazu *et al*, [2009] and Pam [2007] that the northern part of the country is most suitable for wind energy conversion. From the country's wind regime, it can be deduced that Nigeria falls within various classes of wind power; this is in agreement with Lehmeyer [2005] that wind regime in Nigeria falls between poor, moderate and excellent sites. It was, however, observed that wide variation exist in wind speed of stations in the north central and north east, with Maiduguri having a mean wind speed of 5.8 m/s while Yola in the same region had 1.78 m/s, also in the north central, Jos had 9.8 m/s while Abuja had 3.2 m/s. Smaller variations occurred in the wind speed of stations in the other regions, these variations are due to varying topography and geographical morphology of the country. This report is in conformity with Renewable Electricity Policy Guidelines [2012]. Peak wind speed occurred between April and June in the northern stations expect in Jos (December), while peak wind speed was observed between March and April for the southern stations except for Port Harcourt (August), with the least mean wind speed across the country occurring between September and January this agrees with the report of Nigeria Power Reform [2013].

CONCLUSION

This study showed that the wind energy potential of Nigeria varies from one zone to the other. It was discovered that wind energy availability in the south-western and south-southern parts of the country was relatively poor while the far north and the middle belt zones of the country have a huge potential for wind energy utilization. In order to solve the nation energy crisis wind power plants should be established for excellent stations such as Jos, Kano and Sokoto, for the generation of electricity which should be integrated into the present national grid. Even in the south-west and south- south, with "poor" wind energy potential, wind energy can still be harnessed for use in rural areas that require lesser supply of electricity for agricultural or other purposes.

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