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Wind Speed Pattern in Nigeria (A Case Study of Some Coastal and Inland Areas)

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ABSTRACT: In this study, wind speeds were analysed using the daily wind data obtained from Nigeria Meteorological Agency, Oshodi Lagos at the height of 10m at the different stations during the period of 2000-2010. Weibull , lognormal and normal probability density functions were employed. It was found that the daily mean wind speed groups and percentage frequency of occurrence in brackets in the inland locations (Jos, Kano, and Ilorin) and in the coastal locations (Lagos, and Port Harcourt) ranged from (13-18) ms^{-1} (70.6%), (8-12)ms^{-1} (84.4%), (4-5)ms^{-1} (67%) and (8-12)ms^{-1} 75.8% to (4-7)ms^{-1} 97% of the observations respectively. Weibull shape parameters K ranged from 3.07 to 3.82. While the scale parameter C ranged from 9.91 to 15.07ms^{-1} for Kano; K ranged from2.75 to 4.04 while C ranged from 12.75 to 17.44ms^{-1} for Jos; K ranged from 2.61 to 2.76 while C ranged from10.58 to 10.79ms^{-1} for Lagos; K ranged from 1.95 to 1.98 while C ranged from 6.10 to 6.35ms^{-1} for Port Harcourt; and K ranged from 3.10 -5.60 while C ranged from 3.80 to 6.00ms^{-1} for Ilorin.

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Key words: Weibull, Ikeja, Jos, Kano and Port Harcourt

Nigeria is a country whose energy demand exceeds supply from the national utility. 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 (Ajayi,2009;Ajayi et al,2009). One way through this is to develop the available renewable energy resources of which wind energy technology is a major. Works have been carried out to investigate the characteristics and pattern of wind speed across Nigeria. Due to accessibility to wind speed data information, some researchers reported wind speed data in one city (e.g. Medugu and Malgwi, 2005; Ngala *et al*., 2007; Oriaku *et al*., 2007; Fadare, 2008) while others reported wind speed data across the country (e.g. Fagbenle *et al*., 1980; Ojosu and Salawu, 1990a, b; Fadare, 2010; Okeniyi et al., 2015; Aliyu and Mohammed, 2014; Ahmed et al., 2014; Udoakah and Ikafia, 2017). Further study by these authors (1990b) that was based on another set of wind speed data (1968-1983) classified wind speeds across Nigeria into four different regimes: 1.0-2.0 m/s (e.g. Oshogbo, Minna and Yola), 2.1- 3.0 m/s (e.g. Lagos, Makurdi and Port Harcourt), 3.1-4.0 m/s (e.g. Enugu, Kano, Maiduguri) and > 4.1 m/s (e.g. Jos, Nguru, Sokoto) regimes. In general, the findings of Ojosu and Salawu (1990a, b) are similar to that of Fagbenle et al., (1980). Studies on the wind speed across Nigeria by Fagbenle and Karayiannis (1994) based on wind data for 18 stations and from 1979-1988, are consistent with previous studies mentioned above. Fagbenle and Karayiannis (1994) specifically mentioned that average wind speeds in Nigeria range from about 2 m/s to about 4 m/s with highest average speeds of about 3.5 m/s and 7.5 m/s in the south and north areas, respectively. Recent study by Fadare (2010) make use of artificial neural networks to predict the wind speeds distribution across Nigeria and compared the predicted wind speeds with measurements data from 28 stations that span between 1983 and 2003. This analysis predicted monthly average wind speed ranging from a minimum of 0.8 m/s for Ondo (in south region) to maximum value of about 13.1 m/s for Kano (in north region) with both values occurred in December. The overall average annual wind speed of 4.7 m/s was predicted for Nigeria.

Various distributions exist for describing and analysing wind resource data. Some of these include normal and lognormal, Rayleigh and Weibull probability distributions to mention a few (Carta et al, 2009). However, of the statistical methods, the Weibull distribution has been found to be accurate and adequate in analysing and interpreting the situation of measured wind speed and in predicting the characteristics of prevailing wind profile over a place. Thus, in this study, the Weibull (two parameter), Lognormal and Normal Probability Density Function (PDF), were employed in carrying out the analyses of wind speed potentials over the sites considered.

MATERIALS AND METHODS

Source of Data: The source of the data used in this study was Nigeria Meteorological Station, Oshodi, Lagos state where all the meteorology data all over the country are archived. The observation is actually done at various meteorological stations established at these different locations. Cup generator anemometer at height 10m to the ground level was used at the observation stations for data collection. Eleven years

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(2000-2010) daily wind speed data for the sites were assessed and subjected to various statistical analysis.

The Study Area

Fig 1: Study areas shown on the Map of Nigeria

Jos, situated almost at the geographical centre of Nigeria and about 179 kilometres (111 miles) from Abuja, the nation's capital, is linked by road, rail and air to the rest of the country.

Jos is at an altitude of 1,217m (3,993 ft.) above sea level, Jos enjoys a more temperate climate than much of the rest of Nigeria. Average monthly temperatures range from 21–25 °C (70–77 °F), and from mid-November to late January, night-time temperatures drop as low as 11 °C (52 °F). Hail sometimes falls during the rainy season because of the cooler temperatures at high altitudes.

According to the Köppen Climate Classification system, Jos has a Tropical Savanna climate and it is located within 9.89^0N, 8.85^0E

Kano is on the elevation of about 481 meters (or about 1580 feet) above sea level. The city lies to the north of the Jos Plateau also in the Sudanian Savanna region.

The region features Savana vegetation and a hot, semi-arid climate. Night-s time temperatures are cool during the months of December, January and February, with average low temperatures of 11 to 15 °C (52 to 59 °F).It is bounded within 12.00^0N, 8.59^0E.

Lagos is in the west of the country, on the coast of the Gulf of Guinea, close to the border with Benin. It is located on the Longitude and latitude (6.5244° N, 3.3792° E) with an elevation 41 m (135 ft).

Port Harcourt is in the south-south of Nigeria, the largest city and the capital of Rivers State. It lies along the Bonny River and is located within Longitude and latitude (4.8156° N, 7.0498° E) and on an elevation 20 m (64 ft).

*Methodology:*The daily, monthly and yearly mean of the data were computed alongside with their respective variance and standard deviation using equations 1, 2 and 3 below. It should be noted that using monthly and yearly wind speeds data which all the referred researchers have used in the past have some peculiar limitations such as loosing extremely low or high wind speeds within the month as well as inability to observe diurnal variations in the wind speed. Hence the daily mean wind speed was deliberately analysed to conquer this limitations. However, using monthly mean wind speed, which is more easily accessible for most locations, can be used to study the seasonal changes in wind speed.

$$\bar{u} = \frac{1}{n}\sum_{i=1}^{n} u_i \qquad (1)$$

$$\sigma^2 = \frac{1}{n-1}\sum_{i=1}^{n}(u_i - \bar{u})^2 \qquad (2)$$

$$\sigma = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(u_i - \bar{u})^2} \qquad (3)$$

RESULTS OF DATA ANALYSIS

The probability density frequency and cumulative distributions of wind speed for the five locations were obtained using excel package and the results are shown in the tables below. The probability density function is used to illustrate the fraction of time for which given wind speed possibly prevails at a location. The cumulative distribution function can be used for estimating the time for which wind speed is within a certain speed interval

*General Discussions: Coastal***:** With reference to table 2, the minimum speed was observed in Port Harcourt over the period of three months, November to January when the values ranged in between 4.25ms^{-1} to 4.81ms^{-1}. However, in Ikeja, for the same period, the minimum speed also occurred in November (7.50ms^{-1}) and progressively reduced till it reached 6.35ms^{-1} in January. In Port Harcourt, the speed appeared steady at around 5.6ms^{-1} from March till July during the onset and the mid of the rainy season. There was a sharp contrast in Ikeja. In the months of February till May average daily mean wind speed rose to above10ms^{-1} .This coincides with the transition period(from dry season to rainy season) and the wind speed dropped in the months of June and July which were the peak of rainy period. It is worth noting that the peak mean wind speed at the coastal area occurred in the month of August, 12.79ms^{-1} and 6.24ms^{-1} for Ikeja and Port Harcourt respectively

Table 1: Summary of the Weibull Probability Density and Cumulative Distribution Functions for All Stations Derived From the Windspeed Data (2000-20102

	Coastal Stations				**Inland Stations**					
	IKEJA		**P/H**		**ILORIN**		**JOS**		**KANO**	
MONTHS	PDF.	CDF.	PDF.	CDF.	PDF.	CDF.	PDF.	CDF.	PDF.	CDF.
JANUARY	0.100	0.515	0.126	0.55	0.258	0.506	0.071	0.514	0.088	0.518
FEBRUARY	0.100	0.575	0.126	0.54	0.350	0.483	0.075	0.506	0.094	0.523
MARCH	0.100	0.576	0.127	0.55	0.363	0.473	0.081	0.501	0.100	0.567
APRIL	0.100	0.516	0.127	0.55	0.246	0.492	0.099	0.490	0.112	0.535
MAY	0.100	0.517	0.127	0.55	0.309	0.482	0.086	0.498	0.112	0.446
JUNE	0.099	0.517	0.127	0.55	0.384	0.475	0.092	0.503	0.112	0.539
JULY	0.099	0.517	0.127	0.55	0.316	0.483	0.095	0.500	0.111	0.650
AUGUST	0.099	0.517	0.128	0.55	0.282	0.490	0.082	0.516	0.117	0.625
SEPTEMBER	0.099	0.518	0.128	0.55	0.421	0.480	0.094	0.508	0.119	0.485
OCTOBER	0.098	0.518	0.129	0.55	0.406	0.484	0.081	0.506	0.090	0.322
NOVEMBER	0.098	0.519	0.129	0.55	0.366	0.495	0.076	0.500	0.111	0.436
DECEMBER	0.097	0.519	0.129	0.55	0.306	0.504	0.086	0.496	0.084	0.312

Table 2: Comparism of Cumulative Variation in the Daily Mean Speed in the Coastal and Inland Stations (2000-2010)

Months	IKEJA		PORTHARCOURT		JOS		KANO		ILORIN	
	MEAN (ms^{-1})	STD (ms-^{1})	MEAN (ms^{-1})	STD (ms$^{-1)}$	MEAN (ms^{-1})	STD (ms$^{-1)}$	MEAN (ms^{-1})	STD (ms^{-1})	MEAN (ms^{-1})	STD (ms-^{1})
JAN	10.9	1.5	4.9	2.8	13.8	5.3	12.2	4.1	4.2	1.5
FEB	10.4	1.4	5.8	3.4	14.7	5.0	12.4	4.4	4.5	1.1
MAR	11.9	1.4	5.8	2.8	14.8	4.4	12,1	3.9	5.2	1.1
APRIL	11.7	1.7	5.8	2.9	14.0	3.9	11.5	3.4	5.4	1.6
MAY	9.8	1.2	5.6	2.9	12.2	4.4	11.2	3.2	5.2	1.2
JUNE	10.6	4.9	5.6	2.9	12.5	3.9	11.6	3.5	4.8	1.0
JULY	12.0	3.3	6.2	3.5	12.1	3.8	11.2	3.5	4.9	1.2
AUG	11.8	1.7	6.5	3.2	11.7	4.4	9.9	3.3	4.9	1.4
SEPT	11.6	1.6	5.8	2.7	11.4	3.9	8.9	2.9	3.9	0.9
OCT	8.9	0.5	4.9	3.5	13.5	4.4	9.1	2.9	3.8	0.9
NOV	8.9	0.9	4.1	2.6	15.6	4.9	11.1	3.1	3.5	1.0
DEC	9.2	1.2	4.6	2.7	14.5	4.1	11.6	3.4	3.6	1.2

The aggregate mean wind speed in Port Harcourt was found to be 5.51ms^{-1} and in Ikeja 10.63ms^{-1} in spite the fact that they are both coastal areas. The likely reason may be due to the difference in the elevation of the two locations. Ikeja is at a higher elevation (41m) and Portharcourt at a lower elevation (20m) above sea level. This may be responsible for different frictions experienced by the wind from these locations. The higher the elevation the reduced the friction and hence the higher the wind speed hence the significant difference noticed.

The probability density function (PDF) and the cumulative distribution function (CDF) for Ikeja and Port Harcourt varied between (0.097 – 0.129) and (0.51 – 0.58) with a deviation of 0.03 and 0.07 respectively which shows high degree of consistency. This indicates that the mean speeds in the locations can be utilized or planned upon since it is stable all

the year round. Citing a Wind farm there will be highly productive. The Weibull parameter for Ikeja varied between 10.80ms^{-1} in January and 10.59ms^{-1} in December while K varied between 2.76 and 2.61 within the same period. These results show the suitability of Ikeja for a possible site for wind farm installation for the purpose of electricity generation
.

Table 3
Cumulative Daily Mean Speed and Standard Deviation for the stations

MONTHS	STATIONS							
	IKEJA		PORTHARCOURT		JOS		KANO	
	MWS (m/s)	RATE (m/s)	MWS (m/s)	RATE (m/s)	MWS (m/s)	RATE (m/s)	MWS (m/s)	RATE (m/s)
JAN	6.35	0.108	4.80	0.010	13.63	0.011	12.11	0.019
FEB	9.46	0.034	6.19	-0.023	15.57	-0.064	13.24	-0.064
MAR	9.69	0.060	5.64	0.007	13.97	0.040	13.07	-0.060
APR	10.94	-0.035	5.40	0.055	14.17	-0.023	11.38	0.005
MAY	10.10	-0.049	5.50	0.010	13.19	-0.013	10.75	0.029
JUNE	7.80	0.064	5.98	-0.018	12.36	0.013	11.34	0.014
JULY	9.53	0.085	5.62	0.159	11.98	0.023	11.88	-0.054
AUG.	12.79	-0.063	6.24	0.014	13.04	-0.038	10.81	-0.068
SEPT.	10.48	-0.034	6.09	-0.007	11.02	0.029	8.47	0.018
OCT.	8.53	-0.030	5.16	-0.014	11.33	0.140	7.88	0.086
NOV.	7.50	-0.007	4.27	-0.009	15.54	0.009	10.46	0.035
DEC.	7.12	0.010	4.63	-0.001	15.30	-0.039	11.09	0.026

In Port Harcourt, the Weibull parameter C varied between 6.35ms^{-1} in January and 6.10 in December with deviation of 0.25ms^{-1} while the K value also ranged between 1.98 and 1.95 with maximum deviation of 0.03. The steadiness of the wind speed throughout the year shows that a suitable wind turbine can be installed there and possibility of having steady wind speed is certain.

*Inland***:** The Weibull parameter C for Ilorin varied between 6.0ms^{-1} in April and 3.85ms^{-1} in November while K value varied between 5.65 and 3.11 with a deviation of 2.54 (the highest of the stations under study). Gust in Kano over the study period occurred in January and about the middle of the month, the value was 14.8ms^{-1}. The least occurred in September at the tail end of the month and the value was 11.1ms^{-1}. Generally, the mean speed in Kano varied between 8.9ms^{-1} to 12.4ms^{-1} which occurred in September and January respectively.

Highest standard deviation of 4.4ms^{-1} occurred in January and the least of 2.9ms^{-1} occurred in September and October together. The highest mean wind speed occurred in February for both Kano and Jos. The values are 13.24m/s and 15.57ms^{-1} respectively. In Jos, there was a gradual decline in the speed till October with the values swinging between (14 – 11) ms^{-1}and it picked up from November and reached 15.30ms^{-1} by December. In Kano, the trend is similar except that the mean speed as at October was 7.88ms^{-1}, the least in all the months. However, it start to build up rapidly again from November (10.46 ms^{-1}) and increase till February.

The difference in the value of their mean wind speed may be due to the physical features in the two locations. Since they are exposed to same trade wind from the same direction the most likely reasons for the observed difference may be due to the following:
The elevation of Jos (1217a.s.l) is higher than that of Kano (481a.s.l). The local winds as a result of the topography of Jos can also contribute.

*Conclusion***:** In conclusion, it has been sufficiently established in this work that a sharp deviation from the point of view of many researchers about the wind potentials in Nigeria exist. The mean wind speed of the various locations in this study can conveniently support the installation of wind energy system. This outcome buttresses the fact that working with daily time series data of any meteorological parameter gives a more robust results than the average monthly data mostly used.

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