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Evaluation of Spatial and Temporal Characteristics of Wind and Wind Resources: A Case Study of Some Nigerian Cities

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ABSTRACT
Wind Energy available in 24 Nigeria cities is estimated using monthly wind speed data. The country is grouped into zones, namely: Coastal, Inland, Middle Belt and far Northern regions for effective characterization into areas of similar climatic conditions. To analyze the wind data, a check on the reliability is made to ensure adequacy for the estimation of spatial and temporal characteristics of the nation's wind resources. The long-term average wind speed, standard deviation, coefficient of variation, shape and scale factors and wind power densities are estimated for each city and averaged for zones. From the results generated, the classification of the 24 stations into class 1-7 is made. Classification indicates class 1 for the weakest location for siting of wind power generators to class 7 the strongest possible site for electric energy generator site. Sites with high altitude mostly in the Northern part of the country, such as Jos, Minna, Sokoto, Gusau, Katsina and Kano show potentials for investment in wind power generators. In the southern part of the country, possible offshore wind generator is advocated. For cities such as Ikeja, Enugu and Ikom, generators may be considered though not very economical when average yearly wind speed is the subject.

Keywords- wind speed, wind power, zones, seasons and characteristics.

1.0 INTRODUCTION:

Wind is described as air mass in motion and it is one of the climate parameters according to Ayoade (2004). This motion is caused by pressure differences across the earth's surface due to the uneven heating of the earth by solar radiation (Manwell, 2002).Energy for electricity and other uses in some part of Africa has been on the decline, and its demand has been on the increase irrespective of this fact. This fact aforementioned has prompted the supreme council of energy in Egypt to come up with a blue print geared towards improving/or improvising other potential and viable energy sources in the electricity sector thereby cutting down on dependents on fossil fuels (Abdel, 2003; Ibrahim, 2011) and to some scholars, wind is a viable option. Nigeria is growing rapidly with estimated population of over 140million (Eniayejuni, 2011) and will shoot up undoubtedly in the coming years. This will adversely affect the need for more energy and this calls for concern.In a quest to cushion the effects of human wants, lot of natural resources is required with most of these resources used for this purpose are not sustainable (Omole, 2014).Unfortunately, the daily activities of humans are hugely dependent on the natural resources available and their longevity somewhat proportionate to sustainable practise (Omole, 2014).

In Nigeria, as well as obtained elsewhere, it is necessary to determine the amount of air mass in motion to enable:

i). Proper design of Civil Engineering Structures.
ii). Planning for siting of wind turbines/generators
iii). Evaluation of productivity and cost effectiveness of a particular wind energy system based on available wind resources.
iv). Determine operational requirements such as resource information, load management, procedure and prediction of maintenance or system life.

Previous attempts aimed at determining the characteristics of wind energy in Nigeria have been insufficient as they are regional in nature. Such effort in literature include the works of (Ajayi, 2010; Ododo and Aidan, 2010; Abisoye, 2011; Odo and Akubue, 2012; Oyedepo et. al., 2012; Dikko and Yahaya, 2012).The current study is aimed at determining the country wide character variation of Nigeria wind both in terms of location and time. It involves determining the shape and scale factors of various sites and hence the wind power densities will be ascertained to enable classification of sites in terms of their wind densities. Furthermore, the coefficient of variation of different sites is determined including the relationship it has with wind speed. Both the relationship between wind speed, altitude, the monthly and annual variation are computed for the various zones viz: Coastal, Inland, Middle Belt and the Far-Northern region of Nigeria. The various characteristics of wind mentioned above gives an insight to the productivity of a turbine generator, hence, the need for proper location for their optimal and efficient utilization in electricity generation is required (Odo and Akubue, 2012). According to Houghton (2004), sites with average wind speed of 7.5m/s in Europe will generate wind power up to 250KW. Using this criterion alone will limit the number of stations for possible wind turbine generators in Nigeria, hence further analysis to point out other areas of possible siting of such systems. This research uses wind speed data from the Nigeria Meteorological Agency to determine available wind resources for each of the 24 stations in the Network. It further shows the zoning effects of the stations and how the area of same physical and climatic conditions affect wind speed and wind power density.

2.0 MATERIALS AND METHODS
THE STUDY AREA
STUDY SITE

The study site is about Nigeria, a country in West Africa. It is bordered in the North by Niger and the Sahara desert, West by Benin Republic, East by the Cameroun and Chad Republics and the South by the Atlantic Ocean. Physical environment of the country and climate of the study site is described next. Figure 1 below illustrates the country Nigeria with its border neighbours and wind zones.

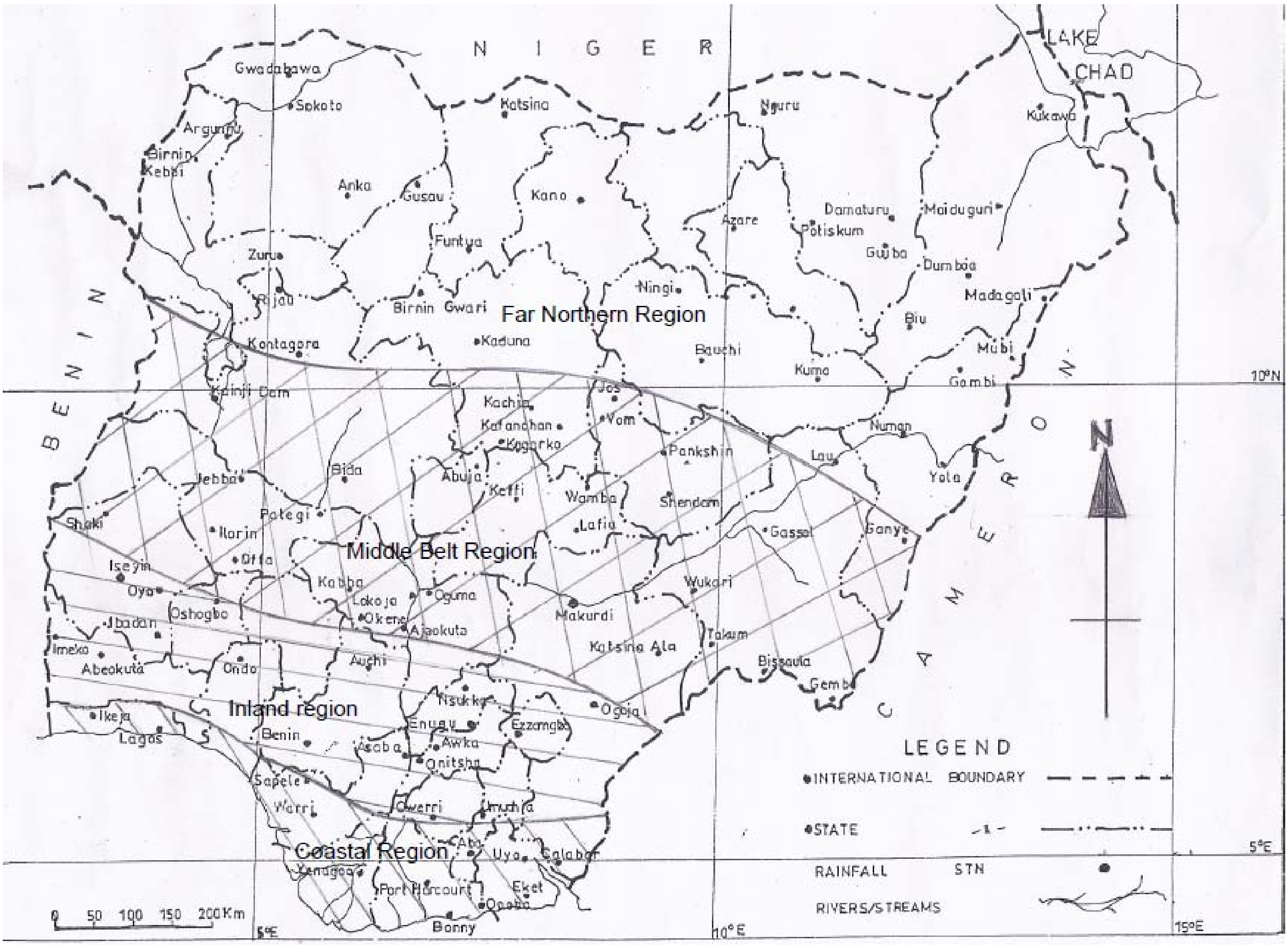

Fig. 1 Map of Nigeria showing zonal arrangement of areas of similar wind pattern

Physical Environment

Nigeria is located within latitudes $4° - 14°N$ and longitudes $3° - 15°E$ and has a total area of 923, 300 square kilometer. Outside Jos which has an attitude above 1200m, other areas of the country range from 5m in the coast to above 650m in the far north (see table 1 below). According to Iloeje (2009) the country has some of the oldest rocks in Africa, while newer deposits are being laid in the south by the River Niger. The main River basins of Nigeria are the Niger and Benue which drains into the Atlantic Ocean through the Niger Delta.

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Table 1: CLASSIFICATION OF WIND POWER DENSITY ACCORDING TO LOCATION IN NIGERIA

STATION	TOPOGRAPHICAL SITUATION	ALTITUDE (m)	DATA PERIOD	ANNUAL AVERAGE SPEED	STANDARD DEVIATION	COEFFICIENT OF VARIATION	SHAPE FACTOR (K)	SCALE PARAMETER (C)	YRLY AVE. WIND POWER DENSITY (W/m^2)	REMARKS
CALABAR	Coastal City	28	1995-2009	4.3	0.2	0.04	28	4	51	CLASS 1
IKEJA	Coastal City	36	1995-2009	5.7	0.5	0.09	14	5	150	CLASS 3
PORTHARCOURT	Coastal City	19	1995-2009	3.1	0.2	0.07	20	3	24	CLASS 1
WARRI	Coastal City	5	1995-2009	3.1	0.2	0.06	20	3	21	CLASS 1
BENIN	Inland City	82	1995-2009	3.2	0.1	0.03	43	3	21	CLASS 1
ENUGU	Inland City	167	1995-2009	5.7	0.3	0.04	24	5	122	CLASS 2
IJEBU-ODE	Inland City	78	1995-2009	3.3	0.3	0.09	14	3	30	CLASS 1
IKOM	Inland City	101	1995-2009	5.2	0.3	0.05	22	5	107	CLASS 2
OWERRI	Inland City	72	1995-2009	3.7	0.3	0.08	15	3	35	CLASS 1
ONITSHA	Inland City	68	1995-2009	4.0	0.1	0.03	55	4	43	CLASS 1
BIDA	Middle Belt City	111	1995-2009	2.6	0.2	0.07	16	2	12	CLASS 1
MINNA	Middle Belt City	272	1995-2009	5.8	0.7	0.11	10	5	182	CLASS 3
ABUJA	Middle Belt City	475	1995-2009	3.7	0.3	0.07	15	3	40	CLASS 1
JOS	Middle Belt City	1172	1995-2009	10.4	0.5	0.05	27	10	759	CLASS 7
LOKOJA	Middle Belt City	36	1995-2009	2.8	0.2	0.07	18	3	19	CLASS 1
SOKOTO	Northern City	285	1995-2009	7.2	0.3	0.04	32	7	266	CLASS 5
GUSAU	Northern City	432	1995-2009	6.5	0.6	0.09	13	6	214	CLASS 4
KADUNA	Northern City	603	1995-2009	5.4	0.3	0.05	23	5	114	CLASS 2
KATSINA	Northern City	526	1995-2009	7.8	0.7	0.09	14	7	396	CLASS 6
ZARIA	Northern City	650	1995-2009	6.1	0.5	0.08	15	6	176	CLASS 3
KANO	Northern City	484	1995-2009	9.1	0.4	0.04	30	9	521	CLASS 7
BAUCHI	Northern City	628	1995-2009	3.6	0.7	0.20	6	3	59	CLASS 1
MAIDUGURI	Northern City	300	1995-2009	5.6	0.3	0.06	24	5	127	CLASS 2
YOLA	Northern City	180	1995-2009	2.1	0.2	0.10	13	2	10	CLASS 1

Climate of Study Area.

Gbuyiro (2002) has observed that the climate of the country is relatively uniform with only the major Rivers indicating the differentiation of vegetation types and agricultural practice. The climate of Nigeria is classified into Rainy (April – October) and Dry (November – March) seasons, with each of the seasons lasting approximately six months. Annual rainfall ranges from 500m in the extreme north to 3000m along the coast. Nigeria is governed by high pressure southwest monsoon wind from the Atlantic in June-July pushing the inter-tropical front to the Sahara (northern) region of the country (Balogun, 1972; Iloeje, 2009). At this point the sun is around the tropic of cancer or close to it, hence high temperature ($25°C$ south and $40°C$ north) and low pressure. In December-January, on the other hand, the sun is at the tropic of Capricorn causing the wind system to shift to the south. At this time, the Sahara region becomes the high pressure belt forcing dry and cold wind to blow northeasterly to the low pressure area of the south. The wind system usually arrive the country about September and gradually spread throughout the country and last until March when the sun repeats the processes again. This process represents the wet and dry seasons of Nigeria.

The data used for this study are the monthly wind speed collected from the Nigeria Meteorological Agency, Lagos. This climate data is for period 1995-2009 for the twenty four (24) cities spread all over the country. The coefficient of variation of the data was determined to enable a check on the reliability and consistency of the data.

General Characteristics of Nigeria Wind

(Manwell et.al, 2002) has observed that wind energy varies in both time (second and month) and space (Km^2). Space variations are function of elevation above sea level and global and local geographical conditions. In Nigeria, regions of high altitude are observed to have higher wind speed, with Jos having the highest average wind speed in the country. For the twenty four stations in Nigeria where records of wind speed are kept, measurement is made with cup anemometers at 10m height. The nature of the wind in Nigeria is observed to follow the seasons, viz: Rainy and Dry seasons. To determine the characteristics of Nigeria wind, the country is divided into four zones namely: Far-North, Middle Belt, Inland and Coastal areas. The monthly and annual characteristics of the wind speed for each zone are determined using the following parameters.

Long-term average wind speed,

$$\bar{V} = \frac{1}{N}\sum_{i=1}^{N} Vi \qquad (1)$$

Standard Deviation,

$$\sigma = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(Vi - \bar{V})^2} \qquad (2)$$

Coefficient of variation,

$$Cv = \frac{\sigma}{\bar{V}} \qquad (3)$$

Shape factor,

$$k = \left(\frac{\sigma}{\bar{V}}\right)^{-1.086} \qquad (4)$$

and Scale factor,

$$c = \frac{\bar{v}}{\Gamma\left(1+\frac{1}{k}\right)} \quad (5)$$

Analysis of Wind Speed

a). Time Variation

The study looked at time variation in terms of Inter-annual and annual relationship.

i) Inter-annual

This shows the difference in wind speed overtime scale of more than one year, Manwell (2002). They have effect in the estimation of long-term wind for turbine production. Fourteen years record used for this work is adequate for long-term planning. Aspliden et al. (1986) has suggested that one year mean wind speed have accuracy of 10% and is within 90% confidence level.

ii) Annual

Significant variations exist within seasons (Wet and Dry) and monthly averaged wind speeds. The zonal average wind speed are calculated and plotted to show the seasonal variation.

b). Location Variation

Local topographical and ground cover variations affect wind speed. Hiester and Pennell (1981) have shown that difference of mean between two cities close to each other can be significant. Within each zone, a plot of the monthly and annual trend of wind against average wind speed is made. The plots are made for Coastal, Inland, Middle Belt and Far-Northern zones.

Estimation of Available Wind Power Resources

Available wind power density is calculated according to Ko et. al., (2010) and Oyedepo et al. (2012) as:

$$\frac{P}{A} = \frac{1}{2}\rho\frac{1}{N}\sum_{i=1}^{N} v_i^3 \quad (6)$$

Where ρ is the air density (assumed 1.225Kg/m^3), N the number of data, i the sample number and v is the wind speed. The computed wind power density is compared with the wind classification according to Manwell et al. (2002). Table 1 above shows the result of classification of wind power density for various stations.

3.0 RESULTS AND DISCUSSIONS

From table 1 above, it shows that the coefficient of variation of wind is lowest around the coast progressing up to the far-North where it is highest. This pattern has reversed analogous to the rainfall system of the country, which has high value in the coast and low rainfall in the North. Camberlin and Wairoto (1996) have shown that there exist a relationship between the Westerlies anomalous wind pattern of Western Kenya and the rainfall of the area. More work need to be done on Nigeria wind speed and rainfall pattern.

Another important observation to make is that most cities with high altitude especially in the far north have good/higher wind speed and hence wind power density. This is illustrated in figure 2 below where elevation values are plotted against average wind speed.

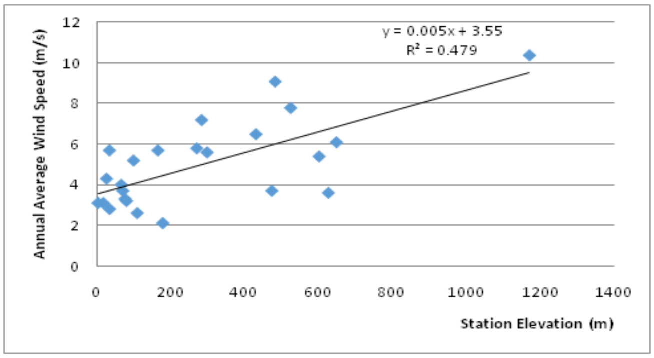

Fig 2: Annual average wind speed (m/s) against Station elevation (m)

However, Bauchi which is at the base of Jos plateau with an altitude of 628m is of class 1, the same be said of Yola, which is on the foot of Alantika mountains. Both Weibull scale and shape factors c and k, are related by a second degree polynomial as shown in figure 3 below:

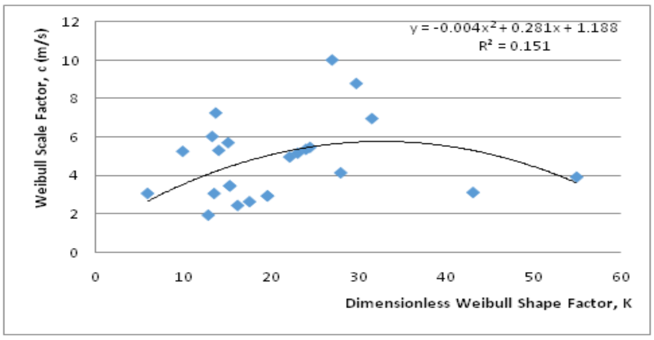

Fig 3: Scale factor c (m/s) against Shape factor

In Nigeria, average yearly wind speed varies from region to region. Analysis of this average indicates that Coastal area has 4.1m/s, Inland cities has 4.2m/s, Middle Belt area 5.0m/s, and Far-Northern cities 5.9m/s. This is illustrated in figure 4a-4d below:

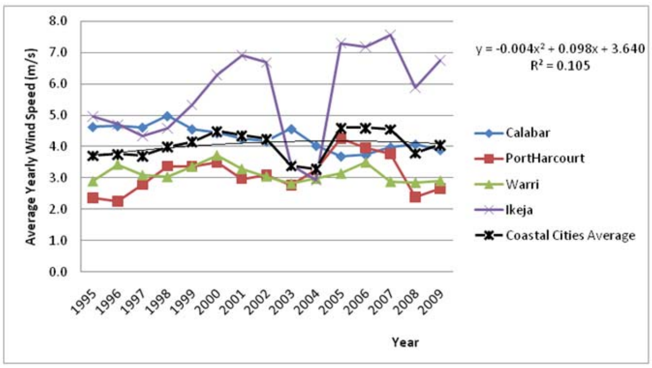

Fig 4a: Trend showing Annual average wind speed (m/s) for Coastal cities against year

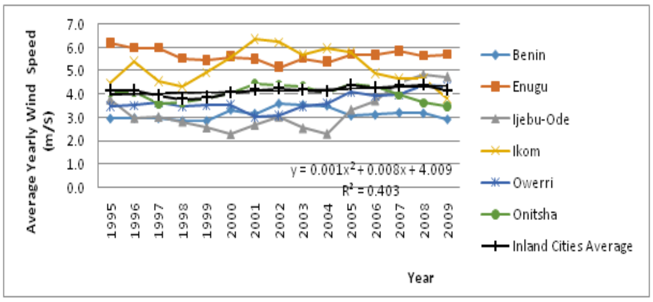

Fig 4b: Trend showing Annual average wind speed (m/s) for Inland cities against year.

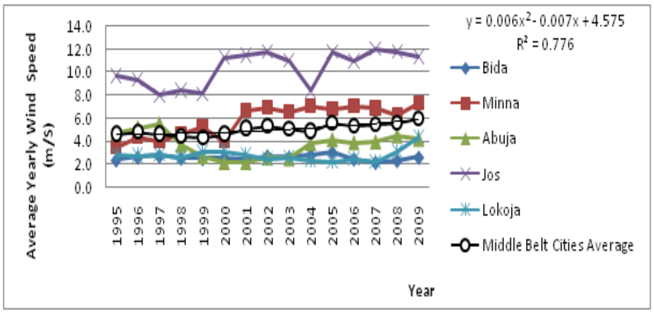

Fig 4c: Trend showing Annual average wind speed (m/s) for Middle against year Belt cities.

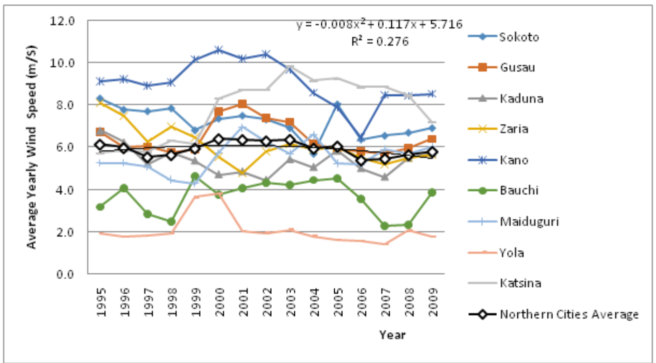

Fig 4d: Trend showing Annual average wind speed (m/s) for Northern cities against year.

Inland and Middle Belt areas have strong correlation coefficient above 0.8 while Coastal and Far-Northern zone show weak correlation below 0.25.This study has also show that Nigeria wind system exhibit bimodal peak pattern especially in the Coastal and the Inland cities corresponding with the rainfall seasons of the country while the middle belt and far-north has unimodal peak mode. From figure 5a-5d below, the Coast and Inland cities have their minimum wind speed in November at an average of 3.3m/s and 3.2m/s respectively. The maximum wind speed for the zones are however highest in April and August with values of 4.6m/s for both months in the Coast and 4.9m/s and 4.3m/s for Inland cities. The middle belt and far north have minimum wind speed of 4.1m/s and 4.4m/s respectively in October and maximum of 6.0m/s and 6.8m/s respectively in April.

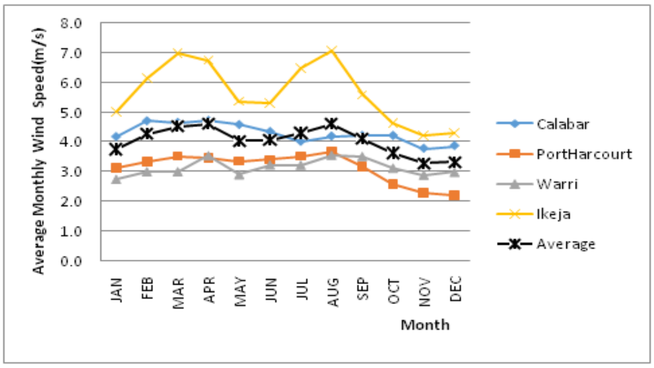

Fig 5a: Seasonal variation of Average Monthly wind speed (m/s) for Coastal cities against Months of the year.

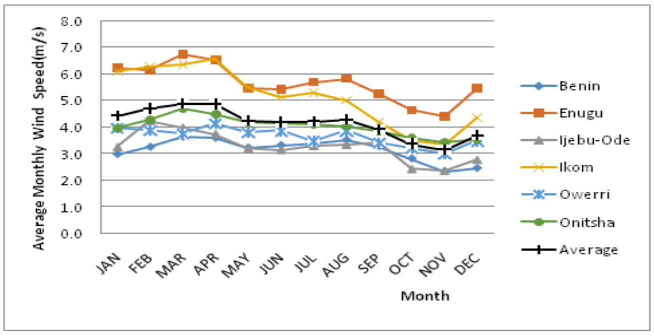

Fig 5b: Seasonal variation of Average Monthly wind speed (m/s) for Inland cities against Months of the year.

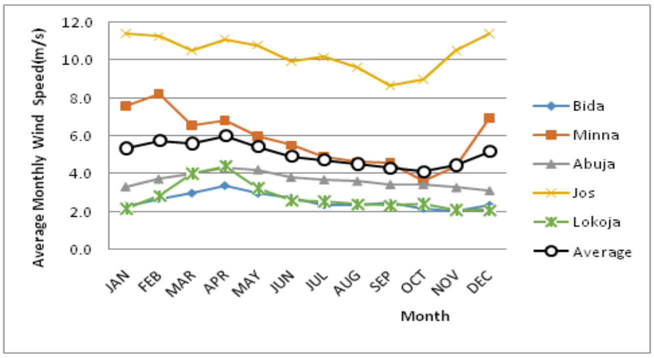

Fig 5c: Seasonal variation of Average Monthly wind speed (m/s) for Middle Belt cities against Months of the year.

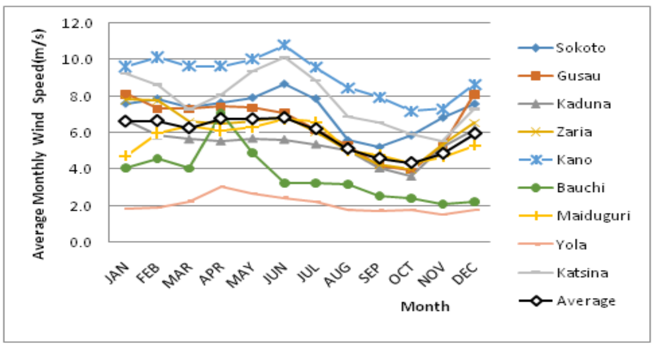

Fig 5d: Seasonal variation of Average Monthly wind speed (m/s) for Far-Northern cities against Months of the year.

For all the regions, as shown from the graphs above, the maximum wind speed occurs in April-May which is the onset of Rainy season and minimum in October-November the start of Dry season in Nigeria.

4.0 CONCLUSIONS:

From the computed wind parameters of the 24 stations in Nigeria, it is obvious that:-

i) Most of the Coastal regions are of class 1, that is, poor wind power density. Ikeja in the South-western part of the country is however an exception with good wind power density. Hence good location for siting wind power generators.

ii) In the Inland region most cities show poor wind power density of class 1. Enugu and Ikom are however in class 2.

iii) Minna and Jos are good sites for power generators with class 3 and class 7 wind power densities respectively. The presence of high altitude in Jos may explain the very high wind power density of the area. From this study, Jos presents the best choice for location of wind generator systems as it has the lowest average wind speed of 8.7m/s in September and hence good year round electricity production.

iv) The worst wind power density location in the far Northern part of Nigeria is located in the North Eastern part of the region with class 1 classification. On the average, most far-Northern cities can be good locations for wind energy generators. Many cities bordering the Sahara desert with poor or no electricity can be supplied through this renewable energy source at minimal cost.

v) Coastal locations may be considered for offshore wind farms if further studies on this are conclusive.

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