Available online www.ejaet.com

European Journal of Advances in Engineering and Technology, 2020, 7(1):21-31

Research Article ISSN: 2394 - 658X

# Harnessing Wind Energy Potential for Power Generation in Nigeria

**E. O. Ogolo, J. O. Apata and O. S. Ojo***

*The Federal University of Technology, Department of Physics, Akure*
*Corresponding Author: ojoso@futa.edu.ng*

**ABSTRACT**
*This study analyzed and characterized the wind energy potentials over Nigeria using the 12-hourly synoptic wind speed data span 2006 – 2010 at different atmospheric heights (10m, 30m, 60m and 100m). The wind speed data were retrieved from ERA-Interim reanalysis database of the European Centre for Medium-Range Weather Forecast (ECMWF). The twelve stations were further grouped into four climatic regions (Coastal, Derived savannah, Guinea savannah and Sahel savannah). Weibull statistical distribution function was employed to analyze and characterize the wind profile of the stations. The results showed that the wind energy potential is maximum in the Sahel savannah region and minimum in the Derived savannah region. Also, the maximum wind power density is at 100m height and minimum at 10m height in all the regions and stations considered. The results indicate that wind energy has a viable potential as a renewable energy to generate electricity at the height of 100 m in all the studied regions and stations. Therefore, from this research, it is observed that Nigeria is a good base for the generation of electricity from wind energy especially at the 12:00 hours when there is occurrence of intensive wind speed at 100m isobaric height. It can be concluded that the higher the height, the better the reception of wind energy by the wind conversion systems*

**Key words:** Wind energy potential, Wind power, Synoptic, Weibull, Nigeria

## INTRODUCTION

Energy is an essential and integral ingredient for socio-economic and technological development of a nation [1]. It is one of the mainstays of the economy and one of the most important factors of national development. Despite the abundance of energy resources in Nigeria, the country is still in short supply of electrical power. Only about 40% of the nation's over 140 million has access to grid electricity [2]. Even the electricity supply to the consumers that are connected to the grid is erratic. Nigeria's energy is supplied from different hydro-power and thermal power stations. The country is located between longitude 3°E and 15°E and latitude 4°N and 15°N, and has two major seasons, wet and dry. The seasonality makes water availability at the different hydro-power stations variable, leading to intermittent/irregular supply at times of low water levels. Also, the thermal stations have been bedeviled by lack of adequate supplies of natural gas from various Niger Delta gas wells, thereby making continuous energy production from these installations difficult [3]. However, current energy production within Nigeria is not sufficient due to fluctuations in its availability and poor maintenance of generating equipment [4].

Due to these challenges, most Nigerians are now at the mercy of private alternative power through the use of diesel and petrol generators. The emissions from these generating sets have also been subjects of critical global discussions because they release a lot of greenhouse gases to the atmosphere [5]. Thus, Nigeria still has a long way to go in achieving energy sufficiency. Therefore, the present energy generation needs augmentation with the aim of maximizing sustainable energy production [4]. However, one way out for the nation energy crisis is in energy diversification, increasing the present energy sources which have been grossly inadequate and inconsistent for reliable power supply to include renewable energy resources, especially wind energy. These resources such as wind are cheap, easily accessible, naturally applicable, enormously available, environmentally friendly, non-toxic and non-depleting source of valuable and usable energy [4].

Various studies [6-8] have been carried out on how to harness the wind energy potentials for power generation in Nigeria. Study had also been carried out and it was established that wind speeds are generally weak in the south except for the coastal regions and offshore, which are windy. Inland, the wind was reported strongest in the hilly regions of the North, while the mountainous terrains of the middle belt and northern fringes demonstrated high potential for great wind energy harvest. Hence, the main objectives of this study are to characterize the wind speed intensity of some selected locations in Nigeria using Weibull distribution parameters, to obtain the wind power potential for different pressure height in the selected locations over Nigeria and to observe the variation of the wind energy potential over the twelve (12) stations at synoptic hours of 00:00 and 12:00 and also at different height across Nigeria.

## MATERIALS AND METHOD

A 5-year (2006-2010) 12-hourly mean wind speed data at different atmospheric heights and also at different synoptic hours of 00:00 and 12:00 were retrieved from ERA-Interim reanalysed data set for twelve stations as shown in Figure 1 over Nigeria and the stations were further grouped into four climatic regions (Coastal, Derived, Guinea and Sahel) as shown in Table 1.

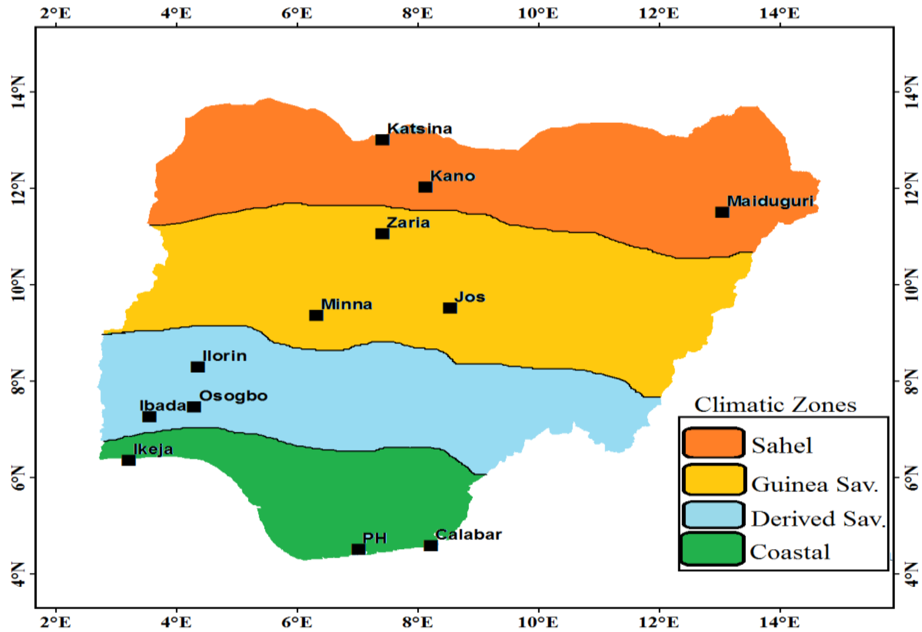



**Fig. 1** A map of Nigeria showing the selected stations (Source: Ojo and Tawose, 2017)

**Table -1 Geographical Coordinates of the Stations Used in the Study**

| Station | Latitude ($^0$N) | Longitude ($^0$E) | Air Density (kg.m$^{-3}$) | Altitude (m) | Climatic Region |
|---|---|---|---|---|---|
| Ikeja | 06.35 | 03.20 | 1.22 | 39.40 | Coastal Region |
| Port-harcourt | 04.51 | 07.01 | 1.23 | 19.50 | |
| Calabar | 04.58 | 08.21 | 1.21 | 61.90 | |
| Ibadan | 07.26 | 03.54 | 1.21 | 227.20 | Derived Region |
| Ilorin | 08.29 | 04.35 | 1.21 | 307.40 | |
| Osogbo | 07.47 | 04.29 | 1.19 | 302.00 | |
| Minna | 09.37 | 06.32 | 1.17 | 256.40 | Guinea Region |
| Jos | 09.52 | 08.54 | 1.22 | 1295.00 | |
| Zaria | 11.06 | 07.41 | 1.20 | 110.90 | |
| Maiduguri | 11.51 | 13.05 | 1.18 | 358.80 | Sahel Region |
| Katsina | 13.01 | 07.41 | 1.15 | 513.00 | |
| Kano | 12.03 | 08.12 | 1.16 | 472.50 | |

### Data Analysis

Weibull statistical distribution function was employed to analyze and characterise the wind profile in the stations and four climatic regions in Nigeria. The Weibull parameters (c and k) were estimated by using the Empirical method with mean wind speed and its variance as shown in equation (1) and (2) according to Gupta and Biswas [9]; and Jowder, [10]:

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

$$c = \frac{v_m}{\Gamma\left(1 + \frac{1}{k}\right)} \quad (2)$$

where: c = the Weibull scale parameter (m/s), k = the dimensionless Weibull shape parameter σ = standard deviation and $v_m$ = mean wind speed (m/s).

The wind power density (W/m$^2$) which is the quantitative measure of the wind energy available at any location was estimated from the equation (3) in terms of Weibull parameters according to Nze-Esiaga and Okogbue [11]:

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

where: p(v) = wind power density (W/m$^2$), ρ = the air density at the site (kg/m$^3$), Γ = gamma function.

## RESULTS AND DISCUSSION

In using wind speed to generate Weibull parameters, the stations with highest wind speed have the highest scale parameter. Meanwhile it has been established in the literature that the intensity of wind speed in any location depends on the Weibull parameters [12]. The value of the scale parameter, c, shows the high intensity of the wind, while the shape parameter, k, indicates stability of the wind distribution in a given location and the tendency of producing high wind energy potential in the such area.

At 00:00 hrs. (Table 2) in the Coastal stations, it was observed that Ikeja has the highest value of scale parameter in all the heights considered, showing that it has the highest wind energy potential compared with the other two stations, while the same situation was observed in Ilorin, Zaria and Kastina in the Derived Savannah stations, Guinea Savannah stations and Sahel savannah stations respectively. This observation may be attributed to night time stable condition which is in agreement with Oluleye and Ogungbenro [13] that at night time, the atmosphere become stable, then wind speed will be high and wind turbine will produce more power than expected most especially at 100 m height due to the fact that the wind speed increases with height above the ground [7].

The observation at 12:00 hrs. (Table 3) was a little bit different in Derived savannah stations where Osogbo overtook Ilorin as the maximum scale parameter in all the heights considered. The general reason for high scale parameter in Ikeja, Osogbo, Zaria and Katsina in their respective region across the heights when compared to other stations at 12:00 hr can be attributed to the variation in the latitudinal distribution of wind speed caused by the solar heating of the surface [14]. Also, the observation could also be linked to sea breeze [15].

The results presented in Tables 4-5 are Weibull parameters for the regions at different heights and also at different synoptic hours. It was observed in all the hours (Table 4-5) considered, Sahel savannah region has the highest Weibull scale parameters in all the heights considered compared to the other three regions. This shows that Sahel savannah has the highest wind energy potential. This may be linked to its high receptive solar radiation at this hour of the day, hence bringing forth high wind speed at the region. Also, Sahel savannah region is a desert region characterized with low vegetation, open land and no source of wind breaker [16].

**Table -2 Weibull Parameters of the Wind Speed for Different Heights at 00:00 hrs. for all the Stations using Empirical method**

| **00:00HR** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 10 m | | 30 m | | 60 m | | 100 m | |
| **STATIONS** | c (m/s) | k | c (m/s) | k | c (m/s) | k | c (m/s) | k |
| **COASTAL STATIONS** | | | | | | | | |
| PHC | 0.18 | 6.00 | 0.28 | 6.21 | 0.47 | 6.86 | 0.86 | 7.37 |
| IKEJA | 0.87 | 3.54 | 1.24 | 3.57 | 2.11 | 3.64 | 3.83 | 4.52 |
| CALABAR | 0.30 | 4.98 | 0.47 | 5.63 | 0.80 | 5.75 | 1.44 | 6.98 |
| **DERIVED SAVANNAH STATIONS** | | | | | | | | |
| IBADAN | 0.24 | 5.69 | 0.38 | 6.28 | 0.64 | 6.69 | 1.17 | 6.96 |
| ILORIN | 0.32 | 2.20 | 0.49 | 4.56 | 0.84 | 5.48 | 1.53 | 5.90 |
| OSOGBO | 0.27 | 5.00 | 0.41 | 5.47 | 0.71 | 6.00 | 1.28 | 6.36 |
| **GUINEA SAVANNAH STATIONS** | | | | | | | | |
| MINNA | 0.52 | 5.14 | 0.81 | 5.32 | 1.39 | 5.58 | 2.52 | 6.14 |
| JOS | 0.51 | 6.32 | 0.80 | 6.44 | 1.37 | 6.68 | 2.48 | 6.96 |
| ZARIA | 0.69 | 4.23 | 1.08 | 4.42 | 1.84 | 4.65 | 3.33 | 5.23 |
| **SAHEL SAVANNAH STATIONS** | | | | | | | | |
| MAIDUGURI | 0.75 | 6.32 | 1.17 | 6.54 | 2.00 | 6.76 | 3.63 | 6.88 |
| KATSINA | 0.76 | 6.10 | 1.19 | 6.30 | 2.02 | 6.58 | 3.67 | 6.70 |
| KANO | 0.69 | 6.56 | 1.08 | 6.66 | 1.84 | 6.88 | 3.33 | 6.96 |

**Table -3 Weibull Parameters of the Wind Speed for Different Heights at 12:00hrs. for all the Stations using Empirical method.**

| 12:00HR | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 10 m | | 30 m | | 60 m | | 100 m | |
| **STATIONS** | c (m/s) | k | c (m/s) | k | c (m/s) | k | c (m/s) | k |
| **COASTAL STATIONS** | | | | | | | | |
| PHC | 0.20 | 2.21 | 0.31 | 2.31 | 0.53 | 2.51 | 0.96 | 3.47 |
| IKEJA | 0.64 | 1.50 | 1.00 | 1.62 | 1.71 | 2.00 | 3.10 | 3.21 |
| CALABAR | 0.34 | 2.15 | 0.53 | 2.23 | 0.91 | 2.35 | 1.65 | 3.35 |
| **DERIVED SAVANNAH STATIONS** | | | | | | | | |
| IBADAN | 0.23 | 1.46 | 0.36 | 1.64 | 0.62 | 1.76 | 1.12 | 1.96 |
| ILORIN | 0.22 | 2.01 | 0.35 | 2.21 | 0.59 | 2.33 | 1.08 | 2.71 |
| OSOGBO | 0.25 | 1.38 | 0.40 | 1.56 | 0.68 | 1.66 | 1.23 | 1.78 |
| **GUINEA SAVANNAH STATIONS** | | | | | | | | |
| MINNA | 0.43 | 1.35 | 0.68 | 1.57 | 1.15 | 2.35 | 2.09 | 3.89 |
| JOS | 0.22 | 2.11 | 0.35 | 2.23 | 0.59 | 2.51 | 1.08 | 3.91 |
| ZARIA | 0.77 | 1.18 | 1.20 | 1.38 | 2.04 | 2.16 | 3.70 | 3.87 |
| **SAHEL SAVANNAH STATIONS** | | | | | | | | |
| MAID | 0.77 | 1.28 | 1.20 | 2.36 | 2.05 | 2.78 | 3.72 | 3.88 |
| KATSINA | 0.79 | 1.21 | 1.23 | 2.31 | 2.10 | 2.71 | 3.81 | 3.83 |
| KANO | 0.66 | 1.66 | 1.03 | 2.67 | 1.76 | 2.98 | 3.20 | 3.92 |

**Table -4 Weibull Distribution Parameters for each Region at 00:00 hrs**

| **00:00HR** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **10 m** | | **30 m** | | **60 m** | | **100 m** | |
| | **c (m/s)** | **k** | **c (m/s)** | **k** | **c (m/s)** | **k** | **c (m/s)** | **k** |
| COASTAL | 0.45 | 5.23 | 0.66 | 5.44 | 1.13 | 6.06 | 2.04 | 6.41 |
| DERIVED SAVANNAH | 0.27 | 6.33 | 0.43 | 6.50 | 0.73 | 6.74 | 1.33 | 6.85 |
| GUINEA SAVANNAH | 0.57 | 4.96 | 0.90 | 5.39 | 1.53 | 5.64 | 2.77 | 6.29 |
| SAHEL SAVANNAH | 0.73 | 4.84 | 1.15 | 5.14 | 1.95 | 5.42 | 3.54 | 6.11 |

**Table -5 Weibull Distribution Parameters for the Climatic Regions at 12:00 hr**

| **00:00HR** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **10 m** | | **30 m** | | **60 m** | | **100 m** | |
| | **c (m/s)** | **k** | **c (m/s)** | **k** | **c (m/s)** | **k** | **c (m/s)** | **k** |
| COASTAL | 0.39 | 1.62 | 0.62 | 2.05 | 1.05 | 2.34 | 1.91 | 3.88 |
| DERIVED SAVANNAH | 0.24 | 1.95 | 0.37 | 2.45 | 0.63 | 2.82 | 1.14 | 3.89 |
| GUINEA SAVANNAH | 0.47 | 1.55 | 0.74 | 1.80 | 1.26 | 2.29 | 2.29 | 3.34 |
| SAHEL SAVANNAH | 0.74 | 1.38 | 1.16 | 1.73 | 1.97 | 1.92 | 3.57 | 2.15 |

Figure 2 shows the monthly variation of the wind power density (WPD) at 00:00 hrs. for 100 m height over all the selected stations in Coastal, Derived savannah,Guinea savannah and Sahel savannah regions.

In Coastal stations (Port-Harcourt, Ikeja and Calabar), the maximum WPD was observed in Ikeja with 125.11 W/m$^2$in the month of July, while the minimum was in Port-Harcourt with 25.05 W/m$^2$ in September. The reason may be as a result of the location which is closer to the Atlantic Ocean, thus the sea breeze blows into the city which agrees with Nze-Esiaga and Okogbue [11]. In Derived savannah region, the highest month of occurrence was in March with 30.26 W/m$^2$ in Ilorin, while the least was in Ibadan with 3.68 W/m$^2$ in the month of October. This may be attributed to night time mountain breeze [17]. However, Guinea savannah region has its highest peak value in Zaria in the month of June with 91.60 W/m$^2$ and the least was observed in Minna with 30.64 W/m$^2$ in August. Sahel Savannah region has its maximum in Katsina with 90.16 W/m$^2$ in June, while the minimum is in Kano with 27.17 W/m$^2$ in September. The observation in Guinea and Sahel savannah stations at 00:00 hour of the day could be attributed to convection current [18].

Figures 3-5 show the monthly variation of the WPD at 00:00 hrs. for 60 m, 30 m and 10 m heights respectively over all the selected stations in Coastal, Derived savannah,Guinea savannah and Sahel savannah regions. The observation in these Figures (3-5) show the same situation and also follow the same pattern with the observation in Figure 2 as earlier discussed. The only differences observed are the minimum and the maximum values for each station and also the pattern observed in Port-Harcourt and Ibadan at 10 m height (Figure 5) which are not rising. This may be as a result of the obstruction to the wind by vegetation or hills [19].

Figure 6 shows the monthly variation of WPD at 12:00 hrs. for 100 m height over all the selected stations in Coastal, Derived savannah, Guinea savannah and Sahel savannah regions.

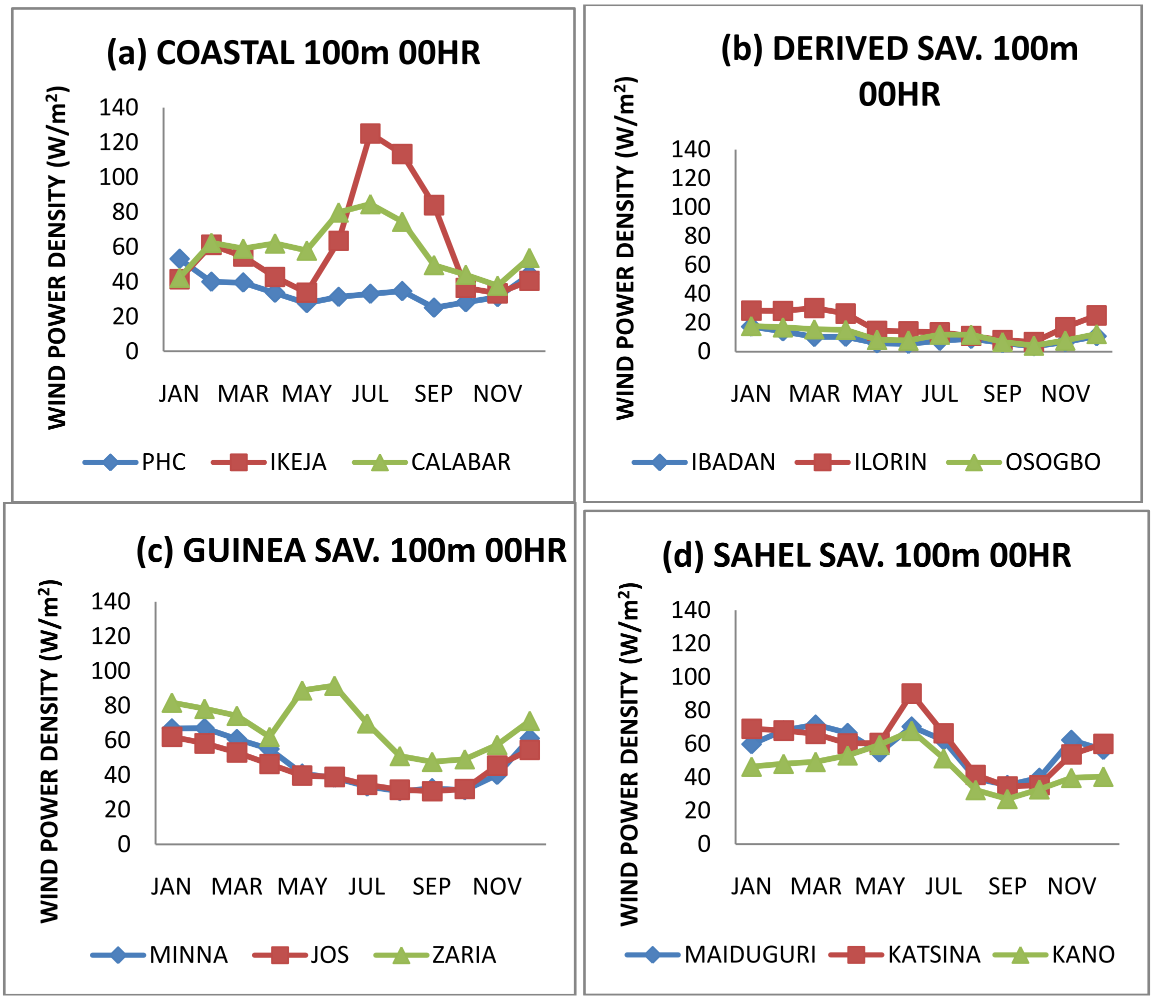
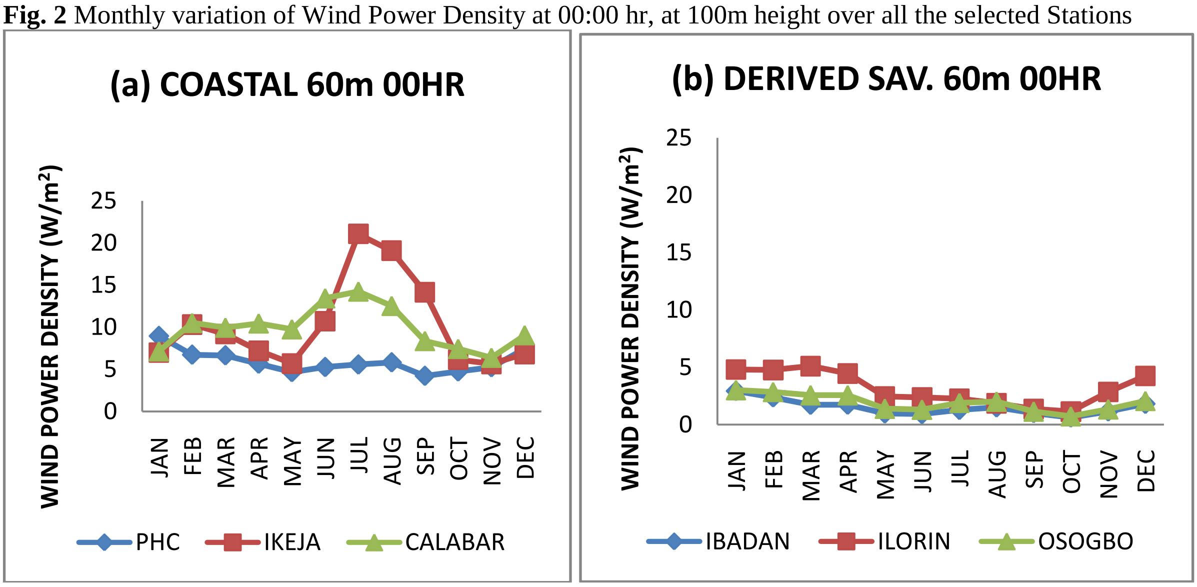



**Fig. 2** Monthly variation of Wind Power Density at 00:00 hr, at 100m height over all the selected Stations



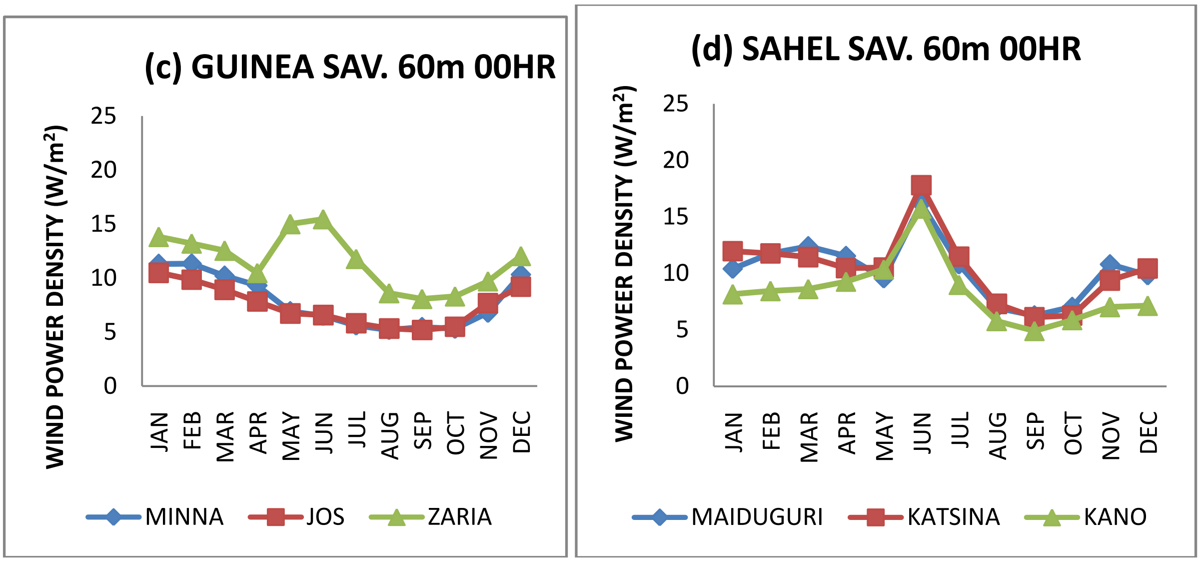



**Fig. 3** Monthly variation of Wind Power Density at 00:00 hr, at 60m height over all the selected Stations

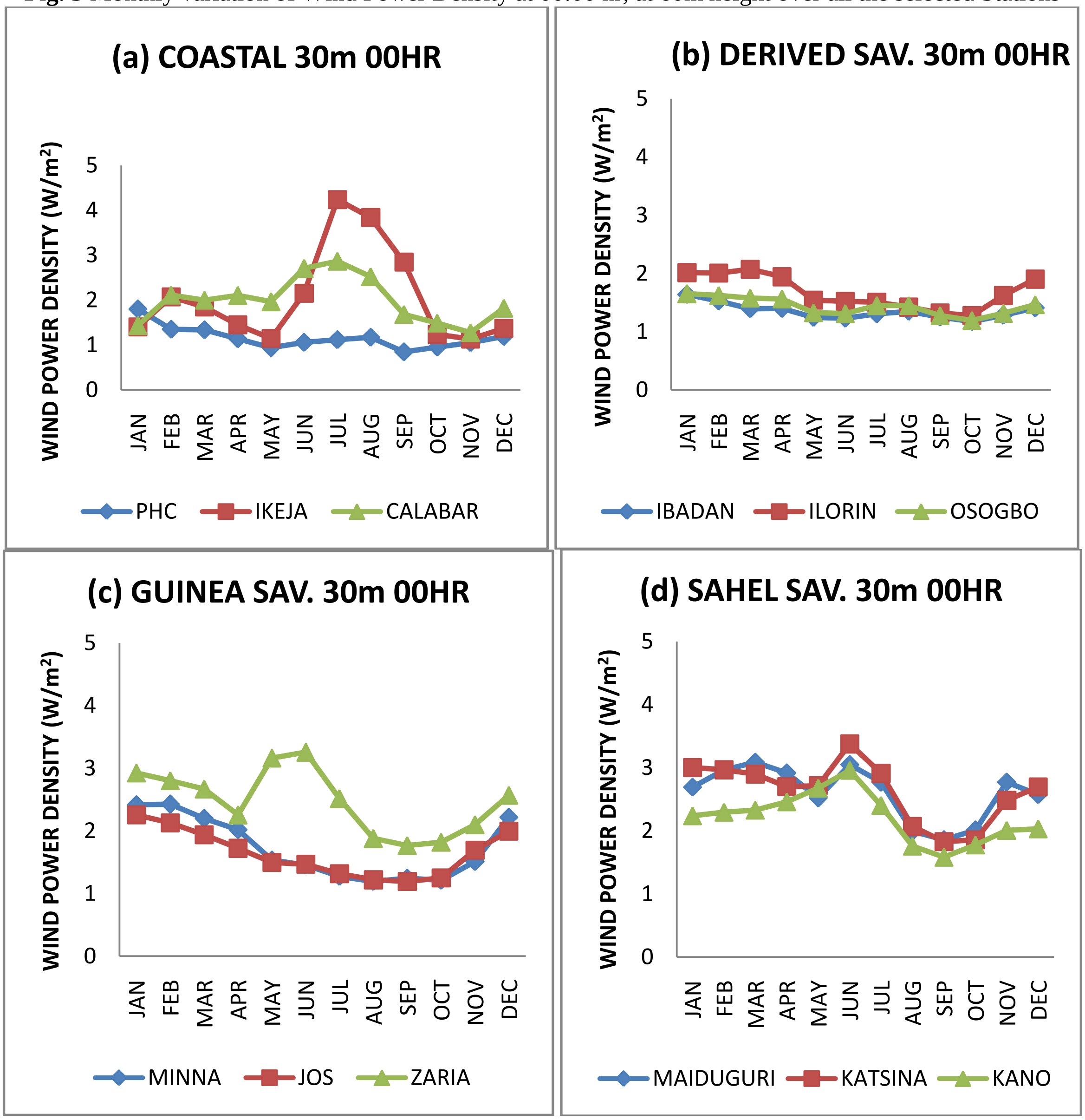



**Fig. 4** Monthly variation of Wind Power Density at 00:00 hr, at 30m height over all the selected Stations

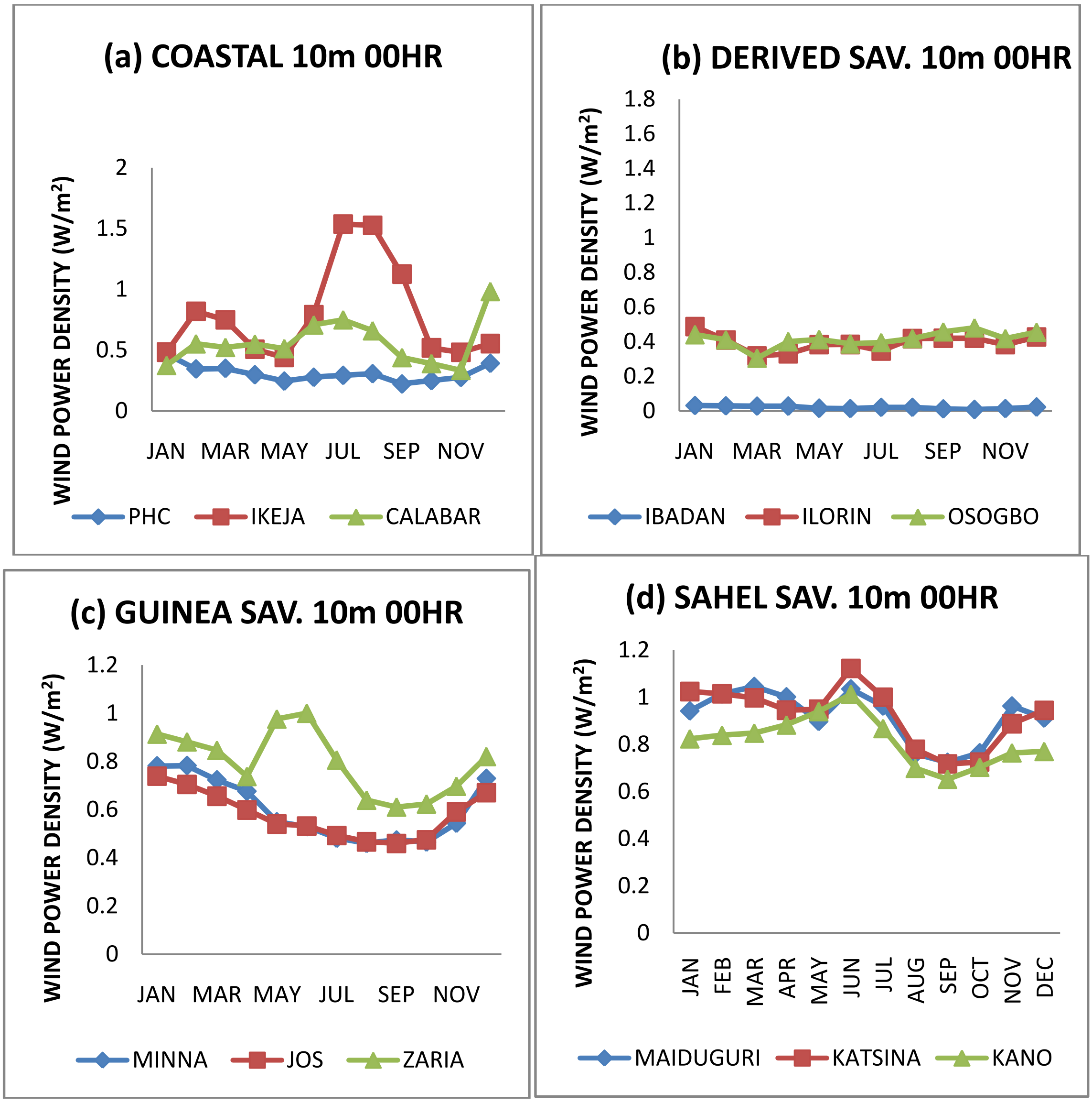
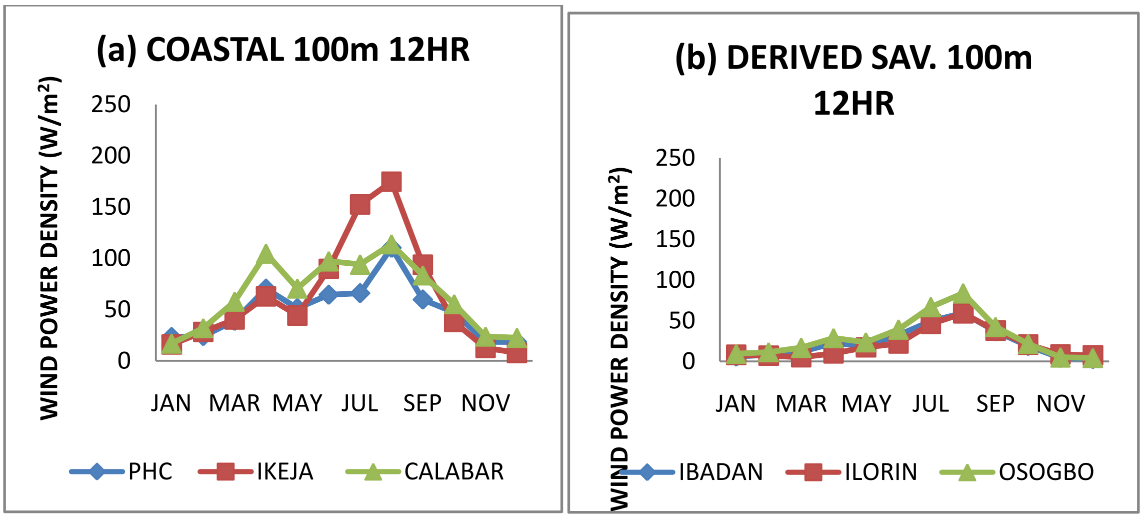



**Fig. 5** Monthly variation of Wind Power Density at 00:00 hr, at 10m height over all the selected Stations



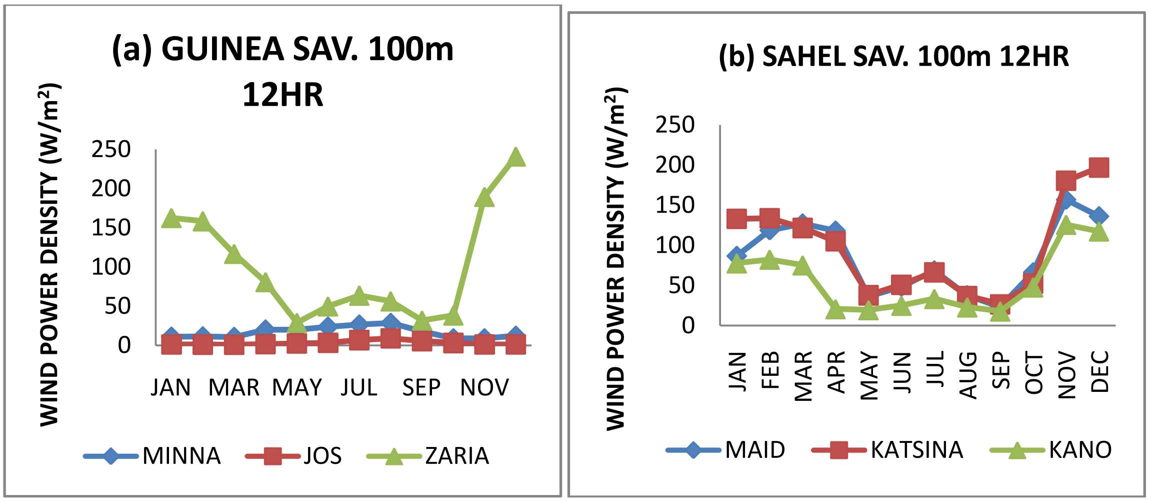
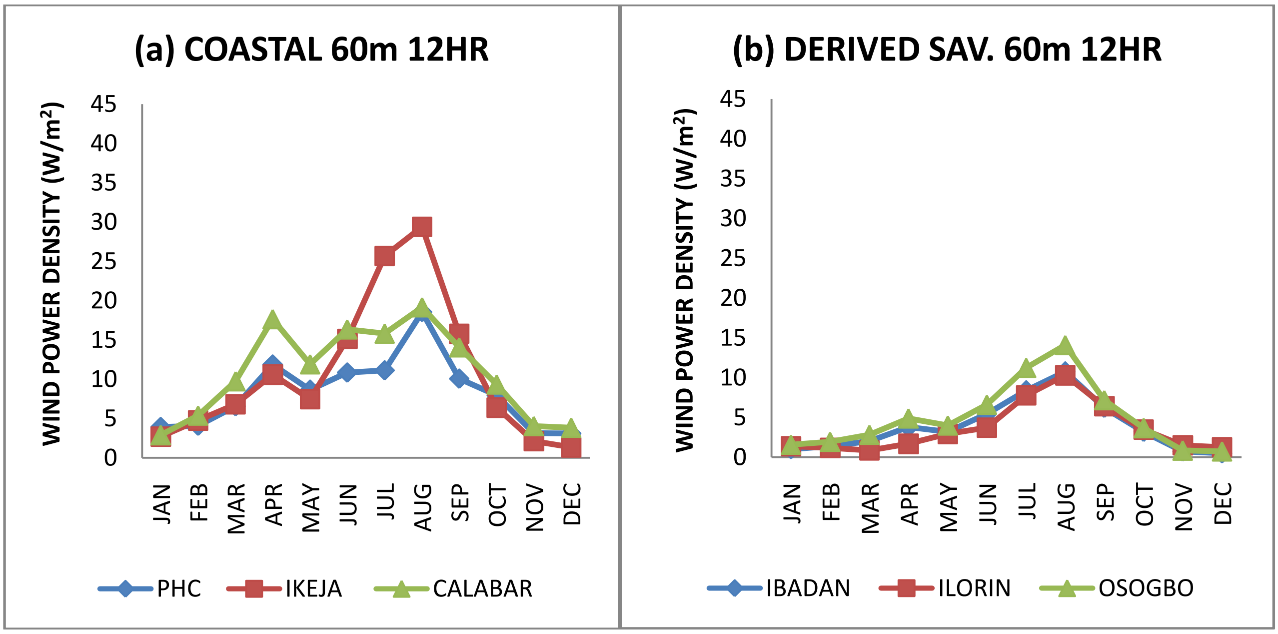



**Fig. 6** Monthly variation of Wind Power Density at 12:00 hr, at 100 m height over all the selected Stations

In the Coastal stations which comprises of Port-Harcourt, Ikeja and Calabar, it was observed that Ikeja has the highest and the least WPD among the three stations with 174.69 W/m$^2$ in the month August and 7.89 W/m$^2$ in December respectively. Though, the three stations are in the same region and also characterized with same climatic factors such as temperature, sunshine etc which could be a determinant to the wind energy generated in the stations [18]. It may also be as a result of sea breeze [20]. Also in the Derived savannah region at this same hour of the day, the highest wind power density was observed in Osogbo with 83.77 W/m$^2$ in August and the least in Ibadan in the month of December with 2.96 W/m$^2$. Zaria has the highest in the Guinea savannah region with 241.19 W/m$^2$ in December due to high temperature associated with the month, while stations like Minna and Jos did not rise, most especially Jos. This may be linked to the decrease in temperature at this period [18]. In Sahel savannah region which is made up of Maiduguri, Katsina and Kano, it was noticed that Katsina has the maximum WPD in the month of December with 196.88 W/m$^2$ and the minimum in Kano with 17.89 W/m$^2$ in September.

Wind energy potential can be harnessed properly in Coastal region, Sahel and Guinea savannah region as supported by Akinbami [14], because anywhere and each time there are differences in atmospheric (air) pressure, there will be a wind. The winds may be even stronger where the difference in the air pressure is greater.

Figures (7-9) show the distribution of the WPD at 12:00 hrs. for 60 m, 30 m, and 10 m heights respectively over all the selected stations in Coastal, Derived savannah, Guinea savannah and Sahel savannah regions. The observation here is the same as that of Figure 6 discussed above. But it was noticed that at each height, wind energy potential was decreasing compared to the observation in Figure 6.



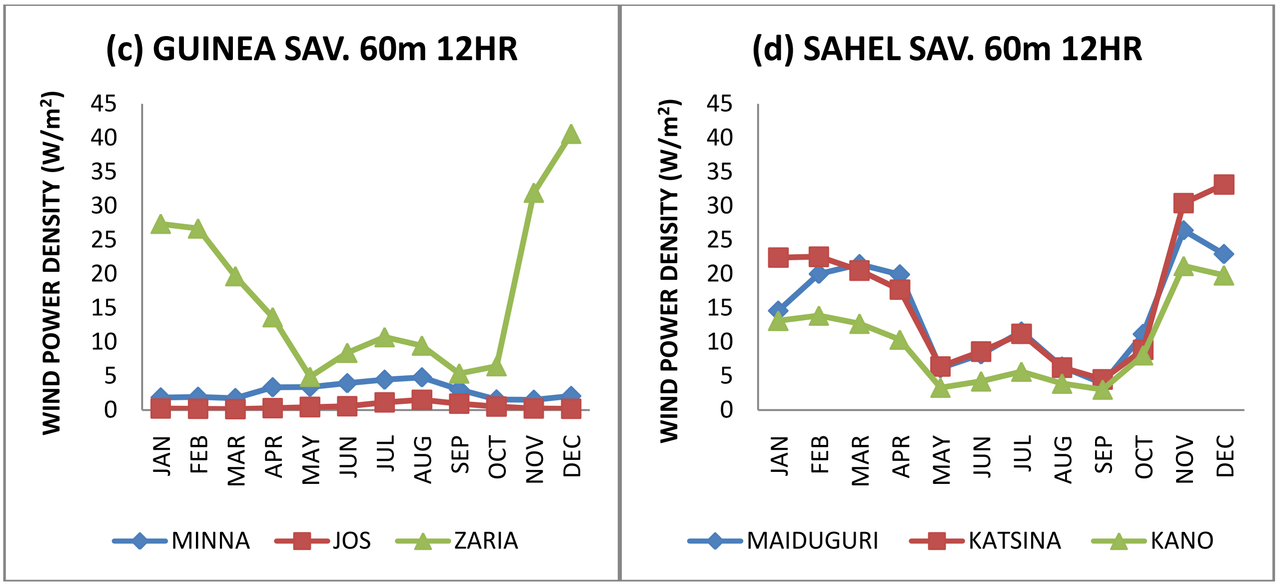



**Fig. 7** Monthly variation of Wind Power Density at 12:00 hr, at 60 m height over all the selected Stations

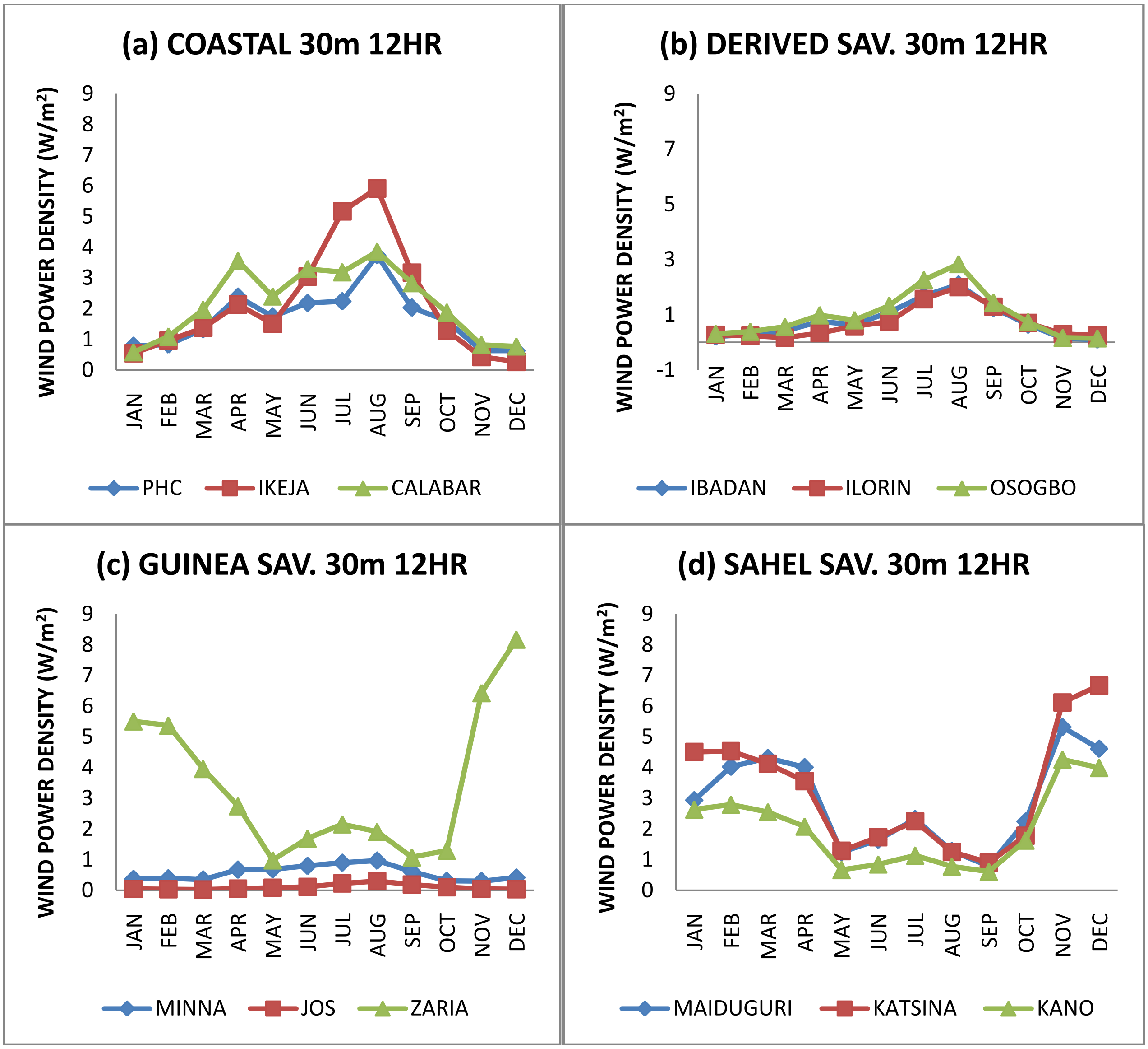



**Fig. 8** Monthly variation of Wind Power Density at 12:00 hr, at 30 m height over all the selected Stations

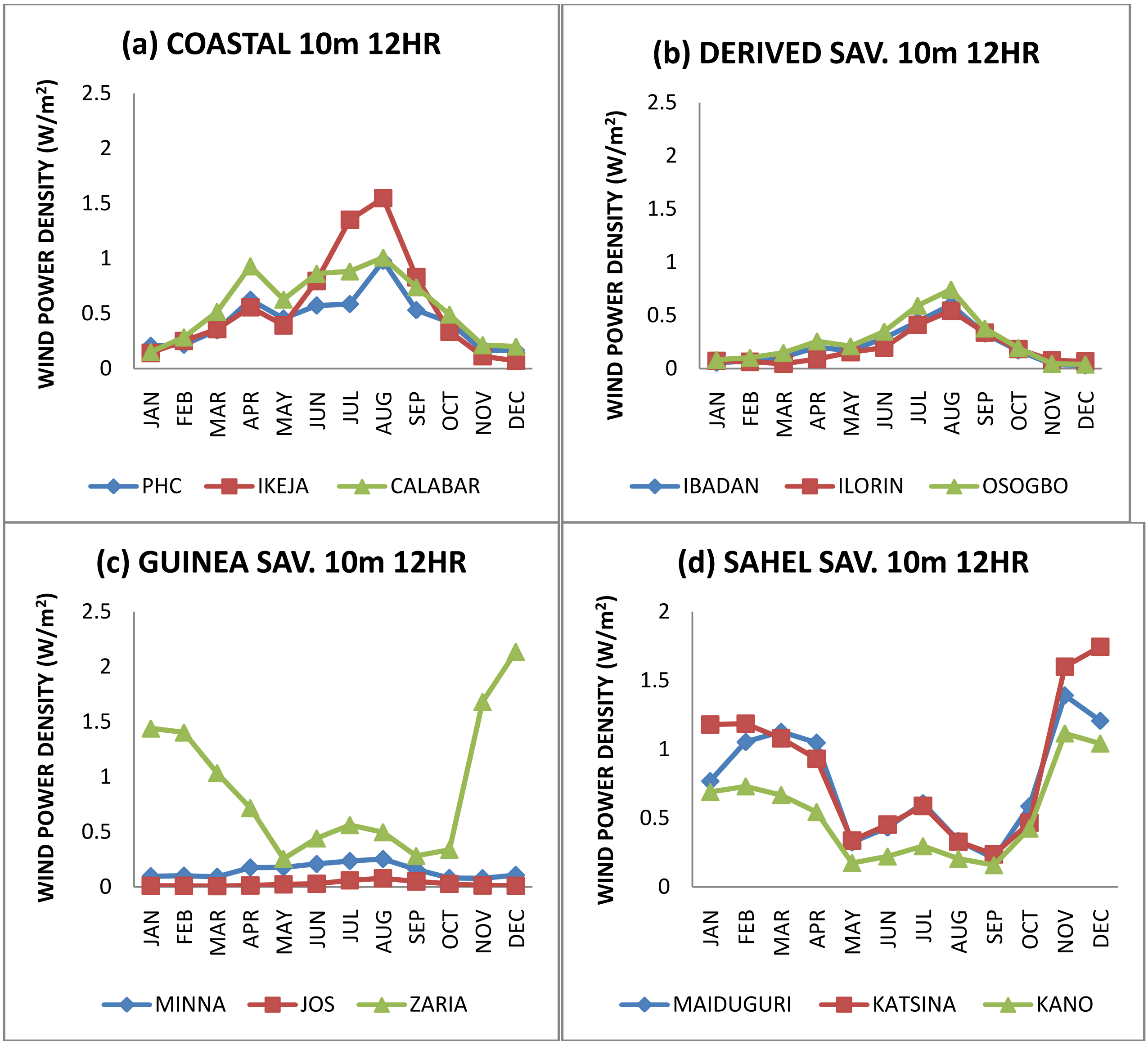



**Fig. 9** Monthly variation of Wind Power Density at 12:00 hr, at 10m height over all the selected Stations

## CONCLUSIONS

The research is clearly based on harnessing the wind energy potential for power generation in some selected locations across the different regions in Nigeria. It was found out that harnessing the wind energy potential is a viable renewable energy for the generation of the electricity in Nigeria. Also, in the course of this work, it was observed that wind speed was high in the Sahel savannah, Guinea savannah and Coastal stations except for the Derived savannah stations with relatively low wind speed throughout the period considered and at the different explored isobaric heights. In all the stations and regions considered, wind speed tends to be maximum at 100 m heights.

Therefore, from the research, it can be concluded that Nigeria is a good base for the generation of electricity from wind energy especially at 12:00 hrs. of the day characterized with intensive high wind speed as shown by the result, which revealed many promising areas like Maiduguri, Katsina, Kano, Minna and Ikeja in Nigeria in which wind farms can be erected and installed.

## REFERENCES

[1]. Oladeji, J.T., (2012). Utilization of Potential of Melon Shells for Pyrolysis as Biomass Fuels. World Rural Observation, 4(2):60-64.

[2]. Sambo A. S. (2006). Renewable Energy option for sustainable development", Paper presented at the Renewable Electricity Policy Conference held at Shehu Musa Yar'adua Centre, Abuja, 11-12.

[3]. Iwayemi, A. (2008). Nigeria's dual energy problems: Policy issues and challenges. International Association for energy economics, Fourth Quarter, 21: 17–21.

[4]. Ajayi, O. O. (2010). The potential for wind energy in Nigeria. Wind Eng. 34(3): 303–312.

[5]. Ajayi, O. O. (2008). Encyclopedia of Global Warming and Climate Change, Vol. 3, Sage Publication, California, USA: 976–979.

[6]. Asiegbu, A.D. and Iwuoha, G.S. (2007). Studies of wind resources in Umudike, South East Nigeria – An assessment of economic viability, *Journal of Engineering and Applied sciences* 2(10): 1539–1541.

[7]. Fadare, D.A. (2008). A Statistical analysis of wind energy potential in Ibadan, Nigeria, based on Weibull distribution function, The pacific journal of science and technology, 9(1): 110–119.

[8]. Agbetuyi, A.F., Odigwe, I.A., Awelewa, A.A. and Awosope, C.O.A. (2013), Wind power potential and integration in Africa, *International Journal of Development and Sustainability,*2(1): 232-239.

[9]. Gupta, R. and Biswas, A. (2010). Wind Data Analysis of Silchar (Assam, India) by Rayleigh, S and Weibull Methods. Journal of Mechanical Engineering Research, 2: 10-24.

[10]. Jowder, F. A. L. (2009). Wind power analysis and site matching of wind turbine generators in Kingdom of Bahrain. Applied Energy 83: 538–545.

[11]. Nze-Esiaga, N. and Okogbue, E.C. (2014). Assessment of Wind Energy Potential as a Power Generation Source in Five Locations of South Western Nigeria. Journal of Power and Energy Engineering, **2:** 1-13.

[12]. Udoakah, Y. and Ikafia, U. (2017). Determinate of Weibull Parameters and Analysis of Wind Power Potential in Coastal and Non-Coastal Sites in AkwaIbom State". Nigeria Journal of Technology (NIJOTECH) 36(3): 923 – 926.

[13]. Oluleye A. and Ogungbenro S.B. (2011). Estimating the wind energy potential over the coastal stations of Nigeria using power law and diabatic methods. African Journal of Environmental Science and Technology 5(11): 985-992.

[14]. Akinbami, J.F.K. (2001). Renewable Energy Resources and Technologies in Nigeria: Present Situation, Future Prospects and Policy Framework. Mitigation and Adaptation Strategies for Global Change.

[15]. Bolonkin A. (2008). Cheap Artificial AB-Mountains, Extraction of Water and Energy from Atmosphere and Change of Regional Climate. C&R, 1310 Avenue R, #F-6, Brooklyn, NY 11229, USA.

[16]. Ohunakin, O. S., Adaramola, M. S. Oyewola, O. M. and Fagbenle, R. O. (2011). Wind energy evaluation of electricity generation using WECS in seven selected locstions in Nigeria. Journal of Applied Energy, 88: 3197-3206.

[17]. Oliver J. E. and Fairbridge R. W. (2005). Mountain and Valley winds. In: Oliver J.E (eds) Encyclopedia of Earth Sciences Series. Spring, Dordrecht.

[18]. Ohunakin, O. S (2011) Wind Characteristics and Wind Energy Assessment in Uyo, Nigeria. Journal of Engineering and Applied Sciences, 6(2): 141-146.

[19]. Olaofe, Z.O. (2015). On the Remapping and Identification of Potential Wind Sites in Nigeria. Energy and Power Engineering, 7: 477-499.

[20]. Ayoade J. O. (2002). Introduction to Agro Climatology, Ibadan: Vintage Publishers.