

Estimating Wind Energy Potential in Some Coastal Cities of the Niger-Delta Region of Nigeria.

Victor N. Dike, M.Sc.[†]; Chidiezie T. Chineke, Ph.D.; Okey K. Nwofor, Ph.D.;
and Ugochukwu K. Okoro, M.Sc.

Atmospheric Physics Group, Department of Physics and Industrial Physics,
Imo State University, PMB 2000, Owerri, Imo State, Nigeria

E-mail: asldikvin@yahoo.com*

ABSTRACT

Modeling of wind speed characteristics is essential for the assessment of wind energy potentials and performance of wind energy conversion systems for electricity generation. We have fitted wind speed data obtained from National Aeronautic Space Administration (NASA) to two-parameter Weibull distribution functions. The results of the goodness-of-fit and other statistical tests show that the distribution adequately fit the data and as such suitable for modeling of the wind speed distributions in the Niger-Delta region of Nigeria.

(Keywords: wind energy, renewable energy, Weibull distribution, coastal sites, Niger Delta)

INTRODUCTION

In recent times, considerable importance has been attached to renewable energy systems as alternatives to convectional energy sources which have proven to be effective drivers of economic processes, contributing over 90% of national energy consumption but unfortunately, are highly damaging to the environment and human health (Akinbanmi, 2001).

Wind energy resource is one of such clean and cost effective energy alternatives, which also is one of the key elements of the Renewable Energy Master Plan (REMP) of the Federal Government of Nigeria. The share of wind energy in the national energy consumption has remained on the lower end with no commercial wind power plant connected to the national grid (Fadare, 2008). Wind energy is one of the fastest growing renewable energy sources across the globe. Countries around the world are scaling up their wind power generation. Most Asian countries are

set to be the most dynamic geographical zone with a growth of 48%. Japan aims to generate wind energy up to three million kWh in 2010 (Azami et al., 2008) which are geared towards low-carbon emission. The need to explore the wind power potentials in Nigeria is important as the Government has intensified efforts in solving its energy problems through concerted efforts and accelerated implementation of the REMP.

It is important to note that the Nigerian climate system, just like other West African countries, is determined by the interplay of three major airstreams; tropical maritime (Tm) air mass, the tropical continental (Tc) air mass, and the equatorial easterlies (Adejuwom and Odekunle, 2006). The Tm air mass originates from the St. Helena anticyclone located off the coast of Namibia and in its trajectory, picks up moisture over the South Atlantic Ocean, crosses the equator, and enters southern Nigeria. The two air masses (Tm and Tc) meet along a slanting surface called Intertropical Discontinuity (ITD) over the continent or Intertropical Convergence Zone (ITCZ) over the Ocean (Peter and Tetzlaff, 1988; Chineke, 2009).

Occasionally, the equatorial easterlies dives and undercuts the Tm or Tc air mass and gives rise to squall lines during which time the wind speed will be higher. The availability of the requisite wind speed is therefore necessary for applications of probability distribution functions which are important wind characteristics for the evaluation of wind energy conversion systems since wind speed is characterized by high variability both in space and time in any given location. It is also necessary to describe these variations for the benefit of optimizing, siting and proper sizing of the wind energy systems in order to reduce energy generating cost (Akpınar and Akpınar, 2004).

A thorough analysis and understanding of the characteristic wind regimes in which a wind energy turbine is expected to work is important for successful planning and implementation of wind power projects (Anyanwu and Iwuagwu, 1995; Celik et al., 2010).

Currently, numerous statistical distribution models have been developed to model wind speed distributions at different time scales and the quantum energy associated with the wind spectrum. These models include: Rayleigh, lognormal, two-parameter Weibull, stochastic models and three-parameter Weibull distribution functions to mention but a few (Fadare, 2008; Celik et al., 2010).

This paper presents the Weibull two-parameter (scale and shape) distribution function which has been found to fit a wide collection of data and has been mostly used in specialized literature on wind energy analysis (Agbaka, 1987; Akpinar and Akpinar, 2004; Ngala et al., 2007; Celik et al., 2010).

This approach aims at modeling wind speed variation and prediction of wind energy output as well as the potentials of wind power systems for some selected Coastal sites in the Niger Delta region of Nigeria namely; Rivers State (Port Harcourt), Akwa Ibom State (Uyo) and Bayelsa State (Yenegoa). Their geographical coordinates, elevation and descriptive statistics of the fitted distribution are listed in Table 1.

DATA AND METHODS

Wind Speed Data

The wind speed data used in this work was obtained from the US National Aeronautic and Space Administration (NASA) online data store via the website (<http://eosweb.larc.nasa.gov/sse>).

The data which are satellite measured form important tools in the study of climate systems and climatic processes. It is a research demonstration and policy support instrument for geographical assessment of Atmospheric and renewable energy resources in the content of integrated management of distributed energy generation.

These data include long-term estimates of meteorological quantities of wind/solar energy fluxes. The data have been adjudged accurate enough to provide reliable wind and meteorological resource over regions where surface measurements are sparse or nonexistent (Chineke and Dike, 2010) based on the estimates of the levels of uncertainties in comparison with ground measured data (Bais -0.2 and Root Mean Square 1.3).

NASA has continued to support the development of surface meteorology, which has been formulated specifically for renewable energy system design. For this study, a 22 year (1983-2005) monthly average of wind speed (ms^{-1}) data has been obtained.

Table 1: Descriptive Statistics of the Fitted Distribution.

Site	Long	Lat.	Elevation (Above Sea Level)	Skewness	Kurtosis	Variance
PH (Rivers State)	7.00	4.75	180	0.76	-0.53	0.36
Uyo (Akwa Ibom State)	7.93	5.05	68.0	0.35	-1.0	0.09
Yenegoa(Beyelsa State)	6.26	4.92	89.0	0.67	-0.61	0.30

Legend: PH = Port Harcourt, Long = Longitude, Lat = Latitude

Statistical Methods

a) The Weibull Distribution: In recent years much attention has been focused on this statistical method for wind speed analysis due to its great flexibility and simplicity. This method also gives a good fit to experimental data. Studies carried out on the assessment of wind characteristics in some locations in Nigeria include (Ojosu and Salawu, 1990; Anyanwu and Iwuagwu, 1995; Ngala et al., 2007; Oriaku et al., 2007; Fadare, 2008) etc. In the present statistical modelling of wind speed variation, the Weibull two parameter (shape parameter β and scale parameter α) functions has been applied. The probability density function of the Weibull distribution is given as (Akpinar and Akpinar, 2004; Fadare, 2008):

$$f(x) = \left(\frac{\beta}{\alpha}\right) \left(\frac{x}{\alpha}\right)^{\beta-1} \exp\left[-\left(\frac{x}{\alpha}\right)^\beta\right] \quad (1)$$

Where $f(x)$ is the probability of observing wind speed x , β is the dimensionless Weibull shape parameter and α is the Weibull scale parameter, which has reference value in the units of wind speed (ms^{-1}).

The corresponding cumulative probability function of the Weibull distribution is given as (Akpinar and Akpinar, 2004; Fadare, 2008):

$$F(x) = 1 - \exp\left[-\left(\frac{x}{\alpha}\right)^\beta\right] \quad (2)$$

b) Estimation of the Parameters: The shape and scale parameters were estimated using the Maximum Likelihood Estimation (MLE) techniques. This can also be evaluated by a good fit of eqn (2) to the recorded discrete cumulative frequency distribution. This equation can be made linear by taking double natural logarithm of both sides of the equation which gives:

$$\ln\{-\ln[1 - F(x)]\} = \beta \ln(x) - \beta \ln \alpha \quad (3)$$

Therefore, a plot of $\ln\{-\ln[1 - F(x)]\}$ versus $\ln(x)$ will give a straight line. The gradient of the

line is β and the intercept with the y axis is $-\beta \ln \alpha$. Generally, the shape parameter β value ranges from 1.5 - 3.0 for most wind conditions, (Fadare, 2008). This is consistent with our observations.

The available power in the wind flowing at mean speed (v_m) through a wind rotor blade with sweep area (A) at any given site can be estimated as (Akpinar and Akpinar, 2004; Oriaku et al., 2007; Fadare, 2008; Celik et al., 2010).

$$p(x) = \frac{1}{2} \rho A V_m^3 \quad (4)$$

where ρ is the air density. Since the study sites is within the coastal region and almost at sea level and with moderate climate, using the value of 1.225 kg/m^3 will be adequate as it reduces error in the estimate of Wind Power Density. However, if the area is much above sea level, or if one wants to be more precise, one can use the following approximation to account for elevation change.

$$\rho = 1.225 - [1.194(10^{-4})]z$$

(z = the location's elevation above sea level in meters)

The mean value of V_m can be defined in terms of the Weibull parameters β and α as:

$$V_m = \alpha \Gamma\left(1 + \frac{1}{\beta}\right) \quad (5)$$

where V_m is the mean value of the wind speed and Γ is the gamma function which has been estimated using Equation (6) as:

$$\Gamma(x) = \int_0^{\infty} t^{x-1} e^{-t} dt \quad (6)$$

and Wind Power:

The wind power density (wind power per unit area) based on the Weibull Probability Density Function (PDF) can be calculated as:

$$P(x) = \frac{p(x)}{A} \quad (7)$$

c) Goodness of Fit Tests (GOF): The GOF tests measures the compatibility of a random sample with a theoretical probability distribution function based on the empirical cumulative distribution function. These tests show how well the Weibull distribution fits the data. For this study, Kolmogorov-Smirnov, Anderson-Darling and Chi-Squared test methods has been used. The results are presented in the form of interactive tables that helps in deciding which model describes the data most. The GOF statistics is calculated for various significance levels (α), as well as the acceptance of the null hypothesis for each of the level values. Easyfit 5.4[®] software calculates the P-values based on the Kolmogorov-Smirnov and Chi-Squared GOF statistics. The p-value is calculated based on the test statistic, and denotes the threshold value of the significance level in the sense that the null hypothesis (H_0) will be accepted for all values of less than the P-value.

RESULTS AND ANALYSIS

Estimation of parameters for all the sites was done using the Microsoft Excel[®] and Easyfit 5.4[®] software. The Weibull distribution scale and shape parameter were calculated based on maximum likelihood estimation technique, the mean wind speed and the wind power density were estimated using Equations 5 and 7, respectively. Table 1 shows the descriptive statistics; geographical coordinates, elevation,

kurtosis, the skewness of the probability distribution function and variance.

The GOF parameters (Kolmogorov-Smirnov test, Anderson- Darling Test and Chi-squared Test) for the wind speed distribution are shown in Table 2.

These tests were evaluated using the Easyfit 5.4[®] software. This is important in verification of the adequacy of these data sets.

The yearly Weibull distribution parameters, mean wind speed, shape and scale parameters and the power density are shown in Table 3.

It can be seen that scale parameter (α) varies between 5.1 ms^{-1} and 7.7 ms^{-1} , while the shape parameter (β) range from 2.2 to 3.0. A high variation in scale parameter was observed as compared with that of shape parameter. It is important to note that higher values of α indicates higher mean wind speeds, while the value of β indicates wind stability. The mean wind speed range from 2.1 ms^{-1} to 3.0 ms^{-1} , the scale parameter usually slightly bigger than the mean wind speed for values of shape parameter between 1.5 ms^{-1} to 3.0 ms^{-1} (Fadare, 2008; Celik et al., 2010). Power density predicted by the Weibull PDF for the sites range from 6.00 Wm^{-2} to 16.3 Wm^{-2} , (Port Harcourt 13.2 Wm^{-2} , Uyo 6.00 Wm^{-2} and Yenegoa 16.3 Wm^{-2}).

Table 2: Goodness of Fit Tests.

Site	K.S	AD	Chi-Squared
PH (Rivers State)	0.18	0.67	2.5×10^{-5}
Uyo (Akwa Ibom State)	0.16	0.46	0.14
Yenegoa (Beyelsa State)	0.16	0.61	0.00

Legend: KS=Kolmogrov-Smirnov, AD=Anderson- Darling

Table 3: Weibull Parameters, Predicted Mean Wind Speed, and Power Density.

Site	Scale Parameter (α)	Shape Parameter (β)	V_m	Power Density (Wm^{-2})
PH (Rivers State)	2.9	5.1	2.8	13.2
Uyo (Akwa Ibom State)	2.2	7.7	2.1	6.00
Yenegoa(Beyelsa State)	3.0	5.6	3.0	16.3

Figures 1, 2 and 3, shows the PDF plots of the Weibull distribution for the sites with the histogram density plot superimposed on the PDF plot for the sites namely Port Harcourt, Uyo, and Yenegoa. These curves can be seen apparently skewed to the right; this is consistent with the calculated result of the skewness of 0.67 for Yenegoa, Port Harcourt 0.76, and Uyo 0.35. The kurtosis value for the sites, shows that the peak is narrow than the normal distribution. In Figure 1, it is clear that there is high probability of observing wind speed (2.57 ms^{-1} to 3.00 ms^{-1}) in Port Harcourt. While wind speeds between 2.11 ms^{-1} to 2.57 ms^{-1} shows appreciable occurrence.

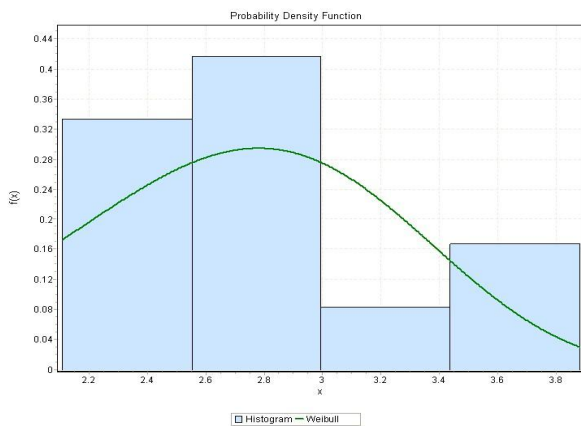


Figure 1: Probability Distribution Function Plot for Port Harcourt.

Figure 2 shows that the occurrence of wind speed between 1.76 ms^{-1} to 1.9 ms^{-1} is higher in Uyo.

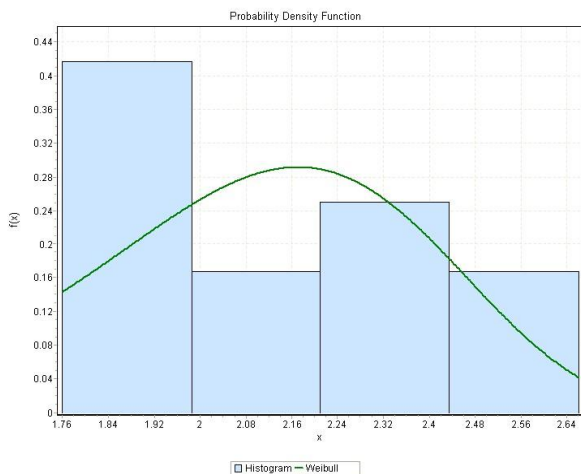


Figure 2: Probability Distribution Function Plot for Uyo.

As shown in Figure 3, Yenegoa has the highest wind energy potential amongst the study sites because probability of finding wind speed between 2.75 ms^{-1} to 3.1 ms^{-1} is closer to unity while wind speed between 3.56 ms^{-1} to 3.98 ms^{-1} is quite appreciable.

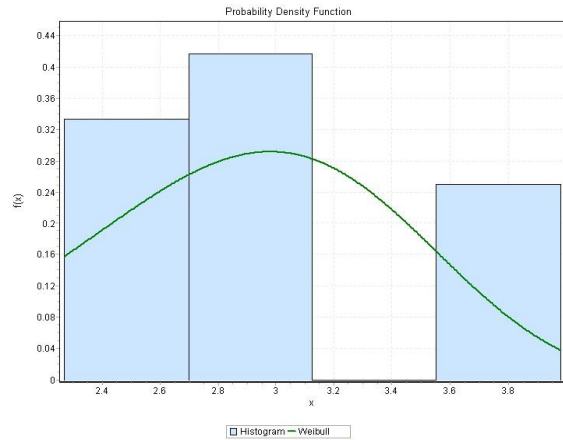


Figure 3: Probability Distribution Function Plot for Yenegoa.

In Figures 4, 5, and 6 we show the CDF plots for the sites as compared with the observed cumulative distribution. From these graphical representations, it can be concluded that Weibull distribution fit the data well because of its closeness to observed distributions and with the calculated parameters of these distributions, wind energy potential can be predicted for the locations studied.

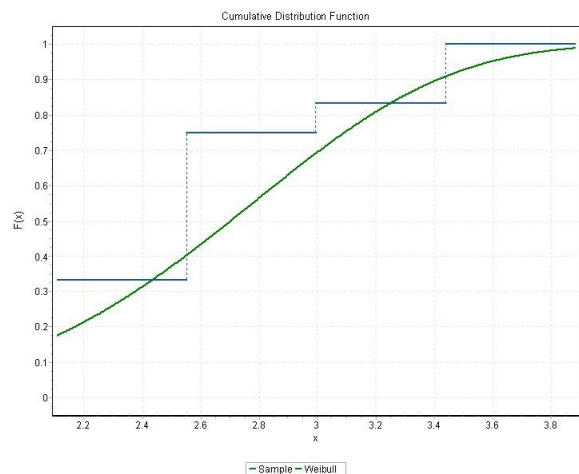


Figure 4: Cumulative Distribution Function Plot for Port-Harcourt.

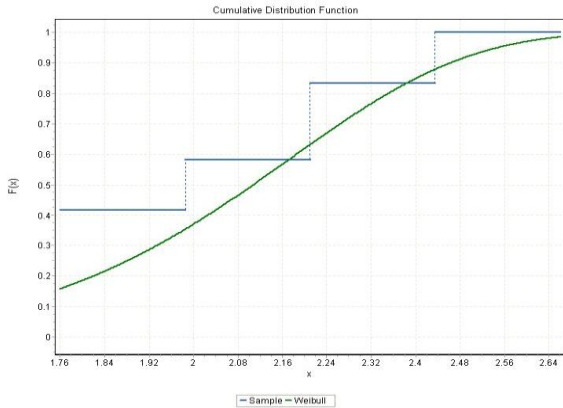


Figure 5: Cumulative Distribution Function Plot for Uyo.

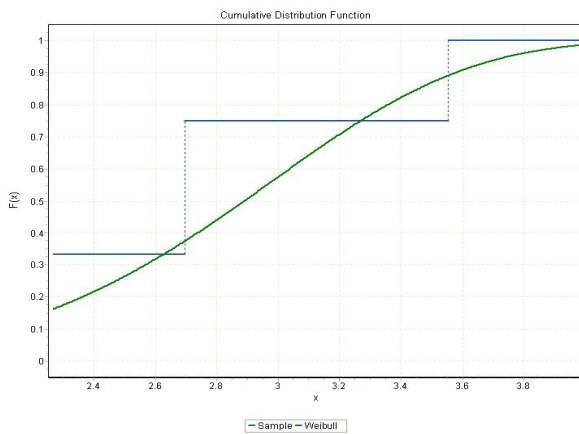


Figure 6: Cumulative Distribution Function Plot for Yenegoa.

CONCLUSION

A number of studies have developed adequate statistical model for describing wind speed frequency distribution. In this paper, we have fitted wind speed data obtained from National Aeronautic Space Administration (NASA) to two-parameter Weibull distribution functions. The monthly average wind speed data for some coastal cities in the states of the Niger Delta region of Nigeria namely; Port Harcourt, Uyo, and Yenegoa has been statistically analyzed based on the Weibull distribution function. The mean wind speed, PDF, CDF and Wind Power density Wm^{-2} has been determined. The following conclusions can be made from the results:

- 1) It can be seen from Table 2 the description of the GOF which verifies the adequacy of the Weibull distribution to the wind speed data. The comparative analysis of the values obtained from the three GOF test shows that at 0.20 significance level, for all values (p -value), the Weibull distribution fits the data and therefore the results can be accepted for the prediction of wind energy output required for preliminary design of wind energy systems.
- 2) The mean wind speed of (2.1 to 3.0) ms^{-1} for the sites shows that these sites are low wind speed regions.
- 3) Wind power values of 6.0 Wm^{-2} to 16.3 Wm^{-2} for the sites shows that these sites belongs to wind power class 1, since the wind power density value is less than 100 Wm^{-2} . Hence, wind power available in the sites can be used for small stand-alone wind power systems, which can be scaled up using modern wind energy technologies for integration with other renewable energy frameworks.
- 4) Integration of wind energy with other renewable energy sources like solar and tidal energies in these sites will boost power production because it will address the problem of variability and intermittency associated with these sources when used separately (Chineke and Nwofor, 2007).
- 5) The Weibull probability distribution scale parameter (α) is consistently higher in values and shows high variability than the shape parameter (β) for the wind speed distribution.

Access to clean, affordable and appropriate energy is an important enabler of development. Energy allows households to meet their most basic subsistence needs. This is a central feature for all Millennium Development Goals (MDGs) addressing the energy needs of the impoverished provides access to services that address the causes of poverty (Chineke and Ezike, 2010). Generally, the share of renewable in the national energy consumption has remained low despite the fact that untapped renewable energy has a considerable high potential in Nigeria (Iloeje, 2002; Fadare, 2008; Chineke and Dike, 2010). If there is political will, transparent energy policy and modern energy technologies, wind energy will contribute tangible power to the national

energy supply (Chineke and Ezike, 2010). This will address energy problems and ensure low-carbon emissions since the effect of climate change is evident in our climate pattern (Adejuwon and Odekunle, 2006).

REFERENCES

- Adejuwon, J.O. and T.O. Odekunle. 2006. "Variability and Severity of the "Little Dry Season" in Southwestern Nigeria". *Journal of Climate*. 19: 483-493.
- Agbaka, A.C. 1987. "Experimental Investigation of the Possible Correction of Wind Speed on Insolation". *Energy Conversion & Management*. 27(1): 4-48.
- Akinbami, J.F.K. 2001 "Renewable Energy Resources and Technologies in Nigeria: Present Situation, Future Prospect and Policy Framework". *Mitigation and Adaptation Strategies for Global Change*. 6:155-181.
- Akpinar, E.K. and S. Akpinar. 2004 "Statistical Analysis of Wind Energy Potential on the Basis of the Weibull and Rayleigh Distributions for Agin-Elazig, Turkey". *Journal of Power and Energy*. 218:557-565.
- Anyanwu, E.E. and C.J. Iwuagwu. 1995 "Wind Characteristics and Energy Potential for Owerri, Nigeria". *Renewable Energy*. 6(2):125-128.
- Azami, Z., Ahmad, M.R., Rozaimah, Z.A., and S. Kamaruzzaman. 2008 "Wind Speed Analysis in the East Coast of Malaysia". *European Journal of Scientific Research*. 26(1):208-215.
- Celik, A.N., Makkawi, A., and T. Muneer. 2010. "Critical Evaluation of Wind Speed Frequency Distribution Functions". *Journal of Renewable and Sustainable Energy*. 2(013102):1-18.
- Chineke, T.C. and V.N. Dike. 2010. "Correlation of PVGIS Data with other Solar Radiation Estimates in the Niger Delta Region of Nigeria". *International Journal of Natural and Applied Sciences*. 6(2): 173-180.
- Chineke, T.C. and F.M. Ezike. 2010. "Political Will and Collaboration for Electric Power Reform through Renewable Energy in Africa". *Energy Policy*. 38:678-684.
- Chineke, T.C. and O.K. Nwofor. 2007. "A Solar-Wind-Tide Scheme for Renewable Electricity Production in Nigeria". *Advances in Science and Technology*. 1(2/3):78-86.
- Chineke, C.T. 2009 "Boosting Electricity Supply in Nigeria: Wind Energy to the Rescue?". *Pacific Journal of Science and Technology*. 10(2) 553-560.
- Fadare, 2008. "A Statistical Analysis of Wind Energy Potential in Ibadan, Nigeria, Based on Weibull Distribution Function". *Pacific Journal of Science and Technology*. 9(1):111 -119.
- Iloeje, O.C. 2002. "Renewable Energy Development in Nigeria: Status and Prospects". Ewah, O.E. (editor). *Proceedings of a National Workshop on Energising Rural Energy Market Development*. Federal Ministry of Power and Steel: Abuja, Nigeria.
- Ngala, G.M., B. Akali, and M.A. Aji. 2007 "Viability of Wind Energy as a Power Generation Source in Maiduguri, Borno State, Nigeria". *Renewable Energy*. 32(13): 2242-2246.
- Ojosu, J.O. and R.I. Salawu. 1990. "Wind Energy Development in Nigeria". *Nigerian Journal of Solar Energy*. 9:29-32.
- Oriaku, C.I, J.C Osuwa, A.D. Asiegbu, G.U. Chukwu, and C.O. Kanu. 2007. "Frequency Distribution Analysis of Available Wind Resources in Umudike, Abia State, Nigeria, for Wind Energy Conversion System Design". *Pacific Journal of Science and Technology*. 8(2):203-206.
- Peter, M. and G. Tetzlaff. 1988. "The Structure of West African Squalls line and their Environmental Moisture Budget". *Meteorology and Atmospheric Physics*. 39: 74-84.

SUGGESTED CITATION

Dike, V.N., C.T. Chineke, O.K. Nwofor, and U.K. Okoro. 2011. "Estimating Wind Potential in Some Coastal Cities of the Niger-Delta Region of Nigeria". *Pacific Journal of Science and Technology*. 12(1):598-604.

 [Pacific Journal of Science and Technology](http://www.akamaiuniversity.us/PJST.htm)