Assessment of Wind Power Potential and Wind Electricity Generation Using WECS of Two Sites in South West, Nigeria

Ajayi, O.O. [1*], Fagbenle, R.O[2], Katende, J[3]
[1]Mechanical Engineering Department, [3]Electrical and Information Engineering Department,
Covenant University
Ota, Nigeria
[2]Mechanical Engineering Department,
Obafemi Awolowo University
Ile Ife, Nigeria
[1]oluseyi.ajayi@covenantuniversity.edu.ng

***Abstract*-The study was used to analyze the wind characteristics of Shaki (08.40' N; 03.23' E; Altitude 457.0 m; Air density 1.1723 kg/m^3) and Iseyin (07.58' N; 03.36' E; Altitude 330.0 m; Air density 1.1869 kg/m^3), two local sites in Oyo State, Nigeria. 21 years monthly mean wind speeds at 10 m height obtained from the Nigeria meteorological department were employed together with the Weibull 2-parameter distribution and other statistics to carry out monthly, seasonal and whole years' analyses of the sites' wind profiles for electricity generation. It was found that the whole data spread ranged between 0.9 and 9.1 m/s for the two sites while the 21 years' average ranged between 3.2 and 5.1 m/s and 2.9 and 4.7 m/s for Shaki and Iseyin sites respectively. Three wind energy conversion systems were employed with the results and it was discovered that, the sites have capacity to generate MWh to GWh of electricity at an average cost/kWh of between € (0.025 and 0.049) and that a turbine with technical parameters of cut-in, cut-out and rated wind speeds of 3.0, 25 and 11.6 m/s is appropriate for the sites.**

Key words-Wind power, wind speed, Turbine cost, Iseyin, Shaki, Nigeria

I. INTRODUCTION

The concern over the production of adequate electricity to drive economic developments is a global issue. Moreover, the need to generate such magnitude of needed electricity from environmentally friendly and non-toxic sources has further heightened the concern. This has led to various efforts at measuring and assessing the potentials and viability of generating electricity from renewable energy resources of which wind is a veritable source. Wind Energy Technology (WET) application involves three important stages of resource assessment, hardware development and installation, and also electricity generation and distribution. Moreover, the first stage, which in this case is the potential resource assessment, is very important to the other two stages and therefore to WET. It determines the turbine selection criteria based on the turbine's wind speed technical rating of cut-in, cut-out and rated wind speeds. It also determines the magnitude of wind power that can possibly be generated from a site based on the historical wind speed assessment results.

Various wind resource assessment studies have been conducted around the world to determine the potentialities of local sites for wind power/electricity generation (Feretic et al., 1999; Oztopal et al., 2000; Sulaiman et al., 2002; Rehman and Ahmed, 2005; Akpinar and Akpinar, 2005; Ahmed and Hanitsch, 2006; Albadi et al., 2009; Ahmed, 2010). The case of Nigeria is not left out and the reports are available (Ojosu and Salawu, 1990a, 1990b; Adekoya and Adewale, 1992; Fagbenle and Karayiannis, 1994; ECN-UNDP, 2005; Asiegbu and Iwuoha, 2007; Fadare, 2008; Ajayi, 2009; Ogbonnaya et al., 2009; Fadare, 2010; Fagbenle et al., 2011). Each one of these reports considered different sites and presented analyses to justify their results. Moreover, ECN-UNDP (2005) reported that due to the varying topography and roughness of the nation, large differences in wind distribution within the same locality exist. This is corroborated by the fact that wind resources are site specific and despite reports summarizing for the country, a site-by-site assessment is necessary in order to have proper wind classification for the nation. More so, considering all the available reports on Nigeria, none have focused on Iseyin and Shaki, two towns in Oyo State, South-West of Nigeria. This work is therefore used to focus on the wind resource assessment study of a wind measuring site in each of the towns. It assessed the wind energy resources of the sites to determine its monthly, yearly and seasonal potentials for electricity generation. It also considered the economic viability of wind electricity production by adapting three practical wind energy conversion systems (turbine models) to the results of the Weibull analysis to determine the econometrics analysis of generating wind electricity in the sites.

II. MATERIALS AND METHOD

Twenty one years (1987 – 2007) monthly mean wind speed data employed for this study were obtained from the Nigeria meteorological department, Oshodi, Lagos, Nigeria. The data were measured continuously using three cup generator anemometer and recorded for a height of 10 m above sea level. Figs. 1 and 2 gives the data spread for the two sites while Table 1 presents information regarding the sites. The data were then analyzed to determine the monthly, seasonal and yearly wind resource potentials for power generation.

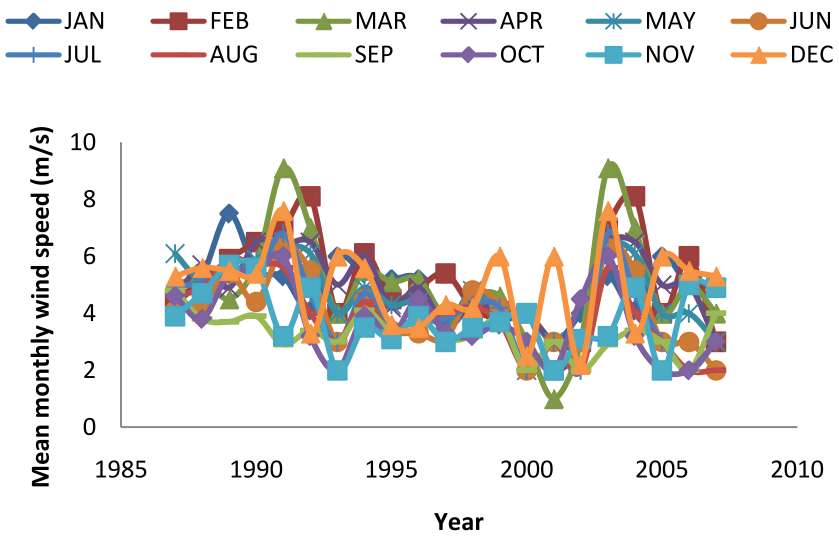


Fig. 1: Whole data plot for Shaki

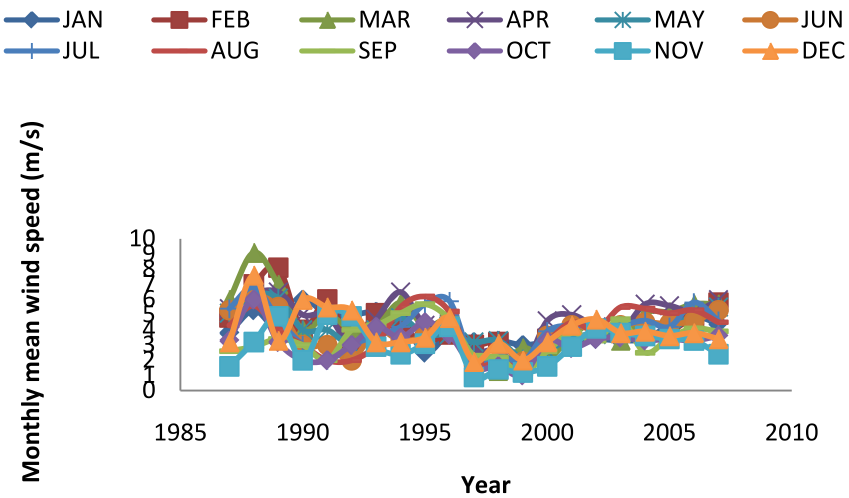


Fig. 2: Whole data plot for Iseyin

TABLE 1: DETAILS OF THE TWO SITES FOR WHICH WIND DATA WERE OBTAINED AND ANALYZED

Sites	Location	Latitude	Longitude	Air Density (kg/m3)	Elevation (m)
Shaki	Oyo State	08.40’	03.23’	1.1723	457
Iseyin	Oyo State	07.58’	03.36’	1.1869	330.0

Statistical Analysis

The Weibull 2-parameter statistical distribution was employed for the data analysis in accordance with literatures (Feretic et al., 1999; Sulaiman et al., 2002; Montogomery and Runger, 2003; Akpinar and Akpinar, 2005; Ahmed and Hanitsch, 2006; Tina et al., 2006; Hau, 2006; Fadare, 2008; Fagbenle et al., 2011). The goodness-of-fit test was carried out using the Kolmogorov-Smirnov (K-S) statistics (Roberge, 2003; Polyanin, 2007; Omotosho et al., 2010).

The Probability Density Function (PDF) and the corresponding Cumulative Density Function (CDF) associated with the 2-parameter Weibull distribution are given by Eqs.1 and 2. The K-S statistical test was based on a 95% significance level of $\alpha = 0.05$. Based on this value of α, the assumption that the two-parameter Weibull distribution is suitable at explaining the situation of wind speed profiles in the sites is accepted if $P \geq 0.05$.

$$f(v) = \left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{k-1} \exp\left[-\left(\frac{v}{c}\right)^{k}\right] \quad (1)$$

$$F(v) = 1 - \exp\left[-\left(\frac{v}{c}\right)^k\right] \quad (2)$$

Where:

f (v) = the probability of observing wind speed *v*, *k* = the dimensionless Weibull shape parameter and *c* (m/s) = the Weibull scale parameter.

Performance Estimation of the Weibull Statistics

In estimating the accuracy and performance of the Weibull statistical distribution to predict wind speed profile of a place, various methods suffice. However, for the purpose of this study, the Root Mean Square Error, Nash-Sutcliffe model Coefficient Of Efficiency (COE) and the Coefficient of Determination, R2, were employed. These are given as (Montgomery and Runger, 2003; Krause et al., 2005):

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}\left(y_i - x_i\right)^2\right]^{\frac{1}{2}} \quad (4)$$

$$COE = 1 - \frac{\sum_{i=1}^{N}\left(y_i - x_i\right)^2}{\sum_{i=1}^{N}\left(y_i - \overline{x}\right)^2} \quad (5)$$

$$R^2 = \frac{\sum_{i=1}^{N}(y_i - z_i)^2 - \sum_{i=1}^{N}(x_i - y_i)^2}{\sum_{i=1}^{N}(y_i - z_i)^2} \quad (6)$$

Where:

yi = the ith actual data, xi = the ith predicted data with the Weibull distribution, z = the mean of the actual data and N = the number of observations.

Thus, a Weibull predicted result is adjudged accurate if the estimated values of R2 and COE are close to 1 and those of RMSE are close to zero.

Determinations of the Weibull mean wind speed and standard deviation

The mean value of the wind speed, vm, and standard deviation,σ, for the Weibull distribution is defined in terms of the Weibull parameters, k and c, as (Sulaiman et al., 2002; Akpinar and Akpinar, 2005; Fagbenle et al., 2011; Keyhani et al., 2010):

$$v_m = c\Gamma\left(1 + \frac{1}{k}\right) \quad (7)$$

And

$$\sigma = \sqrt{c^2\left\{\Gamma\left(1 + \frac{2}{k}\right) - \left[\Gamma\left(1 + \frac{1}{k}\right)\right]^2\right\}} \quad (8)$$

where Γ ( ) is the gamma function of ( ).

Evaluation of the most probable and maximum energy carrying wind speeds

These wind speeds are very important to wind energy assessors. They can be evaluated from Eq. 9 and 10 (Fagbenle et al., 2011):

$$v_{mp} = c\left(\frac{k-1}{k}\right)^{\frac{1}{k}} \quad (9)$$

$$v_{Emax} = c\left(\frac{k+2}{k}\right)^{\frac{1}{k}} \quad (10)$$

where:

vmp = most probable wind speed and vEmax = maximum energy carrying wind speed

Simulation of the electrical power output from practical wind turbine models

Three practical Wind Energy Conversion Systems (WECS) (turbine models) were employed with the Weibull results. One of the models was from General Electric (model GE 1.5xle), and the remaining two were from Avantis Group (models AV 927 and AV 928). Table 2 presents the technical details of the turbine models. Eq. 11 (Fagbenle et al., 2011) was used to simulate the magnitude of electrical output which the turbine models will generate if employed at the sites.

$$P_e = \begin{cases} 0 & (v < v_c) \\ P_{eR}\dfrac{v^k - v_c^k}{v_R^k - v_c^k} & v_c \le v \le v_R \\ P_{eR} & v_R \le v \le v_F \\ 0 & v > v_F \end{cases} \quad (11)$$

TABLE 2: TECHNICAL DATA OF WIND TURBINE MODELS USED IN THE ANALYSIS (GE ENERGY, 2010; AVANTIS, 2011)

Wind Machine	**V_c (m/s)**	**V_F (m/s)**	**V_R (m/s)**	**P_{eR} (kW)**	**Hub Height (m)**	**Rotor Diameter (m)**
GE 1.5xle	3.5	20	11.5	1500	80	82.5
AV 928	3	25	11.6	2500	80	93.2
AV 927	3	25	13.1	3300	60-80	93.2

A very important parameter of a practical wind turbine model is the average power output (Pe,ave) from the turbine. It can be used to determine the total energy production and by extension the total income/cost analysis. It is evaluated from (Akpinar and Akpinar, 2005):

$$P_{e,ave} = P_{eR}\left\{\frac{e^{-\left(v_c/c\right)^k} - e^{-\left(v_R/c\right)^k}}{\left(v_R/c\right)^k - \left(v_c/c\right)^k} - e^{\left(v_F/c\right)^k}\right\} \quad (12)$$

The capacity factor, CF, associated with using a wind turbine to generate electricity is given as (Rehman and Ahmed, 2005; Akpinar and Akpinar, 2005):

$$CF = \left\{\frac{e^{-\left(v_c/c\right)^k} - e^{-\left(v_R/c\right)^k}}{\left(v_R/c\right)^k - \left(v_c/c\right)^k} - e^{\left(v_F/c\right)^k}\right\} \quad (13)$$

where:

vc = cut in wind speed, vR = rated wind speed, vF = cut off wind speed and PeR = rated electrical power

Total income/Cost analysis of electrical generation from a practical wind turbine

Based on the results obtained for Pe,ave, the total income/cost analysis of generating certain magnitude of electricity for a given life or period of the turbine can be evaluated from (Ahmed and Hanitsch, 2006):

$$C_{PV} = x\left(1+R_C\right) + \frac{x}{t}R_{om}\left[\frac{1+I_R}{R_I - I_R}\right]?\left[-\left(\frac{1+I_R}{1+R_I}\right)^t\right] - xR_{sc}\left(1+R_C\right)\left(\frac{1+I_R}{1+R_I}\right)^t \quad (14)$$

Furthermore, the specific cost per kWh of wind turbines can be estimated from:

$$C_{SC/kWh} = \frac{C_{PV}}{\text{Annual } P_{e,ave} \times t} \quad (15)$$

where: Cpv = present cost, x = turbine price, RC = rate chargeable on turbine price to arrive at the cost for civil/structural works, Rom = rate chargeable on annual turbine price to arrive at the cost for Operation and Maintenance (O & M), RI = prevailing interest rate, IR = prevailing inflation rate, RSC = rate chargeable on total investment cost, t = turbine life or period of operation of turbine availability, CSC/kWh = specific cost per kWh.

III. RESULTS AND DISCUSSION

The distributions of the sites' wind speed profiles across the whole period from 1987 to 2007, representing the whole data spread, are presented using Figs. 1 and 2. Analysis of this data spread revealed that the minimum and maximum wind speed values for the two sites lay between 0.9 and 9.1 m/s respectively. The frequency of occurrence of the wind speed data are also presented in Fig. 3. This shows that, of the 252 wind speed data for each of the sites, 85% of Shaki site's wind speed data lay between 2.0 and 5.9 m/s. Only 14.6% of the data were values within the range 6 to 9.1 m/s. Also 52% of Iseyin site's wind speed data have values within the range 0.9 to 3.9 m/s while 46% of the data have values between 4.0 and 7.9 m/s respectively.

Furthermore, for the fact that most new wind turbine designs can operate with cut-in wind speed of 3.0 m/s, the frequency of occurrence of wind speed values from 3.0 m/s and above were determined. It was discovered that 90% of wind speed data for Shaki and 80% of those for Iseyin were from 3.0 m/s and above. This means that wind turbines installed at the sites will work for most of the time.

Moreover, in order to understand the exact fluctuation of the wind profile distributions across the period, the 21 years average monthly and yearly wind speeds of Figs. 1 and 2 were evaluated and represented as Figs. 4 and 5. Figs. 4 and 5 reveals that average wind speed values for the period lay between 2.9 and 4.7 m/s for Iseyin and 3.2 and 5.1 m/s for Shaki for the period from January to December. The annual range lay between 1.8 and 6.0 m/s for Iseyin and between 2.8 and 6.0 m/s for Shaki respectively. In addition, Fig. 4 showed that the months with highest and lowest wind energy potential for Iseyin occurred in April and November respectively while for Shaki it was February and September respectively. However, the period for highest wind energy potential for the two sites lay between January and April for Iseyin and December to May for Shaki.

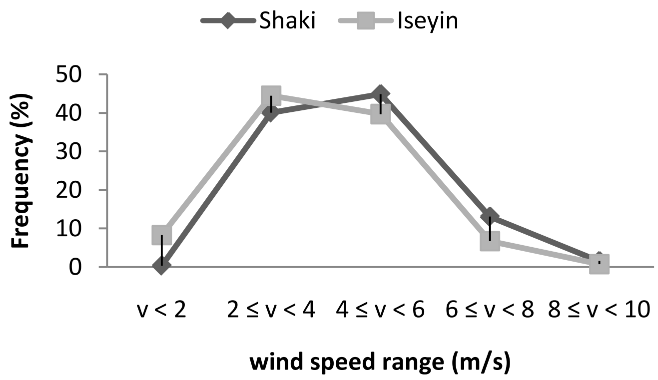


Fig. 3: Measured wind speed frequency plot for the sites

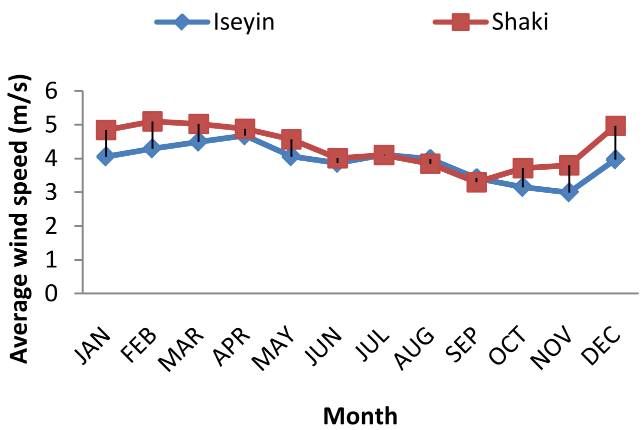


Fig. 4: 21 years average monthly wind speed profiles

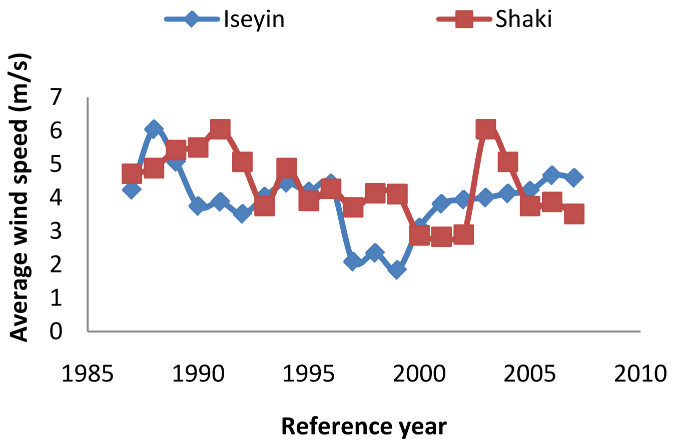


Fig. 5: 21 years annual average wind speed profiles

Seasonally, Fig. 6 clearly demonstrated that Shaki site has a better magnitude of wind speed profile in the dry season (October to March) than in the wet (April to September). Iseyin site however showed better wind speed profile in the wet than the dry season. The mean measured data distribution between the dry and wet periods gave the range of mean wind speeds as 1.0 to 9.1 m/s and 2.0 to 6.8 m/s for Shaki. For Iseyin it was 0.9 to 9.1 m/s and 1.1 to 6.8 m/s respectively. The seasons 21 years' average gave 4.6 (dry) and 4.1 m/s (wet) for Shaki and 3.8 (dry) and 4.0 m/s (wet) for Iseyin respectively.

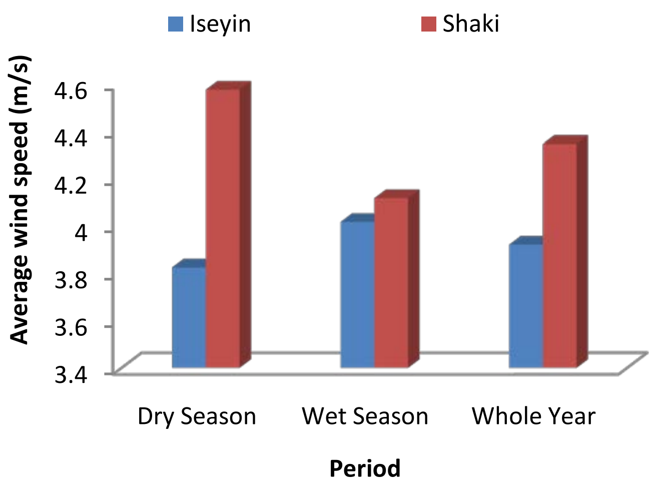


Fig. 6: Seasonal and whole year variation of average wind speed values

Comparing the two sites, Figs. 1 to 6 revealed that Shaki site has better wind speed profiles for power generation than Iseyin across the months and years.

Performance of a statistical Weibull analysis on the wind speed data of the two sites gave results of Table 3. The CDF and PDF plots for the whole data series separated into monthly, seasonal and whole years' analyses are also presented using Figs. 7 – 10. Figs. 7 – 10 clearly demonstrate that the wind speed profiles of the two sites for the stated periods follow the same cumulative distribution patterns.

The differences in the shapes of the CDF and PDF plots were as a result of the varying values of k and c of Table 3. Figs. 7 and 9 revealed that, 82% of the data series were values that ranged from about 3.9 to 7.0 m/s and below for Shaki site. For Iseyin site, 82% of the data series ranged from about 3.7 to 6.0 m/s and below. The dry and wet seasons' Weibull plots of Figs. 8 and 10 also reveals that up to 82% of the different seasons' data series were values that ranged from 2.0 to 5.6 m/s (wet) and 1.0 to 5.9 m/s (dry) for Shaki site. For Iseyin site the data ranged from 1.1 to 5.4 m/s (wet) and 0.9 to 5.0 m/s (dry) respectively. In order to establish the validity and reliability of the Weibull results, the K-S P-value, coefficient of determination, RMSE and COE statistics were evaluated and presented in Fig. 11. The K-S P-values for the periodic and yearly analyses showed that the Weibull 2-parameter statistics was adequate at predicting and characterizing the wind speed profiles of the sites. This gave $P > 0.05$ across the whole period of analyses.

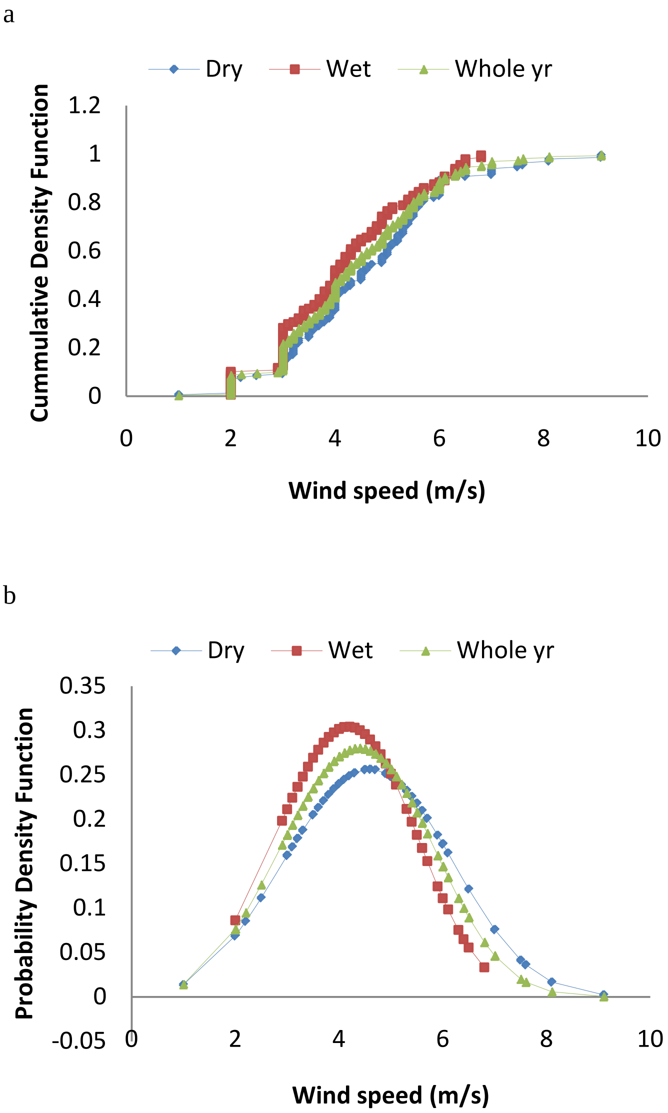
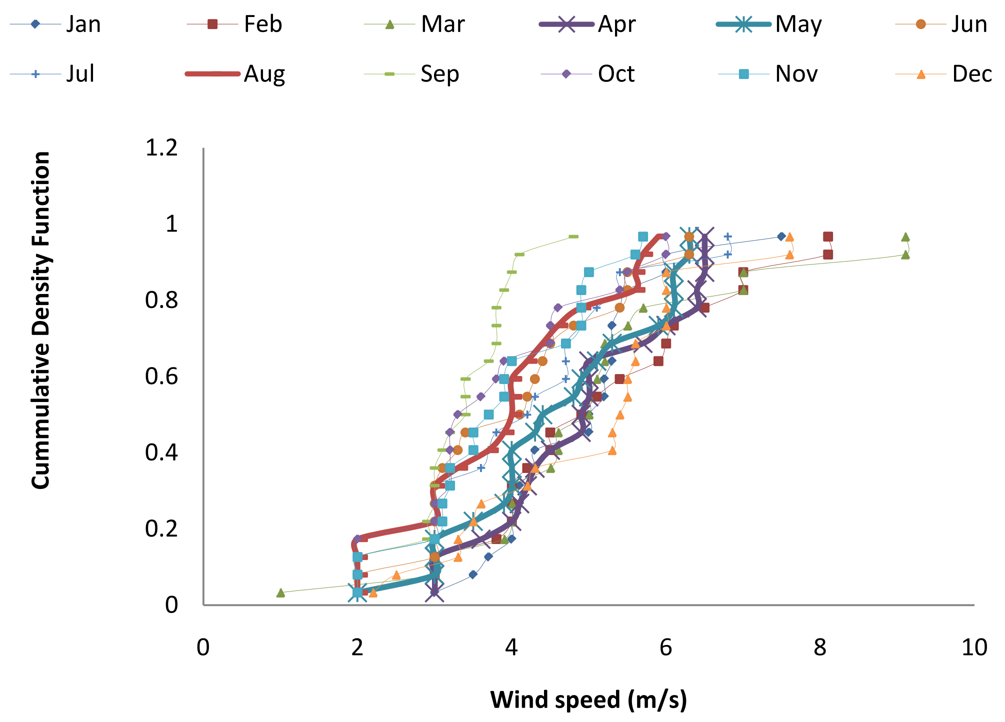


Fig. 8: Plot showing the (a) CDF and (b) PDF for Shaki site representing seasonal and whole year analyses



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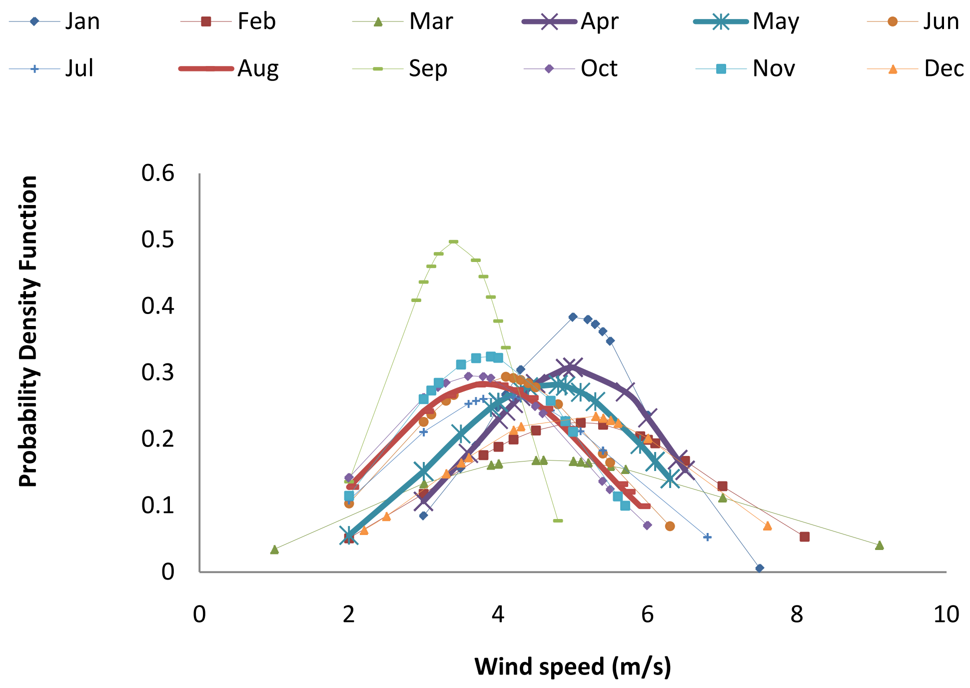

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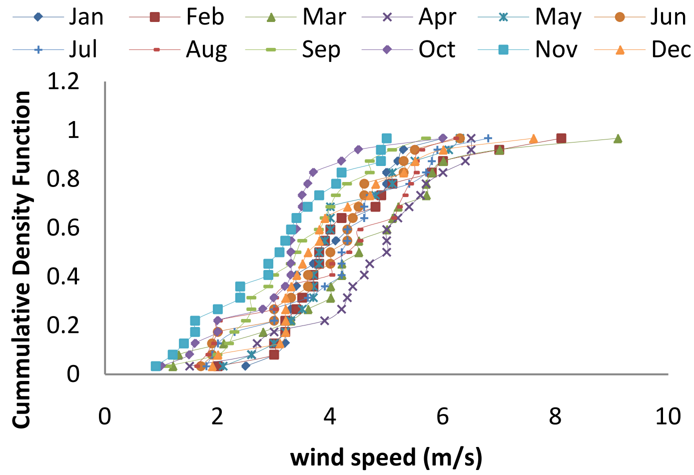
Fig. 7: Plot showing the (a) CDF and (b) PDF for Shaki site

TABLE 3: SOME WEIBULL RESULTS FOR THE WHOLE 21 YEARS

	Shaki					Iseyin				
Period	$V_{weibull}$ ***(m/s)***	***k (-)***	***c (m/s)***	$\sigma_{weibull}$ ***(m/s)***	σ_{actual} ***(m/s)***	$V_{weibull}$ ***(m/s)***	***k (-)***	***c (m/s)***	$\sigma_{weibull}$ ***(m/s)***	σ_{actual} ***(m/s)***
JAN	4.8	5.4	5.2	1.0	1.0	4.1	4.9	4.4	1.0	0.9
FEB	5.1	3.3	5.7	1.7	1.7	4.3	3.5	4.8	1.4	1.5
MAR	5.1	2.4	5.8	2.3	1.9	4.6	2.3	5.2	2.1	1.8
APR	4.9	4.4	5.4	1.3	1.2	4.7	3.1	5.3	1.6	1.4
MAY	4.6	3.8	5.1	1.4	1.3	4.1	4.3	4.5	1.1	1.1
JUN	4.0	3.4	4.5	1.3	1.3	3.9	3.0	4.4	1.4	1.3
JUL	4.1	3.1	4.6	1.4	1.4	4.1	3.0	4.6	1.5	1.4
AUG	3.9	3.1	4.3	1.3	1.3	4.0	2.6	4.5	1.7	1.5
SEP	3.3	4.8	3.6	0.8	0.7	3.4	3.1	3.8	1.2	1.1
OCT	3.7	3.2	4.2	1.3	1.3	3.2	2.8	3.6	1.2	1.1
NOV	3.8	3.6	4.2	1.2	1.1	3.0	2.4	3.4	1.3	1.2
DEC	5.0	3.4	5.5	1.6	1.5	4.0	3.4	4.4	1.3	1.3
Dry Season	4.6	3.4	5.1	1.5	1.5	3.8	2.9	4.3	1.4	1.4
Wet Season	4.1	3.6	4.6	1.3	1.3	4.0	3.3	4.5	1.4	1.3
Whole Year	4.3	3.5	4.8	1.4	1.4	3.9	3.1	4.4	1.4	1.4
1987	4.7	9.0	5.0	0.6	0.6	4.3	2.9	4.8	1.6	1.3
1988	4.9	8.1	5.2	0.7	0.6	6.1	3.3	6.8	2.1	1.7
1989	5.4	6.4	5.8	1.0	0.9	5.1	3.5	5.6	1.6	1.6
1990	5.5	7.4	5.9	0.9	0.7	3.8	2.9	4.2	1.4	1.4
1991	6.1	3.3	6.8	2.1	1.7	4.0	2.2	4.5	1.9	1.6
1992	5.1	3.5	5.6	1.6	1.6	3.5	3.3	3.9	1.2	1.1
1993	3.8	2.9	4.2	1.4	1.4	4.0	5.7	4.4	0.8	0.8
1994	4.9	6.3	5.2	0.9	0.8	4.4	3.9	4.9	1.3	1.2
1995	3.9	5.7	4.2	0.8	0.7	4.2	4.0	4.6	1.2	1.2
1996	4.3	6.9	4.6	0.7	0.7	4.4	6.9	4.7	0.8	0.7
1997	3.7	6.2	4.0	0.7	0.7	2.1	2.8	2.4	0.8	0.8
1998	4.1	7.6	4.4	0.6	0.6	2.4	3.3	2.6	0.8	0.8
1999	4.1	6.2	4.4	0.8	0.7	1.8	3.2	2.1	0.6	0.6
2000	2.9	3.1	3.3	1.0	0.9	3.1	3.9	3.4	0.9	0.8
2001	2.9	2.4	3.3	1.3	1.2	3.8	6.2	4.1	0.7	0.7
2002	2.9	3.9	3.2	0.8	0.8	3.9	9.8	4.1	0.5	0.4
2003	6.1	3.3	6.8	2.1	1.7	4.0	6.9	4.3	0.7	0.6
2004	5.1	3.5	5.6	1.6	1.6	4.1	4.7	4.5	1.0	0.9
2005	3.8	2.9	4.2	1.4	1.4	4.2	6.1	4.5	0.8	0.7
2006	4.0	2.2	4.5	1.9	1.6	4.7	5.6	5.0	1.0	0.9
2007	3.5	3.3	3.9	1.2	1.1	4.6	4.1	5.1	1.3	1.1

a



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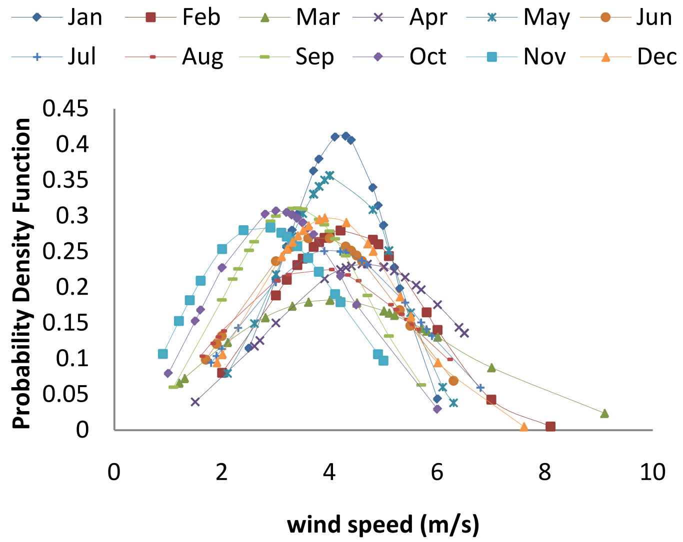

Fig. 9: Plot showing the (a) CDF and (b) PDF for Iseyin site

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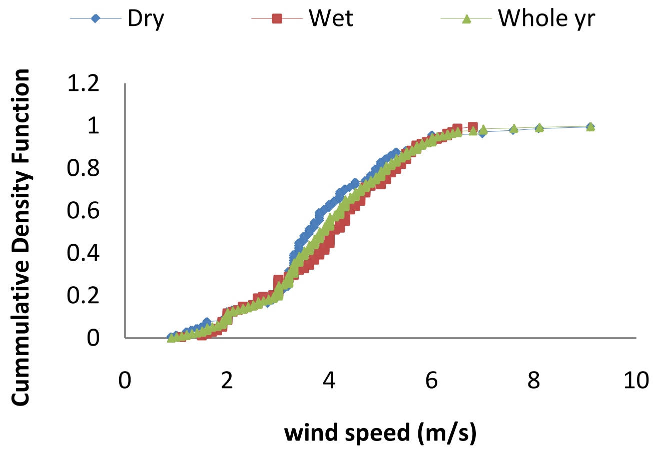

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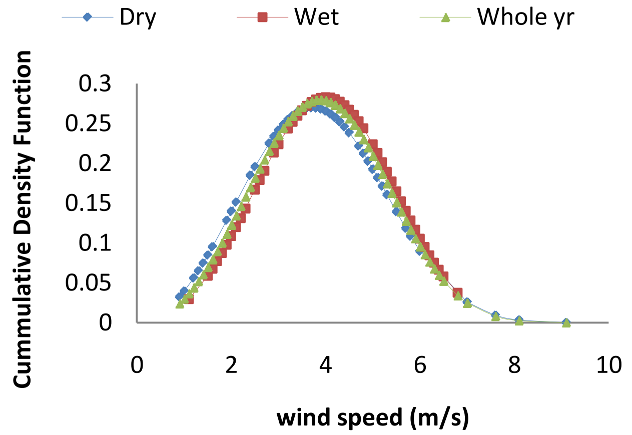
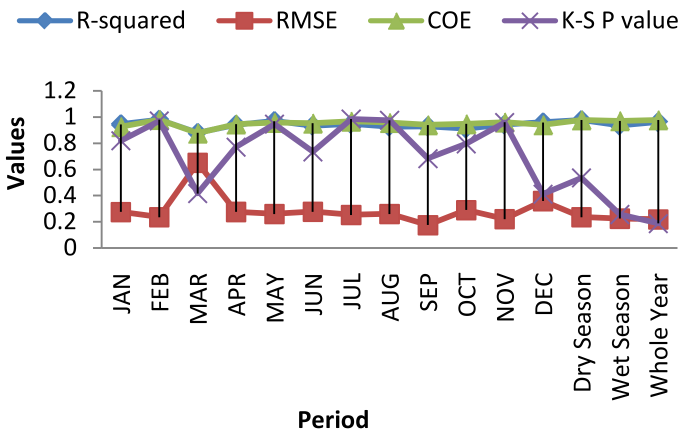


Fig. 10: Plot showing the (a) CDF and (b) PDF for Iseyin site representing seasonal and whole year analyses

i)



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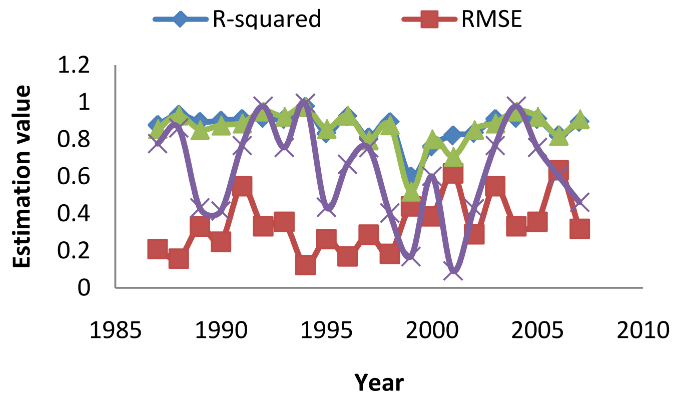


Fig. 11a: Estimation parameters of the Weibull statistical distribution for Shaki (i) Periodic analyses (ii) annual analyses

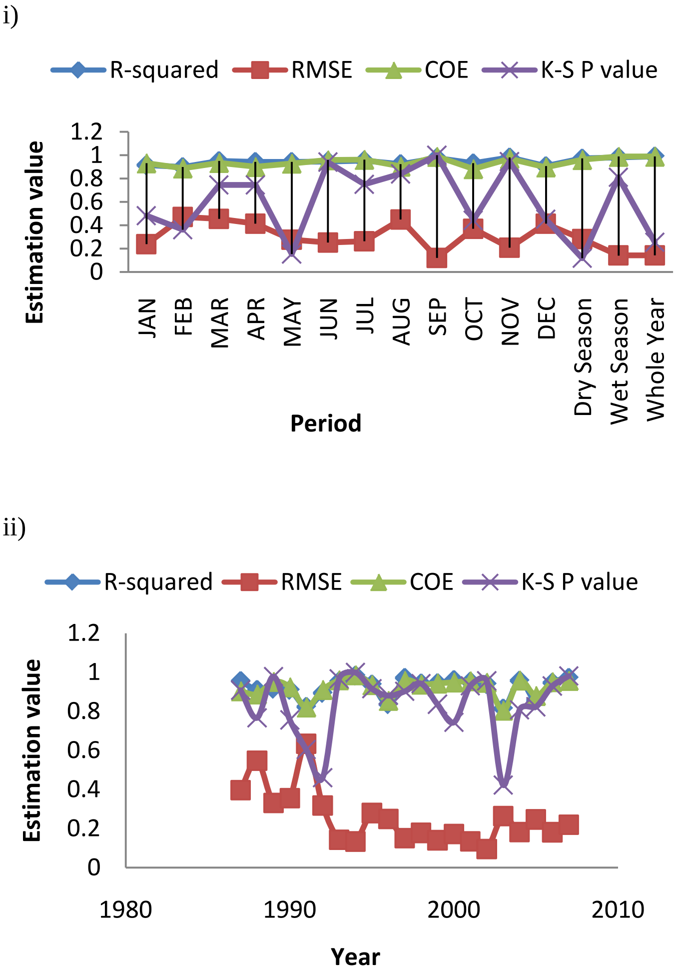


Fig. 11b: Estimation parameters of the Weibull statistical distribution for Iseyin (i) Periodic analyses (ii) annual analyses

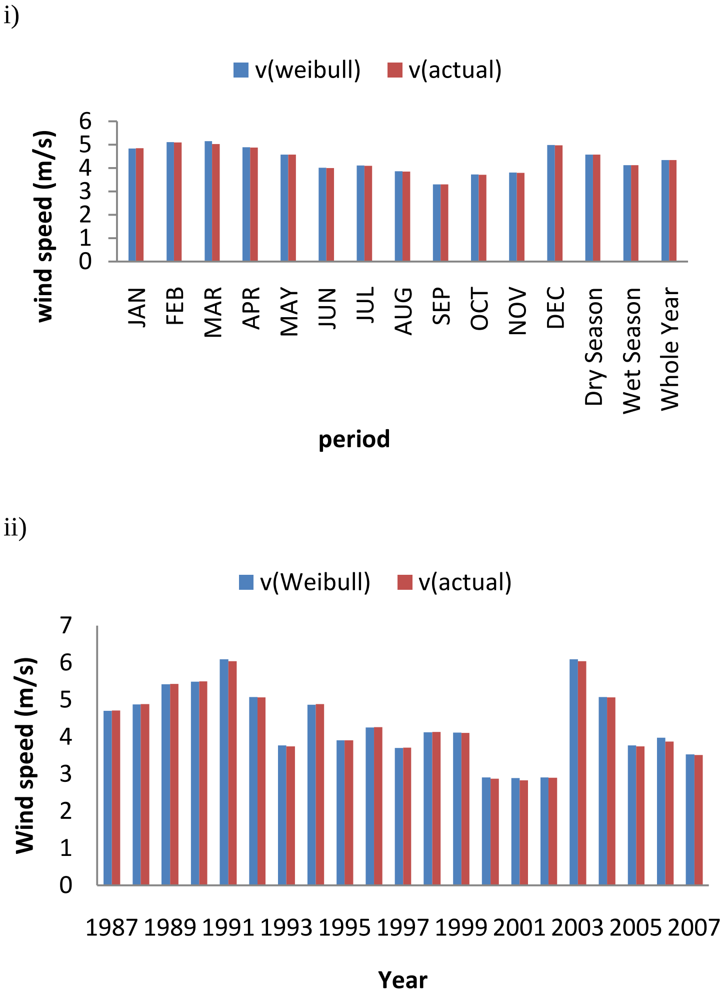
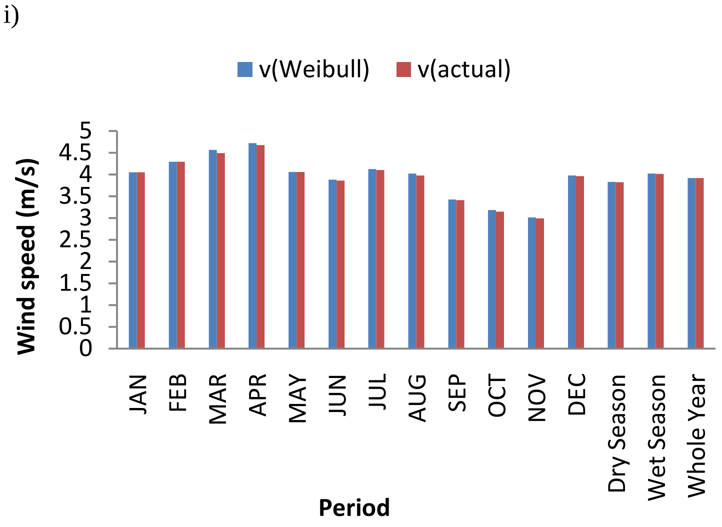


Fig. 12a: Plot comparing the Weibull prediction with actual data for Shaki (i) periodic analyses (ii) Annual analyses

Furthermore, the performance estimation results (Fig. 11) of the Weibull distribution clearly demonstrated that the obtained results were very reliable. However, some of the values of RMSE were greater than 0.5 as shown in Fig. 11. Thereby presenting a situation that required further investigation in order to determine the exact interpretation of the results. This involved comparing the Weibull results with the actual measured data as presented in Fig. 12. Clearly, Fig. 12 showed that at each point the value of RMSE > 0.5, the Weibull predicted result is higher than the actual measured data value. This is a case of over prediction and the full interpretation depends on the value of COE at the points, whether positive or negative. A negative COE value means the actual data value is a better predictor of the true situation than the Weibull result. In this study however, the COE reported positive values throughout. This points to the conclusion that although the Weibull result is higher, it is a better predictor of the true value.



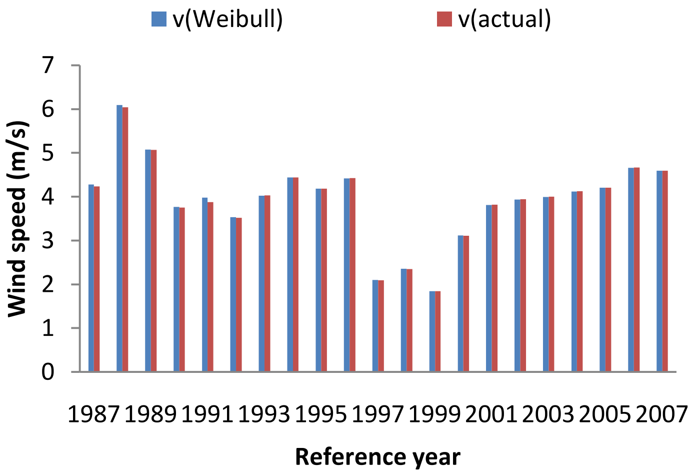
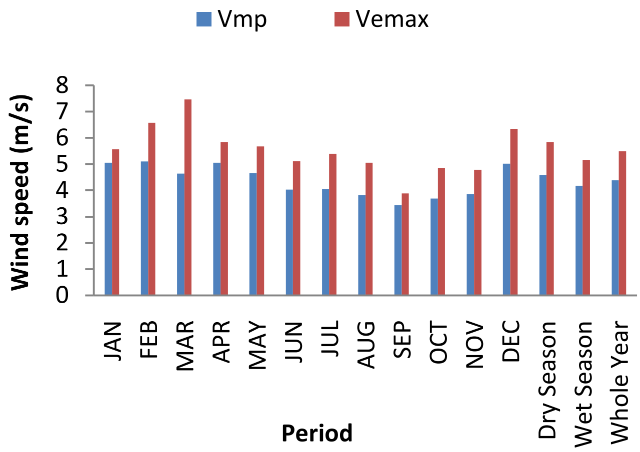


Fig. 12b: Plot comparing the Weibull prediction with actual data for Iseyin (i) periodic analyses (ii) Annual analyses

Assessing a site's wind resources for power generation involves not only profiling the wind power potential. It also involves evaluating two important wind speeds that will aid in the determination of the wind speed rating of a suitable wind turbine. These wind speeds are the most probable wind speed (vmp) and the maximum energy carrying wind speed (vEmax) (Fagbenle et al., 2011) evaluated from Eqs.9 and 10. Fig. 13 displays the monthly, seasonal and whole years' values of these wind speeds. It showed that the range of values for vmp and vEmax for Shaki site were 3.4 to 5.1 m/s and 3.9 to 7.5 m/s (from January to December), 4.6 m/s and 5.8 m/s (Dry), 4.2 m/s and 5.2 m/s (wet) and 4.4 m/s and 5.5 m/s (whole years) respectively. While for Iseyin site, the values were from 2.7 to 4.7 m/s and 4.4 to 6.8 m/s (from January to December), 3.7 m/s and 5.1 m/s (Dry), 4.0 m/s and 5.2 m/s (wet) and 3.9 m/s and 5.0 m/s (whole years) respectively. Thus, a wind turbine having cut-in wind speed of 3.0 m/s at 10 m height will likely work to produce electricity at Shaki site, while that with cut-in wind speed of 2.5 m/s will likely be more appropriate at 10 m height for Iseyin site.

a



b

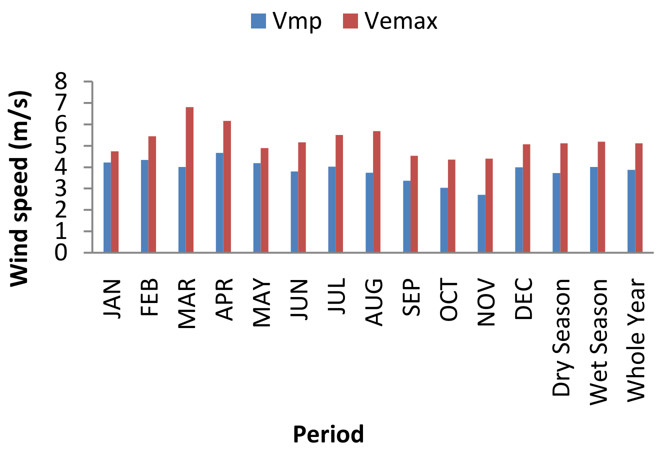


Fig. 13: Plot showing most probable and maximum energy carrying wind speeds for periodic analyses (a) Shaki (b) Iseyin

Wind turbine electricity and cost benefit analyses

The magnitudes of wind power that may likely be generated if wind turbine models were installed at the sites were evaluated. This involved subjecting the wind profiles at the sites to the three wind turbine models mentioned earlier. However, since the data were of the 10 m height, the corresponding wind speed values at the turbines' hub heights (80 m) were estimated from (Oztopal et al., 2000):

$$v_{ref} = v_{10}\left(\frac{h_{ref}}{h_{10}}\right)^{\alpha} = \left(\frac{80}{10}\right)^{\alpha} = v_{10}\left(8\right)^{\alpha} = v_{80}$$

where:

vref = v80 = wind speed at reference height of 80 m, v10 = wind speed at 10 m height, href = reference height = 80 m, h10 = 10 m height, α = roughness factor for the sites. This was taken to be 0.3 according to Asiegbu and Iwuoha (2007), for small towns and suburb with high woods and many trees. A description that is adequate for the sites.

With the wind speeds at 80 m height, the Weibull parameters for analyses at the new height were evaluated and used with Eqs.11 – 13. The results are presented in Table 4 for the two sites. Table 4 however showed that, though the turbines can be employed at the two sites, they produced higher average power output at the Shaki site than at Iseyin.

The monthly average power output across the turbine series varied from the lowest in September to the highest in March with values ranged from 0.08 to 1.20 GWh in Shaki site. In Iseyin site, it varied from the lowest in January to the highest also in March except for the GE 1.5 xle which had the lowest value in October. The range of average power output for Iseyin site across the turbine series was from 0.21 to 1.01 GWh.

When sites' turbine to turbine productions were compared (Fig. 14a), the range of monthly average power output of turbines at Iseyin were more than those at Shaki except for AV 927 model. However, on annual production values (Fig. 14b), the range of production at Shaki site was consistently more than those of Iseyin.

TABLE 4A: RESULTS FROM SIMULATING ELECTRICAL POWER OUTPUT WITH THE WIND TURBINE MODELS FOR ISEYIN

	GE 1.5xle			AV 928			AV 927		
Period	**P_e (GWh)**	**P_{eAve} (GWh)**	**CF (%)**	**P_e (GWh)**	**P_{eAve} (GWh)**	**CF (%)**	**P_e (GWh)**	**P_{eAve} (GWh)**	**CF (%)**
Jan	0.14	0.22	19.42	0.23	0.35	18.76	0.17	0.26	10.41
Feb	0.28	0.37	36.59	0.45	0.61	36.14	0.39	0.56	25.20
Mar	0.53	0.54	48.15	0.88	0.91	49.01	0.87	1.01	41.08
Apr	0.45	0.52	47.94	0.74	0.86	47.59	0.66	0.86	36.40
May	0.18	0.27	24.54	0.30	0.45	23.93	0.24	0.36	14.49
Jun	0.25	0.34	31.53	0.42	0.57	31.51	0.38	0.54	22.77
Jul	0.32	0.41	36.79	0.53	0.68	36.71	0.48	0.67	27.19
Aug	0.34	0.42	37.91	0.57	0.71	38.16	0.55	0.73	29.75
Sep	0.15	0.23	21.06	0.26	0.38	21.21	0.24	0.35	14.67
Oct	0.14	0.21	19.06	0.25	0.36	19.50	0.24	0.34	13.94
Nov	0.16	0.24	22.17	0.30	0.42	23.22	0.31	0.44	18.40
Dec	0.24	0.33	29.94	0.40	0.55	29.66	0.34	0.50	20.30
1987	4.33	5.35	40.74	7.20	8.90	40.66	6.65	8.93	30.90
1988	12.67	9.11	69.32	20.53	15.35	70.10	18.15	17.37	60.08
1989	6.61	7.10	54.07	10.75	11.72	53.50	9.26	11.85	41.00
1990	2.81	3.89	29.58	4.76	6.49	29.65	4.37	6.20	21.43
1991	4.30	5.10	38.81	7.34	8.63	39.43	7.30	9.24	31.98
1992	1.91	2.81	21.39	3.24	4.69	21.40	2.86	4.19	14.50
1993	1.13	1.77	13.46	1.80	2.82	12.87	1.19	1.85	6.41
1994	3.57	4.85	36.89	5.81	7.93	36.19	4.76	6.94	24.02
1995	2.68	3.86	29.41	4.39	6.31	28.79	3.55	5.28	18.26
1996	1.35	2.14	16.32	2.12	3.37	15.41	1.22	1.94	6.71
1997	0.19	0.55	4.19	0.57	1.06	4.84	0.53	0.99	3.42
1998	0.32	0.62	4.73	0.69	1.14	5.20	0.62	1.01	3.50
1999	0.00	0.18	1.37	0.15	0.39	1.77	0.13	0.34	1.18
2000	0.80	1.25	9.50	1.38	2.09	9.53	1.13	1.71	5.91
2001	0.65	1.03	7.86	1.04	1.64	7.49	0.65	1.02	3.53
2002	0.18	0.29	2.22	0.27	0.45	2.04	0.11	0.18	0.64
2003	0.66	1.06	8.05	1.04	1.66	7.60	0.60	0.95	3.28
2004	1.92	2.91	22.17	3.11	4.70	21.46	2.31	3.53	12.20
2005	1.25	1.97	14.96	1.98	3.12	14.23	1.25	1.96	6.79
2006	2.65	3.96	30.16	4.21	6.34	28.93	2.77	4.32	14.95
2007	3.86	5.17	39.35	6.26	8.44	38.52	5.00	7.32	25.31

TABLE 4B: RESULTS FROM SIMULATING ELECTRICAL POWER OUTPUT WITH THE WIND TURBINE MODELS FOR SHAKI

	GE 1.5xle			AV 928			AV 927		
Period	**P_e (GWh)**	**P_{eAve} (GWh)**	**CF (%)**	**P_e (GWh)**	**P_{eAve} (GWh)**	**CF (%)**	**P_e (GWh)**	**P_{eAve} (GWh)**	**CF (%)**
Jan	0.72	0.58	51.81	1.20	1.03	55.18	1.23	1.19	48.64
Feb	0.53	0.56	55.16	0.87	0.92	54.72	0.77	0.95	42.96
Mar	0.70	0.62	55.87	1.15	1.06	57.14	1.12	1.20	48.78
Apr	0.38	0.49	45.08	0.62	0.79	44.09	0.48	0.69	29.10
May	0.36	0.46	41.63	0.59	0.76	40.97	0.49	0.70	28.46
Jun	0.24	0.33	30.92	0.40	0.55	30.63	0.35	0.50	21.07
Jul	0.30	0.40	35.47	0.50	0.66	35.30	0.45	0.63	25.60
Aug	0.24	0.33	29.74	0.40	0.55	29.65	0.36	0.51	20.94
Sep	0.05	0.08	7.77	0.09	0.14	7.63	0.07	0.10	4.31
Oct	0.21	0.30	26.74	0.35	0.50	26.71	0.32	0.46	18.65
Nov	0.18	0.26	24.48	0.30	0.44	24.22	0.26	0.38	15.95
Dec	0.53	0.58	52.31	0.86	0.96	51.78	0.75	0.97	39.51
1987	1.18	1.92	14.59	1.81	2.96	13.51	0.80	1.31	4.54
1988	1.92	3.06	23.27	2.98	4.77	21.77	1.46	2.36	8.17
1989	5.80	6.98	53.11	9.16	11.28	51.51	5.59	8.49	29.37
1990	5.55	6.87	52.30	8.68	11.04	50.40	4.63	7.28	25.19
1991	12.67	9.11	69.32	20.53	15.35	70.10	18.15	17.37	60.08
1992	6.61	7.10	54.07	10.75	11.72	53.50	9.26	11.85	41.00
1993	2.81	3.89	29.58	4.76	6.49	29.65	4.37	6.20	21.43
1994	2.97	4.41	33.55	4.70	7.03	32.08	2.87	4.53	15.66
1995	0.95	1.49	11.36	1.52	2.38	10.86	1.00	1.57	5.42
1996	0.99	1.58	12.05	1.56	2.49	11.36	0.88	1.41	4.87
1997	0.57	0.90	6.82	0.90	1.42	6.50	0.56	0.89	3.07
1998	0.61	0.99	7.54	0.96	1.55	7.06	0.50	0.81	2.80
1999	1.07	1.69	12.89	1.70	2.68	12.25	1.06	1.67	5.77
2000	0.99	1.57	11.98	1.81	2.71	12.38	1.63	2.45	8.47
2001	1.41	2.22	16.91	2.65	3.87	17.67	2.57	3.79	13.09
2002	0.61	0.98	7.43	1.08	1.66	7.57	0.90	1.37	4.74
2003	12.67	9.11	69.32	20.53	15.35	70.10	18.15	17.37	60.08
2004	6.61	7.10	54.07	10.75	11.72	53.50	9.26	11.85	41.00
2005	2.81	3.89	29.58	4.76	6.49	29.65	4.37	6.20	21.43
2006	4.30	5.10	38.81	7.34	8.63	39.43	7.30	9.24	31.98
2007	1.91	2.81	21.39	3.24	4.69	21.40	2.86	4.19	14.50

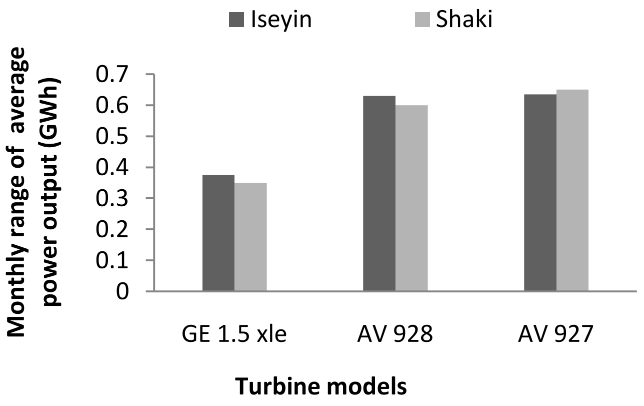


Fig. 14a: Plot comparing the monthly range of average power output of the turbines at the two sites

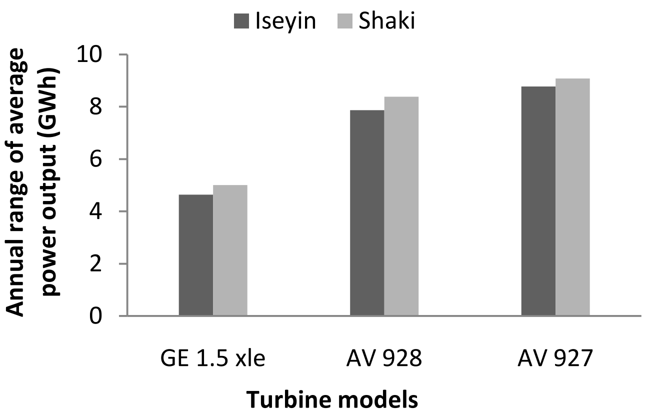


Fig. 14b: Plot comparing the anneal range of average power output of the turbines at the two sites

Comparing the performance characteristics of the turbines at the two sites (Fig. 15), showed also that, GE 1.5 xle and AV 928 turbine models were more suitable for the sites than AV 927. This may be partly due to the nature of wind profiles of the sites which can be classified as low to moderate or wind power class 2 to 4 according to NREL (2011). It may also be due to the fact that the rated wind speed of AV 927 is higher.

Substituting the rate assumptions of Table 6 into Eq. 14 gives:

$$C_{PV} = 1.2x + \frac{0.25x}{t}\left[\frac{1+I_R}{R_I - I_R}\right] \times \left[1 - \left(\frac{1+I_R}{1+R_I}\right)^t\right] - 0.12x\left(\frac{1+I_R}{1+R_I}\right)^t \tag{16}$$

TABLE 5: ASSUMED TURBINE MODEL PRICE

Turbine model	Assumed price (€)
GE 1.5xle	1,500,000
AV 928	2,500,000
AV 927	3,500,000

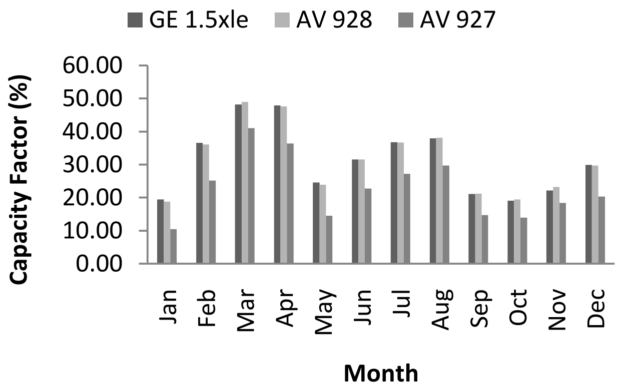


Fig. 15a: Plot comparing the monthly values of capacity factor for the three turbine models employed for Iseyin site

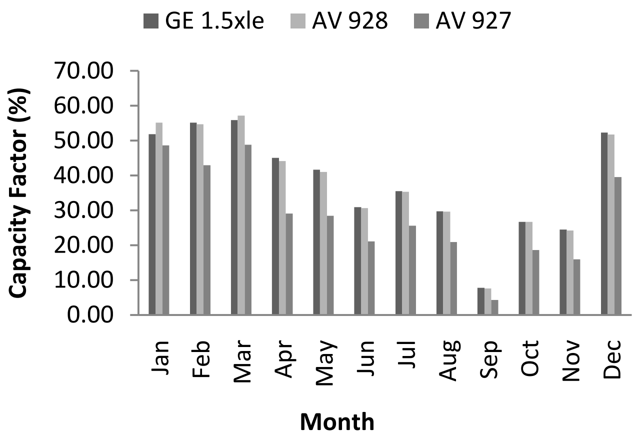


Fig. 15b: Plot comparing the monthly values of capacity factor for the three turbine models employed for Shaki site

Cost benefit analysis

This is estimated from Eqs.14 and 15 based on the assumptions presented in Tables 5 and 6.

TABLE 6: ASSUMPTIONS FOR COST BENEFIT ANALYSIS

Item	Assumed value
R_C	20%
R_{OM}	25%
R_I	6%
I_R	12%
R_{SC}	10%
t	20 years

Further substituting the interest and inflation rates into Eq. 16 gives:

$$C_{PV} = 1.30755x \tag{17}$$

Therefore, substituting the turbine prices into Eq. 17 and employing Eq. 15 gives Table 7.

TABLE 7A: COST BENEFIT ANALYSIS FOR WIND ELECTRICITY PRODUCTION AT ISEYIN SITE

Turbine model	Present cost	Average $P_{e,ave}$ per annum (from Table 4) $\times 10^6$ kWh	20 years average $P_{e,ave}$ (t $\times P_{e,ave}$) $\times 10^6$ kWh	Specific cost per kWh (€)	Specific cost per kWh (Nigeria naira)
GE1.5 xle	1,961,325	3.09	61.8	0.032	6.82
AV 928	3,268,875	5.11	102.2	0.032	6.82
AV 927	4,576,425	4.63	92.6	0.049	10.437

TABLE 7B: COST BENEFIT ANALYSIS FOR WIND ELECTRICITY PRODUCTION AT SHAKI SITE

Turbine model	Present cost	Average $P_{e,ave}$ per annum (from Table 4) $\times 10^6$ kWh	20 years average $P_{e,ave}$ (t $\times P_{e,ave}$) $\times 10^6$ kWh	Specific cost per kWh (€)	Specific cost per kWh (Nigeria naira)
GE 1.5 xle	1,961,325	3.94	78.8	0.025	5.33
AV 928	3,268,875	6.49	129.8	0.025	5.33
AV 927	4,576,425	5.82	116.4	0.039	8.31

From Table 7, the best turbine model for the sites is AV 928. Its cost per kWh is the same as GE 1.5xle, but has the capacity of producing peak generation of 2.5MW of electricity. However, with the present national electricity tariff put at about €0.015 (Ajayi, 2010), it can be concluded from Table 7 that the cost of producing wind electricity at the sites is greater. Moreover, considering the environmental friendliness of wind electricity and the progression of its technology advancement, the cost of wind electricity is expected to decline in the near future.

IV. CONCLUSION

The study has been used to assess the viability of wind energy resources for power generation of two local sites in Oyo State, Nigeria. Monthly mean wind speed data for the study were obtained from the Nigerian meteorological agency, Oshodi, Lagos State and subjected to the Weibull statistical distribution and other analyses to determine the potential of the sites' wind resources for power generation. It was found that the Weibull 2-parameter statistical distribution was adequate at characterizing the wind profiles of the sites. The range of the monthly and annual Weibull k and c parameters for the two sites were each found to be greater than two, indicating that the data spread exhibited good uniformity with relatively small scatter and also that the Weibull predicted results were accurate at explaining the wind profile situation of the sites (Keyhani et al., 2010). Furthermore, adapting the results to three practical wind turbine models revealed that the sites are capable of generating MWh of electricity, while turbine model AV 928 appeared to be the most suitable of the three used in the study. Thus, the sites are good enough for small scale wind farm projects.

REFERENCES

[1] Adekoya, L.O. Adewale, A.A., (1992). Wind energy potential of Nigeria, Renewable Energy, 2(1): 35-39

[2] Ahmed Shata, A.S. Hanitsch, R., (2006). Evaluation of wind energy potential and electricity generation on the coast of Mediterranean Sea in Egypt, Renewable Energy, 31: 1183-1202

[3] Ahmed, S.A., (2010). Wind energy as a potential generation source at Ras Benas, Egypt, Renewable and Sustainable Energy Reviews, 14: 2167-2173

[4] Ajayi, O.O., (2009). Assessment of utilization of wind energy resources in Nigeria, Energy Policy, 37: 750-753

[5] Ajayi, Oluseyi O., (2010). The Potential for Wind Energy in Nigeria, Wind Engineering, 34(3): 303 – 312

[6] Akpinar, E.K. and Akpinar, S., (2005). An assessment on seasonal analysis of wind energy characteristics and wind turbine characteristics, Energy Conversion and Management, 46: 1848–1867

[7] Albadi, M.H. El-Saadany, E.F. Albadi, H.A., (2009). Wind to power a new city in Oman, Energy, 34: 1579-1586

[8] Asiegbu, A.D. 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

[9] Avantis Group., (2011). Avantis wind turbines genral ratings, available online [www.avantis-energy.com, accessed March 8, 2011]

[10] Energy Commission of Nigeria and United Nations Development Programme (ECN-UNDP)., (2005). Renewable energy master plan: final draft report, available online [http://www.iceednigeria.org /REMP%20Final%20Report.pdf, accessed 17 June 2007]

[11] Fadare D.A., (2010). The application of artificial neural networks to mapping of wind speed profile for energy application in Nigeria, Applied Energy, 87: 934 – 942

[12] Fadare, D.A. A., (2008)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

[13] Fagbenle, R.O. Karayiannis, T.G., (1994). On the wind energy resources of Nigeria, International Journal of Energy research, 18 (5): 493-508

[14] Fagbenle, R.O, Katende, J, Ajayi, O.O. Okeniyi, J.O., (2011). Assessment of wind energy potential of two sites in North - East, Nigeria, Renewable Energy, 36: 1277 – 1283

[15] Feretic´, D. Tomisic, Z. Calina, N., (1999). Feasibility analysis of wind-energy utilization in Croatia, Energy, 24: 239-246

[16] GE Energy., (2009). 1.5 MW wind turbine, available online [http://www.ge-energy.com/prod_serv /products/wind_turbines/en/downloads/GEA14954C15-MW-Broch.pdf, accessed September 29, 2010]

[17] Hau, E., (2006). Wind Turbines - Fundamentals, Technologies, Application, Economics, 2nd ed. Springer, Verlag, 451-483

[18] Keyhani A, Ghasemi-Varnamkhasti M, Khanali M, Abbaszadeh, R., (2010). An assessment of wind energy potential as a power generation source in the capital of Iran, Tehran, Energy, 35: 188-201

[19] Krause, P. Boyle, D. P. Bäse, F., (2005). Comparison of Different Efficiency Criteria for Hydrological Model Assessment, Advances in Geosciences, 5: 89–97

[20] Montgomery DC. Runger, G.C., (2003). Applied Statistics and Probability for Engineers, 3rd ed. Wiley, New Jersey

[21] National Renewable Energy Laboratory (NREL)., (2011). Dynamics maps, GIS data and Analysis tools, available online [http://www.nrel.gov/gis/wind.html, accessed March 8, 2011]

[22] Ogbonnaya, I.O, Chikuni, E. Govender, P., (2009). Prospect of wind energy in Nigeria, available online [http://active.cput.ac.za/energy/web/due/papers/2007/023O_Okoro.pdf, accessed July 16, 2009]

[23] Ojosu, J. O. Salawu, R. I., (1990a). A Survey of Wind Energy Potential in Nigeria, Solar and Wind Technology, 7 (2 and 3): 155-167

[24] Ojosu, J.O. Salawu, R.I., (1990b). An Evaluation of Wind Energy Potential as a Power Generation Source in Nigeria', Solar and Wind Technology, 7 (6): 663-673

[25] Omotosho, O.A., Okeniyi, J.O. Ajayi, O.O., (2010). Performance Evaluation of Potassium Dichromate and Potassium Chromate

Inhibitors on Concrete Steel Rebar Corrosion, Journal of Failure Analysis and Prevention, 10 (5): 408 – 415

[26] Oztopal, A. Sahin, A.D. Akgun, N. Sen, Z., (2000). On the regional wind energy potential of Turkey, Energy, 25: 189-200

[27] Polyanin A.D. Manzhirov, A.V., (2007). Handbook of mathematics for engineers and scientists, Chapman & Hall/CRC, Boca Raton

[28] Rehman, S. Ahmed, A., (2005). Assessment of wind energy potential for coastal locations of the kingdom of Saudi Arabia, Energy, 29: 1105-1115

[29] Roberge, P.R., (2003). Statistical Interpretation of Corrosion Test Results, In: Corrosion: Fundamentals, Testing, and Protection, ASM Handbook, Vol 13A, ASM International, 425-429

[30] Sulaiman, M.Y. Akaak, A.M. Abd. Wahab, M. Zakaria, A. Sulaiman, Z.A. Suradi, J., (2002). Wind characteristic of Oman, Energy, 27: 35-46

[31] Tina, G, Gagliano, S. Raiti, S., (2006). Hybrid Solar/Wind Power System Probabilistic Modelling for Long-Term Performance Assessment, Solar Energy, 80: 578–588