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Effects of Some Meteorological Parameters on Wind Energy Potential in Calabar, Nigeria

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Authors' contributions

This work was carried out in collaboration between all authors. Author COE designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors FAK and AON managed the analyses of the study. Author AON managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Effects of some meteorological parameters on wind energy potential in Calabar have been investigated. The data on wind speed, temperature and relative humidity was obtained by in-situ measurement approach. The relationships between the given meteorological parameters were obtained from plots of wind speed against temperature and relative humidity as independent variables. Statistical correlation of wind speed values and the two meteorological parameters was done, which yielded 0.89 as correlation coefficient for wind speed and temperature, -0.88 for wind speed and relative humidity with the relevant plots; these clearly shows that of all the two meteorological parameters, temperature contributes most to the wind speed in Calabar. On the other hand, the negative correlation of wind speed and relative humidity (%) shows that as humidity increases, wind speed decreases.

Keywords: Wind energy; wind speed; relative humidity; temperature; energy; meteorological parameter.

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1. INTRODUCTION

Wind is a renewable source of energy and is one of the fastest growing energy resource in the world, which is clean and offers many benefits to human. Wind energy has received immense attention because renewable energy is on tremendous focus. Due to increase in cost of fossil fuel and the various environmental problems, it is important to appreciate the potential of electricity generation from nonconventional sources [1]. Renewable energy sources such as solar thermal, geothermal, biomass, tidal and wind power are effective ways to mitigate energy shortage and reduce environmental pollutions.

Nigeria stands at the threshold of rapid depletion of conventional energy resources, it is expedient to know that renewable energy source (such as wind) has been identified as an attractive area for research and development and should receive substantial attention for investment purposes. In many rural locations of Nigeria, wind energy could provide a cost effective and unique way out of both metropolitan and rural electrification failure. High level of both economic and agricultural activities take place in these areas with little or no access to energy and water supply.

Wind energy has been exploited by mankind for more than 2000 years and represents a reliable source of renewable energy [2]. In the present day, the wind energy technology has reached such a matured level that it is being used as one of the main sources of producing electricity in many countries including Germany, Spain, United States, China and India [3] and [4].

[5] used the correlation between the average wind speed and ambient temperature to develop models for predicting wind potentials for two Nigerian locations. It was reported that wind speed clearly correlates with ambient temperature in a simple polynomial of 3rd degree. Their results suggest that the temperature-based model can be used, with acceptable accuracy, in predicting wind potentials needed for preliminary design assessment of wind energy conversion devices for the locations and others with similar meteorological conditions.

[6] investigated the variation of atmospheric visibility with meteorological parameters of measured monthly average daily visibility, mean temperature, relative humidity, atmospheric pressure, rainfall and wind speed for a period of 12-years over Ikeja, Lagos State, South Western, Nigeria at an altitude of 40 m above sea level. The results indicated that the seasonal variation of atmospheric visibility is greater during the rainy season than in the dry season.

[7] presented a study on the comparative study of some meteorological parameters for predicting global solar radiation in Kano, Nigeria Based on Three Variable Correlations, twenty empirical regression equations based on three variable correlations were developed and used to estimate the monthly average daily global solar radiation on a horizontal surface using measured monthly average daily global solar radiation, sunshine duration, wind speed, maximum and minimum temperatures, rainfall, cloud cover and relative humidity parameters during the period of thirty one years (1980 – 2010) for Kano, Nigeria at an altitude of 472.5 m above sea level. The comparative performance of the developed models was evaluated on the basis of statistical parameters using Mean Bias Error (MBE), Root Mean Square Error (RMSE), Mean Percentage Error (MPE), t – test and Nash – Sutcliffe Equation (NSE). These developed models can be used for estimating monthly average daily global solar radiation for Kano, North – Western, Nigeria and other locations with similar weather conditions where the solar radiation data is unavailable.

The aim of this research is to determine the effect of some meteorological parameters on wind energy potential in Calabar.

1.1 Study Area

Calabar, the capital of Cross River State located in the southern part of Nigeria experiences a rare type of climate known as the tropical monsoon climate, Calabar is on Latitude 4°57'06''N and longitude 8°19'19''E at an elevation of 42m above sea level. It experiences precipitations almost throughout the whole year except in the core months of the dry season which occurs in two short periods of January to March and October to December during a calendar year [8]. But the location selected for this study is on Latitude 4°57ˈ38.6161ˮ N and Longitude 8°18ˈ58.482ˮ E, it is about 500metre away from the Calabar River. The arrow in the map indicates where the study location is sited. This location was selected because we seek to see if the turbulent water waves have any significant effect on wind speed, since power is dependent on wind speed. Key spells out the map details.

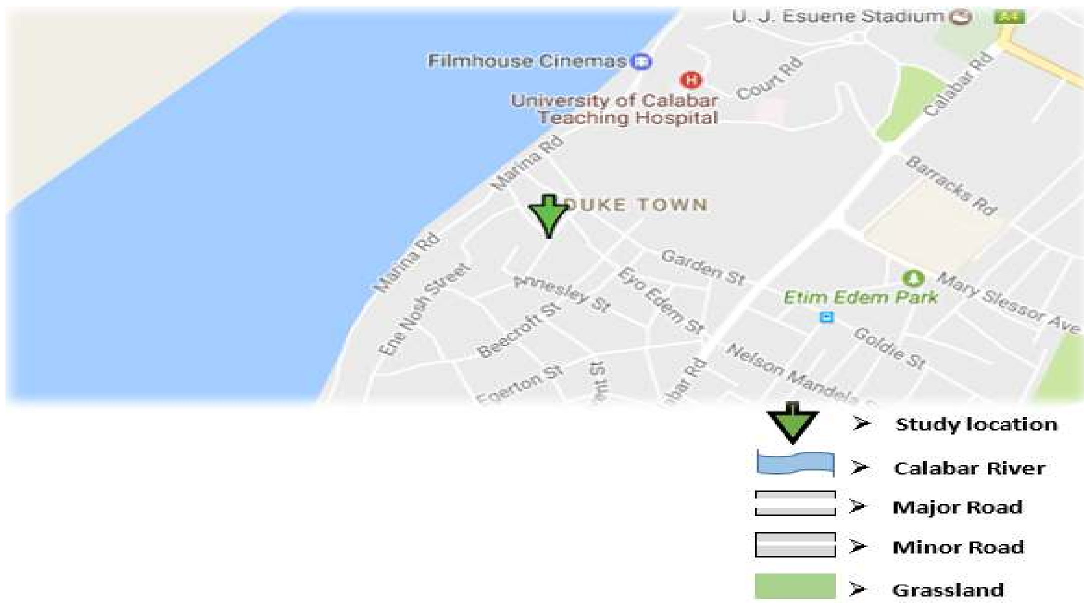

Fig. 1. Wind map of study location

2. MATERIALS AND METHODS

2.1 Materials

The instruments used for the course of this research include; a hand held anemometer (made of China, GM816 model) and a hand held Hygrometer (made in China, KT-908 model).

An Anemometer is displays its count on a Liquid Crystal Display (LCD) in seconds based on the adjustment of the automatic and manual model known. It has a high precision pressure sensor which is optimized to detect pressure and measure wind speed up to the range of 0-30 m/s; wind temperature up to; -10 – 45℃ (14-113F) and also an operating Humidity less than or equal to 90%. It can be used for industrial and home purposes such as measuring speed and temperature of CPU computer fans, air-conditioners, air flow rate over the roof tops.

A Hygrometer is another instrument used and it is optimized to measure Relative Humidity (%) and Temperature of 14.0 to 122.0℉/ -10.0 to 50.0℃ for indoor, and -58.0 to 158.0℃/ -50.0 to 70.0℃ for outdoor. It has a high stability and accuracy up to ±2℉ or ± 1℃ for temperature and ±5% for relative humidity, with a multi-functional LCD display.

A metre rule with an accuracy of ±0.5 cm is used to measure height above sea level.

2.2 Methods

Wind speed, Relative Humidity and Temperature data were captured using an Anemometer and a multipurpose hygrometer accordingly. The data measurement was obtained at 4 m above the sea level. The data was collected for 12 hrs daily at an interval of 30 mins (i.e. 6 am -6 pm) for 14 days.

Fig. 2. An anemometer

Fig. 3. A hygrometer

3. THEORETICAL FRAMEWORK

The maximum power that can be extracted from the wind at any speed (*v*) is given by a cubic function of the form:

$$P = \frac{1}{2} C_p \rho A v^3 \quad (1)$$

where $C_p = 0.59$ is the power coefficient, ρ is the density(kg/m^3) of the air and A is the area(m^2) swept by the blade of the conversion device, v is wind Speed(m/s) and *P* is the Power (W) [9].

Thus, the power derivable from a particular wind turbine depends on the height (*h*) of installation above the ground $h \propto \frac{1}{\rho}$ according to the Hellman's exponential law given by:

$$\frac{v}{v_0} = \left(\frac{h}{h_0}\right)^{\alpha} \quad (2)$$

where h_0 is any reference height(m) and v_0 is the wind speed(m/s) at h_0, while *α* is the Hellman's constant(surface roughness), a constants value ranging between 0.05 – 0.5 [10] and [11].

Equation (2) suggests that the derivable power increases with increasing height only if the change in density of air is negligible. It has been shown by [12] that within the troposphere (*h* ≤ 10 km) the density of air varies very little for any location.

If the troposphere is considered to be a mixture of ideal gases, the principle of equipartition of energy suggests that, at any absolute temperature, T in Kelvin, the translational kinetic energy, E in joule of a mole of the gas is given by:

$$E = \frac{3}{2} RT \quad (3)$$

where R = 8.3Jmol^{-1}K^{-1} is the universal molar gas constant [13].

In thermal equilibrium, the ambient temperature of the air in a region/location is a measure of the average kinetic energy of the constituent air masses. Thus, if the speed of an air mass, m (kg) arises entirely from the combined effects of the thermal motion of the various components, we can write:

$$\frac{1}{2} m v^2 = \frac{3}{2} RT \quad (4)$$

which gives us;

$$v^2 = \frac{3R}{m} T = \sqrt{\frac{3kT}{m}} \quad (5)$$

$$v \propto \sqrt{T} \quad (6)$$

The last equation therefore suggests a relationship between the wind speed and the absolute temperature of an atmospheric air mass in the form:

$$v \approx \omega T^{\phi} \quad (7)$$

where ω and ϕ are constants which describe the velocity–temperature (v–T) dependence and are expected to be location specific.

4. RESULTS AND DISCUSSION

The developed models obtained from this study are;

$$\mathrm{WS} = 0.1739\mathrm{T} - 51.618 \quad (8)$$

$$\mathrm{WS} = -0.0513\mathrm{RH} + 4.9862 \quad (9)$$

In the models above, WS is the wind speed, RH is the relative humidity and T is the temperature.

Based on R and R^2 value shown in Table 1, the model relating the Temperature is ranked the best performing model which is in agreement with earlier studies by [5] and the model relating the Relative Humidity is ranked the least. Therefore the regression equation model given in equation (8) is most suitable for predicting wind speed for the study area under investigation based on the correlation coefficient and coefficient of determination.

Table 2 shows data obtained from in-situ measurement, the plots of Wind Speed against the given meteorological parameters are shown in Figs. 4, 5 and 6 .the expected scatter of wind speed values in the respective cases is evident. This is what necessitated the correlation approach that yielded the best fits indicated in each of the graphs.

Table 1. Correlation coefficient and coefficient of determination (R^2) validating the models

Models	Correlation coefficient (R)	Coefficient of determination (R^2)
Temperature	0.89	0.7841
Relative Humidity	-0.88	0.7724

Table 2. Average data obtained from in-situ measurement of atmospheric parameters for 14 days

Time of day (mins)	Wind speed (m/s)	Ambient temperature (K)	Relative humidity (%)
6:00	1.11	300.8	83
6:30	0.86	300.3	86
7:00	0.53	300.5	85
7:30	0.66	300.6	84
8:00	0.71	301.6	81
8:30	0.50	302.3	80
9:00	0.69	303.2	75
9:30	0.91	303.5	74
10:00	1.22	304.3	71
10:30	1.13	304.7	71
11:00	1.69	305.4	68
11:30	1.41	306.0	66
12:00	1.34	306.8	62
12:30	1.82	307.3	62
13:00	1.96	307.5	62
13:30	1.81	307.3	61
14:00	1.99	308.2	59
14:30	1.97	308.1	60
15:00	2.14	307.4	61
15:30	1.86	307.5	61
16:00	1.91	306.9	64
16:30	1.47	306.3	66
17:00	1.75	305.1	70
17:30	1.49	304.4	73
18:00	1.39	303.1	75

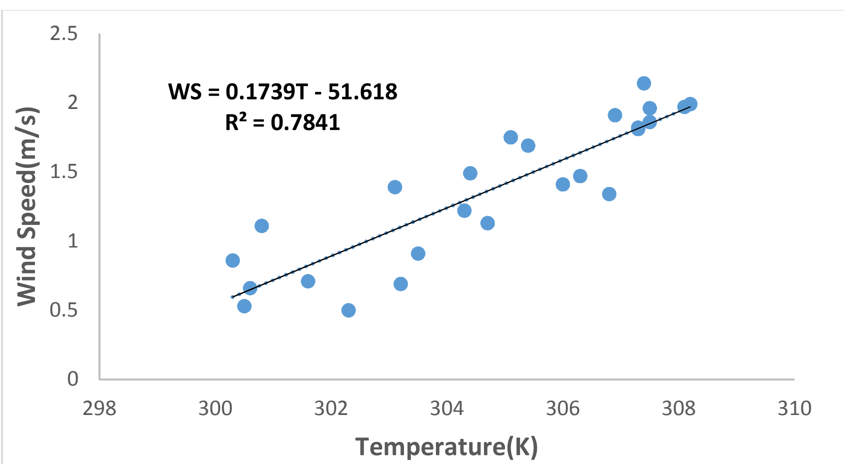

Fig. 4. Wind speed (m/s) against temperature (K)

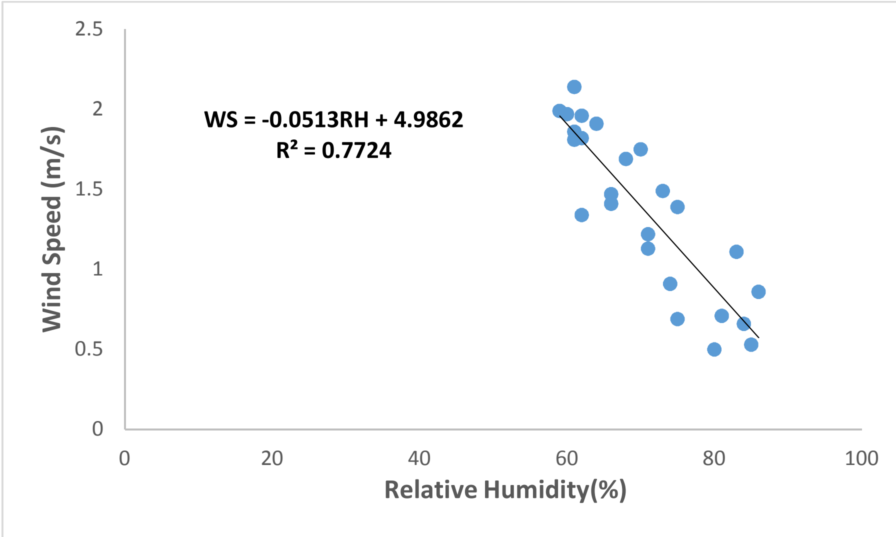

Fig. 5. Wind speed (m/s) against relative humidity (%)

Fig. 4 clearly shows a positive correlation which here confirms a linear relationship between wind speed in Calabar and temperature during the period under investigation. On the other hand, Fig. 5 shows a high negative correlation of wind speed and relative humidity (%).The meaning is that as humidity increases, wind speed decreases; this conforms to our calculated result of statistical correlation. This further shows that Calabar is a low wind region which is in agreement with earlier studies by [14].

5. CONCLUSION

Our results for the study area indicated that, increase in relative humidity decreases wind speed and temperature does the converse. It is advised that electrical engineers willing to design and install wind power generating systems in any location should investigate into the effects of meteorological parameters on wind speed. The result obtained in this study clearly indicates that Calabar wind cannot be used to generate electricity because of the effect of relative humidity on wind speed.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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