TREND ANALYSIS OF WIND SPEED VARIABILITY IN MINNA, NIGERIA

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Abstract
Many countries have included renewable energy systems in their future energy plans so that they can produce reliable and environmentally friendly energy. Weather and climate have a profound influence on life on earth. They are part of the daily experiences of human beings and are essential for health, food production and well-being. Wind power consumes no fuel, and emits no air pollution. However, it's advisable to realize that wind energy is based on natural force which means it's highly spatial correlated, and is also variable over time. Moreover, wind regimes are not static; they are dynamic in nature. The daily wind speed data was obtained from the Minna Airport Meteorological Centre for the period of 2000 to 2010. The wind speed data was subjected to trend and regression analysis. The analysis was carried out using Microsoft Excel 2010 and Statistics 7.It was concluded that the actual mean yearly wind speed was 2.93 m/s and the regression model performance parameters are all measures that incorporate both systematic and random errors which are within the actual range. This further implies that the average wind speed is enough to transport pollen grains from one location to another provided there are no obstacles.

Keywords: Climate, speed, variation, weather, wind

Introduction

Weather and climate have a profound influence on life and earth. They are part of the daily experiences of human beings and are essential for health, food production and well-being (Baede*et al*., 2002). The weather, as we experience it, is the fluctuating state of the atmosphere around us, characterized by the temperature, wind, precipitation, clouds and other weather elements. Climate, on the other hand, refers to the average weather in terms of the mean and its variability over a certain time-span and a certain area. The classical period often referred to in climate change studies is 30 years (Hannah *et al*., 2005). Climate varies from place to place, depending on latitude, distance to the sea, vegetation, presence or absence of mountains or other geographical factors (Baede*et al*., 2002). Climate varies also in time; from season to season, year to year, decade to decade or on much longer time scales, such as the Ice Ages.

Climate change is a physical process but because of the dependency of humans on the availability and quality of natural resources (e.g., air, land, water, biota and materials) any changes in the physical characteristics of the environment will be reflected by cumulative, interacting social and economic impacts. Their intensity and frequency will not be the same due to variations in site-specific characteristics (Scotland and Northern Ireland Forum for Environmental Research (SNIFFER) 2009). Around the world, the effects of climate change are already upon us. Many countries have included renewable energy systems in their future energy plans so that they can produce reliable and environmentally friendly energy. Compare to the environmental effects of traditional energy sources, the environmental effects of wind power are relatively minor (Dvorak *et al*., 2010; Migoya*et al*., 2007). Wind power consumes no fuel, and emits no air pollution. However, it's desirable to realize that wind energy is based on natural force which means it's highly spatially correlated, and is also variable over time. Moreover, wind regimes are not static; they are dynamic in nature. James (2008) stated that wind regimes are sensitive to natural climate variability as well as anthropogenic-driven climate change. He further stated that natural factors such as solar variations, wind variations and volcanic activities occur beyond human activities. Anthropogenic factors are human based activities causing changes in earth's atmosphere. The fundamental concern with all renewable energy based on meteorological parameters is determining the variability of that resource on spatial and temporal scales (Krauze, 2009). As the climate warms, global weather patterns will change, affecting local climates everywhere. Changes will occur to local wind speeds and precipitation, as well as to temperature. Both the average wind speed and the variability of the wind are likely to be affected.

If global patterns change, local wind patterns might change as well. A Geophysical Research Letters Study notes that any change in near-surface wind velocities caused by global climate change could have large societal impacts (Pryor *etal.*, 2006). Therefore, understanding the influences of climate change on wind speed is important for forecasting potential changes in wind velocity on a seasonal basis because wind climate are sensitive to changes in seasons. Climate variations and change, caused by external forcing, may be partly predictable, particularly on the larger, continental and global, spatial scales (Baede*et al.*, 2002). Because human activities, such as the emission of greenhouse gases or land-use change, do result in external forcing, it is believed that the large-scale aspects of human-induced climate change are also partly predictable (Baede*et al.*, 2002). However, the ability to actually do so is limited because we cannot accurately predict population change, economic change, technological development, and other relevant characteristics of future human activity. In practice, therefore, one has to rely on carefully constructed scenarios of human behavior and determine climate projections on the basis of such scenarios.

The aim and objective of this study is to analyze wind variation in Minna using statistical approach/method and to study wind speed changes on a seasonal basis.

Materials and Methods

Study Area: Minna metropolis was selected for the study. Minna, the Capital city of Niger state, is a city in North Central Nigeria. The estimated population of Minna was 304,113 (NPC, 2006) with an average temperature of 31^0C and wind speed at 10km/h (MMS, 2013). Minna lies on the geographical coordinates of latitude $9^0 36' 50''$ north of the equator and longitude $6^0 33' 24''$ east of the Greenwich Meridian, on geological base of undifferentiated basement complex rock of mainly quartz and magnetite situated at the base of prominent hills in an undulating plain. The average elevation of Minna is 272m and altitude 1007 feet.

Fig. 1: Map of Minna, Nigeria

Wind Speed Data: The daily wind speed data used in this study was obtained from the Minna Airport Meteorological Centre for the period of 2000 to 2010 (11 years) were there are no tall buildings or trees. The wind speed data was measured continuously with a cup-generator anemometer at a hub height of 10m. The daily mean speeds were computed as the average of the speeds for each day.The wind speed data was subjected to trend and regression analysis. The analysis was carried out using Microsoft Excel 2010 and Statistics 7.

A trend line represents the long-term movement in time series data after other components have been accounted for. It tells whether the data set have increased or decreased over the period of time. Trend line thus shows observed changes in the wind speed data at a point in time.Regression analysis, on the other hand, is employed to determine how a straight line can be drawn through a series of wind speed data points in order to provide the best fit. The calculations involved are used to determine the slope and intercept of the line. The measure of how good a fit is obtained is done using the R-square value.

A line of best fitis drawn through the wind speed data points. This line is also called the regression line. Excel refers to it as a Trend line. The line of best fit is a straight line in which the data fits a linear equation. This equation is generally written in the form

$$y = mx + b \quad \text{.......} \quad 1$$

where b is the intercept and m is the slope. Having drawn the line of best fit, the values of the slope, intercept and R-square (R^2) are calculated. Knowing the slope and the intercept of the line of best fit, the expected y values are calculated. Excel provides the forecast function that gives another way to get the expected y values. The formula computes the slope and intercept and finds the expected y value.

Prediction/Forecast Performance Evaluation: The prediction accuracy of the model in the estimation of the wind speeds with respect to the actual values were evaluated based on the correlation coefficient (R^2), Root Mean Square Error (RMSE), MeanAbsolute Error (MAE), and Mean Absolute Percentage Error (MAPE). These parameters were calculated based on the following equations:

$$R^2 = \frac{\sum_{i=1}^{N}(yi - z)^2 - \sum_{i=1}^{N}(xi - z)^2}{\sum_{i=1}^{N}(yi - z)^2} \quad \ldots\ldots 2$$

$$RMSE = [\frac{1}{N}\sum_{i=1}^{N}(yi - xi)^2]^{1/2} \quad \ldots\ldots 3$$

$$MAE = \frac{1}{N}\sum_{i=1}^{N}|yi - xi| \quad \ldots\ldots 4$$

$$MAPE = \frac{1}{N}\sum_{i=1}^{N}\left(\frac{(|yi - xi|)}{yi}\right) \quad \ldots\ldots 5$$

Where y_i is the i^{th} actual data, x_i is the i^{th} predicted data, z is the mean of actual data, N is the number of observations, RMSE is the root mean square error, MAE is the mean average error and MAPE ismean absolute percentage error.

Results and Discussion

The monthly wind speed values over the period of 11 years from 2000 – 2010 are presented in Table 1, while the monthly mean wind speed values are presented in Table 2. It can be observed from Table 2 that the highest monthly wind speeds occur in the months of January (4.65 m/s), February (4.98 m/s), March (3.72 m/s) and April (3.74 m/s) for the whole year, while the minimum monthly wind speeds occur in the months of August (1.82 m/s), September (1.83 m/s) and October (1.37 m/s). The highest wind speed of 3.33 m/s occurs in the year 2002, while the minimum wind speed of 2.44 m/s occurs in the year 2009. The overall yearly wind speed in Minna is found to be 2.93 m/s.

Table 1: Monthly and Yearly Actual Wind Speeds in Minna from 2000 to 2010 (Unit: m/s).

Month	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Average
January	133.8	157	224.7	104.1	116.6	198.5	68.1	214.5	181	75.5	108	143.8
February	227.3	188	142.8	100	172.6	114.1	86.3	127.9	196	76.8	99.7	139.2
March	144.3	136	98.6	117.3	142.9	83.7	89.8	113.2	89.5	99.4	150	115
April	120.3	111	113.6	124.3	122.4	113.8	96.3	107.8	105	110.8	109	112.2
May	105.1	96	107.3	112	106.5	94.6	83.5	72.3	97.5	81.7	87.5	94.9
June	82.6	72.5	94.6	75.2	79.9	79.9	69.9	68.9	89.2	82.8	48.2	76.7
July	68.2	68.1	68	72	75.6	61.9	64.3	58	64.5	73.8	44	65.3
August	58.5	57.9	66.7	61.9	65.5	65.9	52.5	45.3	63.5	47.5	31.7	56.1
September	63.8	65.3	61.8	66.7	66.4	63.9	54.8	39.7	47.4	45.9	30	55.1
October	44.1	59.2	41	52.6	42.4	45.5	43.4	25.4	41.9	35.4	38.3	42.7
November	46.3	69.4	53.3	65.3	66.1	63.6	94.4	26	60.3	75	41.6	60.1
December	97.3	106	134.3	110.2	80.5	81.3	131	98.9	97.8	90.8	113	103.8
Yearly Average	99.3	98.8	100.6	88.5	94.8	88.9	77.9	83.2	94.4	74.6	75.1	88.7

The monthly model performance parameters for the 12th year is presented in Table 3. The model prediction performance parameters for the monthly wind speed distributions showed that the forecasted values ranged between 41 and 153 (m/s), R^2 values rangedbetween 0.853 and 1, the root mean square error (RMSE) ranged between 6.8 and 53.8, the mean average error (MAE) ranged between 5 and 48 while the mean absolute percentage error(MAPE) ranged between 5 and 43 respectively. When the forecasted values are compared with the average values of the previous eleven years, it was observed that the actual wind speed values ranged between 42.7 and 143.8 m/s while the forecasted value ranged between 41 and 153 m/s. this shows that there is a close correlation between the actual and the forecasted values.Fadare (2008) reported similar observation for the wind speed analysis for Ibadan, Nigeria.

Table 3: Monthly Performance Parameters in Minna for the 12th year

Month	Forecast (m/s)	Model Performance Parameters R^2	RMSE	MAE	MAPE
January	153	0.98	53.8	48	43
February	123	1	45.9	38	26
March	107	1	26.6	19	16
April	111	1	7	6	5
May	91	1	12	10	11
June	75	1	10.7	9	12
July	65	1	7.3	5	9
August	57	1	8.6	7	15
September	56	1	6.8	5	11
October	41	1	7.6	7	18
November	61	0.85	17	13	28
December	104	0.98	16.9	14	13
Yearly	87	1	6.6	5	5

The correlation coefficient, R^2, is an index of the degree of linear association between two variables. The magnitude of R^2 indicates whether or not the regression will provide accurate predictions of the criterion variable. It can be seen in Table 4.3 that the R^2 values and other model performance parameters were found to be good as the measured and predicted values agreed. Therefore, all these parameters could be used as a measure of the accuracy of future prediction.

Minna is located in the Guinea Savannah having a climate with well-marked dry and rainy seasons. In order to determine the seasonal mean wind speed, the months are divided into two seasons identified as follows:

(a) Rain season: May to October.

(b) Dry season: November to April.

Table 4 shows the forecasted wind speed and its mean for the year 2012 while the forecast mean, mean actual wind speed and performance parameters for the two seasons for the whole year are given in Table 5. The mean wind speed for rain and dry seasons are 2.12 and 3.74 m/s, while the forecast mean predicted by the regression model are 2.32 and 3.63 m/srespectively. The forecast mean and mean wind speed was higher during the dry season than the rainy season because the equator-to-pole temperature and pressure gradients are most intense during this period.

Table 4: Forecast Mean Wind Speed in Minna.

Month	Forecast (m/s)	Forecast Mean (m/s)
January	153	4.94
February	123	4.39

March	107	3.45
April	111	3.7
May	91	2.94
June	75	2.5
July	65	2.1
August	57	1.84
September	56	1.87
October	41	1.32
November	61	2.03
December	104	3.36
Yearly	87	2.87

Table 5: Seasonal mean actual, forecast and forecast mean wind speeds with performance parameters in Minna

Season	**Actual Mean (m/s)**	**Forecast (m/s)**	**Forecast Mean (m/s)**	**Model Performance Parameters**			
				R^2	**RMSE**	**MAE**	**MAPE**
Rain	2.12	64.17	2.32	0.997	8.8	7.2	12.7
Dry	3.74	109.83	3.63	0.969	27.9	22.7	21.8

The average wind speed data alongside forecast performance parameters for Minna between 2012 and 2015 are given in Table 6 and presented graphically in figure 1. The line of best fit as observed in figure 1 gives an intercept of 106.79, a slope of -3.28333 and the R^2-value of 0.999.

Table 6: Yearly (Average) and Forecast Wind Speeds in Minna from 2000 to 2015.

Year	Average	Forecast	Error	Absolute Error	% Error	Square Error	U-Stat
2000	99	104	-4.7	4.7	4.73	22.09	
2001	99	100	-1.17	1.17	1.18	1.36	0.22
2002	101	97	3.56	3.56	3.54	12.66	2.98
2003	88	94	-5.53	5.53	6.25	30.62	146.21
2004	95	90	4.78	4.78	5.05	22.88	39.9
2005	89	87	1.89	1.89	2.13	3.58	34.71
2006	78	84	-6.11	6.11	7.84	37.31	121
2007	83	81	2.16	2.16	2.6	4.66	27.74
2008	94	71	17.43	17.43	18.45	303.63	126.94
2009	75	74	0.62	0.62	0.83	0.38	392.37
2010	75	71	4.09	4.09	5.45	16.74	0.23
2011		67					
2012		64					
2013		61					
2014		58					
2015		54					

It is observed from the figure 1 below that the wind speed in Minna was cyclic in nature and decreases' as the years increased from 2010. This implies that less wind activities will be observed in the area which have its toll on agricultural activities. Though, most of the land mass has being turned residential in the last decade, the impact of wind speed may not be felt.

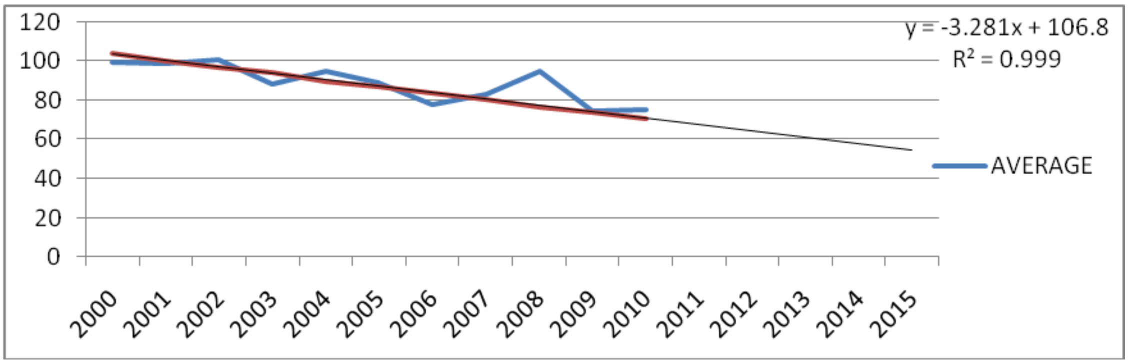

Fig. 1: Average Trend of Wind Speeds in Minna from 2000 to 2015.

Conclusion

The daily measured time series wind speed data for Minna, Nigeria have been analyzed statistically based on trend and regression analysis. The daily, monthly, seasonal and yearly mean wind speeds for the location have been determined. Based on the analysis, the following conclusions can be made:

(a) The actual mean yearly wind speed of 2.93 m/s for Minna shows that Minna is in a low wind speed region.

(b) The regression model performance parameters are all measures that incorporate both systematic and random errors that are within the acceptable range.

(c) The coefficient of determination (R^2) between the measured and forecast wind speed data ranges between 0.853 - 1. The trend and regression analysis can be used with acceptable accuracy for prediction of wind speed.
(d) This further implies that the average wind speed is enough to transport pollen grains from one location to another provided there are no obstacles.

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