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Analysis of Trends and Variations of Monthly Mean Wind Speed Data in Nigeria

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Abstract: *Trends and variations of monthly mean wind speed data in Nigeria were analyzed. The data used were obtained from the Nigerian Meteorological Agency, Oshodi, Lagos. 20 land anemometer stations across various ecological zones and climatic belts in Nigeria were selected for the analyses. The data length spanned from 1951–2012 with some variations in data length across the stations. Statistical techniques used for the analyses are Mann-Kendall's rank correlation tests, simple linear regression, Pearson's product moment correlations, time series plots, descriptive statistics and bar charts. The Mann-Kendall's test results indicate dominant declining trends over the period. 11 stations show downward trends, with 8 showing significant downward trends at the 1% level. 9 stations show upward trends, with 7 showing significant upward trends at the 1% level. The Pearson's product moment correlation coefficients indicate that some of the station pairs have negative correlations significant at the 1% and 5% levels. Other station pairs show significant positive correlations at the 1% and 5% levels while other station pairs show negative and positive correlations that are not significant at the chosen significance levels. The seasonal variations represented in the bar charts indicate that spring is the windiest period in most of the stations while autumn dominates the calm period in most stations across Nigeria. Majority of the stations show high coefficients of variation which increases northwards along with the monthly mean wind speeds. The results have implications for air quality management, modeling of wind speed regimes, planning and financing of wind energy and heat and moisture transfer between the earth's surface and the atmosphere.*

Key words: *Trends, Variations, Wind speeds, Mann-Kendall, Nigeria, Linear Regression.*

I. Introduction

This research is undertaken to analyze the trends and variations of monthly mean wind speed data in Nigeria as an index of climate change using Mann-Kendall rank correlation tests and other statistical techniques. Even though most of the climate change and variability studies have so far focused on temperature and precipitation, variation in wind speed distribution is also important with respect to the impacts of climate variability and change (Abhistek *et al*,2010; Turkes, 1996; Turkes, 1999; Turkes *et al*, 2008;Zhihua *et al*,2013; Amadi *et al*, 2014;Abiodun *et al*, 2011; Karabulut *et al*, 2008; Karaburun *et al*, 2012;).Tuller (2004) observed that most practical effects of variations and trends in climate do not involve a single climate parameter but are the synergistic result of multiple climatic parameters. We have reached a stage in the atmospheric variation where much effort is focused on other parameters such as wind speed. Different weather systems characterize different seasons, bringing about a marked seasonal variation in prevailing wind speed and direction.

Almost every impact of climate variation involves wind speed either directly or indirectly (Abhishek *et al*, 2010; Tuller, 2004). For instance, one of the ways that air temperature variations affect objects and living organisms is through sensible heat flux density, which is a function of wind speed. According to Troccoli *et al*, (2012), accurate estimates of long-term linear trends of wind speed provide a useful indicator for circulation changes in the atmosphere and are invaluable for the planning and financing of wind energy.

Until recently, air pollution was thought to be just a problem of the vicinity or locality of occurrence. New data reveal that air pollution is transported across continents and ocean basins due to fast long-range transport, resulting in trans-oceanic and trans-continental plumes of atmospheric brown clouds (ABCs) containing sub micron sized particles called aerosols (Ramanathan and Feng, 2009). Wind is instrumental to the transport of particulates from industries and mobile sources (Cabezudo *et al*, 1997), and in the transfer of heat and moisture between the earth's surface and the atmosphere. It therefore follows that the heat and moisture transfer between the earth's surface and the atmosphere is attenuated if wind speed decreases over the period. Studies have found that weaker winds in a warmer climate led to higher concentrations in pollution plumes (Ramanathan and Feng, 2009; Jacob and Winner, 2009; Holzer and Boer, 2001). Reduced wind speed can imply poor ventilation of pollutants and thereby exacerbating lung and heart diseases especially for asthmatics (Abhishek *et al*, 2010). Jacob and Winner (2009) noted that the two air pollutants of most concern for public health are surface ozone and particulate matter, which are subject to long-range transport by the winds. According to Hwang *et al*, (2007), strong correlation exists between ozone distribution pattern, and local and synoptic meteorological conditions, especially wind speed. The analysis of wind speed patterns is also important in estimating the surface energy balance (Rayner, 2007) and mitigating coastal erosion (Viles and Goudie, 2003). Wind pattern information is beneficial to agricultural industry (O' Neal *et al*, 2005), and forest and infrastructure protection communities (Jungo *et al*, 2002). Wind trend analysis is equally important for basic climatic processes such as evapo-transpiration and land surface – atmosphere feedback processes, and also for diverse applications such as wind power generation (Mc Vicar and Roderick, 2010). Furthermore, wind speed and direction data are useful in air dispersion modeling and identifying pollutant emission sources (Droppo and Napier, 2008; Wu *et al*, 2008).

Thus, wind speed is an important element in the study of atmospheric variations, hence the justification of this paper. Studies on measured wind speed variations have been carried out (Tuller, 2004; Abhishek *et al*, 2010; Bichet *et al*, 2012; Ko *et al*, 2010b; Ewona and Udo, 2008; Mc Vicar *et al*, 2010; Troccoli *et al*, 2012). These studies observed decrease in annual wind speed in numerous sites around the globe during the past few decades. Roderick *et al*, (2007) had shown that these observations are not products of measurement artefacts.

Other studies (e.g Kumar and Philip, 2010; Wu and Mok, 2013; Ko *et al*, 2010a) show that the direction of trend and variation are location dependent. On the other hand, Cardone *et al* (1990) observed surface wind strengthening for marine wind data.

The purpose of this study is to:

1. Examine the trends and variations in measured wind speed data at 20 anemometer stations across Nigeria.
2. Quantify the spatial and temporal relationships of the wind speed data by carrying out correlation analysis of the individual stations.
3. Examine descriptive statistical features of mean monthly wind speed data of the stations from 1950 – 2012.

II. Study Area

Nigeria co-ordinates on latitude 10.00^{o}N and longitude 8.00^{o}E. The climate is tropical; humid in the south and semi-arid in the north. It comprises various ecotypes and climatic zones. There are two main seasons, namely, rainy and dry seasons. The rainy season lasts from March to November in the south and May to October in the north. During December to March, the Nigerian climate is entirely dominated by the north east trade winds, locally called "harmattan", which originate from Sub-Tropical Anticyclones (STA).This"harmattan" is associated with the occurrence of thick dust haze and early morning fog and mist as a result of radiation cooling at night under clear skies. The climate is dominated by the influence of Tropical Maritime (TM) air mass, the Tropical Continental (TC) air mass and the Equatorial Easterlies (EE) (Ojo, 1977) in (Abiodun *et al*, 2011). According to Abiodun *et al* (2011), the TM air mass originates from the southern high-pressure belt located off the Namibian coast. This air mass becomes a moisture – laden air mass after picking up moisture from over the Atlantic Ocean. The TC air mass originates from the high-pressure belt north of the Tropic of cancer. This air mass is always dry and travels towards Nigeria over the Sahara desert. The TM and TC air masses meet at the Inter-Tropical Convergence Zone (ITCZ). The EE air mass is an erratic cool air mass which comes from the east and flows in the upper atmosphere along the ITCZ. The seasonal north-south migration of the ITCZ dictates the Nigerian weather pattern. Fig 1 is the map of Nigeria indicating the anemometer stations used in the study.

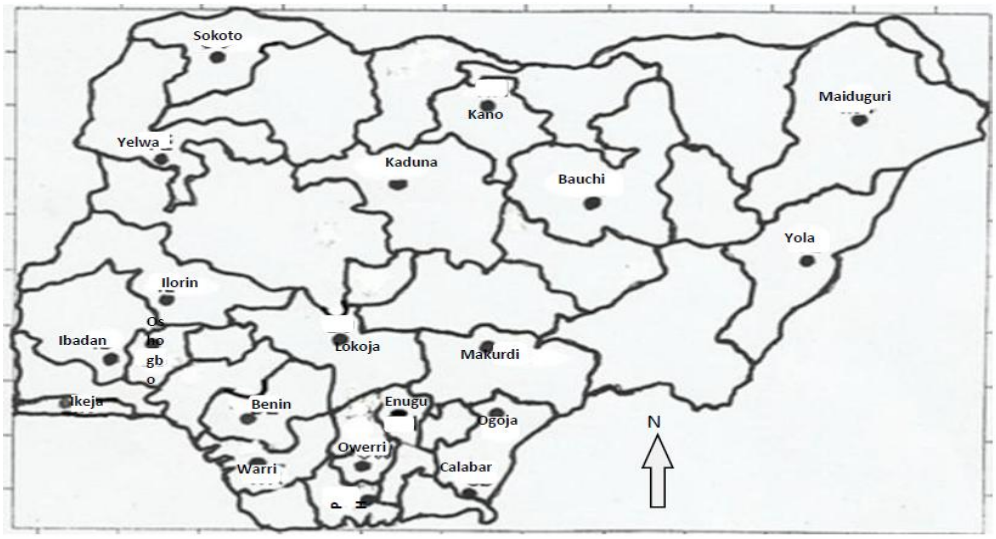


Fig. 1: Map Nigeria showing meteorological locations for the study

III. The Data

3.1 The Database

Monthly mean wind speed data of 20 anemometer stations spread across Nigeria were obtained from the archives of the Nigerian Meteorological Agency (NIMET) Oshodi, Lagos Nigeria. The period of the data spanned from 1951 to 2012. Table 1 below gives the summary information of the stations used in the study.

Table 1: Anemometer stations and details of the data used

S/N	Station Name	Latitude (°N)	Longitude (°E)	Altitude (m)	Period	Sequence length (months)	Missing data (%)
1.	Yelwa	10.53	4.45	244	1962-2012	612	11.76
2.	Sokoto	12.55	5.12	351	1968-2012	552	2.17
3.	Kaduna	10.42	7.19	645	1967-2012	564	10.64
4.	Kano	12.03	8.32	476	1961-2012	624	7.69
5.	Bauchi	10.17	9.49	591	1961-2012	624	21.15
6.	Maiduguri	11.51	13.05	354	1961-2012	624	9.62
7.	Ilorin	8.26	4.30	308	1961-2012	624	5.77
8.	Yola	9.16	12.26	191	1963-2012	600	2
9.	Ikeja	6.35	3.20	40	1951-2012	744	0
10.	Ibadan	7.22	3.59	234	1961-2012	624	9.62
11.	Oshogbo	7.47	4.29	305	1961-2012	624	11.54
12.	Benin	6.19	5.36	77.80	1967-2012	552	0
13.	Warri	5.31	5.44	6.00	1967-2012	552	30.43
14.	Lokoja	7.48	6.44	113	1964-2012	588	2.04
15.	Port Harcourt	5.01	6.57	18	1960-2012	636	0
16.	Owerri	5.25	7.13	91	1977-2012	432	0
17.	Enugu	6.28	7.34	142	1961-2012	624	5.77
18.	Calabar	4.58	8.21	62	1961-2012	624	0
19.	Makurdi	7.42	8.37	113	1961-2012	624	13.46
20.	Ogoja	6.40	8.48	117	1978-2012	420	17.14

3.2 Data Quality Check And Database Construction

The monthly data required careful scrutiny. This necessitated the construction of the database. Some missing entries were observed (see table 1 above) and were not replaced. Only 5 stations did not have missing observations. The missing observations ranged from 2% to about 30%. Shongwe *et al* (2006) suggested the use of data from stations with missing records not greater than 5%. However, this can be a major challenge to achieve especially in data scarce regions (as is the case here). Ngongondo *et al* (2011) adopted a more flexible 10% maximum threshold recommended by Hosking and Wallis (1997). In the case here, only 13 out of the 20 stations meet the 10% maximum threshold recommendation. Helsel and Hirsch (1992) in National Nonpoint Source Monitoring Programme (NNSMP) (2011) recommended that monotonic trend analysis could be applied if the data gap does not exceed one-third of the total record. This recommendation is based on the use of non-parametric tests that are robust against large data gaps. This is adopted in this study.

A preliminary step in analysis of homogeneity is to plot the time series on a linear scale. Visual inspection of the plots could reveal the existence of the marked changes in the time series which can be further investigated by statistical procedures. In the case here, plot inspection immediately revealed the existence of missing data for some of the stations. Statistical test for homogeneity was done using the non-parametric Kruskal-Wallis (K-W) test (Turkes *et al* 2008).

Homogeneity means that there are no jumps (non-climatological abrupt rises or falls) in the climatic series of observation (Turkes 1999). Most of the statistical in homogeneities noticed in the result of the K-W test are very much likely related to the long period fluctuations and trends. According to Syners (1990), in Turkes (1999) and Turkes (1996), these are acceptable within non-randomness characteristics of series of climatological observations.

IV. Methodology

4.1 Processing Software Packages

Database construction and quality control of the wind speed data were first performed by checking for missing entries, outliers and temporal homogeneity as discussed in the preceding section. The descriptive statistics of the distribution was evaluated using the SPSS package. SPSS computer package was also used to evaluate the Mann-Kendall's rank correlation tests and the Pearson's product moment correlation coefficients. The non-parametric Mann-Kendall's rank correlation tests were used to detect the presence, direction and significance of the trends. The Pearson's product moment correlation coefficients revealed the spatial and temporal relationships of the wind speed data. The Mann-Kendall tests detect trends but cannot provide an estimate of the trend magnitude. The trend magnitudes were quantified by a linear regression model. Regression analysis was executed using the MATLAB software package. The Time series plots with the trend lines were done using the MATLAB. The R programming language was used to do the bar charts to indicate the seasonal variations of the wind speed data of the stations.

Two non-parametric statistics are in common use in trend studies: Mann-Kendall's (M-K) test and Spearman's test. Compared to the parametric tests, the non-parametric tests have been proved to provide higher statistical power in cases of non-normality of the distribution, and they are robust against outliers and missing data (Turkes 1996, Turkes, 1999; Turkes et al, 2008, Zhihua et al, 2013). Furthermore, non-parametric tests represent a measure of monotonic dependence whether linear or not (Davies, 1986; Rossi et al, 1992) in De Luis et al (2000). In this work, Mann-Kendall's (M-K) rank correlation tests were chosen to detect significant trends.

4.2 The Mann-Kendall (M-K) Correlation Test

Within the M-K test, the data $(x_1, x_2, \ldots., x_n)$ of time series as null hypothesis, H_o, are independent identically distributed random samples. Given n size data for n≥10, the M-K test statistic S is defined as follows (Rai *et al*, 2010; Zhihua *et al*, 2013):

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn\,(x_j - x_i) \ldots\ldots\ldots\ldots\ldots (1)$$

Where x_j and x_j are the sequential data for the i^{th} and j^{th} terms, and $j > i$

$$sgn\,(x_j - x_i) = \begin{cases} 1\ , & x_j > x_i \\ 0, & x_j = x_o \\ -1 & x_j < x_i \end{cases} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

When S is a large positive number, later values exceed earlier values and upward trend is indicated. When later values are less than earlier values, S is negative and downward trend results. Under the null hypothesis of independent and randomly distributed random variables, when n≥10, the S statistic is approximately normally distributed, with zero mean and variance as follows in the absence of ties:

$$\sigma^2 = \frac{n(n-1)(2n+5)}{18} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots..(3)$$

The value of S and $\boldsymbol{\sigma}^2$ are used to compute the Z statistic, which follows a normal standardized distribution thus:

$$Z = \begin{cases} \dfrac{S-1}{\boldsymbol{\sigma}}, & S > 0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(4) \\ 0\ , & S = 0 \\ \dfrac{S+1}{\boldsymbol{\sigma}}, & S < 0 \end{cases}$$

The null hypothesis H_o that there is no trend is rejected when the absolute Z value computed by eqn (4) is greater than the critical value Z_α at a chosen level of significanceα. Conversely, the alternative hypothesis H_1 that the data follow a monotonic trend over time is accepted. The test statistic *tau* (τ) is computed as

$$\tau = \frac{S}{n(n-1)/2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

In this study, the Z value is tested at the 1% and 5% significance levels. The trend is upwards for positive values of Z and downwards for negative values of Z. The test statistic τ (Kendall's *tau b*) has a range of -1 to +1, and is analogous to the correlation coefficient in regression analysis. The null hypothesis is rejected when the *tau b* (τ) is significantly different from zero. To test the trend significance, Z is computed and the cumulative probability for a standard normal distribution at /Z/ is found. For a two tailed test, the value of the cumulative probability is multiplied by 2 to obtain the p value. If the p value is below a given level of significance, the trend is significant.

4.3 Linear Regression

The Mann-Kendall tests described above detect nature and significance of the trends but do not provide an estimate of their magnitudes. The slopes (magnitudes) of the trends were quantified by a linear regression model of the form:

$$y = mx + C \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

Where *y* is the wind speed (in m/s), *x* is the number of months, *m* is the slope of the trend (in m/s per month) indicating the detected change, and *C* is a regression coefficient (the intercept). When the slope *m* is positive, it means that the wind speed has an upward trend and vice versa. The larger the absolute value of *m*, the more obvious the variation trend is.

V. Results And Discussion

Table 2 shows the wind speed characteristics of the stations. The coefficients of variation (CV) are high for majority of the stations which indicates high wind speed variability across the country. A cursory look at the table indicates that there is no discernible pattern of distribution of both the mean and the CV. Table 2 further portrays Sokoto and Kano in the North West as the windiest stations with spectacular mean wind speeds of 7.471 m/s and 7.9 m/s respectively. The CV of 50.32% and 49.37% are outstanding for the north east stations of Yola and Bauchi respectively. The monthly mean of the wind speed data are relatively low in the south western cities of Oshogbo (2.966 m/s), Benin (3.481 m/s), Warri (3.23 m/s) and in the north central city of Lokoja (3.063 m/s). The variation of wind speed across the stations as observed in table 2 could be attributed to a number of potential causes ranging from orographic, orogenic and topographic features. Roughness of the environment surrounding the stations, variations in the height and position of anemometers, and atmospheric forcing (atmospheric circulation) changes also produce substantial effects. Some studies (e.g Bichet *et al*, 2012) have found that increasing the vegetation roughness length (caused by increasing vegetation) decreases the land wind speed. Wind speed tend to be higher at well exposed sites than at stations in the vicinity of forests, hills, mountains and other intervening structures such as high rise buildings. Suffice it to say that changes in measured wind speed can result from both atmospheric and ground surface controls. The result observed here is expected since the north belongs to the arid and semi-arid ecotypes while the south is dominated by mangrove, swamp forests, tropical rainforests and guinea savanna tall grasslands.

The Mann-Kendall's test results presented in table 3 show the Kendall's *tau b* (coefficients of the time trends) for the individual stations along with the *p* values of the test statistic. The levels of statistical significance of the time trend coefficients are also indicated. The extreme right columns of table 3 show the estimates of the trend magnitudes in m/s per month, m/s per year and m/s per decade. The dominant trend in the time series of the wind speeds is the decline over the periods considered here. 11 stations (representing 55%) show downward trends out of which 8 stations (representing 40% of the stations) show decreasing trend significant at the 1% level. These are Sokoto, Kaduna, Bauchi, Yola, Oshogbo, Benin, Lokoja and Port Harcourt. 9 stations (representing 45%) show upward trend out of which 7 stations (representing 35%) show significant upward trend at the 1% level. These are Kano, Maiduguri, Ilorin, Ikeja, Enugu, Calabar and Makurdi. Owerri and Warri show upward trends that are not significant while Yelwa, Ibadan and Ogoja show non-significant downward trends at the chosen levels of significance.

Table 4 is the Person Product Moment Correlation matrix of monthly mean wind speeds. Their significance levels are also shown to give a general indication of coincidence between stations and index time series. The inter station spatial coherence of the monthly mean wind speed is objectively quantified by using the station to station correlation coefficients. Some of the anemometer station pairs show negative correlations significant at the 1% and 5% levels. Other station pairs show positive correlations significant at the 1% and 5% levels. There are equally other station pairs that show positive and negative correlations that are not significant at the chosen levels of significance. There is no discernible pattern in the correlation coefficients among the pairs of anemometer stations.

Table 2: Descriptive statistics for wind speed

Stations	N	Minimum	Maximum	Mean	Std. Deviation	Range	C.V (%)
Yelwa	540	0.0	8.0	3.524	1.4164	8.0	40.19
Sokoto	540	2.4	12.9	7.471	1.9474	10.5	26.07
Kaduna	504	2.4	10.9	5.285	1.4716	8.5	27.84
Kano	576	2.0	15.0	7.900	2.4256	13.0	30.7
Bauchi	492	0.0	10.9	4.621	2.2814	10.9	49.37
Maiduguri	564	1.2	9.1	5.227	1.6468	7.9	31.51
Ilorin	588	1.0	8.6	4.411	1.4821	7.6	33.6
Yola	588	0.5	11.0	3.993	2.0091	10.5	50.32
Ikeja	744	0.3	10.5	4.635	1.6960	10.2	36.59
Ibadan	564	0.2	8.6	4.060	1.2619	8.4	31.08
Oshogbo	552	0.0	5.6	2.966	1.1029	5.6	37.18
Benin	552	1.1	8.2	3.481	0.9266	7.1	26.62
Warri	384	0.5	6.8	3.231	0.6419	6.3	19.87
Lokoja	576	0.3	6.2	3.063	1.0555	5.9	34.46
Port Harcourt	636	0.0	7.0	3.633	0.9971	7.0	27.45
Owerri	432	1.8	8.1	3.455	0.7840	6.3	22.69
Enugu	588	0.0	11.0	5.282	1.4183	11.0	26.85

Calabar	624	0.0	8.3	3.871	1.1474	8.3	29.64
Makurdi	540	1.3	9.2	4.781	1.4973	7.9	31.32
Ogoja	348	1.2	9.8	3.633	1.1195	8.6	30.81

Table 3: Mann-Kendall's test results and estimates of trend magnitudes of the wind speed.

Stations	**Kendall's *tau b***	***p* value**	**m/s/month**	**m/s/year**	**m/s/decade**
Yelwa	-0.040	0.175	0.0013	0.0156	0.156
Sokoto	-0.094**	0.001	0.0012	0.0144	0.144
Kaduna	-0.095**	0.002	0.002	0.024	0.24
Kano	0.354**	0.000	0.0048	0.0576	0.576
Bauchi	-0.382**	0.000	0.0009	0.0108	0.108
Maiduguri	0.178**	0.000	0.0014	0.0168	0.168
Ilorin	0.295**	0.000	0.0018	0.0216	0.216
Yola	-0.438**	0.000	0.0058	0.0696	0.696
Ikeja	0.121**	0.000	0.0002	0.0024	0.024
Ibadan	-0.043	0.134	0.0028	0.0336	0.336
Oshogbo	-0.162**	0.000	0.005	0.06	0.6
Benin	-0.097**	0.001	0.0001	0.0012	0.012
Warri	0.003	0.926	0.0003	0.0036	0.036
Lokoja	-0.209**	0.000	0.001	0.012	0.12
Port Harcourt	-0.271**	0.000	0.0015	0.018	0.18
Owerri	0.025	0.443	0.00039	0.00468	0.0468
Enugu	0.193**	0.000	0.0011	0.0132	0.132
Calabar	0.317**	0.000	0.0022	0.0264	0.264
Makurdi	0.259**	0.000	0.0018	0.0216	0.216
Ogoja	-0.052	0.153	0.00042	0.00504	0.0504

** Kendall's *tau b* is significant at the 0.01 level (two-tailed).

Table 4– Correlation coefficients for Wind Speed across the stations

	Stations																			
Stations	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	1																			
2	.195**	1																		
3	.103*	.404**	1																	
4	.033	.214**	.264**	1																
5	.061	.116*	.147**	-.086	1															
6	.303**	.371**	.186**	.271**	-.242**	1														
7	.196**	.092*	.010	.388**	-.095*	.261**	1													
8	.243**	.135**	.129**	-.266**	.448**	-.034	-.126**	1												
9	.176**	-.148**	-.079	.054	-.150**	.198**	.156**	-.338**	1											
10	.211**	-.061	-.054	-.038	.161**	-.007	.221**	.260**	.174**	1										
11	.377**	.051	.058	.147**	.231**	.131**	.345**	.191**	.276**	.293**	1									
12	.089	-.027	.010	.129**	.277**	.005	.219**	.452**	-.057	.362**	.329**	1								
13	.027	-.144**	-.066	.058	.136*	-.049	.101*	.040	.263**	.137**	.104*	.157**	1							
14	.310**	-.014	.093*	-.078	.247**	.209**	.154**	.335**	-.001	.138**	.270**	.302**	.042	1						
15	.134**	-.097*	.132**	-.155**	.351**	.030	-.153**	.361**	.001	.114**	.258**	.206**	.206**	.254**	1					
16	.060	.039	.155**	.176**	.358**	.009	.162**	.255**	.162**	.386**	.176**	.236**	.149**	.135**	.114*	1				
17	.238**	.072	.204**	.308**	-.180**	.537**	.242**	-.098*	.357**	.093*	.239**	.064	.137**	.274**	.146**	.200**	1			
18	.024	.020	.036	.552**	-.236**	.270**	.430**	-.223**	.100*	.096*	.214**	.252**	-.003	-.043	-.156**	.069	.317**	1		
19	.036	.050	.241**	.523**	.195**	.267**	.336**	-.088*	.136**	.216**	.247**	.239**	.077	.086*	.071	.261**	.350**	.401**	1	
20	.146**	.030	.030	.114*	.136*	-.049	.220**	-.171**	.342**	.149**	.406**	-.061	.113	.022	.096	.135*	.263**	.217**	.046	1

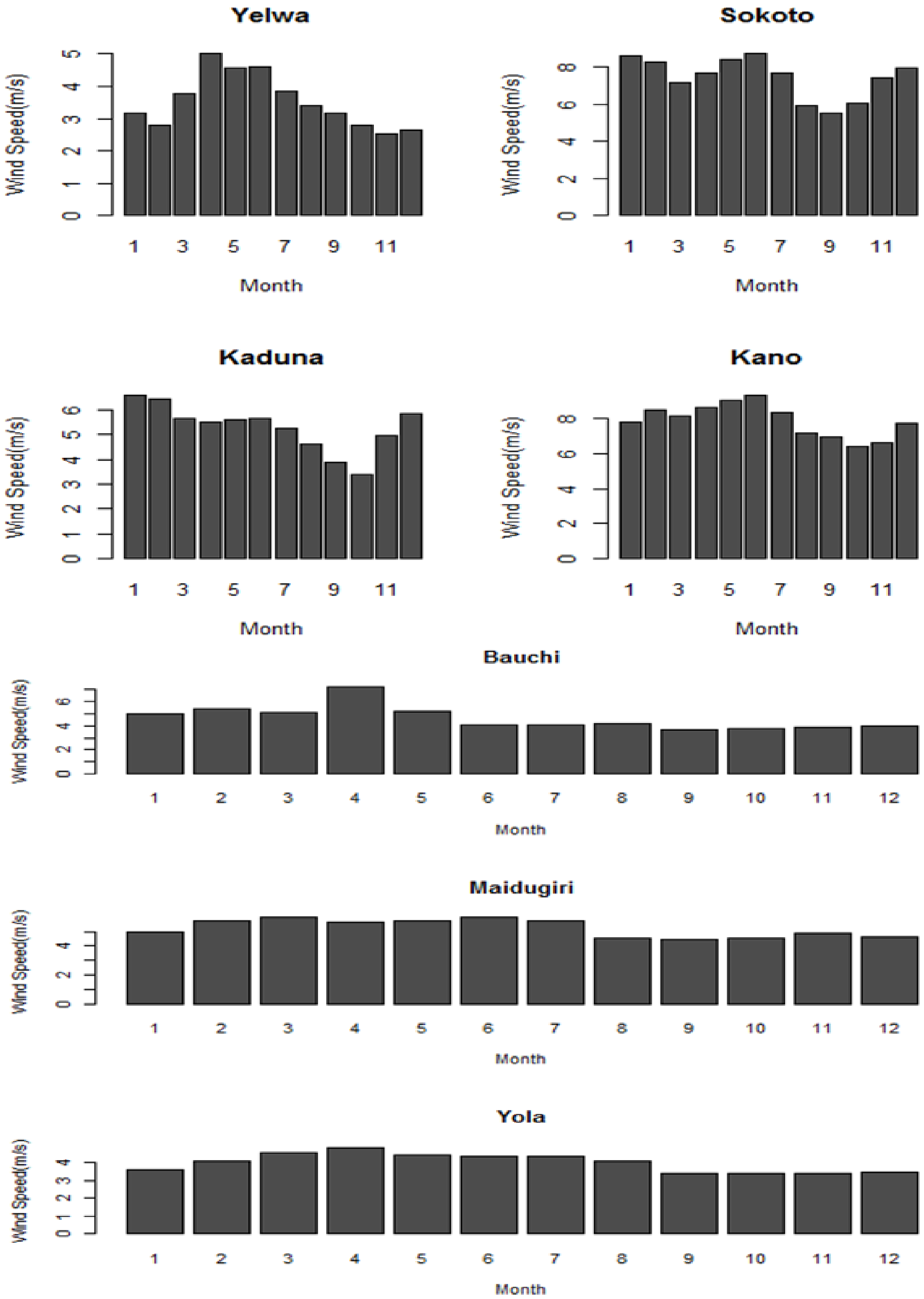
**Correlation is significant at 0.01 (two-tailed); *Correlation is significant at 0.05 (two-tailed).

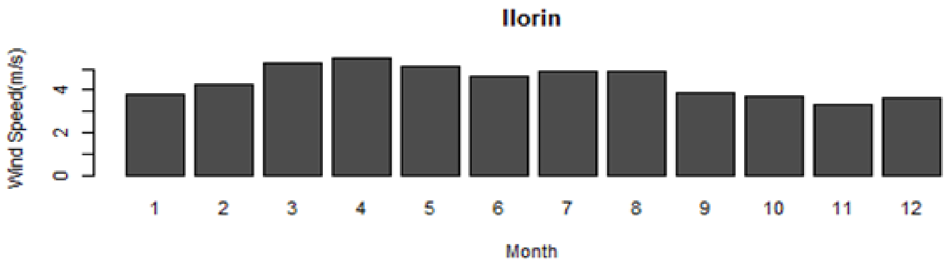
The observed changes over time in the measured wind speed data can result from both atmospheric circulation changes and ground surface variations. Ramanathan *et al*, (2001) noted that aerosol emissions, greenhouse gas concentrations, sea surface temperatures, can affect the atmospheric circulation and stability thereby wind speeds. Bichet *et al*, (2012) observed that sea-induced circulation changes have a regional character and can decrease or increase the wind speeds, whereas in contrast, higher aerosol concentrations appear to generally reduce the land and ocean wind speeds. This response could be linked to the role of atmospheric aerosols upon the stratification of the atmosphere. Whereas increasing aerosols emissions cool the surface, carbonaceous aerosols also warm the aerosol layer in the troposphere. This would increase the atmospheric density gradient between the surface and the troposphere, and thus reduce the rate of atmospheric circulation (Ramanathan *et al*, 2005). Suffice it to say that the observed dominant downward trends in wind speed could be linked to climate variability and change.

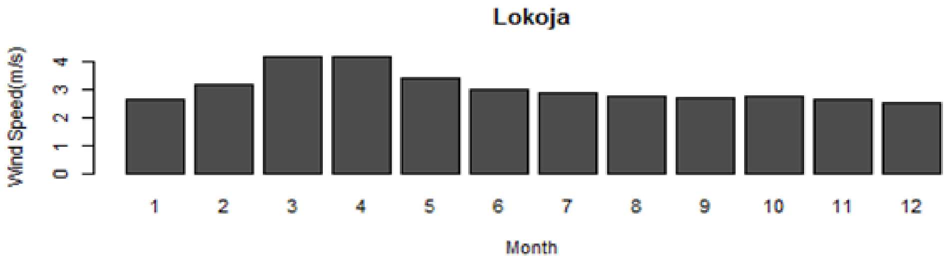
The time series plots with the trend lines (not shown) indicate that the trend lines uphold the Kendall's test result with respect to the direction of trends in the stations.

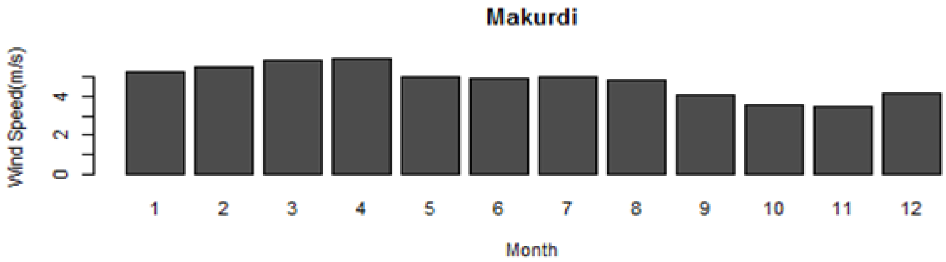
The seasonal variations of monthly mean wind speed are presented in Bar charts in Figs 2a – t. The figures show that for the north western cities of Yelwa, Kaduna, Sokoto and Kano, there is a bimodal maxima. These occur in Winter (Dec, Jan, Feb) and early Summer (June). In this region, the most calm periods are observed from late summer (August) to mid autumn (October). Yelwa station is exceptional here in that the wind speed reaches its crescendo between mid spring (April) to early summer (June), and its lowest in late autumn (November).

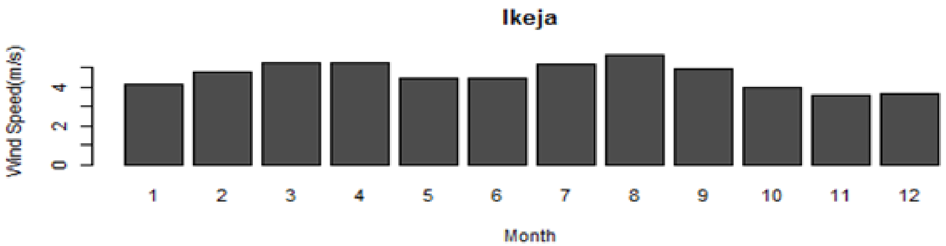
The north eastern cities of Bauchi, Maiduguri and Yola record their maxima in mid spring (April) and their minima in autumn (Sept, Oct, and Nov). However, Maiduguri deviates slightly from this pattern in that it records its maxima in early spring (March) and early summer (June). The north central cities (Lokoja, Ilorin, and Makurdi) have their windiest period in spring (March, April & May) and their most calm period in autumn (Sept, Oct, Nov), similar to the situation in the north eastern zone. The south western cities (Ibadan, Oshogbo and Ikeja) recorded double maxima which are observed in spring (March and April) and summer (July and August).

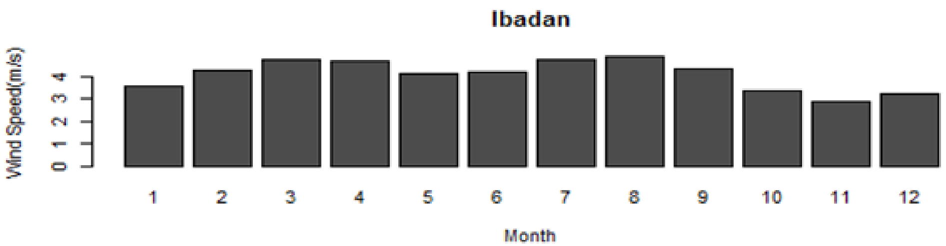


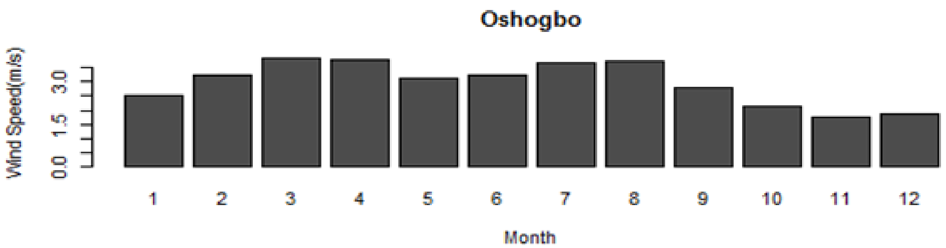

Ilorin
Wind Speed(m/s)
0 2 4
1 2 3 4 5 6 7 8 9 10 11 12
Month

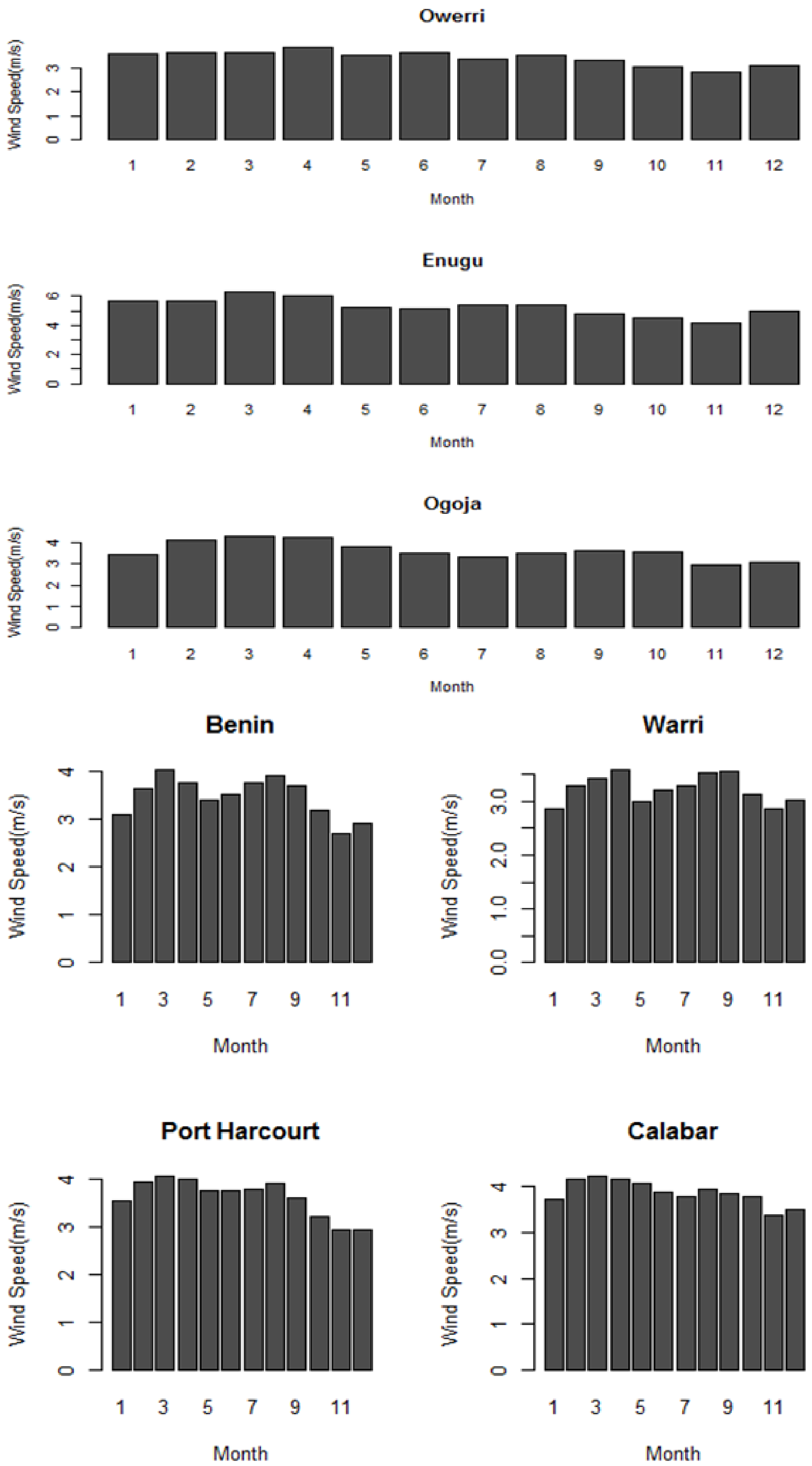

Lokoja
Wind Speed(m/s)
0 1 2 3 4
1 2 3 4 5 6 7 8 9 10 11 12
Month


Makurdi
Wind Speed(m/s)
0 2 4
1 2 3 4 5 6 7 8 9 10 11 12
Month


Ikeja
Wind Speed(m/s)
0 2 4
1 2 3 4 5 6 7 8 9 10 11 12
Month


Ibadan
Wind Speed(m/s)
0 1 2 3 4
1 2 3 4 5 6 7 8 9 10 11 12
Month


Oshogbo
Wind Speed(m/s)
0.0 1.5 3.0
1 2 3 4 5 6 7 8 9 10 11 12
Month


Owerri
Wind Speed(m/s)
Month
Enugu
Wind Speed(m/s)
Month
Ogoja
Wind Speed(m/s)
Month
Benin
Wind Speed(m/s)
Month
Warri
Wind Speed(m/s)
Month
Port Harcourt
Wind Speed(m/s)
Month
Calabar
Wind Speed(m/s)
Month

Their minima are observed in late autumn (November). For cities in the south eastern geographical zones (Enugu, Owerri and Ogoja), maxima are observed in spring (March and April) and the minima occurred in late autumn (November). For the core southern cities of Benin, Port Harcourt, Warri and Calabar, double maxima are observed in spring (March & April) and late summer (August). The calm periods are witnessed in late autumn (November). From the foregoing, it is clear that the spring season (March and April in most cases) dominates the periods of high wind speed while the autumn (November precisely) dominates the periods of calm across Nigeria.

The result of this research is in complete agreement with that of Ogolo and Adeyemi (2009) that observed declining trends in wind speed for Ibadan using the M-K test. However, the results do not partially agree with that of Ewona and Udo (2008) that observed decreasing trends in wind speed for Calabar. The variation in result is perhaps, due to differences in record length of the data used. The result of this work is consistent with other regional and international studies where the results indicate dominant declining trends in the wind speed data (Tuller, 2004;Abhishek *et al*, 2010; Bichet *et al*, 2012; Ko *et al*, 2010b; Mc Vicar *et al*, 2010; Troccoli *et al*, 2012;). Presence of decreasing, increasing and random trends across the stations as shown in the M-K test show that the direction of trends and variations are location dependent as observed by some studies (e.g Kumar and Philip, 2010; Wu and Mok, 2013 and Ko*et al*, 2010a).

VI. Conclusion

It has been the main objective of this study to examine the trends and variations of measured wind speed data at 20 land anemometer stations spread across Nigeria and to quantify the statistical significance of the trends. The coefficients of variations (CV) are high, ranging from 19.87% to 50.32%. The northern part of the country tends to show higher CV and monthly mean daily wind speeds. The inter station spatial coherence of the monthly mean daily wind speed as quantified by the Pearson Product Moment Correlation Coefficients indicate some negative and positive correlations significant at the 0.01 and 0.05 levels. The Mann-Kendall’s test results show a dominant decreasing trend in the time series of the period considered in the study, of which most of them are significant at the 0.01 level. Nevertheless, there are also upward trends of which some are significant at the 0.01 level. It is clear from the seasonal variation Bar charts that the spring period (March and April precisely) is the windiest period while autumn (precisely November) dominates the period of calms across Nigeria.

The results of the M-K tests portray the fact that surface wind pattern could be an alternative to surface air temperature and precipitation as an indicator of climate variability and change. Variations in wind speed pattern may provide a critical context for climate change research and a platform for forecasting and modeling of wind speed regimes under the global climate change scenarios. The knowledge of contemporary wind climate data and its historical trends can be useful to various agencies and industries. The results presented here have implications for the air quality management attempts in these regions as decreasing wind speed would affect ozone and aerosol distribution rates and patterns. Consequently, this may signal a need to make significant changes to their air pollution mitigation strategies for effective results. This is necessary because downward trends in wind speed may imply poorer ventilation of pollutants from these areas which could constitute serious health-related problems especially for people with heart-related diseases such as asthmatic patients.

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