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Statistical Analysis of the Effect of Air Pollution on Air Quality and Climate Change

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Abstract

Climate change is the statistical distribution changes of weather pattern over time and air pollution is the presence of harmful substances in the air. Then, this research work was used to discuss and analyse the effects of air pollutants [Sulphur (iv) oxide (SO_4), Carbon monoxide (CO), Fine particulate matter ($PM_{2.5}$) and Nitrogen dioxide (NO_2)] on environment air quality and climate change with respect to rainfall series in Lagos State, South Western, Nigeria. The statistical analysis and test were carried out using Descriptive Statistics, Pearson correlation coefficient, Kruskal-Wallis test (H Test), Mann Kendall test and Mann Whitney statistical tests. The result revealed that the average mean of $PM_{2.5}$ under residential and heavy traffic was showed to exceed the international standard. A comparative analysis showed that the average mean of Heavy traffic pollutants had the highest values. Pearson correlation coefficients matrix showed a positive relationship between the air pollutants but little or no relationship with rainfall series. The Kruskal-Wallis test indicated that the effect of air pollutants varies across the land use type. Mann Kendell test revealed mostly an increase in monthly rainfall but no trends and the magnitude of trends range between -0.482 and 4.535 with lowest and highest magnitude occurring in December and April. Mann Whitney test revealed the existence of a significant difference between the two rainfall periods compared and this may be attributed to high level of air pollutants. In conclusion, air pollution with respect to land use types has been shown to have an effect on atmospheric air quality and thus contributes to climate change in Lagos State, South Western, Nigeria. However, proper monitoring should be put in place to reduce and curtail the effects of air pollution in Lagos South Western, Nigeria.

Keywords: Air pollutants, Non-Parametric tests, Climatic Variables, Air Quality, Climate change,

Introduction

The advent of the industrial revolution has made earth's atmospheric condition to undergo serious forms of change both in form and content. This has caused diverse kinds of challenges to the environment and very noticeable among this is extreme weather events and harmful atmospheric air which have caused havoc to lives and property in recent years (Dipeolu and Fadamiro, 2013). More so, concentrations of many gases and other constituents in the atmosphere have been raised to a very high level resulting in Climate change and weather conditions at all levels. Air pollution as a major factor that causes climate change occurs as a result of the heavy combination of high emissions of pollutants and this typically causes global warming and ozone layer depletion (Komolafe *et al.*, 2014). The World Bank Report (2016) described air pollution as the presence in the outdoor atmosphere of one or more contaminants such as dust, fumes, gas, mist, odour, smoke or vapour in such quantities, characteristics and duration as to make them actually harmful or potentially injurious to human, plant, animal life, property and which unreasonably interfere with the comfortable enjoyment of life and property.

The subject of air pollution and its effects on the environment is referred to as one of the Universal Commons that many countries across the world are seeking to address (Puppim de Oliveira, 2011). Air pollution has been the shared challenge for megacities or metropolitan regions across the world, especially in developing countries such as the United State of American and China (Fenger, 2009). The problem of air pollution has seemingly become intractable with the incessant failure of both global and local environmental policies purportedly emplaced to address its devastating trend, particularly in growing megacities of the world. The study of air pollution sources and characteristics is strongly dependent on the knowledge of the land use types as they influence a variety of processes that define air quality, the most important one being the distribution of emissions (Cheng *et al.*, 2008). As observed by Houghton (2004), various human activities in the industry, in the field, in form of deforestation, in transportation and at home result in emissions of gaseous pollutants. These cause variability in climatic variables and in-turn caused climate change.

Several research works have been done on the concentration of air pollution in Nigeria and its effects on our environment. These include the works of Awofolu (2004), Efe (2008), Akanni (2008), Akanni (2010), Olowoporoku *et al.*, (2012), Akinola *et al.*, (2014), Akpan (2016), Sanni (2017) and many more. But particular interest has not been placed on air pollutant emissions attributed to land use type and its effects on climate change in industrialized, commercialized and emerging megacities in Nigeria. Hence, this research work will be used to examine and analyse the effects of air pollution from three different classifications and these include residential, heavy traffic and industrial areas pollutants on environmental air quality and climate change using Lagos State, South Western, Nigeria as a case study. Also, the level of the air pollutant will be measured for compliance based on the World Health Organisation standard. The methods used were Descriptive statistics, Kruskal-Wallis test (H Test), Mann Kendall test, Mann Whitney statistical test and Pearson correlation coefficient.

Materials and Methods

Descriptive statistics

Descriptive statistics are used to provide simple summaries about the sample and about the observations that have been made. Such summaries may be either quantitative, i.e. summary statistics, or visual, that is simple-to-understand graphs. These summaries may either form the basis of the initial description of the data as part of a more extensive statistical analysis, or they may be sufficient in and of themselves for a particular investigation. Descriptive statistics to be used are Table, Bar chart and Measure of Central tendencies.

Correlation analysis

This is a statistical technique used for estimating the closeness or degree of association between two or more variables. The correlation coefficient is a measure of the strength of the linear relationship between two variables. The Pearson correlation coefficient considered is defined as

$$r = \frac{n\sum XY - \sum X \sum Y}{\sqrt{n\sum X^2 - (\sum X)^2}\sqrt{n\sum Y^2 - (\sum Y)^2}} \quad (1)$$

when $r = 1$, there is a perfectly positive correlation, $r = -1$, there is a perfectly negative correlation and $r = 0$, there is no correlation. Hence $r\ must\ \ lies\ between -1 \leq r \leq 1.$

Kruskal-Wallis one-way analysis of variance test (H Test)

Kruskal-Wallis One Way Analysis of Variance test is a non-parametric test used for testing whether samples originate from the same distribution. It is used for comparing two or more independent samples of equal or different sample sizes. It extends the Mann–Whitney *U* test when there are more than two groups. The parametric equivalent of the Kruskal–Wallis test is the one-way analysis of variance (ANOVA). A significant Kruskal–

Wallis test indicates that at least one sample stochastically dominates one other Corder and Foreman, (2009).
The steps in Kruskal-Wallis One Way Analysis of Variance test involved ranking all data from all groups together; that is, rank the data from 1 to N ignoring group membership.

Assign any tied values the average of the ranks they would have received had they not been tied.
The test statistic is given by:

$$H = (N-1)\frac{\sum_{i=1}^{g} n_i(\bar{r}_{i.} - \bar{r})^2}{\sum_{i=1}^{g}\sum_{j=1}^{n_i}(r_{ij} - \bar{r})^2} \qquad (2)$$

where n_i is the number of observations in the group i, r_{ij} is the rank of observations j in the group i, N is the total number of observations across all groups, $\bar{r}_{i.} = \frac{\sum_{j=1}^{n_i} r_{ij}}{n_i}$ is the average rank of all observations in the group i and $\bar{r} = \frac{1}{2}(N+1)$ is the average of all the r_{ij}. If the data contain no ties, the denominator of the expression for H is exactly $(N-1)N(N+1)/12$ and $\bar{r} = \frac{1}{2}(N+1)$. Thus

$$H = \frac{12}{N(N+1)}\sum_{i=1}^{g} n_i\left(\bar{r}_{i.} - \frac{N+1}{2}\right)^2 \qquad (3)$$

By expanding equation (3), this gives

$$= \frac{12}{N(N+1)}\left[\sum_{i=1}^{g} n_i\left(\bar{r}_{i.}^2 - \left(\frac{N^2+2N+1}{4}\right)\right)\right]$$

$$= \frac{12}{N(N+1)}\sum_{i=1}^{g} n_i\,\bar{r}_{i.}^2 - N\left(\frac{N^2+2N+1}{4}\right)\left(\frac{12}{N(N+1)}\right)$$

$$= \frac{12}{N(N+1)}\sum_{i=1}^{g} n_i\,\bar{r}_{i.}^2 - N\frac{3(N^2+2N+1)}{N(N+1)}$$

$$H = \frac{12}{N(N+1)} \sum_{i=1}^{g} n_i \bar{r}_{i.} - 3(N+1) \quad (4)$$

The $P - valve$ is approximated by $P_r(\chi^2_{g-1} \geq H)$. If some n_i values are small, that is less than 5, the probability distribution of H can be quite different from this chi-squared distribution. If a table of the chi-squared probability distribution is available, the critical value of chi-squared $\chi^2_{\alpha:g-1}$ can be found by entering the table at g − 1 degrees of freedom and looking under the desired significance or alpha level. If the statistic is not significant, then there is no evidence of stochastic dominance between the samples. However, if the test is significant then at least one sample stochastically dominates another sample.

Mann-Kendall trend test

The Mann-Kendall tests are based on the calculation of Kendall's tau measure of association between two samples, which is itself based on the ranks with the samples. The computations assume that the observations are independent. The Kendall's tau statistic is defined as follows based on the work of Nelsen (2001).

Let $(X_1,Y_1)(X_2,Y_2),\ldots,(X_n,Y_n)$ be a set of observations of the joint random variable X and Y respectively such that all the values of (x_i) and (y_i). Any pair of observation (x_i,y_i) and (x_j,y_j) where $i \neq j$ are said to be concordant if the rank for both elements agrees, that is

if $x_i > x_j$ and $y_i > y_j$: if $x_i > x_j$ and $y_i < y_j$: if $x_i = x_j$ or $y_i = y_j$, the pair neither concordant nor discordant. The Kendall's tau statistic is calculated as thus,

$$\tau = \frac{(number\ of\ concordant\ pairs) - (number\ of\ discordant\ pairs)}{n(n-1)/2} \quad (5)$$

It can as well be defined as

$$\tau = \frac{(n_c) - (n_d)}{n(n-1)/2} \quad (6)$$

where n_c is number of concordant pairs and n_d is the number of discordant pairs. The null hypothesis H_0 for these tests is that there is no trend in the series and the alternative hypothesis is that there is a trend in the series.

2.5. Sen's slope estimator

Given a linear model of the form

$$f(t) = Qt + B \tag{7}$$

where Q is the slope and B is the constant.

The estimator of the slope $Q$for all slopes of the data pairs is calculated by

$$Q_i = \frac{x_j - x_k}{j - k}, \qquad i = 1,2, \ldots, N, \qquad j > k \tag{8}$$

Mann Whitney U Test

This is a nonparametric method used to test the null hypothesis of equally likely of a randomly selected value from one sample which may be less than or greater than a randomly selected value from a second sample. The test involves the calculation of a statistic, usually called *U*, whose distribution under the null hypothesis is known. In the case of small samples, the distribution is tabulated, but for sample sizes above ~20, approximation using the normal distribution is fairly good. Mann Whitney statistic is calculated by comparing two sets of observations and counting the number of times this first value wins over any observations in the other set (the other value loses if this first is larger). Count 0.5 is for any ties. The sum of wins and ties is *U* for the first set. *U* for the other set is the converse.

Results and Discussions

The climatic data used in this study was obtained from Nigerian Meteorological Agency NIMET), Lagos from 1985 – 2015. The variables collected were Rainfall and Temperature while the air pollutants data based on land use type and heavy traffic from 2012 – 2015 were obtained from Environmental Planning and Climate Change Department Laboratory Unit, Office of Environmental Services, Lagos State. The air pollutants were Sulphur (iv) Oxide, Nitrogen dioxide, Particulate Matter and Carbon Monoxide.

Descriptive Statistics analysis of air pollutants with respect to residential land use type

Based on the descriptive Statistics in Table 1, the concentration of CO in Lagos ranges from a minimum value of 0.0mg/m^3 to a maximum value of 2.0mg/m^3, coupled with an average value of 0.7475mg/m^3. Similarly, the concentration of NO_2 in Lagos ranges from a minimum value of 0.0mg/m^3 to a maximum value of 0.1mg/m^3, coupled with an average value of 0.0245mg/m^{3}which falls below maximum limit acceptable by WHO standard. The maximum and minimum concentration values of SO_4 are 0.0mg/m^3 and 0.12mg/m^3

respectively while $PM_{2.5}$ has a minimum and maximum values of 5mg/m^3 and 60mg/m^3 respectively. The average values of SO_4 and $PM_{2.5}$ are 0.0308mg/m^3 and 19.400mg/m^3 as well. But the average mean for PM $_{2.5}$ under residential land use type exceeds the maximum limit acceptable by WHO standard.

Table 1. Air quality parameters for residential land use pollutant

Parameter (mg/m^3)	Year	Minimum	Maximum	Mean	Std. Dev.
Carbon (II) oxide	2012-2015	0.0	2.0	0.7475	0.55423
Sulphur (IV) Oxide	2012-2015	0.0	0.1	0.0245	.02970
Nitrogen dioxide	2012-2015	0.0	0.12	0.0308	0.03041
Fine Particulate Matter	2012-2015	5	60	19.4000	11.80569

Key: CO- Carbon (II) oxide, SO_4- Sulphur (IV) Oxide, NO_2- Nitrogen dioxide, $PM_{2.5}$- Fine Particulate Matter, Std. Dev.- Standard Deviation

Descriptive Statistics analysis of air pollutants with respect to heavy traffic

From Table 2, the minimum and maximum values of the concentrate of CO under the heavy traffic range from 2.00mg/m^3 to 7.80mg/m^3 and the mean concentration is 4.3625mg/m^3. The minimum and maximum values of SO_4 and NO_2 are 0.00mg/m^3 and 0.036mg/m^{3}while their mean values are 0.1107mg/m^3 and 0.1183mg/m^{3}respectively. $PM_{2.5}$ has 8mg/m^3 and 66mg/m^3 as its minimum and maximum concentrations while its mean value is 27.9500mg/m^3.

Table 2. Air quality Parameters for heavy traffic pollutants

Parameter (mg/m^3)	Year	Minimum	Maximum	Mean	Std. Dev.
Carbon (II) oxide	2012-2015	2.0	7.8	4.3625	1.41597
Sulphur (IV) Oxide	2012-2015	0.00	0.36	0.1107	0.`10499
Nitrogen (IV) Oxide	2012-2015	0.00	0.36	0.1183	0.09361
Fine Particulate Matter	2012-2015	8	66	27.9500	14.16741

Key: CO- Carbon (II) oxide, SO_4- Sulphur (IV) Oxide, NO_2- Nitrogen dioxide, $PM_{2.5}$- Fine Particulate Matter, Std. Dev.- Standard Deviation

Descriptive Statistics analysis of air pollutant with respect to industrial land use type

From Table 3, the concentrations of carbon (ii) Oxide (CO) range from 0.00mg/m^3 to 7.60mg/m^3 and fine particulate matter ($PM_{2.5}$) ranges from 0.00mg/m^3 to 76mg/m^3 while both have average concentrations of 2.2500mg/m^3 respectively. Within this period, the average concentrations of $PM_{2.5}$ and CO present in the air are 25.5000mg/m^3 and 2.2500mg/m^3 respectively. Similarly, the concentrations of SO_4 and NO_2 in air range from 0.00mg/m^3 to 0.45mg/m^3 for SO_4 and 0.00mg/m^3 to 0.26mg/m^3 for NO_2 respectively. Their average concentrations are 0.0975mg/m^3 and 0.0520mg/m^3 respectively. But the average concentrations of $PM_{2.5}$is above the acceptable WHO standard in respect to industrial caused emissions in Lagos, Nigeria industrial areas.

Table 3. Air quality Parameters for industrial land use type pollutants

Parameter (mg/m^3)	Year	Minimum	Maximum	Mean	Std. Dev.
Carbon (II) oxide	2012-2015	0.00	7.60	2.2500	1.50708
Sulphur (IV) Oxide	2012-2015	0.00	0.26	0.0520	0.06005
Nitrogen dioxide	2012-2015	0.00	0.45	0.0975	0.16894
Fine Particulate Matter	2012-2015	0.00	76	25.2000	15.09661

Key: CO- Carbon (II) oxide, SO_4- Sulphur (IV) Oxide, NO_2- Nitrogen dioxide, $PM_{2.5}$- Fine Particulate Matter, Std. Dev.- Standard Deviation

Comparative Analyses of Air Quality with respect to types of Pollutants

The average values of CO emissions for residential, heavy traffic and industrial areas are $0.7475mg/m^3$, $4.3625mg/m^3$ and $2.2500mg/m^3$ respectively. Fig. 1 showed that the heavy traffic land use type emissions is the highest and may have the major effects on air quality in Lagos, Nigeria. The average concentrations of SO_4 under residential, heavy traffic and industrial land use emissions are 0.0308mg/m3, $0.1183mg/m^3$ and $0.0975mg/m^3$ respectively. From Fig. 2, heavy traffic emission was the highest and this is believed to affect air quality most. The fine particulate matters (PM) mean concentrations under the land use type emissions were $19.4000mg/m^3$, $25.2000mg/m^3$ and $27.9500mg/m^3$ respectively. Based on Fig. 3, heavy traffic emissions contribute the highest amount of fine particulate matter to the atmospheric environment of Lagos State and may likely lead to harmful air quality. The mean concentrations of NO_2 in Lagos air based on land use type emissions were $0.0245mg/m^3$, $0.1107mg/m^3$ and $0.0520mg/m^3$ respectively. Using the fact from Fig. 4, heavy traffic land use emissions contribute the highest NO_2 to the atmospheric environment of Lagos State, South Western, Nigeria.

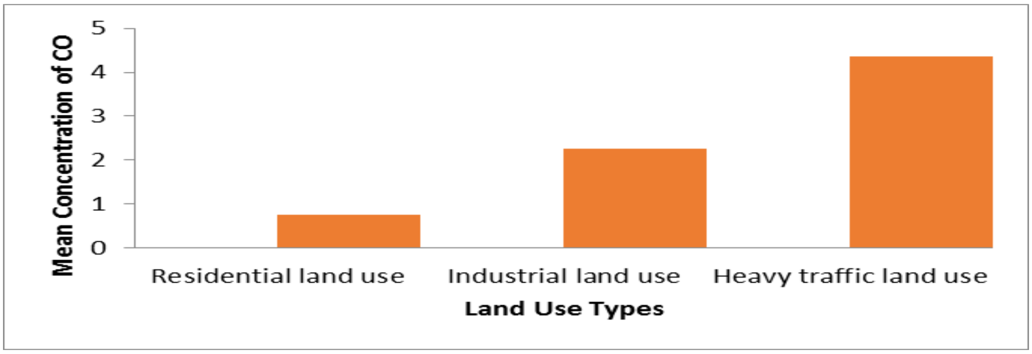

Fig. 1: Mean Values of CO under different land use types emission

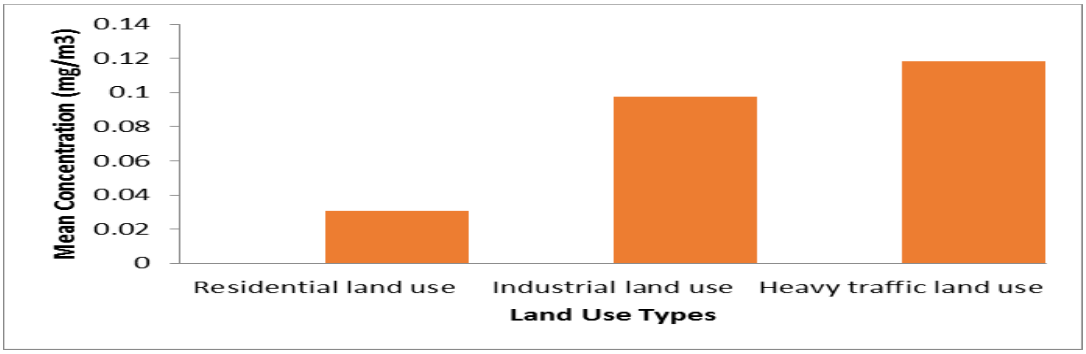

Fig. 2: Mean Values of SO_4 under different land use type emissions

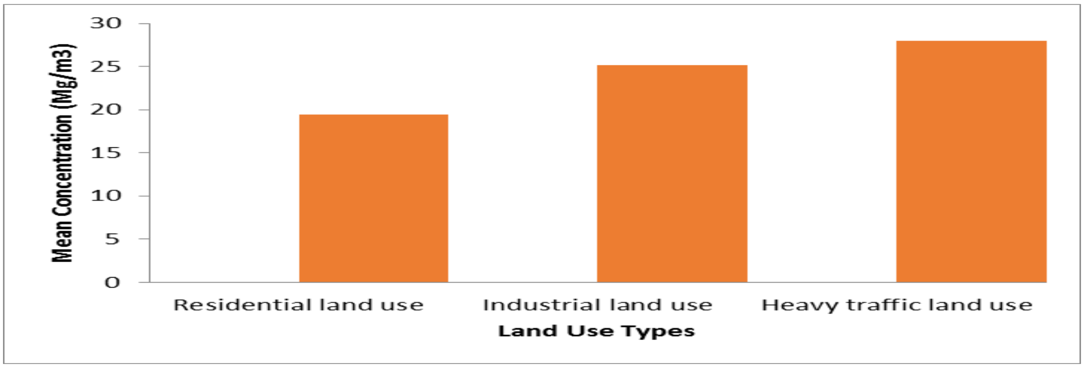

Fig. 3: Mean values of fine particulate matter under different land use type emission

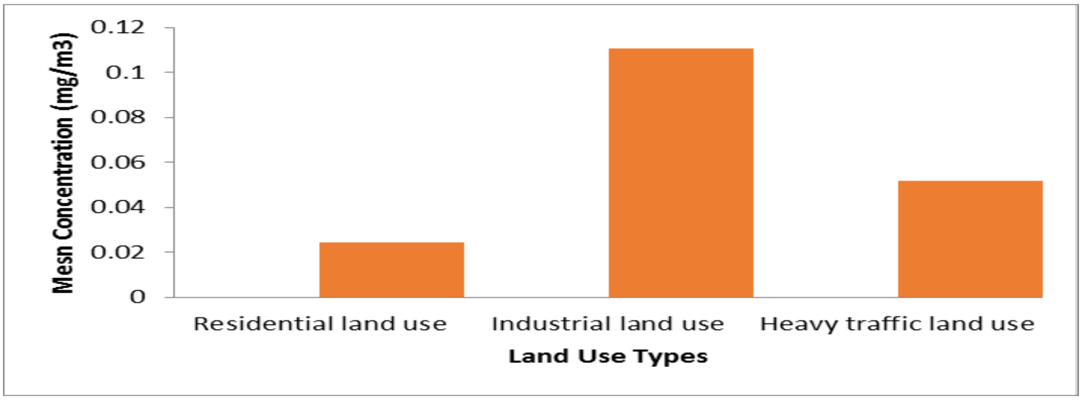

Fig. 4: Mean values of NO_2 under different land use type emissions

Correlation Analysis between Air Pollution and Climatic Variables

From table 4, positive association exists between and SO_4 (r = 0.524); CO and NO_2 (r = 0.329); CO and $PM_{2.5}$ (r = 0.196). This implies that an increase in carbon monoxide (CO) stirs an increase in Nitrogen dioxide, sulphur (IV) oxide and fine particulate matter respectively. There exists as well a weak positive and negative relationship between the air pollutants and climatic variables.

Table 4. Pearson correlation Analysis between air pollution and climatic variables

Parameter	CO	SO_4	NO_2	$PM_{2.5}$	AT	MR
CO	1	0.524	0.329	0.196	0.053	0.056
SO_4	0.524	1	0.346	0.067	0.028	0.064
NO_2	0.329	0.346	1	-0.146	-0.029	0.026
$PM_{2.5}$	0.196	-0.067	-0.0146	1	-0.104	-0.084
AT	-0.053	-0.028	-0.029	-0.0104	1	0.042
AR	-0.056	0.064	-0.026	-0.084	0.042	1

Key: SO_4-Sulphur (IV) oxide; CO-Carbon monoxide; NO_2-Nitrogen dioxide; $PM_{2.5}$-Fine particulate matter; AT- Air temperature; MR-Monthly amount of rainfall.

Kruskal Wallis Test (H test) for significant difference among Air Pollutants

Based on the sample size of the available data, this informs the choice of H test for analysing the significant difference among the Air Pollutants. From table 5, for each air pollutant, the null hypothesis (H_0) was rejected and the alternative hypothesis (H_1) accepted.

We, therefore, concluded that there are significant differences among the air pollutants under the heavy traffic, industrial and residential land use types.

Table 5: Results of Kruskal -Wallis test for significant difference among Air Pollutants

Parameter	**RLU(mean rank)**	**ILU(mean rank)**	**HTLU(mean rank)**	**Chi-square**	**DF**	**H test**
CO	25.45	60.53	95.53	81.309	2	0.000
SO_4	40.84	62.58	78.09	23.455	2	0.000
NO_2	45.59	60.03	75.89	15.906	2	0.000
$PM_{2.5}$	46.21	63.43	71.86	11.316	2	0.000

Key: Industrial land use (ILU), Residential land use (RLU), Agricultural Land Use (ALU), Carbon monoxide (CO), Nitrogen dioxide (NO_2), Sulphur (IV) Oxide (SO_4), $PM_{2.5}$ (Fine Particulate Matter).

Mann Kendell Trend test for Monthly Rainfall

Trends in monthly rainfall data within the years under consideration are examined using Mann- Kendell test. From table 6, we have three decreasing and nine increasing trends in the monthly rainfall data between 1985 and 2015. Based on p-values, all decreasing trends are significant and there is no trend. Three of the increasing trends accounted for 33.3% are significant while the remaining nine months accounted for 66.7% are non-significant.

The Sen's slope showed the magnitude of trends ranges between -0.482 and 4.535, hence the lowest magnitude is recorded in the month of December while the highest magnitude is recorded in April.

Table 6. Trend analysis of Monthly Rainfall using Mann Kendell test

Month	MK (S)	P- Value	Sen's Slope	Remarks
January	32	0.493	0.094	Increasing, no trend
February	106	0.038	1.192	Increasing, trend available
March	-30	0.605	-0.465	Decreasing, no trend
April	1	1.000	0.057	Increasing, no trend
May	39	0.502	1.4	Increasing, no trend
June	111	0.049	4.535	Increasing, trend available
July	8	0.901	0.22	Increasing, no trend
August	-13	0.832	-0.2	Decreasing, no trend
September	85	0.135	2.185	Increasing, no trend
October	31	0.596	0.63	Increasing, no trend
November	183	0.001	4.106	Increasing, trend available
December	-46	0.343	-0.482	Decreasing, no trend

Decision Rules: A positive (negative) value of Sen's slope indicates an increasing (decreasing) trend. P-value greater than the significance level $(\alpha = 0.05)$, the null hypothesis H_0 (there is no trend in the series) is accepted or otherwise.

Mann Whitney test for significant difference in Periods of Rainfall Series

The significant difference between annual Rainfall data is tested by grouping the series into two periods (1985-1999 and 2000-2015) using Mann Whitney test. The result in Table 7 indicated the computed p-value is less than the significance level and the null hypothesis is rejected. We conclude that there is a significant difference between the two periods compared and this may be attributed to the high level of air pollutants in recent years.

Table 7. Mann-Whitney test result for annual rainfall in periods

U	87.000
Expected value	112.500
Variance (U)	581.250
p-value (Two-tailed)	0.0300
$(\alpha = 0.05)$	0.05

Conclusions

This research work was used to discuss and analyse the effects of air pollutants from different land use types [Sulphur (iv) oxide (SO_4), Carbon monoxide (CO), Fine particulate matter ($PM_{2.5}$) and Nitrogen dioxide (NO_2)] on environment air quality and climate change with respect to rainfall series in Lagos state, South Western, Nigeria. The rainfall series used was collected from Nigerian Meteorological Agency NIMET), Lagos from 1985 – 2015. The air pollutants data based on land use type and heavy traffic from 2012 – 2015 were obtained from Environmental Planning and Climate Change Department Laboratory Unit, Office of Environmental Services, Lagos State.

From the findings, the average mean of $PM_{2.5}$ under residential and heavy traffic was showed to exceed the international standard. A comparative analysis showed the average mean of Heavy traffic pollutants has the highest values. Pearson correlation coefficients matrix showed a positive relationship between the air pollutants but little or no relationship with rainfall series. The Kruskal-Wallis test indicated that the effect of air pollutants varies across the land use type. Mann Kendell test revealed mostly an increase in monthly rainfall but no trends and the magnitude of trends range between -0.482 and 4.535 with lowest and highest magnitude occurring in December and April. Mann Whitney test revealed the existence of the significant difference between the two rainfall periods compared and this may be attributed to high level of air pollutants in recent years. In conclusion, air pollution with respect to land use types has been showed to affect atmospheric air quality and contribute to climate change in Lagos State, South Western, Nigeria. However, proper monitoring should be put in place to reduce and curtail the effects of air pollution in South Western and Nigeria as a whole.

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