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Study on the Impact of Some Selected Variables on the Dispersion of Dinitrogen Oxide (NO_2) using Distribution Lag Model (DLM)

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Abstract

Current studies on declining air quality and its associated hazard has shown a strong correlation between the growing rate of urbanization and increasing number of vehicles on our roads. It is also worthy to know that a growing numbers of pollutants emitted from vehicular activities such as NO_2 have adverse effects on individuals as well as the atmosphere. The aim of the study is to analyze the impact of some selected variables on the dispersion of dinitrogen oxide NO_2 using Distribution Lag Model (DLM).
Seven (7) selected locations, namely; University of Benin Main Gate, Ekosodin junction, Agen Junction, Super D junction, Nitel junction, Okhunmwun junction and Oluku Market junction were used for data collection. Pollutant from vehicular emission such as dinitrogen oxide (NO_2), was monitored in the morning and evening for a period of 35 days (7th July to 12th August 2020) with the aid of Aeroqual multi-parameter environmental monitor (series 500) and radiation alert meters. Other parameters of interest which were also measured include; maximum temperature and wind speed using infra-red thermometers and Sky master thermo anemometer (SM-28). To ascertain the quality of the data for regression analysis, diagnostic statistics such as autocorrelation test, heteroscedasticity, variance inflation factor and test of reliability were done while the distribution lag model was employed to investigate potential collinearity among the regressor variables and to test the significant effects of each independent variable on the dependent variable
Result of the study revealed a high concentration of NO_2 around Ugbowo maingate and Okhunmwun community and environs especially during the peak hours (4-6pm) when the traffic load is high. In addition, the outcome of the distribution lag model has revealed potential collinearity between sampling distance and wind speed; hence a reasonable conclusion was reached that; sampling distance and wind speed did not contribute to change in the concentration of NO_2 around the study area. More also, based on the computed p-value of 0.0340, it was concluded that; the impact of temperature on the dispersion of NO_2 is significant at the 5% confidence interval.

1. Introduction

Transportation is a major source of air pollution in many countries due to the high number of vehicles that are available on the roads today, and this number is continuously rising with population growth and purchasing power [1]. The major outdoor sources of NO_x are primarily emissions from transportation (virtually all of which are from motor vehicles) and fuel combustion [2]. Nitrogen oxide (NO_x) pollution is formed whenever fuel is combusted at high temperatures by a 'fixing' of the nitrogen in the combustion chamber's dilution air into NO_x. Many of the nitrogen oxides are colorless and odorless. However, one common NO_x, nitrogen dioxide (NO_2), along with particles in the air, can often be seen as a reddish-brown layer in the air over urban areas. NO_x is one of the main ingredients involved in the formation of ground-level ozone, which can trigger serious respiratory problems. It also reacts to form nitrate particles and acidic aerosols, contributing to the formation of acid rain. Particulate nitrates resulting from NO_x contribute to fine atmospheric particles that can cause visibility impairment. NO_x gases also contribute to the global warming problem [2, 3]. According to the World Health Organization (WHO), air pollutants emitted from vehicles are believed to increase the risk of stroke, lung cancer, chronic and acute respiratory diseases such as asthma, heart disease, birth defects and eye irritation [3, 4]

In addition, extremely high-dose exposure to NO_2 may result in pulmonary edema and diffuse lung injury while continued exposure to high NO_2 levels can contribute to the development of acute or chronic bronchitis [5]. A review of some related literature on the danger of vehicular emission revealed that some of the pollutants and particulate matter from cars can be deposited on soil and surface waters and eventually enters the food chain where they get into the human bio-system.

These substances can affect the reproductive, respiratory, immune and neurological systems of animals [6]. In a study by [7], the authors affirmed that the majority of vehicles used today are mostly powered by internal combustion engines that burn gasoline or other petroleum products and consequently give rise to harmful toxic gases such as NO_2 that have adverse effects on our immediate environment. The reaction of nitrogen and oxygen to form nitrogen oxides (NO_x) is also critical to the concept of air pollution by vehicular emission. In the presence of sunlight, nitrogen oxides (NO_x) can react with fumes from the volatilization of hydrocarbon to form the soup of photochemical smog for which the bad ozone is a major component [8]. This smog can combine with particulate matter; which is small particles of foreign substances in the air to form haze which can cause damage to the lungs.

It is the general believed that real-time, public air quality information is essential not only to empower populations to respond to current conditions and protect human health, it is also a cornerstone in generating public awareness and driving action to combat air pollution in the long-term [9, 10]. In addition, air pollutant dispersion whether horizontal or vertical dispersion is influenced by numerous factors such as; wind speed and wind direction, prevailing environmental temperature, distance, aerodynamics and even buildings.

This study attempt to investigate the influence of selected factors, such as; distance, prevailing environmental temperature and wind speed on the dispersion of NO_2 within the study area.

2. Research Methodology

2.1 Description of study area

The study area is limited to some parts of Ovia North East Local Government Area of Edo State particularly Ugbowo and environs where serious traffic jam is experienced on daily bases. The selected location falls within the administrative area of the State. From the onset and even now, Benin City remains the principal administrative and socio-economic center of Edo State in Nigeria. Benin City is a humid tropical urban settlement which comprises three Local Government Areas namely Egor, Ikpoba Okha and Oredo. It is located within latitudes $6^{0}20'$N and $6^{0}58'$N and longitudes $5^{0}35'$E and $5^{0}41'$E. It broadly occupies an area of approximately 112.552 sq. km. This extensive coverage suggests spatial variability of weather and climatic elements. Benin City lies visibly in the southern most corner of a dissected margin: a prominent topographical unit which lies north of the Niger Delta, west of the lower Niger Valley, and south of the Western Plain [11]. The specific locations employed for data collection are presented in Figure 1a

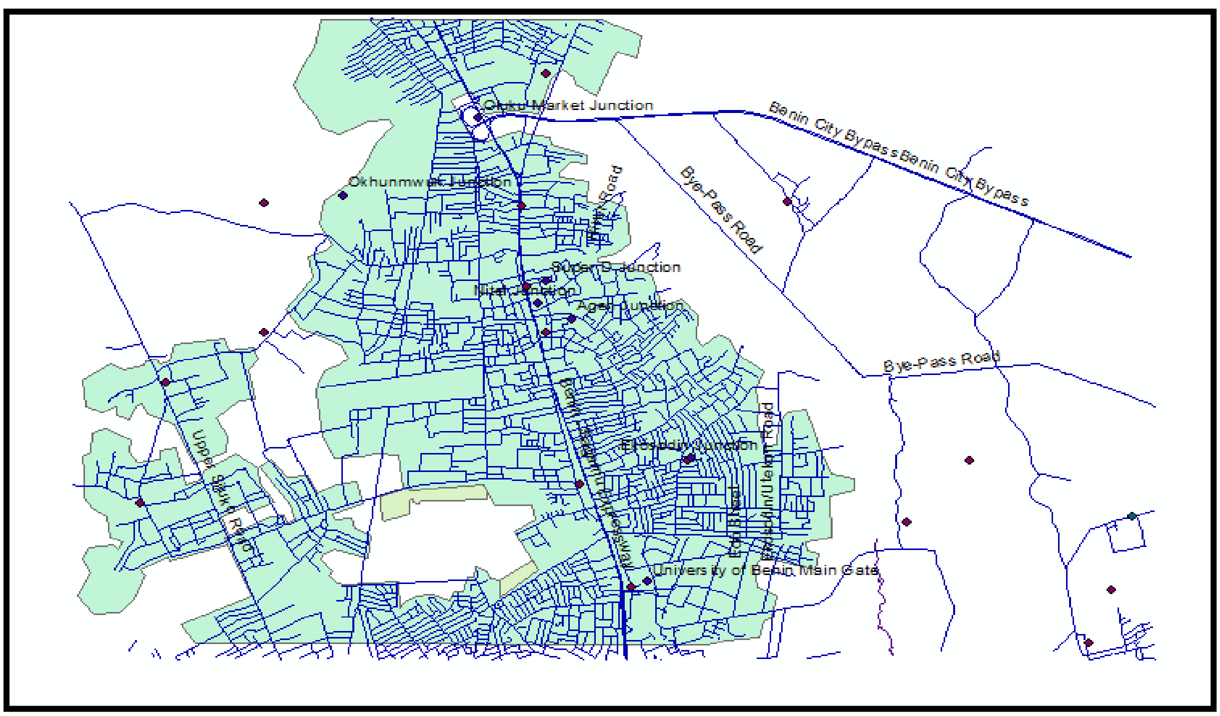

Figure 1a: Map of study area (Google map)

2.2 Data collection

Seven (7) selected locations, namely; University of Benin Main Gate, Ekosodin junction, Agen Junction, Super D junction, Nitel junction, Okhunmwun junction and Oluku Market junction were used for data collection. Pollutant from vehicular emission such as dinitrogen oxide (NO_2) was monitored in the morning and evening for a period of 35 days (7th July to 12th August 2020) with the aid of Aeroqual multi-parameter environmental monitor (series 500) and radiation alert meter. Other parameters of interest which were also measured include; maximum temperature and wind speed using infra-red thermometers and Sky master thermo anemometer (SM-28). The duration of measurement, including the calibrated unit of the gas detector is presented in Table 1a

Table 1a: Measurement procedures and equipment used

S/N	Pollutant	Daily duration of Exposure (hrs.)	Equipment	Unit
1	NO_2	1hr (9am to 10am) 1hr (5pm to 6pm)	Aeroqual multi-parameter environmental monitor (series 500)	ppm

The Global Positioning System (GPS) receiver and point positioning techniques were used to obtain the geographical coordinates at each monitoring location in the study area. The coordinates were converted to decimal degrees' format using the Universal Traverse Mercator (UTM) software version 1.0. The maximum concentration of each monitored pollutant during the monitoring period was selected and recorded for data processing.

2.3 Data Analysis

2.3.1 Regression Analysis Approach

One dependent and three independent variables were employed for this analysis. The selected dependent and independent variables are presented in Table 1b

Table 1b: Selected dependent and independent variables

S/No	**Variables**	**Variable Type**	**Symbol**
1	Dinitrogen Oxide (ppm)	Dependent	NO_2
2	Sampling distance (m)	Independent	SD
3	Temperature (^{0}C)	Independent	Temp
4	Wind speed (m/s)	Independent	WS

The dependence of the dependent variable on the selected independent variables was evaluated using the coded least square regression equation presented as follows;

(NO_2) C SD Temp WS (1)

It is pertinent to note that standard error estimation and computation of t-statistics are appropriate in calculating the probability (p-value) by which you test the significance of the regression model. In the presence of heteroscedasticity, it is assumed that the overall standard error of regression and the t-statistics computed for each independent variable may not be completely adequate to estimate the resulting probability (p-value) of regression. In addition, the presence of serial correlation can lead to a number of issues, namely;

i. Make reported standard error and t-statistics to be invalid
ii. Coefficient may be biased, though not necessarily inconsistent

Based on this argument, selected diagnostic statistics were conducted to verify the statistical properties of the overall regression model. The selected diagnostic statistics include;

i. Heteroscedasticity test using Breusch-Pagan Godfrey
ii. Serial Correlation test using Breusch Godfrey
iii. Variance Inflation Factor (VIF)

Heteroscedasticity is a diagnostic test statistic use to diagnose the adequacy of the probability (p-value) calculated for each individual variable. Hence it is important to know whether there is or there isn't heteroscedasticity in our data. The null and alternate hypothesis of heteroscedasticity was formulated as follows;

For p-value < 0.05 reject H0
H0 = Presence of homoscedasticity
H1 = Absence of heteroscedasticity
For p-value > 0.05 accept H0
H0 = Absence of homoscedasticity
H1 = Presence of heteroscedasticity
Serial correlation is a common occurrence in time series data because the data is ordered (overtime). It is therefore not surprising that neighbouring error terms turn out to be correlated. Serial correlation violates the standard assumption of regression theory that error terms are uncorrelated. The null and alternate hypothesis of serial correlation was formulated as follows;
H0 = Absence of serial correlation
H1 = Presence of serial correlation

Variance inflation factor (VIF) measures the correlation of the dependent variable with the independent variables. Ideal VIF is 1; VIF greater than 10 is cause for alarm showing the variables are uncorrelated due to multicollinearity.

2.3.2 Distribution Lag Model Procedures
Distribution lag model methodology is presented in Figure 1b

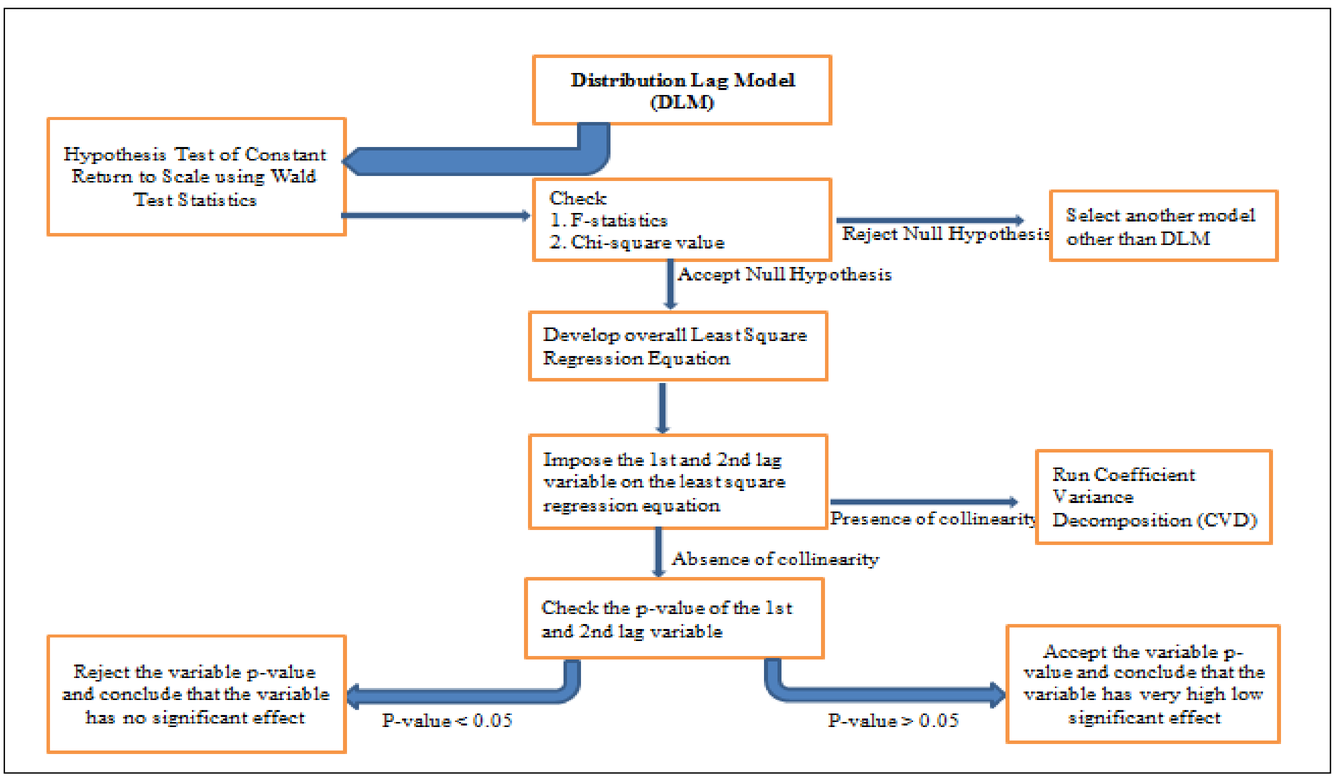

Figure 1b: Distribution lag model methodology

3. Results and Discussion

3.1 Result of Descriptive Statistics

The descriptive statistics of the data collected during the period of investigation which comprises of the mean, maximum and minimum values including the variance and standard deviation is presented in Table 1

Table 1: Descriptive Statistics of data collected

	N	Minimum	Maximum	Sum	Mean	Std. Deviation	Variance
NO_2 (ppm)	245	.01	.05	5.11	.0209	.00990	.000
Temp. (^{0}C)	245	27.4	32.6	7484.6	30.549	1.3716	1.881
Wind Speed (m/s)	245	2.301	2.545	593.635	2.42300	.070870	.005
Sampling Distance (m)	245	10	1534	164325	670.71	448.961	2.016E5
Valid N (list wise)	245						

No standard has been agreed upon for nitrogen oxides in indoor air. The USEPA National Ambient Air Quality Standards list 0.053 ppm as the average 24-hour limit for NO_2 in outdoor air. Although, the outcome of Table 1 revealed that the maximum concentration of NO_2 stands at 0.050ppm within the period of investigation, it is important that factors that are capable of increasing this concentration are quickly identified and appropriate measure taken to forestall further increase. On whether the concentration of NO_2 and other variables within the study location follows a normal probability distribution, the Jarque-Bera test statistics was employed and result obtained is presented in Figures 2, 3 and 4 respectively

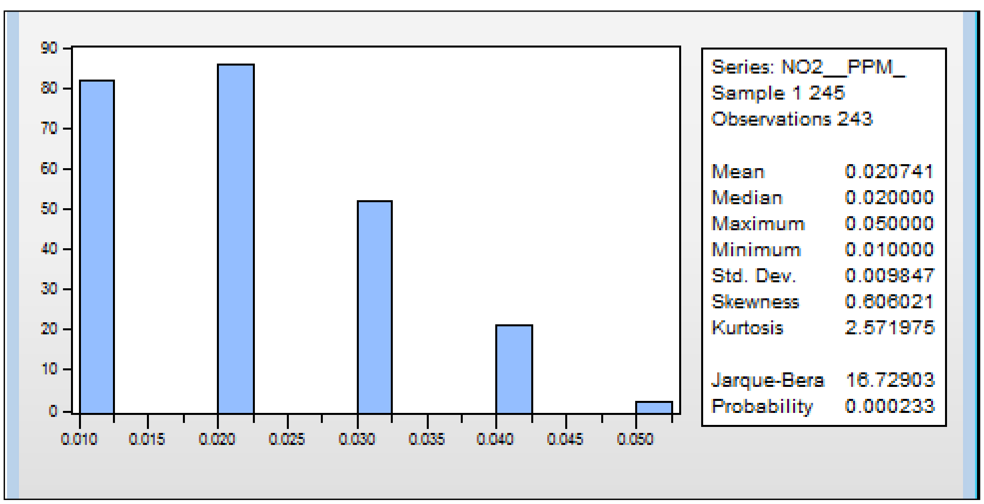

Figure 2: Normality test of NO_2 data

Jarque-Bera test value of 16.72903 and a probability (p-value) of 0.000233% as observed in Figure 2 indicates that the NO_2 data is not normally distributed. A value of JB greater than 10 means that the null hypothesis has been rejected at the 5% significance level. In other words, the data do not come from a normal distribution.

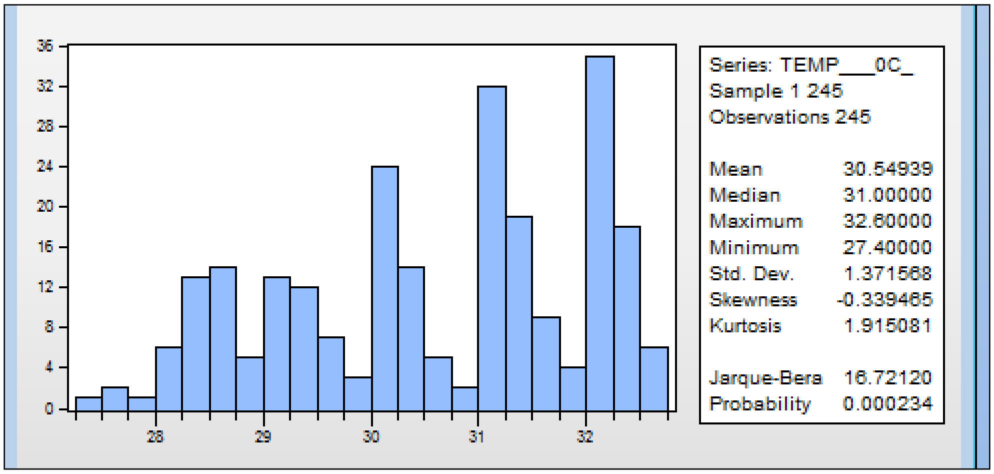

Figure 3: Normality test of temperature data

Jarque-Bera test value of 16.72120 and a probability (p-value) of 0.000234% as observed in Figure 3 indicates that the temperature data is not normally distributed. A value of JB greater than 10 means that the null hypothesis has been rejected at the 5% significance level. In other words, the data do not come from a normal distribution.

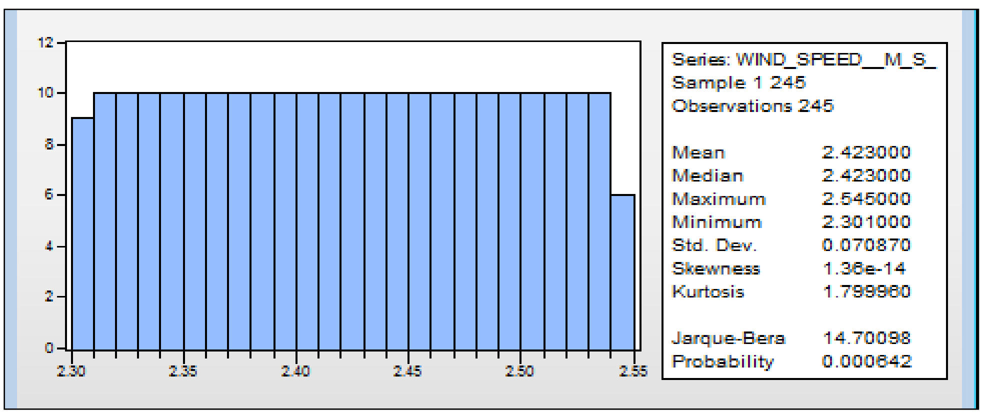

Figure 4: Normality test of wind speed data

Jarque-Bera test value of 14.70098 and a probability (p-value) of 0.000642% as observed in Figure 4 indicates that the wind speed data is not normally distributed. A value of JB greater than 10 means that the null hypothesis has been rejected at the 5% significance level. In other words, the data do not come from a normal distribution.

3.2 Result of Diagnostic Statistics

Results of the diagnostic statistics which were employed to diagnose the statistical properties of the data for use in regression analysis is presented in Tables 3, 4 and 5 representing the results of heteroscedasticity, autocorrelation and variance inflation factor.

Table 3: Heteroscedasticity Test: Breusch-Pagan-Godfrey

F-statistic	0.583099	Prob. F(3,239)	0.6266
Obs*R-squared	1.765652	Prob. Chi-Square(3)	0.6224
Scaled explained SS	1.320212	Prob. Chi-Square(3)	0.7243

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.001234	0.001113	1.108669	0.2687
SAMPLING_DISTANCE	9.36E-08	7.79E-08	1.201751	0.2306
TEMP___0C_	4.21E-06	5.77E-06	0.728948	0.4667
WIND_SPEED__M_S_	-0.000549	0.000497	-1.105157	0.2702

R-squared	0.007266	Mean dependent var	9.39E-05
Adjusted R-squared	-0.005195	S.D. dependent var	0.000117
S.E. of regression	0.000117	Akaike info criterion	-15.24769
Sum squared resid	3.29E-06	Schwarz criterion	-15.19019
Log likelihood	1856.594	Hannan-Quinn criter.	-15.22453
F-statistic	0.583099	Durbin-Watson stat	2.116735
Prob(F-statistic)	0.626631		

Table 4: Breusch-Godfrey Serial Correlation LM Test:

F-statistic	3.927983	Prob. F(2,237)	0.0210
Obs*R-squared	7.796419	Prob. Chi-Square(2)	0.0203

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-0.013263	0.091776	-0.144517	0.8852
SAMPLING_DISTANCE__M_	-1.05E-06	6.43E-06	-0.163117	0.8706
TEMP___0C_	-6.45E-05	0.000476	-0.135467	0.8924
WIND_SPEED__M_S_	0.006568	0.041017	0.160136	0.8729
RESID(-1)	-0.177365	0.065930	-2.690217	0.0076
RESID(-2)	-0.054300	0.065477	-0.829298	0.4078

R-squared	0.032084	Mean dependent var	-7.57E-18
Adjusted R-squared	0.011664	S.D. dependent var	0.009710
S.E. of regression	0.009653	Akaike info criterion	-6.418756
Sum squared resid	0.022083	Schwarz criterion	-6.332508
Log likelihood	785.8789	Hannan-Quinn criter.	-6.384016
F-statistic	1.571193	Durbin-Watson stat	1.965911

Prob(F-statistic)	0.168948

Table 5: Variance Inflation Factors

Variable	Coefficient Variance	Uncentered VIF	Centered VIF
C	0.008593	21874.61	NA
SAMPLING_DISTANCE__M_	4.21E-11	69.89555	21.57172
TEMP___0C_	2.31E-07	550.6631	1.106153
WIND_SPEED__M_S_	0.001715	25654.01	21.86343

From the result of Table 3, it was observed that;

i. The calculated (p-value) based on F-statistics is 0.6266
ii. The calculated (p-value) based on langrange multiplier (LM) is 0.6224

Since the computed (p-value) based on F-statistics and langrange multiplier is greater than 0.05 ($P > 0.05$), we rejected the null hypothesis of homoskedasticity and conclude that there is heteroscedasticity in the data. From the result of Table 4, it was observed that;

i. The calculated (p-value) based on the F-statistics is 0.0210
ii. The calculated (p-value) based on langrange multiplier (LM) is 0.0203

Since the computed (p-value) based on F-statistics and langrange multiplier is less than 0.05 ($P < 0.05$), the null hypothesis of serial correlation was accepted and it was concluded that; there is no serial correlation in the data. Since the computed variance inflation factors (centered VIF) for the selected independent variables as observed in Table 5 is less than 10, it was concluded that the variables are well correlated with the dependent variable, hence absence of multicollinearity. To determine the variable that mostly influenced the dispersion of NO_2 around the study area, distribution lag model was employed as follows

3.3 Distribution Lag Model

In this model, one or more independent variables affect the dependent variable with a lag. Suppose we want to determine how each of the independent variables affects the dependent variable then we need to first test if the difference between the coefficient estimates of the independent variables is statistically significant using the hypothesis test of constant return to scale. To test the hypothesis of constant return to scale, a restriction equation of three (3) independent variables was written as follows;

$$C(2) + C(3) + C(4) = 1 \quad (1)$$

Result obtained is presented in Table 6

n/

Table 6: Result of Wald Test:

Test Statistic	Value	df	Probability
t-statistic	-26.30865	239	0.0000
F-statistic	692.1452	(1, 239)	0.0000
Chi-square	692.1452	1	0.0000

Null Hypothesis: C(2)+C(3)+C(4)= 1
Null Hypothesis Summary:

Normalized Restriction (= 0)	Value	Std. Err.
-1 + C(2) + C(3) + C(4)	1.085598	0.041264

F-statistical value of 0.0000 and chi-square value of 0.0000 shows a strong similarity between both of them. In addition, standard error value of 0.041264 and a p-value greater than 0.05 shows that we decisively accept the null hypothesis of constant return to scale and conclude that the restrictions are linear in coefficient. Using the distribution lag model, an overall regression equation was developed in syntax form and presented as follows;

LS NO2__PPM_ C SAMPLING_DISTANCE__M_ TEMP___0C_ WIND_SPEED__M_S_ (2)

Estimation Equation:
=========================
NO2__PPM_ = C(1) + C(2)*SAMPLING_DISTANCE__M_ + C(3)*TEMP___0C_ + C(4)*WIND_SPEED__M_S_ (3)

Forecasting Equation:
=========================
NO2__PPM_ = C(1) + C(2)*SAMPLING_DISTANCE__M_ + C(3)*TEMP___0C_ + C(4)*WIND_SPEED__M_S_ (4)

Substituted Coefficients:
=========================
NO2__PPM_ = 0.191617948648 + 1.25629468641e-05*SAMPLING_DISTANCE__M_ + 0.00100022166099*TEMP___0C_ - 0.0866107870409*WIND_SPEED__M_S_ (5)

To evaluate the effect of each independent variable on the dependent variable, first and second lag variable were imposed on the least square regression equation as follows;

LS NO2__PPM_ C SAMPLING_DISTANCE__M_ TEMP___0C_ WIND_SPEED__M_S_
(SAMPLING_DISTANCE__M_ (-1)) (SAMPLING_DISTANCE__M_ (-2)) (6)

LS NO2__PPM_ C SAMPLING_DISTANCE__M_ TEMP___0C_ WIND_SPEED__M_S_
(TEMP___0C_ (-1)) (TEMP___0C_ (-2)) (7)

LS NO2__PPM_ C SAMPLING_DISTANCE__M_ TEMP___0C_ WIND_SPEED__M_S_
(WIND_SPEED__M_S_ (-1)) (WIND_SPEED__M_S_ (-2)) (8)

Equation 6, 7 and 8 were employed to study the effects of sampling distance, temperature and wind speed on the dispersion of NO_2 around the study area. Result of the effect of sampling distance on the dispersion of NO_2 using equation 6 is presented in Table 7

Table 7: Effect of Sampling distance on NO_2 dispersion

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.184570	0.095296	1.936812	0.0040
SAMPLING_DISTANCE__M_	1.22E-06	2.09E-05	0.058698	0.9532
TEMP___0C_	0.001039	0.000491	2.117495	0.0353
WIND_SPEED__M_S_	-0.084130	0.042323	-1.987806	0.0480
SAMPLING_DISTANCE__M_(-1)	2.67E-05	2.87E-05	0.932865	0.3518
SAMPLING_DISTANCE__M_(-2)	-1.57E-05	2.09E-05	-0.752300	0.4526

R-squared	0.930506	Mean dependent var	0.020705
Adjusted R-squared	0.987800	S.D. dependent var	0.009870
S.E. of regression	0.009821	Akaike info criterion	-6.383979
Sum squared resid	0.022667	Schwarz criterion	-6.297220
Log likelihood	775.2694	Hannan-Quinn criter.	-6.349025
F-statistic	1.478873	Durbin-Watson stat	2.312897
Prob(F-statistic)	0.197458		

Result of the distribution lag model shows an improvement in the R-squared value and the Adjusted R-squared value. In addition since the p-value of the first and second lag variable is greater than 0.05, it was concluded that the lag variables are significant hence the p-value of 0.9532 for sampling distance is valid. Based on the computed p-value of 0.9532, it was concluded that; the impact of sampling distance on the dispersion of NO_2 is not significant at the 5% confidence interval. Distribution lag result on the effect of temperature on the dispersion of NO_2 is presented in Table 8

Table 8: Effect of temperature on NO_2 dispersion

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.183772	0.093663	1.962058	0.0509
SAMPLING_DISTANCE__M_	1.20E-05	6.57E-06	1.833612	0.0680
TEMP___0C_	0.001323	0.000621	2.132302	0.0340
WIND_SPEED__M_S_	-0.082640	0.042077	-1.964031	0.0507
TEMP___0C_(-1)	-0.000869	0.000703	-1.235807	0.2178
TEMP___0C_(-2)	0.000499	0.000612	0.815567	0.4156

R-squared	0.933250	Mean dependent var	0.020705
Adjusted R-squared	0.927580	S.D. dependent var	0.009870
S.E. of regression	0.009807	Akaike info criterion	-6.386891
Sum squared resid	0.022601	Schwarz criterion	-6.300133
Log likelihood	775.6204	Hannan-Quinn criter.	-6.351938
F-statistic	1.620291	Durbin-Watson stat	2.308314
Prob(F-statistic)	0.155383		

Result of the distribution lag model also shows an improvement in the R-squared value and the Adjusted R-squared value. In addition since the p-value of the first and second lag variable is greater than 0.05, it was concluded that the lag variables are significant hence the p-value of 0.0340

for temperature is valid. Based on the computed p-value of 0.0340, it was concluded that; the impact of temperature on the dispersion of NO_2 is significant at the 5% confidence interval.
The distribution lag result of the effect of wind speed shows a perfect collinearity. A more formal approach to investigate the collinearity among regressor variables was to conduct coefficient variance decomposition analysis.

Coefficient variance decomposition view of an equation provides information on the eigenvector decomposition of the coefficient covariance matrix. This decomposition is a useful tool to help diagnose potential collinearity problems among the regressor which the simple correlation matrix may fail to detect. That is;

$$X_1 = X_2 + 3X_3 \quad (9)$$

In the case of a simple linear least square regression, the coefficient variance covariance matrix can be decomposed as follows;

$$Var(\beta) = \sigma^2 (X^1 X)^{-1} = \sigma^2 V S^{-1} V^1 \quad (10)$$

Where;
S is a diagonal matrix containing the eigenvalues of X^1X and
V is a matrix whose columns are equal to the corresponding eigenvector
Result of the coefficient variance decomposition employed to test potential collinearity among the regressor is presented in Table 9

Table 9: Coefficient Variance Decomposition

Eigenvalues	0.010276	3.29E-05	1.36E-09	6.02E-13
Condition	5.86E-11	1.83E-08	0.000443	1.000000

Variance Decomposition Proportions

Variable	Associated Eigenvalue 1	2	3	4
C	0.999376	0.000624	1.68E-10	7.43E-17
SAMPLING_DISTANCE__M_	0.938278	0.015131	0.032313	0.014278
TEMP___0C_	0.032709	0.961460	0.005831	2.59E-09
WIND_SPEED__M_S_	0.984095	0.015905	4.52E-09	2.27E-15

Eigenvectors

Variable	Associated Eigenvalue 1	2	3	4
C	-0.914192	-0.403972	-0.032550	0.001030
SAMPLING_DISTANCE__M_	-6.20E-05	0.000139	0.031639	0.999499
TEMP___0C_	-0.000858	0.082284	-0.996110	0.031520
WIND_SPEED__M_S_	0.405281	-0.911063	-0.075527	0.002543

From the result of Table 9, the conditional number was observed to be 5.86E-11. Conditional number less than 0.001 as observed in Table 9, signify potential collinearity among the regressor.

From the result of variance decomposition proportion, it was observed that sampling distance and wind speed had associated eigenvalues of 0.938278 and 0.984095 which is greater than 0.5. This indicates that; there is a high level of collinearity between these variables. By implication therefore, sampling distance and wind speed did not contribute to change in the concentration of NO_2 around the study area.

4. Conclusion

In this study, the performance of distribution lag model in identifying potential collinearity among regressor variables has been adequately investigated. The outcome of the model has revealed potential collinearity between sampling distance and wind speed; hence a reasonable conclusion was reached that; sampling distance and wind speed did not contribute to change in the concentration of NO_2 around the study area. In addition, based on the computed p-value of 0.0340, it was concluded that; the impact of temperature on the dispersion of NO_2 is significant at the 5% confidence interval.

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