MODELING OF CO AND $PM_{2.5}$ CONCENTRATION LEVEL IN HIGH TRAFFIC DENSITY AREAS, USING REGRESSION MODEL

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ABSTRACT: *The study modeled air pollutants concentration level in selected high traffic density areas of Port Harcourt, Nigeria. It also investigated the factors that affect the concentration of air pollutants and the effects of vehicular density on the daytime, seasonal and annual patterns. This was with the view to ascertain the pattern of air pollutant concentrations in high traffic density areas of the city. Traffic records were taken at the designated locations by counting the number of vehicles passing through a point for two hours in the morning, afternoon and evening, using a close circuit television (Plate 5.1). All the parameters were monitored in each location once every month (Monday to Friday) for two years (2016-2017). Data obtained were analyzed using ANOVA and multiple linear regressions, where appropriate. Results obtained revealed that the concentration of CO and $PM_{2.5}$varied significantly ($p < 0.05$) between 2016 and 2017. Traffic volume was found to contribute significantly to the concentration of the air pollutants while meteorological factors such as temperature, humidity and wind speed had significant effects on their dispersion. The study concluded that significant relationship exists between the daytime pattern in vehicular volume and air pollutants concentration in the study area. Also, there was an increase in concentration of average air pollutants across the areas monitored between 2016 and 2017. The variation was attributed to increase in vehicular traffic volume. Furthermore, concentration of air pollutants varied at different degrees of temperature, humidity and wind speed. A model was developed to predict the concentration of CO and $PM_{2.5}$ at various metrological factors and vehicular volume.*

KEYWORDS*:* modeling, concentration level, traffic, vehicular volume, air pollutants

INTRODUCTION

There is concern that contribution of vehicular emission to air pollution in Nigeria is increasing, especially in the major cities like Port Harcourt. The concern is probably based on increasing vehicular population and heavy traffic congestion on many roads. Of particular concern is the growing traffic congestion experienced in many of such cities. Traffic congestion has disproportionate contributions to air pollution probably as a result of incomplete combustion in stationary vehicles [1].

The land transport system is rapidly increasing in major cities like Port Harcourt, due to rapid development of the city, which is characterized by increased industrialization. Road traffic emissions are increasing, producing many negative impacts on air quality on roads, intersections and ring roads. Traffic emissions, such as carbon monoxide (CO) and $PM_{2.5}$, are one the primary contributor to overall air pollution from this infrastructure, and the primary source of traffic emissions is vehicular exhausts [2] Consideration has been growing regarding the effects of vehicle traffic on pollutant concentrations and health outcomes. In most cities, air quality challenges are caused mainly by vehicle emissions, and epidemiological studies have revealed excess morbidity and mortality for people living and doing business close to roadways [3].

Several studies, [1] [4] [5] [6] have shown how motor vehicles have emerged as the largest source of urban air pollution. [7] reported that in Nigeria and many other developing countries, poor urban air quality is largely attributable to motor vehicle emissions. This problem is bound to grow worse as problem of vehicles increases. There is concern that contribution of vehicular emission to air pollution in Nigeria is increasing, especially in the major cities like Port Harcourt.

[8] have shown to an extent how vehicular emissions due to traffic congestions contribute highly to air pollution in Port Harcourt. Such studies suggested that effective environmental management of traffic emissions in urban cities requires adequate knowledge of pollutant characteristics in each city. Besides all these investigation into what constitute air pollution in major cities like Port Harcourt, little attention seems to have been given on the concentration level of these emissions at different time of the day and for more than one season (24months). Producing a model, which will help understand the behavior of some of the air pollutants (CO and $PM_{2.5}$) with regards to factors responsible for its concentration have not been widely researched on, especially for two seasons in Port Harcourt, Nigeria. Therefore, the aim of this study is to examine the concentration level of CO and $PM_{2.5}$ in high traffic density areas within the study area. Also, pollutant concentration model based on the traffic volume and meteorological pattern in the study area was produced. The modeling was done in order to evaluate possible future emission using mathematical estimation. This study used a time series model which was done for two years (24 months). The rationale behind this study is based on the growing need for transportation, due to increase in human population in urban cities, resulting to increased vehicular movements.

MATERIALS AND METHODS

Sampling Technique

Sampling stations for the study was identified by purposive method, based on existing information on traffic density in different parts of Port Harcourt, Nigeria. According to [8] there are ten high traffic density junctions in Port Harcourt, while the remaining is of medium to low density. Three (3) high traffic density locations (Rumuokoro roundabout, Rumuola and Location/Adageorge) were selected for the study, through stratified random sampling.

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Method of Data Collection

Information was collected from each of the selected locations in three sessions, namely morning (7:00am to 9:00am), afternoon (12.00 noon-2.00pm) and evening (5:00pm to 8:00pm) periods. According to [8] the morning and evening are peak periods of traffic density while the afternoon is low density period in Port Harcourt. Each location was monitored from Mondays to Friday every month for twenty-four months. Information collected during each session of investigation includes:

Traffic Volume Count: The number of vehicles that cross a given point during each sampling session was collected using a close circuit television (Plate 5.1).

By Pollutant Monitoring: The pollutants monitored on each sampling day which include; Carbon monoxide (CO) and Particulate matters ($PM_{2.5}$). The concentration of CO was determined by using MX6 Ibrid Multigas monitor hand held device and MET ONE GT 321 particulate matter counter for Particulate matter ($PM_{2.5}$). Also, the meteorological parameters (wind speed, temperature, and humidity) were determined using Davis Vantage Vue Weather Station which was mounted at each of designated locations for the period specified.

Statistical Analysis

The data that was obtained by the investigation was analyzed using appropriate descriptive and inferential statistical methods. Descriptive statistics data were summarized in tables and graphs, while Multiple Linear Regression (MLR) was used for the relationship between variables (Pollutants and predictors). Multivariate statistical approaches such as Multiple Linear Regressions (MLR) are used to predict the relationship between input variables (predictors) and output variables (CO, $PM_{2.5}$) [9]. The use of the MLR model allows the formulation of explicit equations that are simple and can be used to improve understanding [10]. The MLR Model has been adopted in previous studies [11].

In developing the model, the air pollutants, metrological parameters and traffic volume collected in the first 12-months, were used in calibrating the equation for predicting pollutants concentration at different sites. The data (measured) collated in the second 12-months was used in validating the air pollutant concentration model. The Statistical Package for Social Science (SPSS) version 23 and Excel (Window 7) were used for the analysis.

$$P = a + b_1AT + b_2RH + b_3WS + b_4\,TV$$

Where

P = Pollutants monitored (Predicted value of the criterion variable)

b = Coefficients (slope of the plane associated with AT, H, WS, TV)

a = Constant (intercept)

AT, RH, WS, TV = Atmospheric temperature, Relative Humidity, Wind Speed and Traffic Volume (Predictor Variables).

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RESULT

Table 1: Summary of Statistics on Traffic Volume of CO and $PM_{2.5}$ Concentration (2016-2017)

	CO Concentration (ppm)			**$PM_{2.5}$ Concentration ($\mu g/m^3$)**		
Time	Min	Max	Mean	Min	Max	Mean
Morning	1.01	44.00	19.73	17.00	328	157.79
Afternoon	0.02	39.00	7.78	6.00	286	79.35
Evening	0.09	48.00	21.00 222.411	11.00	336	184.81
	0.000			276.650		
F-value				0.000		
P-value						

Table 1 presented the concentration of air pollutants at different times of the day within the study sites in Port Harcourt. The mean concentration of all the air pollutants decreased from their peak values in the morning to their lowest values in the afternoon before rising again to a higher peak in the evening peak. Statistical analysis showed that the variation in pollutants concentration over the period of the day was significantly ($p < 0.05$) different. This survey agrees with the study of [8].

Table 2: Statistics of Pollutants, Meteorological Variables and Traffic Variables in the Analysis

Variables	N	Minimum	Maximum	Mean	Std. Deviation
CO (ppm)	1800	0.02	48.00	16.17	13.38
$PM_{2.5}$ ($\mu g/m^3$)	1800	6.00	336.00	140.65	92.21
Air temp (^oC)	1800	16.00	34.00	25.12	4.33
Wind speed (MS^{-1})	1800	1.28	2.39	1.37	.056
Rel. Humidity (%)	1800	30.00	52.00	39.20	4.10
Traffic Volume (Vehicles/hr)	1800	7.00	2107.00	588.00	763.00

Table 2 presented the concentration of air pollutants, metrological variables and traffic volume within the study sites in Port Harcourt. The lowest mean concentration of all the air pollutants, and traffic volume were far lower than the maximum values. This demonstrates high variation of air pollutants and traffic volume respectively experienced between the two study years.

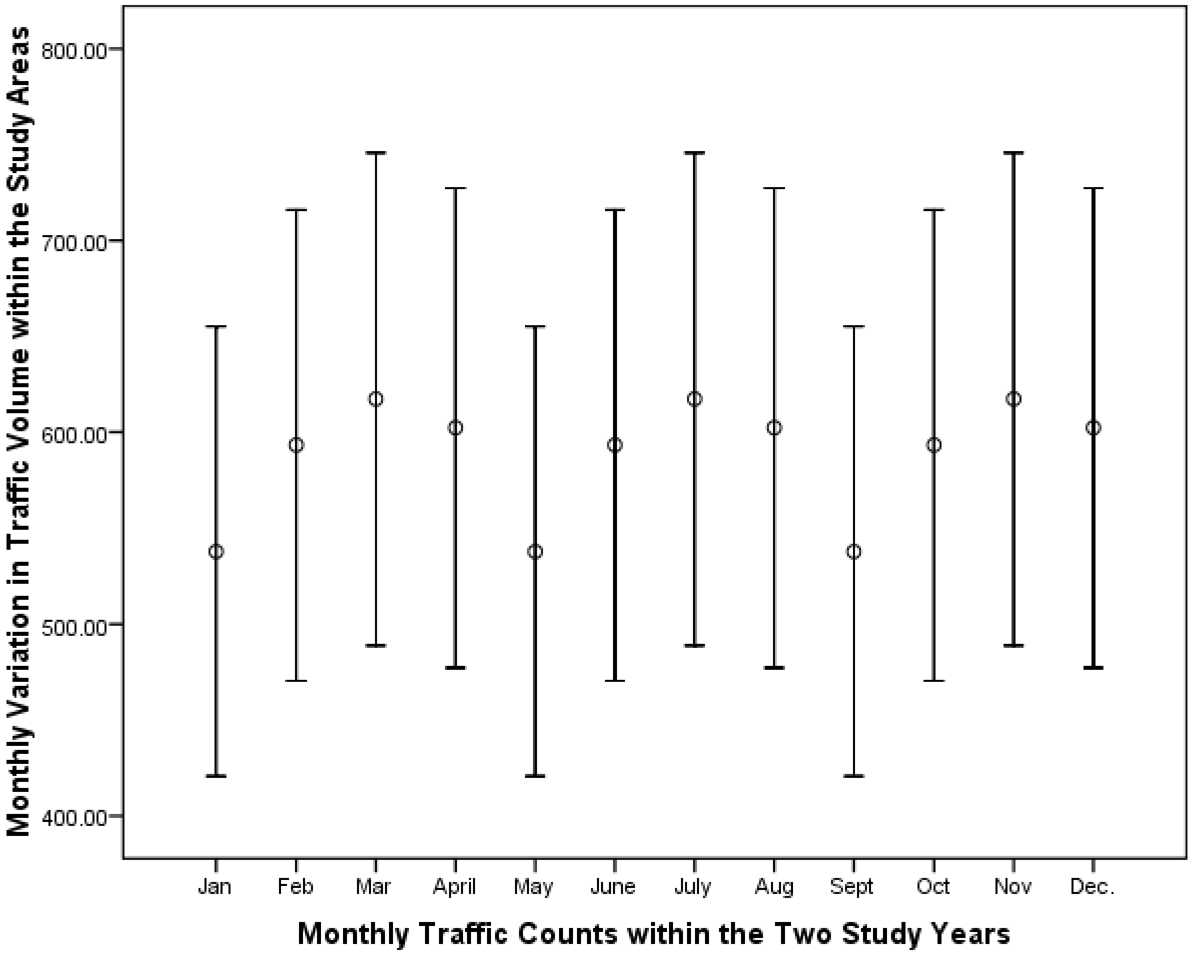

Figure 1: Monthly variations in traffic volume within the study areas in Port Harcourt, Nigeria

The pattern of monthly distribution of traffic volume is shown in Figure 1

Figure 1, showed the monthly values of traffic volume within the study areas in Port Harcourt, Nigeria. The mean value of traffic volume varied between January to December. The values of traffic volume occurred highest (617±796 vehicles/hr) in November and lowest (538±726 vehicles/hr) in January. Statistically, traffic volume did not vary significantly ($p>0.05$) between the month of January to December.

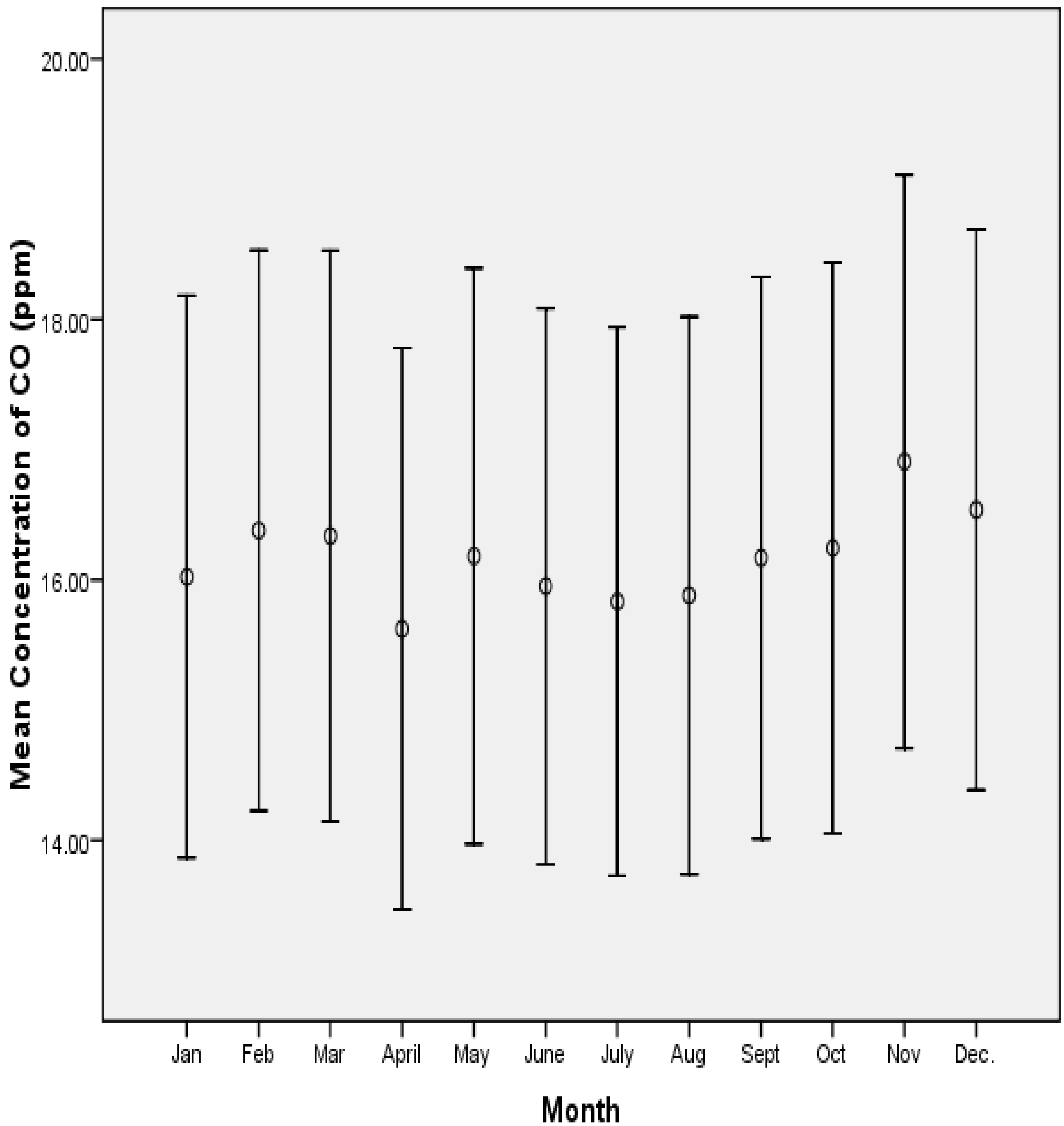

Figure 2: Monthly variations in CO concentration within the study areas in Port Harcourt, Nigeria

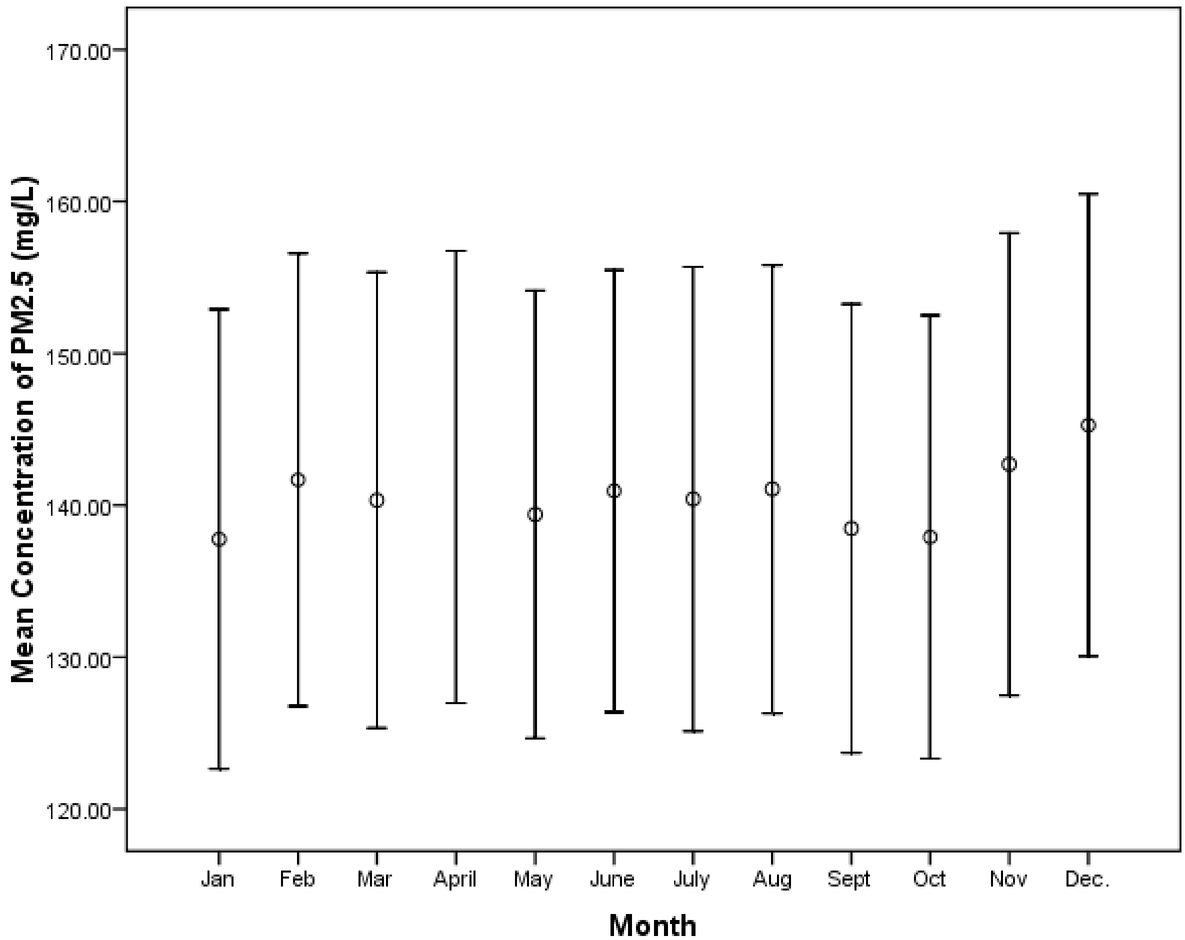

Figure 3: Monthly variations in $PM_{2.5}$ concentration within the study areas in Port Harcourt, Nigeria

The pattern of monthly distribution of pollutants is shown in Figures 2 to 3

Figures 2 and 3 revealed the monthly concentration of air pollutants within the study areas in Port Harcourt. The mean concentration of all the pollutants varied slightly between January to December. CO concentration occurred highest (16.91±13.65 ppm) in November and lowest (15.62±13.36 ppm) in the month of April. However, for particulate matter, mean concentration of $PM_{2.5}$ occurred highest (145.27±94.31µg/m^3) and lowest (137.77±93.69 µg/m^3) in the month of December and January respectively. Statistically, there was no significant variation of CO and $PM_{2.5}$ ($p>0.05$) between the month of January to December.

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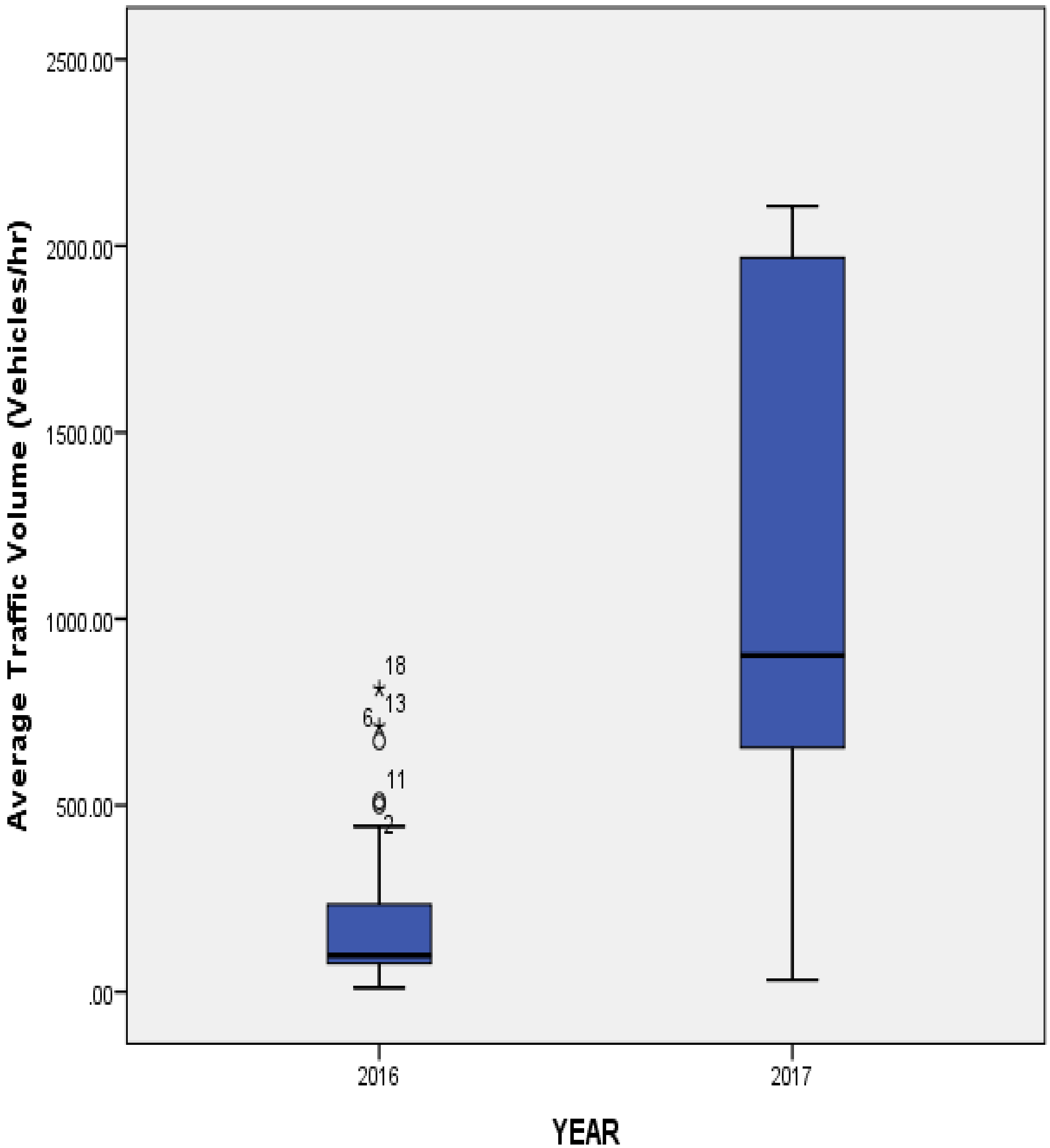

Figure 4: Yearly variations in traffic volume within the study areas in Port Harcourt, Nigeria

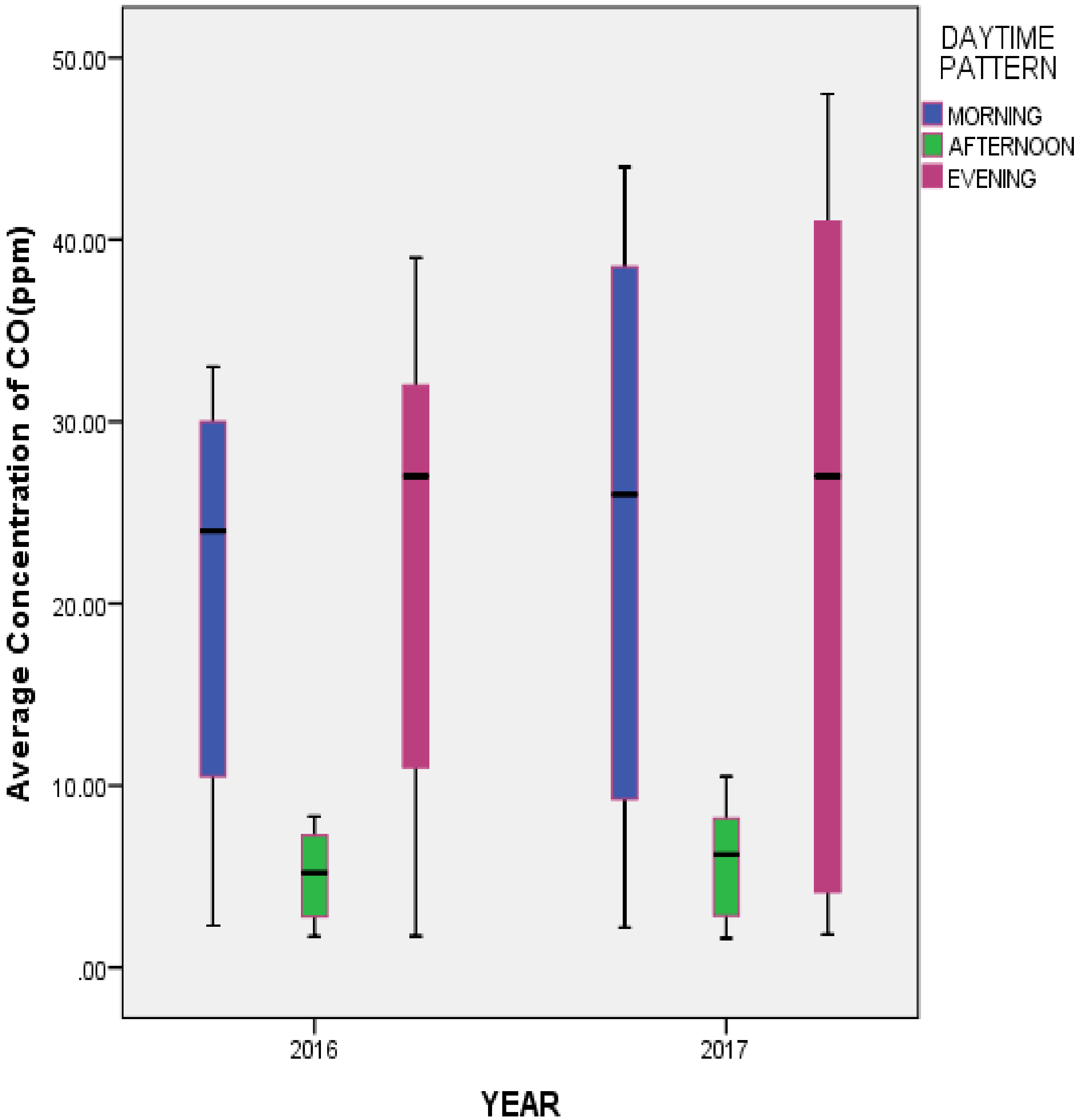

Figure 5: Annual variations in CO concentration between 2016 and 2017 in Port Harcourt, Nigeria

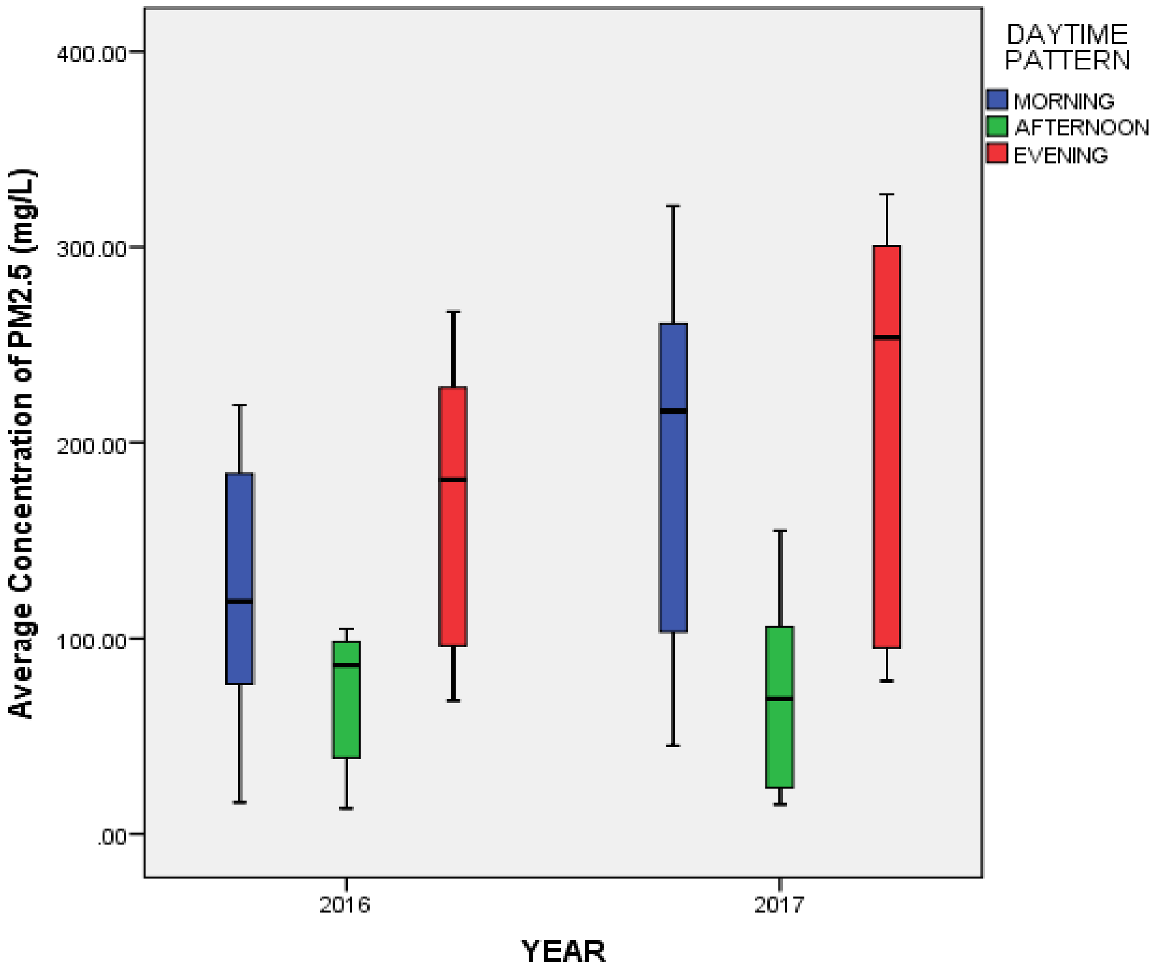

Figure 6: Annual variations in $PM_{2.5}$ concentration between 2016 and 2017 in Port Harcourt, Nigeria

Seasonal distribution of traffic volume and air pollutants

Figures 4, 5 and 6 revealed the concentration of the traffic volume and air pollutants in 2016 and 2017. The mean traffic volume varied highly and significantly from 44.17±30.18 in 2016 to 1131±757.21 in 2017. The overall mean concentration of CO was different in the two years, increasing only slightly and significantly from 15.51±8.21 ppm in 2016 to 17.58±8.03 ppm in 2017. The corresponding value for $PM_{2.5}$ also varied highly and significantly from 124.29±91.21 in 2016 to 160.71±93.25 in 2017. Therefore, all the pollutants exhibited a similar pattern in their trend of temporal variation, the lower concentration of each. Statistically, traffic volume varied ($P<0.05$) significantly, while there was a significant variation in the CO and $PM_{2.5}$between the two study years. Furthermore, mean concentration of CO and $PM_{2.5}$ were highest in the evening peak and lowest in the afternoon peak. This can be attributed to the high traffic volume experience during the evening hours within the Port Harcourt city, Nigeria.

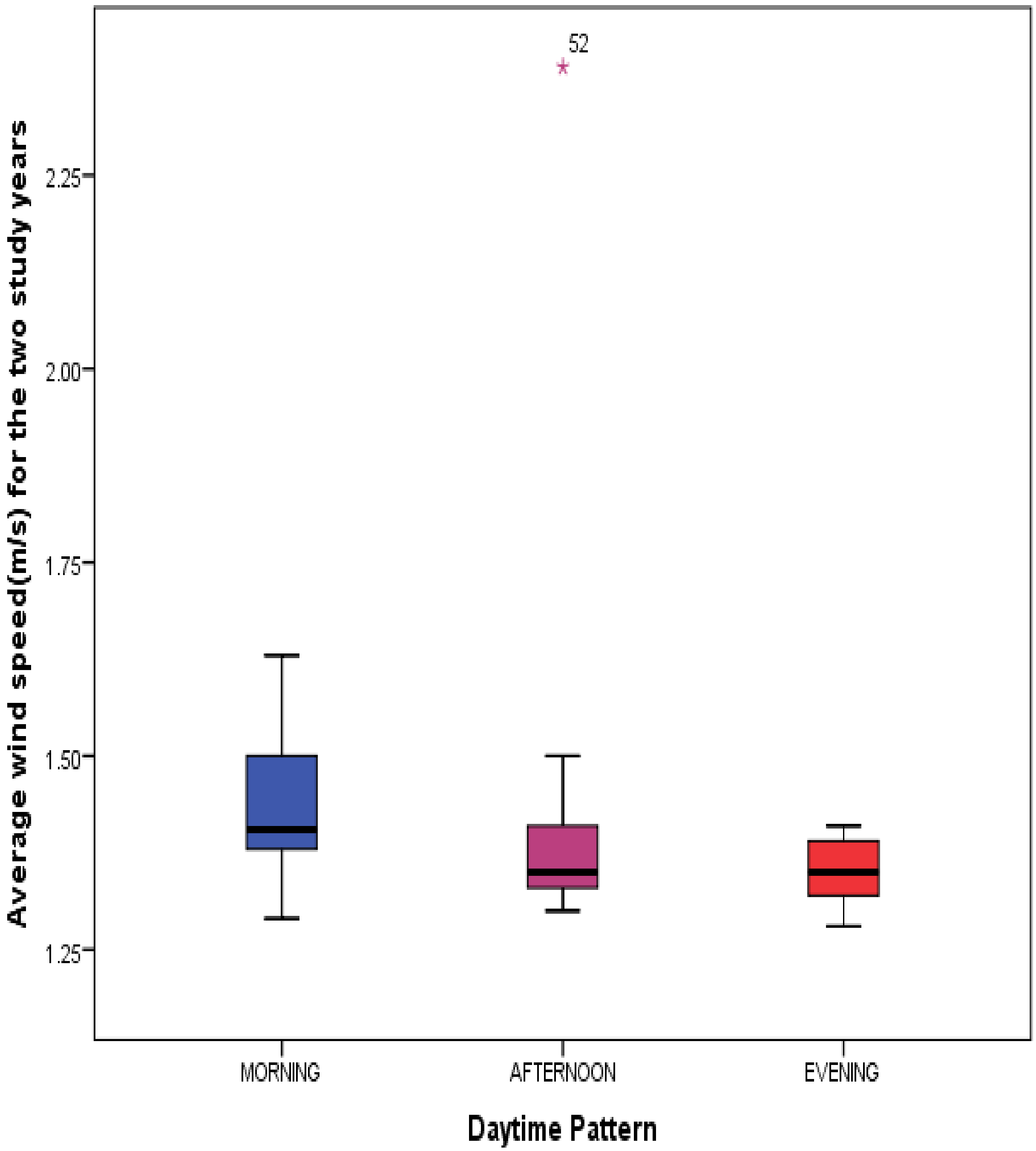

Figure 7: Average wind speed within the daytime pattern between 2016 and 2017 in Port Harcourt, Nigeria

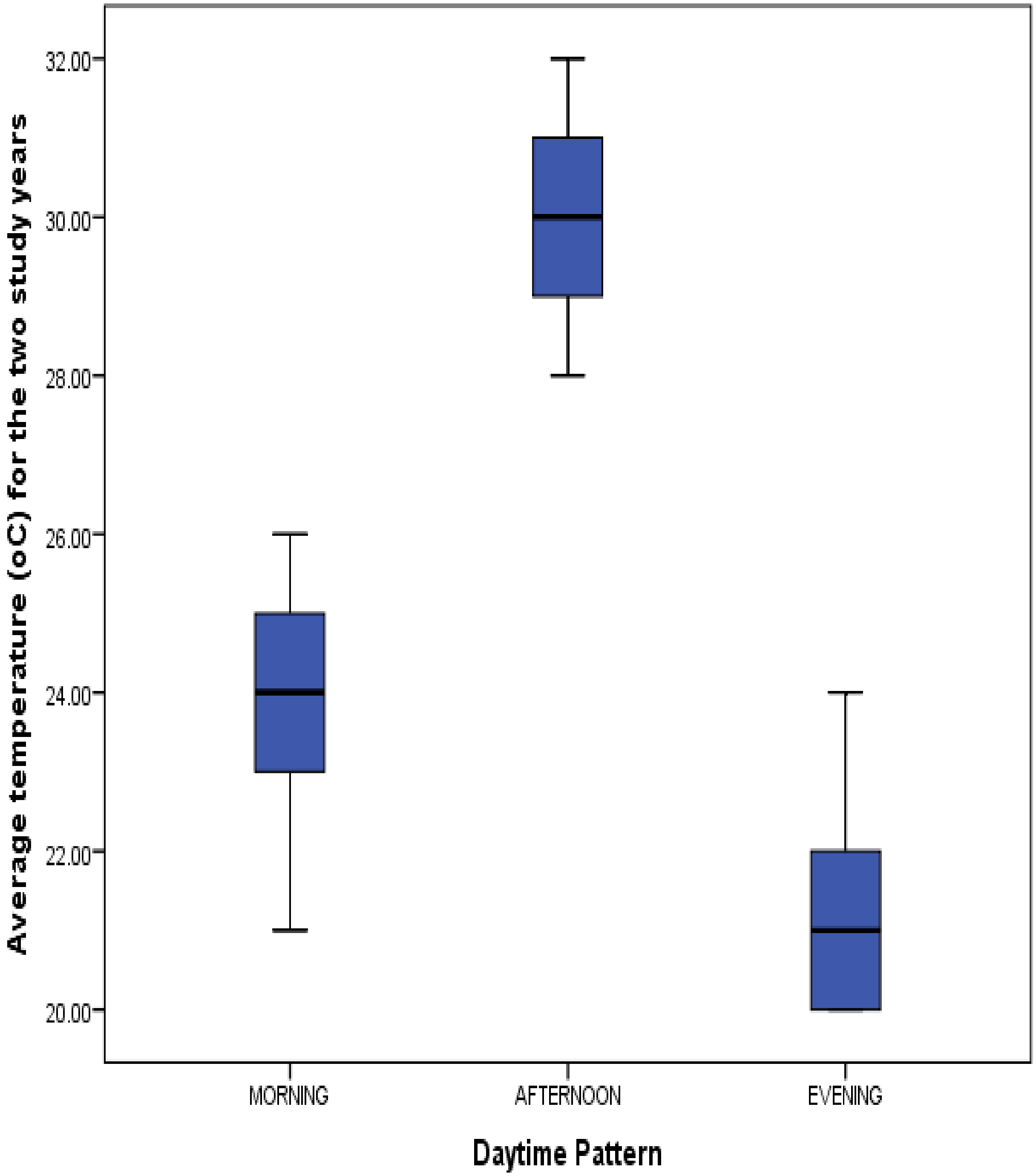

Figure 8: Average temperature within the daytime pattern between 2016 and 2017 in Port Harcourt, Nigeria

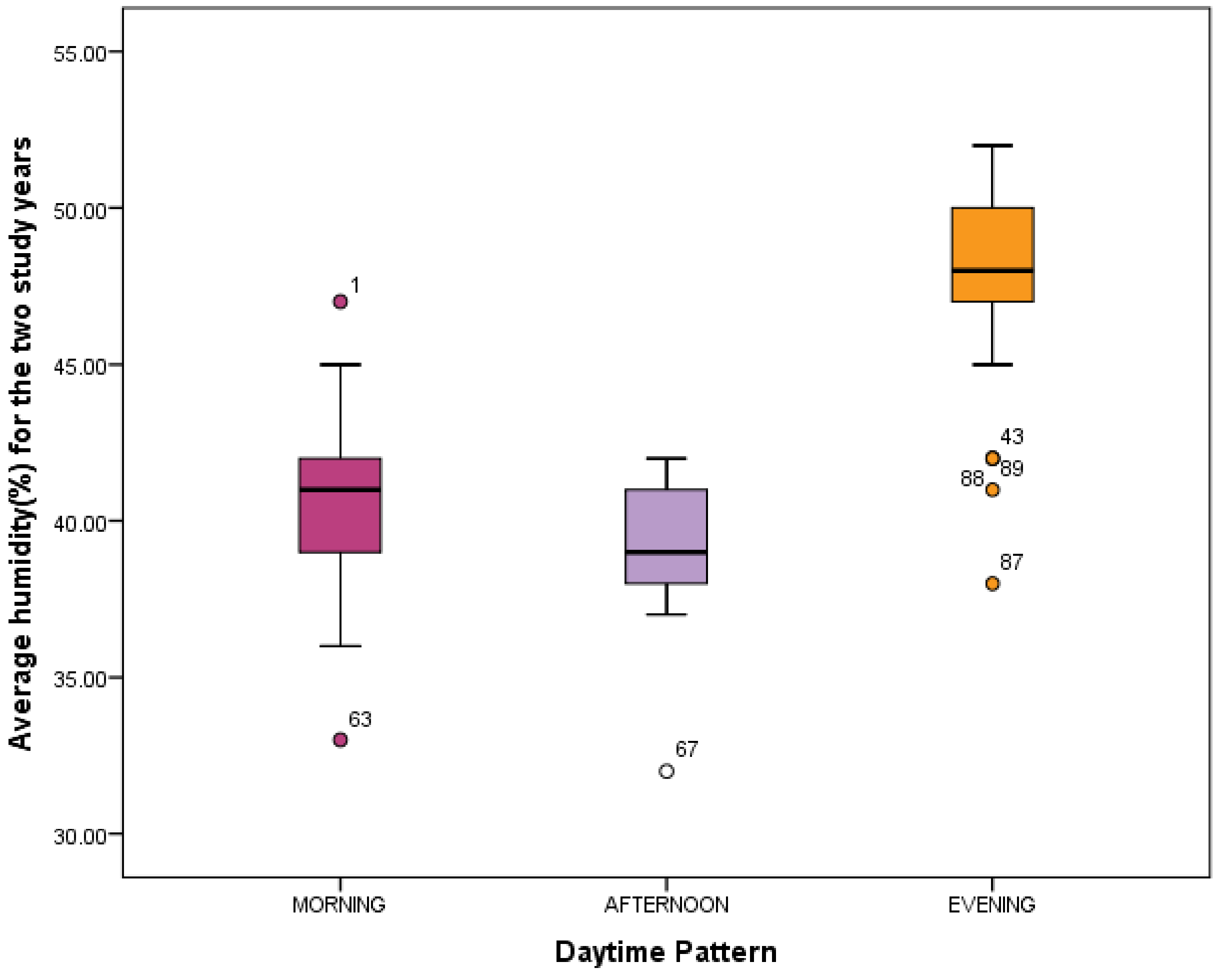

Figure 9: Average humidity within the daytime pattern between 2016 and 2017 in Port Harcourt, Nigeria

Seasonal variation of metrological variables

Figures 7, 8 and 9, showed the variation of wind speed, temperature and humidity within the daytime in 2016 and 2017. The average wind speed was strongest in the morning (1.43±0.08m/s)and weakest in the evening peak (1.35±0.05m/s) across the two study years. The overall mean variation of temperature was highest in afternoon peak (30.13±1.36^{o}C) and lowest in the evening peak (21.23±1.19^{o}C). On the contrary, average humidity was highest in the evening peak (47.50±3.39%) and lowest in the afternoon peak (39.23±2.13%). The overall mean variation of wind speed, temperature and humidity were significantly ($P<0.05$) different within the daytime. Similarly, the average variations of all the metrological variables were significantly ($P<0.05$) different between the two study years. This accounts for the increase in concentration level of the air pollutants between the two study years in Port Harcourt city, Nigeria. Furthermore, the change

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in metrological variables can also be attributed to the black soot from burning of fossil fuel experienced in the city within the study years.

Table 3: Relationship between AT, WS, RH and TV on Mean Concentration of CO in the Study Areas

Dependent Variables (Y)	Independents Variables(X)	N	Mean ± SD	T-value	B	P-value	R^2
	Air Temp	1800	25.12±4.33	-41.545	-2.538	0.000	
CO	Wind Speed	1800	1.37±0.06	1.836	16.668	0.067	0.917
	Rel. Humidity	1800	39.20±4.10	-2.079	-0.116	0.038	
	Traffic Volume	1800	588.00±763.00	2.938	0.001	0.004	
Constant				5.440	71.991	0.000	

Table 3 presented the result of multiple regression analysis of air temperature (AT), wind speed (WS), relative humidity (RH) and traffic volume (TV) on the concentration of CO within the study areas of Port Harcourt, Nigeria. The concentration of CO increased with increasing wind speed and traffic volume. However, air temperature, relative humidity and traffic volume were significantly ($P<0.05$) predictive of CO. The coefficient of determination ($R^2 = 0.917$) revealed that 91.7% variation in concentration of CO can be explained by air temperature, wind speed, relative humidity and traffic volume.
Predicted Equation for CO is stated below;
CO = 71.991 -2.538AT+ 16.668WS -0.116RH + 0.001TV………… (i)

Table 4: Relationship between AT, WS, RH and TV on Mean Concentration of $PM_{2.5}$ in the Study Areas

Dependent Variables (Y)	Independents Variables(X)	N	Mean ± SD	T-value	B	P-value	R^2
	Air Temp	1800	25.12±4.33	-30.528	-15.754	0.000	
$PM_{2.5}$	Wind Speed	1800	1.37±0.06	2.596	199.123	0.010	0.868
	Rel. Humidity	1800	39.20±4.10	0.841	0.398	0.401	
	Traffic Volume	1800	588.00±763.00	1.485	0.003	0.138	
Constant				2.999	335.222	0.003	

Table 4 presented the result of multiple regression analysis of air temperature (AT), wind speed (WS), relative humidity (RH) and traffic volume (TV) on concentration of $PM_{2.5}$ within the study

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areas of Port Harcourt, Nigeria. The concentration of $PM_{2.5}$ increased with increasing wind speed, relative humidity and traffic volume. Furthermore, air temperature and wind speed were significantly ($P<0.05$) related to $PM_{2.5}$. The coefficient of determination ($R^2 = 0.868$) revealed that 86.8% change in concentration of $PM_{2.5}$ can be explained by air temperature, wind speed, relative humidity and traffic volume.
Predicted Equation for $PM_{2.5}$ is stated below;

$PM_{2.5} = 335.222 - 15.754AT + 199.123WS + 0.398RH + 0.003TV$………… (ii)

Air Pollutants Model Validation

Plot of Predicted CO Concentration and Measured CO Concentration Level in Port Harcourt, Nigeria

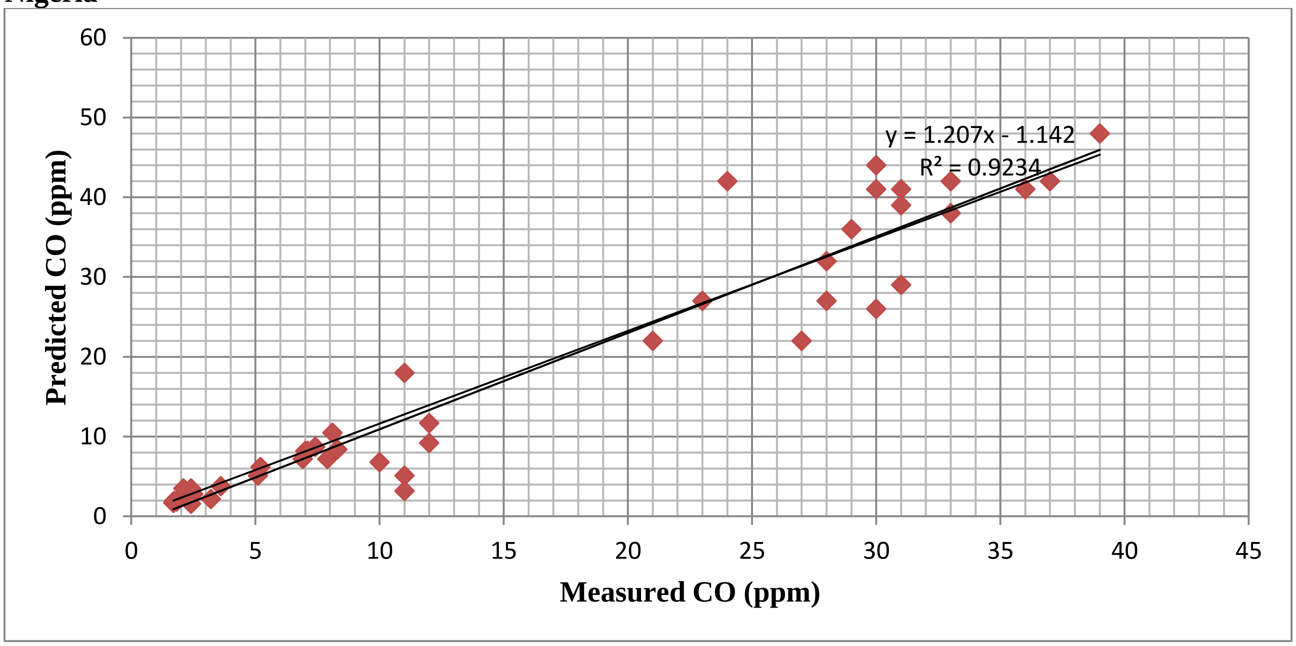

Fig 10: Linear Graph with R^2 = 0.92 on Predicted and Measured values

Plot of Predicted $PM_{2.5}$ Concentration and Measured $PM_{2.5}$ Concentration Level in Port Harcourt, Nigeria

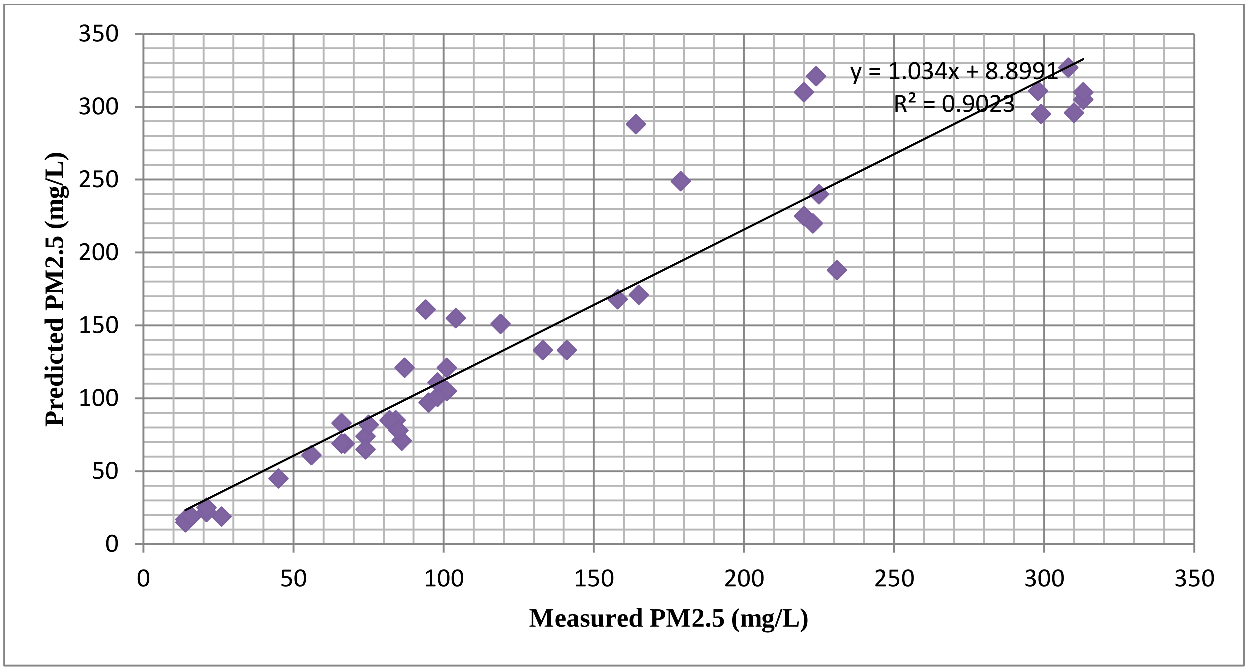

Fig 11: Linear Graph with R^2 = 0.90 on Predicted and Measured values

From the graphs in fig 7 and 8, linear equation has high coefficient of determination (R^2 = 0.92 and 0.90). This revealed that linear regression equation model is good in predicting concentration of CO and $PM_{2.5}$ respectively at high traffic density areas of Port Harcourt, Nigeria. Also, over 92% and 90% concentrations of CO and $PM_{2.5}$ predicted values can be explained by the concentration of CO and $PM_{2.5}$ measured values respectively. This implies that the calibrated equation for predicting air pollutants concentration level at high traffic density areas in Port Harcourt, Nigeria is valid, with a very high predictive power.

DISCUSSION/CONTRIBUTIONS TO KNOWLEDGE

The outcome of the study agrees with Grzegorz Piotr, Artur and Andrzej [12] who made an attempt to estimate the influence of the prevailing meteorological conditions on PM_{10} emission and also to determine those parameter groups that enable the best description of monthly and seasonal variability in particulate matter in Warszawa. Their study concluded that air quality in Warszawa agglomeration is poor and the main cause of high PM concentration was vehicular traffic emission due to ever-increasing number of cars in the city. Similarly, Luo Ip, Li, Tao and Li [13]; Yong and Wulin [14] Ucheje and Ikebude [15] reported the effect of vehicular volume and meteorological factors on the concentration of CO and other particulate matters in major cities. Findings indicated that a significant relationship exist between the concentration of pollutants and traffic volume. The following contributions were made by the researchers;

1. The outcome of this study has revealed an increasing level of air pollution in the study area, by demonstrating that high traffic density areas are problem.
2. The study also showed that vehicular emissions constitute important source of air pollution in the area.
3. This study has formed a baseline for pollutant concentration modeling in high traffic density areas for more than one season which have not really been well investigated in Nigeria, especially populated cities like Port Harcourt.

CONCLUSION

This paper modeled air pollutants concentration level in a high traffic density areas of Port Harcourt, Nigeria. In other for the researchers to fully develop a trend for the CO and $PM_{2.5}$ concentration level, two seasons were (24months) investigated. It was revealed that metrological variables and traffic volume affects air pollutants concentration in the study areas. Also, significant relationship exists between the daytime pattern in vehicular volume and air pollutants concentration in the study area. Furthermore, there was an increase in concentration of average air pollutants across the areas monitored between 2016 and 2017. The variation was attributed to increase in vehicular traffic volume.

Concentration of air pollutants varied at different degrees of temperature, humidity and wind speed. Therefore, there was difference in the overall mean for wind speed, temperature and humidity in both 2016 and 2017 respectively. A baseline model was developed, which revealed the multiple regression equation that can be used in predicting the concentration of CO and $PM_{2.5}$ at various metrological variables and vehicular volume in similar cities in Nigeria.

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