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Influence of Vehicle Traffic Emissions on Spatial Variation of Ozone and its Precursors in Air of Port Harcourt City, Nigeria

***[1]OKON, IE; [2]OMONIYI, KI; [2]PAUL, ED; [2]EKWUMEMGBO, PA**

**[1]Nigerian Institute of Transport Technology (NITT), Zaria, Kaduna State, Nigeria*
[2]Department of Chemistry, Ahmadu Bello University, Zaria
**Corresponding Author Email: idokon22@yahoo.com; Tel: 08032606180*

ABSTRACT: This study aimed at assessing the influence of vehicle traffic on spatial variation of ozone (O_3) and its vehicular emission precursors in the air of Port Harcourt city. Sampling was carried out in ten (10) sites, eight (8) located within the high traffic density area (study sites) and two (2) located within the very low traffic density area (reference sites). The precursor pollutants measured were nitrogen dioxide (NO_2), carbon monoxide (CO) and volatile organic compounds (VOCSs). Ozone and the precursor pollutants were measured *in situ* using AeroQUAL 500 series portable ambient air analyzer while traffic flow survey was achieved by direct counting. Measurements were carried out at morning, evening and off-peak traffic periods respectively. The mean concentrations of ozone and the precursor pollutants were significantly higher ($p = 0.05$) in the study sites than in the reference sites. Mean concentrations were higher at peak traffic periods than at off-peak traffic periods except for ozone that was higher at off-peak than at morning peak. There was significant correlation between traffic density and each of the pollutants including ozone. The spatial variability in concentration of pollutants was influenced by vehicular traffic. VOCs and NO_2 levels were higher than the National Ambient Air Quality Standard (NAAQS) limit of 0.05 ppm and 0.04 – 0.06 ppm respectively, O_3 concentration was below the standard limit (0.06 ppm) but was at the verge of exceeding. Traffic emission within the city was significant and could be mitigated through regular monitoring and control.

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Transport plays significant role in modern economic development as it creates time and place utility. Transportation expands overall accessibility in terms of business, education, employment and services (Emenike and Orjinmo, 2017). Road transport is a vital part of modern life; it provides opportunity to travel for personal development and professional activities and the economic development of the various regions of the world is facilitated by contemporary transport technology (Oderinde *et al*., 2016). This positive side of transport is not without problems, as it has led to environmental crisis in terms of air pollution and congestion (Oderinde *et al*., 2016). Good number of traffic-related studies has revealed that high traffic flow particularly in urban areas, contributes to more traffic emissions than low traffic flow (Nazatul *et al*., 2014). In the United State of America, motor vehicles were found to be responsible for nearly one half of smog-forming volatile organic compounds (VOCs), more than half of the nitrogen dioxide (NO_2) emissions, and about 75 percent of carbon monoxide (CO) emissions nationwide (USEPA, 2014 as sited in Emenike and Orjinmo, 2017). In general, there is traffic-related pollution or the tendency of it occurring in many parts of the world but more pronounced in developing countries, which experience higher levels of traffic-related pollution compared to developed countries because of inadequate pollution control measures or lack of it. There is an increase in vehicle ownership in Nigeria and this scenario has led to increase in traffic-related air pollution in Nigerian cities (Atubi, 2015). Port Harcourt city in particular is not left out from this current trend of road vehicle increase (Ucheje and Chidozie, 2015). This had led to traffic congestion especially at intersections and in turn increases combustion of fuel by vehicles engines, creating impact on air environment as a result of heavy emissions from these road vehicles (Zagha and Nwaogazie, 2015). Despite the rapid increase in traffic-related pollution in Nigeria, little attention has been given to the pollution damage caused by auto-mobile transportation as evidenced in the very little number of research carried out on transport related pollution in Nigeria (Atubi, 2015). A survey by Okonkwo *et al*. (2014) on traffic flow in Port Harcourt revealed that there is always heavy traffic congestion in morning and evening hours at some junctions as

Port-Harcourt is a fast growing city in terms of human population and commercial activities. Consequently, effects of emissions from this vehicular traffic have become a source of concern. From the studies on traffic-related pollution, only few like Emenike and Orjinmo (2017) relate traffic density to concentration of ozone and primary pollutants in the ambient air of Port Harcourt city. Ground level ozone (O_3) is one of the most harmful air pollutants (Marais *et al*., 2014), it is not directly emitted into the air by vehicle combustion processes but formed photochemically from the oxidation of volatile organic compounds in the presence of nitrogen oxides and other pollutants including carbon monoxide in the atmosphere (Sharma *et al*., 2017). In a simplified form, tropospheric ozone (O_3) formation processes from vehicular emission precursors (NO_2, CO and VOCs) are as follows:

Photolysis of NO_2

$$NO_2 \xrightarrow{\text{uv (400–430 nm)}} O + NO \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$
$$O + O_2 \rightarrow O_3 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2$$

Oxidation of CO

$$CO + OH^{\cdot} \rightarrow CO_2 + H \quad \ldots\ldots\ldots\ldots\ldots 3$$
$$H + O_2 \rightarrow HO_2^{\cdot} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 4$$
$$HO_2^{\cdot} + NO \rightarrow OH^{\cdot} + NO_2 \quad \ldots\ldots\ldots\ldots\ldots 5$$
$$NO_2 \xrightarrow{\text{uv (400–430 nm)}} O + NO \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 6$$
$$O + O_2 \rightarrow O_3 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 7$$
$$\text{Net: } CO + 2O_2 \rightarrow CO_2 + O_3 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 8$$

Oxidation of VOCs (RH)

$$RH + OH^{\cdot} \rightarrow R^{\cdot} + H_2O \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 9$$
$$R^{\cdot} + O_2 \rightarrow RO_2^{\cdot} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 10$$
$$RO_2^{\cdot} + NO \rightarrow NO_2 + RO^{\cdot} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 11$$
$$RO^{\cdot} + 0 \rightarrow RCHO + HO_2^{\cdot} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 12$$
$$HO_2^{\cdot} + NO \rightarrow OH^{\cdot} + NO_2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 13$$
$$\text{Net: } RH + 2O_2 + 2NO \rightarrow RCHO + H_2O + 2NO_2 \quad \ldots\ldots 14$$
$$NO_2 + O_2 \xrightarrow{UV} NO + O_3 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 15$$
$$\text{Yield: } RH + 2O_2 + uv \xrightarrow{NOx,\ OH^{\cdot}} RCHO + H_2O + 2O_3 \quad 16$$

(William, 1994; Warmiński and Bęś, 2018)

The precursors too are also harmful to health at high exposure as CO causes blood poisoning by forming carboxyheamoglobin (Jason *et al*., 2017; Olusola *et al*., 2018). NO_2 causes respiratory irritation and cardiovascular related mortality **(**Faustini *et al*., 2014). Furthermore, some VOCs are carcinogenic for humans (Wen-Tien, 2016). The objective of this study is to assess the influence of vehicle traffic emissions on spatial variation of ozone and its vehicular emission precursors (NO_2, CO and VOCs) in the air of Port Harcourt city, Nigeria

MATERIALS AND METHODS

Study Area: This study was conducted in Port Harcourt city, Rivers State, Nigeria which is located within latitudes 4º 44’ 58.8’’N ; 4º 56’ 4.6’’N and longitudes 6º 52’ 7.2’’E ; 7º 7’ 37.7’’E, the city experiences a tropical humid climate with lengthy and heavy rainy seasons and very short dry seasons (Emenike and Orjinmo, 2017). Port Harcourt is found in the coastal belt which is dominated by low lying coastal plains, which structurally belong to the sedimentary formations of Niger Delta, it covers an estimated area of 1811.6 square kilometer, slightly elevated though no significant structural control on the evolution of the drainage network (Chiadikobi *et al*., 2011). The city is the nucleus of administrative, commercial industrial, educational and other economic activities in the state and is commonly referred to as the treasure base of the nation.

Reconnaissance survey was conducted to be acquainted with the study area, from the survey, ten (10) traffic junctions were chosen as sampling sites considering hotspots, intersections and vehicular traffic levels, eight (8) of them located within the high traffic density area (study sites) while two (2) located within the very low traffic density area (reference sites). The eight (8) study sites in the busy area were all located along three important corridors in the city: Port Harcourt- Aba Express Road, East-West Road and the Ikwerre Road. These three major roads were chosen because of the high traffic flow resulting from them being main connectors to many feeder roads that link to almost every part of the city (Kio-Lawson and

Dekor, 2014). The study site junctions were Water Lines (site 1) , Air Force (site 2) and Rumukwurushi (site 3) along Port Harcourt- Aba Express Road; Eliogbolo (site 4), Rumuokoro (site 5) and Nkpolu (site 6) along East-West Road; Rumukwuta (site 7) and Rumuola (site 8) along Ikwerre Road. The reference sites junctions were Odi (site 9) and Opukuma (site 10) along Force Avenue.

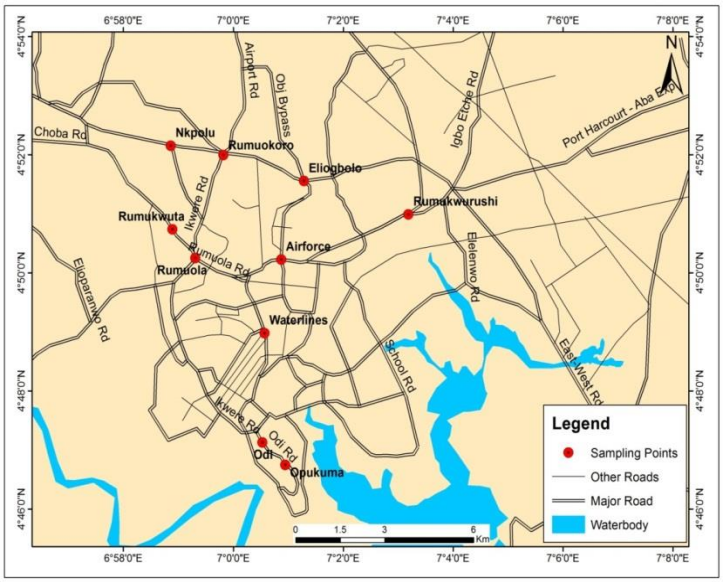

Fig 1: Map of Port Harcourt showing Sampling Sites

Data Collection and Analysis: Data on sampling points, concentration of O_3 and the precursor pollutants (NO_2, CO and VOCs), and traffic flow survey were collected between December 2017 and November 2018. AeroQUAL 500 series (Aeroqual, New Zealand) portable ambient air analyzer with different sensors for individual gases was used for *in situ* measurement of O_3 and the precursor pollutants (NO_2, CO and VOCs). Measurements were conducted with preference to favourable positions considering wind direction.

Traffic flow survey was achieved through collection of traffic density data at each of the sampling sites by direct counting. The time blocks chosen for measurement covered expected periods of high and low traffic (Utang and Peterside, 2011; Emenike and Orjinmo, 2017). The high traffic peaks were the "rush hours" of 7:00 – 9:00 am and 4:00 – 6:00 pm, which served as morning and evening peak traffic periods respectively. The expected periods of low traffic (12:00 - 2:00 pm) served as off-peak traffic period.

Statistical Data Analysis: Data were presented in Tables and graphs and further analysis was based on descriptive and inferential statistics. The descriptive statistics included mean and dispersion while the inferential statistics used included Student's T test and simple regression analysis. Data collection was carried out in triplicate for each of the parameters, which the mean served as the observed value.

RESULTS AND DISCUSSION

Air Pollutants: Figures 2, 3, 4 and 5 present the mean concentration of NO_2, CO, VOCs and O_3 respectively at each of the sampling site. Maximal mean concentration for NO_2 (0.079 ± 0.007 ppm), for CO (15.862 ± 0.55 ppm), for VOCs (1.813 ± 0.113ppm) and for O_3 (0.053 ± 0.008 ppm) was observed at sites 5, 2,1 and 5 respectively during evening peak as adjudged from results in Figures 2 – 5. The maximal concentrations recorded at these sites during evening traffic period are not unconnected with the fact that evening hours coincides with more traffic congestion coupled with residual accumulation from other periods as was also established by Ucheje and Chiedozie (2015). Moreover, these sites are adjoined to more commercial and major intersections between the major roads making vehicles sometimes to be at "idle speed" because of the slow pace of traffic at which condition they tend to emit more pollutants. Minimal mean concentration for NO_2 (0.034 ± 0.003 ppm) was observed at sites 9 and 10; for CO (7.261 ± 0.499 ppm) at site 10; for VOCs (0.749 ± 0 0.022 ppm) at site 9 and 10; for O_3 (0.033 ± 0.002) at site 9. The minimal concentrations were all observed at off-peak except for ozone that was at morning peak. The minimal concentrations at sites 9 and 10 (reference sites) could result from them being located in the less busy area and do not have direct link to any of the arterial roads hence, having very low traffic flow with lesser volume of vehicular emissions. The mean concentration of CO was far higher than that of NO_2, VOCs, and O_3 across

periods; this could come from vehicle engines emitting more CO than the other pollutants. The highest level observed for CO among other pollutants agrees with a documented report by Ucheje and Chiedozie (2015) and Etim (2016). Concentrations of the pollutants were higher at peak traffic period than at off-peak traffic period except for O_3 as presented in Figures 2 – 5, this could be explained by higher number of vehicle at traffic peak period. Concentrations for O_3 were higher at off-peak traffic period (afternoon) than at morning peak despite higher volume of precursor pollutants resulting from heavy traffic at morning as the concentration range ($0.034 \pm 0.002 – 0.051 \pm 0.008$ ppm) for off-peak was higher than the range ($0.033 \pm 0.002 – 0.048 \pm 0.007$ ppm) for morning peak as presented in Figure 5. This occurrence of lower amount of precursors giving rise to higher concentration of O_3 at off-peak could be triggered by higher temperature as photochemical reactions needed for O_3 formation occurs more at higher temperature (Melkonyan and Wagner, 2013).

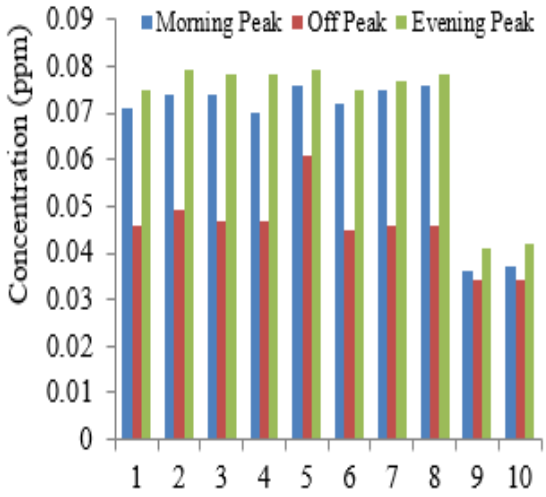

Fig 2: Mean Concentration of NO_2 across Sites

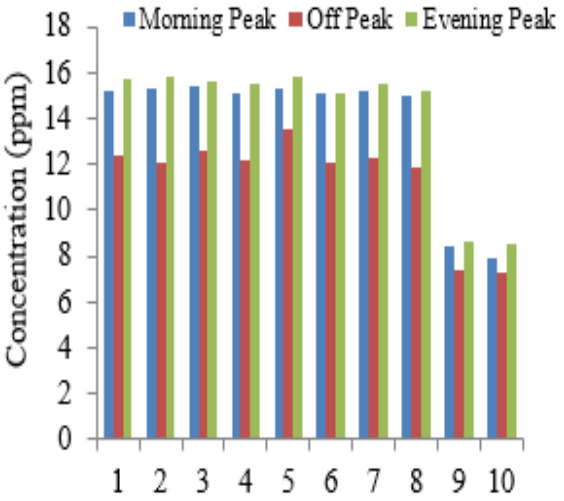

Fig 3: Mean Concentration of CO across Sites

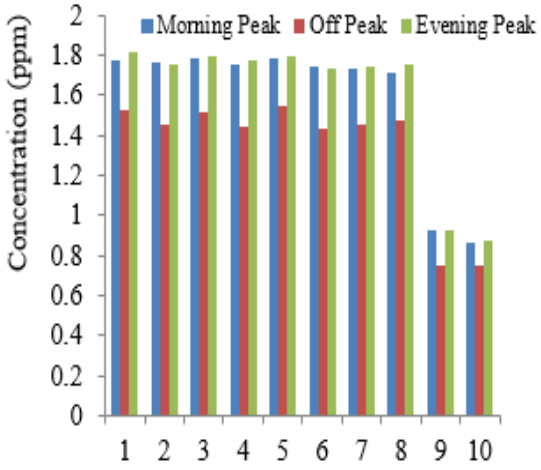

Fig 4: Mean Concentration of VOCs across Sites

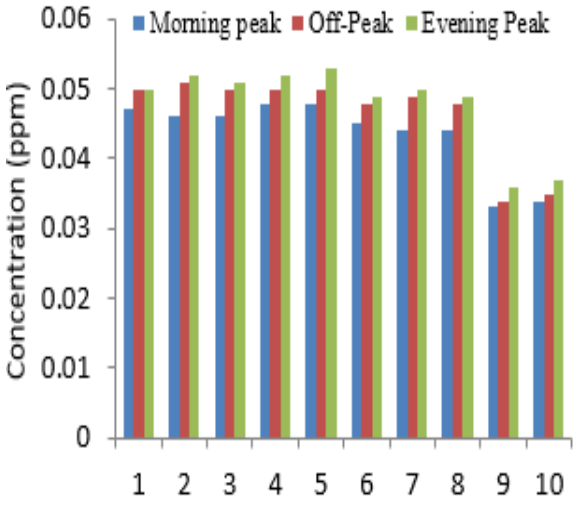

Fig 5: Mean Concentration of O_3 across Sites

Traffic Density: Figure 6 shows the mean spatial variation of traffic flow across traffic periods in vehicles per hour (v/h). Maximum value for traffic density (1434 ± 148 v/h) was observed at site 3 during evening peak while the lowest density (365 ± 87 v/h) was observed at site 10 during off-peak.

The range across study sites for morning peak, off-peak and evening peak were1167 ± 220 – 1363 ± 273 v/h, 778 ± 115 – 1042 ± 98 v/h and 1241 ± 248 – 1434 ± 148 v/h.

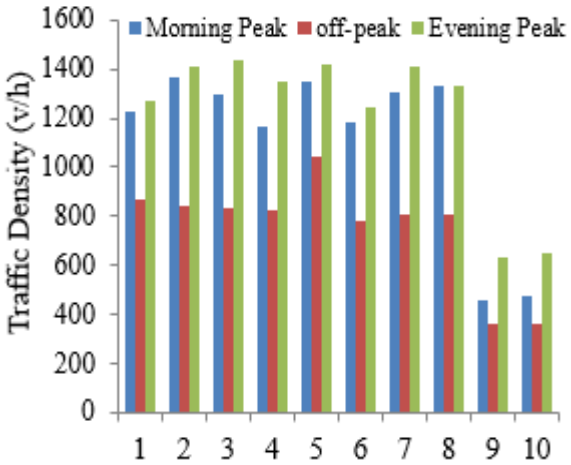

Fig 6: Average Traffic Density across Sites

These were higher than the range 458 ± 124 – 479 ± 116 v/h, 364 ± 92 –365 ± 87 v/h and 629 ± 134 – 647 ± 70 v/h across the reference sites. The traffic density was in the order: evening peak > morning peak >> off-peak. The maximal traffic density observed during evening peak traffic period could be attributed to the smaller travel time (rush) during evening which leads to higher density of vehicles.

Influence of Vehicle Traffic on Concentration of Pollutants: Student's T-test was employed to compare the level of parameters across study sites to those of reference sites as shown in Table 1.

Traffic levels and concentrations for each of the pollutants in the study sites were significantly higher than in the reference sites across periods (p = 0.05). This higher concentration of air pollutants in the study sites could be as a result of high traffic volume, this agrees with the report of Ucheje and Chiedozie (2015) and Nazatul *et al*. (2014) where it was established that high traffic density contributes to more emissions than low traffic density. Table 2 present simple regression analyses for relationship between each of the pollutants and traffic density (p = 0.05), the coefficient of determination (R^2) ranged from 0.875 to 0.995 across traffic periods. The high positive coefficient for all the pollutants signifies similarities of the emissions source and that the quantity of emissions generated by this source could influence the concentration of these pollutants in the air (Sharma *et al*., 2009).

Table 1: T-Test Values at p=0.05 for comparing Mean Parameters in the Study Sites with those of the Reference Sites (two-tail)

Parameters	Morning Peak		Off Peak		Evening Peak	
	T Calculated	*T Critical*	*T Calculated*	*T Critical*	*T Calculated*	*T Critical*
NO_2	23.660	2.200	8.770	2.200	20.520	2.200
CO	43.580	,,	47.790	,,	40.950	,,
VOCs	87.900	,,	32.840	,,	30.300	,,
Traffic Density	28.510	,,	30.710	,,	21.820	,,

This high correlation between each of the pollutants and traffic density was validated using F test; the significance F for each of the pollutants was far less than the 0.05 significance level (very close to zero), implying that the correlation between each of the pollutants and traffic density was not from an off-chance situation. This affirms that increase in traffic density could increase the volume of vehicular emissions, hence, higher concentrations of pollutants (Okonkwo *et al*., 2014). The high correlation between each of the pollutants and traffic density has revealed that traffic density had actually influenced the variability of these pollutants in the city of Port Harcourt.

Implication of Pollutants Concentration on Air Quality Standard: The impact of the pollutants concentration on air quality was assessed by comparing the concentrations observed for each of the pollutants with the Nigerian Ambient Air Quality Standard (NAAQS) limits. The mean ranges of concentration (in ppm) for NO_2 across study sites: 0.070 ± 0.009 – 0.076 ± 0.007, 0.045 ± 0.003 – 0.061 ± 0.009 and 0.075 ± 0.009 – 0.079 ± 0.008 at morning peak, off-peak and evening peak respectively were higher than the NAAQS limit range of 0.04 – 0.06 ppm.

For CO, the mean ranges of concentration (in ppm) across study sites: 14.972 ± 0.586 – 15.374 ± 0.670, 11.902 ± 0.530 – 13.492 ± 0.986 and 15.144 ± 0.615 – 15.862 ± 0.550 at morning peak, off-peak and evening peak respectively were within the NAAQS limit range of 10 – 20 ppm.

Table 2: Correlation Coefficients of Air Quality Parameters and Traffic Density

Morning Peak Traffic Period				
Coefficients	NO_2	CO	VOCs	O_3
R	0.995	0.982	0.979	0.936
R^2	0.990	0.963	0.959	0.875
F	802	211	187	56.187
Sig. F	0.000	0.000	0.000	0.000
Off- Peak Traffic Period (Afternoon)				
	NO_2	CO	VOCs	O_3
R	0.943	0.986	0.968	0.954
R^2	0.889	0.972	0.938	0.910
F	64	282	121	80.664
Sig. F	0.000	0.000	0.000	0.000
Evening Peak Traffic Period				
	NO_2	CO	VOCs	O_3
R	0.991	0.986	0.978	0.984
R^2	0.981	0.972	0.957	0.968
F	417	282	177	241
Sig. F	0.000	0.000	0.000	0.000

For VOCs, the mean ranges of concentration (in ppm) across study sites: 1.711 ± 0.061 – 1.786 ± 0.072, 1.438 ± 0.098 – 1.552 ± 0.134 and 1.729 ± 0.123 – 1.813 ± 0.113 at morning peak, off-peak and evening peak respectively were higher than the NAAQS limit of 0.05 ppm. For O_3, the concentration in ppm across study sites varies between 0.044 ± 0.005 – 0.048 ± 0.007, 0.048 ± 0.005 – 0.051 ± 0.008, 0.049 ± 0.006 – 0.053 ± 0.008 at morning peak, off-peak and evening peak respectively, showing that O_3 concentrations were below the 0.060 ppm NAAQS limit. This result reveals that there was pollution from NO_2 and VOCs as their range of concentrations were higher than the NAAQS limit. There was no pollution from CO and O_3, however, the city was not very safe from ozone pollution as the maximal concentrations (ppm) of 0.051 and 0.053 at off-peak and evening peak respectively were at the verge of pollution.

Conclusion: From results obtained, mean concentration of O_3 and each of the precursor pollutants was higher at peak traffic period than at off-peak. Maximal concentrations were observed at evening peak, followed by morning peak and then off-peak with exemption of O_3 that was higher at off-peak than at morning peak. Concentrations were significantly higher in the study sites than reference sites. Variability in concentration of O_3 and the precursors was influenced by vehicular traffic. NO_2 and VOCs level were above standard limits while CO and O_3 were within limit.

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