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SEASONAL VARIATIONS OF TRAFFIC-RELATED OZONE AND ITS PRECURSORS IN PORT HARCOURT, NIGERIA

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ABSTRACT

This study assessed seasonal variations in concentration of traffic-related ozone (O_3) and its precursors (NO_2, CO and VOCs) in the air of Port Harcourt, Nigeria. Measurements of pollutants were carried out *in situ* at ten different sites across the high and low vehicular traffic areas of the city using hand-held ambient air analyzer from December 2017 to November 2018. Traffic flow survey was achieved by direct counting. Measurements were taken at morning, evening and afternoon traffic period. Concentrations (ppm) ranges for dry season were 0.055 – 0.088, 12.748 – 16.381, 1.608 – 1.900 and 0.054 – 0.060 for NO_2, CO, VOC and O_3 respectively. For rainy season, ranges of concentrations (ppm) were 0.046 – 0.074, 12.114 – 15.265, 1.390 – 1.723 and 0.043 – 0.049 for NO_2, CO, VOC and O_3 respectively. Levels of parameters across study sites were higher than across Control sites and were higher for dry season compared to rainy season. In comparison to National Ambient Air Quality Standard (NAAQS), there was pollution from NO_2 and VOCs. Levels of O_3 and CO were within the NAAQS limit but O_3 maximum level (0.060 ppm) during dry season was at the verge of causing pollution. Vehicular emissions monitoring and control should be enforced to reduce pollution.

Keywords: Ozone**,** vehicular traffic, vehicular emissions, precursor pollutants, seasonal variation.

INTRODUCTION

Traffic-related ozone (O_3) is associated with vehicular emissions and volume of these emissions varies with vehicular traffic flow [1]. Vehicular traffic is one of the main sources of air pollution in urban environments [2, 3]. In 2017, about 25% of greenhouse gases (GHGs) emission emanated from transport sector in Europe [4] as cited by Riccardo *et al*. [5]. Also, in 2020, 28%

of GHGs from anthropogenic sources came from transport of which about 72% came from road transport alone in United States of America [6]. With this high amount of GHGs coming from transport activities, there is no doubt, that transport is a major contributor to climate change and needed to be checked by proper monitoring and control of its emissions.

Tropospheric ozone is a key air pollutant and greenhouse gas. Its variations influence climate and can lead to climate change through altering radiation and atmosphere-biosphere interactions [7]. Ground level ozone is a harmful air pollutant, which can cause various health problems and damage to man, animals and plants [1, 8 - 11]. The precursors are also dangerous to living organisms [12 – 14]. According to Hesham [15] and Wałaszek *et al*. [16], the precursor pollutants from vehicular emissions for ozone formation include nitrogen dioxide (NO_2), carbon monoxide (CO) and volatile organic compounds (VOCs).

High volume of vehicular traffic in urban cities has increased the concentration of these precursor pollutants in the air of many cities including Port Harcourt, and these pollutants can vary in time and space [1, 17]. Ozone is not emitted directly into the atmosphere by vehicle engine combustion processes, but formed through photochemical processes involving primary vehicular emission pollutants (NO_2, CO and VOCs). These photochemical processes involving the precursor pollutants are more important sources of O_3 in ground-level ambient air [18]. Equations 1 – 4 present simple formation processes for ground level ozone from vehicular emission precursors [19 – 21].

Photolysis of NO_2

$$NO_2 + \text{uv radiation}\ (400 - 430\ \text{nm}) \rightarrow O + NO \quad \ldots\ldots\ldots\ldots \quad 1$$

$$O + O_2 \rightarrow O_3 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 2$$

Oxidation of CO

$$CO + 2O_2 \xrightarrow{NO_x,\ OH^{\cdot},\ uv\ (400-430\ nm)} CO_2 + O_3 \ldots\ldots\ldots\ldots\ldots \quad 3$$

Oxidation of VOCs (e.g. C_2H_6):

$$C_2H_6 + 4O_2 \xrightarrow{NO_x,\ OH^{\cdot},\ uv\ (400-430\ nm)} CH_3CHO + H_2O + 2O_3 \quad \ldots 4$$

Seasonal variations follow changes in meteorological conditions and the degree of air pollution in a particular geographical area tends to vary widely with meteorological variations [22]. Hence, the degree of variation of ozone and its precursors tends to vary commonly with seasonal variations. The understanding of seasonal conditions in an area is necessary for proper

monitoring as well as implementing suitable control measures for air pollutants [23]. Seasonality plays a key role in determining the levels of pollutants in the lower atmosphere [24]. Therefore, the objective of this study is to assess the seasonal variation of traffic-related ozone and its precursors (NO_2, CO and VOCs) in the city of Port Harcourt, Nigeria.

MATERIALS AND METHODS

Study Area

Port Harcourt city is the capital of Rivers State, found on the coastal region of southern part of Nigeria. The city is located in latitudes, between 4º44' 58.8''N and 4º56' 4.6''N; and longitudes, between 6º52' 7.2''E and 7º7' 37.7''E [25-26]. Port Harcourt city falls within the tropical humid climate and has a lengthy and heavy rainy season and very short dry season [25 – 26]. As part of Niger Delta region of Nigeria, the city experiences two major seasons, the rainy season, which starts from February/March to November, and the dry season, which starts from December to January/February [27]. Three major corridors take traffic in and out of the city: Port Harcourt-Aba Express Road, East-West Road and the Ikwerre Road. These three corridors are main links to many feeder roads that connect almost every part of the city [28]. Economic activities in the city have resulted in the influx of people and a corresponding increase in vehicular traffic and emissions of pollutants [25]. This informed the choice of Port-Harcourt city for the study.

Ten (10) traffic junctions were chosen for data collection, eight (8) of them located along the three major corridors within the high vehicular traffic area of the city, while two (2) were located within the low vehicular traffic area. The eight (8) Junctions in the high traffic flow area served as study sites and they were: Water Lines, Air Force and Rumukwurushi along Port Harcourt- Aba Express Road; Eliogbolo, Rumuokoro and Nkpolu along East-West Road; Rumukwuta and Rumuola along Ikwerre Road. The remaining two (2) junctions in the low traffic flow area of the city served as Control sites, and they were: Odi and Opukuma in the old Government Reservation Area (GRA).

Table 1: Coordinates of Sampling Sites

S/N	Sampling Sites	Latitude	Longitude
1	Water Lines	4.816361	7.009470
2	Air Force	4.836382	7.016661
3	Rumukurushi	4.849853	7.053112
4	Eliogbolo	4.860062	7.018651
5	Rumuokoro	4.866571	6.996971
6	Nkpolu	4.869228	6.981012
7	Rumuokwuta	4.839500	6.987855
8	Rumuola	4.837511	6.988443
9	Odi	4.777868	7.011109
10	Opukuma	4.778004	7.015933

Data Collection and Analysis

Data were collected for dry season (DS) and rainy season (RS) to cater for seasonal variations. Data for concentrations of ozone and the precursor pollutants (NO_2, CO and VOCs), and vehicle traffic flow were collected between December 2017 and November 2018. The gaseous pollutants were measured *in situ* using AeroQUAL 500 series (Aeroqual, New Zealand) hand-held ambient air analyzer.

Measurements of pollutants were carried out at 1.5 metres above the ground at each of the sampling sites. The height of 1.5 metres was chosen because it represented the breathing zone of people [29 – 30]. Data for vehicle traffic flow were collected by tally sheet method (direct counting) and were presented as traffic density (TD) in vehicle per hour (v/h). Coordinates of the sampling sites as presented in Table 1, were captured with the use of GPS (Global Positioning System). Data collection covered high and low traffic peak periods. The rush hours of 7:00 – 9:00 am and 4:00 – 6:00 pm characterized by high volume of traffic served as peak traffic periods for morning peak (MP) and evening peak (EP) respectively, 12:00 - 2:00 pm having low traffic served as off-peak traffic period (OP).

The mean of the pollutants from all the study sites for a particular season was used to represent the seasonal data across the study sites while the mean of the pollutants in the two Control sites were also used to represent the seasonal data across the Control sites.

Statistical Data Analysis

Data were presented in Tables and graphs. Further analysis was achieved using descriptive and inferential statistics. The descriptive statistics used was mean while the inferential statistics was Student's T test.

RESULTS AND DISCUSSION

The results obtained from field assessment for seasonal variation in levels of parameters are presented in Figures 1 – 10. Figures 1 – 8 present variations in concentrations of air quality parameters (NO_2, CO, VOCs and O_3), while Figures 9 – 10 show variation in traffic densities. Tables 2 – 3 show the results of the T-test, which determined if there were significant differences in seasonal mean values of all parameters across study sites and across Control sites.

The seasonal variations in concentrations of the pollutants across the study sites were far higher than the concentrations across the Control sites as presented in Figures 1 – 8. This resulted from the fact that the maximal concentrations (ppm) of 0.088 for NO_2, 16.381 for CO, 1.900 for VOCs, and 0.060 for O_3 across study sites were higher than the 0.043 for NO_2, 8.808 for CO, 0.929 for VOCs and 0.040 for O_3 across the Control sites. This could be attributed to higher volume of vehicular traffic across the study sites compared to the Control sites as presented in Figures 9 – 10. The seasonal variation of parameters including the pollutants and vehicular traffic was in the order evening peak > morning peak >> off-peak (afternoon) except for O_3 where the seasonal average range (0.034 – 0.058 ppm) at off-peak was higher than the range (0.033 – 0.054 ppm) at morning peak. The higher concentration of O_3 at off-peak despite more availability of precursor pollutants at morning could result from higher temperature that favoured photochemical reactions that could yield more ozone in the afternoon [3, 31].

The data in Figures 1 – 10 show higher seasonal mean values for air quality parameters and vehicular traffic in the dry season compared to rainy season across study sites and Control sites. Across the study sites, dry season concentration ranges of 0.055 – 0.088 ppm, 12.748 – 16.381 ppm, 1.608 – 1.900 ppm and 0.054 – 0.060 ppm for NO_2, CO, VOC and O_3 respectively were higher than the range 0.046 – 0.074 ppm, 12.114 – 15.265 ppm, 1.390 – 1.723 ppm, 0.043 – 0.049 ppm for NO_2, CO, VOC and O_3 respectively for rainy season. Across the Control sites, the dry season concentration ranges of 0.038 – 0.043 ppm, 7.723 – 8.808 ppm, 0.771 – 0.941 ppm and 0.037 – 0.040 ppm for NO_2, CO, VOC and O_3 respectively were higher than the range 0.033 – 0.041 ppm, 7.216 – 8.506 ppm, 0.742 – 0.892 ppm and 0.033 – 0.035 ppm for NO_2, CO, VOC and O_3 respectively for rainy season. These levels of pollutants observed for dry season are in line with what was observed by Balogun and Orimoogunje [24] and by Attah [30]. The higher seasonal concentration of pollutants in dry season could be the consequence of higher vehicular traffic and low precipitation. This higher vehicular traffic observed during dry season could

result from favourable weather condition that allows for easy movement, hence more vehicles on the road.

There was pollution from NO_2 across the study sites as the range of 0.055 – 0.088 ppm and 0.046 – 0.071 ppm observed for dry and rainy seasons respectively were higher than the NAAQS limit range of 0.04 – 0.06 ppm. No pollution was observed for NO_2 across the Control sites. There was pollution from VOCs in both study sites and Control sites as the concentration range of 0.742 – 1.900 ppm observed across dry and rainy seasons were higher than the NAAQS limit of 0.05 ppm reported by Ideriah *et al*. [32].

Ozone maximum concentration range of 0.054 – 0.060 ppm across study sites in the dry season was within NAAQS limit of 0.06 ppm but was at the verge of causing pollution as the maximum concentration (0.060 ppm) has reached the limit already. All the concentrations observed for CO were below and within the NAAQS limit range of 10 – 20 ppm.

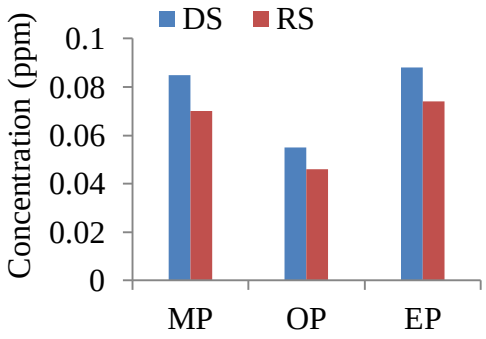

Figure 1: Seasonal variation in levels of NO_2 across study sites

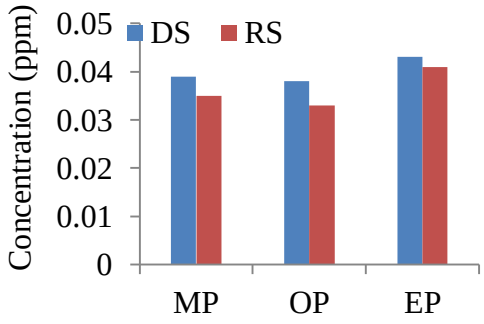

Figure 2: Seasonal variation in levels of NO_2 across Control sites

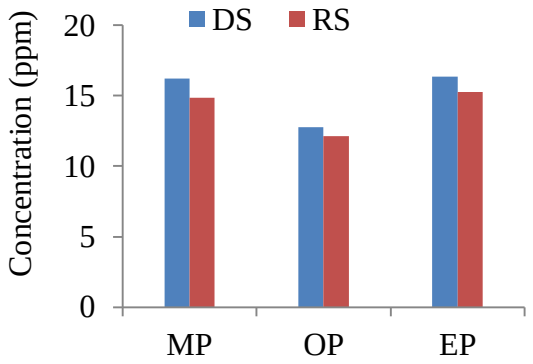

Figure 3: Seasonal variation in levels of CO across study sites

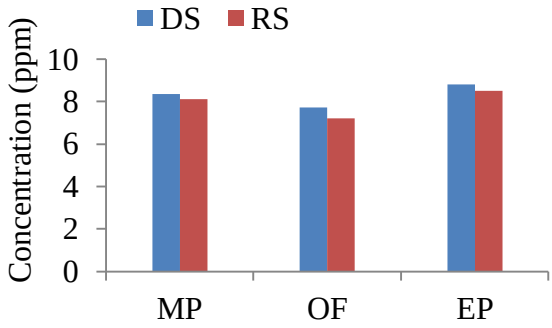

Figure 4: Seasonal varition in levels of CO across Control sites

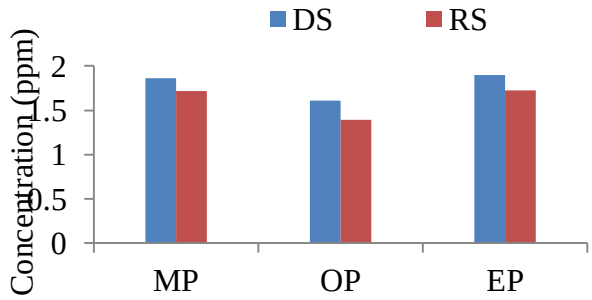

Figure 5: Seasonal variation in levels of VOCS across study sites

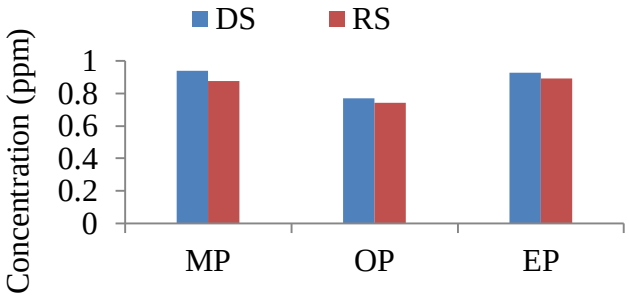

Figure 6: Seasonal variation in levels of VOCs across Control sites

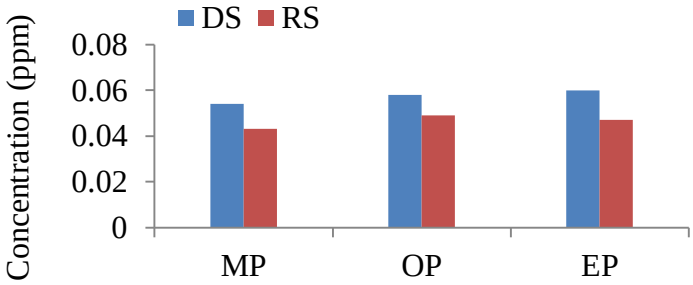

Figure 7: Seasonal variation in levels of O_3 acros study sites

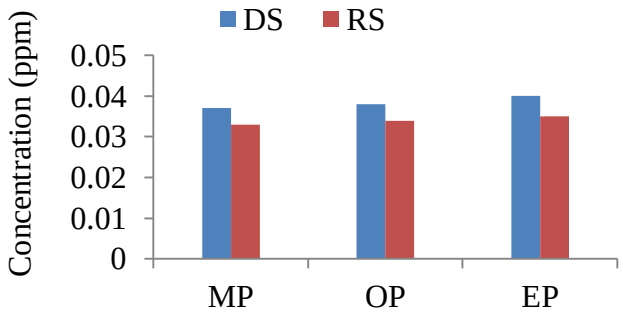

Figure 8: Sesonal variation in levels of O_3 across Control sites

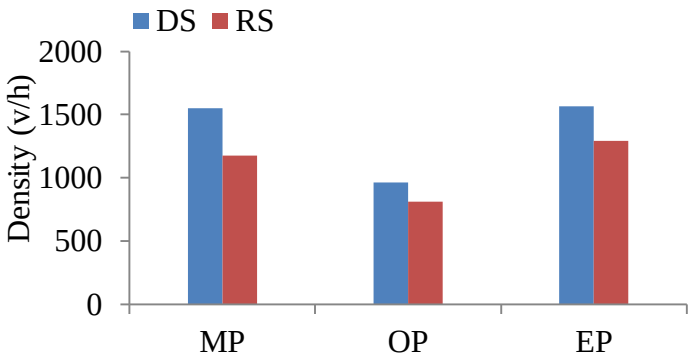

Figure 9: Variation in vehicle traffic across study sites

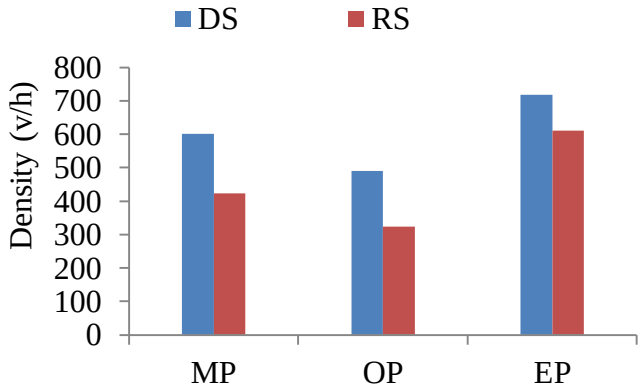

Figure 10: Variation in vehicle traffic across Control sites

The analysis in Table 2 revealed that the difference in seasonal variations of parameters in the study sites was significant across traffic periods with exception of NO_2 where the difference was not significant at off-peak as t-calculated (3.75) was lower than the t-critical (4.30).

The T test values in Table 3 show that the seasonal variations in concentrations of pollutants across the Control sites were significantly higher in the dry season than in the rainy season but with exemptions also. The seasonal variation of CO at morning peak period was not significant as t-calculated (0.96) was less than t-critical (3.18). The same was said for VOC at off-peak, as t-calculated (2.24) was less than t-critical (3.18). Furthermore, the seasonal variation of NO_2 and VOC were not significant at evening peak period as the t-calculated were 2.24 and 2.15 respectively, which were lower that the t-critical 2.57 and 2.77 for NO_2 and VOC respectively. However, these exemptions in seasonal significant variation of pollutants do not

alter the fact that the seasonal averages for all pollutants were numerically higher in the dry season than in the rainy season.

Table 2: T-test values for comparing variations in levels of parameters between dry and rainy seasons across study sites (High Traffic Area)

Parameters	MP		OP		EP	
	T *Cal.*	T *Crit.*	T *Cal.*	T *Crit.*	T *Cal.*	T *Crit.*
NO_2	8.21	2.78	3.56	4.30	9.07	2.57
CO	7.12	2.78	3.91	2.26	5.53	3.18
VOC	6.71	2.26	3.90	2.23	4.45	2.22
O_3	5.25	3.18	5.21	2.31	5.53	2.45
TD	10.53	2.23	5.93	2.26	6.03	2.23

Table 3: T-test values for comparing variations in levels of parameters between dry and rainy seasons across Control sites (Low Traffic Area)

	MP		OP		EP	
	T *Cal.*	T *Crit.*	T *Cal.*	T *Crit.*	T *Cal.*	T *Crit.*
NO_2	3.55	2.78	5.42	2.22	2.24	2.57
CO	0.96	3.18	3.67	2.26	2.38	2.31
VOC	3.26	2.57	2.24	3.18	2.15	2.77
O_3	5.20	2.36	4.22	2.57	4.01	2.45
TD	4.93	2.23	5.04	4.30	3.48	2.23

T Cal. = T calculated; T Crit. = T critical

CONCLUSION

The assessment of seasonal variation of ozone and its precursor pollutants revealed that variations in concentration of pollutants were influenced by change in season and vehicular traffic. Variations in levels of pollutants were higher in dry season compared to the rainy season. Vehicular traffic influenced the variations in levels of pollutants, as seasonal concentrations of pollutants were higher across study sites (high traffic area) than across the Control sites (low traffic area). In comparison to NAAQS, there was pollution from NO_2 and VOCs. The levels of O_3 and CO were within the NAAQS limit but O_3 maximum level (0.060 ppm) in the dry season was at the verge of causing pollution.

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