Distribution of Ambient Suspended Particulates and Volatile Organic Carbon in a Fast Developing Metropolis in the Niger Delta, Nigeria

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Research Article

Abstract: The concentrations of various sizes of suspended particulates and volatile organic carbons along selected roadsides and control sites in the fast developing city of Port Harcourt in the Niger Delta were determined at 0m and 50m from roads during the dry and rainy seasons. The parameters were determined using portable hand held air monitors which include an Industrial Scientific Corporation ITX Multi Gas Monitor and Aerosol Mass Monitor by Met One Instrument INC. The results showed highest concentrations of PM_1 (0.004mg/m^3), $PM_{2.5}$ (0.19 mg/m^3), PM_7 (0.715 mg/m^3), PM_{10} (0.829 mg/m^3), TSP (0.946 mg/m^3) and VOC (4.2ppm) in the dry season and PM_1 (0.004mg/m^3), $PM_{2.5}$ (0.28 mg/m^3), PM_7 (0.226 mg/m^3), PM_{10} (0.109 mg/m^3), TSP (0.129 mg/m^3) and VOC (1.2ppm) in the rainy season. The differences between the dry and rainy season values were significant at $P \geq 0.05$. The concentrations of the pollutants measured at the high density areas were generally higher than the concentrations measured at low density areas; however PM_1, $PM_{2.5}$, PM_{10} and VOC showed significant differences with traffic density at $P \geq 0.05$. There was no significant difference between the mean concentrations measured at 0m and 50m. The results showed very strong relationship between PM_{10} and TSP in both season, PM_7 and TSP in the dry season as well as PM_1 with $PM_{2.5}$ and PM_7 in the rainy season implying similarity in sources of the particulates. The pollutants in the study area do not originate from the same sources as the correlations between $PM_{2.5}$ and other fractions as well as between the suspended particulates and VOC were very low with decreasing mean r = 0.2174PM_1, 0.2052 $PM_{2.5}$, 0.0591 PM_7, 0.0386 PM_{10} and 0.0209 TSP. The levels of VOC call for serious environmental concern as their concentrations at the high density stations exceeded permissible limit recommended by the Federal Environmental Protection Agency of Nigeria and United States. The levels of the pollutants were influenced by traffic density, seasonal variations and distances from major roads, therefore farming activities and consumption of exposed foodstuffs should be discouraged in the study areas.

Key words: Suspended Particulate Matter, Volatile Organic Carbon, Traffic density, Distance, Seasonal variation, Port Harcourt, Niger Delta

Introduction:

Air pollution is usually concentrated in densely populated metropolitan areas, especially in developing countries where environmental regulations are relatively lax or nonexistent. However, even populated areas in developed countries attain

unhealthy levels of pollution. In the United States, unhealthy levels of pollution are measured by the Environmental Protection Agency and independent researchers or agencies [1].

Air pollution problems have been well documented in Europe and the United States with motor vehicles being the main contributors [2]. In developing countries, automobile air pollution is mostly a problem in large cities with high level of traffic. In Nigeria, it has been reported that automobile exhaust accounts for about 80% of the air pollution problems in urban areas, the remaining 20% being contributed from industrial sources, the burning of refuse and forest as well as civil engineering activities [3].

In developing countries, automobile air pollution is mostly a problem in large cities with high level of traffic, such as Mexico City, Bangkok, and Lagos, Nigeria [2]. In Nigeria, it has been reported that automobile exhaust accounts for about 80% of the air pollution problems in urban areas, the remaining 20% being contributed from industrial sources, the burning of refuse and forest as well as civil engineering activities [3].

Air pollution could be serious. According to [4], this is more so in Nigeria because, in addition to increased vehicular and industrial activities in the country, most households in both rural and urban areas use lanterns and cook with kerosene stoves owing to irregular electricity supply and frequent scarcity of gas or liquefied petroleum gas.

Port- Harcourt being the capital and major city of Rivers State, with rapid urbanization and an associated growth in industry and vehicle use, an increase in the emissions of sulphur dioxide, hydrocarbons, nitrogen oxide, and other industrial and automobile emissions are bound to be expected [5]. If these pollutants exceed the recommended levels, then there is no doubt that they will become harmful to higher animals including humans through the soil, water and plants, since their existence is in close proximity.

Report [5] stated that mounting population pressure and urbanization has resulted in ever increasing smaller farm sizes and, in some cases, the complete clearing of farms for other uses. Small scale farmers are left with the option of raising home gardens where annual and perennial vegetables are grown along with the common short gestation fruit crops such as banana, paw-paw, pineapple, etc. Other fruit crops such as mango, guava, avocado, etc are also grown along roadsides and around the houses. It is not uncommon to find people plucking and eating these unwashed raw fruits, or food hawkers displaying their stuff openly and unwrapped alongside heavy traffic roads which are apparently contaminated with air pollutants [5].

The primary air pollutants found in most urban areas are carbon monoxide, nitrogen oxides, sulphur oxides, hydrocarbons, and particulate matter (both solid and liquid). These pollutants are dispersed throughout the world's atmosphere in concentrations high enough to gradually cause serious health problems [6].

According to [7] evidence exists that many air pollutants irritate eyes and cause inflammation of the respiratory tract, suppress the immune system and increase susceptibility to infection. In addition, evidence continues to accumulate indicating that exposure to air pollution during respiratory illnesses may result in people developing chronic respiratory diseases such as emphysema and bronchitis as they get older. Other health problems that can result from long-term exposure to toxic air pollutants are cancer, chronic obstructive pulmonary disease, asthma, respiratory infections, and cardiovascular disease [7]. It was also reported [7] that air pollutants can also cause acidification of lakes and soils and impact on crop productivity, forest growth, and biodiversity. The potential for crop losses in Asia has been indicated by a study in Pakistan where 40% of reduction in rice yields was linked to the presence of pollutants in the air [7].

Suspended Particulate Matter is a mixture of solid and liquid particles suspended in the air. Suspended particulates are seen as dust, smoke, and haze which can make breathing difficult, especially for people with chronic respiratory problems [7]. It can be caused by incomplete combustion of fuel [8]. In addition to direct emissions of fine particles, automobiles release nitrogen oxides, hydrocarbons, and sulphur dioxides, which generate additional fine particles as secondary pollutant [9].

Fine Particles are composed of a wide range of materials arising from a variety of sources including: combustion sources (mainly road traffic); secondary particles, mainly sulphate and nitrate formed by chemical reactions in the atmosphere, coarse particles, suspended soils and dusts (e.g. from the Sahara), sea salt, biological particles and particles from construction work [10]. According to [11], Particulates include various solids in suspension in the atmosphere such as smoke, soot, and dust and result of the incomplete combustion of fossil fuels, notably coal. They may also carry traces of other toxic substances like hydrocarbon/volatile organic carbons. Transportation accounts for around 25% of total emissions of particulates. Diesel engines are the main emitters. The accumulation of particulates in the atmosphere and deposition on leaves may reduce photosynthesis and plant growth [11].

Report, [10] stated that particles are measured in a number of different size fractions according to their mean aerodynamic diameter. Most monitoring is currently focused on PM_{10}, but the finer fractions such as $PM_{2.5}$ and PM_1 are becoming of increasing interest in terms of health effects. Fine particles can be carried deep into the lungs where they can cause inflammation and a worsening of the condition of people with heart and lung diseases. In addition, they may carry surface-absorbed carcinogenic compounds into the lungs [10].

Reports [11], [12] stated that several Hydrocarbons (HCs) and volatile organic carbons (VOCs) are mostly the result of the incomplete combustion of gasoline or by-products of the petrochemical industry. They stated that the hydrocarbons include: methane (CH_4), gasoline (C_8H_{18}) and diesel vapours, benzene (C_6H_6), formaldehyde (CH_2O), butadiene (C_4H_6) and acetaldehyde (CH_3CHO). Transportation accounts for 40 to 50% of total emissions of HC/VOC. They can be emitted by incomplete combustion (70%), during refueling (10%) or by evaporation from storage units (20%), particularly gas tanks. For instance, a car parked overnight during summer emits approximately 4 grams of HC/VOC [11].

Volatile organic compounds are also found in paints and solvents used to finish automotive bodies [8]. They evaporate and enter the air as vapour and as molecules resulting from the incomplete burning of fuels and wastes [7]. Volatile organic compounds react with NOx in the presence of sunlight to form low-level ozone and also contribute to global warming [8].

The report, [13], stated that volatile organic compounds are emitted from a variety of sources, including motor vehicles, chemical plants, refineries, factories, consumer and commercial products, and other industrial sources. Volatile organic compounds are also emitted by natural sources such as vegetation. [13], [14]. Exposure can cause headaches or nausea, while some compounds may cause cancer. Some may also damage plants [14].

There is growing awareness in Nigeria of the adverse effects of air pollution on human health and the environment. Therefore, this study aims to evaluate the effect of automobile emissions on the levels of total suspended particulates (TSP) and Volatile organic carbon (VOC) in Port Harcourt by determining the effect of traffic density on the levels of the specific pollutants in air at the study area.

Study area

The study area, Port-Harcourt, is a fast growing, industrialized city in the Niger Delta area of Nigeria and a major industrial center as it has a large number of multinational firms as well as other industrial concerns, particularly businesses related to the petroleum industry. Port-Harcourt lies within latitudes 4 º43' and 4 º54'N and longitudes 6 º56' and 7 º03'E, 18 meters (59 feet) above sea level (Fig. 1) with a mean annual rainfall of over 2000mm and mean annual temperature of about 29ºC [15].

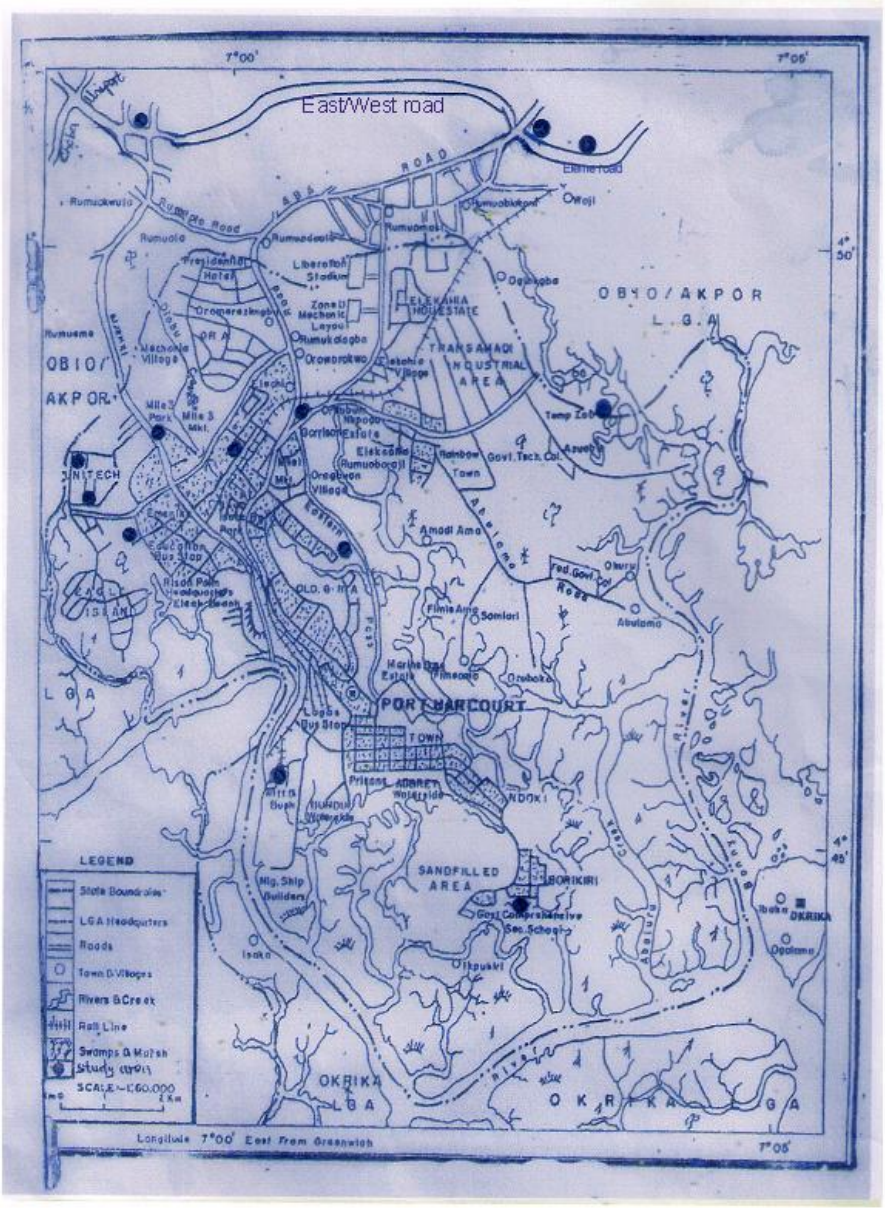

Fig 1: MAP OF PORT-HARCOURT SHOWING STUDY AREAS

Materials and Methods:

Materials:

The sampling equipment used to determine the particulates and VOCs were portable hand held air monitors which include an Industrial Scientific Corporation ITX Multi Gas Monitor and Aerosol Mass Monitor by MET One Instrument INC .

Selection of Sampling Sites:

The criteria used in selecting the stations (Table 1) included traffic density: high density (>400,000 vehicles per day), low density (<400,000 vehicles per day), and control (approximately 20 vehicles per day) and the availability of plants at the stations. The vehicles at the stations included cars, trucks, tractors, trailers, tankers and motor cycles, On the whole six high density stations, five low density stations and two control stations were selected. Fig. 1 shows the map of Port Harcourt with an indication of the selected stations.

Table 1: Identification of study stations with geographical references and Traffic Density

Station no	Station name	Station code	GPS	Traffic density
I	Aba road by Garrison junction	AR/GJ	N 04º 48.413' E 007º 00.567'	High
2	Trans-Amadi by Port Harcourt Zoo	TA/PZ	N 04º 48. 758' E 007º 02.673'	High
3	Aba road by Eleme Junction	AR/EJ	N 04º 51.427' E007º 04.120'	High
4	East-West road by Eleme junction	EW/EJ	N 04º 51.418' E 007º 04.170'	High
5	Eastwest road by Rumuokoro	EW/RU	N 04º 52.052' E 006º 59.780'	High
6	Ikwere road by Mile 3 junction	IR/M3	N 04º 48.308' E 006º 59.351'	High
7	RSUST School Farm	UST/F	N 04º 48.233' E 006º 58.622'	Control
8	RSUST Road E	UST/E	N 04º 47.308' E 006º 58.807'	Control
9	Reclammation Road by Emmanuel close	RR/EC	N 04º 45.745' E 007º 00.700'	Low
10	Lumumba Street Diobu	LS/DB	N 04º 47.516' E 006º 59.346'	Low
11	Manilla-Pepple Street D/Line	MP/DL	N 04º 47.990' E 006º 59.902'	Low
12	Government Comprehensive Sec. Sch. By Borikiri	GCSS/B	N 04º 44.535' E 007º 02.101'	Low
13	Eastern by Pass LNG round about	EB/RA	N 04º 47.516' E 007º 00.984'	Low

Collection and Measurement of Samples:

Particulate and volatile organic carbon samples in air from selected stations were collected during the rainy season (September) and during the dry season (January) to determine the effect of seasonal variation on the concentrations of air pollutants around Port Harcourt metropolis. At each station, particulates were measured at 0m and 50m along a transect 50m away from the road. Collection of particulates was done at each sampling station by holding the air sampling equipment to a height of about two meters in the direction of the prevailing wind and readings recorded at stability. Three readings of about 15mins intervals were recorded for each pollutant.

A MET One Instrument INC aerosol mass monitor was used for the detection of TSP. This mass monitor with recorder collects and records real-time information on airborne particulate concentration in addition to providing continuous particle monitoring. A Laser optical sensor for detecting and measuring particulate concentrations up to 1 milligram per cubic meter is included. The mass monitor uses light scatter to measure individual particles instead of clouds. The concentration is limited to 300 micrograms with a measuring sensitivity of 0.1 microgram. Particulate matter was categorized and measured according to their mean aerodynamic sizes of PM_1, $PM_{2.5}$, PM_7 and PM_{10}.

A Multi REA PLUS (PGM-50), a programmable Multi Gas Monitor was used to determine organic vapours. It has a photo-ionization detector (PID) using 10.6 ev or 11.7 ev gas discharging lamp. It includes an integrated sampling pump diaphragm

providing about 250 cc per minute flow at high setting. It measures VOC over two ranges; 0-200 ppm with a resolution of 0.1 ppm and 200-2,000ppm, with a resolution of 1ppm.

Results and Discussion:

Results;

The results of this study are presented in Table 2 and Figs. 2 - 6 while differences among mean concentrations are shown in Tables 3 and 4.

The variations in concentrations of PM_1 with season, station and distance are shown in Fig 2. The highest PM_1 concentration of 0.004mg/m^3 in the wet season was recorded at stations 1and 3, while the highest concentration of 0.004 mg/m^3 for the dry season was recorded at station 2. However, PM_1 was not detected in both rainy and dry seasons at stations 6, 9 and 12. As indicated in Fig. 2, only five stations out of the thirteen stations around Port Harcourt showed PM_1 concentrations during the rainy season. Concentrations of PM_1 were higher in the dry season with mean concentration of 0.013 mg/m^3 (Table 3). T-test showed that there was a significant difference between the dry and rainy season concentrations of PM_1 at $P \leq 0.005$.

Similarly, the highest concentration of $PM_{2.5}$ in the rainy season (0.028 mg/m^3) was recorded at stations 1 and 3. The highest concentration of $PM_{2.5}$ in the dry season was recorded at the same stations (Fig 3). Also $PM_{2.5}$ was not detected at station 5 at 0m and at station 10 at 50m during the rainy season. The concentrations of $PM_{2.5}$ measured during the dry season were higher than the concentrations measured in the rainy season at all the stations monitored apart from the stations 1 and 3. The concentrations of $PM_{2.5}$ in the rainy season ranged from 0.000 mg/m^3 to 0.028 mg/m^3, while the concentrations in the dry season ranged from 0.003 mg/m^3 to 0.019 mg/m^3.

Table 2: Mean concentrations of Particulate matter (mg/m^3) and Volatile Organic Carbon (ppm) around Port Harcourt (Dry and Rainy season)

Station No	Station Code	Distance (m)	PM_1		$PM_{2.5}$		PM_7		PM_{10}		TSP		VOC	
			Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
1	AR/GJ	0	0.002	0.004	0.013	0.021	0.05	0.068	0.065	0.075	0.081	0.082	3.0	0.9
		50	0.002	0.001	0.016	0.003	0.051	0.006	0.068	0.007	0.085	0.008	3.0	0.9
2	TA/PZ	0	0.004	0.001	0.012	0.004	0.039	0.016	0.048	0.021	0.057	0.024	3.0	1.0
		50	0.004	0.001	0.013	0.004	0.038	0.034	0.049	0.046	0.066	0.059	3.0	1.0
3	AR/EJ	0	0.002	0.004	0.018	0.028	0.057	0.226	0.071	0.038	0.088	0.068	3.0	1.0
		50	0.002	0.001	0.019	0.005	0.056	0.02	0.072	0.027	0.089	0.031	3.0	1.0
4	EW/EJ	0	0.002	0.004	0.018	0.028	0.057	0.226	0.071	0.038	0.088	0.068	3.0	1.0
		50	0.002	0.001	0.019	0.005	0.056	0.02	0.072	0.027	0.089	0.031	3.0	1.0
5	EW/RU	0	0.001	0.000	0.003	0.000	0.714	0.055	0.828	0.091	0.944	0.129	3.0	1.0
		50	0.001	0.000	0.004	0.003	0.715	0.006	0.829	0.007	0.946	0.009	3.0	1.0
6	IR/M3	0	0.000	0.000	0.012	0.003	0.019	0.007	0.026	0.016	0.041	0.025	4.2	1.2
		50	0.000	0.000	0.011	0.006	0.021	0.009	0.027	0.012	0.042	0.021	4.2	1.0
7	UST/F	0	0.001	0.000	0.003	0.001	0.053	0.002	0.057	0.003	0.065	0.004	4.1	1.0
		50	0.001	0.000	0.003	0.001	0.054	0.002	0.058	0.004	0.066	0.006	4.2	1.0
8	UST/E	0	0.001	0.000	0.006	0.005	0.016	0.025	0.019	0.031	0.022	0.034	4.6	1.2
		50	0.001	0.000	0.006	0.001	0.016	0.005	0.021	0.007	0.023	0.011	4.6	1.2
9	RR/EC	0	0.000	0.000	0.006	0.003	0.099	0.006	0.131	0.008	0.157	0.01	0.0	0.0
		50	0.000	0.000	0.007	0.003	0.098	0.007	0.132	0.009	0.158	0.012	0.0	0.0
10	LS/DB	0	0.002	0.000	0.009	0.001	0.026	0.004	0.038	0.008	0.054	0.019	3.0	1.0
		50	0.002	0.000	0.009	0.000	0.027	0.099	0.039	0.109	0.056	0.12	2.0	1.0
11	MP/DL	0	0.001	0.001	0.006	0.004	0.015	0.012	0.023	0.019	0.031	0.025	3.0	0.0
		50	0.001	0.001	0.007	0.005	0.016	0.009	0.024	0.021	0.032	0.026	3.0	0.0
12	GCSS	0	0.000	0.000	0.004	0.001	0.03	0.012	0.034	0.023	0.042	0.037	0.0	0.0
		50	0.000	0.000	0.004	0.001	0.031	0.01	0.036	0.03	0.046	0.035	0.0	0.0
13	EB/RA	0	0.001	0.000	0.005	0.001	0.022	0.014	0.024	0.019	0.028	0.021	0.0	0.0
		50	0.001	0.000	0.005	0.001	0.02	0.011	0.023	0.015	0.027	0.018	0.0	0.0

T- test revealed a significant difference between the rainy and dry season concentrations of $PM_{2.5}$ at $P \leq 0.05$.The dry season mean concentration (0.0922mg/m^3) of $PM_{2.5}$was higher than the rainy season mean concentration (0.0054mg/m^3) using DMRT (Table 3).

The concentrations of $PM_{7,}$ PM_{10} and TSP are shown in Figs. 3-5. The highest concentrations of 0.715 mg/m^3 PM_7, 0.829 mg/m^3 PM_{10} and 0.948 mg/m^3 TSP were measured at station 5 in the dry season. Stations 3 and 4 recorded the highest concentration of PM_7 (0.226 mg/m^3) during the rainy season.

Statistical analysis (t-test) showed no significant difference between the rainy and dry seasons concentrations of PM_7 at $P \geq 0.05$. However, Table 3 showed that the mean concentrations of PM_1, $PM_{2.5}$ PM_{10} and TSP during the dry season were significantly higher than the rainy season mean concentrations at $P \leq 0.05$ using DMRT.

Table 3: Mean Concentrations of Particulate Matter Measured at the Study stations

	Mean concentrations of Particulate Matters (mg/m^3)				
	PM_1	**$PM_{2.5}$**	**PM_7**	**PM_{10}**	**TSP**
Dry Season	0.0013^a	0.0922^a	0.0921^a	0.1109^a	0.1316^a
Wet Season	0.0007^b	0.0054^b	0.0350^a	0.0273^b	0.0359^b
High Density	0.0040^c	0.0267^c	0.2557^c	0.2313^c	0.0282^c
Low Density	0.0008^d	0.0067^d	0.0400^d	0.0683^d	0.0707^c
Distance (0m)	0.0011^e	0.0086^e	0.0686^e	0.0702^e	0.086^d
Distance (50m)	0.0016^f	0.0062^e	0.0548^e	0.0681^e	0.0816^d

Means with different superscript within columns are significantly different at $P \leq 0.05$ using DMRT

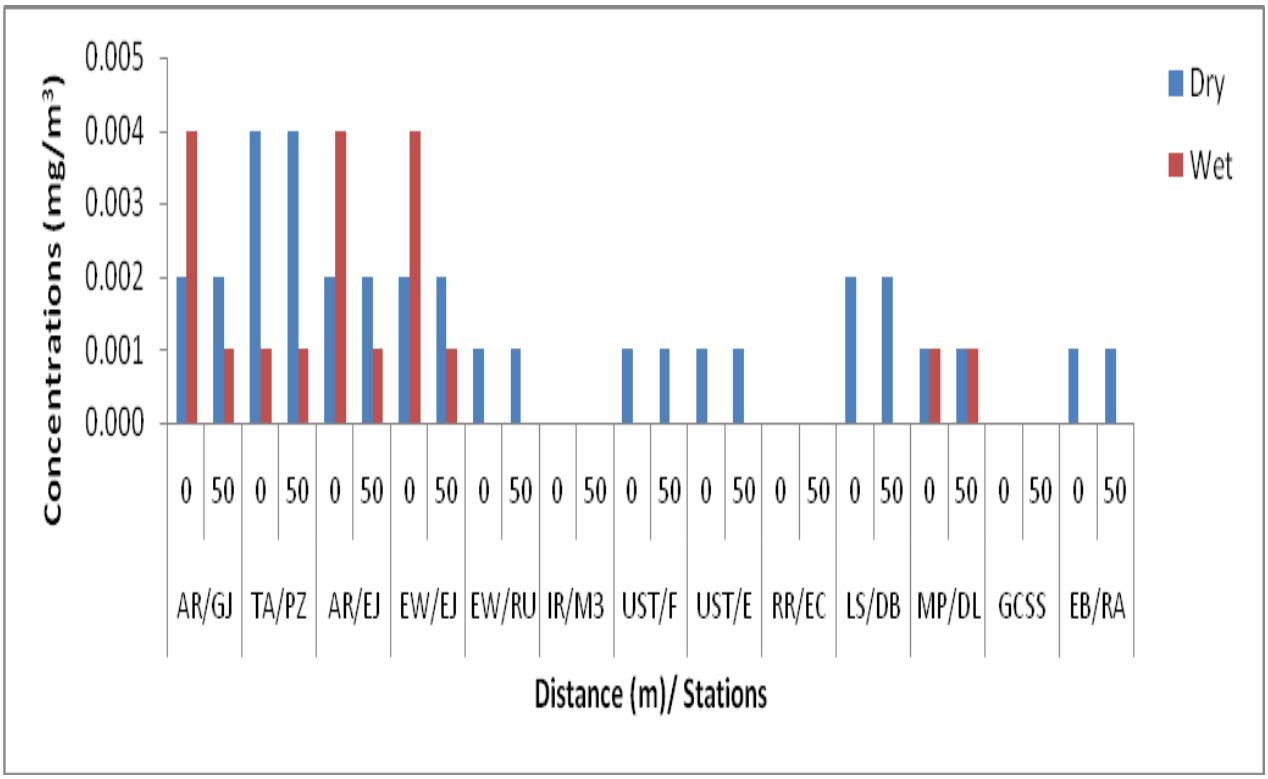

Fig 2: Variations in concentrations of PM_1 with seasons, stations and distance

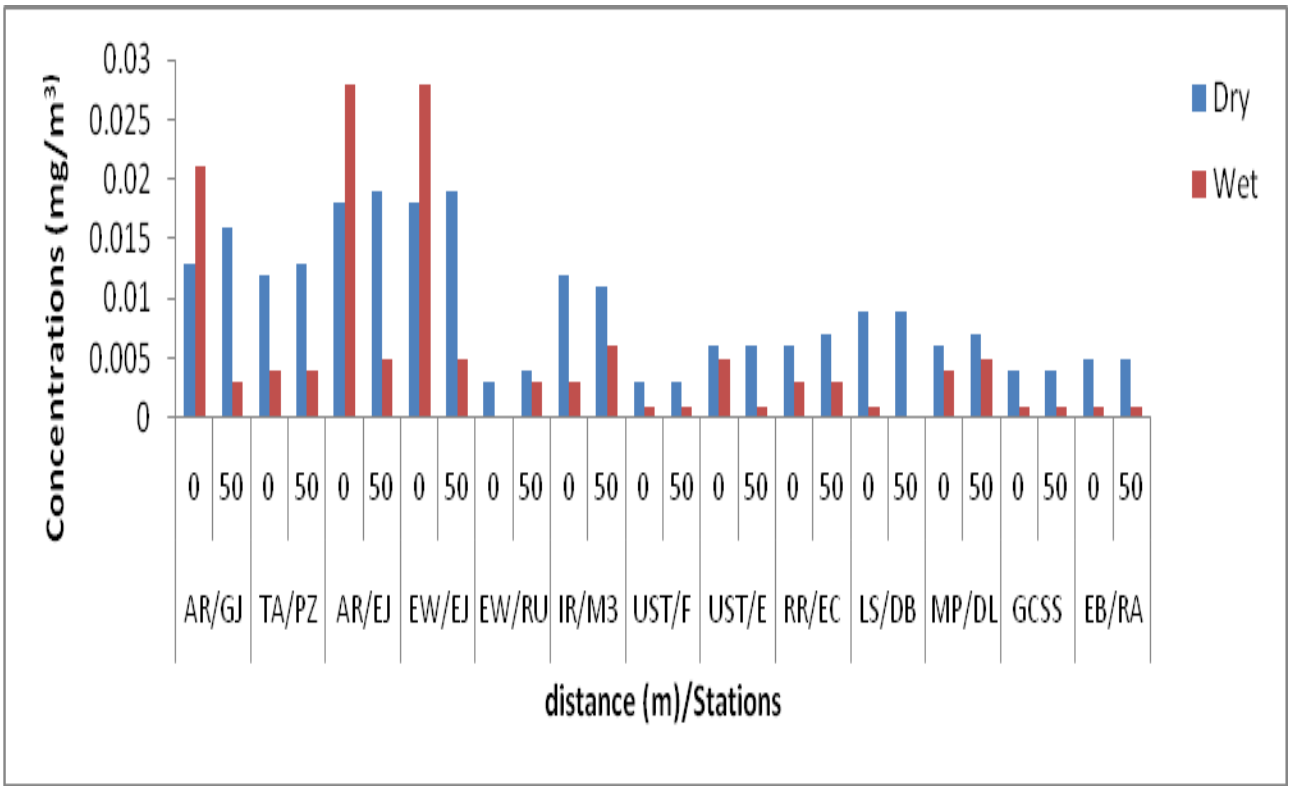

Fig 3: Variations in concentrations of $PM_{2.5}$ with seasons, stations and distance

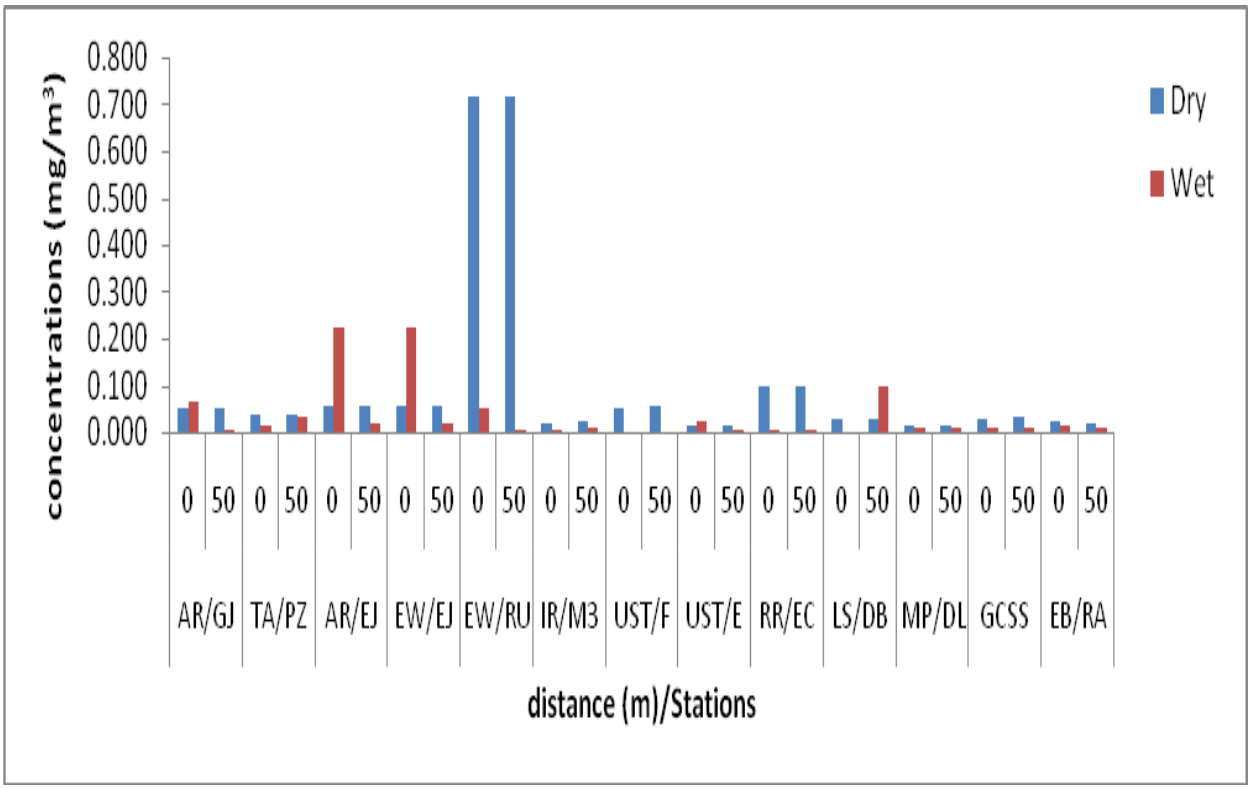

Fig 4: Variations in concentrations of PM_7 with seasons, stations and distance

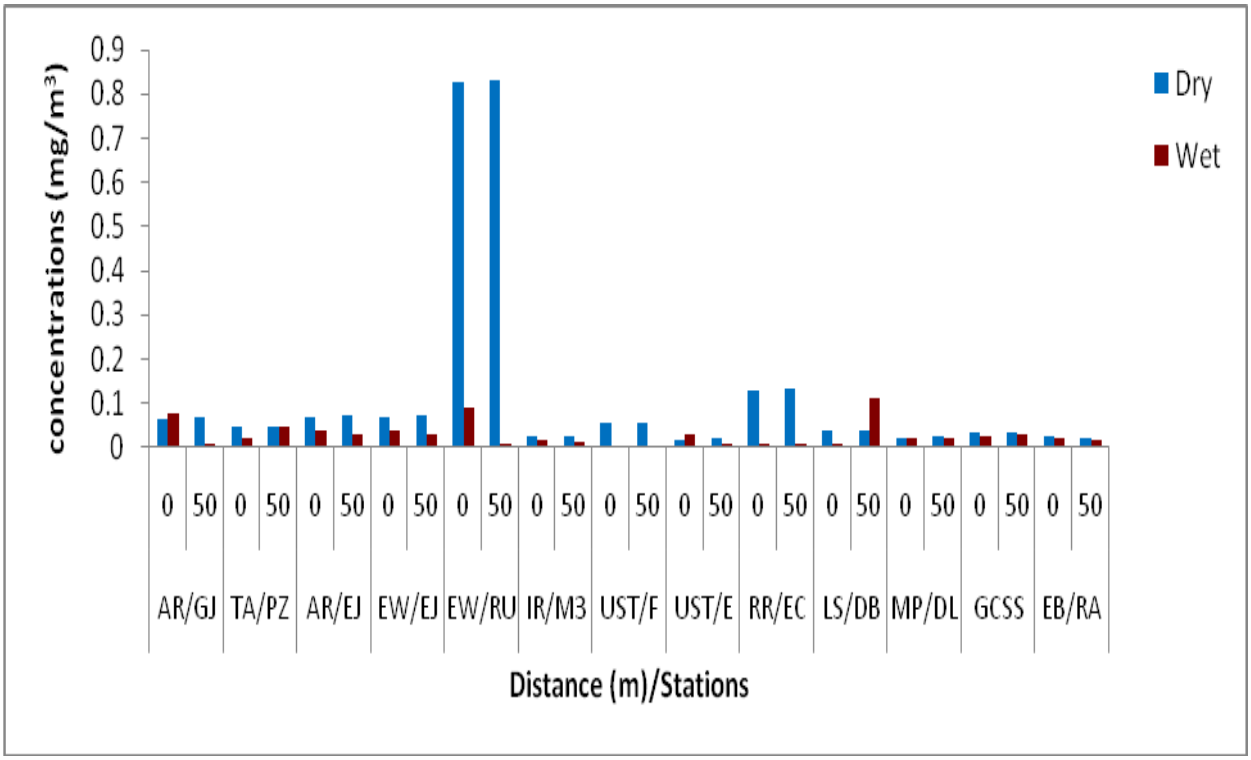

Fig 5: Variations in concentrations of PM_{10} with seasons, stations and distance

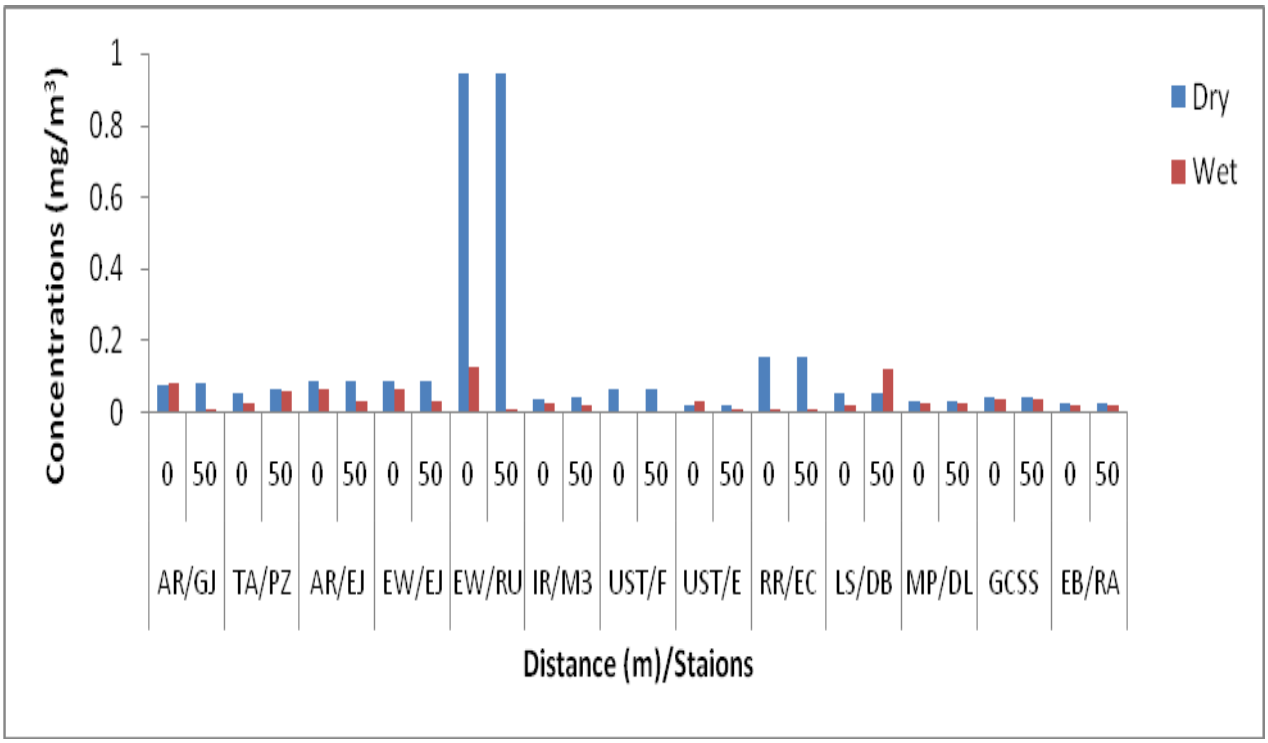

Fig 6: Variations in concentrations of TSP with seasons, stations and distance

The concentrations of PM_1 were higher in stations 1, 2, 3 and 4 (Fig. 2) while the concentrations of $PM_{2.5}$ were higher in stations 3 and 4 (Fig 3). The mean

concentration of PM_1 (0.004ppm) in the high traffic density stations was higher than PM_1 mean concentration (0.0008ppm) in the low traffic density stations (Table 3). The mean concentration of $PM_{2.5}$ (0.0267ppm) in the high traffic density stations was also higher than the $PM_{2.5}$ mean concentration (0.0067ppm) in the low traffic density stations (Table 3). The concentrations of $PM_{7,}$ PM_{10} and TSP were highest at station 5 with concentration of 0.715ppm, 0.829ppm, and 0.946ppm respectively.

Using the Duncan Multiple Range Test (DMRT) for the comparison of means at $P \leq 0.005$, the results (Table 1) showed that the mean concentrations of $PM_{2.5}$ PM_7 and PM_{10} were significantly higher in the high traffic density stations than the low traffic density stations

Figs. 2- 6 show the concentrations of the various sizes of particulate matter monitored at the two distances (0m and 50m) away from the roads at all the stations. The concentrations of PM_1 at both 0m and 50m were the same at all the stations during the dry season, while during the rainy season the concentrations at 0m were higher than those at 50m in stations 1, 3 and 4. However statistical analysis (Table 3) showed no significant difference between the mean concentrations of particulate matter at 0m and 50m.

Table 4 showed that the mean concentrations of VOC at the study stations were higher during the dry season than the rainy season at $P \leq 0.05$.

Table 4: Mean concentrations of VOC measured at the study stations

	Mean concentrations of VOC (ppm)
Dry Season	2.365^a
Wet Season	0.708^b
High Density	4.200^c
Low Density	0.633^d
Distance (0m)	2.025^e
Distance (50m)	1.970^e

Means with different superscript within columns are significantly different at $P \leq 0.05$ using DMRT.

Volatile Organic Carbon was not detected in three stations (9, 12, and 13) in both rainy and dry seasons (Fig. 7). The VOC concentrations in the other ten stations in the dry season ranged from 2.0ppm at station 11 to 4.6ppm at station 8, while the VOC concentrations in the wet season ranged from 0.9ppm to 1.2ppm (Fig. 7). The mean VOC concentration (2.365ppm) in the dry season was significantly higher than the mean VOC concentration (0.708ppm) in the rainy season at $P \leq 0.05$ using DMRT (Table 4).

The mean concentrations of VOC at the study stations were higher during the dry season than the rainy season at $P \leq 0.05$. VOC was detected in all the stations except stations 9, 12 and 13. The mean concentration (4.200ppm) at the high traffic

density stations was significantly higher than the mean concentration (0.633ppm) at the low traffic density stations as shown on Table 4.

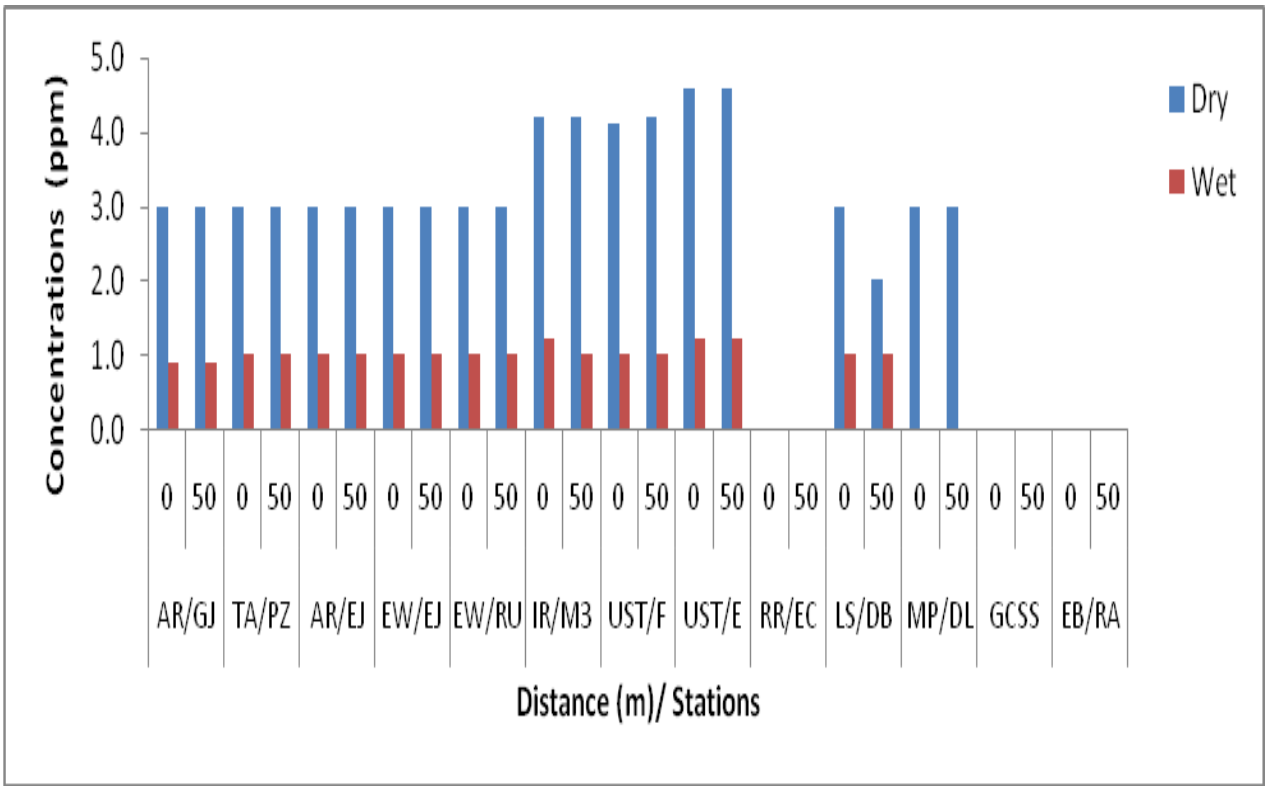

Fig. 7: Variations in concentrations of VOC with seasons, stations and distance

Discussion:

The mean concentrations of PM_1, $PM_{2.5}$, PM_7, PM_{10} and TSP during the dry season were higher than the mean concentrations observed during the rainy season. Statistical analysis showed rainy season concentrations to be significantly lower than the dry season concentrations. This observation is in consonance with the report by [16], which stated that the concentrations of particulate matter in the rainy season months in Igwuruta/Umuechem communities of Rivers State were lower than the concentrations recorded in the dry season. According to that report, the uniquely high levels of particulate matter observed during the dry season across all the study stations can be attributed to the high content of dust particles from the North -East Trade wind (Hamarttan). The report, [17] observed the same general increase in particulate matter concentration during the dry seasons after a six year study on the distribution of particulate air pollution in Nigerian cities. According to his report, the increase in particulate concentration during the dry season was a confirmation of earlier views that deposition of particulates or dust during the Hamarttan season, wind movement of dry particulates, aerosols from the Sahara desert and burning of anthropogenic substances were the major factors responsible for the increase.

Test of significance showed particulate matter concentrations in the high traffic density areas to be significantly different from concentrations in the low traffic density areas. This observation agrees with the report by [10], implicating road traffic as a major source of anthropogenic distribution of particulate matter.

The high concentrations of particulate matter recorded for the high traffic density stations in this study can also be attributed to industrial and commercial activities at the

study areas. For instance, the high concentration (0.004 mg/m^3) of PM_1 at station 2 (Trans/Amadi by Port Harcourt zoo) can be attributed to dust, sooth and smoke particles generated from the Slaughter market and the abattoir activities which include the burning of animal skin with worn out motor tyres. The dark smoke generated from this activity is clearly visible at the station. Station 5 (East/West road by Rumuokoro) is a major junction linking Port Harcourt to other LGAs in Rivers State and a major link to other Western States. This station recorded the highest concentrations of PM_7, (0.715 mg/m^3), PM_{10} (0.829 mg/m^3) and TSP (0.946 mg/m^3). Apart from automobile sources, the high concentration of particulate matter in this station can also be attributed to dust generated from the Rumuokoro market and adjacent slaughter market and abattoir as was observed in station 2.

The mean concentrations of $PM_{2.5}$, PM_7, PM_{10}, and TSP were higher at 0m than at 50m away from roadsides in all the study stations. Although statistical analysis showed no significant difference between 0m and 50m distances, the high concentrations at 0m further implicates automobiles as a major source of the particulates, while other roadside activities (roasting of yam, fish and plantain with charcoal, popularly known as bole joints in Port Harcourt) also contributed to the concentrations measured at the study areas.

The concentration of particulate matter were compared with permissible limits recommended by [18] and found to be below limits. In particular, the concentrations of TSP in all the stations were below the permissible limit of 100mg/m^3, and therefore do not pose serious environmental problems. Similarly the particulates showed concentrations much lower than the United States ambient air quality standards of 35mg/ m^3 (24 hour mean for $PM_{2.5}$), and 150 mg/ m^3 (24 hour mean for PM_{10}) [13]. These observations do not agree with the reports [4a, b] that with respect to TSP, air quality in Port Harcourt and Yenagoa are unhealthy.

Statistical analysis using t-test at $P \leq 0.05$ showed significant difference between the mean concentration of VOC in the dry season and concentrations in the rainy season. Further analysis using DMRT at $P \leq 0.05$ showed that the dry season mean concentration of VOC (2.365ppm) was higher than the rainy season mean concentration VOC (0.7077ppm). The rainy season showed concentrations lower than the dry season values. This is attributed to the cleansing effects of rain fall on the atmosphere [19]. During the rainy season, a combination of heavy rainfall and, in some cases, high wind speed off the oceans, significantly improve air quality [20]. It has been observed that the percentage of calm period is higher during the dry season than during the rainy season, the higher percentage of calm period during the dry season means high concentration of pollutant VOC during the dry season than the rainy season [21].

Statistical analysis showed significant difference between the mean concentrations of VOC in the high traffic density areas (4.200ppm) and the low traffic density areas (0.633ppm). This observation indicates that traffic density is a major contributor to atmospheric VOC and agreed with the report by [6]. The report by [10] stressed that petrol and diesel engine motor vehicles emit a wide variety of pollutants including VOCs and particulates (PM_{10}). According to [22] report, traffic can be responsible for as much as 80 to 90% of VOC and a large portion of the particulates in the city centers, especially along highly congested streets.

Volatile organic compounds were the only air pollutants that were significantly higher in the high traffic density stations as compared to the low traffic density stations; this can be attributed to the fact that gasoline and diesel fuels used by automobiles are formed from a combination of petroleum and natural gas which are all mixtures of hydrocarbons [8].

Concentrations of VOC (Fig. 7) were higher at stations 6, 7 and 8. Fewer motor vehicles ply the control stations 7 and 8. Therefore, the high concentration measured in the control stations could probably be due to the industrial and vehicular activities of the adjacent Nigerian Agip Oil Company, while the high concentrations at station 6 could be from the road and flyover bridge construction work along the Ikwerre road/Agip round about.

The concentrations of VOC recorded at the high density stations exceeded the permissible limit of 0.05ppm recommended by the [18]. These levels of pollutants call for serious environmental concern. However, VOC concentrations in the low density stations (9, 12 and 13) were observed to be lower than the set limit and, hence, do not pose serious problems in those stations.

The concentrations of VOC measured at 0m were not significantly different from the concentrations measured at 50m away from the roadsides. This observation suggests that automobiles are not the only sources of gaseous air pollutants. The report by [6] stated that the two major sources of pollutants in urban areas were transportation (predominantly automobile) and fuel combustion in stationary sources such as domestic, commercial, and industrial heating and cooling power plants.

The correlations between the pollutants determined in air are shown in Table 5. It is observed that very high, positive and significant relation existed between some of the particulate fractions/pollutants with correlation coefficient, r = 0.9463 (PM_1rainy/$PM_{2.5}$ rainy), 0.8613 (PM_1 rainy/PM_7 rainy), 0.8941 ($PM_{2.5}$ rainy/$PM_{2.5}$ rainy), 0.9997 (PM_7 dry/PM_{10} dry), 0.9993 (PM_7 dry/TSP dry), 0.9999 (PM_{10} dry/TSP dry), 0.9699 (PM_{10} rainy/TSP rainy), 0.8229 (VOC dry/VOC rainy). High, positive and significant relationship was seen between PM_1 dry and $PM_{2.5}$ dry, PM_1 rainy and $PM_{2.5}$ dry, $PM_{2.5}$ dry and $PM_{2.5}$ rainy and PM_7 rainy and TSP rainy with r = 0.5300, 0.6930, 0.6083 and 0.5890 respectively. These observations indicate very strong relationship between PM_{10} and TSP in both season, PM_7 and $PM_7$and TSP in the dry season as well as PM_1 with $PM_{2.5}$ and PM_7 in the rainy season. These also imply similarity in sources of the particulates. The correlations between $PM_{2.5}$ and other fractions were very low and insignificant. The relationship between the suspended particulates and VOC was very low and insignificant with decreasing mean r = 0.2174PM_1, 0.2052 $PM_{2.5}$, 0.0591 PM_7, 0.0386 PM_{10} and 0.0209 TSP indicating that the pollutants do not originate from the same sources in the study area.

Conclusion and Recommendations:

The findings of this study have shown that seasonal variations, traffic density and distance from road significantly influenced the concentrations of the pollutants. The study also indicated that automobiles are a major but not the only source of the pollutants in the Port Harcourt metropolis. Therefore, farming activities and consumption of exposed foodstuff along the roadsides should be discouraged. Also, efforts should be made by government at earmarking special zones for all industries away from metropolitan areas in order to ensure environmental improvement. There should be regular monitoring of air pollutants and their possible effects on the general environment around Port Harcourt city and appropriate mitigation measures developed.

Table 5: Correlation matrix of the Air pollutants measured at the study area

	PM_1		$PM_{2.5}$		PM_7		PM_{10}		TSP		VOC	
	DRY	RAINY	DRY	RAINY	DRY	RAINY	DRY	RAINY	DRY	RAINY	DRY	RAINY
PM_1 DRY	1											
PM_1 RAINY	0.4337	1										
$PM_{2.5}$ DRY	0.53	0.69302	1									
$PM_{2.5}$ RAINY	0.2316	0.94633	0.6083	1								
PM_7 DRY	-0.0793	-0.1348	-0.2759	-0.1032	1							
PM_7 RAINY	0.2861	0.86126	0.4951	0.89412	0.00459	1						
PM_{10} DRY	-0.079	-0.1316	-0.2669	-0.1004	0.99969	0.0064	1					
PM_{10} RAINY	0.2672	0.13281	0.0947	0.07886	0.26092	0.4601	0.2621	1				
TSP DRY	-0.0773	-0.1287	-0.2586	-0.0973	0.99932	0.0099	0.9999	0.2666	1			
TSP RAINY	0.2526	0.27355	0.1456	0.23784	0.31055	0.589	0.3115	0.9699	0.3162	1		
VOC DRY	0.2788	0.15604	0.2489	0.16158	0.04689	0.0713	0.0401	-0.037	0.0399	-0.0019	1	
VOC RAINY	0.4439	0.1807	0.4138	0.20468	0.16901	0.245	0.1646	0.1888	0.1673	0.2199	0.8229	1

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