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Research Article

Assessment of Air Pollutant Concentration Levels in High and Low Traffic Density Areas in Urban City: A Case of Port Harcourt, Nigeria

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Abstract

Vehicular emissions are a major source of air pollution, affecting air quality and human health. Port Harcourt faces increasing pollution due to high traffic, but the patterns and influencing factors are not well studied. This research examines air pollutant levels in high- and low-traffic areas, considering the effects of traffic and weather conditions. This was done to determine the pattern of air pollution concentrations in the city's high and low traffic density zones. Five locations—Ozuoba, Umuechi, Rumuokoro, Rumuola, and Ada George—were chosen based on traffic density, and the concentrations of air pollutants and particle matter were tracked there. This is with the view to understand the extent traffic contributes to vehicular pollution and its consequences on human health. MX6 Ibrid Multigas Monitors (CO, VOC, SO_2, NO_2), MET ONE GT 321 for particle matter, Davis Vantage Vue and Weather Station for meteorological data, were used to monitor the quality of the air. The number of cars traveling through a site during three hours in the morning, afternoon, and nighttime was counted to create traffic records at the chosen places. Over two years (2018-2019), every parameter was observed in every site five days a week. PCA, t-test, One-way ANOVA, correlation, and regression were used to evaluate the data, were needed. The mean concentration of all pollutants was substantially ($p < 0.001$) greater in high-traffic density areas (HTDA) than in low-traffic density areas (LTDA), according to the results. CO (5.20±3.11-23.49±11.67 ppm), SO_2 (0.03±0.02-0.28±0.25 ppm), NO_2 (0.05±0.05-0.37±0.31 ppm), $PM_{2.5}$ (67.18±37.33-189.63±77.10µg/m3), PM_{10} (65.90±45.04-175.29±65.07 µg/m3), and VOC (0.06±0.07-0.37±0.36 ppm) were among the range of mean concentrations. Between 2018 and 2019, there was a substantial ($p < 0.01$) variation in the levels of CO and VOC, while other variables were similar. The concentrations of the other pollutants were similar ($P>0.05$), while the VOC concentrations differed significantly ($p<0.05$) between January and December. It was discovered that while weather variables including temperature, humidity, and wind speed had a major impact on the contaminants' distribution, traffic volume greatly contributed to their concentration. Pollutants and meteorological elements are loaded into two components, according to principal component analysis. The major factor includes all of the pollutants and traffic volume, while the minor factor was the weather-related parameters. The study concluded that there was a distinctive pattern of air pollutant emissions in the studied area and that, although traffic levels greatly influence the pollutants' concentration, meteorological factors also had an impact. Also, pollutants emitted from vehicles advanced over the years, thereby threatening human health. Among other things, it was suggested that air quality monitors be installed at various traffic crossings to track exhaust emissions levels for improved regulation and impact checks.

Keywords: air-pollutants, vehicles, emission, meteorological, traffic

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1. Introduction

Air is a universal gas that is mostly made up of oxygen (21%), nitrogen (78%) and the remaining 1% for all other constituents. Most likely because of the oxygen component, it is thought to be the most significant natural life support system [1, 2]. No living thing can endure hypoxia for longer than five minutes, because oxygen is necessary for all living things to breathe. Thus, air is essential to the existence of humans and other living things. However, the quality of the air determines how well it can support life. Most people agree that quality air is defined as having the proper natural proportion. The air becomes contaminated when this is not followed. The additional components or toxins it contains determine how polluted an area is. Numerous pollutants are categorized according to their sources, types, and toxicity; therefore, while clean air is vital to life, contaminated air is harmful to it [3, 4]. Air pollution comes from a variety of sources, but it is generally accepted that human activity is the main one.

Any substance in the air that, in sufficient quantity, could endanger people, animals, plants, or artificial compositions of matter capable of being airborne is considered air pollution, according to the WHO [3]. Numerous alternative definitions concur with the one above. However, it is crucial to realize that human activity is the primary cause of air pollution, which poses a threat to the ecosystem [5, 6]. Air pollution in the atmosphere is caused by two types of pollutants: primary sources, which are compounds released directly from a process, and secondary sources, which are created by reactions between primary pollutants. Among these sources are the transportation and manufacturing sectors. Transportation is one of these sources that emit a higher percentage of harmful pollutants [7].

Combustion engine emissions from vehicles are a significant cause of air pollution and a serious global health issue that endangers both the environment and human health [8, 9]. Every year, air pollution causes seven million deaths worldwide, primarily from non-communicable diseases [10, 11]. Due to growing activities and ongoing urbanization, there is an imbalance between the supply and demand for transportation, which has led to significant traffic congestion and environmental problems with traffic emissions [12]. The quality of the urban living environment is being limited by the degradation of ambient air quality, which is mostly caused by emissions from automobile traffic. Africa's population has been growing at a rapid rate, which has led to an increase in motor vehicles. Premature fatalities have been the result in many cities, particularly in low- and middle-income nations where the elderly, women, and children are most vulnerable [9, 13].

According to Ucheje and Ikebude [14] and Ipeaiyeda and Adegboyega [15], the majority of these pollutants' high concentration levels are typically seen in places with extremely heavy traffic. Several other studies have documented the rise in these pollutants' concentrations in various cities, which is brought on by high automobile traffic [16, 17].

Van Donkelaar *et al*. [18] stated that 80 percent of people on Earth reside in areas where average annual $PM_{2.5}$ concentrations are higher than the WHO's recommended level of 10 g/m3. According to estimates, exposure to ambient $PM_{2.5}$ resulted in 2.9 million untimely deaths globally in 2017 [19], or over 9% of all deaths. Approximately 80,000 of these deaths were attributed to ischemic heart disease in the West African region. The issue is most severe in Nigeria, where $PM_{2.5}$ levels have been linked to 11,200 premature deaths in the West African region, mostly in Lagos, the nation's commercial hub and one of the world's fastest-growing megacities [20]. However, Port Harcourt is another industrialized city that has been known to experience heavy traffic with high concentration of pollutants in major part of the city, at different times of the day and hours [2], which requires attention.

Numerous researches, such as [21, 22, 23, 24. 25, 26], have examined the concentration of contaminants on the road, but they have not evaluated the impact on public health by an efficient perception survey. Moreover, a great deal of research on raising public awareness about other man-made sources of air pollution, like household, industrial, agricultural, and power generating, has been done. However, additional investigation is needed into the proportional health risk posed by vehicle traffic pollution, particularly in Port Harcourt, Nigeria.

Port Harcourt city in Nigeria is one of these cities; [14, 27], observed that it generates substantial traffic between the morning and evening peaks. However, it appears that no many research has taken into account modeling statistically, high and low traffic density locations in south-south Nigeria. In order to predict the concentration, this study will look into vehicle emissions induced by heavy traffic in more detail.

2. Rationale for the Study

In Nigerian cities, air pollution is progressively becoming a major threat. High levels of localized air pollution are caused by the transportation sector's improper use of energy in metropolitan areas [28]. The general level of air pollution has also increased as a result of Nigeria's increased importation of used automobiles. The use of motor vehicles has increased as a result of that. Additionally, increased vehicle use brought about by urbanization and modernity has greatly advanced global air pollution [29, 30, 31, 32]. According to several studies [30. 33, 34, 35, 36], motor vehicles are now the main cause of air pollution in cities. According to Prince and Essiet [37], motor vehicle emissions are mostly to blame for the poor quality of urban air in Nigeria and many other developing nations. As the number of automobile problems rises, this issue will inevitably get worse.

There is worry that automobile emissions are becoming a bigger source of air pollution in Nigeria, particularly in large cities like Port Harcourt [38]. The growing number of vehicles and the severe traffic congestion on numerous highways were most likely the causes of the concern. The increasing traffic congestion in several of these cities is particularly disturbing. Due to incomplete combustion in parked automobiles, traffic congestion contributes disproportionately to air pollution [34, 39]. For example, it has been demonstrated that traffic congestion accounts for between 50 and 80 percent of the concentrations of carbon monoxide (CO) and nitrogen dioxide (NO_2) in developing nations [39].

According to Saville's [40] estimation, traffic-related emissions account for 90–95% of global ambient CO levels and 80–90% of NOx, hydrocarbons, and particulate matter. A recent study conducted in Port Harcourt, Nigeria, confirmed this tendency by identifying two significant traffic emission peaks, one in the morning and one in the evening [38]. According to previous research, the pattern, rate, and direction of emissions' dispersion determine their overall impact on the environment and human health [14, 41]. Together with Utang and Peterside [27], these studies have partially demonstrated how traffic congestion-related vehicle emissions significantly increase air pollution in Port Harcourt, Nigeria. According to these researches, sufficient understanding of the characteristics of pollutants in each city is necessary for the efficient environmental control of air emissions in urban areas.

Furthermore, it appears that the concentration level of these pollutants throughout the day at various periods has received little attention despite all of the research into what constitutes air pollution in large cities like Port Harcourt, Nigeria. Second, many locations, such as regions with almost minimal traffic density, which will help determine the level of pollution in areas with high traffic, have not been taken into account. There hasn't been much research done on determining the extent of pollution in comparison to low and high traffic milieus in a growing city like Port Harcourt. Also, a linear statistical model that can aid in comprehending how air pollutants behave concerning the elements that cause their concentration, particularly during two periods in Port Harcourt, Nigeria needs to be considered. Therefore, the researcher tries to close the gap that has been overlooked based on these assumptions, to understand its consequences on human health. However, this study is aimed at determining the concentration levels of air pollutants in low and high-traffic density areas of Port Harcourt city in Nigeria (2018 to 2019). The specific objectives of the study are to; (a) characterize the pattern of air pollutants emission in selected low and high-traffic density areas in Port Harcourt, Nigeria; (b) assess the impact of meteorological factors on the concentration of pollutants in the chosen areas; (c) determine the connection between the study area's concentration of air pollutants and the daily pattern of vehicle volume; (d) examine if there is a significant difference in the concentration of air pollutant emission in low and high-traffic density areas in Port Harcourt.

3. Materials and Method

The study was carried out in the southern Nigerian metropolis of Port Harcourt. The capital and largest city of Rivers State, Nigeria, is Port Harcourt. According to Figure **1**, it is situated between latitude 6' 54°N and longitude 4°E. The framework for data collecting, measurement, and analysis is known as the research design [42, 43]. An experimental research design was used in this investigation. In this instance, measurements of vehicle emissions of air pollutants and meteorological data were collected over 24 months. Carbon monoxide (CO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), volatile organic compounds (VOC), and particulate matter ($PM_{2.5}$, PM_{10}) are among the data obtained from field research. Additionally, the following meteorological parameters were gathered: air temperature (°C), relative humidity (%), and wind speed (M/S). Also, a traffic count was obtained.

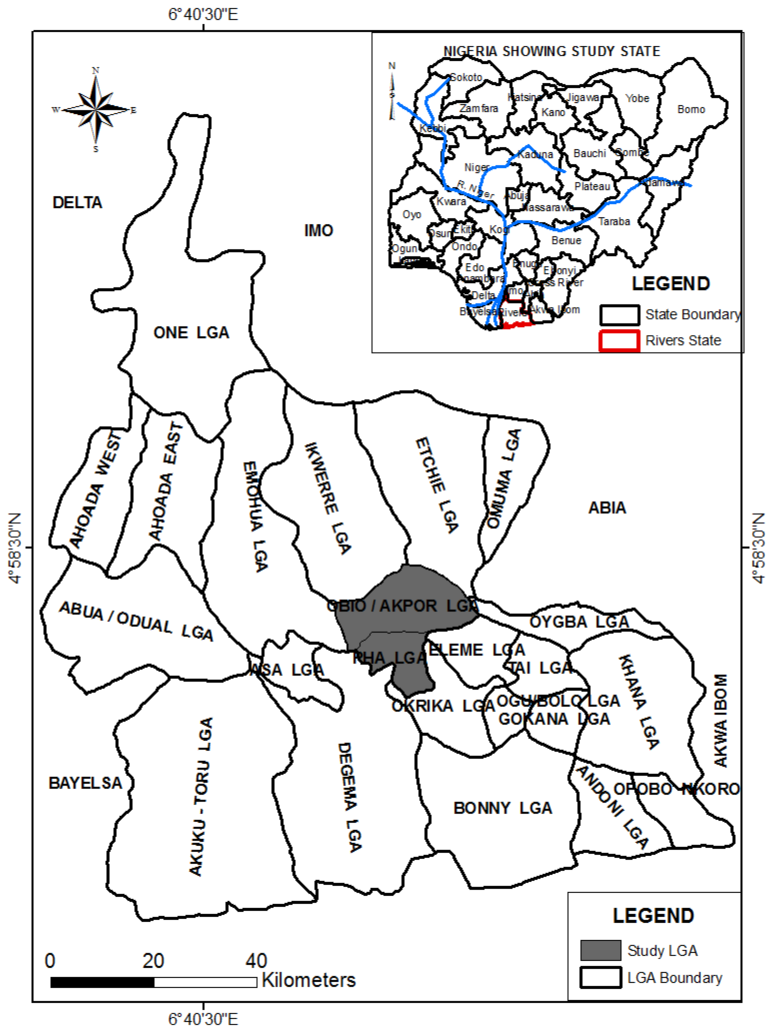

Figure 1: Rivers State Showing Port Harcourt City (Source: [38]).

Using a purposive approach, the study's sampling stations were chosen based on data on traffic density in various Port Harcourt neighborhoods (see Figure **2**). Ten of Port Harcourt's intersections have high traffic densities, while the others have medium to low densities, according to Utang and Peterside [27]; and Ucheje and Ikebude [14]. For the study, one medium-to-low traffic density location (Ozuoba/Uniport) and three (3) high-traffic density areas (Rumuokoro roundabout, Rumuola, and Location/Ada George) were chosen. The fifth site, Umuechi, which was used as a control, was situated in an area with almost little traffic, such as a forest, and was at least 10 kilometers from the closest highway. The chosen sampling sites were quite remote from any industrial areas.

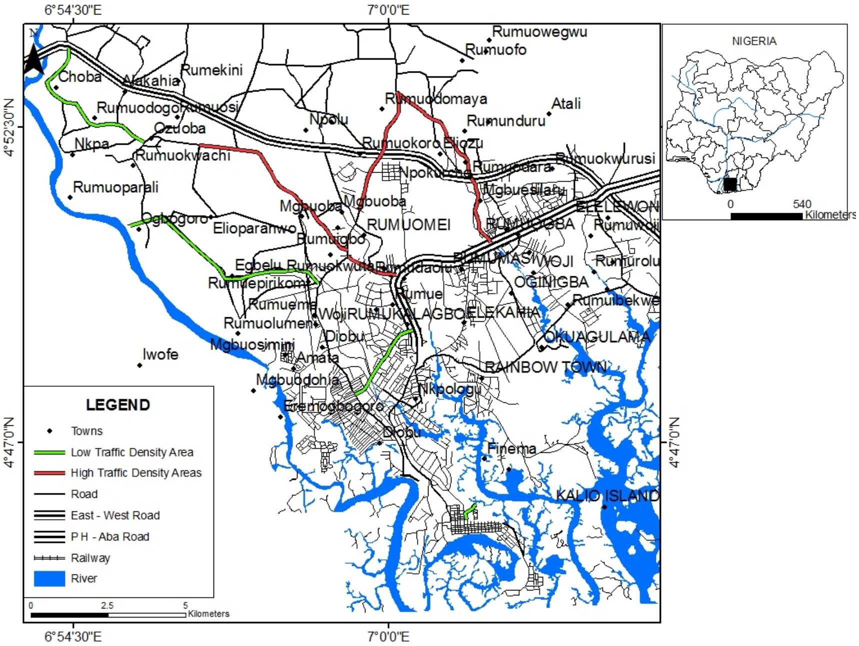

Figure 2: Port Harcourt Showing the Study Area (Source: [38]).

Three sessions were used to gather information from each of the chosen locations: morning (7:00 am to 10:00 am), afternoon (12.00 noon to 3.00 pm), and evening (5:00 pm to 8:00 pm). According to Utang and Peterside [27], Port Harcourt experiences low traffic density in the afternoon and high traffic density in the morning and evening. For twenty-four months, every place was observed Monday through Friday. In 2021, 12 more months of data collection were conducted to validate the model. Additionally, information on the diurnal pattern was gathered from 7:00 to 10:00 am and from 7:00 to 9:00 pm. Information collected during each session of investigation includes: (a) Traffic volume count which is the number of vehicles that cross a given point during each sampling session was collected using a closed circuit television (Plate 5.1). (b) Pollutant monitoring**:** The MX6 Ibrid Multigas monitor handheld device and the MET ONE GT 321 particulate matter counter for Particular Matters ($PM_{2.5}$ & PM_{10}) were used to measure the concentrations of CO, NO_2, SO_2, and VOC, as well as $PM_{2.5}$ & PM_{10} respectively. Additionally, the Davis Vantage Vue Weather Station, which was installed at each of the chosen places for the stipulated period, was used to determine the meteorological parameters (temperature, humidity, and wind speed).

The investigation's data was examined utilizing suitable descriptive and inferential statistical techniques. Data summaries in tables and graphs were part of descriptive presentations. The correlation between variables was investigated using multiple linear regression (MLRM), independent t-test for variables with two or fewer means, and one-way analysis of variance (one-way ANOVA) for variables with more than two means. Also, Factor analysis which made use of principal component analysis (PCA) was used. A statistical model was developed using the Multiple Regression Model (MRM) for the concentration of air pollutants with meteorological parameters and traffic volume. In this instance, it was applied to forecast air pollution levels based on traffic volume and meteorological factors.

$$K = x + x_1A + x_2B + x_3C + x_4D$$

where *K* is pollutants monitored (Predicted value of the criterion variable), x_1, x_2, x_3, and x_4 are coefficients (slope of the plane associated with A, B, C, D), x is constant (intercept), and A, B, C, and D are atmospheric temperature, humidity, wind speed and traffic volume (Predictor Variables).

4. Results and Discussion

4.1. Patterns of pollutants distribution in the study area

Table **1** shows the mean concentration of air pollutants in low and high-traffic zones of Port Harcourt, South-South, Nigeria from 2018 and 2019. The mean concentration of carbon dioxide (CO) was less than 9 ppm within the Low Traffic Density area (LTDA) of Ozuoba and Umuechi, but in the High Traffic Density area (HTDA) it ranged from 19.9 at Ada George to 26.3 ppm at Rumuokoro. The concentration of all the other pollutants investigated viz. SO_2, NO_2, $PM_{2.5}$, PM_{10} and VOC followed a similar pattern outlined for CO above in the various stations investigated. Generally, the lowest concentration of each pollutant was recorded in Umechi in the LTDA, while the highest concentration occurred in Rumuokoro Roundabout in the HTDA. The highest concentration recorded for each pollutant in the LTDA was at least two times lower than the concentration of the lowest concentration in the HTDA. Statistically, the concentration of all the pollutants varied significantly ($p < 0.001$) among the stations and between the LTDA and HTDA of Port Harcourt.

Table 1: Mean Concentration of Air Pollutants in Low and High Density Areas of Port Harcourt.

Traffic Density	Study Area	N	CO (PPM)	SO_2 (PPM)	NO_2 (PPM)	$PM_{2.5}$ (µg/m^3)	PM_{10} (µg/m^3)	VOC (PPM)
Low	Ozuoba/ Uniport Road	360	8.97±5.69	0.05±0.02	0.09±0.09	85.64±46.82	85.61±58.51	**0.10±0.13**
	Umuechi	360	1.42±0.52	0.01±0.01	0.01±0.01	48.71±27.83	46.18±31.57	**0.02±0.01**
	Total	**720**	**5.20±3.11**	**0.03±0.02**	**0.05±0.05**	**67.18±37.33**	**65.90±45.04**	**0.06±0.07**
High	Rumuokoro Roundabout	360	26.26±12.74	0.33±0.35	0.49±0.44	223.77±85.36	202.10±80.64	**0.48±0.45**
	Rumuola	360	24.36±11.65	0.44±0.35	0.45±0.33	195.01±83.36	180.69±71.55	**0.43±0.39**
	Location/ Ada George	360	19.85±10.62	0.08±0.05	0.18±0.16	150.11±62.59	143.87±43.01	**0.21±0.23**
	Total	**1080**	**23.49±11.67**	**0.28±0.25**	**0.37±0.31**	**189.63±77.10**	**175.29±65.07**	**0.37±0.36**
	T-Value **P-Value**		**38.305** **0.000**	**20.841** **0.000**	**24.160** **0.000**	**36.340** **0.000**	**35.703** **0.000**	**21.311** **0.000**

4.2. Seasonal variations in air pollution levels

The concentrations of air pollutants in 2018 and 2019 are shown in Figures **3** to **5**. Throughout the two years, the average CO concentration remained relatively constant, rising only marginally and non-significantly from 16.15±8.21 ppm in 2018 to 16.19±8.03 ppm in 2019. The other pollutants had the following corresponding values: $PM_{2.5}$ (140.04±91.21 in 2018 to 141.26±93.25 in 2019), PM_{10} (132.06±84.21 in 2018 to 131.32±82.69 in 2019), SO_2 (0.18±0.28 in 2018 to 0.19±0.28 in 2019), NO_2 (0.24±0.32 in 2018 to 0.25±0.33 in 2019), and VOC (0.22±0.33 in 2018 to 0.27±0.35 in 2019). As a result, the trend of temporal variation for all the pollutants showed a similar pattern, with the highest concentration of PM_{10} occurring in 2019 and the lowest concentration of the others occurring in 2018. While other characteristics were similar between the two research years, statistical analysis showed that the concentrations of CO and VOC differed significantly ($p < 0.01$) between 2018 and 2019.

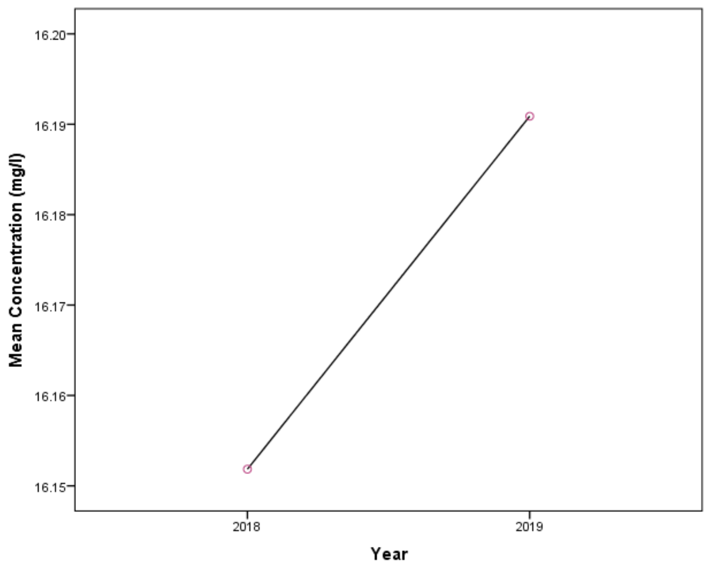

Figure 3: Yearly deviations in CO concentration between 2018 and 2019 in Port Harcourt.

4.3. The monthly distribution pattern of pollutants is displayed in Figures 6 through 8

The monthly concentration of air pollutants in the Port Harcourt study regions is shown in Figures **6**, **7**, and **8**. Between January and December, there was a modest variation in the average concentration of all the contaminants. November had the greatest CO concentration (16.91±13.65 ppm), while April had the minimum (15.62±13.36 ppm). However, the highest concentration of NO_2 (0.27±0.34 ppm) was recorded in September, and the lowest value (0.21±0.28 ppm) was observed in October. Similarly, the maximum concentration of SO_2 (0.20±0.31 ppm) was recorded in April, and the least concentration (0.16±0.25 ppm) was recorded in October. The months of December and January had the highest mean concentration of

$PM_{2.5}$ (145.27±94.31µg/m3) and the lowest (137.77±93.69 µg/m3) for particulate matter, while January and November had the highest (136.08±104.06µg/m3) and lowest (129.23±82.63 µg/m3) for PM_{10}. Additionally, the VOC content was lowest in June (0.19±0.29 ppm) and highest in February (0.32±0.40 ppm). The only statistically significant change ($p<0.05$) from January to December was in VOC.

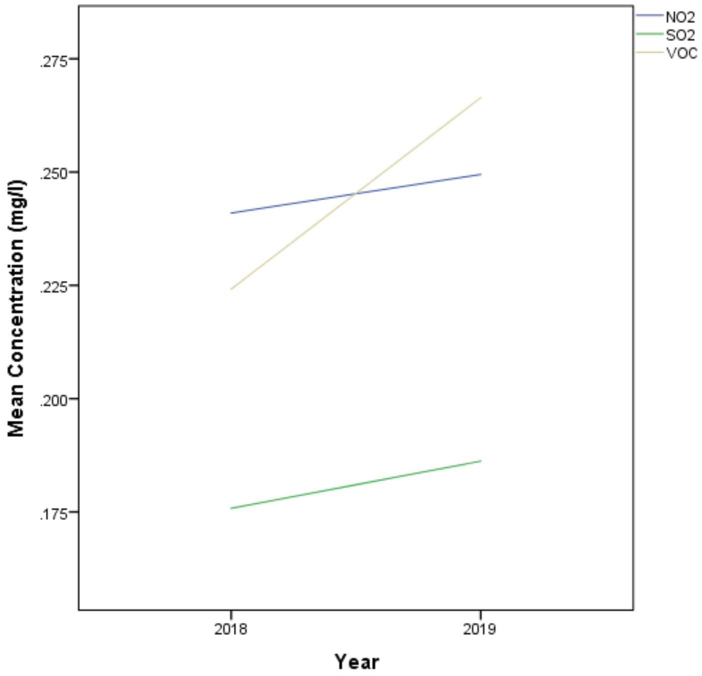

Figure 4: Annual variations in VOC, NO_2, and SO_2 concentration between 2018 and 2019 in Port Harcourt.

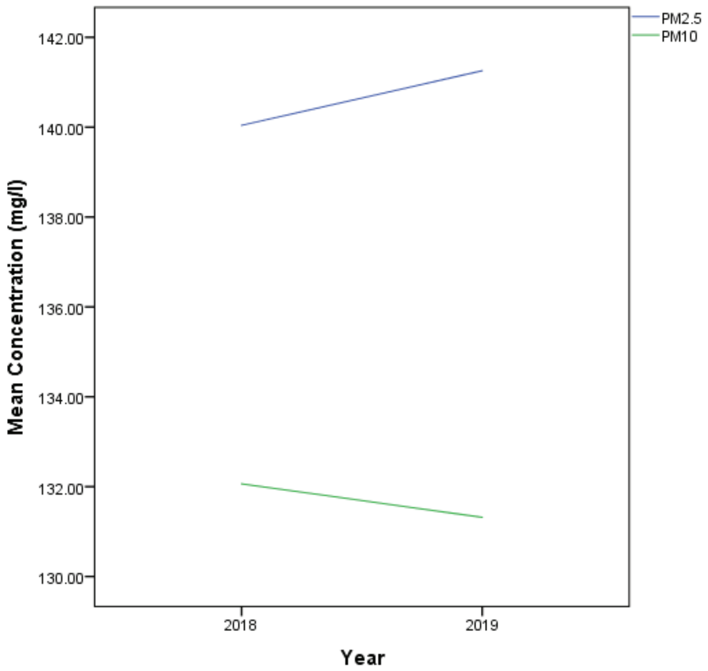

Figure 5: Yearly deviations in $PM_{2.5}$ and PM_{10} concentration between 2018 and 2019 in Port Harcourt.

Figure **9** shows a bar chart of monthly traffic volume within the study areas between 2018 and 2019. The chart revealed that traffic volume was highest in December, followed by March and lowest in January for the two years monitored. The number of vehicles on the road in December could be attributed to the holiday period notable within the region, where there are a lot of movements in and out of the city. On the other hand, the region is usually known to experience fewer vehicular movements in January.

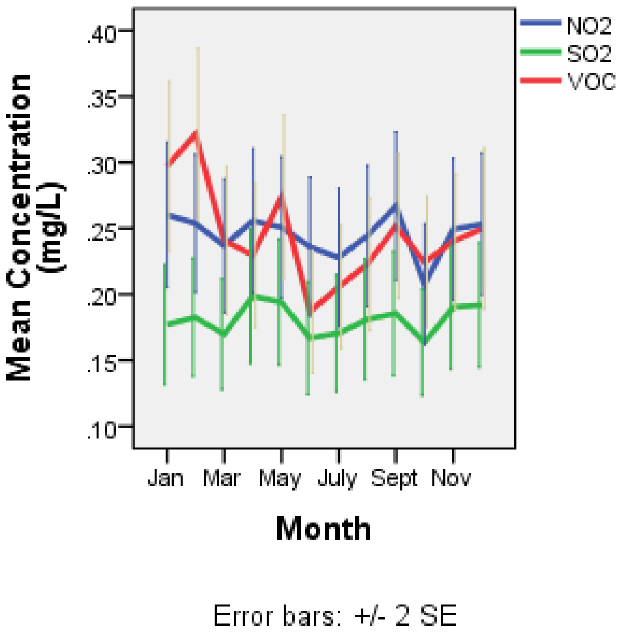

Figure 6: Monthly deviations in NO_2, SO_2 and VOC concentration in Port Harcourt.

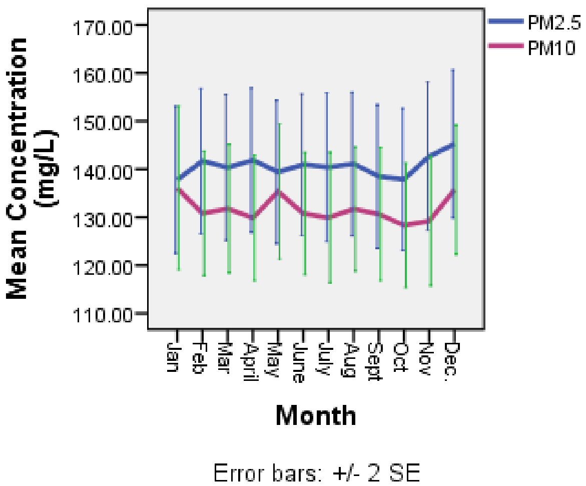

Figure 7: Monthly variations in $PM_{2.5}$ and PM_{10} concentration in Port Harcourt.

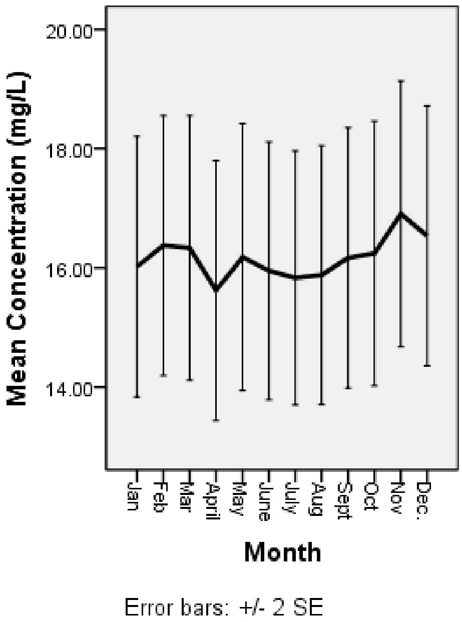

Figure 8: Monthly deviations in CO concentration in Port Harcourt.

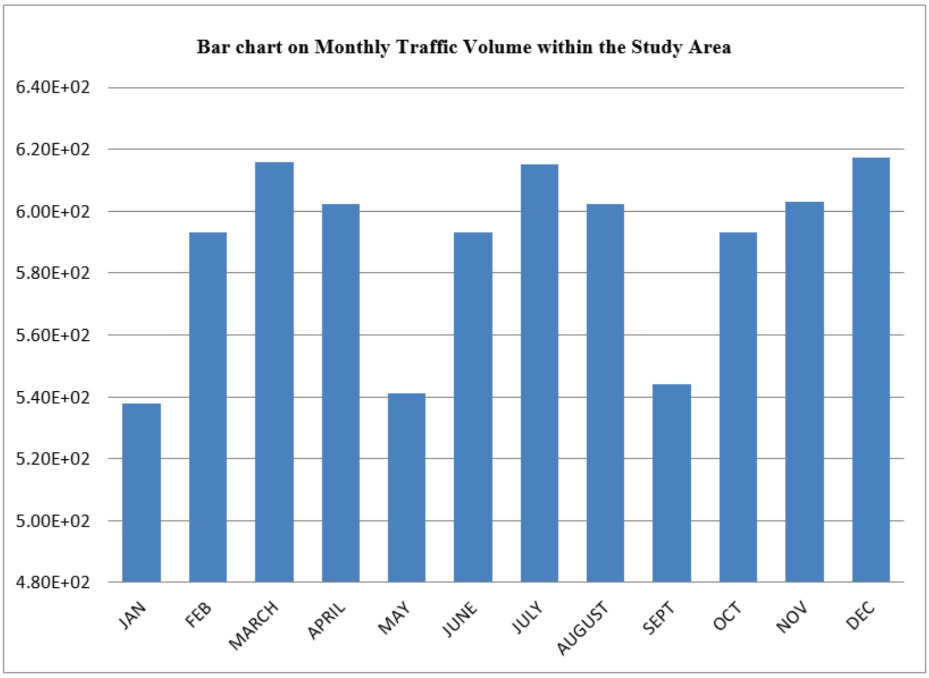

Figure 9: Monthly deviations in the amount of traffic within the study locations in Port Harcourt.

4.4. The distribution pattern of air contaminants throughout the week at various times

The concentration of air pollutants at various times of the day within the Port Harcourt research locations is shown in Table **2**. All of the pollutants' mean concentrations dropped from their morning peak to their afternoon lowest points before increasing once again to reach their evening peak. According to statistical analysis, there was a significant difference ($p < 0.001$) in the change of pollutants' concentrations throughout the day. The concentration of air pollutants in the Port Harcourt study locations on various days of the week is shown in Table **3**. Every air pollutant changed a little bit throughout the week. Friday had the greatest mean concentrations of CO, $PM_{2.5}$, and PM_{10}, at 17.61±12.32 ppm, 147.88±93.01μg/m3, and 136.68±83.81 μg/m3, respectively. CO, NO_2, SO_2, $PM_{2.5}$, and PM_{10} concentration variations were not statistically different (P>0.05), however VOC concentrations changed considerably by day of the week.

Table 2: Average Air Pollutant Concentration in Port Harcourt at Various Times of the Day.

Period	**N**	**CO (PPM)**	**SO_2 (PPM)**	**NO_2 (PPM)**	**$PM_{2.5}$ (μg/m^3)**	**PM_{10} (μg/m^3)**	**VOC (PPM)**
7am-10 am	600	22.01±12.15	0.19±0.35	0.35±0.33	163.68±73.71	154.51±81.27	**0.30±0.21**
12noon-3pm	600	8.91±7.14	0.07±0.13	0.09±0.15	81.19±49.71	77.60±50.06	**0.16±0.28**
5pm-8pm	600	19.73±13.85	0.26±0.35	0.36±0.39	184.81±104.48	167.07±89.70	**0.31±0.37**
F-Value **P-Value**		**222.411** **0.000**	**75.894** **0.000**	**136.097** **0.000**	**276.650** **0.000**	**248.927** **0.000**	**40.609** **0.000**

Table 3: Mean Concentration of Air Pollutants at different days of the week in Port Harcourt.

Days	**N**	**CO(PPM)**	**NO_2(PPM)**	**SO_2(PPM)**	**$PM_{2.5}$(μg/m^3)**	**PM_{10}(μg/m^3)**	**VOC(PPM)**
Monday	360	16.89±12.61	0.36±0.22	0.19±0.28	139.69±92.54	133.26±91.85	**0.26±0.34**
Tuesday	360	17.33±12.34	0.37±0.23	0.19±0.27	139.67±91.95	132.13±82.34	**0.26±0.35**
Wednesday	360	17.39±12.19	0.34±0.20	0.19±0.27	141.01±90.44	130.82±81.50	**0.31±0.35**
Thursday	360	17.19±12.07	0.34±0.20	0.19±0.26	140.05±88.33	130.60±82.52	**0.24±0.32**
Friday	360	17.61±12.32	0.36±0.22	0.19±0.26	147.88±93.01	136.68±83.81	**0.21±0.28**
Total	**1800**	**17.28±12.31**	**0.35±0.21**	**0.19±0.27**	**141.66±91.25**	**132.70±84.40**	**0.26±0.33**
F-value		0.178	0.421	0.012	0.415	0.205	**4.283**
P-value		**0.834**	**0.603**	**0.899**	**0.708**	**0.758**	**0.000**

4.5. Variations in meteorological parameters

Table **4** presents the values of meteorological parameters at different locations in the study locations in Port Harcourt. The average air temperature ranged from 24.63±5.01°C at Umuechi to 25.42±3.94°C at Rumuola. . Conversely, the values of humidity and wind speed were highest at Umuechi (40.34±3.46%; 1.39±0.05 ms^1) and lowest at Rumuola (37.85±4.43%) and Rumuokoro (1.36±0.03 ms^1) respectively. The highest volume of vehicles also occurred at Rumuokoro Roundabout (1039.60±964.13) while the least occurred at Umuechi (23.21±31.57).Statistical analysis revealed that the values of all meteorological parameters except air temperature varied significantly ($P < 0.001$) among the stations investigated in diverse areas of Port Harcourt.

In Table **5**, the mean air temperature ranged from 22.84±1.37°C in the morning to 22.74±3.37°C in the evening. The variation in humidity and traffic volume was highest in the evening peak and ranged from (38.90±3.15% to 41.17±5.25%) for humidity, (583.45±757.61 to 594.08±770.55) for traffic volume, between morning and evening peak respectively. Wind speed recorded its highest value (1.39±0.06 ms^1) in the morning and lowest (1.35±0.06 ms^1) in the afternoon peak. Statistically, the variation in air temperature, humidity and wind speed concentration over the day was significantly ($P < 0.001$) different, but was the same ($P>0.05$) for traffic volume.

Table **6** reveals the values of meteorological parameters on different days of the week in Port Harcourt. The mean air temperature between Monday to Friday was 25.12±4.33°C and recorded the highest value on Tuesday (25.17±4.37°C). The highest value occurred on Monday for humidity, wind speed and traffic volume (39.60±4.56%, 1.37±0.08 ms^1, and 587.69±764.11) and the lowest on Friday (38.57±3.62%, 1.37±0.05 ms^1, and 586.69±764.11). Statistical analysis revealed that only humidity was significantly ($P<0.001$) different, while air temperature, wind speed and traffic volume were insignificantly ($P>0.05$) different within the days of the week.

In Table **7**, the overall air temperature value revealed a slight increase from 2018 to 2019 (25.09±4.38°C to 25.14±4.28°C). Wind speed and traffic volume followed the same pattern and ranged from (1.37±0.05 ms^1 in 2018 to 1.37±0.06 ms^1in 2019), and (44.17±30.18 in 2018 to 1131.20±757.21 in 2019). There was a slight decrease in the value for humidity from (39.26±4.13% in 2018 to 39.13±4.07% in 2019). The statistical analysis showed that only traffic volume varied significantly.

Table 4: Mean Metrological Conditions and Traffic Volume at different Locations in Port Harcourt.

Study Area	N	Air Temperature (°C)	Humidity (%)	Wind Speed (MS^{-1})	Traffic Volume (M^3)
Rumuokoro Roundabout	360	25.41±4.71	38.84±3.80	1.36±0.03	**1039.60±964.13**
Rumuola	360	25.42±3.94	37.85±4.43	1.36±0.07	**1020.70±946.06**
Ozuoba/Uniport Road	360	25.08±3. 77	38.89±4.64	1.36±0.06	**444.17±415.49**
Location/Ada George	360	25.03±4.06	40.06±3.53	1.36±0.06	**410.75±396.82**
Umuechi	360	24.63±5.01	40.34±3.46	1.39±0.05	**23.21±31.57**
Total	**1800**	**25.12±5.33**	**39.20±4.10**	**1.37±0.06**	587.69±763.26
F-value		2.03.610	22.960	25.023	**159.188**
P-value		**0.089**	**0.000**	**0.000**	**0.000**

Table 5: Mean Metrological Conditions and Traffic Volume over Day time Periods in Port Harcourt.

Period	N	Air Temperature (°C)	Humidity (%)	Wind Speed (MS^{-1})	Traffic Volume (M^3)
7am-10am	600	22.84±1.37	38.90±3.15	1.39±0.06	**583.45±757.61**
12noon-3pm	600	29.77±3.23	37.52±2.48	1.35±0.06	**585.55±762.79**
5pm-8pm	600	22.74±3.37	41.17±5.25	1.36±0.04	**594.08±770.55**
Total	**1800**	**25.12±4.33**	**39.20±4.10**	**1.37±0.06**	587.69±763.26
F-value		1235	139.588	84.439	**0.033**
P-value		**0.000**	**0.000**	**0.000**	**0.968**

Table 6: Mean Metrological Conditions and Traffic Volume at different days of the week in Port Harcourt.

Days	N	Air Temperature (^{0}C)	Humidity (%)	Wind Speed (MS^{-1})	Traffic Volume (M^3)
Monday	360	25.08±4.37	39.60±4.56	1.37±0.08	**587.69±764.11**
Tuesday	360	25.17±4.37	39.16±4.08	1.37±0.05	**587.69±764.11**
Wednesday	360	25.08±4. 26	38.94±3.98	1.36±0.05	**587.69±764.11**
Thursday	360	25.15±4.34	39.72±4.10	1.37±0.05	**587.69±764.11**
Friday	360	25.09±4.32	38.56±3.62	1.37±0.05	**586.69±764.11**
Total	**1800**	**25.12±4.33**	**39.20±4.10**	**1.37±0.06**	587.69±763.26
F-value		0.035	4.914	1.585	**0.000**
P-value		**0.998**	**0.000**	**0.176**	**1.000**

Table 7: Mean Metrological Conditions and Traffic Volume in Port Harcourt in 2018 and 2019.

Year	**N**	**Air Temperature (°C)**	**Humidity (%)**	**Wind Speed (MS^{-1})**	**Traffic Volume (M^3)**
2018	900	25.09±4.38	39.26±4.13	1.37±0.05	**44.17±30.18**
2019	900	25.14±4.28	39.13±4.07	1.37±0.06	**1131.20±757.21**
Total	**1800**	**25.12±4.33**	**39.20±4.10**	**1.37±0.06**	**587.69±763.26**
F-value		0.060	0.430	0.002	**1853**
P-value		**0.806**	**0.512**	**0.966**	**0.000**

4.6. Impact of traffic volume on average air pollution concentrations across Port Harcourt

The results of a regression analysis of traffic volume and air pollution concentration within the Port Harcourt research locations are shown in Table **8**. As traffic volume rose, so did the concentrations of CO, SO_2, NO_2, VOC, $PM_{2.5}$, and PM_{10}. However, CO, SO_2, NO_2, VOC, $PM_{2.5}$, and PM_{10} were all significantly predicted by traffic volume.

Table 8: Impact of Traffic Volume on the Average Air Pollutant Concentration in Various Port Harcourt Areas.

Independent Variable (X)	**Dependent Variables (Y)**	**N**	**Mean ± SD**	**T-value**	**B**	**SE of B**	**P-value**
	CO	1800	17.18±14.39	16.27	0.00	0.00	< **0.01**
	NO_2	1800	0.36±0.43	15.11	0.00	0.00	< **0.01**
Traffic Volume	SO_2	1800	0.29±0.39	14.84	0.00	0.00	< **0.01**
	$PM_{2.5}$	1800	141.66±93.32	16.77	0.02	0.00	< **0.01**
	PM_{10}	1800	132.70±94.54	16.01	0.02	0.00	< **0.01**
	VOC	**1800**	**0.25±0.34**	**15.83**	**0.00**	**0.00**	< **0.01**

A model that can predict the concentration of CO, NO_2, SO_2, $PM_{2.5}$, PM_{10} and VOC at different locations, variation of temperature, humidity, wind speed and vehicular counts is stated below;

RUMUOKORO ROUNDABOUT

$CO = 71.991 - 2.538A - 0.116B + 16.668C + 0.001D$ (1a)

$NO_2 = 3.640 - 0.066A - 0.011B - 0.401C + 1.625E\text{-}5D$ (2a)

SO_2 = -4.686 – 0.013A + 0.003B +3.849C + 1.3292E-5D (3a)

$PM_{2.5}$ = 335.222 – 15.754A +0.398B + 199.123C + 0.003D (4a)

PM_{10} = 255.084 -14.737A +1.034B + 205.397C + 0.002D (5a)

VOC = -0.859 – 0.018A + 0.044B - 0.007C + 8.749E-5D (6a)

RUMUOLA

CO = 111.138 -2.827A -0.133B - 7.572C + 0.001D (1b)

NO_2 = 1.918 - 0.061A + 0.006B – 0.121C + 1.127E-5D (2b)

SO_2 = 2.142 – 0.058A + 0.004B -0.275C + 1.104E-6D (3b)

$PM_{2.5}$ = 703.939 – 18.017A +1.468B - 79.593C + 0.002D (4b)

PM_{10} = 770.684 -16.957A -1.053B - 88.132C + 0.001D (5b)

VOC = -0.108 – 0.042A + 0.024B + 0.495C + 9.070E-6D (6b)

OZUOBA/UNIPORT ROAD

CO = 25.834 -0.843A -0.033B +5.635C - 0.005D (1c)

NO_2 = 0.860 - 0.009A + 0.002B – 0.321C - 1.613E-5D (2c)

SO_2 = 0.167 – 0.002A + 0.000B -0.062C + 6.540E-7D (3c)

$PM_{2.5}$ = 257.383 – 7.875A -0.936B +48.573C - 0.008D (4c)

PM_{10} = 272.599 -7.033A +0.817B - 25.712C - 0.017D (5c)

VOC = 0.1 – 0.007A + 0.004B + 0.018C -7.577E-6D (6c)

LOCATION/ADAGEORGE ROAD

CO = 26.873 -2.094A +0.084B + 29.881C + 0.003D (1d)

NO_2 = 0.529 - 0.013A + 0.020B – 0.608C + 1.439E-5D (2d)

SO_2 = 0.477 – 0.005A + 2.889E-5B -0.208C + 2.448E-5D (3d)

$PM_{2.5}$ = 779.889 – 13.895A +1.632B – 257.397C + 0.010D (4d)

PM_{10} = 607.589 -9.431A +0.877B - 195.020C + 0.008D (5d)

VOC = -0.602 – 0.002A + 0.023B - 0.049C + 5.920E-5D (6d)

UMUECHI/ALUU ROAD

CO = -0.598 -0.035A +0.022B + 1.453B - 0.001D (1e)

NO_2 = -0.052 + 0.000A + 0.001B + 0.025C - 1.433E-5D (2e)

SO_2 = 0.021 – 0.000A + 7.415E-5B -0.014C - 2.976E-6D (3e)

$PM_{2.5}$ = 133.678 – 4.081A +1.719B – 37.663C - 0.059D (4e)

PM_{10} = 265.343 -3.608A +2.967B - 178.358C - 0.069D (4.5e)

VOC = 0.023 – 0.000A + 0.001B - 0.005C + 0.000D (4.6e)

This study examined the impact of vehicle exhaust emissions on air quality in Port Harcourt neighborhoods with low and high-traffic densities. It was predicated on the idea that particle emissions from exhaust pipes increased with the amount of traffic in a given location. Five locations were chosen for the study: two from low-traffic density regions (Ozuoba and Umuechi) and three from heavy-traffic areas (Rumuokoro, Rumuola, and Ada George/Location). The findings showed that all of the air pollutants that were examined—CO, NO_2, SO_2, $PM_{2.5}$, PM_{10}, and VOC—had considerably greater concentrations in high-traffic areas compared to low-traffic areas. Additionally, the concentration of every pollutant in the study area is positively and significantly correlated ($p<0.001$) with traffic volume. Regression analysis revealed that only CO, VOC, and SO_2 had a significant dependent association with traffic volume, indicating that the concentration of these pollutants rises and air quality falls as traffic volume rises, thereby adversely affecting the health of people living around the study sites. The findings of [44] indicate that while traffic volumes were high in the Motor Park, the concentrations of CO, SO_2, $PM_{2.5}$, and PM_{10} were higher in the morning and evening (6 a.m. to 7 a.m. and 6 p.m. to 7 p.m.), agrees with the present study. However, this is in agreement with previous studies carried out in other cities of the world [45, 46, 47, 48]. Also, the study of [49] supported the outcome of this study.

Additionally, this study found a substantial correlation between the concentration of air contaminants and the pattern of vehicle volume during the day. There was a positive and substantial correlation between the density of traffic vehicles and the levels of all contaminants. The results of this study concurred with those of Prince and Essiet [37], who looked into vehicle pollution at intersections on a few chosen highways in Uyo, Nigeria, during periods of high traffic. Their findings showed that during moments of significant traffic congestion, the concentration of CO was higher. They linked the high pollution loading during these times to both the high traffic volume and the lengthy wait times, which cause the vehicles' carburetors to release products of incomplete combustion. Furthermore, the current study's results are in perfect agreement with the mean diurnal tendencies of experimentally determined concentrations in central Budapest [50, 51] and conform to the time variations in numerous other European cities [52, 53, 54, 55, 56].

Furthermore, Mikkonen *et al.*'s [57] investigation revealed that the diurnal statistical patterns indicated that the observed changes were probably caused by a reduction in traffic emissions. It is anticipated that during the period of interest, traffic intensity in the city center would have changed somewhat. Their findings suggested that the decreases are probably due to fewer emission components, which is consistent with the current study's findings.

Further, temperature, relative humidity, and wind speed all showed significant correlations with air pollution concentrations, according to the examination of meteorological factors. The dispersion rate that CO, NO_2, SO_2, $PM_{2.5}$, PM_{10}, and VOC experienced at various peak periods was explained by variations in the metrological parameters. A pattern in the concentration of the air pollutants under investigation was shown by the modest changes in average temperature, humidity, and wind speed between 2018 and 2019. This collaborated with [65], who stated that significant positive relationships were found between particulate matters concentration and variables such as sea level pressure and humidity. The findings aligned with the study outcome of [58, 59, 60, 61, 62, 63, 64]. Also, the study of [66] which revealed that CO_2, NO_2, SO_2, $PM_{2.5}$, and VOC were significantly correlated with atmospheric pressure, temperature, and relative humidity, agreed with the present study's outcome.

In support of the findings of the present research, [67, 68, 69] asserted that to comprehend the causes of air pollution and develop efficient mitigation techniques, it is essential to characterize the diurnal changes and the impact of meteorological elements, especially determining $PM_{2.5}$ concentration. This implies that meteorological factors are vital to the understanding of air pollutants dispersion. From high to low, the correlation between $PM_{2.5}$ concentration and meteorological parameters was as follows: relative air humidity > soil temperature > air temperature > soil humidity > wind velocity > rainfall, according to the correlation study by [70], which collaborated with the present study.

Answers to the Objectives

Objective 1: Characterizing the pattern of air pollutants emission in selected low and high-traffic density areas in Port Harcourt, Nigeria

The Principal component analysis (PCA) used diurnal and seasonal data on air pollutants emissions and selected climate variables collected in Port Harcourt over 2018 and 2019. The specific data used were CO, NO_2, SO_2, $PM_{2.5}$, PM_{10}, VOC, air temperature, humidity, wind speed and traffic volume (see data in Tables **9** to **12**). The result of the PCA includes KMO, communalities, total variance explained, Eigenvalue, Scree plot and rotated component matrix.

The Kaiser-Meyer-Olkin value of 0.89 indicates a fairly strong measure of sampling adequacy (Table **9**). This was further confirmed by Bartlett's test of sphericity to be very highly significant ($p< 0.05$) with χ^2 of 73.58. The test of the relative importance of the 10 parameters (principal components) entered into the analysis showed that only two had eigenvalue greater than 1 and together both explained over 65% of the total variability in the data (Table **10**). This is a clear indication that the two factors are sufficient in significantly explaining the characteristic pattern of air pollutants emissions in the study area. Therefore, 35.6% of the variance in the data set was not explained. The pattern of air pollutants was also validated with the extraction of communalities which is the estimate of each variable that is shared with others (Table **11**).

It is also noteworthy that among the 10 variables entered in the commonality analysis, 8 variables shared more than 50% of their variability while only 2 variables shared less than 50%. The implication is that there is a significant characteristics pattern of air pollutant emissions within the study area in 2018 and 2019. The varimax rotation (Table **12**) reduced the 10 variables used in the analysis to 2 components of characteristics air pollutants pattern, which includes components 1 and 2. The variables in component 1 are $PM_{2.5}$ with 0.928, PM_{10} with 0.923, CO with 0.900, NO_2 with 0.884, SO_2 with 0.802, VOC with 0.730 and traffic volume with 0.493. The characteristics pattern in component 2 are humidity with 0.741, air temperature with -0.711 and wind speed with 0.585. Hence, the two loading characteristics pattern of the variables in components 1 and 2 could be described as derived parameters. Therefore, the components of derived parameters are related, thereby having the same pattern with the study years. The eigenvalue Scree plot shown in Figure **10** reveals graphically the pattern of pollutants emissions in the study area. The Scree plot helps the study to determine the number of components accountable for characteristics the pattern of air pollutants emissions in the study area. The sum of the Eigenvalue equals the number of characteristics variables component. Also, Bartlett's Test of Sphericity of 0.000 ($P<0.001$) validates the similarity of air pollutants emission patterns.

Table 9: KMO and Bartlett's test of sphericity and sampling adequacy.

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.890
Bartlett's Test of Sphericity	Approx. Chi-Square	14729.478
	Df	55
	Sig.	.000

Table 10: Total explained variance of characteristic pattern of air pollutant emission.

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	5.007	50.066	50.066	5.007	50.066	50.066	4.911	49.105	49.105
2	1.538	15.376	65.442	1.538	15.376	65.442	1.634	16.337	65.442
3	.877	8.771	74.214						
4	.777	7.769	81.982						
5	.670	6.704	88.686						
6	.377	3.769	92.455						
7	.352	3.516	95.971						
8	.226	2.261	98.232						
9	.107	1.067	99.299						
10	.070	.701	100.000						

Table 11: Communality of characteristic pattern of air pollutant emission.

Parameter	**Initial**	**Extraction**
CO	1.000	**0.831**
NO_2	1.000	**0.785**
SO_2	1.000	**0.646**
$PM_{2.5}$	1.000	**0.887**
PM_{10}	1.000	**0.871**
VOC	1.000	**0.535**
Air Temperature	1.000	**0.683**
Humidity	1.000	**0.554**
Wind Speed	1.000	**0.344**
Traffic Volume	**1.000**	**0.410**

Table 12: Rotated Component Matrix of the variables.

	Component	
Variables	1	2
PM2.5	.928	
PM10	.923	
CO	.900	
NO2	.884	
SO2	.802	
VOC	.730	
Traffic Volume	.493	-.408
Humidity		.741
Air temperature	-.421	-.711
Wind speed		.585

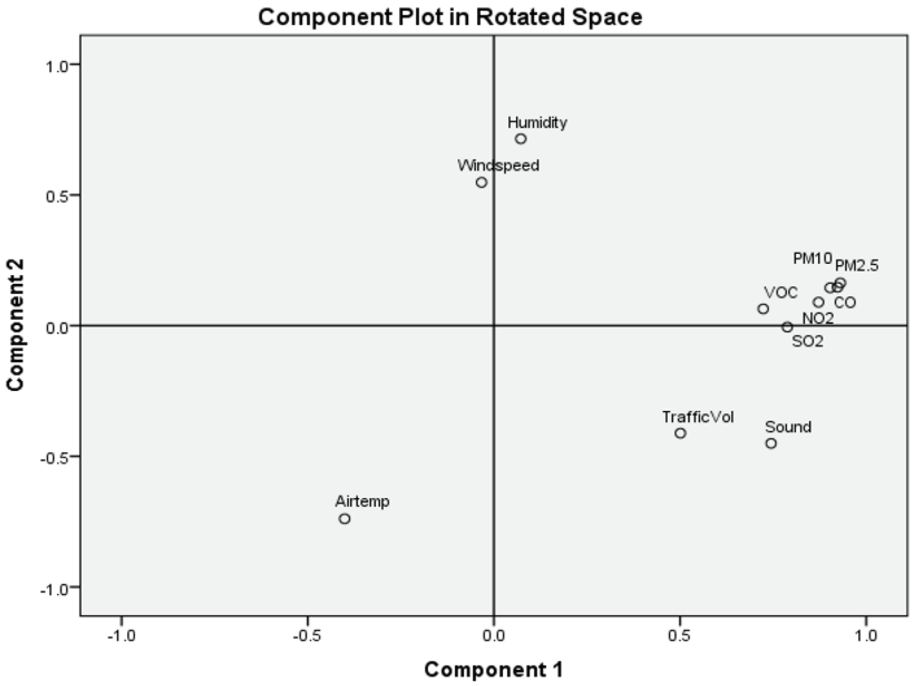

Figure 10: Component plot in rotated space.

Objective 2: Assess the impact of meteorological factors on the concentration of pollutants in the chosen areas

Table **13** displays the findings of a regression analysis conducted on the variables influencing the concentration of pollutants in the study areas. The three climatic factors (wind speed, humidity, and air temperature) that were evaluated had a substantial ($p<0.05$) impact on the levels of CO, NO_2, $PM_{2.5}$, and PM_{10}. However, in the Port Harcourt research sites, two of the parameters (air temperature and humidity) considerably ($P<0.001$) aids the concentration of SO_2 and VOC. Meteorological conditions, however, have a major impact on the concentration of pollutants in the studied locations.

Table 13: Findings from a statistical analysis of the meteorological variables influencing the concentration of pollutants in the research areas.

Parameter	Air Temp				Humidity				Wind Speed			
	B	R^2	SE of B	P-value	B	R^2	SE of B	P-value	B	R^2	SE of B	**P-value**
CO	-1.65	0.24	0.07	0.000	-0.37	0.24	0.07	0.000	-11.92	0.24	5.11	**0.020**
NO_2	-0.03	0.15	0.00	0.000	-0.00	0.15	0.00	0.025	-0.50	0.15	0.13	**0.000**
SO_2	-0.02	0.07	0.00	0.000	-0.01	0.07	0.00	0.000	-0.16	0.07	0.12	**0.172**
$PM_{2.5}$	-12.08	0.28	0.48	0.000	-1.47	0.28	0.50	0.003	-182.32	0.28	34.31	**0.000**
PM_{10}	-10.74	0.27	0.43	0.000	-1.36	0.27	0.45	0.003	-211.11	0.27	31.26	**0.000**
VOC	**-0.01**	**0.06**	**0.00**	**0.000**	**0.01**	**0.04**	**0.06**	**0.000**	**-0.16**	**0.06**	**0.15**	**0.28**

Objective 3: Determine the connection between the study area's concentration of air pollutants and the daily pattern of vehicle volume

Table **14** displays the findings of a regression analysis conducted on the correlation between the study area's concentration of air pollutants and the diurnal pattern in vehicular counts. All of the air contaminants examined at the research site have a significant ($p<0.001$) relationship with the vehicle volume. Vehicular volume also accounts for at least 44% of each pollutant concentration. This indicates a pattern in the amount of vehicles and air pollution during the day. Consequently, there is a correlation between the research area's concentration of air contaminants and the diurnal pattern in vehicular volume.

Table 14: Findings from a statistical analysis of the correlation between the study areas' concentrations of air pollutants and the diurnal pattern in vehicle volume.

Parameter	Traffic Volume			
	B	R^2	SE of B	**P-value**
CO	0.01	0.59	0.00	**0.000**
NO_2	0.01	0.54	0.00	**0.000**
SO_2	0.00	0.56	0.00	**0.000**
$PM_{2.5}$	0.03	0.55	0.00	**0.000**
PM_{10}	0.03	0.56	0.00	**0.000**
VOC	**0.00**	**0.55**	**0.00**	**0.000**

Objective 4: Examine if there is a significant difference in the concentration of air pollutant emission in low and high-traffic density areas in Port Harcourt

The results of Independent T-test carried out on the concentration of air pollutants in the low and high-traffic congested areas of Port Harcourt are presented in Table **15**. All the air pollutants investigated varied significantly ($p< 0.01$) between the low and high-traffic zones. Each pollutant was significantly higher in the high-traffic density area than in the low traffic density area of Port Harcourt. Based on that, there is a significant difference in the concentration of air pollutant emission in low and high-traffic density areas in Port Harcourt

Table 15: Findings from a statistical analysis comparing the levels of air pollutants in Port Harcourt's low- and high-traffic zones.

Parameter	F-value	Mean Difference	T-Value	Df	P-value
CO	887.63	18.30	38.31	1798	0.000
NO_2	1482.54	0.33	24.16	1798	0.000
SO_2	1095.95	0.25	20.84	1798	0.000
$PM_{2.5}$	495.55	122.45	36.34	1798	0.000
PM_{10}	233.607	109.66	35.70	1798	0.000
VOC	1200.41	0.31	21.31	1798	0.000

5. Conclusion

The average concentration of air pollutants in all locations under observation increased somewhat between 2018 and 2019. The increase in vehicle traffic volume was the reason for the variation. Due to higher traffic volumes, the concentration of CO was comparatively high in the high density locations (Rumuokoro roundabout, Rumuola road, and Location/Ada George road). The extra air and compression circumstances for diesels result in spark-ignited emissions that are, in certain situations, an order of magnitude higher than those for hydrocarbons and carbon monoxide. Due to incomplete combustion during driving, the majority of automobiles and buses that run on gasoline emit carbon monoxide. Additionally, this study found a substantial correlation between the concentration of air contaminants and the pattern of vehicle volume during the day. There was a positive and substantial correlation between the density of traffic vehicles and the levels of all contaminants. As a result, Port Harcourt's high traffic density zones are in grave danger due to the contribution of vehicle emissions to air pollution, hence requiring immediate intervention in other to meet United Nations sustainable development goals (SDG). Variations in temperature, humidity, and wind speed were associated with various concentrations of air contaminants. The overall mean score for relative humidity varied somewhat between 2018 and 2019, however there was no difference in the overall mean for temperature or wind speed in either of those years. With a relative humidity of 40.34±3.46%, Umuechi/Aluu has the lowest concentration of contaminants, which explains why the area's pollution levels are so low. Finally, the statistical model that was created showed the regression equation that can be used to estimate the concentration of pollutants (CO, NO_2, SO_2, $PM_{2.5}$, PM_{10}, and VOC) at different vehicular volumes and metrological parameters. However, Nigeria's environmental policy is set up to include components that encourage industries and individuals to act responsibly toward the environment. Forming, passing, implementing, and possibly enforcing current laws that provide environmental protection through efficient action towards environmental planning, as well as pollution prevention and control, will help to reduce air pollution from vehicles, which is in agreement with SDG, since the study has shown the extent of pollution caused by vehicular emissions, which poses a threat to people living and working in such areas in Port Harcourt city, Nigeria. Accordingly, the Nigerian government must implement the recommendations by the United Nations SDG for further measures, which include planting trees and implementing other tactics, to maintain the quality of the air.

Ethical Issue

Authors are aware of and comply with, best practices in publication ethics specifically about authorship (avoidance of guest authorship), dual submission, manipulation of figures, competing interests, and compliance with policies on research ethics. Authors adhere to publication requirements that the submitted work is original and has not been published elsewhere in any language.

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Conflicts of Interest

The authors declare that no conflict of interest would prejudice the impartiality of this scientific work.

Author Contributions

All the authors have the same contribution to data collection, data analyses, and manuscript writing.

Artificial Intelligence (AI)

During the preparation of this work, the authors may have used AI to enhance the manuscript writing. After using the AI tool, the authors reviewed and edited the content as needed and took full responsibility for the content of this manuscript.

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