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2. Assessment of Air Pollutant Variation in Selected Residential Areas of Lagos State, Nigeria

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Abstract

The study examined variations in air pollutants across residential areas in Lagos State and identified the spatial distributions of pollutants as well as the seasonal variations in air quality characteristics. Data was gathered using primary and secondary sources. The secondary data covered air pollutants (CO and O_3) from 1980 to 2022 and NO_2 and SO_2 from 2005 to 2022 across residential areas. Data obtained was analyzed using ANOVA, stepwise multiple regression and PCA. The result revealed that seasonal variation in air pollutants showed that the contents of CO and NO_2 were high in the dry season, while those of O_3 and SO_2 were high in the wet season. Air pollutants were also observed to be higher in the morning than in the evening across the residential area. Results of PCA identified anthropogenic activities across the two residential areas responsible for the emission of PM and CO. In the high and low residential areas, only temperature was significantly positive and explained 30.8% and 31.3% of the variation (increase) in CO_2. In the high residential area, a positive and significant association was observed between temperature and CO_2 (rho = 0.579, $p<0.05$); a negative association existed between wind and CO_2 (rho = -0.627, $p<0.05$), while in the low-density areas, a positive and significant association was observed between temperature and CO_2 (rho = 0.610, $p<0.05$). Based on the findings, the study suggested that the road network should be rehabilitated and widened to accommodate the increasing volume of vehicular traffic. In addition, afforestation should be encouraged, to serve as a carbon sink along the major highway roads, to achieve Sustainable Development Goals (SDG 9 & SDG11).

Keywords: Air Pollutants, Particulate matter (PM), Residential, Variation.

Introduction

Urban air pollution has become an issue of serious environmental concern. The threat posed on human life, living organisms and property makes it mandatory to devise control measures to combat it. This can only be achieved by establishing reliable information about the source-receptor relationship of the pollutants (Oluyemi and Asubiojo, 2001; Adejobi, 2020).

The man might survive weeks without food and days without water, but he can only last a few seconds without clean air. An average person breathes over 3,000 gallons of air each day. The World Health Organisation (WHO,2018). What happens when the air is polluted? Air or tropospheric- pollution can make breathing difficult. Children and senior citizens are especially vulnerable, but anyone who inhales deeply can suffer asthma attacks, coughing and wheezing, and shortness of breath (Raheem and Adekola, 2009; Magaji and Hassan, 2015).

In Nigeria, air pollution has affected the local weather conditions. This is apparent in the change in the duration and intensity of rainy, harmattan and dry seasons. Recently, the heat emissions of the sun have become rather scorching, and experts believe it is due to the depletion of the protective ozone layer. The warming effect that results from this phenomenon could affect significantly the comfort and the livability of the urban people

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(Ukemenam, 2014). Also, the distribution and abundance of particulate matter is responsible for local rainfall patterns and hence there is a significant increase in precipitation in and around cities and is due to air pollution. Air pollution causes weather to change on a continental or global basis. According to modern environmentalists, increasing particulate matter pollution may reduce the amount of sunlight reaching the surface of the earth thereby lowering solar radiation energy at the earth's surface (Adejobi,2020).

Air pollution arising essentially from anthropogenic activities constitutes a serious environmental problem. Atmospheric pollution has emerged as a problem in most African countries only in the past few decades, its severity and impacts are still largely unknown, although it is believed that gaseous pollutants and acid rain have adversely affected vegetation, soils and water in some areas.

There is burgeoning literature that shows that air pollutants have several consequences on the environment and its effect is manifested in man and living organisms. Literature shows that air pollution can contribute to increase in hospital admission, lead to absence from work and school, increase in mortality rate (Giri et al., 2006; Hopke, 2009); for animals, there are the problems of mottled teeth and condition of the joints known as exostosis leading to lameness and ultimate death (Han and Naeher; 2006) and for vegetations, gaseous pollutants are reported to cause destruction of the chlorophyll and photosynthetic activity which untimely leads to death of plant (Qi, et al., 2000).

In the case of atmospheric properties, air pollutants cause visibility reduction which may lead to safety hazards, fog formation and precipitation, solar radiation reduction and alteration in temperatures and wind distribution (Chow et al., 2002; Watson, 2002; Cao et al., 2004).

Despite this, the atmospheric chemistry of the tropics has not been adequately studied in the past, placing our current understanding in doubt. Air pollution in Nigeria and across the globe is not a new phenomenon and several scholars have attempted to examine the concentration of pollutants and their effect on our environment. In Nigeria, empirical studies have been carried out on the spatial pattern of microclimatic variables, energy distribution in urban centres, thermal responses, comparative study of urban heat island syndrome within the urban canopy (Efe, 2006; Oke, 2004) and biomonitoring of air quality (Ogunsola et al.,1993; Odukoya et al., 2000; Obioh et al., 2005).

However, in all these studies, the spatial and temporal variation in ambient air quality across residential density areas has not been adequately studied and documented. This is because the majority of the studies simply categorize and establish patterns in ambient air quality across selected land uses between urban-rural gradients or divides. Also, the present study contributes to the literature by introducing a different methodological approach in the collection of air quality data. Instead of relying on the usual conventional method of collecting air quality data directly from the field via the use of standard equipment, the present study used remote sensing techniques to generate air quality data, which is indeed specific, more precise and convenient. Satellite data are more accurate and reflect area-specific conditions. Such data enable the trend (increase or decrease) in air quality to be established over time which enables area-specific air quality monitoring to be carried out (Adejobi, 2020). The study of ambient air quality across residential density areas is worthwhile in the understanding of the pattern and variability in air quality assessment concerning diverse anthropogenic activities which are site-or-area specific and can have immense impacts on air quality concentration. Based, however, on the argument above, the present study therefore empirically assessed the spatial variation in ambient air quality across three residential areas in Lagos State, Nigeria. So that the achievement of United Nations SDG goals 9 & 11 can be met by developing sustainable, resilient and inclusive infrastructures; promoting inclusive and sustainable industrialization, lower carbon emissions, and renew and plan cities that offer opportunities for all with access to basic services ,while reducing resource use and environmental impacts..

Materials and methods

Study area

The study area is Lagos State. Lagos State is in the coastal region along the southwest corner of the country; it experiences a high density of rainfall all year round. The daily temperature is high and ranges between 25 to 32°C. Rainfall is prominent between March and October every year. The topography is flat and undulating. The structure of the terrain and slope of the city has serious consequences on the flow of water and aids flooding (Odumosu et al.,1999). Lagos State is one of the fifteen largest population agglomerations in the world. Lagos State the commercial hub of Nigeria with heavy vehicular movement and traffic which could affect ambient air quality.

Methodology

Research design

The experimental and historical research designs were employed in the process of data gathering. Experiment design enabled answers on 'how' and 'why' air quality varied across residential density types to be examined. On the other hand, historical research enabled events that happened in the past to be used to explain situations in the present (Singh, 2006 cited Adejobi, 2020). Yearly air quality data over 14 and 39 years were obtained through this approach. These two research designs were ideal for the present study because they enabled quantitative data to be collected to provide explanations for the variation in ambient air quality across residential density areas.

Data types and sources

The study collected diurnal (daily) air pollutants (CO, CO_2, $PM_{2.5}$ and PM_{10}) data across residential density areas in Lagos state; and data on seasonal air pollutants (NO_2, SO_2, O_3, and CO) across residential land uses. Diurnal (daily) air quality parameters were obtained or sourced basically from physical measurements, i.e. field experiments using standardized equipment. Data on CO, CO_2, $PM_{2.5}$ and PM_{10}were collected from identified points across residential density areas (high, medium and low) in Lagos State using Minivol Portable Air Sampler. The set of secondary data on NO_2, SO_2, O_3, and CO for 14 and 39 years was collected from Satellite data actively assimilated in the ERA-Interim reanalysis. These contain profile (PROF), total column (TC), partial column (PC) and tropospheric column (TRC) data sets.

Sampling

Sampling was carried out in two ways. Residential areas for diurnal (daily) air pollutants were ascertained and sampled using stratified and random sampling techniques. a, stratified sampling technique was used to classify the study area (Lagos State) into homogenous groups with similar characteristics, which is high-density,

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medium-density and low-density residential areas. In the second stage, settlements that fall within these residential classifications were identified and grouped. In the high-residential density area, 113streetswere identified out of which 16 streets were randomly selected for data collection. In the medium-residential density area, 39 streets were identified out of which 13 streets were randomly selected, while in low-density area, 33 streets were identified from which 12 streets were randomly selected. This process enabled air quality data to be collected across varied residential areas (Adejobi, 2020).

Diurnal air pollutants (CO, CO_2, $M_{2.5}$ and PM_{10}) were collected in each street in the morning between 10 – 11 am and in the evening between 5pm with the help of field assistants positioned at different streets. The data collection period spanned over two months, which enabled air quality data to be collected across the three residential density areas. In addition, secondary data on NO_2, SO_2, O_3, and CO for 14 and 39 years collected using a satellite approach were generated for three locations that depicted the three residential density zones. For the high-density residential area, Agege was used, in the medium-density residential area, Oworonshoki was used, while in the low-density residential area, Victoria Island was used. These three locations were chosen because of the diverse human activities prevalent in them which are believed to contribute to ambient air pollutants over time.

Secondary data collection

For secondary data, satellite data were used in the reanalysis of greenhouse gas (GHG) datasets actively assimilated in the ERA-Interim reanalysis to constrain the reactive gases. These contain profile (PROF), total column (TC), partial column (PC) and tropospheric column (TRC) data sets. The data were archived in the ECMWF data archive (MARS) and a pertinent subset of the data, interpolated to a regular latitude/longitude grid. The ERA5 dataset contains one (31 km) high resolution realization (HRES) and a reduced resolution ten-member ensemble (EDA). Generally, the data are available at a sub-daily and monthly frequency and consist of analyses and short (18-hour) forecasts, initialized twice daily from analyses at 06 and 18 UTC. Most analyzed parameters are also available from the forecasts. There are forecast parameters, e.g. mean rates and accumulations that are not available from the analyses. The prevailing large uncertainty involved in GHG flux estimates for over the study area, essentially due to the paucity of available data, is coupled with a poor understanding of underlying processes, both of which preclude gauging of future fluxes in response to human pressures and anthropogenic activities.

Method of data analysis

Data obtained were analyzed with the aid of means and ANOVA. One-way analysis of Variance Test (ANOVA) enables us to make the comparison between the mean variations in the diurnal air quality parameters across different residential areas.

Results and Discussion

Seasonal variation in air quality in the high-density residential area

In the high-density residential area, the concentration of ambient air pollutants varied across the months and seasons. The results in Table 1 and Figure 1 showed that a high concentration of CO was recorded in the dry

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season, precisely in January and December with values of 326.6ppm and 325.4ppm respectively, while low concentration was observed in April and March representing the wet season with values of 177.5ppm and 194.4ppm respectively. For NO_2, high content was recorded in January and December with values of 261.5ppm and 255.6ppm respectively and low in August followed by September with values of 97.6ppm and 98.8ppm respectively. In addition, O_3 concentration was high in July (272.7ppm), followed by August (271.2ppm) and low in January (249.2ppm) followed by February (250.5ppm). The study also showed that SO2, contents in the high-density residential zone were high in August (0.13ppm) followed by July (0.12ppm) and low values of SO_2 were recorded in January (0.00ppm) and April/May (0.01ppm).

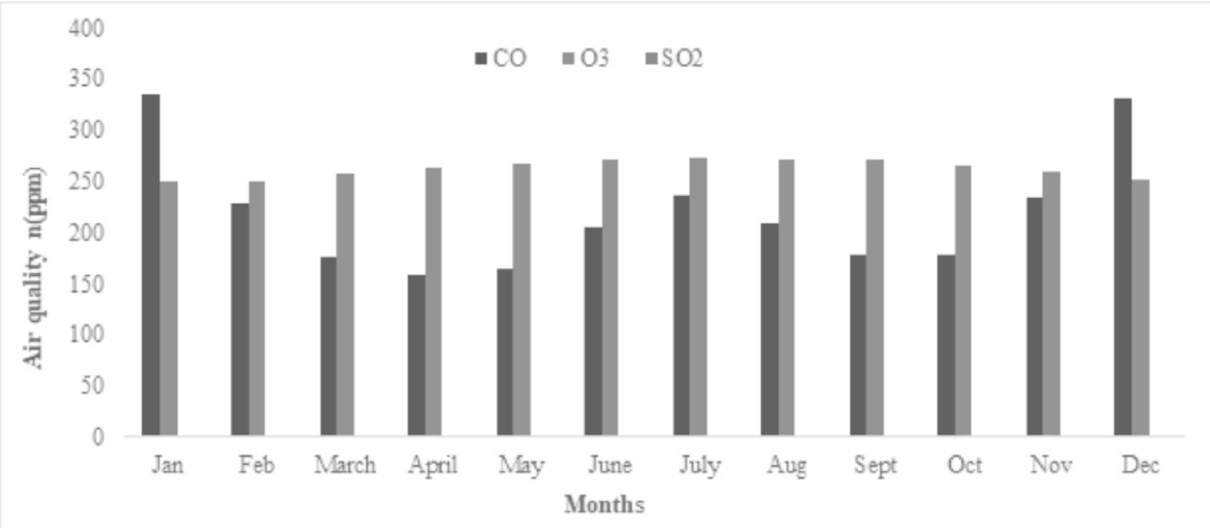

Fig. 1: Monthly ambient air quality in the high density residential zone

Table 1: Seasonal variation in air quality in the high density area

Seasons	Months	Air pollutants			
		CO (ppm)	NO_2(ppm)	O_3(ppm)	SO_2(ppm)
	Jan	326.6	261.5	249.2	0.00
	Feb	241.6	104.9	250.5	0.02
Dry	Nov	[illegible]	[illegible]	[illegible]	0.02
	Dec	325.4	255.6	[illegible]	0.02
	Total	**1146.9**	**[illegible]**	**1011.6**	**0.06**

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	March	194.4	145.0	257.1	0.02
	April	177.5	118.8	264.4	0.01
	May	185.4	115.7	267.6	0.01
Wet season	June	229.0	114.5	271.0	0.04
	July	258.7	93.6	272.7	0.12
	Aug	228.8	97.6	272.2	0.13
	Sept	200.4	98.8	271.5	0.11
	Oct	203.2	132.1	266.0	0.06
	Total	**1677.4**	**916.1**	**2142.5**	**0.5**

Seasonal variation in air quality in the medium-density residential area

The results in Table 2 and Fig 2 showed that a high concentration of CO was recorded in January (331.2ppm) followed closely by December (328.3ppm), while low concentration of CO was observed in April and May with values of 168.3ppm and 175.1ppm respectively. The high content of NO_2 was recorded in January followed by December with values of 320.6ppm and 315.4ppm respectively and low in August (117.1ppm) followed by July with a value of 131.4ppm. The content of O_3 was high in July (273.0ppm), followed by August (272.6ppm) and low in January followed by February with values of 249.8ppm and 251.0ppm respectively.

In addition, SO_2 contents were high in August (0.12ppm) followed by September (0.10ppm) and low in January and February with values of 0.01ppm. The result presented in Table 2.2 identifies January as the month with high concentrations of CO and NO_2, while O_3 and SO_2 are high in July and August respectively. This means that CO and NO_2 are high in the dry season, while O_3 and $SO_2$are high in the wet season. This result shows a similar pattern with the high-density residential zone and the possible reason is that air pollutants are controlled by wind and as such could be carried from one location to the other. Another reason is that the residential areas are contiguous, as such they are influenced by similar environmental conditions.

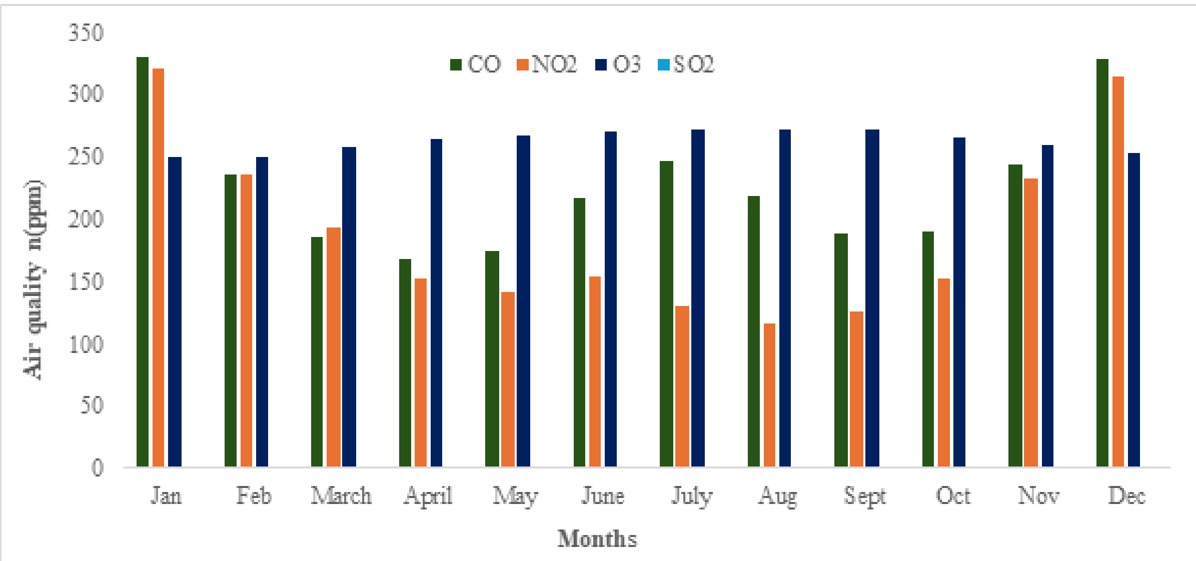

Fig 2: Monthly ambient air quality in the high-density residential zone

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Table 2: Seasonal variation in air quality in the medium-density area

Seasons	Months	Air pollutants			
		CO (ppm)	NO_2(ppm)	O_3(ppm)	SO_2(ppm)
Dry	Jan	331.2	320.6	249.8	0.00
	Feb	235.4	236.7	251.0	0.00
	Nov	243.5	233.0	259.8	0.01
	Dec	328.3	315.4	253.1	0.04
	Total	**1138.4**	**1105.7**	**1013.7**	**0.05**
Wet season	March	185.1	193.6	257.6	0.02
	April	168.3	152.6	264.9	0.05
	May	175.1	141.7	268.1	0.01
	June	217.2	154.2	271.4	0.05
	July	247.7	131.4	273.0	0.06
	Aug	219.3	117.1	272.6	0.12
	Sept	189.3	126.5	271.9	0.10
	Oct	191.2	152.1	266.4	0.08
Total		**1593.2**	**1169.2**	**2145.9**	**0.49**

Seasonal variation in air quality in the low-density residential area

The results in Table 3 and Fig 3 showed that a high concentration of CO in the low-density residential zone was recorded in January (335.7ppm) followed closely by December (331.0ppm), while a low concentration of CO was observed in April (159.0ppm) and May (164.7ppm). The high content of NO_2 was recorded in January (244.6ppm) followed by December (216.3ppm) and low in May (102.3ppm) followed by August (103.9ppm). The content of O_3 was high in July (272.3ppm), followed by August (271.9ppm) and low in January followed by February with values of 249.1ppm and 250.4ppm respectively. SO_2 contents were high in September (0.15ppm) followed by October (0.09ppm) and low in January and November with values of 0.00ppm.

The result in Table 3.3 identifies January as the month with high concentration of CO and NO_2, while O_3 and SO_2 are high in July and September respectively. This means that CO high in the dry season, while O_3 and SO_2 are high in the wet season.

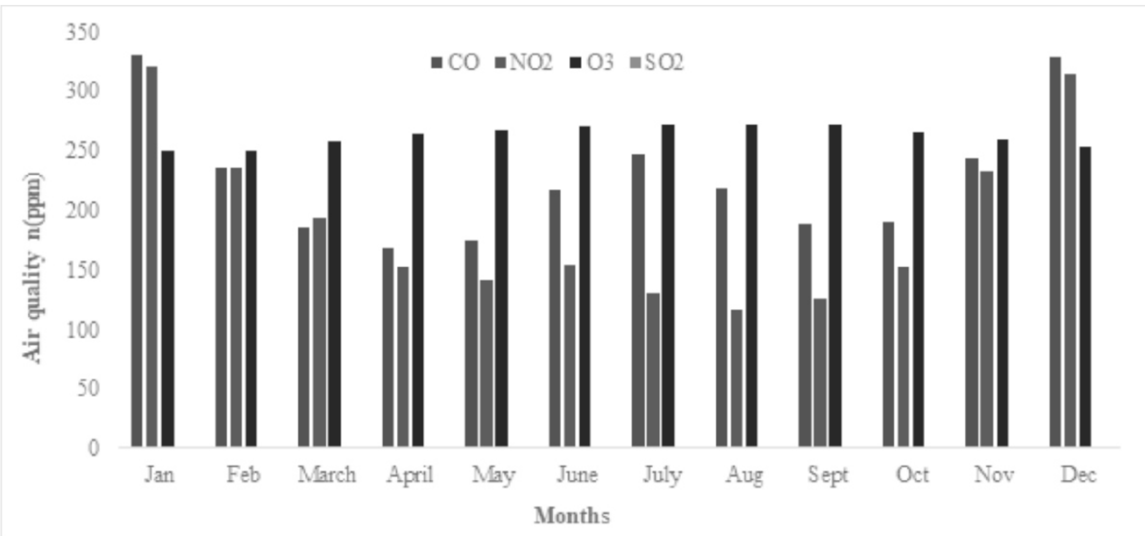

Fig 3: Monthly ambient air quality in the high-density residential zone

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Table 3: Seasonal variation in air quality in the low-density area

Seasons	Months	Air pollutants			
		CO (ppm)	NO_2(ppm)	O_3(ppm)	SO_2(ppm)
Dry	Jan	335.7	244.6	249.1	0.00
	Feb	229.3	183.8	250.4	0.01
	Nov	233.7	146.7	259.1	0.00
	Dec	331.0	216.3	252.5	0.04
	Total	**1129.7**	**791.4**	**1011.1**	**0.05**
Wet season	March	175.7	155.9	257.0	0.01
	April	159.0	116.2	264.3	0.04
	May	164.7	102.3	267.5	0.01
	June	205.3	120.6	270.8	0.07
	July	236.7	115.7	272.3	0.07
	Aug	209.8	103.9	271.9	0.09
	Sept	178.3	106.8	271.2	0.15
	Oct	179.2	113.9	265.7	0.09
	Total	**1508.7**	**935.3**	**2140.7**	**0.53**

Spatial variation in air pollutants (CO) across residential density zones

The content of CO in the high-density area ranged from 0.00 to 26.5ppm with high values recorded in Gowon Estate and Oshodi of 26.5 and 14.5ppm respectively; in the medium-density residential area, CO levels ranged from 0 to 10ppm with high value observed in Ikorodu/ Ayangbure Road, while in other areas, it was not detected. In addition, in the low-residential density area, CO content ranged from 0 to 4ppm with high values recorded in Oniru Estate VI and Ikoyi GRA (Fig:4.1). The ranges of CO recorded in 90% of the locations in the high-density zone and medium and low-residential zones are within the 10ppmrecommended by FEPA (Atubi, 2015: Ebong and Mkpenie, 2016).

However, in Gowon Estate and Oshodi, the CO levels are above the FEPA recommended threshold. This suggests that high emissions of CO are generated in these areas. However, the range reported in the medium and low-density residential areas tends to fall with the range of 1.83 to 2.17ppm obtained by Magaji and Hassan (2015) but falls below the range of 30 - 70ppm reported in Lagos by Adelagun et al., (2012). The concentration of CO in medium and low-density residential areas is within the 10ppmrecommended by FEPA (Atubi, 2015: Ebong and Mkpenie, 2016) and within the WHO permissible limit of 25ppm (Obanya, Amaeze, Togunde *et al.,* 2018). The content of CO is however within the National Institute for Occupational Safety and Health (NIOSH) recommended limit of 200 ppm (NIOSH, 1992 cited in EPA, 2016). Like particulate matter (PM), high concentrations of carbon monoxide (CO) is recorded in the high-density residential area. This is expected as the area has a high concentration of CO due to heavy traffic congestion, and residential and industrial activities prevalent in the area. This agrees with the report of the Scottish Environmental Protection Agency (2019) which stated that high content of CO is usually found in areas with high traffic density. Other man-made sources of CO are power stations and waste incinerators Scottish Environmental Protection Agency (2019).

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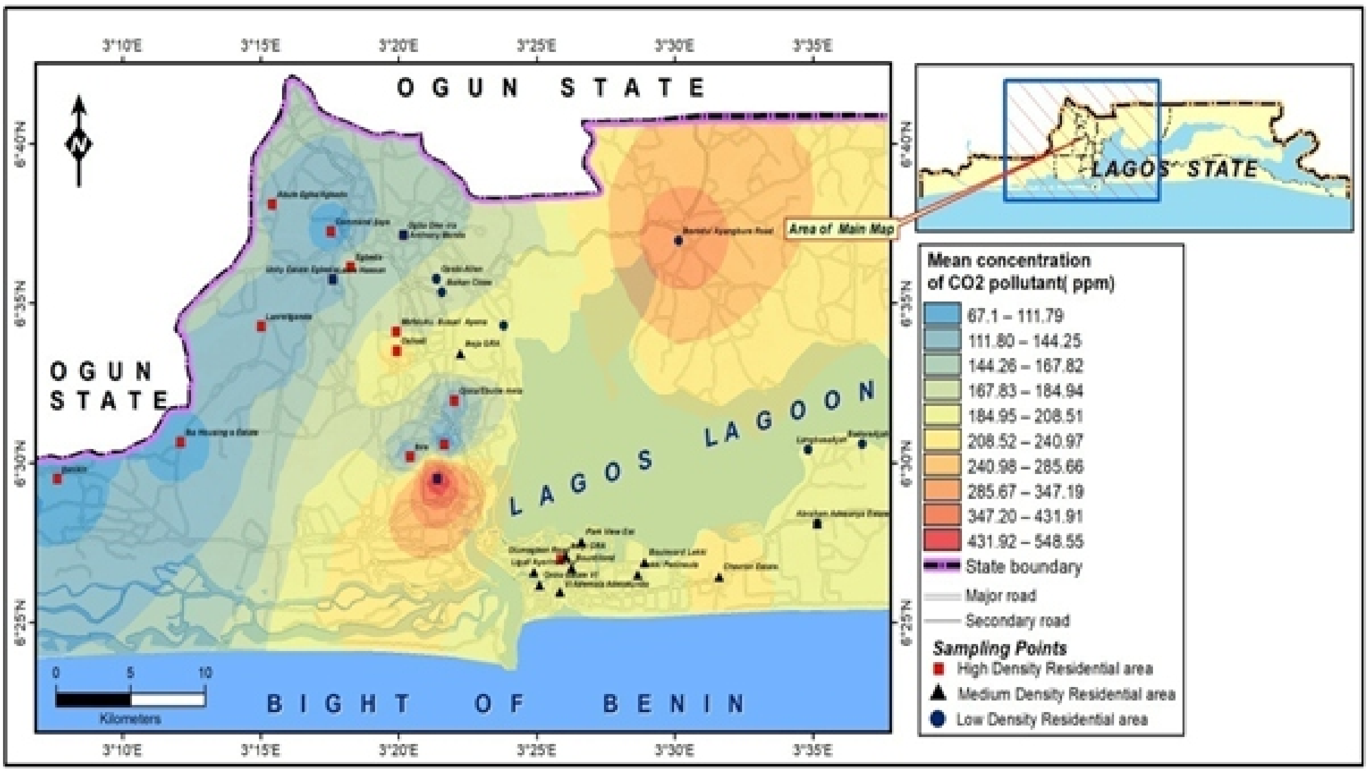

Fig 4.1: Showing the distribution of CO Pollutants in High, Medium and Low residential areas.

In addition, the concentration of carbon dioxide (CO_2) varied across the three residential areas and locations. CO_2 values in the high-density residential area ranged from 67.1 to 974.6ppm with high and low content recorded in Cooperative Villa and Command Ijaye respectively. In the medium-residential density area, CO_2 content ranged from 150 to 313.5ppm with Unity Estate Egbeda and

Ikorodu/ Ayangbure Road recorded high and low concentrations respectively. In the low-residential density area, CO_2 content ranged from 166.5 to 227ppm with Chevron Estate and Ikoyi GRA recording high and low concentrations respectively (Fig 4.1). The range of CO_2recorded in the three residential areas is far below WHO WHO-stipulated maximum value of 20,000ppm (Abamand Unachukwu, 2009). The CO_2 values recorded in the three residential areas fall far below the value of 96,280.8 ppm reported in 2016 by the World Bank (2018). High concentrations of CO_2 have also been reported across cities in Nigeria by Okhimamhe and Okelola (2013). Okhimamhe and Okelola (2013) recorded a high CO_2 emission value of 3236ppm at Suleja, 3043.5ppm at Minna and 3036ppm at Bida. In Nigeria, the problem of air pollution is acknowledged to be caused mainly by the gas-flaring, exhausts of automobiles and diesel power generators (Nwadinigwe, 2015). As expected, CO_2 content is high in the high-density residential zone and low in the low-density residential area. This result agrees with the finding of Akpan and Ndoke (1999) in Northern Nigeria where high concentrations of $CO_2$was reported in heavily congested areas. Environmental Protection Agency (2019) attributed CO_2 to fossil fuels burned for heat, the use of certain products that contain greenhouse gases, and the handling of waste and burning fossil fuel for our cars, trucks, ships, trains, and planes.

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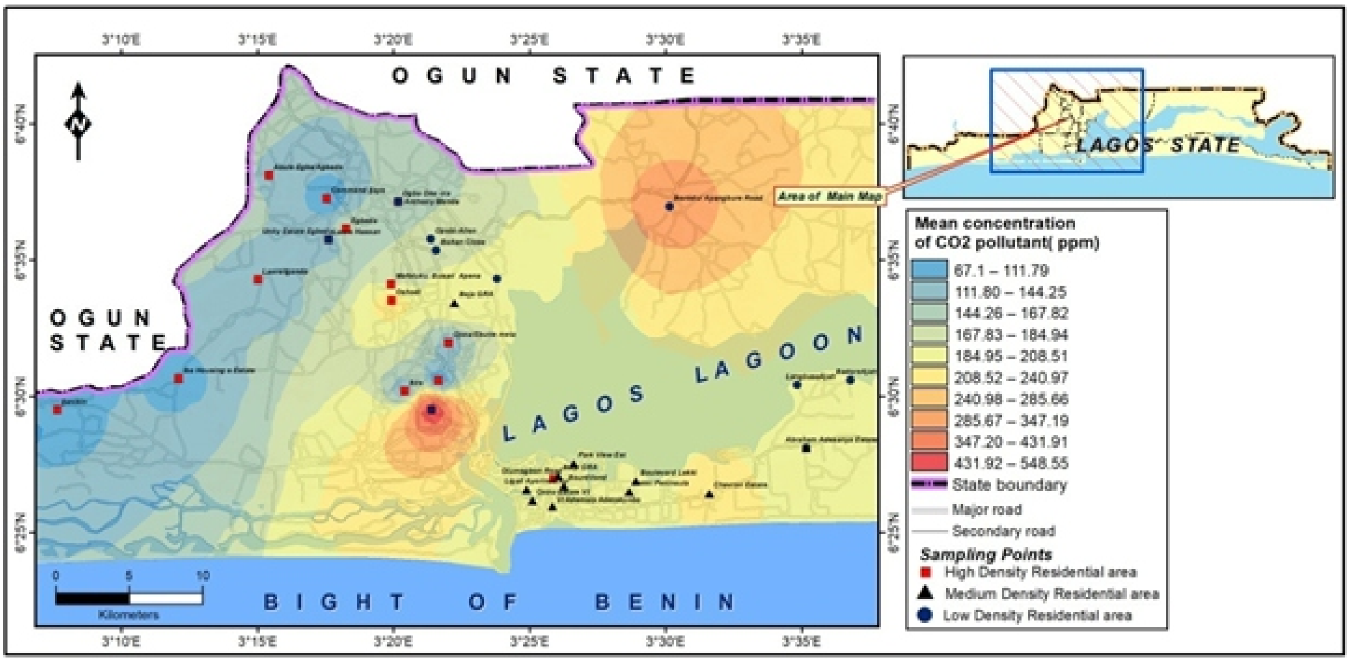

Figure 4.2 : Showing the distribution of Co_2 Pollutant in high. Medium &low residential areas.

Fig: 4.2 shows the concentration of air quality in the residential density zones in Lagos State. It also shows air quality across the three residential density zones and the selected locations in the area. The result shows clear variation in the concentration of air quality. $PM_{2.5}$contents in the high-density residential area ranged from 69.5 to 161.5µg/m^3**,** with high and low values recorded in Ijanikinand Lanre/Igando with values of 69.5 and 161.5µg/m^3 respectively. In the medium-density residential zone it, $PM_{2.5}$ ranged from 64 to 139.5µg/m^3 with high and low values recorded in Agege/Oko-oba (Omotoye Street) and Ojokoro/Ijaye (Onitiri Street) respectively, while in the low-density residential zone, $PM_{2.5}$ ranged from 46 to 102µg/$m^3$with high and low values recorded in Lekki Peninsula (Admiralty Close) and Ikeja GRA respectively.

The range of $PM_{2.5}$recorded across the residential zones are within the threshold of 250µg/m3 recommended by FEPA (Obanya, Amaeze, Togunde et al., 2018). The range however falls with the range of 146 to 238 reported in Lagos State by Obioh, Olise, Owoade et al., (2005). The values are also within the range of 5 to 462µg/m^3 reported in Lagos by Offor, Adieand Ana (2016). The results obtained mean that the high-density residential zones have increased concentrations of $PM_{2.5}$ followed by the medium-density residential zone and the low-density residential zone. The high PM2.5 recorded in the high-density area is expected as the area experiences high fuel combustion from automobiles and commercial activities resulting in the release of matter (Han, 2010; USAID, 2012). The result also identifies Lanre/Igando, Oshodi, Egbeda and Ojota as areas in the high-density residential area with high concentrations of $PM_{2.5}$.

In addition, the concentration of PM_{10} in the high-density residential area ranged from 87 to 220.5µg/m^3**,** with high and low values recorded in Ijanikinand Lanre/Igandorespectively. In the medium-density residential zone it, PM_{10}ranged from 88 to 157.5µg/$m^3$with high and low values recorded in Abraham Adesanya Estate and Opebi-Allen (Wole Ogunjimi) respectively, while in the low-density residential zone, PM_{10}ranged from 80 to 139.5µg/$m^3$with high and low values recorded in Ikoyi Thompson Ave and Ikeja GRA respectively (Fig 4.2). The

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range of PM_{10} recorded across the residential zones is within the threshold of 250µg/m3 recommended by FEPA (Obanya et al., 2018). The range, however, falls with the range of 146 to 238 reported in Lagos State by Obiohet al., (2005). The values are also within the range 41.6 to 326.8µg/m3 reported in Lagos by Offor, Adieand Ana (2016). The results show that the high-density residential zones have increased concentration of PM_{10} followed by the medium-density residential zone and the low-density residential zone. The high PM_{10} in the high-density area as usual is attributed to increased level of automobile combustion and dust in the area. These conditions can increase PM content. Similar reasons for automobile combustion, dust, cooking and incomplete combustion are given by USAID (2012) for high PM_{10} in urban areas. The result also identifies Lanre/Igando, Oshodi, Egbeda and Ojotaas areas in the high-density residential area with high concentration of $PM_{2.5}$.

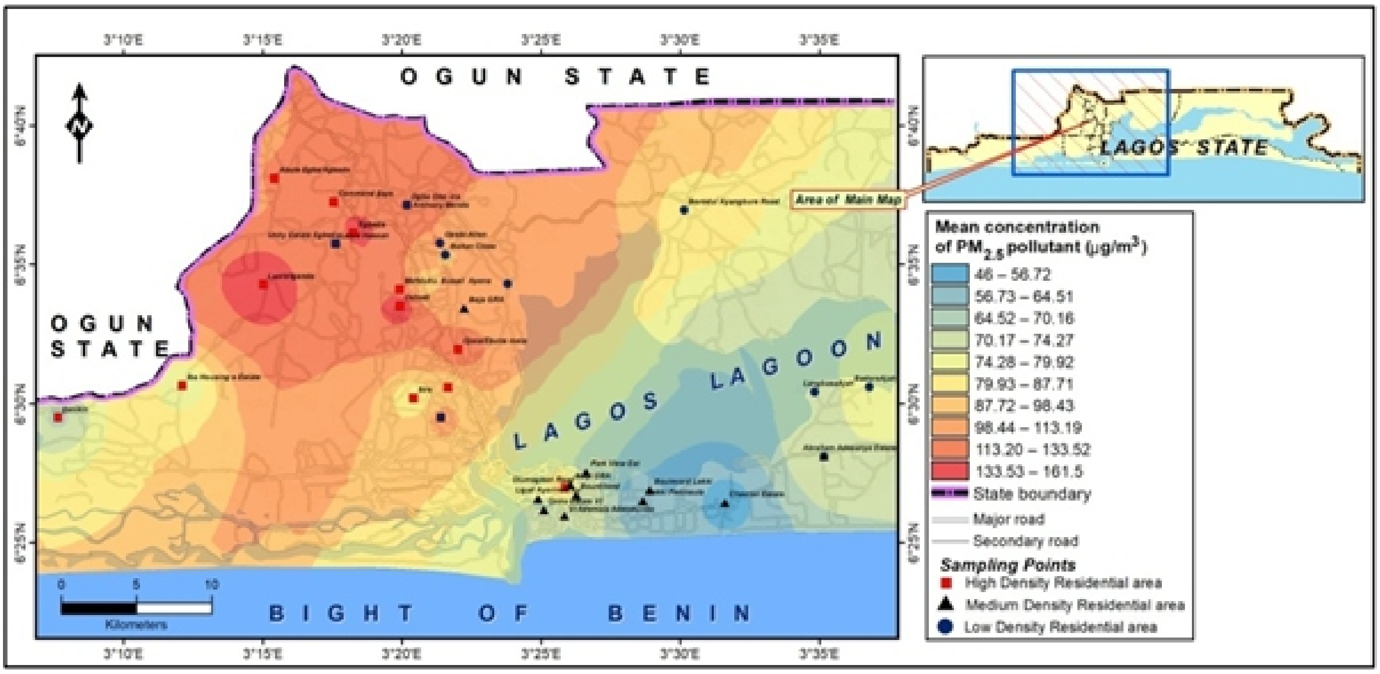

Fig:4.3 Showing the distribution of $PM_{2.5}$ air pollutants in high, medium & low residential density areas.

Table 4: Summary of ANOVA result of the variation in air quality across residential areas

Parameters	Mean values			F-values	Sig
	High-density	Medium-density	Low-density		
$PM_{2.5}$ (µg/m^3)	113.66	92.83	71.27	11.403*	0.000
PM_{10} (µg/m^3)	153.66	125.79	97.50	10.471*	0.000
CO (ppm)	2.72	1.00	0.77	0.700 ns	0.503
CO_2(ppm)	179.54	192.97	203.74	0.110 ns	0.896

*Significant at 5% alpha level; ns = not significant at 5% alpha level

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The result obtained in Table 4. showed that air pollutants vary over space and time. It showed that there is a significant variation in $PM_{2.5}$ contents across residential areas in Lagos State ($F = 11.403$, $p<0.05$). This decision is because the probability of 0.000 is lower than the 5% (0.05) significance level. Looking at mean values indicated the content of $PM_{2.5}$ is high in the high-density zone with a mean value of 11.3.7ppm followed by the medium-density residential zone with a mean value of 92.83ppm, while the lowest content was in the low-density residential zone. Also, the result in Table 4 revealed a significant variation in PM_{10} contents across residential areas in Lagos State ($F = 10.471$, $p<0.05$). Again, this decision is because the probability value of 0.000 is lower than 5% (0.05) significance level. A look at mean values indicated the content of PM_{10} is high in the high-density zone followed by the medium-density residential zone and low in was in the low-density residential zone. The high PM contents in the high-density and medium-density areas are expected because these areas have a high human population and concentration of human activities that emit gases favourable to the formation of PM. This is so as a significant portion of PM is generated from the combustion of wood and fossil fuels, agricultural activities, commercial and industrial activities, construction and demolition activities, and the rising of road dust into the air (USAID, 2012; Guerrieri et al., 2016). These anthropogenic activities release a large amount of PM into the atmosphere.

The content of carbon monoxide (CO) did not vary significantly across the residential zones ($F = 0.700$, $p>0.05$). This decision is because the probability value of 0.503 is greater than 5% (0.05) significance level. The mean values showed that high content of CO was recorded in the high-density residential area (2.72ppm) followed by the medium-density residential zone (1.00ppm). As usual, the low-density residential area had the lowest concentration of CO. The high economic activities and its high traffic congestion are attributed to the high content of CO in the high-density and medium-density residential zones. In a related study, US EPA (2008) stated that CO sources are mobile sources which include both on-road vehicles (e.g., cars, trucks, motorcycles) and non-road vehicles and engines account for the majority of CO emissions. The report also noted that high concentrations of CO normally occur in areas with heavy traffic congestion. These conditions are carried out at unprecedented rates in the high-density and medium-density residential zones which are favourable to CO emissions. Likewise, the content of carbon dioxide (CO_2) did not vary significantly across the residential zones ($F = 0.110$, $p>0.05$). This decision is because the probability of 0.896 is greater than 5% (0.05) significance level. The mean values in Table 4.9 showed that high content of CO_2 is found in the high-density zone followed by the medium-density residential zone. High fossil fuel combustion (electricity, fossil fuel combustion, industrial process, non-road equipment and fire among others) and numerous industrial activities could be responsible for the relatively high contents of CO_2 in the high-density zone compared to the low content in the low-density residential zone.In line with this, Gale, Bradshaw, Chen et al., (2018) stated that emissions of CO_2 arise from a number of sources, mainly fossil fuel combustion in the power generation, industrial, residential and transport sectors.

Temporal variation in air pollutants across residential density zones

The results in Fig: 4 revealed a considerable variation in the concentration of pollutants at different times of the day. In the high-density residential area, the concentration of $PM_{2.5}$ was comparatively high in the morning. The

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high concentration in the morning is expected because it is the period when economic activities are at their peak and this results in the combustion of fuel and an increase in dust content in the atmosphere among others. It is a period in which virtually everybody goes to work, school, hospital market and other reasons for making trips. Traffic congestion is usually a problem at this time of the day due to the increase in vehicular movement and people. A similar pattern was observed for PM_{10}. An increase in industrial activities around this time may also be responsible for the increased PM content. The result therefore shows that particular matter is found to be comparatively higher in the morning than in the evening.

The results for CO and CO_2 also revealed that high content was observed in the morning. The increase in traffic as a result of high trips and burning of fuel at home is responsible for the increase in CO and CO_2 contents in the morning. Similar environmental conditions occur in the evening, but the traffic situation is somehow reduced when some of the trips are made in the afternoon. In the medium-residential density, the concentration of PM2.5 and PM_{10}as well as CO_2 was higher in the morning than in the evening. A similar reason for the buildup of PM2.5 PM_{10} and CO_2 in the morning in the high-density area is applicable here. However, higher CO content was recorded in the evening than in the morning. This may be attributed to increased vehicular traffic and industrial activities. In the low-density residential area, the contents of $PM_{2.5}$ and PM_{10} as well as CO_2 were higher in the morning than in the evening. An increase in fuel combustion and economic activities among others may be attributed to the increase in the concentration of these pollutants in the morning. A cursory look at the pattern of air pollutants in Fig.4.2 reveals that across the three residential densities, high concentrations of $PM_{2.5}$ and PM_{10} and CO_2 occur in the morning. It shows that ambient air quality varies in quantities at different times of the day and this variation is attributed to the nature of activities or economic activities carried out in the area and at that time. In a related study, Makra et al., (2010) stated that in any environment, the daily variations in concentrations of air pollutants are caused by the types of economic activities.

The result obtained in Table 5. therefore, implies that air pollutants tend to be higher in the morning than in the evening. This pattern in the temporal variation in ambient air pollutants or quality is expected due to the increased vehicular movement and traffic buildup, industrial and residential activities, waste incineration and other human activities that favour the emission of these gases into the atmosphere during this time. Traffic congestion is everyday life in the area mostly in the high and medium density residential areas. The increase in traffic in this area according to Njoku, Rumide, Tosin *et al*., (2016) may be attributed to poor road infrastructure, uncontrolled automobile growth, lack of effective urban mass transit system, and inadequate road networks resulting in the burning of fossil fuel known to be the major contributor to CO_2 emission. A similar trend in the concentration of air pollutants at different times of the day was reported by Magaji and Hassan (2015), Oderinde (2016) and Etim (2016). The study of Oderinde (2016) reported high pollutant levels in the morning.

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Table 5: Mean temporal variation in the content of pollutants in the high-density zone

Time of the day	$PM_{2.5}$ (µg/m^3)	PM_{10} (µg/m^3)	CO (ppm)	CO_2 (ppm)
Morning	114.50	154.13	4.25	238.97
Evening	112.81	153.19	1.19	120.08
Medium-density residential are				
	$PM_{2.5}$ (µg/m^3)	**PM_{10} (µg/m^3)**	**CO (ppm)**	**CO_2 (ppm)**
Morning	96.42	133.00	0.41	189.04
Evening	89.25	118.58	1.00	196.88
Low-density residential area				
	$PM_{2.5}$ (µg/m^3)	**PM_{10} (µg/m^3)**	**CO (ppm)**	**CO_2 (ppm)**
Morning	73.85	101.15	0.54	212.08
Evening	68.69	93.85	1.00	195.35

Conclusion

The study has clearly shown that the level of air pollutants tends to decrease from the medium-density residential area to the low-density residential area with increased concentration in the high-density area. Despite the increase in the concentration of pollutants in the high-density residential area, pollutants such as CO and CO_2 do not show clear variation because the residential density areas are contiguous, as such they are influenced by similar environmental conditions. This affirms the first law of Geography by Tobler (1970) which states that everything is related to everything else, but near things are more related than distant things.

The study further shows that high concentrations of CO and NO_2 occur in the dry season with January recorded high contents followed by December, while O_3 and SO_2 are high in the wet season, especially in July and August/September. It further shows that the concentration of pollutants varies in quantities or amount across the residential areas and at different times of the day with high levels found in the morning. The high content in the morning is expected because this period experiences high traffic density and volume as well as experience increased of anthropogenic activities that favour the buildup of pollutants in the atmosphere. Particulate matter and CO are observed to show high concentration in the high and medium-density residential areas because of heavy traffic congestion, and residential and industrial activities prevalent in the area. Across the residential density areas, anthropogenic activities account for the varying levels of ambient air pollutants in the atmosphere. Despite the high contents of pollutants, mostly in high-density areas, the concentrations of pollutants fall within local and international permissible limits such may not pose serious health challenges or problems to people in the area. Based on the research findings, the study suggests that particulate matter is a significant and variant air pollutant across residential areas; as such, government and wealthy private individuals are encouraged to assist in road construction and rehabilitation. As much as possible, unpaved roads should be paved and adequately constructed.

The repairs of roads as well as the completion of abandoned roads will play a significant role in dust generation which reduces the concentration of particulate matter in the atmosphere. and SDG goal 11 can be achieved through the reduction of the adverse effects of natural disasters, the reduction of the environmental impacts of cities and to provision of access to safe and inclusive green and public spaces.

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