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Full Length Research Paper

Identification of the spatial patterns of air pollution and its sources in Ogui New Layout, South-East of Nigeria, using remote sensing and GIS technology

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Air pollution is one of the main risk factors for human health. It is the deadliest form of environmental pollution, which the World Health Organization has recognized as a significant indicator of the status of the environment. Therefore, there is a need for monitoring of air pollution to reduce health hazards associated with it. In this study, Remote Sensing and Geographic Information System were used to examine the spatiotemporal distribution of air pollutants in Ogui New Layout, South-East, Nigeria so as to advise the populace and relevant agencies on the steps and needs in reducing air pollution. Based on dense industrial clusters, heavy traffic and increasing human population density, strategic places were sampled between two peak hours (8 am and 4 pm). A Haze-dust particulate monitor and a Gasman Air Monitor were used to measure the amounts of PM_{10}, CO, SO_2, and NO_2. The global positioning system (GPS) coordinates of the sampling spots were recorded using the portable Germin-300 GPS device analyzer which was also used in data processing for creating spatial interpolation maps in ArcMap. ArcGIS 10.5 Erdas Imaging 9.5 software was used to analyze the spatial distribution of contaminants from a source using remote sensing and geographic information system (GIS) methods. Results showed that during the dry season, the air pollutants (PM_{10}, CO, SO_2, and NO_2) had maximum values of 225, 10.72, 1.74, 1.93 respectively and minimum values of 184, 8.86, 0.82, and 0.45 respectively. During the wet season, PM_{10}, CO, SO_2 and NO_2 had maximum values of 202, 16.66, 1.65, 0.73 respectively and minimum values of 108, 11.85, 0.69 and 0.26 respectively. Based on the study, it is advised that the local people of Ogui New Layout reduce their exposure to the outdoors especially during the dry season.

Key words: Ambient air, air pollutants, spatial-temporal assessment, air quality index.

INTRODUCTION

Air pollution is widely acknowledged as one of the main risk factors for human health (Maheswaran, 2016). It is the deadliest form of environmental pollution recognized by the World Health Organization (WHO) as a significant

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indicator of the status of the environment. In large cities around the world where a substantial percentage of gas emissions are produced by urban activities and residents, air pollution has become a significant environmental issue (Adams and Kanaroglou, 2016; Patton et al., 2016; Raimi et al., 2018a; Clinton-Ezekwe et al., 2022). Harmful substances released into the atmosphere lower the quality of air and this impact negatively on the quality of life. Urbanization, industrialization and population growth are the major causes of air pollution (Moltchanov et al., 2015; Deary et al., 2016; Raimi et al., 2021) and the rise in air pollution in major cities of the world has been attributed to recent upsurge in industrialization, urbanization, and economic expansion (Anake et al, 2016; Bodelier and Steenbergh, 2014; Raimi et al., 2020). Developing countries in Africa (e.g. Nigeria, Egypt and Ghana) are faced with increase in industries and population outburst (Clinton-Ezekwe et al., 2022), hence there is very high level of smoke from industries, automobile exhaust fumes. Over half of the pollution load in cities is due to automobile exhaust as a result of motorization without proper management of traffic (Bada et al., 2019; Raimi et al., 2021). The negative impact of transportation in cities are now obvious due to the deteriorating urban air quality (Erisman and Larsen, 2013; Clinton-Ezekwe et al., 2022).

The world's primary air pollutants include particulate matter (PM_{10}), oxides of sulphur (SO and SO_2), oxides of carbon (CO and CO_2), oxides of nitrogen (NO and NO_2) and a few others. They are typically present in combinations and varying magnitude depending on the location, source activity, season, weather and year. Several studies (Adams and Kanaroglou, 2016; Sameen et al., 2014; Watmough et al., 2014; Raimi et al., 2018a; 2020; 2021) suggest that air pollution is one of the major causes of health and environmental issues such as acid rain, trans-boundary smoke transportation, global warming, ozone layer depletion amongst others (Raimi et al., 2018b; 2019; Morufu et al., 2021b).

Exposure to air contaminants is associated with a variety of unfavorable health outcomes such as respiratory and cardiovascular disorders, asthma flare-ups, decreased lung function, death etc (Erisman and Larsen, 2013; Raimi et al., 2021; Clinton-Ezekwe et al., 2022). Ozcan (2012) and Raimi et al. (2018a) are of the view that air pollution causes a variety of disease in urban areas like irritation of the eye, nose and throat, respiratory infections, allergies, asthma, and lung cancer.

Mobile objects like automobiles and stationary objects (buildings, landfills, and incineration facilities) are sources of air pollution (Schultz et al., 2016; Raimi et al., 2018a). With increase in the number of industries and expansion of modes of transportation, pollution levels have abruptly increased but monitoring and management of pollution is relatively low. For the control of air quality and the execution of anti-pollution regulations, monitoring of pollution and its sources is essential. The monitoring procedure aids in identifying pollution patterns, the types and concentrations of pollutants and, the detrimental consequences they have (Nayeb et al., 2015; Raimi et al., 2018a). On regional, national and international levels, monitoring and modeling of pollution are encouraged (Dubey, 2014). Modern tools are replacing outdated monitoring methods as a result of technological advancements. In comparison to standard surveys and measurements, Obaseki et al. (2014) claim that pollution mapping and its spatial analysis offer a better knowledge of pollution patterns in monitoring and in visualization and, has effectively been used to study pollution pattern of many urban areas.

Traditional ground measurements which are often used for mapping areas with significant levels of air pollution are expensive and time consuming (Dubey, 2014). For this method, the number of air pollution stations in each location limits the coverage of the sensors, such as air samples, which are extremely expensive. As a result, they are unable to accurately distribute air pollution levels over a metropolis. Remote sensing and geographic information system (GIS) are better. They have the advantage of being more accurate, faster and can cover wider areas leading to precise and timely geographic information due to their broad spatial coverage and trustworthy repeated measurements (Dubey, 2014; Sameen et al., 2014). Urban air pollution has been effectively assessed using GIS-based and interpolation methods inverse distance weighting and kriging (Watmough et al., 2014). When used in epidemiological studies and to identify "hot spots" that require additional investigation or monitoring air pollution, air pollution maps created with remote sensing and GIS tools have the potential to be extremely useful, especially for urban areas (Rahman et al., 2015; Sameen et al., 2014). Integrating spatial analysis in GIS and statistical modeling can help the researcher to expand its understanding concerning the distribution of pollutants and to understand the factors that influence the trends.

The present study involves the use of remote sensing and GIS techniques to assess the spatiotemporal variation of air quality indices in Ogui New Layout in Enugu, South-eastern Nigeria. The objective of the study is to assess and analyze the spatial dynamics of the concentration of air pollutants during the dry and wet seasons and then correlate the air quality index for both seasons within Ogui New Layout, in order to produce various spatiotemporal maps.

The study area

Ogui New Layout is residential layout in Enugu, the capital Enugu State, Nigeria (Figure 1). It lies roughly between latitudes 06 30 'N and 06 40' N and longitudes

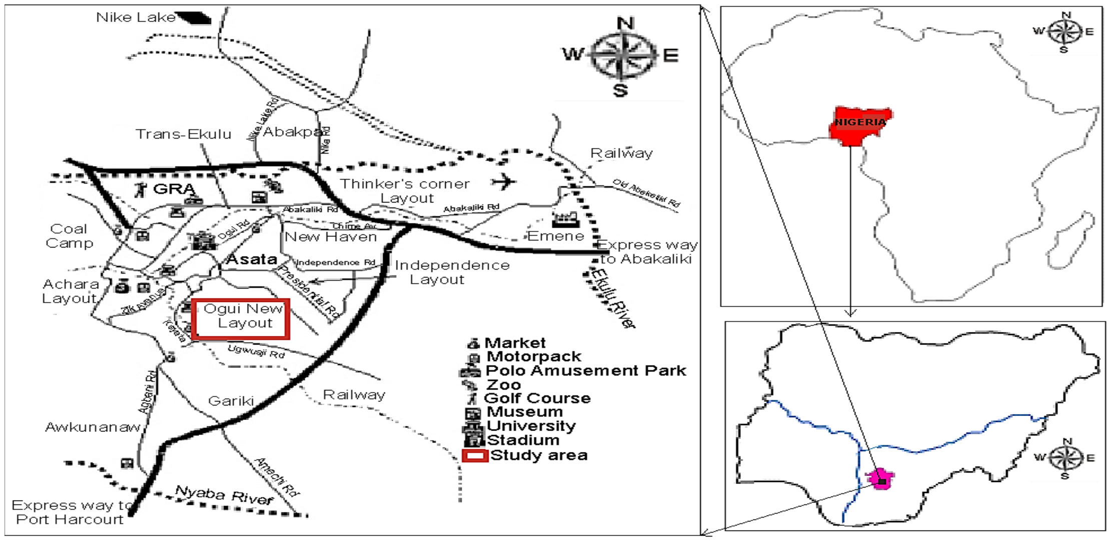

Figure 1. Map of Enugu showing the study area.

07 20' E and 07 35' E. Ogui New Layout is regarded as an educational hub since it is home to a good number of Enugu's oldest and younger educational institutions including University of Nigeria, Enugu Campus, Institute of Management and Technology, Alma Rose High School, City Girls' Secondary School, Urban Girls' Secondary School, Queens Secondary School, Metropolitan Girls' Secondary School and a host of primary schools. Nike people, a group of Igbo tribe, are the original settlers. Ogui New Layout is in the tropical savanna climate with high humidity that peaks between June and September. The average annual maximum temperature is about 28°C but could reach 34°C jn March. The region experiences dry and wet seasons with a brief Harmattan during the dry season months of November through February. The amount of rainfall is roughly 1,800 mm/year. About 70% of the rainfall is experienced between June and September. The town is surrounded by Enugu shale, lower coal measure (Mamu formation), and false bedded sandstone. It is located in the eastern Nigeria sedimentary basin (Ajalli formation).

Its topographic features are divided into the Cross-River Basin's plains and lowlands, and the escarpment zone (Obiora et al., 2015; Ocheli et al., 2021). With an estimated population of about 1.5 million and rapid but unplanned industrialization in this area, there is need to monitor both natural and anthropogenic activities.

MATERIALS AND METHODS

Air pollution sampling

In this study, PM_{10}, CO, SO_2 and NO_2 were selected as markers of some of the most common air pollutants. Based on the measured levels of air quality during the wet and dry seasons, the geographical and temporal patterns of the air pollution in Ogui New layout were analyzed. Air quality measurements were taken at chosen locations and months of 2021 for the wet and dry seasons. The selected months were April, May, June and July for wet season and October, November, December and January for the dry season. The specific locations were selected based on the results of reconnaissance investigation to determine the features and distribution of polluting sources as well as the volume of traffic. Air pollutants (PM_{10}, CO, SO_2, and NO_2) were measured at road junctions, parking lots and markets places with the gas detectable devices. The devices are mounted at roughly 100 m away from the main roadways and 1.50 m above the ground. Measurements were taken twice at 30-min intervals for one hour. To correct instrument drift, background concentration checks with no air were made.

Generation of maps with GIS tools

GIS is a potent instrument for facilitating the connection of geographical and non-spatial data (Rahman et al., 2015). To demonstrate how spatial analysis might be applied to the study area, this study involved integrating field measurements of levels of air pollutants related to air pollution maps into digital map layers. Shape-file of the study area is imported into the ArcGIS 10.5 software and air pollution data and geographical coordinates are entered in excel format. Following the assignment of attribute data to spatial objects, the system was prepared for spatiotemporal analysis and administration. Using a kriging kind of interpolation approach in the ArcGIS 10.5 environment, areas of varying concentrations of air quality in the study area were mapped.

Air quality index (AQI)

The air quality index (AQI), also known as the Air Pollution Index (API), provides the scientific community, policy makers and the general public with a clear and concise summary of the air quality status. Over the past three decades, the idea of an AQI has been created and successfully applied in many industrialized nations and

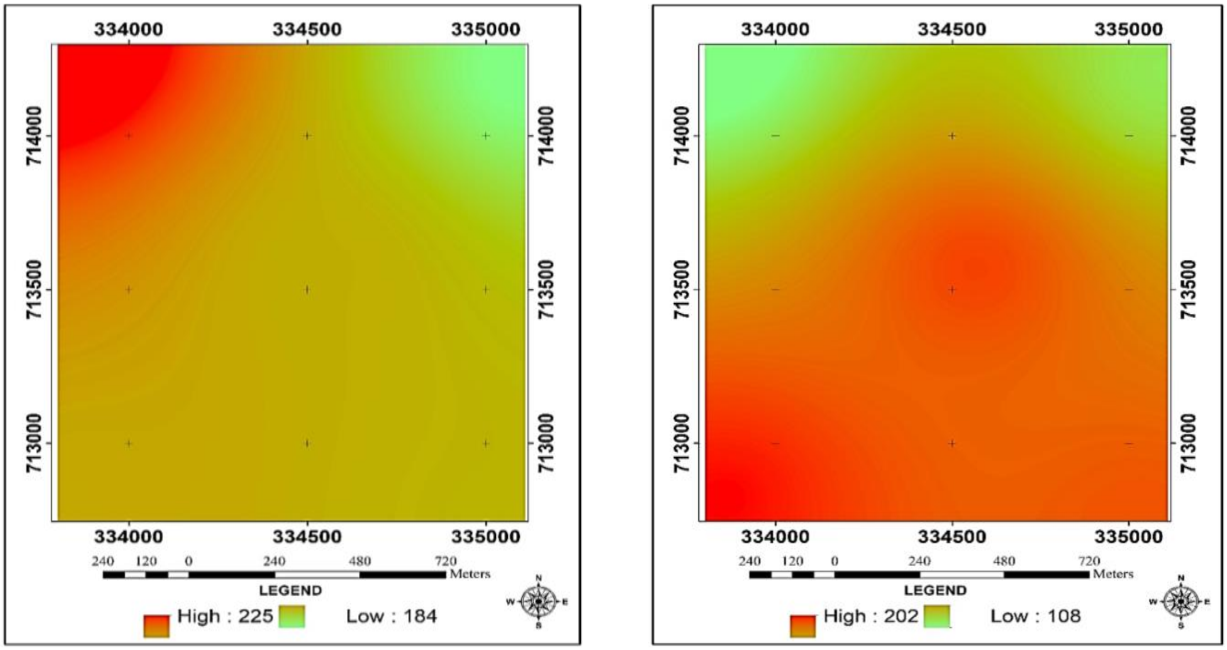

Figure 2. Spatiotemporal variation of PM_{10} (μ/gm^3) for dry season (left panel) and wet season (right panel).

in many studies. AQI refers to generalized method for converting the weighted values of air pollution-related indicators, such as sulphur (IV) oxide (SO_2), nitrogen (IV) oxide (NO_2), and particulate matter (PM_{10}) into a single number or group of numbers. It is a set of guidelines (such as an equation) that use numerical manipulation to convert parameter values into a more frugally formed form. Equation (I) was used to calculate AQI by applying the pollutant concentration data (EPA, 2012).

$$T_p = \frac{I_{Hi} - I_{Lo}}{BP_{HI} - BP_{Lo}} \left(C_p - BP_{Lo}\right) + I_{Lo} \quad (1)$$

Where T_p = the index for pollutant P, C_p = the rounded concentration of pollutant P, BP_{HI} = the breakpoint that is ≥ C_p, BP_{Lo} = the breakpoint that is ≤ C_p, I_{Hi} = the AQI value corresponding to BP_{HI} and I_{Lo} = the AQI value corresponding to BP_{Lo}

Types and sources of data

Concentrations of air pollutants (SO_2, NO_2, CO and PM_{10}) and co-ordinates of the locations were measured in-situ using a Haze-dust Particulate Monitor, a Gasman Air Monitor and a hand-held Garmin GPS. These formed the primary sources of data. The secondary data sources were from literature, climatic data from published journals, gazettes, brochures, the internet and statistical publications from the Environmental Protection Institutions and the Nigerian Meteorological Agency.

RESULTS AND DISCUSSION

In this part of the study, the spatiotemporal analysis of the study were revealed in maps and in charts for both wet and dry seasons to show the spatial distribution of air quality parameters.

Spatiotemporal analysis of PM_{10}

In the study, the inverse weighted model (IDW) tool in ArcGIS was used to perform a spatial interpolation analysis on the PM_{10} data in January and in June 2021 for the dry and wet seasons respectively. It was discovered that during the wet season, the Southern portion of the research region had the highest concentration of PM_{10} and during the dry season, the Northwest portion had the highest concentration of PM_{10}. During dry season, the PM_{10} concentration varied from 225 ppm to 184 ppm, while during rainy season, it varied from 202 ppm to 108 ppm (Figure 2).

Spatiotemporal analysis of Nitrogen (IV) oxide (NO_2)

From Figure 3, the results of the IDW analysis revealed a high concentration of nitrogen (IV) oxide in the central region during the dry season and at the Northeastern region during the wet season respectively. The spatiotemporal distribution of the results revealed that the lowest value was recorded in the central and western region during the wet season and at the Northern and Southeastern region during the dry season respectively. From Figure 3, the NO_2 concentration observed from the

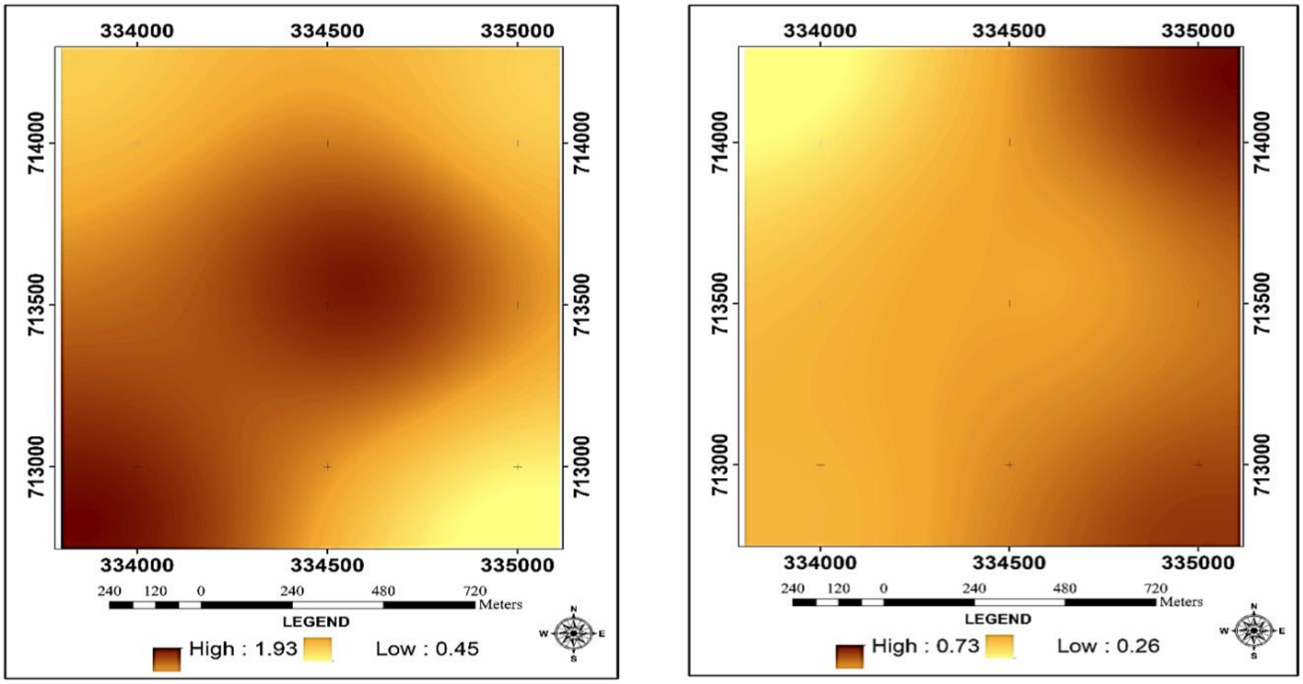

Figure 3. Spatiotemporal variation of NO_2 (ppb) for dry season (left panel) and wet season (right panel).

sampling location ranged from 1.93 to 0.45 ppm during the dry season and from 0.73 to 0.26 ppm during the wet season. High traffic congestion, very low humidity and more exhaust fumes from heavy machineries due to increased road construction activities could be the likely causes of high NO_2 during the dry season.

The combination of NO_2 with moisture in the air and decreased construction activity may have contributed to the low concentration observed during the wet season but this was still above the accepted WHO limits of exposure.

Spatiotemporal analysis of sulphur (IV) oxide (SO_2)

Figure 4 shows the spatiotemporal distribution of concentration of the sulphur (IV) oxide in the study. The SO_2 concentration observed ranged from 1.74 to 0.82 ppm during the dry season and from 1.65 to 0.69 ppm during the wet season (Figure 4). The highest concentration of SO_2 for both seasons was at the Southwestern part of the study area.

Based on the dry season survey, the reason for the high concentration values could be attributed to the anthropogenic activities in the neighboring areas as well as increased traffic congestions which were observed at the road intersections. Wetness dilutes these gases during the rainy season but even the reduced concentrations were still above WHO exposure limits.

Spatiotemporal analysis of carbon (II) oxide (CO)

Figure 5 revealed the distribution of CO in the study area for both the dry and wet seasons. The result of the spatiotemporal analysis for the two study seasons almost followed the same trend revealing that the Southern, Northern, and Western part of the city has the highest concentration of CO in the study area. Within the central part of the study area, carbon (II) oxide was observed to be low in concentration during the dry season and very low in concentration during the wet season. From the map legend, we see that during the dry season, the concentration of CO was between 8.86 and 10.72 ppb and during the wet season, it ranged between 11.85 and 16.66 ppb (Figure 5).

Relationship between some pollutants

When pollutants are found in diverse locations, they tend to be positively correlated with one another which suggest that their sources are the same. From Figures 6 to 9, and Table 1, there are linear positive relationships among the air pollutants during dry and wet seasons. When two variables are compared statistically, correlation is often used to determine how strongly or otherwise they are related (Briggs et al., 1997). Figures 6 to 9 respectively show how the pollutants (CO and NO_2, PM_{10} and CO; SO_2 and NO_2; PM_{10} and SO_2) are correlated. It

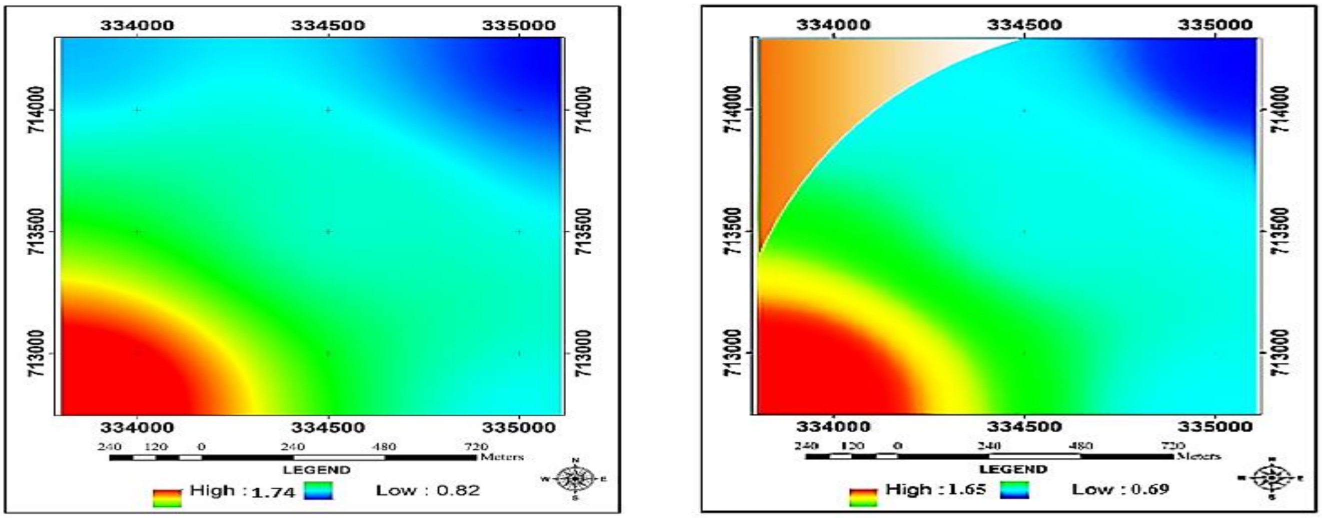

Figure 4. Spatiotemporal variation of SO_2 (ppm) for dry season (left panel) and wet season (right panel).

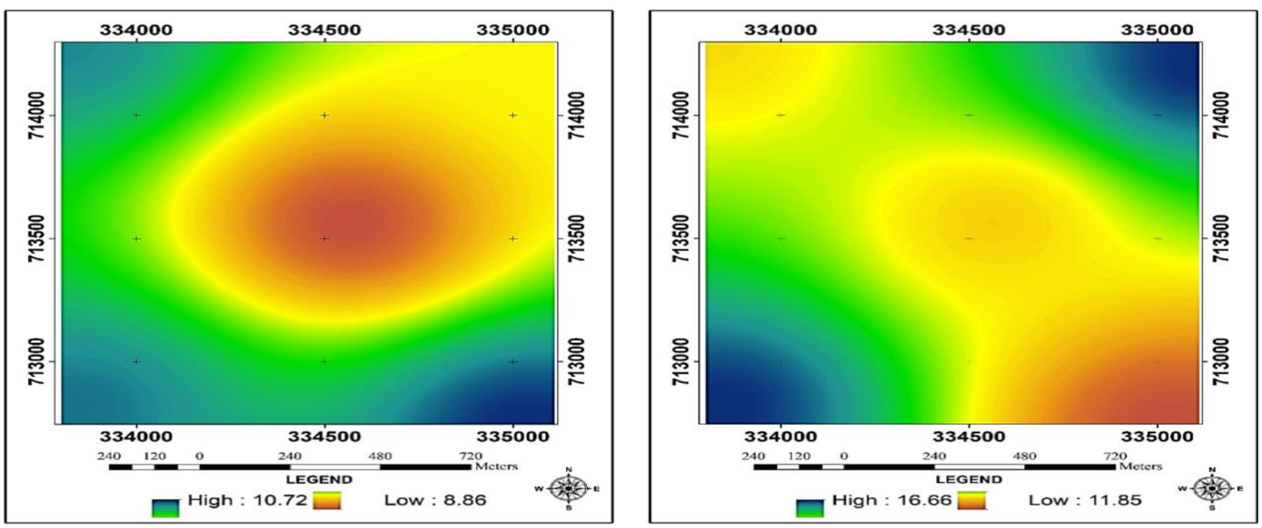

Figure 5. Spatiotemporal variation of CO (ppb) for dry season (left panel) and wet season (right panel).

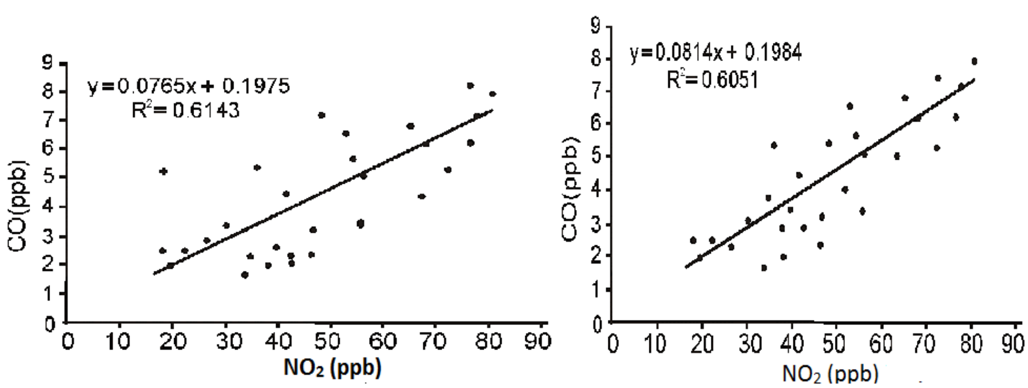

Figure 6. A scatter plot of CO and NO_2 for dry season (left panel) and wet season (right panel).

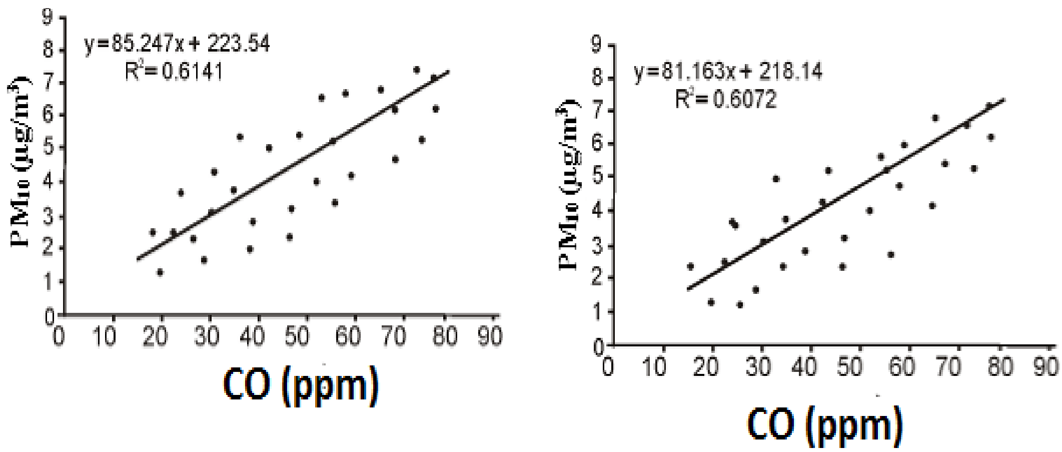

Figure 7. A scatter plot of PM_{10} and CO for dry season (left panel) and wet season (right panel).

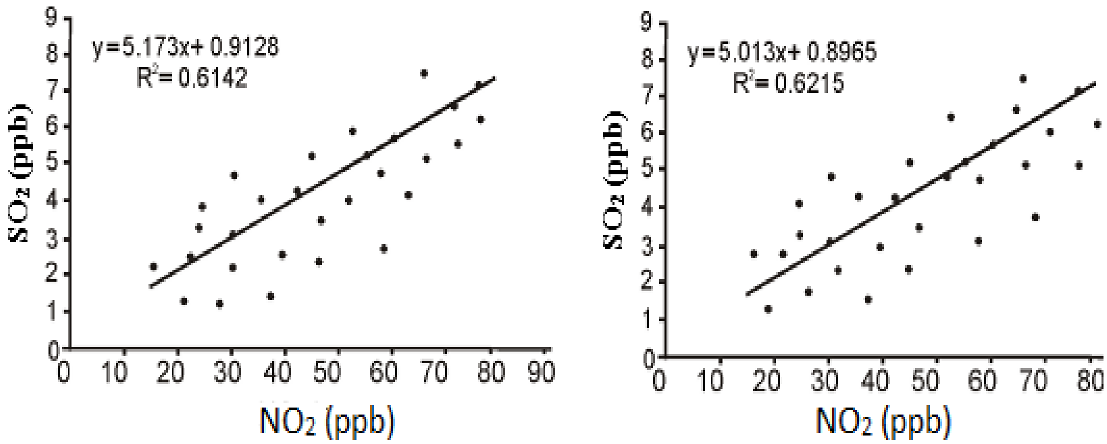

Figure 8. Scatter plot of SO_2 and NO_2 for dry season (left panel) and wet season (right panel).

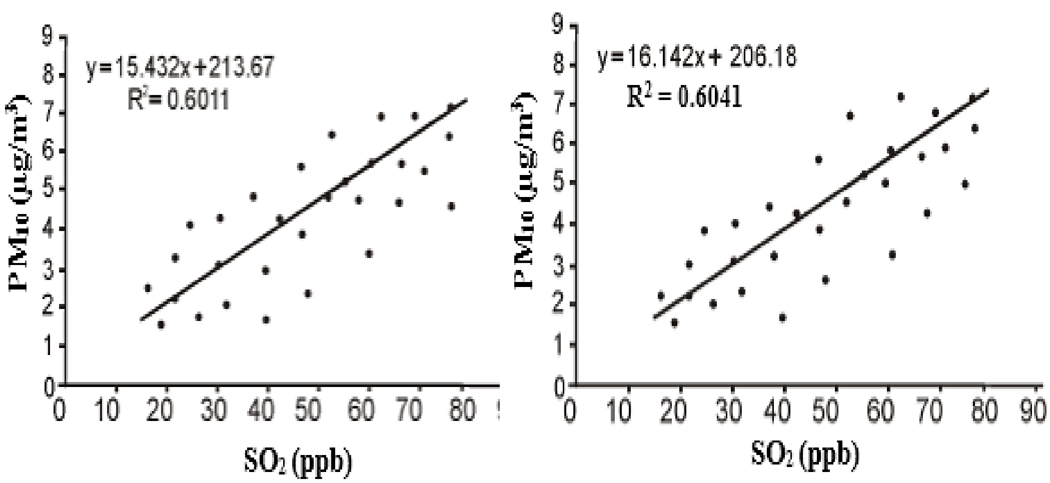

Figure 9. Scatter plot of PM_{10} and SO_2 for dry season (left panel) and wet season (right panel).

Table 1. Summary of graphical results.

	CO and NO_2		PM_{10} and CO		SO_2 and NO_2		PM_{10} and SO_2	
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
R^2	0.6143	0.6051	0.6141	0.6072	0.6142	0.6215	0.6011	0.6041

Table 2. Summary of results.

Compound	Dry season		Wet season		Likely sources
	Maximum	Minimum	Maximum	Minimum	
PM_{10} (μ/gm^3)	225	184	202	108	Dust, waste burning, wildfires, industries, windblown dust from open lands, bacteria fragments, Fumes from small and big engines
NO_2 (ppb)	1.93	0.45	0.73	0.26	Smoke, fumes (from trucks, furnace, cars, incineration plants, small engines)
SO_2 (ppm)	1.74	0.82	1.65	0.69	Fumes (from trucks, furnace, cars, incineration plants, small engines)
CO (ppb)	10.72	8.86	16.66	11.85	fumes (from trucks, furnace, cars, incineration plants, Big and small engines)

is evident that strong positive relationships exist between the pollutants and with the value of coefficient of determination, (R^2) ranging between 0.6011 and 0.6215 at 95% confidence level, the source of the pollutants could be said to be same. For instance, the linear correlation between CO and NO_2 are 0.6143 and 0.6051 for dry and wet season respectively, indicating that their relationship is linear.

CONCLUSION AND RECOMMENDATIONS

The study identified the spatial patterns of air pollution and its sources in Ogui New Layout using Remote Sensing and GIS Technology. From (Table 2) the results showed that during the dry season, the air pollutants (PM_{10}, CO, SO_2, and NO_2) had maximum values of 225, 10.72, 1.74, 1.93 respectively and minimum values of 184, 8.86, 0.82, 0.45 respectively (Table 2); while during the wet season, PM_{10}, CO, SO_2, and NO_2 had maximum values of 202, 16.66, 1.65, 0.73 (Table 2) respectively and minimum values of 108, 11.85, 0.69, and 0.26 (Table 2) respectively. Table 2 shows the likely sources of the pollutants. It has been established that burning of fossil fuels, industrial waste, combustion of plastic and organic products, incomplete combustion of synthetic substances and a number of other anthropogenic factors negatively affect air quality (Adams and Kanaroglou, 2016; Ebuete et al., 2019; Koleayo et al., 2021; Omoyajowo et al., 2022; Glory et al., 2023). Ogui New Layout is heavily populated with lots of existing and upcoming industries.

Based on the results of this study, it is advised that the local people of Ogui New Layout reduce their outdoor exposure, especially during the dry season. It is evident that the majority of the residents are exposed to air pollution such as PM_{10}, CO, SO_2, and NO_2 which is not good for their health. Knowledge of the interactions of these pollutants, their atmospheric lifetimes and concentrations will enhance our understanding of the potential environmental effects of changing their sources. In order to tackle the issues of air pollution in the study area, there should be increased and consistent monitoring of the city's air quality in order to address problems with air pollution. To successfully eradicate unlawful activities that have potential negative impact, standards should be set, implemented, monitored and evaluated from periodically as the need arises for improvement of the health of the citizens. Furthermore, industrial operators should embrace procedural and technological advancements for environmental sustainability with more pragmatism.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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