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Brief Communication

Contributions of some criteria air pollutants by petroleum product retailing stations to Nigeria airshed

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Abstract
This study was carried out on the petroleum product retailing stations to infer the contribution of criteria air pollutants to the host airshed. ToxiRAE II SO_2 and NO_2 detectors (model PGM-1130) were used to measure the concentrations of the gases respectively within four major petroleum products retailing filling stations in Ile-Ife, Nigeria for 10 h each day between the hour of 8.00 am and 6.00 pm with intervals of 30 min for a week per station. Generally, the mean concentrations of SO_2 were comparatively higher than those of NO_2 in the retailing stations. A comparison of the mean values of SO_2 and NO_2 with their USEPA standard permissible limits indicated that the measured air pollutants were present at elevated levels. The SO_2/NO_2 results suggested that the effect of vehicular emissions is about the same as that of industrial pollution on the ambient air quality. Air quality index results suggested that air pollution posed little or no risk, but there is a need for a cautionary statement. It is concluded that strong regulatory structures are needed to lessen the hazardous effects that could arise from the increase in the level of the pollutants in the ambient air. It is recommended that governments should encourage energy producers to clean smoke stacks by using scrubbers which trap pollutants before they are released into the atmosphere and catalytic converters in vehicles to reduce their emissions and that petroleum products retailing stations should be located far away from residential areas.

Keywords Air pollution · Criteria pollutant · Refined petroleum products · Retailing station · Sustainability

1 Introduction

Air pollution is a serious global environmental concern, particularly in developing nations such as Nigeria, where growing urbanisation and industrialisation deteriorate air quality [1]. The retail sector for petroleum products, including filling stations and related vehicle operations, is a substantial source of air pollution [2]. These stations emit toxic chemicals into the atmosphere, including sulphur dioxide (SO_2) and nitrogen dioxide (NO_2), which pose threats to both human health and the environment [3]. Despite worldwide attempts to limit emissions and mitigate their impact, poor countries continue to struggle to execute comprehensive air quality management plans [4].

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The United States Environmental Protection Agency (USEPA) defines criteria air pollutants as those for which national air quality guidelines have been established to protect public health and the environment [5]. Sulphur dioxide (SO_2) is mostly produced through the combustion of sulphur-containing fossil fuels, such as coal and oil [6]. It has been suggested that vehicle emissions, industrial activities, and petroleum product use at filling stations contribute significantly to SO_2 emissions in metropolitan areas [7]. High levels of SO_2 can have negative health impacts, particularly for those with pre-existing respiratory disorders such as asthma or chronic obstructive pulmonary disease (COPD) [8, 9]. Additionally, SO_2 causes acid rain, which can impact ecosystems, buildings, and water quality [10, 11].

Nitrogen dioxide (NO_2) is a major air pollutant caused by the combustion of fossil fuels in vehicles and industrial processes [12]. NO_2 is a precursor to ozone (O_3) and fine particulate matter ($PM_{2.5}$), leading to smog formation and poor air quality in cities [13, 14]. Prolonged exposure to NO_2 has been linked to health difficulties such as decreased lung function, respiratory infections, and higher hospital admissions [15, 16]. Furthermore, NO_2 contributes to eutrophication, where excess nutrient deposits in water bodies generate hazardous algal blooms, endangering aquatic ecosystems [17].

In Nigeria, air quality monitoring is still in its early stages [18–23], and detailed data on the contributions of various industries to air pollution, particularly petroleum product sales, is sparse. This study evaluates the contribution of criteria air pollutants, specifically SO_2 and NO_2, from petroleum product retailing stations to the airshed in Ile-Ife, Nigeria. By analysing pollutant concentrations at four major filling stations over a certain period, the study sheds light on the scope of air pollution and its possible health implications. The results are then compared to USEPA guidelines to determine the severity of pollution and the need for regulatory interventions. This study emphasises the necessity of monitoring air quality in places with a high concentration of petroleum retailers, as well as the need for stricter control measures to reduce these pollutants' detrimental effects on the environment and public health.

2 Experimental

2.1 Study area

Ile–Ife is one of the fastest developing communities in Southwestern Nigeria. It is located at latitude 7º 48′N and longitude 4º 55′E points (Fig. 1). The population of the city is over 400, 000 residents with sizable numbers of small to medium-scale industries, commercial establishments, primary and secondary schools, as well as degree-awarding public academic institutions.

2.2 Sample collection

The study selected four large petroleum product retailing outlets in Ile-Ife, Nigeria, for gas concentration measurements. These stations were chosen for their high patronage in the study area, making them representative of the typical exposure circumstances faced by both customers and workers in congested areas. These stations, run by various companies, sold diesel, gasoline, kerosene, engine oil and natural gas. ToxiRAE II SO_2 and NO_2 detectors (model PGM-1130) were used to test SO_2 and NO_2 levels at these sites. These gas analysers, with a detection range of 0–20 ppm, a resolution of 1 ppm, and a response time of 30 s, provided accurate and rapid measurements.

Each gas detector is of size 9.3 cm × 4.9 cm × 2.2 cm having a weight of 102 g with its clip. The gas detector has a one-button operation keypad, an audible alarm of 90 dB at 10 cm, a visible alarm showing a bright red/green LED bar visible from the top, front, and sides, and an in-built vibration alarm. At each site, sampling was carried out at the center of the station for 10 h each day between the hours of 8.00 am and 6.00 pm with intervals of 30 min per week per station.

2.3 Data treatment

The overall data acquired was subjected to appropriate descriptive and inferential statistical techniques such as Analysis of variance (ANOVA) to interpret the results. The air quality index was also calculated in order to estimate how clean or polluted the air-shed was.

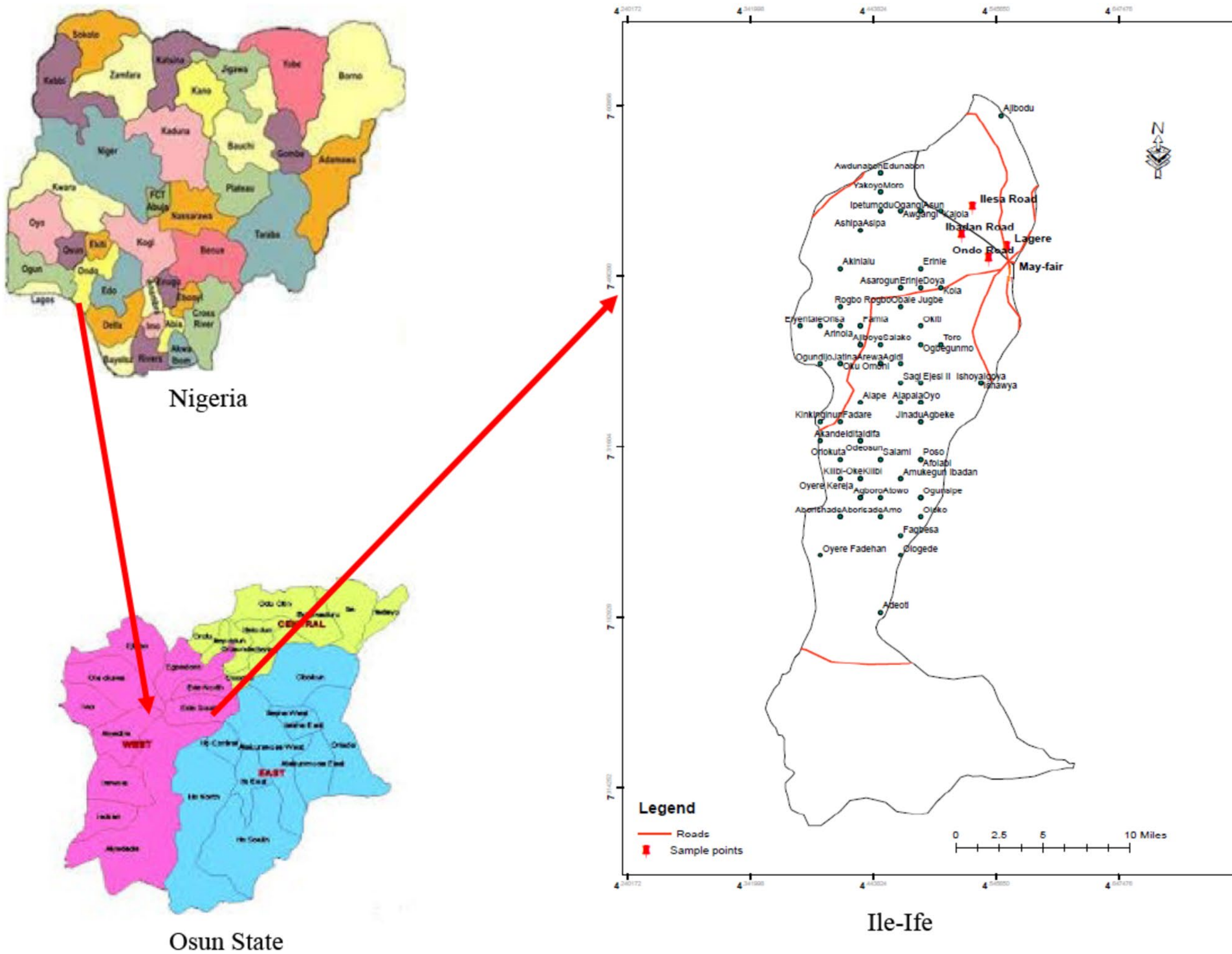

Fig. 1 Map of the study area showing sampling locations

2.3.1 Air quality index (AQI)

An environmental index is a tool known as the Air Quality Index, AQI, which is used to report the overall environmental status and trends based on a specific standard and was developed along the lines of a health index and measured by the degree of human suffering. Each AQI category makes it easier for the general public to comprehend how clean or polluted the air is. Overall AQI can be used to give a significant evaluation of air pollution to humans. They also assist in evaluating alternative air pollution control policies or control equipment which, for instance, can reduce the level of certain pollutants while increasing the levels of others. Air Quality Index can represent the overall air quality status in a better way since the cumulative effect of all the pollutants and the related standards can be taken into account. As a result, an equation can be obtained, which changes the parameter values using numerical operation into a simpler and more precise form. To evaluate overall air pollution due to various pollutants, it is complex as it consists of an ill-defined mixture of several pollutants from different sources. The index of specific pollutants is obtained mainly from the physical measurement of pollutants like SO_2 and NO_2 [24].

The Air Quality Index is calculated based on the average of the sum of the ratios of pollutants (SO_2 and NO_2 in this case) to their respective air quality standards. The average is then multiplied by 100 to get the AQI [25]. For AQI, the air quality rating of each quality parameter/pollutant (here SO_2 and NO_2 only) was calculated first by the following formula:

$$Q = 100\frac{V}{Vs} \tag{1}$$

where,

Q = represents quality rating,

V = the observed value of the air quality parameters pollutant.

V_S = the standard value for that pollutant recommended by NAAQS / CPCB for different areas.

If Q < 100, the given parameter is within the tolerable limit. On the other hand, if Q > 100, it implies that the given parameter exceeds the tolerable limit and the ambient air is harmful for breathing by human beings. It is assumed that all the parameters have equal importance and so only the unweighted air quality indices are calculated. The geometric unweighted AQI may be calculated from the quality rating Q by taking their geometric mean.

$$\text{Geometric mean} = \text{antilog}\left[\left(\log Q_1 + \log Q_2 + \ldots + \log Q_n\right)/ n\right] \tag{2}$$

The ambient air quality index can be calculated using Eqs. 1 and 2. Alam et al. [51] established seven grades of air quality categories such as *very clean* (AQI < 10), *clean* (10 ≥ AQI < 25), *fairly clean* (25 ≥ AQI < 50), *moderately polluted* (50 ≥ AQI < 75), *polluted* (75 ≥ AQI < 100), *highly polluted* (100 ≥ AQI < 125) and *severely polluted* (AQI ≥ 125).

3 Results and discussion

3.1 *Concentrations of the analyzed SO_2 and NO_2*

The mean concentrations of the gases are presented in Table 1. Even though the concentrations of the analyzed gases are close, it is observed that station B has the comparatively highest mean concentrations of SO_2 (2.12 ± 0.68 ppm) and NO_2 (1.36 ± 0.12 ppm) respectively. This might be because the station is a mega station with the highest level of patronage. Also, the mean concentration of SO_2 is relatively higher than the mean concentration of NO_2. SO_2 concentrations at retailing stations are higher than NO_2 due to differences in their sources and combustion characteristics. Sulphur dioxide (SO_2) is mostly produced during the burning of sulphur-containing fuels, especially diesel, which contains more sulphur than gasoline [26]. This is especially obvious at retail stations where diesel is extensively used, particularly by commercial vehicles like trucks and buses that contribute to SO_2 emissions [27]. Despite sulphur restrictions reducing the sulphur content in diesel fuel, considerable emissions continue due to the use of older vehicles and machinery that still operate on high-sulphur diesel [28].

On the other hand, nitrogen dioxide (NO_2) is largely a secondary pollutant produced by the burning of gasoline and diesel in engines [29]. Recent studies showed that strict emission controls, such as catalytic converters and selective catalytic reduction (SCR) systems, have dramatically reduced vehicle NO_2 emissions. These regulations effectively reduce NOx emissions from gasoline automobiles, resulting in decreased NO_2 levels at retailing stations [30–32].

The higher level of SO_2 observed at retail stations can be explained by the kinds of cars and fuels that are typically found there. Due to diesel fuel's higher sulphur content than gasoline, diesel-powered trucks and buses—which regularly stop at these stations—emit more SO_2 [33]. These vehicles' frequent refuelling, particularly in cities and close to highways, continuously adds to the SO_2 emissions at these stations.

The overall mean concentration (1.44 ± 0.49 ppm) for SO_2 measured at the four stations is presented in Table 2. The result indicates that the level of SO_2 in this study is higher than its USEPA standard permissible limit for industrial (0.08 ppm) and residential (0.06 ppm) areas. The result of the T-test comparing the concentration of SO_2 with the standard permissible limit is also presented in Table 3. The result indicates that there is a significant difference between the SO_2 concentration and its standard permissible limits due to the higher level of the SO_2 in the stations than its USEPA standard

Table 1 Mean levels of the NO_2 and SO_2 gases in the refined petroleum products retailing stations

Retailing station	Levels and range (ppm)	
	NO_2	SO_2
A	1.07–1.60 (1.35 ± 0.20)	0.06–1.87 (0.97 ± 1.28)
B	1.18–1.60 (1.36 ± 0.12)	0.97–2.96 (2.12 ± 0.68)
C	1.00–1.56 (1.27 ± 0.20)	0.66–2.70 (1.30 ± 0.71)
D	0.99–1.32 (1.16 ± 0.12)	0.75–1.74 (1.36 ± 0.33)
Overall mean ± SD	1.27 ± 0.09	1.44 ± 0.49

SD Standard deviation

Table 2 Comparison of the overall mean levels with their tolerable limits for industrial areas using T-test analysis

Pollutant gas (ppm)	This study	National Ambient Air Quality Standard (DE, Government of NCT, 2015)	T-value	T-test analysis result remark
NO_2	1.27 ± 0.09	80 (Annual average)	80.2	$t_{expt} > t_{thor}$
SO_2	1.44 ± 0.49	80 (Annual average)	16.8	$t_{expt} > t_{thor}$

t_{expt} = calculated T-test; t_{thor} = theoretical; T-test = 2.086 at 95% confidence limit and degree of freedom; $t_{expt} > t_{thor}$ = Significant difference; $t_{expt} < t_{thor}$ = No significant difference

Table 3 Comparison of the overall mean levels with their tolerable limits for residential areas using T-test analysis

Pollutant gas (ppm)	This study	National Ambient Air Quality Standard (DE, Government of NCT, 2015)	T-value	T-test analysis result remark
NO_2	1.27 ± 0.09	60 (Annual average)	81.5	$t_{expt} > t_{thor}$
SO_2	1.44 ± 0.49	60 (Annual average)	17.1	$t_{expt} > t_{thor}$

t_{expt} calculated T-test, t_{thor} theoretical, *T-test* 2.086 at 95% confidence limit and degree of freedom, $t_{expt} > t_{thor}$ Significant difference, $t_{expt} < t_{thor}$ No significant difference

permissible limit. Excessive SO_2 exposure can lead to respiratory ailments such as asthma, bronchitis, and COPD [34]. SO_2 can irritate the respiratory system, leading to airway inflammation and worsening pre-existing illnesses in vulnerable persons like children, the elderly, and those with asthma [35, 36]. Short-term exposure to elevated SO_2 levels can cause throat irritation, coughing, and trouble breathing, while long-term exposure may result in a reduction in lung function [6, 37]. High levels of SO_2 not only pose health problems but also have significant environmental implications. Acid rain is primarily caused by SO_2, which occurs when sulphur compounds in the atmosphere combine with water vapour to produce sulphuric acid [38]. Acid rain affects ecosystems by acidifying water bodies, destroying aquatic life, and depleting soil nutrients, reducing plant growth and biodiversity [39, 40]. Furthermore, SO_2 can create sulphate aerosols, which reflect sunlight and cool the Earth's surface but can cause respiratory difficulties in humans [41].

The overall mean concentration (1.27 ± 0.09 ppm) of NO_2 measured at the four stations is also presented in Table 2. The result indicates that the mean level of NO_2 in this study is higher than its USEPA standard permissible limit for industrial (0.08 ppm) and residential (0.06 ppm) areas. The result of the T-test comparing the concentration of NO_2 with the standard permissible limit is also presented in Table 3. Similar to that of SO_2, the result indicates that there is a significant difference between the NO_2 concentration and its standard permissible limit due to a higher level of NO_2 in the stations than its USEPA standard permissible limit. Elevated NO_2 concentrations represent a major concern to human health, particularly in urban areas with heavy traffic emissions [42]. NO_2 is a precursor to ozone and particulate matter (PM), causing air pollution and health concerns [43, 44]. Chronic exposure to NO_2 has been related to decreased lung function, increased susceptibility to respiratory infections, and worsened asthma [15, 45]. Acute exposure can irritate the respiratory tract. Children are more vulnerable because of their growing respiratory systems [46]. Ground-level ozone, a potent greenhouse gas and a major component of smog is formed mostly by NO_2 [47]. Elevated NO_2 levels encourage the creation of ozone, which is detrimental to crop yields and forest health in addition to being the primary cause of climate change [48]. Ozone damages plant tissues, reducing their growth and yield. This has important ramifications for food security and agriculture [49, 50].

3.2 Air quality index (AQI)

The variations of the air quality index of the investigated petroleum products retailing stations are presented in Table 4. SO_2/NO_2 was calculated to check the effect of the vehicular movements at the sampling sites. The SO_2/NO_2 values obtained ranged from 0.72 to 0.55 with a mean value of 1.12. This value suggests that the effect of vehicular emission is similar to the effect of pollution via industries on air quality. The mean air quality index of the retailing stations is 10.9 which suggests that the air quality is satisfactory and air pollution poses little or no risk. Based on the grades of air quality categories established by Alam et al. [51], the calculated value for the air quality index falls in the range of $10 \geq AQI < 25$ category, indicating that the air quality is still clean. Nitrogen dioxide (NO_2) and sulphur dioxide (SO_2) in metropolitan environments are primarily released by vehicles, particularly in high-traffic places such as gas stations. Automobile emissions are important, but industrial processes also have a big impact on SO_2 and NO_2 levels. Furthermore, there are

Table 4 Air quality index (AQI) of the petroleum product retailing stations

Sampling locations	SO_2/NO_2	AQI
A	0.72	9.28
B	1.56	13.92
C	1.02	10.28
D	1.17	10.08
Mean	1.12	10.89

additional possible sources of air pollution. Burning biomass for cooking and heating produces a lot of air pollutants in many developing locations, including SO_2 and particulate matter [52]. Local biomass burning can contribute to regional air pollution, even if it is less directly tied to petroleum retailing stations, especially in certain seasons. Air quality can also be lowered by dust and particulate matter from adjacent construction sites or dust resuspension from moving vehicles [53, 54]. The air quality surrounding petroleum retailing stations can be impacted by particulate matter (PM_{10} and $PM_{2.5}$), which can carry adsorbed contaminants including SO_2 and NO_2 [55].

3.3 Analysis of variance (ANOVA)

The single-factor analysis of variance was carried out on the measured criteria air pollutants investigated in the petroleum products retailing stations using the Microsoft Excel software package. If $F_{calculated} > F_{critical}$, the null hypothesis is rejected. However, this is not the case for the petroleum product retailing stations as $1.39 < 6.59$ as shown in Table 5. Therefore, we accept the null hypothesis, meaning that the four populations are not all equal. This suggests that, at the 5% significance level, the variations in mean pollutant levels between the four retail stations are not statistically significant. If the null hypothesis is accepted, then there is not a statistically significant difference between the four petroleum product retailing stations' air pollution levels (as determined by the criteria air pollutants). In general, the pollution levels are similar at each of these sites; any small variations are probably the result of randomness rather than real variations in the concentrations of pollutants. This conclusion implies that air pollution levels at all the analysed sites are fairly constant, from a regulatory or environmental standpoint. Therefore, rather than concentrating efforts on a single place, uniform pollution control methods can be adopted across these stations.

3.4 Comparison of the mean levels of air pollutants in this study with similar studies

The comparison of the mean levels of the air pollutants in this study with national and international studies is presented in Table 6. The mean levels of air pollutants obtained in this study are comparatively lower than those reported on industrial areas by Ipeaiyeda and Adegboyega [56] in Ibadan, Nigeria, Xiao et al. [60] in the Inland Basin City of Chengdu, Southwest China, and Dandotiya et al. [59] in the urban areas of Gwalior City, India but relatively higher than those reported by Wang et al. [57] in Jiangsu Province of China and Khadija and Ibrahim [58] in Kano metropolis, Nigeria. The relatively lower levels of air pollutants in the study area could be attributed to the smaller volume of vehicles and industrial setups

Table 5 Single factor analysis of variance

Groups	Count		Sum		Average	Variance
A	2		2.32		1.16	0.0722
B	2		3.48		1.74	0.2888
C	2		2.57		1.285	0.00045
D	2		2.52		1.26	0.02
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.40	3	0.133	1.398	0.365	6.591
Within Groups	0.38	4	0.095			
Total	0.78	7				

Table 6 Comparison of the mean levels of air pollutants in this study with national and international studies

Air pollutant	This study	[56]	[57]	[58]	[59]	[60]
NO_2	1.27 ± 0.09	63 ± 16	0.78 ± 0.08	0.02 – 0.03	9.08 – 27.6	13 – 95
SO_2	1.44 ± 0.49	30 ± 19	0.61 ± 0.15	0.03 – 0.05	8.56 – 18.75	5 – 61

NDT Not Determined

in the study area (Ile-Ife, Nigeria) compared to the studies in the other metropolitans reported by the authors. Conversely, those that see less industrial activity might have lower pollution levels.

4 Conclusion

In conclusion, the study examined the concentrations of sulphur dioxide (SO_2) and nitrogen dioxide (NO_2) at petroleum product retailing stations. The study found mean SO_2 values of 1.44 ± 0.49 ppm and NO_2 concentrations of 1.27 ± 0.09 ppm, which exceeded USEPA standards for industrial and residential regions. Station B recorded the highest levels of both pollutants. Commercial vehicles' usage of sulphur-containing diesel can contribute to higher SO_2 levels than NO_2 levels. Elevated quantities of these gases pose serious health hazards, including respiratory issues and environmental consequences such as acid rain and reduced biodiversity. T-test analysis indicated that both pollutants' concentrations were significantly higher than the standard limits. The Air Quality Index (AQI) data indicated that, despite these elevated levels, the air quality at these sites remains within the 'satisfactory' range, meaning that there is little immediate risk to public health. While these findings are impressive, it is important to acknowledge some limitations of the study. Because station activity, traffic patterns, and fuel sales volume all change during the day, so can pollutant concentrations such as SO_2 and NO_2. For example, greater vehicle traffic and fuel distribution during morning and evening peak hours may cause emissions to soar, whereas lower pollution levels may be observed during quieter times. Even though extensive, sampling from 8:00 am to 6:00 pm might not fully capture differences in the quality of the air outside of these hours, particularly at night or in the early morning when environmental conditions like temperature inversions could alter the dispersion of pollutants. Also, airborne pollution can be widely affected by a variety of atmospheric factors, such as temperature, precipitation, humidity, wind direction, and speed. Pollutant buildup can occur during calm weather, although wind can disperse pollutants over a greater region and reduce their concentrations at the measuring site. Rain can remove contaminants from the atmosphere, causing sample concentrations to be falsely lowered. The behaviour and emission of pollutants are also affected by temperature variations, especially NO_2, whose concentration tends to rise throughout the winter. The study emphasises the need for more stringent laws, including the use of catalytic converters in cars, to regulate vehicular emissions, particularly those from diesel-powered vehicles, and for ongoing surveillance to lessen the long-term environmental and health effects of elevated SO_2 and NO_2 levels around retail stations. It is also recommended that petroleum products retailing stations should be, if possible, cited far away from residential areas. This is based on safety concerns about the combustible nature of petroleum products and the accompanying dangers to the environment and public health. However, because of overlapping residential and commercial land use brought on by a high population density, restricted space, and urban expansion, putting this into practice in densely populated urban regions could be challenging. The relocation of retail petroleum stations is made more difficult by the strong demand for easily accessible fuel supply in these areas. Nevertheless, alternative safety measures can be put in place to lower risks if moving petrol retail stations is not feasible. These include enforcing zoning laws more strictly, managing emissions and safety risks using cutting-edge technologies, and raising safety requirements for stations that already exist. Strong, effective regulatory structures and monitoring are necessary to stop the increase in pollution levels. Governments need to take a multifaceted approach because of the variety of pollution sources, which might range from residential waste to transportation and industrial pollutants. The public and private sectors should be actively involved in this strategy, which should also include stringent enforcement of pollution restrictions and ongoing monitoring. Understanding daily variations in pollution levels requires real-time monitoring. Air pollution can be continuously measured by installing continuous emission monitoring systems (CEMS) at refineries, industrial facilities, and congested routes. Lawmakers ought to impose requirements on businesses, such as petroleum retail stations, requiring them to install CEMS and adhere to emissions thresholds. Allowing local communities to track and report pollution levels improves accountability and transparency. By offering more information on pollution hotspots, citizen science programs that train people to use portable air quality sensors can enhance official monitoring systems. Governments can set up community-based reporting portals where locals can record data on air quality, report obvious pollution infractions, and participate in larger-scale pollution reduction initiatives.

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Author contributions FMA conceived and designed the experiment, OTO wrote the main manuscript text, GCE, OAO, ABB, AFA, POA, and ODO carried out data analysis and visualization. All authors reviewed the manuscript.

Availability of data and materials The authors declare that the data supporting the findings of this study are available within the paper and its Supplementary Information files. Should any raw data files be needed in another format they are available from the corresponding author upon reasonable request.

Declarations

Competing interests The authors declare no competing interests.

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