# Indoor/Outdoor Concentration of Pollutants Around Major Roundabouts in Ilorin Metropolis, Nigeria

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**Abstract**. The escalation of daily human activities has led to a surge in gaseous pollutants and particulates, with indoor environments often exhibiting higher pollutant levels than outdoor air. This study delves into the intricate relationship between outdoor pollutants and indoor settings near traffic intersections within the Ilorin metropolis. The research focuses on six strategically chosen locations with intensified vehicular and human interactions. Data on particulate concentration were collected at various time intervals.

The Met One Aerocet 531s apparatus assessed indoor and outdoor particulate matter concentrations. Additionally, the Crowcon Gas Pro, a versatile multi-gas measurement equipment, facilitated the quantification of gaseous pollutants, including Oxygen, Carbon monoxide, Carbon dioxide, Hydrogen sulfide, and Methane. The assessment of other gaseous pollutants, such as NO, $NO_2$, and $NH_3$, was conducted using the ToxiRAE II apparatus, which offers diverse measurement capabilities. The Kestrel weather tracker contributed to the study by furnishing microclimatic parameters. All measurement instruments were strategically positioned at approximately 1.5 meters above ground level.

Vehicular density variation emerged as a pivotal criterion in the evaluation process. Findings revealed elevated outdoor PM10 concentrations during rush hours at the roundabouts, indicating heightened pollutant emissions during peak traffic times. Conversely, intriguingly elevated indoor PM10 concentrations were observed within specific indoor environments during non-rush hour periods. This phenomenon potentially results from the interplay of meteorological fluctuations and indoor activities, underscoring the complexity of pollutant dispersion dynamics.

Indoor-to-outdoor concentration ratios emerged as a significant metric, consistently exceeding unity across diverse sites. This observation substantiates the presence of indoor-based pollutant sources, necessitating vigilant monitoring and effective mitigation strategies to mitigate potential health risks for indoor occupants.

This research contributes vital insights into the intricate domain of air quality assessment, offering nuanced perspectives on pollutant distribution dynamics, indoor exposure scenarios, and ensuing health implications. By addressing the complex nexus between outdoor and indoor environments, this study emphasizes the imperative of adopting comprehensive strategies to curtail pollutant emissions at their source, foster sustainable urban planning, and enhance the quality of indoor environments. The outcomes resonate with broader endeavours to address the far-reaching consequences of air pollution on both ecological equilibrium and human well-being.

**Keywords**: air quality assessment; pollutant concentration; air quality; air pollution.

## INTRODUCTION

Air pollution is a significant and widespread environmental issue that affects industrial towns and urban areas worldwide [1, 2]. It refers to introducing harmful substances into the atmosphere, causing damage to the environment, human health, and overall quality of life. Air pollution can occur indoors, in homes, schools, offices, and outdoors, leading to various health and environmental concerns [3].

Air pollutants can be broadly categorized into two main types: gaseous pollutants and particulate matter.

Gaseous pollutants are atmospheric compounds in concentrations typically below 100 parts per million. These pollutants include gases like nitrogen oxides (NOx), sulfur dioxide, ammonia, carbon dioxide, methane, and volatile organic compounds (VOCs) [4]. Some of these gases, such as NOx and $SO_2$, are highly hazardous to human health and associated with various health issues, including respiratory problems and cancer [5]. Radon, a radioactive gas that seeps into homes from the soil, poses a significant health risk and has been linked to lung cancer [6]. Carbon monoxide (CO), another dangerous indoor gas, is produced from the incomplete combustion of fossil fuels and can interfere with oxygen transport in the blood, leading to serious health consequences. Indoor environments are also exposed to organic gases, often called volatile organic compounds (VOCs), which emanate from various household products and materials [7].

Solid particles and liquid droplets suspended in the air are called particulate matter. These particles vary in size and can be categorized based on their diameters. Inhalable coarse particles, with diameters between 2.5 and 10 micrometres, are often found in dusty environments and outdoor settings. Fine particles, with diameters of 2.5 micrometres or less, are commonly associated with smog and can reach deep into the lungs, causing respiratory issues [8].

Vehicle emissions are a significant contributor to the release of pollutants into the atmosphere. Vehicle emissions are an essential contributor to releasing pollutants into the atmosphere, such as unburned hydrocarbons, particulates, carbon dioxide ($CO_2$), and nitrogen oxides (NOx). These emissions lead to smog, acid rain, and greenhouse gas effects, adversely impacting the environment and human health. The combustion of fossil fuels in vehicles releases pollutants that can react in the atmosphere to create photochemical smog and contribute to global warming [9].

Smog, a combination of smoke and fog, is a localized pollution often trapped by thermal inversions. Burning gasoline in vehicles is a primary source of smog in many regions, producing ozone and other harmful substances. Smog can cause eye and lung irritation, damage plants, and contribute to acid rain [10].

Air pollution has significant environmental effects, including ozone depletion, global warming, and acid rain.

Ozone depletion in the stratosphere, caused by releasing substances like chlorofluorocarbons (CFCs), increases exposure to harmful sun ultraviolet rays. This phenomenon can result in higher rates of skin cancer, cataracts and reduced crop yields.

By trapping heat in the Earth's atmosphere, greenhouse gases like carbon dioxide (CO2) contribute to global warming and hurt the climate [11].

Airborne pollutants can combine with water vapour to form acids, leading to the formation of acid rain. Acid rain harms ecosystems and infrastructure, including plants, animals, and building materials [12].

Particulate matter and gaseous pollutants have wide-ranging adverse effects on human health, causing various respiratory, reproductive, carcinogenic, and neurological issues. Particulate matter can penetrate the lungs, leading to respiratory problems, while toxic gases like carbon monoxide (CO) can interfere with oxygen transport in the bloodstream.

Efforts to control and prevent air pollution involve both end-of-the-pipe technologies that capture pollutants and measures to reduce pollution at its source. Regulatory standards, such as those limiting emissions from industrial smokestacks and automobile tailpipes, play a crucial role in curbing pollution. Additionally, interventions like providing vented stoves have improved indoor air quality.

While traffic pollution studies have been conducted in various parts of the world, including developed countries, no research focuses on Nigeria's specific challenges of traffic-related pollution. Understanding the unique dynamics of traffic pollution in Nigeria is crucial for developing effective mitigation strategies tailored to the country's context.

In conclusion, both human health and the ecosystem are seriously threatened by air pollution. Gaseous pollutants and particulate matter, often from human activities such as vehicular emissions, cause various health and environmental concerns. Effective pollution control measures and targeted research are essential to mitigate the adverse impacts of air pollution on both local and global scales.

## METHODOLOGY

*Sampling Locations.* The monitoring was done in Ilorin, the capital city of Kwara state in Nigeria, at some significant roundabouts. The roundabouts were chosen because of the high use rate of the axes by commuters because they are primary access routes to some essential parts of the city. The average patronage of vehicles on the streets is approximately 7,200 at non-rush hours and about 13,200 at rush hours, considering the four lanes leading to the roundabouts, the double-lane road, and the roundabouts cross junctions. Various vehicles such as Motorcycles, Tricycles, Cars, Lorries, and trucks ply the road for commercial and personal services. The diurnal variations of fleet compositions were constant each day, with relatively low traffic numbers during daytime (non-rush hours, i.e., 10:00 am-2:00 pm) and high values during evening time (rush hour, i.e., 4:00 pm-8:00 pm).

The sampling exercise was carried out at the under-listed roundabouts in the Ilorin metropolis: 1) Tipper garage roundabout (Tanke, University Road); 2) Post office roundabout; 3) Unity roundabout; 4) Oja Oba roundabout; 5) Garin-Alimi roundabout; 6) Offa garage roundabout.

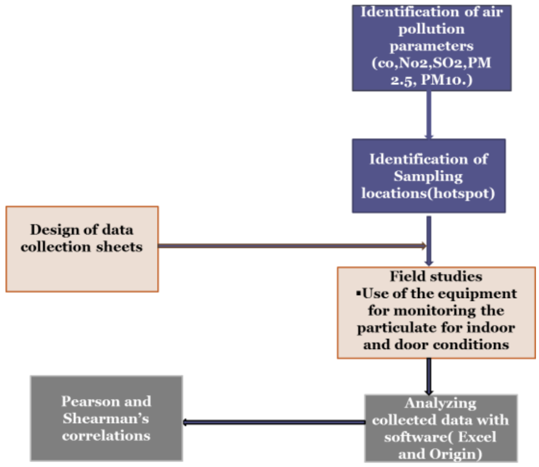


Figure 1 – Flow diagram for the methodology

The map below shows the hotspots' corresponding positions within the Ilorin metropolis.


Figure 2 – Map of selected hotspots within the Ilorin metropolis

*Indoor characteristics of sampling locations in the Ilorin metropolis.* For this research, indoor air samples were taken in shops near the roundabouts for comparison. Below are the indoor areas with the corresponding properties.

Table 1 – Some Indoor characteristics of sampling locations

| Location | Indoor description | Approximate distance from the road | Number of occupants | Ventilation type |
|---|---|---|---|---|
| Tipper garage | A provision store and a building material shop | 8 | 8 | Door. No window |
| Post office | A shoe shop and a clothing shop | 2 | 7 | Door. No window |
| Unity | A provision/cosmetic. Upstairs in a one-story building. | 6 | 7 | Door. No window |
| Ojo-Oba | A provision store/ pharmacy. Upstairs of a 1-storey building. | 3 | 5 | Door. No window |
| Garin-Alimi | Vulcanizer's shop | 4 | 8 | More like a shed |
| Offa Garage | A pharmacy | | 7 | Door |

*Measurements of Particle Numbers and Size Distributions.* The sampling equipment was placed about 1.5 meters from the floor. During the samplings, the primary concerns were the size distribution, number distribution, and the gaseous pollutant constituents. Aerocet 531s, equipment produced by Met One Instruments, was used for the mass and number concentration characterizations, while the Crowcon gas-pro was used for the gas detection. The two instruments are handheld, battery-operated, and completely portable units. The Aerocet 531s measures five number concentration ranges of Total Suspended Particles: $PM_{0.3}$, $PM_{0.5}$, $PM_1$, $PM_5$, and $PM_{10}$. It has a sampling period of 1 minute and a flow rate of 2.83 l/min. The concentrations were extrapolated to 8 hours and 24-hour averaging periods using an atmospheric stability formula given in the equation below:

$$C_0 = C \times F \quad (1)$$

where $C_0$ – the concentration at the averaging period $t_0$;

C – the concentration at the averaging period $t_1$;

F – factor to convert from the averaging period $t_1$ to the averaging period $t_0 = (t_1/t_0)^n$;

n – 0.28, the stability-dependent exponent.

The measurement devices were turned on in the environment of interest and set at a height of about 1 m. After particle collecting, the measured concentration was shown directly on the screen.

*Measurements of Gaseous Pollutants Concentration.* Gaseous pollutants in the selected areas were measured using Crowcon Gas Pro and ToxiRAE equipment of varying specifications, such as NO, $NH_4$, and $SO_2$. The equipment was placed about 1.5 meters above ground level.

*Sampling Equipment Description.* This instrument produced by "Met One instruments" was used in the particulates sample measurement. The equipment displayed below is digital, portable, and battery-operated. To size individual particles that pass through the laser optical system, particle number counts and mass particulate matter measurements are done using the light scattering principle. Equivalent mass concentration has been derived and displayed using a proprietary algorithm.

Oxygen ($O_2$), Carbon monoxide (CO), Carbon dioxide ($CO_2$), Hydrogen sulfide ($H_2S$), and Methane ($CH_4$) gases are among the up to 5 gases that Gas-pro can detect. This device was used to determine the air quality, i.e., what gases and the amount the air in the environment contains. The exhaust from vehicles and emissions from other gaseous pollutant sources were analyzed with this equipment. This real-time monitoring device provides continuous readings that are subsequently subjected to mathematical or computer analysis.

The equipment will undergo fresh air calibration before a sample is taken.

During the data collection operation, the equipment was situated above ground level, some distance from the road.

*ToxiRAE II apparatus.* This single gas personal protection monitor shows the dangerous gas level in real-time. The apparatus can measure a wide range of gases depending on its type. For this research work, CO, $NH_3$, $NO_2$, and $H_2S$ were measured with the available ToxiRAE types.

*Kestrel weather tracker.* This was used to determine microclimatic parameters.


Aerocet 531s Crowcon gas pro

A typical ToxiRAE Kestrel weather track

Figure 3

*Analysis of Correlation.* The link between two elements, like the security price and an indicator, is measured through correlation analysis. The calculated value, often known as the "correlation coefficient," indicates whether changes to one item will also affect the other.

## RESULTS AND DISCUSSION

Table 2 shows the meteorological parameters of the sampling locations. Average temperature values ranged between 31.5 to 38 °C, where 31.5 °C is the lowest recorded value for temperature while 38 °C was the highest recorded. This variation could be due to varying times. Also, the relative humidity was on an average of 62.68%. This is a relatively high value as the quantifying was done during the rainy season.

Table 2 – Meteorological data

| Range | Temperature (°C) | Relative humidity (%) |
|---|---|---|
| Minimum | 31.50 | 53.60 |
| Maximum | 38.00 | 69.20 |
| Average | 33.77 | 62.68 |

*Effect of Vehicular density variation on particulate concentration in Indoor and Outdoor Environments.* Tables 3, and 4 present the averaged values of outdoor and indoor particulate matter concentrations, respectively, with variations in vehicular densities at the spots. It could be observed that virtually all the rush hour values (high vehicular density denoted with RH) values are higher than their corresponding non-rush hour (low vehicular density indicated with NRH) values. This explains that vehicular density dramatically affects the concentration of particulates in the environment. Both coarse and fine particles are at relatively high concentrations.

Though these variations are significantly lower than those seen during rush hour, some areas, like Offa Garage, the Post Office, and Garin Alimi, exhibit a minor increase in PM 2.5 concentrations outside of rush hour. Other than fluctuations in emissions from mobile sources, this could result from weather factors. High humidity and temperature can also lead to a rise in the concentration of some pollutants. Though these variations are significantly lower than those seen during rush hour, some areas, like Offa Garage, the Post Office, and Garin Alimi, exhibit a minor increase in PM 2.5 concentrations outside of rush hour. Other than fluctuations in emissions from mobile sources, this could result from weather factors. High humidity and temperature can also lead to a rise in the concentration of some pollutants [13, 14, 15].

*Indoor and Outdoor Particulate Matter Concentrations.* The study shows the amounts of particulate matter below and above 10 microns indoors and outdoors at the chosen sampling stations. The study shows the parts of particulate matter below and above 10 microns indoors and outdoors at the selected sampling stations.

Table 3 – Averaged values of particulate matter for outdoor sampling at the selected hotspots

| Location | PM Concentration (μg/m³) | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 2.5 | 4 | 7 | 10 | TSP |
| Tipper garage NRH | 60.60 | 62.50 | 148.00 | 312.40 | 449.45 | 703.68 |
| Tipper garage RH | 41.76 | 88.03 | 217.84 | 496.75 | 757.45 | 1307.88 |
| Offa Garage NRH | 34.82 | 56.46 | 119.01 | 261.76 | 395.64 | 654.60 |
| Offa Garage RH | 22.44 | 42.88 | 92.42 | 170.82 | 229.14 | 335.86 |
| Post Office NRH | 42.69 | 61.65 | 99.03 | 163.47 | 217.53 | 321.56 |
| Post Office RH | 50.18 | 85.83 | 175.79 | 342.08 | 485.53 | 753.51 |
| Garin Alimi NRH | 43.01 | 67.49 | 121.78 | 243.08 | 347.46 | 571.96 |
| Garin Alimi RH | 37.78 | 64.18 | 126.89 | 234.78 | 322.63 | 471.56 |
| Unity NRH | 40.15 | 77.21 | 173.19 | 334.30 | 476.89 | 733.18 |
| Unity RH | 49.97 | 87.72 | 189.83 | 409.17 | 615.50 | 1105.12 |
| Oja Oba NRH | 32.43 | 51.01 | 111.95 | 278.38 | 454.07 | 898.97 |
| Oja Oba RH | 68.55 | 98.82 | 185.83 | 423.51 | 668.82 | 1183.94 |

Table 4 – Averaged values of particulate matter for indoor sampling at the selected hot spots

| Location | Particulate Matter Concentration (μg/m³) | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 2.5 | 4 | 7 | 10 | TSP |
| Tipper garage NRH | 26.38 | 61.06 | 168.60 | 391.70 | 590.98 | 996.36 |
| Tipper garage RH | 54.96 | 101.30 | 229.86 | 483.20 | 694.68 | 1116.06 |
| Offa Garage NRH | 54.39 | 79.08 | 157.44 | 357.30 | 555.22 | 936.01 |
| Offa Garage RH | 37.27 | 71.07 | 182.77 | 419.20 | 631.00 | 1004.13 |
| Post Office NRH | 36.03 | 80.62 | 244.50 | 603.71 | 924.06 | 1638.85 |
| Post Office RH | 54.96 | 101.30 | 229.86 | 483.20 | 694.68 | 1116.06 |
| Garin Alimi NRH | 43.17 | 66.59 | 118.07 | 213.70 | 296.84 | 471.10 |
| Garin Alimi RH | 32.83 | 59.60 | 135.63 | 273.87 | 392.97 | 612.27 |
| Unity NRH | 32.20 | 55.42 | 105.66 | 174.58 | 225.18 | 310.64 |
| unity RH | 54.96 | 101.30 | 229.86 | 483.20 | 694.68 | 1116.06 |
| Oja Oba NRH | 26.38 | 61.06 | 168.60 | 391.70 | 590.98 | 996.36 |
| Oja Oba RH | 54.96 | 101.30 | 229.86 | 483.20 | 694.68 | 378.49 |

Tables 3 and 4 summarize the indoor and outdoor particulate matter concentration results in the six locations with high and sometimes low vehicular patronage. Indoor PM10 concentrations varied from 225.18 μg/m³ at the Unity roundabout during a low vehicular patronage period to 694.68 μg/m³ at the Tipper garage roundabout during a relatively high vehicular patronage period.

The outdoor PM10 concentrations varied from 217.53 μg/m³ at the Post Office roundabout during a low vehicular patronage period to 757.45 μg/m³ at the Tipper garage roundabout during a relatively high vehicular patronage period. This range of values establishes the effect of vehicular density on particulate concentration.

As presented in Table 4, it was observed that the indoor environment has a higher concentration of particulates. This could be due to poor ventilation methods in the indoor climate, thereby hindering the dispersion of the particulates. Ventilation is a valuable method of controlling the indoor atmosphere [16].

The amount of contaminants indoors may also rise due to other activities. Environmental tobacco smoke, asbestos from insulating and fire-retardant building supplies, formaldehyde from pressed wood products, other organics from building materials, carpet and other office furnishings, cleaning supplies and activities, restrooms, air fresheners, and print shops are examples of ordinary office (indoor) pollutants and their sources. The amount of contaminants indoors may also rise due to other activities. Environmental tobacco smoke, asbestos from insulating and fire-retardant building supplies, formaldehyde from pressed wood products, other organics from building materials, carpet, and other office furnishings, cleaning supplies and activities, restrooms, air fresheners, and print shops are examples of ordinary office (indoor) pollutants and their sources [15].

Tobacco smoke was perceived in some indoor sampling points; some indoor environments were cosmetics and provisions shops. This will also contribute to the particulate concentration.

*The PM2.5 to PM10 and PM10 to TSP ratio for indoor and outdoor values.* Table 5 gives the fraction of particulate with size ranging from 2.5 μm downwards in diameter in the ones with a diameter ranging from 10 μm downwards and particulate with a diameter ranging from 10 μm downwards to the Total Suspended Particles, respectively.

Table 5 – Indoor and Outdoor ratio particulate matter concentrations

| Location | Indoor/Outdoor ratio | | | | | |
|---|---|---|---|---|---|---|
| | PM1 | PM2.5 | PM4 | PM7 | PM10 | TSP |
| Tipper garage NRH | 0.44 | 0.98 | 1.14 | 1.25 | 1.31 | 1.42 |
| Tipper garage RH | 1.32 | 1.15 | 1.06 | 0.97 | 0.92 | 0.85 |
| Offa Garage NRH | 1.56 | 1.40 | 1.32 | 1.36 | 1.40 | 1.43 |
| Offa Garage RH | 1.66 | 1.66 | 1.98 | 2.45 | 2.75 | 2.99 |
| Post Office NRH | 0.84 | 1.31 | 2.47 | 3.69 | 4.25 | 5.10 |
| Post Office RH | 1.10 | 1.18 | 1.31 | 1.41 | 1.43 | 1.48 |
| Garin Alimi NRH | 1.00 | 0.99 | 0.97 | 0.88 | 0.85 | 0.82 |
| Garin Alimi RH | 0.87 | 0.93 | 1.07 | 1.17 | 1.22 | 1.30 |
| Unity NRH | 0.80 | 0.72 | 0.61 | 0.52 | 0.47 | 0.42 |
| unity RH | 1.10 | 1.15 | 1.21 | 1.18 | 1.13 | 1.01 |
| Oja Oba NRH | 0.81 | 1.20 | 1.51 | 1.41 | 1.30 | 1.11 |
| Oja Oba RH | 0.80 | 1.03 | 1.24 | 1.14 | 1.04 | 0.32 |

It was observed that the indoor and outdoor environments pollutants were predominantly coarse, which could be due to meteorological parameters such as wind speed and wind direction. At the same time, PM10 takes more than half of the fraction of the Total suspended Particles in virtually all the locations at different vehicular density periods.

*The concentration of Gaseous pollutants in indoor and outdoor environments.* Table 6 shows that Carbon monoxide, the primary pollutant, has a higher overall concentration in the indoor environment compared to the outdoor environment.

The concentration of CO is exceptionally high compared to other gases. This could be due to indoor activities that involve combustion, as CO is a product of incomplete combustion of organic matter, such as cooking and tobacco smoking. Improper ventilation is also responsible for the more extended residence of the pollutant in the indoor environment.

*Carbon Monoxide.* This gas is majorly a product of incomplete combustion of organic matter. The concentration of CO is high due to poor ventilation of nearby shops at the roundabouts, which hinders proper circulation of fresh air.

*Pearson and Spearman's Correlations.* The correlation between indoor and outdoor surroundings can be utilized to infer a source link between the two types of environments [17]. When the average I/O ratio is less than or equal to 1, outside sources, particularly diesel motor vehicle exhaust, are the main contributors to PM10 [17]. Results reveal a positive link between microclimatic conditions and particulate matter concentration. Additionally, for indoor settings, the correlation between PM 2.5 and PM 10 and TSP is very high ($r^2$ =.532 and 0.500, respectively). TSP and relative humidity have a positive, albeit slender, connection in an indoor environment ($r^2$= 0.230).

Table 6 – Averaged values of gaseous pollutants at the hotspots

| Location | CO | $CO_2$ | $H_2S$ | CH4 | $NH_3$ | $SO_2$ |
|---|---|---|---|---|---|---|
| Tipper garage Outdoor | 7.79 | 0.02 | 0.05 | 0 | 0.29 | 0.9 |
| Tipper garage Indoor | 4.43 | 0.03 | 0.5 | 0 | 0 | 0 |
| Offa Garage Outdoor | 0.82 | 0.05 | 0 | 0.63 | 0 | 0 |
| Offa Garage Indoor | 7.22 | 0.04 | 0.44 | 0 | 0 | 0 |
| Post Office Outdoor | 6.31 | 0.15 | 0.48 | 0 | 0 | 0 |
| Post Office Indoor | 18.82 | 0.02 | 0.59 | 0 | 0 | 0.56 |
| Garin Alimi Outdoor | 4.98 | 0.04 | 0.44 | 0 | 0 | 0.26 |
| Garin Alimi Indoor | 7.22 | 0.04 | 0.44 | 0 | 0 | 0 |
| Unity Outdoor | 10.23 | 0.04 | 0.47 | 0.5 | 0 | 0.78 |
| Unity Indoor | 4.43 | 0.03 | 0.5 | 0 | 0 | 0 |
| Oja Oba Outdoor | 3.38 | 0.04 | 0.5 | 0 | 0 | 0.32 |
| Oja Oba Indoor | 3.53 | 0.04 | 0.5 | 0 | 0 | 0 |

## CONCLUSION AND RECOMMENDATIONS

The indoor and outdoor ratios are alarmingly high, which shows that indoor air quality is more dangerous. This is due to poor ventilation in the shops, which hinders further dispersion of pollutants from the outdoor environment. This research helped remove the gap in understanding the relationship between indoor and outdoor air pollutants in the Ilorin metropolis. The author [18] predicted that the I/O ratio is (0.4-0.6) in the absence of Indoor air sources. Few sites in this research had such a ratio, while a more significant number of sites showed otherwise, indicating the possible presence of indoor sources and poor ventilation. Gaseous pollutants like CO, $H_2S$, $CH_4$, $CO_2$, and $NO_2$ were analyzed. The air around the roundabouts is not healthy for humans and animals. As determined by Pearson's and Spearman's correlation, indoor and outdoor pollutants have strong correlations.

Shop owners should be enlightened on proper ventilation in their shops to avoid respiratory diseases. Knowing full well that mere advice might not be as practical as expected, disciplinary measures can be implemented to caution culprits. The law should be enforced to curb indiscriminate domestic and industrial activities that could threaten the environment. Kwara State Environmental Protection Agency (KWEPA) can enforce laws on the proximity of shops to roads.

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