Assessment of Outdoor and Indoor Air Quality in Some Secondary Schools in Oyigbo Local Government Area, Rivers State, Nigeria

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ABSTRACT

This study was based on seasonal assessment of outdoor and indoor levels of particulates and gases in secondary schools across Oyigbo Local Government Area in Rivers State, Nigeria. The study adopted the mixed research design. Real-time monitors recorded size-fractionated particulate matter (PM_1, $PM_{2.5}$, PM_4, PM_7, PM_{10}) and gaseous pollutants (CO, NO_2, SO_2, VOCs, O_3 over dry (Harmattan) and wet seasons. Concurrent measurements of temperature, relative humidity, wind speed, and wind direction enabled analysis of meteorological influences on pollutant dynamics. Dry-season outdoor PM_{10} ranged from 131.1 – 168.2 µg/m^3 with a mean of 146.27± 14.1 µg/m^3 and wet-season means ranged from 42.3 ± 24.5 to 148.8 ± 9.8 µg/m^3. Indoor PM_{10} consistently exceeded outdoor levels, with mean indoor/outdoor ratios of 1.05–1.15 for $PM_{2.5}$ Humidity correlated negatively with $PM_{2.5}$ (r = –.68), and wind -speed increases of 1–2 m/s during the wet season enhanced pollutant dispersion. Over 80% of school sites exceeded the Nigerian NAAQS for PM_{10} in the dry season, underscoring urgent need for intervention. Industrial emissions and unpaved roads contributed the highest PM levels in Oyigbo, There is the ardent need to strengthen enforcement of National Ambient Air Quality Standards in school zones, with regular inspections and penalties for nearby industrial and traffic sources that exceed limits. Similarly, update zoning regulations to prevent new schools from being built near heavy-traffic corridors, gas-flaring sites, and industrial plants as well as prioritising relocation or mitigation for existing schools in high-pollution areas is inevitable. Establish green buffer zone around school perimeters and playgrounds to trap windblown dust and absorb gaseous pollutants.

Keywords; Outdoor, Indoor, Air Quality, Particulate Matter, Gases, Secondary Schools, Oyigbo

INTRODUCTION

Air pollution is one of the world's leading causes of death, contributing to seven million deaths annually (Katoto et al., 2021). Urban air quality is presently a key area of concern in the environmental health agenda in many countries. Global estimates show that almost one billion people in urban settings are incessantly exposed to health hazards from air pollutants (Amegah & Agyei-Mensah, 2017). Air pollutants are mobile components that occur in concentrations high enough to cause adverse effects on health, the environment, and indoor/outdoor structures (Manucci & Franchini, 2017). They affect human health in numerous ways and varying degrees of severity, ranging from minor irritation, serious ill-health to premature death (Awe et al., 2015).

Air pollutants can damage human health and cause harm to plants and animals. The emission of air pollutants has led to numerous air quality issues in cities, such as photochemical smog, acid rain, and decreased visibility (Parjuli et al., 2016). A major factor in this is the continued growth in road traffic, as vehicle exhaust contributes up to 50% of urban particulate matter (Cassee, 2013). Keeping the air quality suitable for human use is an essential issue for public health (Cohen et al., 2017). Air pollutants from road traffic include Carbon monoxide (CO), Particulate matter (PM), and Hydrocarbons (HC), known as the product of incomplete combustion. Nitrogen dioxide (NO_2) is a product of high-temperature combustion processes, and Sulphur

dioxide (SO_2) and heavy metals are by-products of combustion due to impurities within the fuel (Guo et al., 2017). Non-combustion products are the evaporative emissions, and the secondary air pollutants such as photochemical oxidants, including ozone (O_3) and peroxyacetyl nitrate (PAN) (Guo et al., 2017).

Ambient air, also known as clean or unpolluted air, is a major determinant of environmental stability, sustainably good for human health. Greater emphasis has been laid on air quality globally because of its direct impact on humans and other environmental components. Air is one of the basic necessities required for human existence (Akinfolarin et al., 2017). However, this environmental compartment has been severely impaired with inimical substances such as particulate matter (PM), sulphur oxides, Nitrogen oxides, and carbon dioxide. This interference with the purity of air in its natural state has become a growing environmental issue both in developed and developing nations of the world (Munir et al., 2017). This is occasioned by industrialisation and urbanisation, which have brought about a higher concentration of human population in cities with viable economic opportunities, such as commercial cities (Koop & Van Leewen, 2017).

Air pollution can be defined as the presence of pollutants, such as sulphur dioxide (SO_2), particulate matter (PM), nitrogen oxides (NOx), hydrocarbons and ozone (O_3) in the air that we inhale at levels which can create some negative effects on the environment and human health (Olayinka & Abdullahi, 2008). It can be classified into natural air pollution which includes wind-blown dust, volcanic ash, and gases, smoke and trace gases from forest fires, and anthropogenic air pollution which includes products of combustion such as nitrogen oxides (NOx), carbon oxides (COx), sulphur dioxide (SO_2) (Akinsanmi et al., 2019). Pollutants that are pumped into the atmosphere and directly pollute the air are called primary pollutants, while those that are formed in the air when primary pollutants react or interact are known as secondary pollutants (Agbaire, 2009).

Commercial cities are characterized with diverse commercial or business activities that range from small scale industries such as ceramics, glass and textile industries, to sales of electronics and household items, abattoir services, auto-repairs, hotel and restaurants, shopping malls, from small unit of cigarettes and freelance street side trading (Ezejiofor et al., 2013). In Nigeria, commercial cities such as Kano, Zaria, Aba and Port Harcourt serve as the backbone of national development (Satope & Akanbi, 2014). Rapid growth in motor vehicles, roasting of animals with tyres and burning of large municipal waste generated in these cities has led to the presence of particulate matter in ambient air (Njoku et al., 2016a).

Animals are exposed to air pollutants via three pathways: Inhalation of gases or small particles, ingestion of particles suspended in food or water, or Absorption of gases through the skin. An individual's response to a pollutant varies greatly and depends on the type of pollutant involved, the duration of exposure and the amount taken up by the animal. Factors such as the individual's age, sex, health and reproductive condition also play a role in their response. In addition to affecting individual animals or populations directly, air pollutants also affect wildlife indirectly by causing changes in the ecosystem (Omoko et al., 2021).

Irrespective of air pollution sources and classification, their impact on man and the environment is a major issue of concern. These impacts are pronounced in their dispersion, travel distance, particle size, transformations and final effect. According to the WHO, air pollution constitutes the largest health risk among all environmental risks, and 92% of the world's population breathes substandard air as they live in places where air pollution exceeds safe limits. WHO attributed annual deaths around the world resulting from poor air quality inside and outside to about 6.5 million, making air pollution the world's fourth-largest threat to human health, behind high blood pressure, dietary risks and smoking. It has also been shown that air pollutants with small particle size (decreased diameter) can infiltrate finer lung structures and cause severe health effects such as asthma (WHO, 2006), chronic obstructive pulmonary disease (COPD) or increased cardiovascular risks (Gauderman et al., 2007). Other air pollution effects include the development of upper airway diseases such as sinusitis, mild otitis, olfactory impairment, rhinitis and sinonasal cancer (Shusterman et al., 2011). Kalagbor et al. (2019) investigated the presence and levels of heavy metals in soot along with a cancer risk assessment of heavy metals exposure in Port Harcourt, Nigeria and found a significant correlation among the metals. The results of their study also showed that the carcinogenic health risks of the heavy metals were within the acceptable limits for cancer risks. However, the cancer health risks for Cd and Pb for children were found to be 3 times higher than those for adults.

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USEPA (2002) considered human health risk assessment as the characterisation of the potential adverse health effects of humans as a result of exposures to environmental hazards. According to Lushenko (2010) potential health risk is a numerical value calculated using information from an identified and measured hazard and the possible route of exposure. Thus, a human health risk assessment involves hazard identification, dose-response assessment, exposure assessment, and risk characterisation. Health risk assessment classifies elements as carcinogenic or non-carcinogenic. Based on the classification, the procedure to be followed when potential risks are calculated is determined. For non-carcinogenic chemicals, a threshold is assumed. The threshold is considered a dose below which no adverse health effects will be observed, and an essential part of the dose-response portion of a risk assessment includes the use of a reference dose (R_fD). For carcinogens, they are assumed to have no effective threshold. This assumption implies that there is a risk of cancer developing with exposures at low doses and, therefore, there is no safe threshold for exposure to carcinogenic chemicals. Carcinogens are expressed by their Cancer Potency Factor (Lushenko, 2010).

Following (Akpodee, 2019), the rate at which the respiratory pollutant level (PM) and meteorological variables (Temperature and Relative Humidity) change over time depends on the following factors such as their intrinsic growth rate parameter, their intra-competition coefficient and their inter-competition coefficient. In terms of the evolution of the respiratory pollutant level ($PM_{2.5}$) and meteorological variables (air-temperature and relative humidity), in the absence of interaction with each other, both variables over time will grow positively exponential using the separation of variable techniques which observation is mathematically tractable but not environmentally wise as it will not be conducive for ecosystem functioning. It's a matter of fact, the growth of the respiratory pollutant level ($PM_{2.5}$) and air temperature dependent variable over time produces a counterintuitive scientific ideology. This is a major hypothesis that underpins this present study. To circumvent this ideology, it is imperative to include two inhibiting factors of the respiratory pollutant level ($PM_{2.5}$) variable which in this study will include the intra-competition coefficient (due to the self-interaction between the components of the respiratory pollutant level ($PM_{2.5}$)) and the inter-competition coefficient (due to the inter-competition interaction between the respiratory pollutant level ($PM_{2.5}$) dependent variable) and this same scenario will also be applied to the air temperature dependent variables. In the sequel, the inhibiting inter-competition coefficients are the contribution of the peak air temperature variable to inhibit the growth of the respiratory pollutant level ($PM_{2.5}$) variable. Deterministically, it is worth mentioning that the evolution of the respiratory pollutant level ($PM_{2.5}$) is not just time-dependent but also depends on the initial volume of the respiratory pollutant level ($PM_{2.5}$). This competition parameter of the model can be carefully chosen to justify the link between the various carrying capacity values of the two environmental variables.

METHODOLOGY

The sampling technique used in this study involves selecting the locations for the air quality and weather measurements to ensure that each location has an equal chance of being selected and to avoid bias. The study selected sampling sites in the study areas randomly. The purposive sampling technique was also used to select the sampling points within each of the LGAs to ensure a representative coverage of the area.

To cover the entire study area, the equipment was located in sampling stations that were pre-selected and strategically distributed. The stations spanned across different sources of pollution. The pollutants in the study area were detected and logged by the gas-sensing monitor and the particle counter. The logged data were transferred to a personal computer for analysis using the software provided by the equipment manufacturers. The sampling stations were georeferenced using a Garmin etrex GPS receiver, which is a device that uses the Global Positioning System (GPS) to determine the location. The study locations were strategically selected to represent various land uses and activities that may influence air quality in the region.

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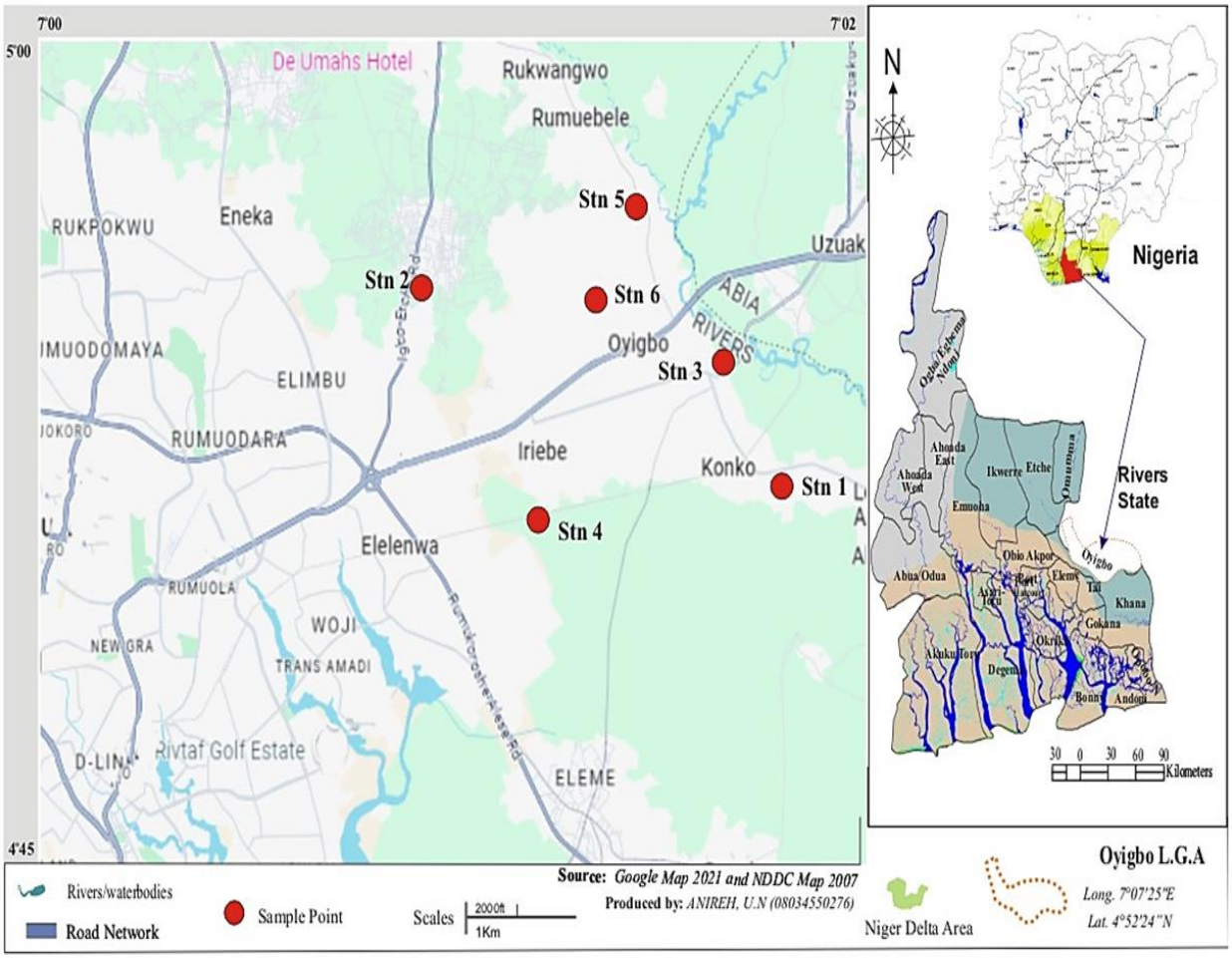

Figure 1: Sampling Locations of Oyigbo LGA

RESULTS AND DISCUSSION

The outdoor and indoor particulate matter (PM) concentrations in secondary schools across the various study locations varied significantly between the dry and wet seasons. The measurements, recorded for PM_1, $PM_{2.5}$, PM_4, PM_7, and PM_{10}, revealed distinct seasonal trends and location-specific differences.

The gaseous pollutant concentrations in secondary schools across Oyigbo exhibited significant seasonal variations, influenced by atmospheric conditions and local emission sources.

During the dry season, CO concentrations were highest at CSS, Komkom, reaching 11.31 mg/m^3, while CITA High School recorded the lowest value at 10.32 mg/m^3. In the wet season, CO levels generally declined, with CSS, Komkom maintaining the highest concentration at 8.97 mg/m^3, and CITA High School showing the lowest at 7.91 mg/m^3. Nitrogen IV oxide (NO_2) concentrations varied across locations, with All Saint's Secondary School recording the highest dry-season value at 0.199 mg/m^3, while Moncodel International School had the lowest at 0.127 mg/m^3. In the wet season, NO_2 levels decreased, with All Saint's Secondary School showing the highest concentration at 0.188 mg/m^3, and Moncodel International School recording the lowest at 0.143 mg/m^3.

VOC concentrations varied, with Bright Hope Standard Schools recording the highest dry-season value at 7 mg/m^3, while Moncodel International School had the lowest at 4 mg/m^3. In the wet season, VOC levels declined, with Bright Hope Standard Schools maintaining the highest concentration at 5 mg/m^3, and Emfode Academy showing the lowest at 1 mg/m^3.

Sulphur IV (SO_2) concentrations were below detection limits across all locations in both seasons, indicating minimal SO_2 pollution in the study area. O_3 concentrations fluctuated across locations, with CSS, Komkom recording the highest dry-season value at 0.11 mg/m^3, while All Saint's Secondary School had the lowest at

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0.08 mg/m^3. In the wet season, O_3 levels generally declined, with CSS, Komkom showing the highest concentration at 0.07 mg/m^3, and All Saint's Secondary School recording the lowest at 0.04 mg/m^3.

Table 1: Outdoor Results of Gaseous Pollutant in Oyigbo Secondary Schools

Location	Concentration (mg/m^3)									
	CO		**NO_2**		**SO_2**		**VOC**		**O_3**	
	Dry	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**
CSS, Komkom	11.31	8.97	0.193	0.134	BDL	BDL	6	4	0.11	0.07
CITA High School	10.32	7.91	0.187	0.147	BDL	BDL	7	4	0.1	0.06
All Saint's Secondary School	11.44	9.12	0.199	0.188	BDL	BDL	4	3	0.08	0.04
Bright Hope Standard Schools	10.23	8.85	0.171	0.164	BDL	BDL	7	5	0.09	0.05
Emfode Academy	12.14	9.78	0.189	0.16	BDL	BDL	5	1	0.1	0.07
Moncodel Int'l school	11.82	8.71	0.127	0.143	BDL	BDL	4	2	0.09	0.05
Range	**6.29 – 10.06**	**5.96 – 10.97**	**0.133 – 0.199**	**0.120 – 0.164**	**BDL**	**BDL**	**1 – 3**	**1 – 2**	**0.08 – 0.11**	**0.04 – 0.07**
Mean ± SD	**11.21± 0.7**	**8.89± 0.6**	**0.178± 0.02**	**0.156± 0.02**	**BDL**	**BDL**	**5.5±1.3**	**3.2±1.3**	**0.1±0.0**	**0.06±0.0**
NAAQS	**10 (1hr)**		**0.2 (1hr)**		**0.35(1hr)**		**–**		**0.18 (1hr)**	

BDL – Below Detection Limit

Table 2: Indoor Results of Gaseous Pollutants in Oyigbo Secondary Schools

Location	Concentration (mg/m^3)									
	CO		**NO_2**		**SO_2**		**VOC**		**O_3**	
	Dry	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**
CSS, Komkom	12.33	9.78	0.210	0.146	BDL	BDL	7	5	0.13	0.08
CITA High School	11.25	8.62	0.204	0.160	BDL	BDL	8	5	0.12	0.07
All Saint's Secondary	12.47	9.94	0.217	0.205	BDL	BDL	5	4	0.09	0.05

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School										
Bright Hope Standard Schools	11.15	9.65	0.186	0.179	BDL	BDL	8	6	0.10	0.06
Emfode Academy	13.23	10.66	0.206	0.174	BDL	BDL	6	1	0.12	0.08
Moncodel Int'l school	12.88	9.49	0.138	0.156	BDL	BDL	5	2	0.10	0.06
Range	**11.15 – 13.23**	**8.62 – 10.66**	**0.138 – 0.217**	**0.146 – 0.205**	**BDL**	**BDL**	**5 – 8**	**1 – 6**	**0.09 – 0.13**	**0.05 – 0.08**
Mean ± SD	**12.22± 0.8**	**9.69± 0.6**	**0.194± 0.03**	**0.17± 0.02**	**BDL**	**BDL**	**6.4±1.5**	**3.7±1.6**	**0.11±0.0**	**0.07±0.0**
NAAQS	**10 (1hr)**		**0.2 (1hr)**		**0.35(1hr)**		**–**		**0.18 (1hr)**	

BDL – Below Detection Limit

Indoor gaseous pollutant concentrations followed similar seasonal trends, with higher values recorded in the dry season compared to the wet season. Carbon II oxide (CO) levels were highest at Emfode Academy, reaching 13.23 mg/m^3 in the dry season, while Bright Hope Standard Schools recorded the lowest at 11.15 mg/m^3. In the wet season, CO concentrations declined, with Emfode Academy maintaining the highest value at 10.66 mg/m^3, and Bright Hope Standard Schools showing the lowest at 9.65 mg/m^3.

The NO_2 concentrations were highest at All Saint's Secondary School in the dry season, measuring 0.217 mg/m^3, while Moncodel International School recorded the lowest at 0.138 mg/m^3. In the wet season, NO_2 levels decreased, with All Saint's Secondary School showing the highest concentration at 0.205 mg/m^3, and Moncodel International School recording the lowest at 0.156 mg/m^3.

The SO_2 concentrations remained below detection limits across all locations in both seasons, indicating minimal indoor SO_2 pollution. VOC concentrations varied, with CITA High School recording the highest dry-season value at 8 mg/m^3, while Moncodel International School had the lowest at 5 mg/m^3. In the wet season, VOC levels declined, with CITA High School maintaining the highest concentration at 5 mg/m^3, and Emfode Academy showing the lowest at 1 mg/m^3.

The O_3 concentrations fluctuated across locations, with CSS, Komkom recording the highest dry-season value at 0.13 mg/m^3, while All Saint's Secondary School had the lowest at 0.09 mg/m^3. In the wet season, O_3 levels generally declined, with CSS, Komkom showing the highest concentration at 0.08 mg/m^3, and All Saint's Secondary School recording the lowest at 0.05 mg/m^3.

Table 3: Meteorological Parameters

Location	**Temperature (°C)**		**Humidity (%)**		**Wind Speed (m/s)**		**Wind Direction (°)**	
	Dry	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**
Port Harcourt	29.0 – 32.5	30.1 – 33.7	62 – 78	65 – 77	0 – 1.0	0 – 3.1	Northeast	Southwest

Obio/Akpor	29.2 – 33.9	29.2 – 32.1	63 – 76	68 – 78	0 – 0.7	0.7 – 2.7	Northeast	Southwest
Eleme	32.0 – 40.7	28.9 – 30.0	57 – 70	80 – 85	0 – 0.7	0.3 – 2	Northeast	Southwest
Oyigbo	30.7 – 31.9	26.8 – 30.0	73 – 77	79 – 92	0.3 – 1.4	0.3 – 1.4	Northeast	Southwest
Isiokpo	30.5 – 31.7	29.7 – 30.2	78 – 80	81 – 85	1.0 – 2.7	0.7 – 2	Northeast	Southwest

Wind speed observations vary notably between seasons. For Port Harcourt, the dry season wind speed is modest, ranging from 0 to 1.0 m/s, whereas the wet season sees an increase, reaching 0 to 3.1 m/s. In Obio/Akpor, the dry season wind speeds range from 0 to 0.7 m/s, and during the wet season, they increase to between 0.7 and 2.7 m/s. Eleme records a low range of 0 to 0.7 m/s in the dry season, with an upward shift to 0.3–2 m/s in the wet season. Oyigbo, on the other hand, maintains the same range of 0.3 to 1.4 m/s in both seasons, suggesting minimal seasonal variation in wind speed. Wind direction exhibits a clear seasonal pattern. In all the study locations, the prevailing wind direction during the dry season is reported as Northeast, while in the wet season it consistently shifts to Southwest.

A paired t-test was conducted to analyse the seasonal variation in air pollutant concentrations, comparing the dry season and wet season measurements for VOC, CO, NO_2, and O_3. The results indicate that there are significant differences in pollutant levels for VOC, CO, and NO_2, while O_3 does not exhibit a statistically significant seasonal variation. For VOC, the mean concentration in the dry season is 3.72, whereas in the wet season it is 1.9, suggesting a notable reduction in pollutant levels during wetter periods. The paired t-test result yields a t-statistic of 3.40, which exceeds the critical value (2.77) for a two-tailed test, and the p-value (0.0272) is below the standard threshold of 0.05. This confirms that the difference in VOC concentrations between seasons is statistically significant. Similarly, CO levels show a significant seasonal variation, with a mean concentration of 9.168 in the dry season compared to 7.612 in the wet season. The test produces a t-statistic of 3.60, with a two-tailed p-value of 0.0228, reinforcing the conclusion that the seasonal differences in CO levels are unlikely to be due to random variability.

The case of NO_2 further supports seasonal influence on air quality. The dry season mean is 0.1678, while the wet season mean is 0.1398. A t-statistic of 4.67, coupled with a p-value of 0.0095, indicates a statistically significant difference between the seasons. Conversely, O_3 does not exhibit a significant seasonal effect. The mean concentration during the dry season is 0.078, slightly higher than the 0.054 observed in the wet season. However, the t-statistic of 1.76 falls below the critical threshold, and the p-value (0.1533) exceeds 0.05, suggesting that the seasonal variation in O_3 levels is not statistically significant.

The PM outdoor results of PM in Oyigbo Secondary Schools showed that PM_1 recorded *t*-value is 4.27434, *p*-value of .000813 hence the result is significant at $p < .05$. $PM_{2.5}$, the *t*-value is 2.54458. The *p*-value is .014567 and result is significant at $p < .05$. PM_4 had *t*-value of 3.49457. The *p*-value is .002889 while the result is significant at $p < .05$. PM_7 was of *t*-value 5.09598, the *p*-value of .000233 and the result is significant at $p < .05$. For PM_{10} the *t*-value is 4.87775. The *p*-value is .000322 but the result is significant at $p < .05$.

The PM indoor results in Oyigbo Secondary Schools showed that PM_1 *t*-value is 4.22176, the *p*-value is .000883 hence the result is significant at $p < .05$. This is similar to $PM_{2.5}$ where the *t*-value is 2.5667. The *p*-value is .014024 and the result is significant at $p < .05$. PM_4 recorded the *t*-value as 3.49604 with *p*-value of .002882. The result is significant at $p < .05$. The PM_7 had *t*-value as 5.09801. The *p*-value is .000233 and the result is significant at $p < .05$ which is similar to PM_{10} which has *t*-value as 4.87628. The *p*-value is .000323 while the result is significant at $p < .05$.

Indoor results of gaseous pollutants in Oyigbo secondary schools showed CO of *t*-value, 5.74321. The *p*-value is .000093 while the result is significant at $p < .05$ as well as VOC and O_3 different from the NO_2 whose *t*-

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value is 1.60624 and *p*-value as .069651 with the result *not* being significant at $p < .05$. The one ANOVA with Tukey's HSD test showed that the F-statistic value was 26.2313 with p-value = 0.0000 indicating conventional criteria, this value is considered to be extremely statistically significant for the outdoor PM during the dry season. The *f*-ratio value is 41.90876 with *p*-value is < .00001. The result is significant at $p < .05$ and showed that PM_1 / PM_4, PM_1/PM_7, and PM_1 /PM_{10}, $PM_{2.5}/PM_4$, $PM_{2.5}/PM_7$, $PM_{2.5}/PM_{10}$, PM_4/PM_{10} and PM_7/PM_{10} had significant variations from the Tukey's HSD test. Similarly, the outdoor spatial variation for the PM during the wet season indicate the *f*-ratio value is 9.21992, *p*-value of .000216 and the results is significant at $p < .05$. The Tukey's HSD test showed that only PM_1/PM_7, PM_1 /PM_{10}, $PM_{2.5}/PM_{10}$ had significant differences at p, .01414, .00026 and .00177 respectively. Indoor PM during the wet season had spatial variation as showed from the ANOVA result with *f*-ratio value of 9.21905, P-value of .000216. The result is significant at $p < .05$. The Tukey's HSD test showed significant paired variations in PM_1/PM_7 (p=.01414), PM_1 /PM_{10} (p= .00027) and $PM_{2.5}/PM_{10}$ (p=.00178).

Outdoor pollutants during the dry season showed that the *f*-ratio value is 43.82661 at *p*-value < .00001 as the result is significant at $p < .05$. The Tukey's HSD also showed that the differences were observed in $PM_1/PM_{2.5}$, PM_1/PM_4, PM_1/PM_7, PM_1 /PM_{10}, $PM_{2.5}/PM_7$, PM_4/PM_7 and PM_7/PM_{10}. Similarly, indoor pollutants during the dry season recorded ANOVA result of *f*-ratio value 41.44966, *p*-value is < .00001 with result significant at $p < .05$. The Tukey's HSD test result indicated noticeable differentials for $PM_1/PM_{2.5}$, PM_1/PM_4, PM_1/PM_7, PM_1 /PM_{10}, $PM_{2.5}/PM_7$, PM_4/PM_7 and PM_7/PM_{10} similar to the outdoor pollutants during the dry season. Outdoor pollutants for the wet season gave ANOVA result of *f*-ratio value 65.25789, *p*-value is < .00001 and a result that is significant at $p < .05$. The Tukey's HSD test result indicated observable differentials for $PM_1/PM_{2.5}$, PM_1/PM_4, PM_1/PM_7, PM_1 /PM_{10}, $PM_{2.5}/PM_7$, PM_4/PM_7 and PM_7/PM_{10}. Outdoor pollutants by the wet season gave *f*-ratio value of 62.52577 with *p*-value is < .00001 hence result significant at $p < .05$. The analysis of the Tukey's HSD test showed valuable differentials between $PM_1/PM_{2.5}$, PM_1/PM_4, PM_1/PM_7, PM_1 /PM_{10}, $PM_{2.5}/PM_7$, PM_4/PM_7 and PM_7/PM_{10}.

In this study wet-season relative humidity frequently exceeded 80% in Oyigbo, coinciding with a 15–30% reduction in both PM_{10} and $PM_{2.5}$. This "wet deposition" mechanism aligns with well-documented meteorological effects whereby precipitation enhances particle removal by impaction and washout (Sapkota et al., 2005; Zhang et al., 2019). In Port Harcourt, where annual rainfall often surpasses 2,000 mm, the wet-season decline in $PM_{2.5}$ by nearly 50% highlights the potency of rainfall-driven cleansing (WHO, 2006). Wind speed and direction further modulate seasonal particulate patterns. During the dry season, prevailing northeast winds, often devoid of significant moisture, facilitated the transport of Saharan dust and local dust emissions into school environments, compounding PM levels (Adejumo et al., 2021). In contrast, the monsoonal southwest winds of the wet season not only bring moisture but also disperse pollutants more effectively, lowering local accumulation. Studies in semi-arid regions of northern Nigeria similarly link low wet-season wind-driven dispersion to marked decreases in $PM_{2.5}$ and PM_{10}. Collectively, the results demonstrate that seasonal fluctuations in precipitation, humidity, and wind patterns are primary drivers of air-quality variability in Nigerian secondary schools. Understanding these natural cleansing processes is essential for timing interventions, such as scheduling outdoor activities during periods of lower particulate burden and enhancing classroom ventilation when dry-season pollution peaks threaten student health (Onunkwo & Nwafor, 2018).

Indoor particulate concentrations consistently exceeded outdoor levels across the study locations, reflecting an indoor amplification phenomenon documented in other Nigerian school-environment studies. Jelili et al. (2020) similarly reported an indoor/outdoor (I/O) ratio of approximately 1.1 for $PM_{2.5}$ in secondary schools in Ogbomoso, attributing the enhancement to particle infiltration through building envelopes and modest indoor emissions from cooking and cleaning activities. Archibong and Okuo (2024) expanded on these dynamics in their assessment of 30 public schools in Benin City, Edo State, where indoor $PM_{2.5}$ peaked at 785 $\mu g/m^3$ during active school hours, far surpassing corresponding outdoor peaks and WHO guidelines. They identified poor natural ventilation, high occupant density, and resuspension of settled dust during classroom activities as principal drivers of elevated indoor concentrations. These factors closely mirror the findings that older school buildings with limited window openings exhibited the most pronounced indoor particulate amplification. Both the current data and the regression analysis by Jelili et al. (2020) reveal only a weak correlation ($R^2 \approx 0.05$) between indoor and outdoor $PM_{2.5}$, underlining the substantial role of localised indoor sources in shaping air

quality within classrooms. This decoupling indicates that improvements in ambient air do not automatically translate to healthier indoor environments. Consequently, interventions such as routine dust control measures, strategic cross-ventilation, and deployment of low-cost air filtration devices are critical to curb indoor exposures.

The indoor amplification of PM poses a significant health risk to students, who spend most of their day inside classrooms ventilated inadequately for particulate removal. Observations from the current study, together with those of Nigerian scholars, reveal that effective air-quality management in schools must address both outdoor infiltration and internal emission sources to safeguard children's respiratory health.

The dry-season carbon monoxide (CO) levels consistently exceeded those measured during the wet season across all five LGAs. Outdoor CO averaged 21 mg/m^3 in Oyigbo during the dry season, indoor values in Oyigbo reached 12.22 mg/m^3 versus 11.21 mg/m^3 outdoors. Indoor CO, NO_2, and VOC concentrations in our secondary school classrooms consistently exceeded outdoor levels, underscoring the ease with which outdoor gases infiltrate indoor spaces. In Port Harcourt, for instance, indoor CO averaged 9.54 mg/m^3 versus 8.76 mg/m^3 outdoors. This infiltration largely occurs through open windows, doors, and building envelope cracks, as well as via pressure differentials that drive outdoor air into rooms (Ite et al., 2019). Ite et al. (2019) observed that in both urban and industrial "oil and gas" zones of Akwa Ibom State, CO and VOC levels indoors peaked during classroom hours, coinciding with periods of heavy traffic nearby and use of diesel generators, highlighting similar transfer pathways.

Studies of naturally ventilated classrooms in Nigeria further clarify how building design governs gas transfer. Mba et al. (2023) reported an average natural ventilation efficiency of 80% across Enugu primary schools, yet noted that pollutant removal rates fluctuated widely with changes in wind direction and classroom occupancy. By contrast, active ventilation strategies, such as mechanical fans, energy recovery ventilators, or HVAC systems, provide more consistent airflow regardless of outdoor conditions. ASHRAE's design guidance recommends supplementing natural ventilation in educational facilities with mechanical systems designed to achieve specified air-change rates, particularly where outdoor air quality is poor (ASHRAE, 2023). In schools adjacent to busy roadways or industrial sites, mechanical ventilation can limit peak indoor NO_2 and CO levels by diluting indoor air more rapidly than passive means alone. These findings indicate that while passive ventilation is cost-effective and widely used in Nigerian schools, its performance can be compromised by meteorological variability and proximity to emission sources. Integrating active ventilation where feasible, and optimising passive designs through strategic placement and sizing of openings, offers a more resilient approach to managing indoor–outdoor gas transfers and safeguarding student health.

CONCLUSION

This study set out to characterise both particulate and gaseous air pollutants inside and outside secondary schools in Oyigbo. The results reveal pronounced seasonal and spatial variability in particulate matter. PM_{10} and $PM_{2.5}$ levels surged during the dry season, often exceeding the Nigerian NAAQS and WHO guidelines by two to threefold, and declined significantly with the onset of rains. Oyigbo emerged as polluted LGAs, driven by industrial emissions and unpaved roads,

Gaseous pollutants followed parallel seasonal patterns. Dry-season CO, NO_2, and VOC levels peaked across all sites before declining in the wet season, reflecting reduced boundary-layer trapping and rainfall scavenging. While surface ozone showed no statistically significant seasonal shift, its mean levels remained nontrivial, showing a complex balance of photochemical production and sink processes. Indoor gas concentrations exceeded outdoor readings, implicating local combustion sources, such as generators, traffic intrusion, and waste burning, as contributors to classroom exposures.

This study shows that the secondary schools remain vulnerable to elevated levels of both particles and gases, particularly during the dry season. By showing the interplay among emissions, building characteristics, and meteorology, this study provides an evidence base for targeted interventions that can protect children's health, sustain their cognitive development, and foster safer learning environments.

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