Journal of the Geographical Association of Tanzania, Vol. 46, No. 1: 1–22

Ambient Particulate and Gaseous Air Pollution Exposure among Secondary School Children in Lagos State, Nigeria

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Abstract

Air pollution remains a major environmental health concern globally, with children being particularly vulnerable due to the ongoing development of their respiratory systems, which typically continues through adolescence. This study analyses exposure to selected air pollutants among school children in Lagos State, Nigeria. A field-based quantitative approach was adopted, involving real-time in-situ air quality measurements conducted across 45 purposively selected secondary schools located in high-traffic, industrial, and residential zones. Measurements were collected during peak school hours using an Aeroqual Series 500 portable monitor (8-hour mean), capturing temporal variations associated with student activity and traffic intensity. Exposure was further quantified using the Total Respiratory Deposition Dose (TRDD) model, which integrates pollutant concentration, inhalation rate, and exposure duration to estimate the actual dose of particulate matter deposited in the respiratory system. The results indicated that while gaseous pollutants generally remained within acceptable limits, particulate matter concentrations frequently exceeded recommended thresholds. The findings also revealed that increased physical activity significantly elevates inhalation dose, indicating that children may experience higher internal exposure during routine school activities such as outdoor play. The elevated exposure and dose levels observed suggest increased risk of adverse respiratory effects, particularly in high-exposure environments. These findings highlight the importance of addressing micro-environmental pollution within school settings. The recommended practical interventions include improved school siting, vegetation buffers, dust control measures, and regulation of traffic emissions around schools.

Keywords: *air pollution exposure, gaseous pollutants, particulate matter ($pm_{2.5}$ and pm_{10}), TRDD, school micro-environments.*

Introduction

Air pollution has become a significant public health challenge, with anthropogenic emissions substantially impairing atmospheric quality, and accounting for approximately 9 million annual deaths (Atuyambe et al., 2024; Manisalidis et al., 2020). While this is a global issue, urban ecosystems are the primary drivers, producing 78% of carbon emissions, and disproportionately affecting city dwellers (Das et al., 2024). When too much carbon is in the air, it

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 ▪ https://doi.org/10.56279/jgat.v46i1.380

replaces oxygen in the red blood cells. The most common effects of carbon exposure are fatigue, headaches, confusion, and dizziness due to inadequate oxygen delivery to the brain. Populations at risk of adverse health outcomes include unborn babies, children, the elderly, and individuals with pre-existing cardiovascular or pulmonary conditions.

Children are particularly susceptible to air pollution due to their developing respiratory systems, higher breathing rates relative to body weight, and extended periods of outdoor activity (Atuyambe et al., 2024; Lim et al., 2024; Aguilar-Gomez et al., 2022). Despite this vulnerability, the current body of research in Nigerian school micro-environments remains largely descriptive and lacks analytical depth. A significant research gap exists because existing studies rely heavily on fixed-site monitoring, which is inadequate for capturing actual personal exposure doses that vary based on physical activity and time spent in specific micro-environments. Furthermore, there is an insufficient emphasis on why these traditional exposure assessment approaches fail to reflect the biological reality of inhalation in high-traffic zones.

The Lagos State, Nigeria, serves as a prime example of these challenges: as one of the world's fastest-growing megacities, where rapid urbanization and industrialization have exposed residents to high levels of pollution despite a critical lack of operational monitoring stations. A 2020 World Bank study estimated that exposure to fine particulate matter ($PM_{2.5}$) in Lagos was responsible for 11,200 premature deaths in 2018 alone (Croitoru et al., 2020). This study addresses these deficiencies by shifting the focus from ambient concentrations to a dose-based methodology. By focusing on secondary schools located along major highways in Lagos, where traffic-related emissions are the primary pollutant source, this paper provides an original contribution through the application of the Total Respiratory Deposition Dose (TRDD) framework. The TRDD methodology is specifically chosen to bridge the identified gap as it allows for a precise calculation of the physical dose of pollutants inhaled by children, accounting for varying activity levels and exposure durations.

This study aims to assess the exposure of school-aged children to a complex mixture of air pollutants, including particulate matter ($PM_{2.5}$ and PM_{10}), nitrogen dioxide (NO_2), carbon monoxide (CO), ozone (O_3), and volatile organic compounds (VOCs). By integrating exposure and dose assessment frameworks, the study moves beyond conventional descriptive analyses to deliver a more rigorous interpretation of the environmental health implications within urban settings.

Literature Review

Nigeria faces significant environmental health challenges driven by rapid urbanisation, weak regulatory enforcement, and poor waste management systems. The major environmental risks include ambient and household air pollution, water contamination, and heavy metal exposure: all of which contribute substantially to disability-adjusted life years (DALYs) and mortality, particularly from respiratory and cardiovascular diseases (Kodiya et al., 2025; Pona et al., 2021). Among these, air pollution remains one of the most critical public health concerns, especially in urban centres.

Lagos—Nigeria's largest urban centre—experiences some of the highest air pollution levels in Sub-Saharan Africa. Studies report particulate matter ($PM_{2.5}$) concentrations exceeding World Health Organization (WHO) guidelines by over 300%, with population-weighted exposure estimated at approximately 47μg/m^3 (Nyekwere et al., 2025). The major pollution sources include vehicular emissions, industrial activities, widespread use of diesel generators, and open waste-burning (Kodiya et al., 2025; Manisalidis et al., 2020). These conditions create a highly polluted urban environment with continuous exposure risks for residents.

Children are particularly vulnerable to air pollution due to their developing respiratory systems, higher breathing rates, and increased time spent outdoors. In urban settings like Lagos, school environments represent critical micro-environments where children experience prolonged exposure to air pollutants; especially in schools located near major roads, industrial zones, or waste disposal sites. Studies in Nigeria indicate that school-age children are frequently exposed to multiple pollutants simultaneously, including particulate matter, carbon monoxide, nitrogen dioxide, and other combustion-related emissions (Yetu et al., 2025). However, few studies explicitly examine pollutant exposure within school settings, or assess how daily school activities influence cumulative exposure levels (Ezani & Brimblecombe, 2022; Kalisa et al., 2023).

Evidence from global and African studies shows that exposure to multiple air pollutants (including particulate matter, gases, heavy metals, and organic compounds) is associated with significant adverse health outcomes in children:

(a) Respiratory outcomes: Increased risk of asthma, bronchitis, pneumonia, and other lower respiratory infections (Manisalidis et al., 2020; Pona et al., 2021).
(b) Lung function impairment: Reduced lung capacity and increased oxidative stress, particularly among children in high-traffic or industrial areas (Oliveira et al., 2019).
(c) Neurodevelopmental effects: Exposure to pollutants such as lead and persistent organic compounds has been linked to cognitive deficits, reduced IQ, and learning difficulties (Adeyi & Babalola, 2017).
(d) Long-term health risks: Associations with low birth weight and increased risk of chronic non-communicable diseases later in life (Manisalidis et al., 2020).

In Sub-Saharan Africa (SSA), household and ambient air pollution have also been linked to increased under-five mortality and higher rates of pneumonia hospitalisation, highlighting the combined effects of indoor and outdoor exposures (Lake et al., 2025).

Despite a growing evidence on air pollution in Nigeria, important methodological gaps remain. Most studies focus on single pollutant categories—such as particulate matter, carbon monoxide, or heavy metals—with limited integration of multi-pollutant exposure frameworks. Additionally, there is a lack of research specifically targeting school environments as key exposure settings for children. Few studies employ real-time or personal exposure monitoring techniques (Koehler & Peters, 2015); and there is also a limited application of exposure-dose assessment approaches such as the TRDD: all of which limit the understanding of how cumulative and time-varying exposures affect children's health.

Material and Methods

Study Area

The study was conducted in Lagos State, Nigeria, one of the most densely populated and rapidly urbanising cities in SSA. Lagos is in the southwestern part of Nigeria, between latitudes approximately 6°23′N and 6°41′N, and longitudes 2°42′E and 3°42′E. The state is characterised by intense urban development, heavy traffic congestion, and diverse land-use patterns: all of which contribute to elevated levels of air pollution. Administratively, Lagos State is divided into five major divisions: Ikeja, Badagry, Ikorodu, Lagos Island, and Epe (Figure 1). These divisions represent varying degrees of urbanisation, traffic density, and industrial activities; making them suitable for assessing spatial variations in air pollution exposure.

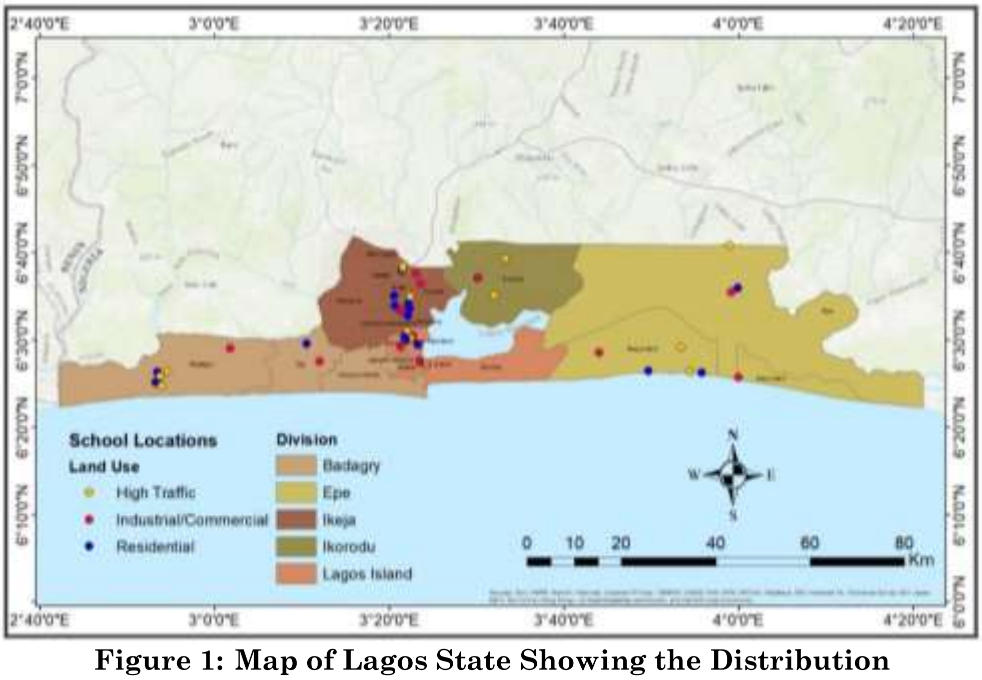

Figure 1: Map of Lagos State Showing the Distribution of the Selected schools

Source: Fieldwork Data, (2024).

Lagos State was selected due to its high population density, intense urbanisation, and well-documented air pollution challenges compared to other Nigerian cities such as Abuja, Port Harcourt or Kano. The concentration of vehicular traffic, industrial activities, and widespread use of electricity generators make Lagos a critical hotspot for air pollution exposure. Additionally, the presence of diverse land-use types within close proximity allows for comparative analysis of pollution exposure across different environmental settings. These characteristics make Lagos an ideal case study for assessing multi-pollutant exposure among school children.

Research Design and Sampling Technique

The methodology for assessing multi-pollutant exposure levels among selected secondary school children in Lagos State utilizes a quantitative research design with a field-based approach. This framework combines real-time environmental monitoring with physiological modelling to estimate the actual physical dose of pollutants inhaled by the students.

A purposive sampling technique was employed to select forty-five (45) public secondary schools across the five administrative divisions of Lagos State. Schools were selected based on their proximity to major highways and representation of different land-use types, including industrial/commercial zones, high-traffic areas, and residential neighbourhoods. Public schools were prioritised because they enrol a substantial proportion of urban children from diverse socio-economic backgrounds, are situated in pollution-prone environments, and fall directly under government oversight; thereby ensuring representativeness, accessibility, and policy relevance of the findings.

Data Collection Methods

Field measurements were conducted using portable monitoring equipment to capture real-time variations in air quality within school environments. Air pollutant concentrations were measured using the Aeroqual Series 500 Portable Air Quality Monitor, equipped with interchangeable sensor heads for detecting particulate matter ($PM_{2.5}$ and PM_{10}), carbon monoxide (CO), nitrogen dioxide (NO_2), ozone (O_3), and volatile organic compounds (VOCs).

Prior to field deployment, the instrument was calibrated according to manufacturer guidelines, and routine zero checks were performed to ensure data accuracy and reliability throughout the sampling period. The measurements were taken at multiple micro-environmental points within each school; including classrooms, school playgrounds, and school entrances/roadside areas. This approach ensured spatial representativeness of pollutant exposure across different activity zones within the school environment. Air quality measurements were conducted during peak school hours (8:00 a.m. to 2:00 p.m.), capturing periods of high student activity and traffic-related emissions. The measurements were recorded at regular intervals (every hour) to capture temporal variability in pollutant concentrations.

Exposure Assessment Models

The analysis involved converting ambient concentration data into biological exposure doses. As mentioned earlier, the study utilized the TRDD to estimate the mass of particulate matter ($PM_{2.5}$ and PM_{10}) that actually deposits in the respiratory tract. The TRDD is an estimate of the amount of inhaled particulate matter (PM) deposited in the respiratory system based on pollutant concentration, deposition fraction, inhalation rate, and exposure duration. The TRDD was computed using the following formula:

$$TRDD = C \times DF \times IR \times ED \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where: *C* = concentration of particulate matter (µg/m^3); *DF* = deposition fraction of particulate matter in the respiratory system; *IR* = inhalation rate (m^3/hour); *ED* = exposure duration (hours/day).

The deposition fraction (DF) is the fraction of inhaled particles that deposit in different regions of the respiratory system. The DF values were adopted from standard respiratory deposition studies for $PM_{2.5}$ and PM_{10} (Cipoli et al., 2023). Different inhalation rates (IR) were used based on age-groups; accounting for variations in respiratory capacity. Exposure duration (ED) was based on average outdoor activity duration for different populations (Cipoli et al., 2023; Paul et al., 2022).

Also, the gaseous pollutant exposure assessment quantified the inhalation dose of various air pollutants (e.g., NO_2, CO, O_3, VOCs) based on exposure scenarios. This assessment followed an inhalation-based risk assessment framework. The inhalation dose was calculated for different activity levels as posited by Paul et al. (2022).

(a) Light Exercise (IR = 0.63 m^3/hour, ED = 8 hours/day).
(b) Moderate Exercise (IR = 1.2 m^3/hour, ED = 6 hours/day).
(c) Heavy Exercise (IR = 2.0 m^3/hour, ED = 4 hours/day).

i.

The inhalation dose was computed using the equation employed by Hammer et al. (2020):

$$ID = C \times IR \times ED \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . (2)$$

Where: *ID* = inhalation dose (µg/day); *C* = pollutant concentration (µg/m^3); *IR* = inhalation rate (m3/ hour); *ED* = exposure duration (hours/day).

The data were analysed using both descriptive and inferential statistical methods. Descriptive statistics (mean, standard deviation, and range) were used to summarise pollutant concentrations and exposure levels across the study locations. The Analysis of Variance (ANOVA) method was employed to assess statistical differences in pollutant exposure across different land-use types and school locations. In addition, regression analysis was used to examine relationships between pollutant concentrations and estimated exposure doses. The results are presented using tables, charts, and geospatial visualisation techniques. Geographic Information System (GIS) tools were used to generate pollution exposure maps, highlight spatial variations, and identify high-risk school locations across Lagos State.

Results and Discussion

Particulate Matter ($PM_{2.5}$) Exposure

$PM_{2.5}$ concentrations across the sampled schools exhibited substantial variability, reflecting the heterogeneous nature of urban environments within Lagos State. This variation is not random but strongly influenced by underlying spatial, socio-economic, and environmental factors, particularly land-use patterns and proximity to dominant emission sources. When evaluated against the WHO (2021) 24-hour guideline value of 15µg/m^3 (Table 1), the results indicate that a significant proportion of schools are exposed to unsafe levels of fine particulate matter.

Table 1: WHO Air Quality Guidelines (2021)

Pollutant	Low Exposure	Moderate Exposure	High Exposure
$PM_{2.5}$	0–12µg/m^3	12–35µg/m^3	> 35µg/m^3
PM_{10}	0–50µg/m^3	50–100µg/m^3	> 100µg/m^3
NO_2	0–40µg/m^3	40–100µg/m^3	> 100µg/m^3
CO	0–4 ppm	4–9 ppm	> 9 ppm

Source: WHO (2021).

Figure 2 shows the results of the $PM_{2.5}$ exposure levels in the study schools. Although 35.56% of the schools (n = 16) fell within the low exposure category, a much larger proportion (64.44%) recorded $PM_{2.5}$ concentrations exceeding the WHO recommended limits. This is a critical finding, as it suggests that most of the school children in the study area are routinely exposed to pollution levels capable of producing adverse health effects. The dominance of moderate exposure levels (42.22%) is particularly concerning because such conditions are often perceived as relatively safe, yet growing epidemiological evidence indicates that even moderate and long-term exposure to $PM_{2.5}$ can impair lung development, and increase susceptibility to respiratory infections in children. The presence of high (17.78%) and very high (4.44%) exposure categories further reinforces the severity of the problem, especially for schools located in more polluted micro-environments.

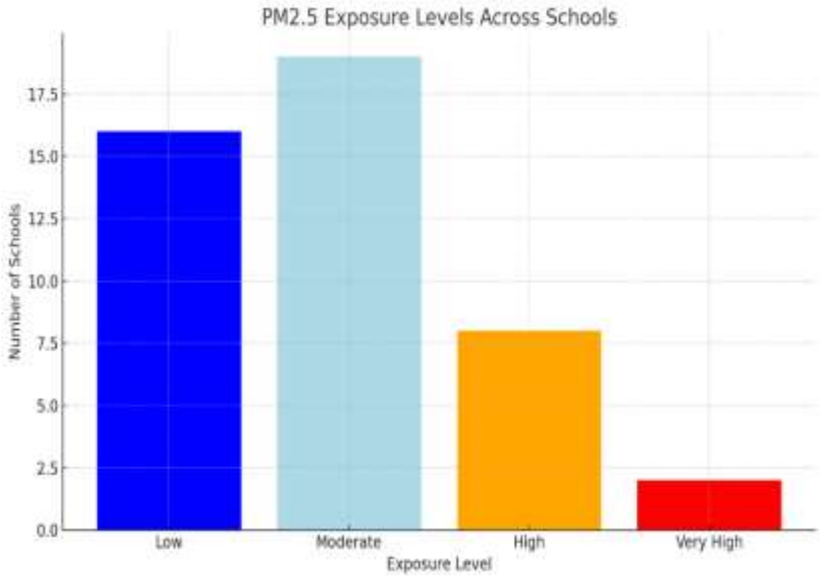

Figure 2: $PM_{2.5}$ Exposure Levels Across Schools
Source: Fieldwork Data (2024).

Spatial Variation in $PM_{2.5}$ Exposure
A distinct spatial pattern is evident in the distribution of $PM_{2.5}$ concentrations, with Lagos Island and Ikeja consistently recording the highest values (Table 2). This pattern reflects the intensity of anthropogenic activities within these divisions. Lagos Island—as a major commercial and administrative hub—experiences persistent traffic congestion, high population density, and extensive commercial operations. All these contribute to elevated emissions of fine particulates in Aiyetoro senior grammar school (43 μ/m^3), Govt senior college (19 μ/m^3) and Isale-eko senior secondary school (50 μ/m^3). Similarly, Ikeja—being both an administrative centre and a transport hub—is characterised by heavy vehicular movement, industrial facilities, and widespread generator use due to unreliable power supply.

The concentration of high $PM_{2.5}$ levels in these areas showed the cumulative effect of multiple emission sources operating simultaneously as revealed in Ilupeju junior grammar school (39 μ/m^3), and Ransome Kuti memorial senior school (63 μ/m^3). Rather than a single dominant source, it is the interaction between traffic emissions, small-scale industrial activities, open waste burning, and energy generation practices that creates persistently high pollution levels. This aligns with existing studies in Nigerian cities, which emphasised the multi-source nature of urban air pollution (Mahmud et al., 2023; Okedere et al., 2021).

Table 2: Schools Within the $PM_{2.5}$ Exposure Levels

Division	Land use Type	Name of Schools	$PM_{2.5}$ (μ/m³) value	Exposure Levels/ Remarks
Ikeja	Residential	Omole Snr Gram Sch	20	Moderate
		Bolade snr grammar school	27	Moderate
		Ikeja snr sec school	17	Moderate
	Industrial	Agidingbi senior high school	12	Low
		Ilupeju junior grammar school	39	High
		Ilupeju senior secondary school	25	Moderate
	High traffic	Babs fafunwa millennium school	29	Moderate
		Ojodu junior high school	17	Moderate
		Ransome kuti mem senior school	63	Very high
Badagry	Residential	Iba housing estate grammar school	0.016	Low
		Badagry senior grammar school	0.12	Low
		Ajara senior grammar school	0.15	Low
		Ansarudeen, grammar school	42	High
	Industrial	Awori senr college	0.024	Low
		Araromi ilogbo high sch	0.019	Low
	High traffic	Methodist senior sec school badagry	44	High
		State senior high sch	0.016	Low
		Govt. Snr college	43	Low
Ikorodu	Residential	Baptist snr high sch	33	High
		Anthony village high sch	32	High
		Mende junior high sch	33	High
	Industrial	Ajegunle snr high school	0.031	Low
		United snr high sch	0.026	Low
		Ayangburen junior sec school	0.026	Low
	High Traffic	Ojota junior high school	0.23	Low
		Oreyo junior sec school	0.027	Low
		Maya snr gram sch	0.025	Low
Lagos Island	Residential	Aiyetoro snr gram sch	43	High
		Stadium snr high school	23	Moderate
		Akintan snr grammar sch	22	Moderate
	Industrial	Govt senior college	19	High
		Isale-eko snr gram sch	50	Very high
		Lagos city college	29	Moderate
	High traffic	Mobolaji bank Anthony	26	Moderate
		Wesley girl's snr sch	24	Moderate
		Boys' senior academy	21	Moderate
Epe	Residential	Comm snr sec sch	30	Low
		Comm high sch akodo	15	Moderate
		Alaro comm hig sch	17	Moderate
	Industrial	Iwerekun comm snr high sch	20	Moderate
		Odo-obara snr hig sch epe	16	Moderate
		Magbon segun comm snr hig sch	14	Low
	High Traffic	Orimedu comm high sch	14	Low
		Ibeju Lekki snr high sch	16	Moderate
		Okemagba senior high sch	29	Moderate

Source: Authors Compilation (2024); WHO (2021) Air Quality Guidelines.

In contrast, relatively lower $PM_{2.5}$ concentrations observed in Epe and Badagry can be attributed to their lower levels of urbanisation, reduced traffic density, and less intensive industrial activity. However, it is important to interpret these 'lower' levels cautiously. In many cases, they still approach or exceed the WHO thresholds, indicating that even less urbanised areas are not entirely free from air quality concerns. This suggests that air pollution in Lagos is not confined to urban cores, but is also increasingly diffused across the metropolitan region.

Figure 3: $PM_{2.5}$ Concentration Across Schools.

Source: Fieldwork Data (2024).

Influence of Land-Use Characteristics.

The analysis further demonstrates that land-use type is a critical determinant of $PM_{2.5}$ exposure levels. Schools located in high-traffic corridors and commercial or industrial zones consistently recorded higher concentrations compared to those in residential or peri-urban settings. This pattern can be explained by the proximity of these schools to major emission sources, particularly vehicular exhaust, which is a well-established contributor to fine particulate pollution.

In high-traffic areas, frequent vehicle acceleration, idling, and congestion lead to continuous emission of fine particles, which accumulate in the immediate environment. Similarly, industrial and commercial zones contribute through combustion processes, material handling, and—in some cases—informal or poorly regulated activities. Therefore, the findings reinforce the concept of micro-environmental exposure, where pollutant levels are significantly shaped by immediate surroundings rather than broader regional air quality (Elisephane & Zoltan, 2025; Mahmud et al., 2024).

However, the observation that some residential areas also recorded moderate to high $PM_{2.5}$ levels suggests that pollution sources are not strictly confined to designated industrial or commercial zones. In the Lagos context, residential areas often experience emissions from domestic energy use (such as generators and biomass cooking), waste burning, and unregulated small-scale enterprises. This distorts the traditional distinction between ‘clean’ and ‘polluted’ land-use categories, and indicates that exposure risk is more widespread than typically assumed.

Temporal Variation and Activity Patterns

Temporal analysis of $PM_{2.5}$ concentrations revealed clear fluctuations linked to daily human activity patterns. Peak concentrations observed during morning school resumption periods can be directly associated with increased vehicular traffic as students, staff, and commuters converge within the same time window (An et al., 2022; Jung et al., 2023). This creates short-term spikes in emissions, particularly in schools located near busy roads, e.g., Isale-eko grammar school. A second peak during midday break periods is influenced by a combination of factors, including increased student movements, resuspension of dust in playgrounds, and ongoing traffic activity in surrounding areas. These findings highlight the dynamic nature of exposure, where children are not subjected to constant pollution levels but rather to fluctuating concentrations that may include short periods of very high exposure (Caballeda et al., 2025).

From a health perspective, these short-term peaks are particularly important. Emerging evidence suggests that intermittent exposure to high concentrations of $PM_{2.5}$ can trigger acute respiratory responses, even when average daily exposure appears moderate. This is especially relevant for school children, whose activity patterns—such as outdoor play during breaks—coincide with periods of elevated pollution. Taken together, these findings suggest that $PM_{2.5}$ exposure among school children in Lagos is shaped by a complex interplay of spatial location, land-use characteristics, and temporal activity patterns. The fact that most of the schools exceed the WHO guidelines indicates that exposure is not an isolated issue, but a systemic environmental health concern.

PM_{10} Exposure Levels in Schools

The PM_{10} concentrations across the sampled schools exhibited a considerable variability; with a distribution pattern that—while similar to $PM_{2.5}$—reflects distinct emission dynamics and environmental influences. Unlike fine particulate matter, PM_{10} is more closely associated with mechanically generated particles, and its spatial behaviour is therefore more sensitive to immediate physical conditions within the environment.

The results indicate that 53.33% of the schools fall within the low exposure category, suggesting that, at face value, most locations may not be experiencing critically elevated PM_{10} levels. However, this apparent 'safety' must be interpreted with caution. A combined 46.99% of the schools fall within moderate to very high exposure categories, including 13.66% being classified as very high. This distribution highlights the presence of localized pollution hotspots, where PM_{10} concentrations rise significantly above acceptable thresholds.

When compared with the WHO (2021) guidelines (24-hour limit of 45µg/m^3), several of the recorded values—particularly in high and very high categories—indicate conditions that can induce respiratory irritation and exacerbating pre-existing health conditions. The presence of extreme values in a subset of schools suggests that exposure is not evenly distributed, but rather concentrated in specific high-risk environments. A clear spatial concentration of elevated PM_{10} levels is observed in Lagos Island and Ikeja, as well as in schools located within high-traffic corridors (Figure 4). This pattern mirrors that of $PM_{2.5}$ to some extent, but is more pronounced in terms of peak values.

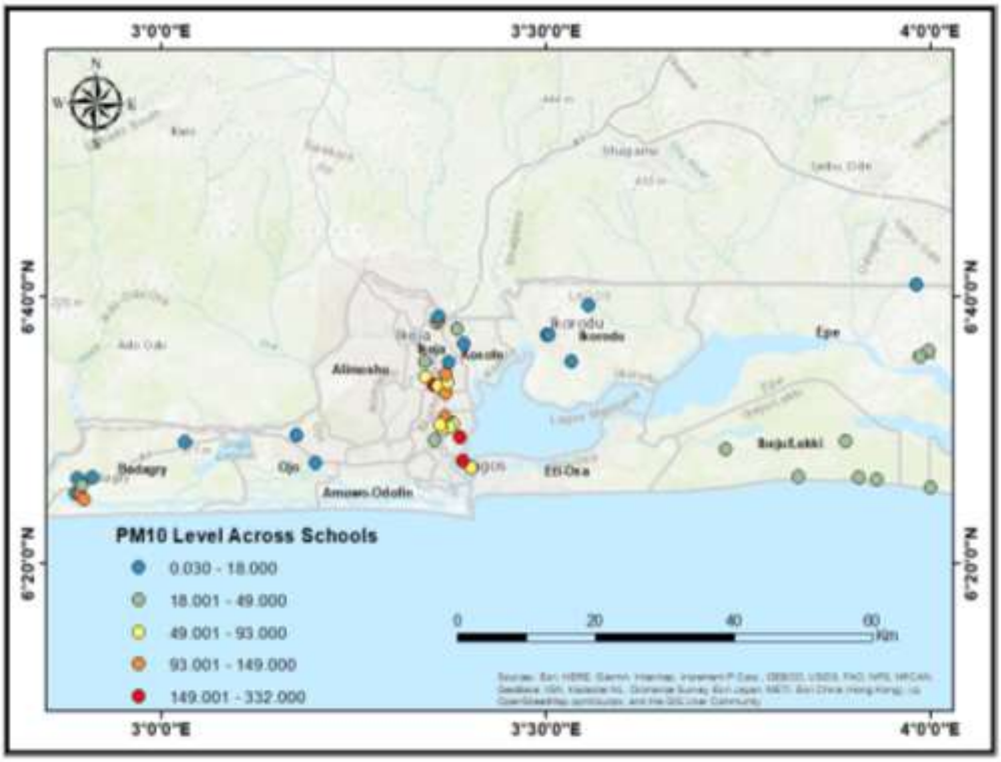

Figure 4: PM_{10} Concentration Across Schools

Source: Fieldwork (2024).

The higher variability in PM_{10} concentrations reflects its sensitivity to localized physical disturbances, which are more prevalent in densely built urban environments (Fonderson et al., 2025). In Lagos Island, the combination of intense commercial activity, narrow road networks, and high pedestrian and vehicular movement contribute to continuous resuspension of surface dust. Similarly, in Ikeja, ongoing infrastructural development and traffic congestion create conditions conducive to elevated coarse particulate levels. The clustering of high PM_{10} values in these areas suggests that urban form and infrastructure quality play a critical role in shaping exposure patterns.

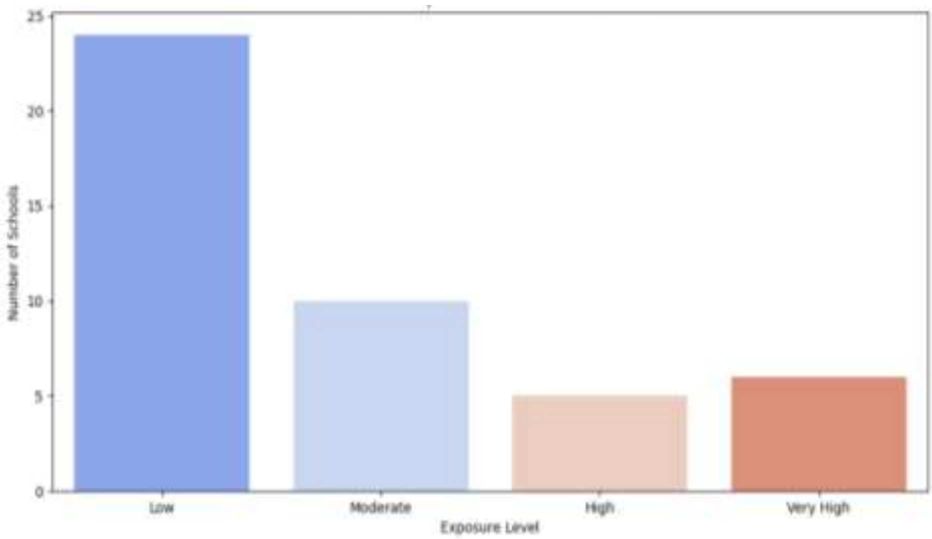

Figure 5: PM_{10} Level Across Schools

Source: Fieldwork (2024).

By contrast, lower concentrations observed in divisions such as Epe and parts of Badagry may be attributed to less intensive land use, lower traffic volumes, and reduced construction activity. However, as with $PM_{2.5}$, these relatively lower values do not necessarily imply the absence of risk, particularly where environmental controls are weak, or seasonal factors (such as dry conditions) may elevate dust levels.

The presence of very high PM_{10} levels in a notable proportion of schools is particularly significant from a public health perspective. While PM_{10} particles do not penetrate as deeply into the lungs as $PM_{2.5}$, they can still deposit in the upper respiratory tract; thereby causing irritation, inflammation, and increased susceptibility to respiratory infections. For school children, repeated exposure, especially during outdoor activities, can contribute to chronic respiratory symptoms and reduced overall respiratory health (Ezani & Brimblecombe, 2025). Moreover, the nature of PM_{10} exposure is an important consideration. Unlike $PM_{2.5}$, which often reflects more stable background pollution, PM_{10} concentrations can spike rapidly in response to specific activities such as vehicle movement on dusty roads, or construction work. This means that short-term exposure events, even if infrequent, may contribute disproportionately to overall health risk.

Assessing School Children Exposure to Pollutants in Lagos State.

The TRDD reflects the amount of particulate matter (PM_{10} and $PM_{2.5}$) that deposits in a person's respiratory tract (Equation 1). While there are no universal statutory limits directly set for TRDD, the values can be interpreted using inferred exposure risk bands, guided by international ambient air quality guidelines such as those from the WHO. Using standard dose modelling assumptions (for a typical inhalation rate and exposure duration), these limits correspond roughly to the those shown in Table 3.

Table 3: TRDD PM Daily Threshold

	Low Risk	**Moderate Risk**	**High Risk**
TRDD thresholds for $PM_{2.5}$:	< 1500µg/day	1500–2500µg/day	> 2500µg/day.
TRDD thresholds for PM_{10}:	< 2000µg/day	2000–3000µg/day	> 3000µg/day

Source: WHO Air Quality Guideline (2021).

These thresholds help us interpret which environments are safer or riskier for human exposure as shown in Table 4.

Table 4: TRDD According to Land Use with Deviation from WHO 24–hour Guideline

Land Use	**Avg TRDD _PM_{10}**	**Level (PM_{10})**	**% Above 2000**	**Avg TRDD_ $PM_{2.5}$**	**Level ($PM_{2.5}$)**	**% Above 1500**
High Traffic	2736.96	High	36.85%	2436.36	High	62.42%
Industrial/Commercial	3545.72	High	77.29%	1793.02	Moderate	19.54%
Residential	3949.61	High	97.48%	2480.00	High	65.33%

Source: Fieldwork, (2024).

Residential areas show the highest TRDD, especially for PM_{10} (3,949.61µg/day), which exceeds the high-risk threshold by nearly 98%. This suggests that residents are at heightened risk, likely due to a mix of household emissions (cooking, generator use), poor ventilation, and ambient dust. Industrial/ commercial zones have the highest PM_{10} TRDD after residential zones, at 3,545.72µg/day; exceeding the moderate-risk limit by 77%. This reflects high coarse particulate levels from construction, factories, or warehouse activity. However, the $PM_{2.5}$ exposure is only moderately elevated, suggesting fewer fine-combustion sources. High traffic areas, while somewhat better than residential zones, still show TRDD values above safe limits for both PM_{10} and $PM_{2.5}$. These are likely due to vehicle emissions and road dust, with $PM_{2.5}$ TRDD at 2,436.36µg/day; exceeding the threshold by about 62%. The study clearly indicates that no land use type is within safe TRDD levels. This implies widespread pollution exposure, with residential zones being the highest.

Additionally, the TRDD values—regarding the Lagos State divisions—show that Lagos Island stands out with the highest average TRDD for both PM_{10} (6197.33) and $PM_{2.5}$ (3198.22). This suggests that Lagos Island experiences the highest levels of particulate matter deposition among the divisions listed. This is likely due to a combination of factors, such as high population density, traffic congestion, commercial activities, and industrial activity. Ikeja also shows relatively high average TRDD values for both PM_{10} (5152.00) and $PM2_{2.5}$ (3098.67). Like Lagos Island, Ikeja experiences significant pollution likely due to its urban characteristics. Badagry, Epe, and Ikorodu show considerably lower average TRDD values compared to Lagos Island and Ikeja.

The results demonstrate a clear and consistent relationship between ambient particulate concentrations and TRDD values across the sampled schools. Locations with elevated $PM_{2.5}$ and PM_{10} concentrations correspondingly recorded higher deposition doses, confirming that increases in environmental pollution translate directly into increased respiratory burden. However, the relationship is not merely linear in a simple sense. The TRDD results reveal that ambient concentration alone may underestimate actual exposure risk, particularly in school environments where children experience prolonged and repeated exposure during active periods. For instance, schools categorized under moderate pollution levels based on ambient concentrations often produced TRDD values that fall within high-risk categories. This discrepancy showed the amplifying effect of time spent in the environment and breathing intensity, which are not captured in concentration-based assessments (Altman et al., 2023).

The elevated TRDD values observed across multiple locations suggest that children in Lagos schools are subject to sustained inhalation of particulate matter at levels capable of producing adverse health outcomes. Given the developmental vulnerability of children's respiratory systems, repeated exposure to such doses may contribute to long-term impairments in lung function, increased incidence of respiratory infections, and heightened susceptibility to chronic diseases later in life.

Gaseous Pollutant Exposure Analysis

The TRDD only measured exposure to pollutants as it related to particulate matter, while gaseous pollutant exposure was analysed for CO, NO_2, O_3, and VOCs for light moderate and heavy exercise (Equation 2). As indicated in Figure 6, the total inhalation dose per day is higher for NO_2 and VOC pollutants for all forms of exercise.

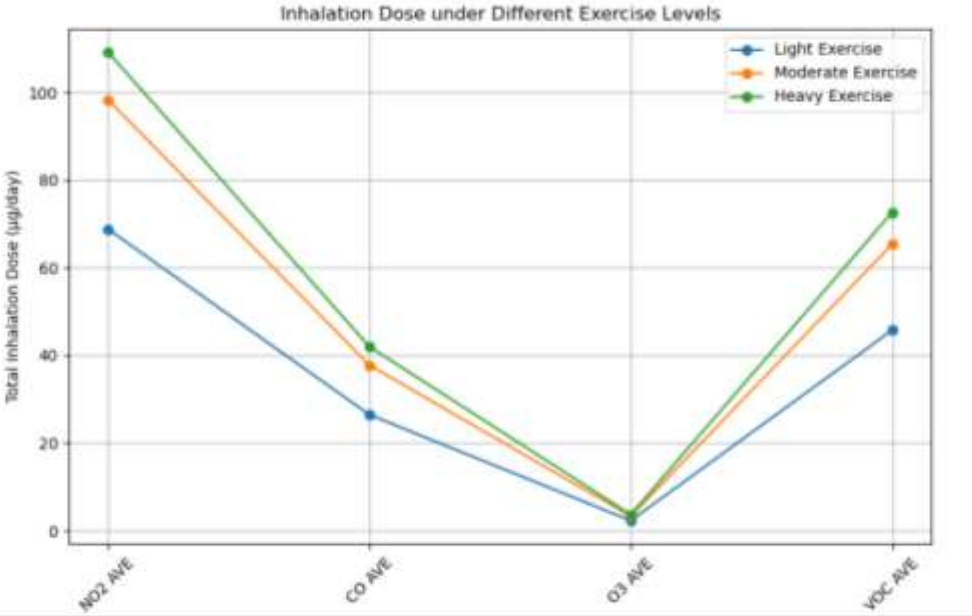

Figure 6: Inhalation Dose Under Different Exercise Levels
Source: Fieldwork (2024).

The analysis of gaseous pollutants (CO, NO_2, O_3, and VOCs) revealed distinct exposure patterns across the sampled schools. Among the pollutants, NO_2 and VOCs recorded the highest inhalation doses (Figure 6), indicating a stronger contribution from traffic emissions and combustion-related activities within the study environment. A consistent increase in inhalation dose was observed with rising physical activity levels. Under light activity, exposure remained relatively low; however, moderate and heavy activity levels resulted in progressively higher doses (Roche et al., 2024). This trend reflects the role of inhalation rate as a key determinant of exposure, as increased breathing frequency during physical exertion leads to greater intake of polluted air. This finding is particularly relevant in school settings where periods of outdoor activity coincide with exposure to traffic-related emissions. It suggests that even when ambient gaseous concentrations are within acceptable limits, actual inhaled doses may still be elevated due to behavioural factors, thereby increasing potential health risk (Maduekwe et al., 2020).

When particulate and gaseous pollutants are considered together, the results indicate that school children are exposed to complex multi-pollutant mixtures rather than isolated contaminants. This reflects real-world conditions where different pollutants coexist, and may interact within the same micro-environment. Exposure was found to be continuous during school hours, with fluctuations linked to activity patterns and surrounding emission sources.

Importantly, both particulate and gaseous pollutant doses increased with activity intensity, reinforcing the combined influence of environmental conditions and human behaviour. These findings point to the limitation of single-pollutant assessments, and highlight the need for integrated exposure approaches that account for multiple pollutants and dynamic exposure conditions within school environments.

The one-way ANOVA results presented in Table 5 reveal statistically significant differences in particulate matter concentrations across Lagos divisions. For $PM_{2.5}$, the f-value of 4.18 with a p-value of 0.0061 indicates that variations in fine particulate concentrations across the sampled locations are significant at the 1% level. Similarly, PM_{10} shows an f-value of 3.82 with a p-value of 0.0094, confirming significant spatial differences in coarse particulate matter concentrations. These findings suggest that particulate matter levels are not uniformly distributed across the study area, but vary according to location. This spatial variability is likely influenced by differences in land use, traffic density, and industrial activities across the divisions. The statistically significant results, therefore, support the conclusion that location plays a critical role in determining exposure levels among school children.

Table 5: ANOVA Results for Particulate Matter across Lagos Divisions

Pollutant	F-value	P-value	Significance
$PM_{2.5}$	4.18	0.0061	Significant ($p < 0.01$)
PM_{10}	3.82	0.0094	Significant ($p < 0.01$)

Source: Authors Computation (2024).

The regression results indicate a strong positive relationship between ambient particulate matter concentrations and TRDD. $PM_{2.5}$ shows a higher explanatory power ($R^2 = 0.84$) compared to PM_{10} ($R^2 = 0.79$); suggesting that fine particles contribute more significantly to respiratory deposition among school children. The statistically significant p-values ($p < 0.0001$) confirm that these relationships are not due to chance. This finding reinforces the importance of considering not only ambient concentrations, but also their translation into actual inhaled doses when assessing exposure risk.

Table 6: Regression Statistics for Ambient Particulate Matter and TRDD

Variable	Coefficient (β)	R^2	p-value
Ambient $PM_{2.5}$ vs. TRDD	118.45	0.84	< 0.0001
Ambient PM_{10} vs. TRDD	18.22	0.79	< 0.0001

The combined results suggest that a considerable proportion of school children in Lagos are exposed to pollutant levels that exceed recommended safety thresholds. Although this study does not directly measure clinical health outcomes, the observed exposure and dose levels are consistent with conditions associated with increased respiratory and cardiovascular risks in children. Potential health implications include:

(a) Increased incidence of respiratory irritation and infections.
(b) Impaired lung development due to prolonged exposure.
(c) Elevated long-term risk of chronic respiratory and cardiovascular conditions.

Children attending schools in high-traffic and densely urbanised areas are likely to experience the greatest exposure, particularly during periods of outdoor activities when inhalation rates are higher. This highlights the vulnerability of school-aged children, whose developing respiratory systems make them more susceptible to environmental pollutants.

Conclusion

This study provided a comprehensive assessment of multi-pollutant exposure among secondary school children in Lagos State, transitioning from traditional ambient monitoring to a robust, dose-based analytical framework. The findings confirm that children in Lagos schools are subject to significant respiratory risks, with over 64% of the sampled schools exceeding the WHO 2021 Air Quality Guidelines for Particulate Matter ($PM_{2.5}$ and PM_{10}). By employing the TRDD model, the study has successfully demonstrated that ambient concentrations alone do not fully represent the biological threat. The spatial analysis identified Lagos Island and Ikeja as critical hotspots, where high-traffic density and commercial activities lead to disproportionately high inhalation doses. Furthermore, the study established a direct linear correlation between physical activity and pollutant uptake, revealing that heavy exercises during school hours can triple the inhalation dose of hazardous gases like NO_2 and VOCs.

Recommendations

To address the critical air quality challenges identified, it is recommended that stakeholders implement a multi-tiered strategy focusing on spatial planning, operational shifts, and enhanced monitoring. This includes establishing mandatory buffer zones of at least 150–200 meters for new school constructions away from major highways, while planting green vegetative barriers in existing high-risk urban ‘hotspots’ like Lagos Island to filter particulate matter. Schools should further mitigate respiratory risks by rescheduling high-intensity physical activities to off-peak traffic hours, and improving classroom ventilation to reduce indoor infiltration of outdoor pollutants.

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