

Ambient Air Quality and Potential Inhalation Exposure Around Selected Waste Dumpsites in Port Harcourt Metropolis, Nigeria

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Abstract

Waste dumpsites are potential sources of ambient air pollution and may expose nearby residents and waste workers to particulate matter and gaseous pollutants. This study assessed ambient air quality and potential exposure around selected waste dumpsites in Port Harcourt Metropolis, Nigeria. A cross-sectional environmental monitoring and exposure-assessment design was adopted. Three active dumpsites (L1–L3) were purposively selected based on waste-handling activities, accessibility, surrounding populations and site characteristics. Temperature, relative humidity, $PM_{2.5}$, PM_{10} , SO_2 , CO, NO_2 and O_3 were monitored for three consecutive days at each site. Additionally, 186 respondents comprising 110 residents and 76 workers provided information on exposure duration, daily exposure time, exposure frequency and distance from dumpsites. Descriptive statistics were used to summarize pollutant concentrations and exposure characteristics, while time-activity-adjusted concentrations were estimated to characterize potential environmental exposure. Temperature ranged from 28–35°C and relative humidity from 56–74%. Mean PM_{10} concentrations were 27.00 ± 5.29 , 27.00 ± 1.00 and $36.00 \pm 20.88 \mu g/m^3$ at L1, L2 and L3, respectively, while $PM_{2.5}$ concentrations were 21.67 ± 4.73 , 21.33 ± 1.15 and $21.67 \pm 5.69 \mu g/m^3$. Mean NO_2 concentrations were 83.97 ± 32.14 , 127.21 ± 29.75 and $97.13 \pm 30.10 \mu g/m^3$, while O_3 concentrations were 84.93 ± 40.80 , 84.93 ± 56.58 and $111.07 \pm 11.32 \mu g/m^3$. SO_2 was not detected, whereas CO ranged from 0–2.63 mg/m³. Screening comparisons indicated potential concern for $PM_{2.5}$ and NO_2 . Furthermore, 58.6% of respondents reported exposure at least five days weekly, while 55.4% lived or worked within 100 m of a dumpsite. Time-activity-adjusted concentrations were higher among workers than residents, particularly for $PM_{2.5}$ and NO_2 . The findings indicate potentially important exposure to particulate and gaseous pollutants around the selected dumpsites, particularly among workers and populations located nearby. Improved waste management, routine air-quality monitoring and exposure-reduction measures are recommended.

Keywords: Ambient air quality; Dumpsites; Health risks; Nitrogen dioxide; Pollution

1. Background to the Study

Poor solid-waste management has become an important environmental and public-health concern, particularly in rapidly growing cities where waste generation often exceeds available collection, treatment, and disposal capacity. Abarca Guerrero et al. (2013) identified solid-waste management as a major challenge in developing cities, while Ferronato and Torretta (2019) emphasized the

environmental consequences of inadequate waste management in developing countries. Open dumpsites are of particular concern because accumulated wastes may generate particulate matter, gases, odours, smoke, and other contaminants capable of degrading surrounding air quality. Ambient air quality around dumpsites is influenced by waste composition, decomposition processes, open burning, vehicular activities, waste handling, and prevailing meteorological conditions. Key pollutants commonly considered in ambient air-quality assessment include particulate matter (PM_{2.5} and PM₁₀), nitrogen dioxide (NO₂), sulphur dioxide (SO₂), carbon monoxide (CO), and ozone (O₃). The World Health Organization (WHO) provides health-based air-quality guideline values for these pollutants because prolonged or elevated exposure may contribute to adverse health effects. The problem is particularly relevant in Port Harcourt Metropolis, where rapid urban development, population growth, and increasing waste generation have contributed to persistent challenges in waste disposal and environmental management. Previous studies have examined air quality around dumpsites within the metropolis. Alilonu et al. (2023) assessed air quality and meteorological parameters around active dumpsites in Port Harcourt, demonstrating the importance of considering atmospheric conditions when evaluating dumpsite environments. Uche (2021) investigated the impact of solid-waste dumpsites on ambient air quality in Nkpolu Community, Obio/Akpor Local Government Area, while Chukwu-Okeah et al. (2021) examined environmental and health-risk implications of air quality around the Port Harcourt Airport Road dumpsite. Recent studies indicate that concern about dumpsite-related environmental and health effects remains relevant. Amuka et al. (2026) assessed ambient air quality and associated health risks in Port Harcourt Metropolis, while Dimkpa et al. (2025) examined environmental and health implications of poor solid-waste disposal around the Aluu/Obiri-Ikwerre dumpsites. Ogboeli et al. (2025) similarly investigated odour and health implications among commuters and residents around the Obiri-Ikwerre solid-waste dumpsite. These studies demonstrate continuing interest in the environmental and public-health implications of waste disposal activities in the metropolis. However, an important methodological gap remains. Existing studies have largely focused on measured ambient pollutant concentrations, individual environmental indicators, or specific health outcomes, with comparatively limited integration of repeated site-specific air-quality measurements and detailed characteristics of human exposure within the same assessment. In particular, limited attention has been given to simultaneously considering PM_{2.5} and PM₁₀, gaseous pollutants, exposure duration, daily exposure time, exposure frequency, distance from dumpsites, and differences between workers and nearby residents. Furthermore, few assessments have incorporated these exposure characteristics to derive time-activity-adjusted ambient concentration estimates, which can provide additional context for interpreting potential exposure among population groups with different patterns of contact with dumpsite environments. Thus, the available evidence does not fully characterize how pollutant concentrations interact with the duration, frequency, intensity, and spatial proximity of human exposure around selected dumpsites in Port Harcourt Metropolis.

Health concerns associated with dumpsite-related air pollution are particularly relevant to residents, waste handlers, commuters, children, older adults, and persons with pre-existing respiratory conditions who may experience repeated exposure. Yu et al. (2018) examined the effects of ambient air pollution from municipal solid-waste landfills on children's immunity and respiratory health, highlighting the importance of considering exposure among potentially vulnerable populations. Therefore, this study was designed to assess ambient air quality around selected waste dumpsites in Port Harcourt Metropolis and to characterize potential human exposure by examining

pollutant concentrations alongside exposure duration, daily exposure time, exposure frequency, distance from dumpsites, and respondent category. The study further estimated time-activity-adjusted ambient concentrations to provide additional evidence on potential exposure among workers and nearby residents. By combining environmental monitoring with human exposure characteristics, the study sought to provide a more integrated assessment of dumpsite-related air-quality concerns and generate evidence to support environmental management and public-health interventions in Port Harcourt Metropolis.

2. Materials and Methods

The study adopted a cross-sectional environmental monitoring and exposure-assessment design to evaluate ambient air quality and potential inhalation exposure around selected waste dumpsites in Port Harcourt Metropolis, Rivers State, Nigeria. The study area is a densely urbanized environment characterized by residential, commercial, industrial, transportation, and waste-management activities. Three active waste dumpsites, designated Location 1 (L1), Location 2 (L2), and Location 3 (L3), were purposively selected based on predefined environmental and exposure-related criteria. The selection of the dumpsites was guided by the following criteria: (i) active receipt or accumulation of municipal solid waste during the study period; (ii) accessibility for repeated environmental monitoring; (iii) evidence of routine waste handling, sorting, scavenging, transportation, or other human activities; (iv) presence of residential, commercial, or other potentially exposed populations within the surrounding environment; (v) representation of different parts of the study area; and (vi) sufficient variation in the intensity and nature of activities around the dumpsites to permit comparison of ambient air-quality conditions and potential exposure patterns. The selected dumpsites were designated L1, L2, and L3 to facilitate objective comparison and maintain consistency throughout the analysis. For each location, the study documented the dumpsite name, community and Local Government Area, geographical coordinates, approximate site size, operational status, dominant waste types, major activities occurring at the site, and surrounding land use. The surrounding land-use characteristics included residential, commercial, industrial, transportation, and other relevant activities where applicable. Geographic coordinates were obtained using a Global Positioning System (GPS) device and were used to develop a location map showing the spatial distribution of the selected dumpsites within Port Harcourt Metropolis.

The selection of three sites was intended to provide site-specific comparisons rather than to statistically represent all waste dumpsites in Port Harcourt Metropolis. Consequently, the findings were interpreted in relation to the environmental and exposure conditions observed at the selected locations, while recognizing that purposive site selection may limit generalization to other dumpsites within or outside the metropolis.

Table 1. Characteristics of the selected waste dumpsites in Port Harcourt Metropolis

Site	Dumpsite/ community	LGA	Coordinates	Approx. size	Operational status	Dominant waste types	Surrounding land use
L1	Rumuosi Dumpsite/ Rumuosi	Obio/Akpor	4°87'95"N, 6°94'46"E	~6.1 ha	Active	Mixed municipal solid waste (domestic, commercial, plastics, organics, some industrial residues)	Residential, commercial, transportation (near Airport Road)
L2	Alakahia Dumpsite / Alakahia	Obio/Akpor	4°88'98"N, 6°91'83"E	~10.9 ha	Active	Mixed MSW (household, market, commercial, limited industrial; extensive scavenging)	Residential, commercial, light industrial, water body proximity
L3	Eneka Dumpsite / Eneka	Obio/Akpor	4°56'06"N, 7°01'58"E	~5–11.3 ha	Active	Mixed municipal solid waste (domestic, commercial, organic fraction dominant)	Residential, farmland, transportation corridors

Ambient Air-Quality Monitoring: Ambient air-quality measurements were conducted at the three selected dumpsites over three consecutive monitoring days, giving nine observations for each measured parameter. The monitored parameters were particulate matter (PM_{2.5} and PM₁₀), sulphur dioxide (SO₂), carbon monoxide (CO), nitrogen dioxide (NO₂), ozone (O₃), temperature and relative humidity. Portable air-quality monitors were used to measure PM_{2.5}, PM₁₀, SO₂, CO, NO₂, O₃, temperature, and relative humidity at L1–L3. Instrument manufacturer, model, measurement range, accuracy, resolution, and detection limits were documented and are presented in Table X. Before monitoring, instruments were inspected, calibrated, and zero-checked according to manufacturers' specifications. The same instruments, settings, and procedures were used across all sites to ensure comparability.

Measurements were conducted over three consecutive days at each dumpsite. Instruments were positioned at approximately [insert height] m above ground and at comparable distances from major emission sources, while avoiding obstructions that could affect airflow. Sampling intervals and averaging periods were kept consistent across sites. Temperature and relative humidity were recorded concurrently to account for meteorological influences on pollutant dispersion.

Table 2. Specifications of portable air-quality monitoring instruments

Parameter	Instrument manufacturer	Model	Measurement range	Accuracy/precision	Detection limit/resolution	Sampling/averaging period
PM _{2.5}	TSI Incorporated	DustTrak II 8530	0.001–400 mg/m ³	±0.1% of reading or ±0.001 mg/m ³	0.001 mg/m ³	1-min average
PM ₁₀	TSI Incorporated	DustTrak II 8530	0.001–400 mg/m ³	±0.1% of reading or ±0.001 mg/m ³	0.001 mg/m ³	1-min average
SO ₂	Aeroqual	Series 500 (SO ₂ sensor)	0–10 ppm	±10% of reading	0.01 ppm	1-min average
CO	Aeroqual / Crowcon	Series 500 / Gas-Pro	0–100 ppm	±5–10% of reading	0.1–1 ppm	1-min average
NO ₂	Aeroqual	Series 500 (NO ₂ sensor)	0–1 ppm	±10% of reading	0.005–0.01 ppm	1-min average
O ₃	Aeroqual	Series 500 (O ₃ sensor)	0–0.15 ppm	±10% of reading	0.001–0.005 ppm	1-min average
Temperature	Built-in (Aeroqual TSI) /	Integrated sensor	–10 to +60 °C	±0.5 °C	0.1 °C	Concurrent with pollutants
Relative humidity	Built-in (Aeroqual TSI) /	Integrated sensor	0–100% RH	±3% RH	0.1% RH	Concurrent with pollutants

For each measurement, the date, site, time, sampling interval, and pollutant concentration were recorded. Instrument performance was monitored throughout fieldwork, and any abnormal readings or malfunctions were documented and addressed. The resulting measurements were summarized by site and monitoring day for subsequent analysis.

The measured concentrations were recorded in their respective units: PM_{2.5}, PM₁₀, NO₂, SO₂ and O₃ in µg/m³; CO in mg/m³; temperature in °C; and relative humidity in percentage. The resulting measurements were subsequently summarized by location and monitoring day.

Air-Quality Guideline Comparison: Measured pollutant concentrations were compared with applicable World Health Organization (WHO) air-quality guideline values and stated Nigerian air-quality standards. The comparison was performed according to the applicable averaging period of each reference value. Where the averaging period of the field measurement did not correspond directly with the guideline averaging period, the comparison was treated as a screening assessment rather than a direct regulatory compliance determination.

The following WHO reference values were used for the statistical screening: $PM_{10} = 45 \mu\text{g}/\text{m}^3$ (24-hour), $PM_{2.5} = 15 \mu\text{g}/\text{m}^3$ (24-hour), $SO_2 = 500 \mu\text{g}/\text{m}^3$ (24-hour), $CO = 4 \text{ mg}/\text{m}^3$ (24-hour), $NO_2 = 25 \mu\text{g}/\text{m}^3$ (24-hour), and $O_3 = 100 \mu\text{g}/\text{m}^3$ (8-hour). Nigerian reference values were also used where applicable.

Pollution Quotient: A Pollution Quotient (PQ) was calculated to indicate the magnitude of measured pollutant concentrations relative to their applicable guideline values:

$$PQ = \frac{C_m}{C_g}$$

where C_m is the measured or mean pollutant concentration and C_g is the applicable guideline value. A $PQ < 1$ indicated a concentration below the reference value, $PQ = 1$ indicated equivalence, while $PQ > 1$ indicated a concentration above the reference value. The PQ was interpreted as a screening indicator of potential exposure concern and not as evidence of clinically established health effects.

Exposure Assessment: A structured questionnaire was administered to 186 respondents, comprising 110 residents and 76 workers associated with the three dumpsite environments. Each location contributed 62 respondents. Information obtained included respondent category, duration of residence or work near the dumpsite, daily time spent in the dumpsite vicinity, number of exposure days per week, and distance of residence or workplace from the dumpsite.

Respondents were categorized according to their exposure circumstances, including residents, nearby traders, waste pickers, scavengers, waste transporters, dumpsite workers and other persons regularly present within the dumpsite environment.

Estimation of Exposure Parameters: Exposure duration (ED), daily exposure time (ET) and annual exposure frequency (EF) were estimated from questionnaire responses. Midpoint values were assigned to categorical responses to obtain representative estimates for exposure calculations. The overall estimated exposure duration was 6.9 years, mean daily exposure time was 5.1 hours/day, and mean exposure frequency was 244 days/year.

A time-activity factor (TAF) was calculated as:

$$TAF = \frac{ET}{24} \times \frac{EF}{365}$$

The resulting overall TAF was 0.142. Group-specific TAFs were also estimated for workers, residents and respondents living or working within 100 m of the dumpsites.

Time-Weighted Inhalation Exposure Concentration: Potential time-weighted inhalation exposure concentrations were estimated by combining measured ambient pollutant concentrations with the estimated time-activity factor:

$$EC = C \times TAF$$

where EC is the estimated time-weighted exposure concentration ($\mu\text{g}/\text{m}^3$ or mg/m^3), C is the mean ambient pollutant concentration, and TAF is the proportion of time spent in the exposure environment.

The overall exposure concentrations were estimated for $PM_{2.5}$, PM_{10} , NO_2 , O_3 , CO and SO_2 . Separate estimates were also calculated for residents, workers and respondents located within 100 m of the dumpsites.

These estimates represented potential inhalation exposure concentrations and were not interpreted as individual absorbed doses, internal concentrations or confirmed health effects.

Data Analysis: Air-quality and exposure data were analyzed using descriptive and inferential statistics. Mean, standard deviation, minimum, maximum and range were calculated for measured

pollutant concentrations. Frequencies and percentages were used to summarize respondents' exposure characteristics.

Percentage difference between measured concentration and the applicable reference value was calculated as:

$$\% \text{ Difference} = \frac{C_m - C_g}{C_g} \times 100$$

where C_m represents the measured or mean concentration and C_g represents the applicable reference value. Positive values indicated concentrations above the reference value, whereas negative values indicated concentrations below the reference value.

A one-sample t -test was used to determine whether the mean concentration of each pollutant differed significantly from its selected WHO reference value. The test statistic was calculated as:

$$t = \frac{\bar{X} - \mu_0}{s/\sqrt{n}}$$

where $\bar{X}$ is the observed mean concentration, μ_0 is the reference value, s is the sample standard deviation and n is the number of observations.

A one-tailed test was applied where the analytical question concerned whether the measured concentration exceeded the reference value. Statistical significance was assessed at $\alpha = 0.05$. The null hypothesis was rejected when the p -value was less than 0.05. Because SO_2 was not detected in any of the nine observations and therefore had zero variance, a conventional one-sample t -test was not performed for SO_2 .

Quality Control and Interpretation: To improve data quality, the same monitoring procedures and measurement equipment were used across the selected locations, and instruments were checked before field deployment. Questionnaire data were reviewed for completeness before analysis. The interpretation of potential health concerns was based on the measured pollutant concentrations, guideline comparisons and estimated exposure concentrations. Because the study did not include clinical examination, biomarkers or longitudinal health-outcome data, elevated pollutant concentrations were interpreted as potential environmental exposure concerns rather than direct evidence of disease or attributable health effects.

3. Results

Daily Ambient Air-Quality Measurements

Table 1 presents the daily measurements of meteorological conditions, particulate matter and gaseous pollutants recorded at the three selected waste dumpsites over the three-day monitoring period. Temperature ranged from 28 to 35°C, while relative humidity ranged from 56% to 74%. PM_{10} concentrations ranged from 22 to 60 $\mu\text{g}/\text{m}^3$ and $\text{PM}_{2.5}$ from 17 to 28 $\mu\text{g}/\text{m}^3$. SO_2 was not detected during any of the monitoring periods. CO concentrations ranged from 0.00 to 2.63 mg/m^3 , while NO_2 ranged from 47.00 to 159.80 $\mu\text{g}/\text{m}^3$. O_3 concentrations ranged from 19.60 to 117.60 $\mu\text{g}/\text{m}^3$.

Table 1: Daily Ambient Air-Quality Measurements across the Selected Waste Dumpsites

Parameter	L1 Day 1	L1 Day 2	L1 Day 3	L2 Day 1	L2 Day 2	L2 Day 3	L3 Day 1	L3 Day 2	L3 Day 3
Temperature (°C)	28	35	33	30	31	30	29	33	31
Relative humidity (%)	74	56	60	66	64	65	70	60	60
PM ₁₀ (µg/m ³)	33	23	25	26	27	28	60	26	22
PM _{2.5} (µg/m ³)	27	18	20	20	22	22	28	20	17
SO ₂ (µg/m ³)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CO (mg/m ³)	0.00	0.00	2.63	1.03	1.37	1.72	0.00	0.00	0.00
NO ₂ (µg/m ³)	99.64	47.00	105.28	101.52	120.32	159.80	95.88	67.68	127.84
O ₃ (µg/m ³)	98.00	39.20	117.60	117.60	19.60	117.60	98.00	117.60	117.60

Source: Field Measurements (2026).

Note: L1 = Location 1; L2 = Location 2; L3 = Location 3.

Meteorological Conditions

Table 2 summarizes the meteorological conditions recorded across the monitoring locations. Location 1 recorded the highest mean temperature ($32.00 \pm 3.61^\circ\text{C}$), followed by Location 3 ($31.00 \pm 2.00^\circ\text{C}$), while Location 2 recorded the lowest mean temperature ($30.33 \pm 0.58^\circ\text{C}$). Relative humidity was highest at Location 2 ($65.00 \pm 1.00\%$) and lowest in terms of mean value at Locations 1 and 3 ($63.33 \pm 9.45\%$ and $63.33 \pm 5.77\%$, respectively). Overall, temperature ranged from 28 to 35°C , while relative humidity ranged from 56 to 74%.

Table 2: Summary of Meteorological Conditions across the Selected Waste Dumpsites

Parameter	Location 1 Mean $\pm$ SD	Location 2 Mean $\pm$ SD	Location 3 Mean $\pm$ SD	Overall Range
Temperature (°C)	32.00 ± 3.61	30.33 ± 0.58	31.00 ± 2.00	28–35
Relative humidity (%)	63.33 ± 9.45	65.00 ± 1.00	63.33 ± 5.77	56–74

Source: Field Measurements (2026).

Particulate Matter Concentrations

Table 3 presents the mean concentrations of PM₁₀ and PM_{2.5} across the three monitoring locations. PM₁₀ concentrations ranged from 22.00 to 60.00 µg/m³. Locations 1 and 2 recorded the same mean concentration of 27.00 ± 5.29 and 27.00 ± 1.00 µg/m³, respectively, whereas Location 3 recorded the highest mean concentration (36.00 ± 20.88 µg/m³). The highest individual PM₁₀ concentration (60.00 µg/m³) was recorded at Location 3 on Day 1.

PM_{2.5} concentrations ranged from 17.00 to 28.00 µg/m³. The mean concentrations were similar across the three locations, ranging from 21.33 ± 1.15 µg/m³ at Location 2 to 21.67 ± 4.73 µg/m³ at Location 1 and 21.67 ± 5.69 µg/m³ at Location 3.

Table 3: Particulate Matter Concentrations across the Selected Waste Dumpsites

Parameter	Location 1 Mean $\pm$ SD	Location 2 Mean $\pm$ SD	Location 3 Mean $\pm$ SD	Minimum	Maximum
PM ₁₀ ($\mu\text{g}/\text{m}^3$)	27.00 $\pm$ 5.29	27.00 $\pm$ 1.00	36.00 $\pm$ 20.88	22.00	60.00
PM _{2.5} ($\mu\text{g}/\text{m}^3$)	21.67 $\pm$ 4.73	21.33 $\pm$ 1.15	21.67 $\pm$ 5.69	17.00	28.00

Source: Field Measurements (2026).

Gaseous Pollutant Concentrations

Table 4 shows the concentrations of gaseous pollutants across the monitoring locations. SO₂ was not detected at any location. CO ranged from 0.00 to 2.63 mg/m³, with the highest mean concentration at Location 2 (1.37 $\pm$ 0.35 mg/m³), followed by Location 1 (0.88 $\pm$ 1.52 mg/m³). No CO was detected at Location 3.

NO₂ concentrations ranged from 47.00 to 159.80 $\mu\text{g}/\text{m}^3$. Location 2 recorded the highest mean concentration (127.21 $\pm$ 29.75 $\mu\text{g}/\text{m}^3$), followed by Location 3 (97.13 $\pm$ 30.10 $\mu\text{g}/\text{m}^3$) and Location 1 (83.97 $\pm$ 32.14 $\mu\text{g}/\text{m}^3$). O₃ ranged from 19.60 to 117.60 $\mu\text{g}/\text{m}^3$, with Location 3 recording the highest mean concentration (111.07 $\pm$ 11.32 $\mu\text{g}/\text{m}^3$).

Table 4: Concentrations of Gaseous Pollutants across the Selected Waste Dumpsites

Parameter	Location 1 Mean $\pm$ SD	Location 2 Mean $\pm$ SD	Location 3 Mean $\pm$ SD	Overall Range
SO ₂ ($\mu\text{g}/\text{m}^3$)	0.00 $\pm$ 0.00	0.00 $\pm$ 0.00	0.00 $\pm$ 0.00	0.00
CO (mg/m ³)	0.88 $\pm$ 1.52	1.37 $\pm$ 0.35	0.00 $\pm$ 0.00	0.00–2.63
NO ₂ ($\mu\text{g}/\text{m}^3$)	83.97 $\pm$ 32.14	127.21 $\pm$ 29.75	97.13 $\pm$ 30.10	47.00–159.80
O ₃ ($\mu\text{g}/\text{m}^3$)	84.93 $\pm$ 40.80	84.93 $\pm$ 56.58	111.07 $\pm$ 11.32	19.60–117.60

Source: Field Measurements (2026).

Comparison with Air-Quality Guideline Values

Table 5 provides a screening comparison of the measured pollutant concentrations with the stated WHO and Nigerian air-quality reference values. PM₁₀ ranged from 22 to 60 $\mu\text{g}/\text{m}^3$, with one reading exceeding the stated WHO 24-hour value of 45 $\mu\text{g}/\text{m}^3$, while all measurements remained below the stated Nigerian value of 150 $\mu\text{g}/\text{m}^3$. All nine PM_{2.5} observations were above the stated WHO 24-hour guideline of 15 $\mu\text{g}/\text{m}^3$.

SO₂ was not detected and was therefore below the stated reference values. CO concentrations were below the stated WHO and Nigerian reference values. NO₂ concentrations exceeded the stated WHO 24-hour value at all monitoring observations, while three observations exceeded the stated Nigerian 24-hour value of 120 $\mu\text{g}/\text{m}^3$. Five O₃ observations were numerically above 100 $\mu\text{g}/\text{m}^3$; however, interpreting O₃ against an 8-hour guideline requires confirming that the measurements represent the same averaging period.

Table 5: Screening Comparison of Measured Pollutants with Air-Quality Guideline Values

Pollutant	Observed Range	WHO Guideline	Nigerian Standard	Numerical Comparison
PM ₁₀	22–60 µg/m ³	45 µg/m ³ (24 h)	150 µg/m ³ (24 h)	One reading above WHO value; all below Nigerian value
PM _{2.5}	17–28 µg/m ³	15 µg/m ³ (24 h)	—	All nine readings above WHO value
SO ₂	0 µg/m ³	40 µg/m ³ (24 h)	120 µg/m ³ (24 h)	All readings below stated values
CO	0–2.63 mg/m ³	4 mg/m ³ (24 h)	5 mg/m ³ (8 h)	All readings below stated values
NO ₂	47–159.80 µg/m ³	25 µg/m ³ (24 h)	120 µg/m ³ (24 h)	All readings above WHO value; three above Nigerian value
O ₃	19.60–117.60 µg/m ³	100 µg/m ³ (8 h)	100 µg/m ³ (8 h)	Five readings numerically above 100 µg/m ³

Source: Field Measurements (2026); World Health Organization (2021); National Environmental (Air Quality Control) Regulations.

Screening Assessment of Potential Health Concerns

Table 6 summarizes the potential health implications of the measured pollutants. PM_{2.5} and NO₂ showed the most consistent numerical elevation relative to the stated WHO reference values. PM₁₀ showed an episodic elevation at Location 3, while O₃ showed elevated individual readings, particularly at Locations 2 and 3. SO₂ was not detected, and CO concentrations remained relatively low in relation to the stated reference values.

Table 6: Screening Assessment of Potential Health Concerns Associated with Measured Pollutants

Pollutant	Result Pattern	Potential Health Concern	Screening Interpretation
PM ₁₀	22–60 µg/m ³ ; highest at L3	Respiratory irritation and adverse respiratory effects at elevated exposure	Potential episodic concern, particularly at L3
PM _{2.5}	17–28 µg/m ³ ; all readings above stated WHO 24-h value	Fine particles may penetrate deeply into the respiratory system and are associated with respiratory and cardiovascular effects	Potential health concern across all three locations
SO ₂	Not detected	Elevated exposure may cause respiratory irritation and aggravate asthma	Minimal measured concern during monitoring
CO	0–2.63 mg/m ³ ; highest at L1	High CO exposure can interfere with oxygen transport and produce systemic effects	Measured concentrations remained below stated reference values
NO ₂	47–159.80 µg/m ³ ; highest at L2	Respiratory irritation and aggravation of respiratory conditions	Important potential respiratory concern, particularly at L2

O ₃	19.60–117.60 µg/m ³ ; highest mean at L3	Elevated exposure may impair respiratory function and aggravate asthma	Potential particularity at L3 and during elevated measurements	concern, L3 and elevated
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Source: Field Measurements (2026); World Health Organization.

Characteristics of Respondents and Exposure Patterns

A total of 186 respondents participated in the exposure assessment, comprising 110 residents and 76 workers. Each monitoring location contributed 62 respondents, representing 33.3% of the total sample. This balanced distribution provided comparable respondent numbers across the three locations.

Table 7: Distribution of Respondents by Location and Category

Location	Residents, n (%)	Workers, n (%)	Total, n (%)
L1	38	24	62 (33.3)
L2	35	27	62 (33.3)
L3	37	25	62 (33.3)
Total	110	76	186 (100.0)

Source: Field Survey (2026).

Duration of Exposure

As shown in Table 8, 67 respondents (36.0%) had lived or worked in the vicinity of the dumpsites for 1–5 years, representing the largest exposure-duration category. This was followed by 53 respondents (28.5%) who reported 6–10 years of exposure. Twenty-eight respondents (15.1%) had less than one year of exposure, while 24 (12.9%) and 14 (7.5%) reported 11–15 years and more than 15 years, respectively.

Table 8: Exposure Duration among Respondents

Duration	L1 (n)	L2 (n)	L3 (n)	Total (n)	%
<1 year	9	11	8	28	15.1
1–5 years	22	24	21	67	36.0
6–10 years	18	16	19	53	28.5
11–15 years	8	7	9	24	12.9
>15 years	5	4	5	14	7.5
Total	62	62	62	186	100.0

Source: Field Survey (2026).

Daily Exposure Time

Table 9 indicates that 55 respondents (29.6%) spent 5–8 hours per day in the dumpsite vicinity, while 54 (29.0%) spent 2–4 hours. Thirty-six respondents (19.4%) reported more than 8 hours per day, and 41 (22.0%) reported less than 2 hours per day.

Table 9: Daily Exposure Time in the Dumpsite Vicinity

Daily exposure time	L1 (n)	L2 (n)	L3 (n)	Total (n)	%
<2 hours	14	12	15	41	22.0
2–4 hours	19	17	18	54	29.0
5–8 hours	18	20	17	55	29.6
>8 hours	11	13	12	36	19.4
Total	62	62	62	186	100.0

Source: Field Survey (2026).

Exposure Frequency

Table 10 shows that 64 respondents (34.4%) reported spending 5–6 days per week in the dumpsite vicinity. Forty-five respondents (24.2%) reported exposure on 3–4 days per week, while another 45 (24.2%) reported exposure every day. Thirty-two respondents (17.2%) reported exposure on 1–2 days per week.

Table 10: Frequency of Exposure to the Dumpsite Vicinity

Days per week	L1 (n)	L2 (n)	L3 (n)	Total (n)	%
1–2 days	11	9	12	32	17.2
3–4 days	16	15	14	45	24.2
5–6 days	21	23	20	64	34.4
7 days	14	15	16	45	24.2
Total	62	62	62	186	100.0

Source: Field Survey (2026).

Occupational and Exposure Categories

Residents constituted the largest exposure category, accounting for 65 respondents (34.9%), followed by nearby traders with 33 (17.7%) and waste pickers with 28 (15.1%). Scavengers constituted 11.8%, while waste transporters and dumpsite workers each accounted for 7.0%.

Table 11: Occupational and Exposure Categories of Respondents

Category	L1 (n)	L2 (n)	L3 (n)	Total (n)	%
Waste picker	9	11	8	28	15.1
Scavenger	7	8	7	22	11.8
Waste transporter	4	5	4	13	7.0
Dumpsite worker	4	3	6	13	7.0
Nearby trader	12	10	11	33	17.7
Resident	22	21	22	65	34.9
Other	4	4	4	12	6.5
Total	62	62	62	186	100.0

Source: Field Survey (2026).

Distance of Residence or Workplace from Dumpsite

Table 12 indicates that 55 respondents (29.6%) lived or worked within 50 m of the dumpsites, while 48 (25.8%) were located 50–100 m away. Forty-two respondents (22.6%) were located 101–

250 m away, 26 (14.0%) were 251–500 m away, and 15 (8.1%) were located more than 500 m from the dumpsites.

Table 12: Distance of Residence or Workplace from Dumpsites

Distance	L1 (n)	L2 (n)	L3 (n)	Total (n)	%
<50 m	18	21	16	55	29.6
50–100 m	16	15	17	48	25.8
101–250 m	14	13	15	42	22.6
251–500 m	9	8	9	26	14.0
>500 m	5	5	5	15	8.1
Total	62	62	62	186	100.0

Source: Field Survey (2026).

Derived Exposure Parameters

Midpoint estimates were used to derive representative exposure duration, daily exposure time and annual exposure frequency for the exposure-concentration calculations. The overall estimated exposure duration was 6.9 years, mean daily exposure time was 5.1 hours/day, and mean exposure frequency was 244 days/year. The corresponding time-activity factor was 0.142.

Workers had the highest estimated time-activity factor (0.252), compared with 0.083 among residents. Respondents located within 100 m of the dumpsites had a time-activity factor of 0.173.

Table 13: Derived Exposure Parameters Used for Time-Weighted Exposure Concentration

Exposure group	Mean ED (years)	Mean ET (h/day)	Mean EF (days/year)	Time-activity factor (ET/24 × EF/365)
Overall	6.9	5.1	244	0.142
Workers	7.4	7.3	302	0.252
Residents	6.5	3.6	203	0.083
<100 m	7.1	5.8	261	0.173

Source: Calculated from Field Survey (2026). **Note:** ED = exposure duration; ET = exposure time; EF = exposure frequency.

Estimated Time-Weighted Inhalation Exposure Concentrations

Time-weighted exposure concentrations were estimated using:

$$EC = C \times \frac{ET}{24} \times \frac{EF}{365}$$

where EC is the estimated exposure concentration and C is the measured ambient concentration.

Using the corrected overall pollutant means, the estimated exposure concentrations were 3.07 µg/m³ for PM_{2.5}, 4.26 µg/m³ for PM₁₀, 14.59 µg/m³ for NO₂, 13.31 µg/m³ for O₃, 0.107 mg/m³ for CO and 0.00 µg/m³ for SO₂.

Table 14: Estimated Time-Weighted Inhalation Exposure Concentrations

Pollutant	Mean ambient concentration	Overall exposure factor	Estimated exposure concentration
PM _{2.5} (µg/m ³)	21.56	0.142	3.07
PM ₁₀ (µg/m ³)	30.00	0.142	4.26
NO ₂ (µg/m ³)	102.77	0.142	14.59
O ₃ (µg/m ³)	93.64	0.142	13.30
CO (mg/m ³)	0.75	0.142	0.107
SO ₂ (µg/m ³)	0.00	0.142	0.00

Source: Calculated from Field Measurements and Field Survey data (2026).

Estimated Inhalation Exposure by Exposure Group

Table 15 presents estimated exposure concentrations according to exposure group. Workers had higher estimated exposure concentrations than residents for all pollutants because of their greater reported daily exposure time and exposure frequency. For example, estimated PM_{2.5} exposure was 5.46 µg/m³ among workers compared with 1.79 µg/m³ among residents. Among respondents located within 100 m of the dumpsites, the estimated PM_{2.5} exposure was 3.73 µg/m³.

Table 15: Estimated Inhalation Exposure Concentrations by Exposure Group

Pollutant	Ambient mean	Residents EC	Workers EC	<100 m EC
PM _{2.5} (µg/m ³)	21.56	1.79	5.45	3.73
PM ₁₀ (µg/m ³)	30.00	2.49	7.56	5.19
NO ₂ (µg/m ³)	102.77	8.53	25.90	17.78
O ₃ (µg/m ³)	93.64	7.77	23.60	16.20
CO (mg/m ³)	0.75	0.062	0.189	0.130
SO ₂ (µg/m ³)	0.00	0.00	0.00	0.00

Source: Calculated from Field Measurements and Field Survey data (2026). EC = estimated exposure concentration.

Hypothesis Testing

H₀₁: The mean concentrations of measured ambient air pollutants do not differ significantly from the applicable air-quality reference values.

PM_{2.5} and NO₂ showed the most consistent numerical elevation relative to the WHO reference values, with all nine observations exceeding the respective 24-hour guidelines. PM₁₀ exhibited a single episodic exceedance (at L3). Five of the nine O₃ readings were numerically higher than 100 µg/m³, although formal comparison with the 8-hour guideline is limited by the averaging-period mismatch. SO₂ was not detected at any location, and CO concentrations remained well below the stated reference value at all sites. These patterns indicate that fine particulate matter and nitrogen dioxide are the pollutants of greatest potential concern under the conditions observed during the monitoring period.

Table 16: One-Sample t-Test of Ambient Air Pollutant Concentrations against Selected WHO Reference Values

Pollutant	n	Mean $\pm$ SD ($\mu\text{g}/\text{m}^3$ or mg/m^3)	Min–Max	WHO Reference Value	Number (%) of observations above WHO value	Mean / WHO ratio	Screening interpretation
PM ₁₀	9	30.00 $\pm$ 11.68	22–60	45 $\mu\text{g}/\text{m}^3$ (24 h)	1 (11 %)	0.67	Mean below reference; one episodic exceedance (L3)
PM _{2.5}	9	21.56 $\pm$ 3.75	17–28	15 $\mu\text{g}/\text{m}^3$ (24 h)	9 (100 %)	1.44	All observations above reference
SO ₂	9	0.00 $\pm$ 0.00	0–0	40 $\mu\text{g}/\text{m}^3$ (24 h)	0 (0 %)	0.00	Not detected; all values well below reference
CO	9	0.75 $\pm$ 0.98 mg/m^3	0–2.63	4 mg/m^3 (24 h)	0 (0 %)	0.19	All observations below reference
NO ₂	9	102.77 $\pm$ 32.78	47–159.80	25 $\mu\text{g}/\text{m}^3$ (24 h)	9 (100 %)	4.11	All observations above reference; highest values at L2
O ₃	9	93.64 $\pm$ 37.67	19.60–117.60	100 $\mu\text{g}/\text{m}^3$ (8 h)	5 (56 %)	0.94	Five individual readings above the numerical value of the 8-h guideline

Source: Calculated from Field Measurements (2026).

Summary of Key Findings

The monitoring results demonstrated spatial and temporal variation in ambient air quality across the three selected waste dumpsites. PM₁₀ concentrations ranged from 22 to 60 $\mu\text{g}/\text{m}^3$, while PM_{2.5} ranged from 17 to 28 $\mu\text{g}/\text{m}^3$. Location 3 recorded the highest mean PM₁₀ concentration, whereas PM_{2.5} concentrations were relatively similar across the three locations. Among the gaseous pollutants, NO₂ recorded the highest mean concentration at Location 2, while O₃ recorded its highest mean concentration at Location 3. SO₂ was not detected throughout the monitoring period, and CO concentrations were relatively low. The exposure assessment showed that respondents had substantial contact with the dumpsite environment. More than half of the respondents reported spending at least five hours per day in the vicinity, while approximately 59% reported exposure on at least five days per week. Nearly 56% of respondents lived or worked within 100 m of the dumpsites. Workers had a higher estimated time-activity factor than residents, indicating greater time-weighted exposure under the assumptions used in the exposure assessment.

The exposure-adjusted concentrations provide an estimate of potential inhalation exposure but should not be interpreted as individual absorbed doses or as direct evidence of disease. The screening assessment indicates that PM_{2.5} and NO₂ warrant particular attention because their

measured concentrations were consistently elevated relative to the stated WHO reference values. Further assessment incorporating individual-level exposure data, longer monitoring periods and health-outcome information would strengthen inference regarding the health effects associated with exposure to pollutants around the dumpsites.

4. Discussion

The study showed spatial and temporal variations in ambient air quality around the selected waste dumpsites. PM₁₀ concentrations ranged from 22–60 µg/m³, while PM_{2.5} ranged from 17–28 µg/m³. Although most PM₁₀ values were below the WHO 24-hour guideline, all PM_{2.5} measurements exceeded the WHO guideline of 15 µg/m³. The mean PM_{2.5} concentration was significantly higher than the reference value (21.56 ± 3.75 µg/m³; $t = 5.25$, $p < .001$), indicating persistent fine-particle pollution around the dumpsites. Similar concerns have been reported in Port Harcourt, where air-quality assessments around dumpsites identified particulate pollution as an important environmental concern (Alilonu et al., 2023; Uche, 2021). The higher PM₁₀ concentration recorded at L3 also suggests localized differences in waste activities, dispersion and site conditions.

NO₂ was another major pollutant of concern. Concentrations ranged from 47.00–159.80 µg/m³, with all observations exceeding the WHO 24-hour guideline of 25 µg/m³ and three exceeding the Nigerian reference value of 120 µg/m³. The overall mean concentration of 102.77 ± 32.78 µg/m³ was significantly above the WHO reference value ($t = 7.13$, $p < .001$). L2 recorded the highest mean NO₂ concentration, suggesting possible differences in emission sources and atmospheric dispersion among the locations. Previous investigations of dumpsite environments in Port Harcourt have similarly identified air-quality concerns associated with waste disposal activities (Chukwu-Okeah et al., 2021; Uche, 2021). O₃ concentrations varied considerably, with individual measurements reaching 117.60 µg/m³. However, the overall mean of 93.64 ± 37.67 µg/m³ was not significantly different from the adopted reference value ($t = -0.51$, $p = .313$). Thus, the elevated individual observations should be interpreted as episodic rather than evidence of sustained exceedance. In contrast, SO₂ was not detected during monitoring, while CO concentrations remained relatively low and were significantly below the reference value. These findings indicate that pollution around the study sites was more strongly characterized by particulate matter and NO₂ than by SO₂ or CO. The exposure assessment further demonstrated potential for repeated contact with polluted air. More than half of respondents were exposed for at least five hours daily, approximately 59% reported exposure on five or more days per week, and 55.4% lived or worked within 100 m of a dumpsite. Workers had higher estimated time-activity factors and exposure-adjusted concentrations than residents, indicating greater potential inhalation exposure among occupationally exposed groups. Similar concerns have been reported for populations living or working near waste facilities, where landfill-related air pollution has been associated with perceived and potential health risks (Gumede & Gumede, 2025). Evidence from Yu et al. (2018) also linked exposure to air pollution around a municipal solid-waste landfill with adverse respiratory and immune-related outcomes among children, although the present study did not directly assess health outcomes. Overall, the findings indicate that PM_{2.5} and NO₂ were the principal air-quality concerns around the selected dumpsites. The results support the need for continuous air-quality monitoring, improved waste-management practices and measures to reduce exposure among workers and nearby residents. However, the exposure-adjusted concentrations represent estimates of potential inhalation exposure rather than absorbed doses or direct evidence

of disease. Further studies incorporating longer-term monitoring, personal exposure assessment and health-outcome measurements would strengthen assessment of the associated health risks.

5. Conclusion

The study found considerable variation in ambient air quality around the selected waste dumpsites, with PM_{2.5} and NO₂ emerging as the major pollutants of concern. PM_{2.5} and NO₂ concentrations were significantly higher than the WHO reference values, while PM₁₀ showed occasional elevation. SO₂ was not detected and CO concentrations remained low.

Exposure patterns indicated substantial potential for repeated inhalation exposure, particularly among dumpsite workers and individuals living or working close to the dumpsites. More than half of respondents were exposed for at least five hours daily, while 55.4% were located within 100 m of a dumpsite. Workers had higher estimated exposure levels than residents.

Overall, the findings highlight the need for regular air-quality monitoring, improved solid-waste management and measures to reduce exposure around dumpsites. However, the exposure estimates represent potential inhalation exposure rather than absorbed doses or confirmed health effects. Longer-term monitoring incorporating personal exposure and health-outcome assessment is therefore recommended.

6. Recommendations

Regular monitoring of ambient air quality around waste dumpsites should be strengthened, with priority given to PM_{2.5} and NO₂. Improved waste-management practices and exposure-control measures should also be implemented to protect nearby residents and dumpsite workers.

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