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Health Risk Characterization and Spatial Variation of Air Pollutants from Agbarho and Igbudu Dumpsites, Delta State, Nigeria

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ABSTRACT

Uncontrolled municipal waste disposal remains a major source of localized air pollution in many developing cities where open dumping and periodic waste burning persist. This study assessed the spatial distribution, temporal variability, and health risks of air pollutants around the Agbarho and Igbudu dumpsites in Delta State, Nigeria. Ambient monitoring was conducted over eight weeks using a radial design at 0, 50, 100, 200, and 500 m from each dumpsite, with an upwind control location. Measured pollutants included $PM_{2.5}$, PM_{10}, CO, NO_2, SO_2, H_2S, CH_4, NH_3, and volatile organic compounds (VOCs). Pollutant concentrations were highest at source zones and declined significantly with increasing distance ($p < 0.05$), confirming strong proximity-driven exposure gradients. Peak $PM_{2.5}$ and PM_{10} levels exceeded World Health Organization guideline values several-fold, while NO_2, SO_2, H_2S, and VOCs also surpassed recommended limits at multiple sampling points. Agbarho generally recorded higher pollutant loads than Igbudu, indicating stronger emission intensity. Morning periods showed elevated particulate concentrations, whereas afternoon periods were characterized by higher gaseous pollutants, reflecting atmospheric mixing and temperature-enhanced volatilization. Human health risk assessment revealed hazard quotient values above unity for $PM_{2.5}$, PM_{10}, NO_2, and VOCs, while the cumulative hazard index (6.78) indicated unacceptable combined non-carcinogenic risk. Estimated carcinogenic risks for selected pollutants exceeded accepted benchmark levels. The findings demonstrate that unmanaged dumpsites function as significant point sources of hazardous air pollution and pose measurable risks to nearby residents, traders, and waste handlers. Immediate transition to engineered waste management systems, prohibition of open burning, and enforcement of protective buffer distances are strongly recommended.

1. INTRODUCTION

Rapid urbanization in sub-Saharan Africa has intensified municipal solid waste generation, while disposal practices remain largely

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dependent on open dumping and uncontrolled burning. In Nigeria, particularly within the Niger Delta, this is compounded by high population density, commercial activity, and limited waste management infrastructure. In Delta State, active dumpsites such as those located at Agbarho and Igbudu Market operate within densely populated environments, functioning as continuous emission sources that release a mixture of particulate and gaseous pollutants through combustion, biodegradation, volatilization, and mechanical disturbance (Adelekan *et al.*, 2022; Eze *et al.*, 2023).

These processes generate pollutants including $PM_{2.5}$, PM_{10}, CO, NO_2, SO_2, CH_4, NH_3, H_2S, and volatile organic compounds, arising from overlapping mechanisms. Combustion activities produce fine particles and carbonaceous gases, while anaerobic decomposition releases reduced gases, with subsequent atmospheric reactions further modifying pollutant composition under the humid tropical conditions of the Niger Delta (Zhang *et al.*, 2021; Okolie and Nwankwo, 2024). In the near-field environment, pollutant concentrations decline with distance from the source, but this attenuation is typically non-linear, governed by wind dynamics, atmospheric stability, and emission intensity, often reflecting exponential dispersion behaviour (Seinfeld and Pandis, 2016; Chen *et al.*, 2022).

Despite increasing attention to urban air pollution, detailed assessments of dumpsite-derived emissions in West Africa remain limited, particularly studies that integrate spatial distribution with quantitative health risk evaluation. Existing work in Nigeria has largely focused on concentration levels, with limited linkage to exposure gradients and risk outcomes (Odeyemi *et al.*, 2021; Nduka *et al.*, 2023). This gap is significant given the close proximity of residential and commercial activities to dumpsites and the potential for sustained exposure.

Exposure to these pollutants has been associated with respiratory and cardiovascular effects linked to particulate matter, impaired oxygen transport from CO exposure, and irritation and systemic effects from gaseous pollutants, with severity largely dependent on proximity and duration of exposure (World Health Organization, 2021; USEPA, 2023).

This study therefore evaluates the spatial distribution of particulate and gaseous pollutants around the Agbarho and Igbudu dumpsites in Delta State, Nigeria, and examines their attenuation patterns and associated health risks using statistical and risk assessment models. It is hypothesized that pollutant concentrations decrease non-linearly with distance due to atmospheric dispersion processes, resulting in significantly elevated exposure and health risk within proximal zones (≤200 m) compared to more distant locations.

2. MATERIALS AND METHODS

2.1 Study Area

The study was conducted at two active municipal dumpsites located within the Warri metropolitan axis of Delta State, southern Nigeria. The Agbarho dumpsite is located at latitude 5.587870° N and longitude

5.857353° E, while the Igbudu Market dumpsite is situated at latitude 5.519496° N and longitude 5.760239° E. Both sites are located within the Niger Delta region and are characterized by intense anthropogenic activities, mixed residential-commercial land use, heavy vehicular movement, and continuous municipal waste deposition.

The dumpsites receive heterogeneous waste streams comprising food residues, plastics, paper, textiles, metals, glass, and other combustible domestic materials. Open dumping, waste compaction, scavenging activities, and periodic burning are common at both locations, creating conditions favorable for sustained atmospheric pollutant emissions.

The area experiences a humid tropical climate characterized by high annual rainfall exceeding 2,000 mm, elevated relative humidity, and mean ambient temperatures ranging from 26–32°C throughout most of the year. Prevailing meteorological conditions, particularly temperature, humidity, and wind dynamics, may significantly influence pollutant generation, transformation, and atmospheric dispersion within the study environment (NIMET, 2023).

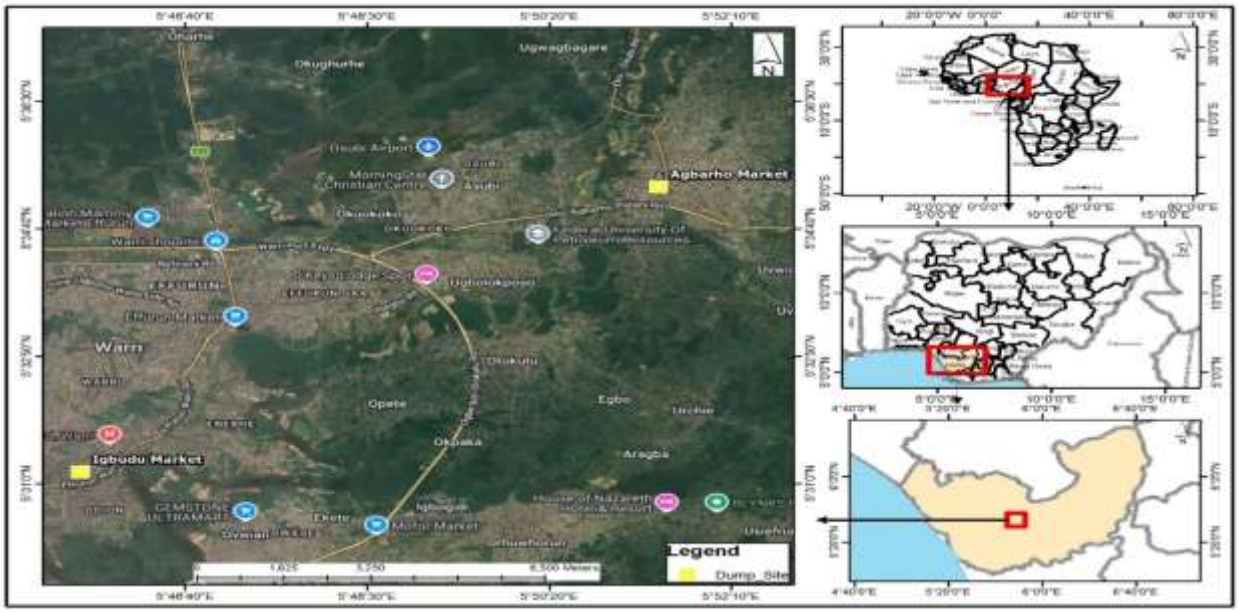


Figure 1: Map of the study area

2.2 Study Design and Sampling Framework

A comparative field monitoring design was adopted to assess ambient air quality around both dumpsites. Sampling points were established radially from the approximate center of each dumpsite at distances of 0 m (source zone), 50 m, 100 m, 200 m, and 500 m. An additional control location was selected approximately 1 km upwind from each dumpsite to represent background air quality outside the direct influence zone.

Measurements were collected in triplicate at each location during morning (07:00–10:00 h) and afternoon (13:00–16:00 h) periods over an eight-week monitoring campaign. Sampling height was standardized at 1.5 m above ground level to approximate the human breathing zone. The total number of observations generated across sites, distances, replicates, and time periods was 144.

2.3 Air Quality Monitoring

Measured pollutants comprised particulate matter with aerodynamic diameters ≤2.5 µm ($PM_{2.5}$) and ≤10 µm (PM_{10}), carbon monoxide (CO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), hydrogen sulfide (H_2S), methane (CH_4), ammonia (NH_3), and total volatile organic compounds (VOCs).

Particulate matter concentrations were measured using a portable laser photometric aerosol monitor (TSI DustTrak II, Model 8530). Gaseous pollutants were measured using a calibrated multi-gas analyzer (MultiRAE Pro, RAE Systems) equipped with electrochemical, photoionization, and infrared sensors as appropriate for individual analytes.

All instruments were operated according to manufacturer guidelines under stable field conditions. Readings were allowed to stabilize before recording, and measurements were taken during periods free from rainfall.

2.4 Quality Assurance and Quality Control

To ensure data reliability, instruments were calibrated before commencement of field monitoring and routinely checked throughout the sampling campaign. Zero checks and sensor response verification were conducted daily. Duplicate and repeated measurements were performed periodically, and precision was considered acceptable at relative standard deviation below 5%.

Data were screened for transcription errors, instrument anomalies, and extreme outliers. Any abnormal values were cross-checked with field notes and retained only where supported by valid sampling conditions.

2.5 Meteorological Parameters

Ambient temperature and relative humidity were recorded in situ during each monitoring session using handheld field sensors. Wind speed and prevailing direction were obtained from the nearest meteorological station and supplemented by field observations. During the study period, wind speeds generally ranged from 1.8 to 3.5 m s^{-1}, with predominantly south-westerly flow.

2.6 Data Analysis

Data were summarized as mean ± standard deviation. Normality and homogeneity of variance were evaluated using Shapiro-Wilk and Levene's tests, respectively. One-way analysis of variance (ANOVA) was used to test differences in pollutant concentrations across sampling distances, followed by Tukey post hoc comparisons where significant differences existed.

Independent samples t-test was used to compare mean pollutant concentrations between Agbarho and Igbudu dumpsites. Pearson correlation analysis was applied to examine interrelationships among pollutants.

Regression modelling was used to evaluate pollutant attenuation with increasing distance from source zones. Statistical significance was accepted at $p < 0.05$. Analyses were conducted using SPSS version 26.0.

2.7 Human Health Risk Assessment

Potential inhalation health risks were estimated using standard United States Environmental Protection Agency risk assessment procedures. Non-carcinogenic risk for individual pollutants was expressed as Hazard Quotient (HQ):

$$HQ = \frac{EC}{RfC}$$

where EC is exposure concentration and RfC is the reference concentration.

The cumulative non-carcinogenic risk from multiple pollutants was expressed as Hazard Index (HI):

$$HI = \sum HQ$$

Carcinogenic risk for pollutants with available inhalation unit risk values was estimated as:

$$LCR = EC \times IUR$$

where LCR is lifetime cancer risk and IUR is inhalation unit risk.

Risk values exceeding unity for HQ or HI were interpreted as potential concern for non-carcinogenic effects, while lifetime cancer risks above conventional benchmark ranges (10^{-6} to 10^{-4}) were considered elevated.

3. RESULTS AND DISCUSSION

3.1 Spatial Distribution of Pollutants Across Distance in Agbarho and Igbudu dumpsites

The spatial distribution data reveals a strong near-source emission profile, with pollutant concentrations declining sharply with distance from both dumpsites. At 0 m, $PM_{2.5}$ and PM_{10} peak at 228.2 µg/m³ and 398.7 µg/m³ at Agbarho, slightly exceeding Igbudu, indicating a more intense emission load. Although concentrations reduce by over 50% at 500 m, they remain above control levels, confirming incomplete near-field attenuation typical of ground-level sources governed by turbulent diffusion, advection, and settling (Holmes and Morawska, 2006).

These particulate levels are markedly higher than reported urban near-dumpsite values in Asia, where $PM_{2.5}$ rarely exceeds 150 µg/m³ within 100 m (Kumar *et al.*, 2023; Zhang *et al.*, 2022) but align with Nigerian studies linking open burning and mechanical waste disturbance to elevated particulate burdens (Efe, 2020; Hassan *et al.*, 2022). The persistence of elevated concentrations up to 500 m suggests sustained emission activity rather than episodic release.

Gaseous pollutants exhibit a similar gradient but with process-dependent variability. CO and NO_2 decline rapidly from near-source maxima, reflecting combustion dominance, whereas CH_4 and NH_3 decrease more gradually, consistent with continuous anaerobic decomposition within waste matrices (Kaza *et al.*, 2018). Agbarho consistently records higher values across

most parameters, suggesting greater waste load or more frequent burning.

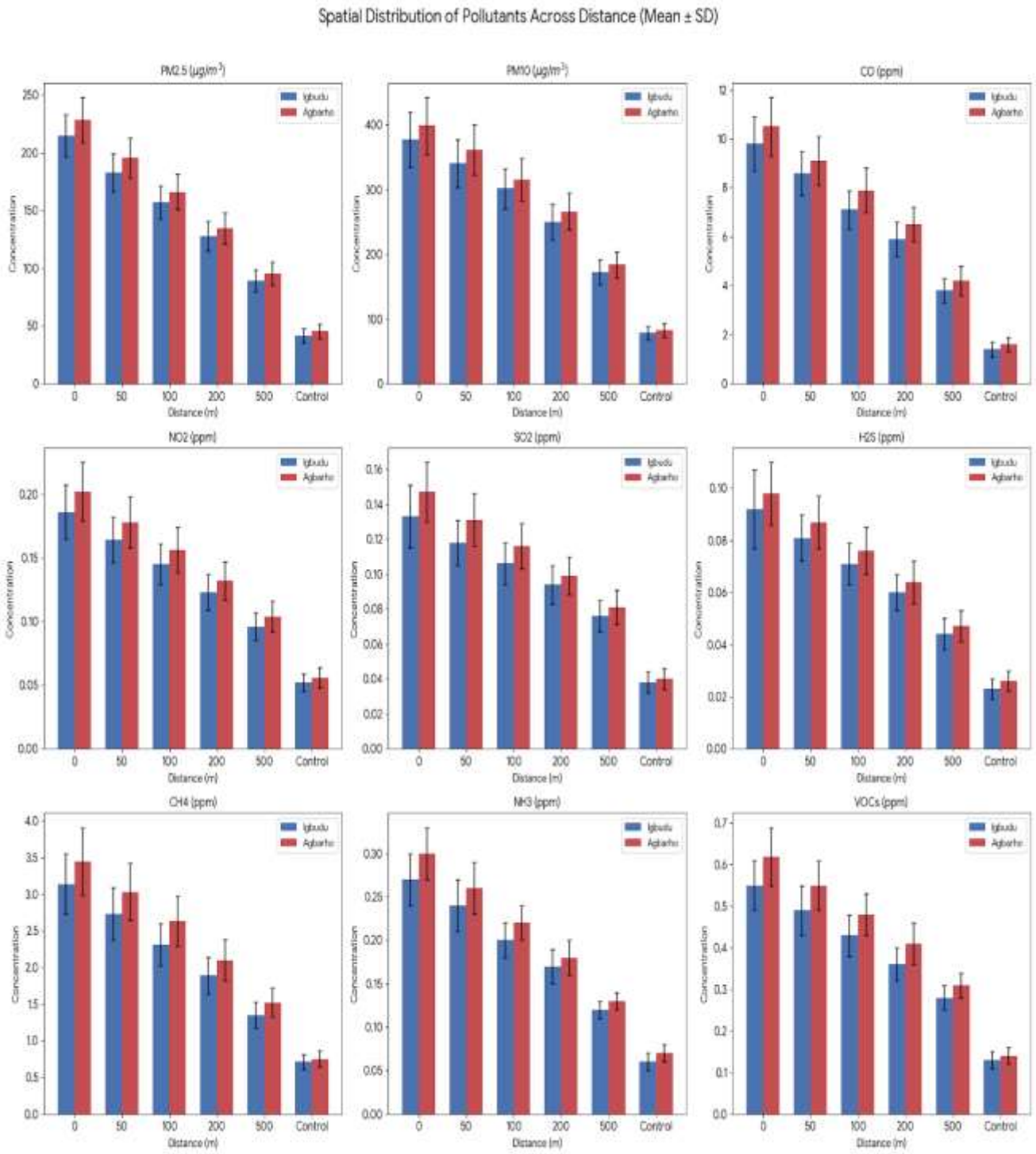


Figure 2: Spatial Distribution of Pollutants Across Distance (Mean ± SD)

Spatially, the first 200 m constitutes a dominant exposure zone with significantly elevated pollutant levels, particularly for fine particulates and reactive gases. Beyond this range, dilution improves but background conditions are only approached near the control site, confirming a clear distance-dependent exposure gradient consistent with near-field dispersion behaviour (Seinfeld and Pandis, 2016).

Table 1: Diurnal Variation of Pollutants

Pollutant	Morning Mean	Afternoon Mean	% Change
$PM_{2.5}$	176.4	158.2	−10.3%
PM_{10}	317.6	291.8	−8.1%
CO	7.7	8.3	+7.8%
NO_2	0.151	0.164	+8.6%
SO_2	0.111	0.119	+7.2%
H_2S	0.073	0.079	+8.2%
CH_4	2.43	2.59	+6.6%
NH_3	0.19	0.21	+10.5%
VOCs	0.42	0.47	+11.9%

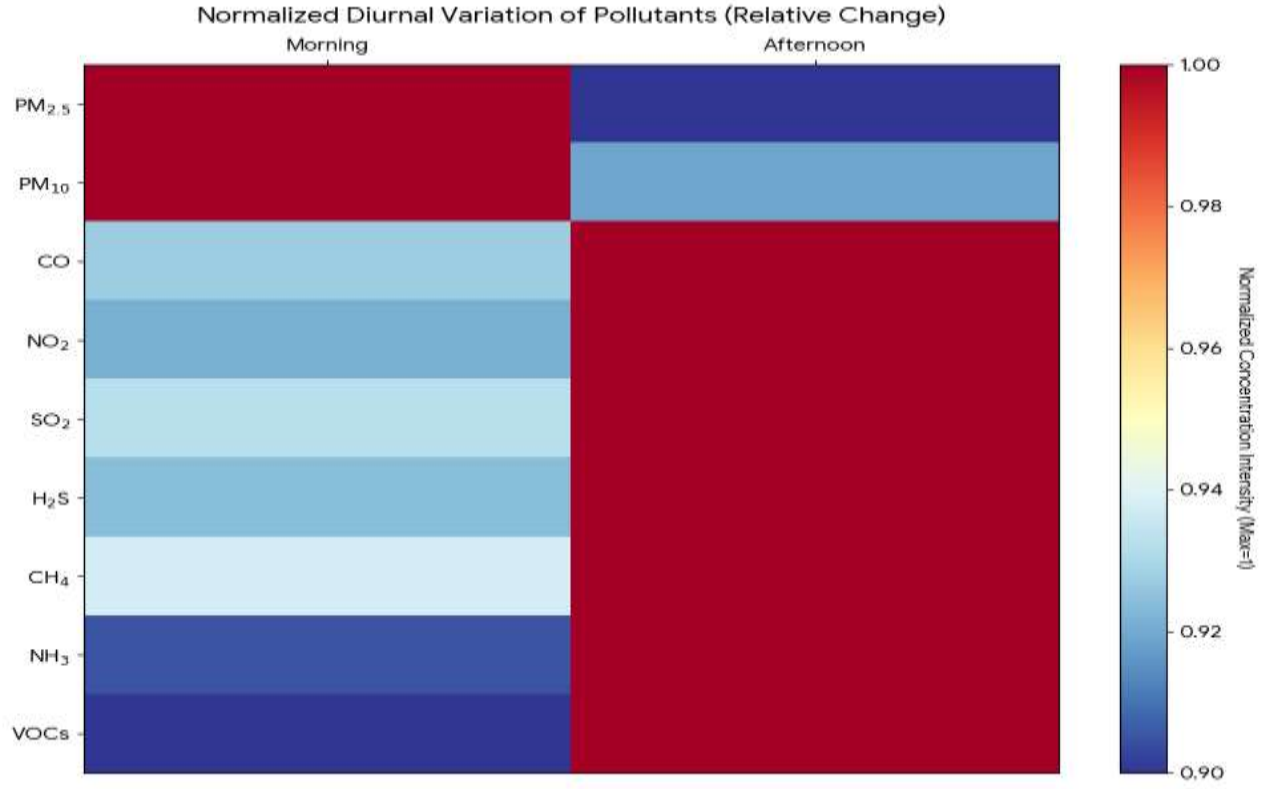


Figure 3: Normalized Diurnal Variation of Pollutants

The diurnal pattern reveals a clear divergence between particulate and gaseous pollutants, reflecting the interplay between atmospheric stability and emission dynamics. Particulate

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matter exhibits a measurable decline from morning to afternoon, with $PM_{2.5}$ decreasing by 10.3% and PM_{10} by 8.1%. This reduction is consistent with the breakdown of early morning atmospheric stability, where temperature inversion layers initially trap particulates near the surface. As solar radiation intensifies, convective mixing enhances vertical dispersion, reducing near-ground particulate concentrations. Comparable reductions have been reported in urban and peri-urban environments where boundary layer expansion governs particulate dilution (Seinfeld and Pandis, 2016; Zhang *et al.*, 2022).

In contrast, all gaseous pollutants show systematic increases in the afternoon, with VOCs (+11.9%), NH_3 (+10.5%), and NO_2 (+8.6%) exhibiting the most pronounced changes. This pattern reflects both enhanced emission activity and atmospheric transformation processes. Elevated afternoon temperatures accelerate volatilization of organic compounds and intensify microbial decomposition, thereby increasing emissions of NH_3, CH_4, and H_2S. Simultaneously, photochemical activity promotes secondary formation of reactive gases such as NO_2 and contributes to the accumulation of VOCs through oxidation pathways. Similar diurnal amplification of gaseous pollutants has been documented in waste handling environments and landfill-adjacent zones (Kumar *et al.*, 2023; Gao *et al.*, 2021).

The opposing trends between particulates and gases underscore the dual control exerted by meteorology and emission processes. While particulate levels are largely governed by atmospheric dispersion conditions, gaseous pollutants remain strongly influenced by temperature-dependent emission rates and chemical transformation kinetics. This temporal variability has direct exposure implications, suggesting that inhalation risk shifts from particulate-dominated exposure in the morning to gas-dominated exposure in the afternoon. Such temporal partitioning of exposure is rarely captured in routine monitoring but is critical for accurate risk characterization in mixed-emission environments like open dumpsites as show in Table 2.

Table 2: Mean Values of pollutants in Agbarho and Igbudu dumpsites Compared to Regulatory Standards

Pollutant	WHO Limit	NESREA Limit	Igbudu Mean	Agbarho Mean	Exceedance
$PM_{2.5}$	25	50	135.4	144.8	442–579%
PM_{10}	50	150	270.0	284.9	80–440%
NO_2	0.106	0.1	0.141	0.154	41–54%
SO_2	0.08	0.1	0.102	0.114	27–42%
H_2S	0.05	0.05	0.072	0.078	44–56%
VOCs	0.2	0.3	0.39	0.43	95–115%

Particulate matter dominates the pollution burden at both sites, with $PM_{2.5}$ exceeding guideline limits by up to 579% and PM_{10} by 440%, far above typical urban background

levels and consistent with heavily combustion-influenced environments. Similar magnitudes have been reported near open dumpsites in South Asia and sub-Saharan Africa, where burning and waste disturbance sustain high particulate loads (Kumar *et al.*, 2023; Efe, 2020). Agbarho records slightly higher values across most pollutants, suggesting stronger emission activity linked to waste composition or burning intensity.

Gaseous pollutants also exceed permissible limits but to varying degrees: NO_2 by 41–54%, SO_2 by 27–42%, H_2S by up to 56%, and VOCs by as much as 115%. These patterns indicate overlapping combustion, sulfur-rich decomposition, and volatilization processes within mixed waste streams (Chen *et al.*, 2022). Comparable VOC elevations have been associated with plastics, solvents, and organic residues in Table 3.

Exceedances span particulates, reactive gases, and reduced sulfur compounds, indicating a chemically complex and continuously emitting system rather than episodic pollution. This persistent multi-pollutant exposure increases the likelihood of synergistic toxicity effects, particularly between particulate matter and gaseous co-pollutants (Seinfeld and Pandis, 2016; Lelieveld *et al.*, 2019). Collectively, both sites fall within a high-risk category where regulatory thresholds are consistently breached, underscoring the need for targeted emission control and spatial management interventions.

The risk characterization shows a cumulative hazard index of 6.78, indicating substantial combined exposure across pollutants. $PM_{2.5}$ (1.82), PM_{10} (1.33), NO_2 (1.06), and VOCs (1.48) exceed unity, identifying them as the primary contributors to non-carcinogenic risk under continuous exposure. CO (0.41), SO_2 (0.91), and H_2S (0.77) remain below unity but still contribute to the overall burden.

Particulate matter is the dominant risk driver, consistent with its high ambient levels and well-established respiratory toxicity (Burnett *et al.*, 2021; Lelieveld *et al.*, 2019). NO_2 further reflects combustion-related exposure with potential for airway inflammation. VOCs are particularly critical, combining a hazard quotient of 1.48 with the highest lifetime cancer risk (3.5×10^{-4}), indicating sustained exposure to toxic organic mixtures. $PM_{2.5}$ (2.1×10^{-4}) and NO_2 (1.7×10^{-4}) also exceed acceptable cancer risk thresholds, reinforcing long-term carcinogenic potential (Chen *et al.*, 2022; Kumar *et al.*, 2023).

Although SO_2 and H_2S remain below unity, they confirm ongoing combustion and anaerobic decomposition, contributing to a multi-source exposure mixture typical of open dumpsites (Kaza *et al.*, 2018). The elevated hazard index and cancer risk values indicate toxicologically meaningful exposure, particularly in near-field zones, supporting the need for emission control and spatial exposure mitigation.

The heatmaps for Agbarho and Igbudu clearly show a consistent near-source dominance of all pollutants, with maximum normalized intensity (≈1.0) at 0 m across $PM_{2.5}$, PM_{10}, CO, NO_2, SO_2, H_2S, CH_4, NH_3, and VOCs. This confirms that both dumpsites function as integrated point sources with

simultaneous emission of particulate and gaseous pollutants, consistent with the source characterization and high concentrations reported in Table 1.

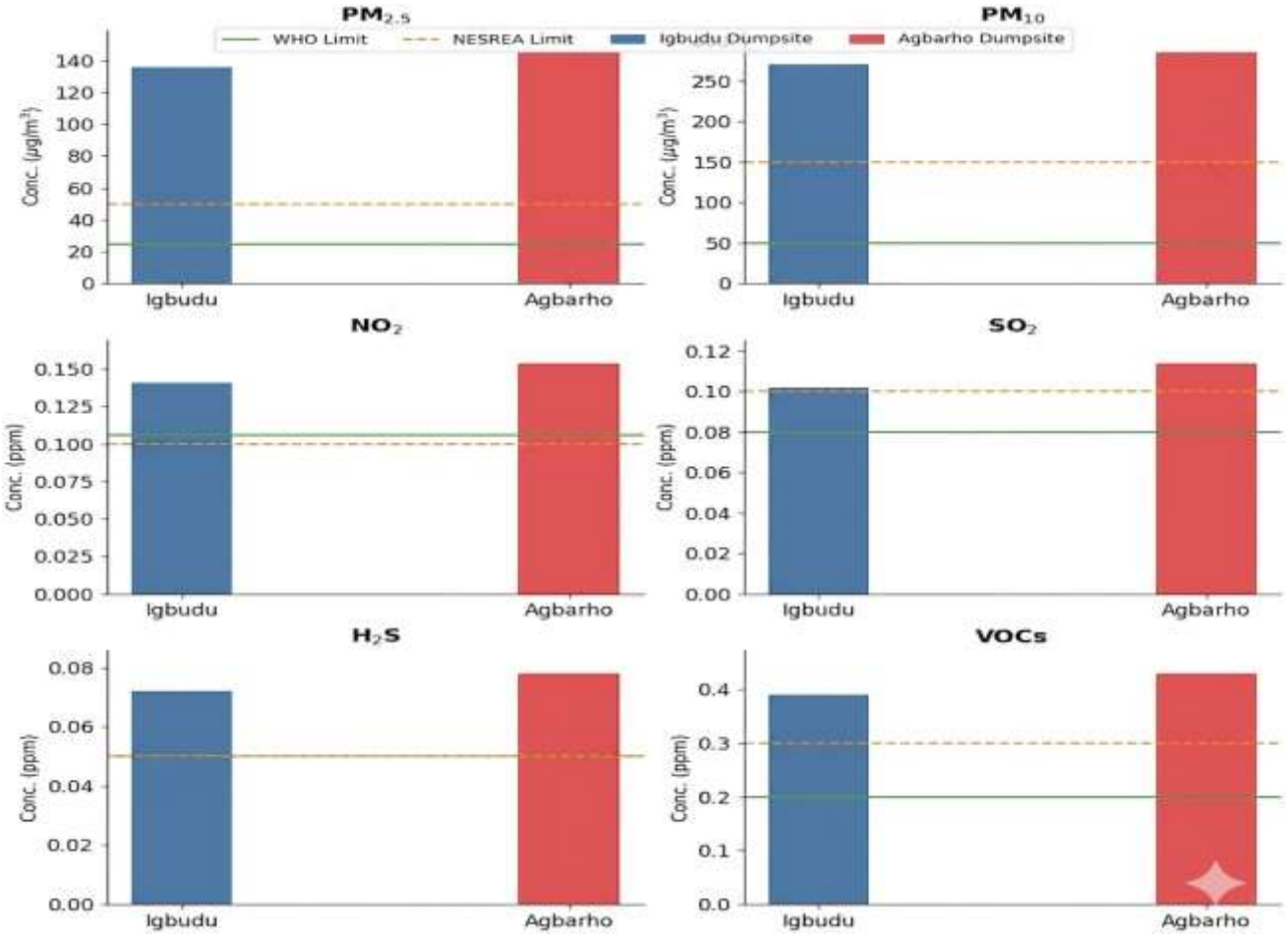


Figure 4: Mean Values of pollutants in Agbarho and Igbudu dumpsites Compared to Regulatory Standards

Table 3: Human Health Risk Characterization Based on Measured Exposure

Pollutant	HQ (Non-cancer)	LCR (Cancer Risk)	Risk Category
$PM_{2.5}$	1.82	2.1×10^{-4}	Moderate
PM_{10}	1.33	—	Moderate
CO	0.41	—	Low
NO_2	1.06	1.7×10^{-4}	Moderate
SO_2	0.91	—	Moderate
H_2S	0.77	—	Moderate
VOCs	1.48	3.5×10^{-4}	High (chronic)

Cumulative Non-carcinogenic Risk (HI) = 6.78

3.2 Comparative heatmaps of Agbarho and Igbudu dumpsites

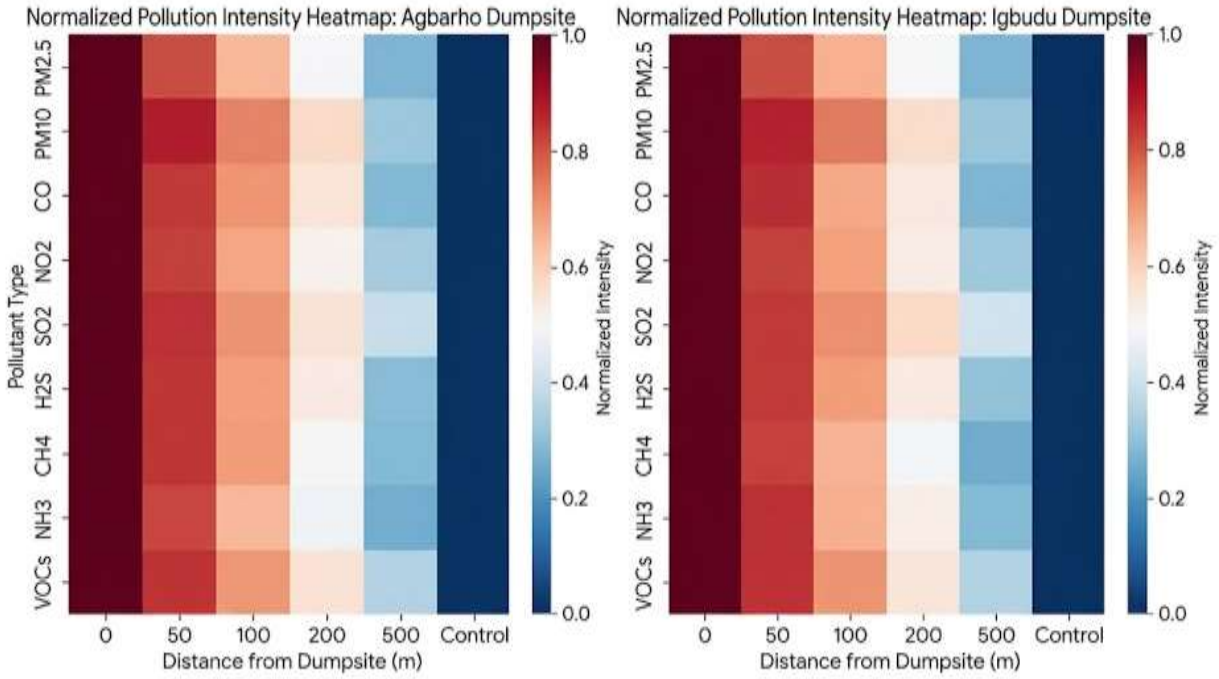


Figure 5: Normalized pollution Intensity Heatmaps of Agbarho and Igbudu dumpsites

A steep decline in intensity is observed from 50 m to 200 m, indicating rapid near-field dispersion driven by atmospheric dilution, turbulent mixing, and particulate settling. This directly supports the regression results showing a strong inverse relationship between concentration and distance, and aligns with the ANOVA findings of significant spatial variation ($p < 0.05$).

Beyond 200 m, attenuation slows and a residual pollution signal persists at 500 m, confirming incomplete dispersion and continued exposure influence within the mid-field zone. The control zone approaches baseline conditions, validating the spatial gradient assumption used in the study design.

Comparatively, Agbarho shows slightly higher normalized intensities than Igbudu across most pollutants at equivalent distances, indicating a stronger emission load or more active waste processing dynamics. Igbudu displays marginally faster attenuation for select gases such as CH_4 and NH_3, suggesting possible differences in waste composition or anaerobic activity.

The heatmaps visually reinforce the study's core findings, showing pronounced near-source emission dominance, a non-linear spatial decay pattern, and continued pollutant persistence beyond 200 m. These spatial signatures substantiate the delineated high-

risk exposure zone and are consistent with the health risk estimates derived in the study.

4. CONCLUSION

Agbarho and Igbudu dumpsites function as dominant point sources of atmospheric pollution, generating steep spatial concentration gradients that decrease with distance yet remain above background levels up to 500 m. Exposure is most severe within 0–200 m, with statistically significant spatial variation ($p < 0.05$) confirming a consistent inverse relationship between pollutant load and distance, alongside diurnal shifts from particulate dominance in the morning to elevated gaseous emissions in the afternoon. Health risk assessment indicates a cumulative hazard index of 6.78, with multiple pollutants exceeding acceptable exposure thresholds and carcinogenic risks above regulatory limits, confirming both acute and chronic health implications.

The study revealed that proximity to dumpsites is the principal determinant of exposure and risk, necessitating immediate cessation of open dumping and burning, implementation of engineered sanitary landfill systems, enforcement of 200–500 m buffer zones, and establishment of continuous air quality and public health monitoring frameworks.

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