



AIR QUALITY AND MICROBIAL CONTAMINATION AROUND CEMENT DEPOTS IN PORT HARCOURT, NIGERIA: AN INTEGRATED ASSESSMENT OF PARTICULATE, CHEMICAL, AND BIOAEROSOL POLLUTION

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Abstract

Air pollution from cement operations is a growing health concern in rapidly industrialising cities. While particulate and gaseous pollutants are routinely assessed, microbial bioaerosols remain overlooked despite respiratory risks. This study integrated chemical, physical, and microbial parameters with Air Quality Index (AQI) evaluation around cement depots in Port Harcourt, Nigeria. PM_{2.5}, PM₁₀, NO_x, SO_x, and CO were measured at four cement depots (Lafarge Rukpokwu, Lafarge Iriebe, Dangote Eleme, Dangote Elioze) and a control site using a Temtop M2000 detector. Microbes were sampled by passive sedimentation and identified morphologically and biochemically. AQI values were calculated using U.S. EPA breakpoints, with clustering and ranking analyses applied to compare sites. PM_{2.5} and PM₁₀ exceeded WHO limits at all depots, peaking at Eleme (55.0 µg/m³; 112.0 µg/m³). NO_x reached 102.1 µg/m³ at Eleme, while SO_x peaked at 209.5 µg/m³ at Elioze, over five times the guideline. CO exceeded limits only at Eleme (4.8 mg/m³). Microbial loads were highest at Rukpokwu (233 CFU/m³ bacteria; 35 CFU/m³ fungi). Isolates included *Enterobacter*, *Serratia*, *Bacillus*, *Acinetobacter*, *Aspergillus*, and *Fusarium*, some of which may be opportunistic pathogens. AQI ranged from 101.4 (Iriebe) to 261.9 (Elioze), while the control (33.3) remained “Good.” Clustering grouped Eleme and Elioze by SO_x-driven pollution, and Rukpokwu and Iriebe by particulates and NO_x. Ranking confirmed Elioze and Eleme as the most polluted sites. Cement depots in Port Harcourt degrade air quality, with PM, NO_x, and SO_x consistently exceeding WHO limits and AQI above 240 at Eleme and Elioze (“Very Unhealthy”). Combined with high microbial contamination, these findings highlight the urgent need for stricter emission controls and integrated monitoring that includes bioaerosols to protect public health.

Keywords:

Cement depots; Air Quality Index (AQI); Particulate matter (PM_{2.5}, PM₁₀); Sulphur oxides (SO_x); Microbial bioaerosols.

1. INTRODUCTION

Air quality is a major environmental and public health concern in urban and industrial regions of low- and middle-income countries where regulatory enforcement is weak and industrial growth is rapid (Abera et al., 2021; Mannucci & Franchini, 2017; Newell et al., 2018; Newell et al., 2017). The World Health Organisation (WHO, 2021a) estimates that exposure to air pollution causes approximately 7 million premature deaths annually, due to respiratory and cardiovascular conditions. Ambient air pollution is primarily driven by particulate matter (PM_{2.5} and PM₁₀), nitrogen oxides (NO_x), sulphur oxides (SO_x), and carbon monoxide (CO), which contribute to smog formation, impaired visibility, and respiratory morbidity (Jyethi, 2016; Khajeamiri et al., 2021; Pompilio & Di Bonaventura, 2020). Alongside these chemical pollutants, bioaerosols of bacterial and fungal origin are increasingly recognised as integral components of air pollution, with implications for respiratory infections, allergies, and antimicrobial resistance (Noda et al., 2022; Ziaei et al., 2025).

Cement production and distribution contribute to urban air pollution (Bărbulescu & Hosen, 2025; Li et al., 2020; Venkata & Reddy, 2023). Globally, between 1928 and 2018, the cement industry was estimated to have accounted for around 7% of the total anthropogenic CO₂ emissions, while also releasing significant levels of dust and gaseous pollutants (Andrew, 2019; Panagoda et al., 2023). In Nigeria, cement production has expanded rapidly to meet construction demand, but environmental monitoring around depots and distribution hubs remains limited (Etim et al., 2021; Evuti et al., 2023; Roche, 2023).

Several studies in Nigeria have highlighted the worsening air quality around cement production and storage facilities. For instance, monitoring around a cement plant in Ewekoro, Ogun State, recorded elevated concentrations of PM_{2.5} and PM₁₀, exceeding WHO safety thresholds (Awos et al., 2024). Similarly, an air quality assessment of the Ibese cement complex reported elevated levels of SO₂ and NO₂ emissions (Adeniran et al., 2019). Likewise, in South-South Nigeria, long-term monitoring around Lafarge Holcim cement operations revealed sustained increases in PM₁₀ (up to 346 µg/m³), SO₂, and CO, with air quality index (AQI) frequently falling into the “hazardous” and “very unhealthy” categories (Nwogu et al., 2025). Moreover, seasonal variations at Dangote Cement in Obajana further demonstrated AQI values for PM_{2.5} exceeding 300 during the dry season, far above WHO guidelines and indicative of severe respiratory risk (Uzor et al., 2025). These findings raise concerns about occupational and residential exposures in nearby communities, yet few studies have simultaneously assessed both chemical pollutants and microbial air quality in these contexts.

The microbial dimension of air pollution is increasingly recognised as an overlooked but critical concern. Bioaerosols associated with cement dust often carry pathogenic microorganisms originating from soil particles, organic debris, and industrial emissions (Sowunmi et al., 2020). Several studies have reported the presence of bacteria and fungi in cement-associated environments (Gutarowska et al., 2018; Sowunmi et al., 2020). Some of these organisms may be opportunistic pathogens linked to respiratory allergies, mycoses, and hospital-acquired infections, particularly in immunocompromised populations (Debnath et al., 2022). Despite these risks, microbial air quality is rarely included in routine surveillance in low- and middle-income countries, resulting in a significant underestimation of the total health burden associated with cement-related air pollution.

Port Harcourt is one of Nigeria’s major industrial hubs and home to multiple cement depots operated by leading producers, such as Lafarge and Dangote. Although several studies on urban air quality in Port Harcourt have documented the occurrence of soot pollution linked to petroleum refining and industrial activity (Akinfolarin et al., 2018; Oriasi et al., 2022; Yakubu, 2018), systematic investigations of cement-related air pollution remain limited. In particular, few studies have simultaneously assessed physical, chemical, and microbial parameters, alongside air quality index (AQI) across multiple cement depots and a non-depot control site.

This study, therefore, evaluates the impact of cement depot operations on air quality in Port Harcourt by integrating chemical, physical, and microbial measurements with AQI evaluation. Specifically, it quantified particulate matter and gaseous pollutants, characterised airborne microbial loads, and compared results with WHO standards and a non-depot control site. By addressing the combined burden of depot emissions, the study highlights important implications for occupational safety, community health, and environmental regulation in rapidly industrialising urban centres.

2. MATERIALS AND METHODS

2.1 Study Area

This investigation was conducted in Port Harcourt, Rivers State, Nigeria (Figure 1). Four cement depots were selected for monitoring: Lafarge Rukpokwu ($4^{\circ}53'36.24''\text{N}$, $6^{\circ}57'46.50''\text{E}$), Lafarge Iriebe ($4^{\circ}52'2.98''\text{N}$, $7^{\circ}6'18.18''\text{E}$), Dangote Eleme ($4^{\circ}50'55.78''\text{N}$, $7^{\circ}4'21.14''\text{E}$), and Dangote Elioizu ($4^{\circ}52'57.63''\text{N}$, $7^{\circ}0'43.13''\text{E}$). A non-depot site served as the control. These depots were selected due to their high traffic and industrial activities, which significantly contribute to air pollution.

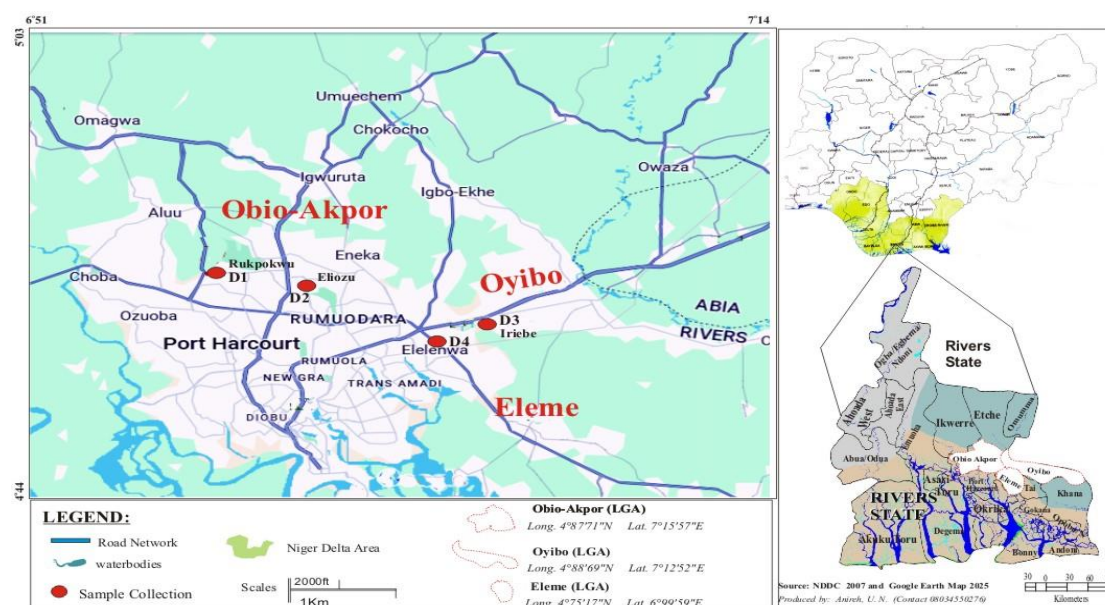


Figure 1: A map showing the study area.

2.2 Measurement of Airborne Physicochemical Pollutants

Ambient concentrations of $\text{PM}_{2.5}$, PM_{10} , NO_x , SO_x , NH_3 , H_2S , and CO were measured using a Temtop M2000 air quality detector (Elitech Technology, USA). Sampling was conducted according to manufacturer protocols and previous studies (Awos et al., 2024). Measurements were taken at several points within each depot and the control site, between 10:00 a.m. and 2:00 p.m., to capture peak activity. $\text{PM}_{2.5}$ and PM_{10} levels were determined by the device's laser scattering system (Chen et al., 2018), while gaseous pollutants were detected with integrated electrochemical sensors. Data were recorded in micrograms per cubic metre ($\mu\text{g}/\text{m}^3$).

2.3 Meteorological and Environmental Parameter Monitoring

Meteorological variables were monitored together with pollutants to understand dispersion patterns. Wind speed and direction were obtained from the anemometer and vane sensors of the Temtop M2000, as described by Rais and Kamil (2022). Temperature and relative humidity were measured using the device's thermo-hygrometer at 1.5 m above ground level. Noise levels

were assessed at ear height using a Benetech GM1356 (Benetech, China) sound level meter, calibrated before use, set to A-weighting and fast response mode (Azhar & Shahid, 2024). Pollutant values were later compared with the WHO (2021b) limits.

2.4 Evaluation of Airborne Microbes

2.4.1 Enumeration of Airborne Bacteria and Fungi

Airborne microbes were sampled using passive sedimentation, following Haas et al. (2017) and Viani et al. (2020). Sterile 90 mm Petri dishes containing nutrient agar (NA) with 1% glycerol were used for bacterial isolation, while potato dextrose agar (PDA) with 0.01% chloramphenicol was used for fungi. Plates were exposed at each site for 30 minutes at a height of 1.5 m, representing the breathing zone. Negative controls were maintained to verify the absence of contamination. Following exposure, plates were sealed, transported aseptically, and incubated (NA: 37 °C for 24 - 48 h; PDA: 25 - 28 °C for 5 - 7 days). Colony counts were expressed as CFU/m³ using the Omeliansky formula:

$$\text{CFU/m}^3 = (a \times 10^4) / (p \times t) \quad (\text{Eq. 1})$$

Where: a = number of colonies per plate, p = surface area of the Petri dish in cm² (63.6 cm² for 90 mm dishes), and t = exposure time in minutes (30 min).

2.4.2 Isolation and Identification of Airborne Bacteria

Distinct bacterial colonies from the exposed Nutrient Agar (NA) plates were purified by streaking and incubated at 37 °C for 24h as described by Ogodo et al. (2022). Isolates were characterised morphologically based on colony colour, texture, shape, elevation, edge, opacity, and size, following Da Silva et al. (2018). Biochemical identification employed standard tests, including Gram stain, catalase, citrate, carbohydrate fermentation, indole, motility, starch hydrolysis, methyl red, Voges-Proskauer, and triple sugar iron agar reactions as described by Da Silva et al. (2018) and Holt et al. (1994). Tests were performed with HiMedia (India) unless otherwise stated.

2.4.3 Isolation and Identification of Airborne Fungi

Fungal colonies from PDA plates were subcultured to obtain pure isolates, incubated at 25 °C for 5 – 7 days, and identified using macroscopic features (colour, texture, elevation, pigmentation, growth rate) and microscopic morphology in lactophenol cotton blue mounts. Microscopic observations included hyphal branching, septation, and conidial structures, examined at ×400 magnification (AmScope B120C, USA). Identification was made using Barnett and Hunter (1998) and Larone (2011).

2.5 Determination of Air Quality Index (AQI) of the Cement Depots

The AQI for each air pollutant was calculated using U.S. Environmental Protection Agency (EPA, 2018) breakpoints in Equation 2.

$$\text{AQI} = [(I_{hi} - I_{lo}) / (C_{hi} - C_{lo})] \times (C - C_{lo}) + I_{lo} \quad (\text{Eq. 2})$$

Where: C = pollutant concentration, C_{lo} and C_{hi} = lower and upper breakpoints, and I_{lo} and I_{hi} = AQI values for that range. Final AQI scores for PM_{2.5}, PM₁₀, NO_x, SO_x, and CO were interpreted using standard categories (Good: 0–50; Moderate: 51–100; Unhealthy for Sensitive Groups: 101–150, etc.).

3. RESULTS

3.1 Air Quality Characteristics of the Cement Depots

Air quality monitoring revealed clear differences between cement depots and the control site (Table 1). Concentrations of PM_{2.5} and PM₁₀ exceeded WHO limits at all depots, with Dangote Cement Depot, Eleme recording the highest levels (55.0 and 112.0 µg/m³, respectively). The control site was the only location within permissible limits, highlighting the impact of depot activities on particulate emissions.

Meteorological factors also varied slightly. Temperatures were generally higher at depot sites, particularly at Dangote Cement Depot, Eleme (33.1 °C), while relative humidity was greatest at the control site (78.4%), suggesting more favourable dispersion and pollutant dilution there. Wind speeds were lowest at Dangote Cement Depot, Eleme (0.7 m/s) and highest at the control site (1.6 m/s), again supporting better ventilation at the latter. Noise levels were elevated across depots, especially at Dangote Cement Depot, Elioza (80.1 dB), compared to 46.5 dB at the control.

For gaseous pollutants, NO_x concentrations at all depots (62.1–102.1 µg/m³) were above the WHO guideline of 25 µg/m³, whereas the control site recorded only 12.0 µg/m³. SO_x was negligible at Lafarge Cement Depot, Rukpokwu, and the control but extremely high at Dangote Cement Depots (193.2–209.5 µg/m³). CO concentration was generally low across the sites; however, Dangote Cement Depot Eleme slightly exceeded the WHO threshold (4.8 µg/m³).

Microbial counts were consistently higher around the depots compared to the control (Table 1). Lafarge Cement Depot Rukpokwu had the highest bacterial (233.0 CFU/m³) and fungal (35.0 CFU/m³) loads, while the control site recorded only 32.0 and 4.0 CFU/m³, respectively. This trend suggests that cement handling environments may favour the accumulation and dispersal of airborne microbes.

Table 1: Air Quality Data of Selected Cement Depots in the Port-Harcourt Metropolis

Parameter (Unit)	Lafarge Cement Depot, Rukpokwu	Lafarge Cement Depot, Iriebe	Dangote Cement Depot, Eleme	Cement Depot, Elioza	Control (Non-Depot) Site	WHO Limits, 2021b (24-hour mean)
PM _{2.5} (µg/m ³)	48.0	36.0	55.0	27.0	10.0	15.0
PM ₁₀ (µg/m ³)	83.0	67.0	112.0	48.0	22.0	45.0
Wind Speed (m/s)	0.8	1.3	0.7	1.5	1.6	-
Temperature (°C)	29.3	30.8	33.1	28.7	27.5	-
Relative Humidity (%)	69.2	63.5	50.4	73.8	78.4	-
Wind Direction	SW	SE	SW	SE	NE	-
Noise (dB)	61.8	67.3	70.3	80.1	46.5	-
NO _x (ug/m ³)	99.31	76.40	102.13	62.10	12.00	25.0
SO _x (ug/m ³)	<0.01	43.90	193.20	209.50	<0.01	40.0
NH ₃ (ug/m ³)	<0.01	<0.01	<0.01	<0.01	<0.01	-
H ₂ S (ug/m ³)	<0.01	<0.01	<0.01	<0.01	<0.01	-
CO (ug/m ³)	2.5	3.1	4.8	3.0	1.2	4.0
Total Heterotrophic Bacteria Count (Cfu/m ³)	233.0	95.5	87.5	65.0	32.0	-
Total Fungi Count (Cfu/m ³)	35.0	8.5	8.0	5.5	4.0	-

*WHO Limits (2021)- World Health Organisation Air Quality Guidelines (AQGs), 2021.

3.2 Diversity of Airborne Bacteria and Fungi Isolated Across Sites

Biochemical and morphological analyses revealed distinct bacterial and fungal profiles across sites (Tables 2a, 2b, and 3). Lafarge Cement Depot Rukpokwu exhibited the highest diversity, with six bacterial taxa (*Enterobacter* spp., *Serratia* spp., *Bacillus* spp., *Acinetobacter* spp., *Aeromonas* spp.) and four fungal taxa (*Penicillium* spp., *Aspergillus niger*, *Aspergillus flavus*,

Trichoderma spp.). Lafarge Cement Depot Iriebe showed moderate diversity, with bacteria such as *Bacillus* spp., *Aeromonas* spp., *Staphylococcus* spp., *Micrococcus* spp., and fungi including *Aspergillus niger*, *Fusarium* spp., and *Neurospora* spp. Dangote Cement Depot Eleme and Dangote Cement Depot Elioizu displayed lesser microbial diversity but harboured clinically relevant species; Eleme was dominated by *Bacillus* spp., *Klebsiella* spp., *Serratia* spp., *Aspergillus niger*, and *Trichoderma* spp., whereas Elioizu contained *Bacillus* spp., *Micrococcus* spp., *Shigella* spp., *Trichoderma* spp., and *Fusarium* spp. The control site, by contrast, exhibited minimal diversity, with only *Aeromonas* spp., *Bacillus* spp., and *Aspergillus flavus*. A clustered heatmap (Figure 2) reinforced these findings, grouping Lafarge Cement Depots at Rukpokwu and Iriebe due to their broader microbial richness, while Dangote Cement Depots at Eleme and Elioizu clustered separately, with narrower microbial assemblages. The control remained distinct with its limited profile.

Table 2a: Morphological Properties of Bacteria Isolated from Air in the Vicinity of Cement Depots

Depot/Location Names	No. of Isolates	Isolate ID	Colour	Surface	Size (cm)	Opacity	Edge	elevation	Shape
Lafarge Rukpokwu	6	Ce1	Cream	Rough, dull	4	Opaque	Serrated	raised	irregular
		Ce2	Yellow	Smooth, shiny	0.2	Translucent	entire	flat	circular
		Ce3	Orange	Smooth, shiny	0.5	Opaque	Entire	flat	circular
		Ce4	White	Rough, dull	0.3	Opaque	Entire	raised	circular
		Ce5	Greyish	Smooth, shiny	0.3	Transparent	Entire	flat	circular
		Ce6	Cream	Smooth, shiny	5	Translucent	Serrated	Flat	Irregular
Lafarge Iriebe	4	Ce7	Pale yellow	Smooth, shiny	0.5	opaque	Entire	Flat	Circular
		Ce8	Cream	Smooth, dull	7	Opaque	Serrated	Raised	Irregular
		Ce9	Greyish	Smooth, shiny	0.2	Opaque	Entire	Flat	Circular
		Ce10	yellow	Smooth, shiny	0.1	opaque	Entire	Flat	Circular
Dangote Eleme	5	Ce11	white	Rough, dull	0.5	Opaque	Serrated	Flat	Irregular
		Ce12	Pale yellow	Smooth, shiny	0.5	opaque	entire	Flat	Circular
		Ce13	Orange	Smooth, shiny	0.4	Opaque	entire	Flat	circular
		Ce14	Cream	Rough, dull	7	Translucent	serrated	Flat	irregular
		Ce15	Greyish	Smooth, shiny	0.1	Transparent	entire	Flat	Circular
Dangote Elioizu	5	Ce16	Light pink	Smooth, shiny	0.3	Opaque	entire	Flat	Circular
		Ce17	White	Rough, dull	4	Opaque	serrated	Flat	Irregular
		Ce18	Cream	Rough, dull	0.2	Opaque	Entire	Flat	Circular
		Ce19	Yellow	Smooth, shiny	0.1	Opaque	Entire	Flat	Circular
		Ce20	Greyish	Smooth, shiny	0.1	Translucent	entire	flat	Circular
Control	2	Ce21	Cream	Smooth, shiny	5	Translucent	Serrated	Flat	Irregular
		Ce22	Pale yellow	Smooth, shiny	0.5	opaque	Entire	Flat	Circular

Table 2b: Biochemical Properties of Probable Bacteria Isolated from Air in the Vicinity of Cement Depots

Depot/Location Names	No. of Isolates	Isolate ID	Colour	Surface	Size (cm)	Opacity	Edge	elevation	Shape
Lafarge Rukpokwu	6	Ce1	Cream	Rough, dull	4	Opaque	Serrated	raised	irregular
		Ce2	Yellow	Smooth, shiny	0.2	Translucent	entire	flat	circular
		Ce3	Orange	Smooth, shiny	0.5	Opaque	Entire	flat	circular
		Ce4	White	Rough, dull	0.3	Opaque	Entire	raised	circular
		Ce5	Greyish	Smooth, shiny	0.3	Transparent	Entire	flat	circular
		Ce6	Cream	Smooth, shiny	5	Translucent	Serrated	Flat	Irregular
Lafarge Iriebe	4	Ce7	Pale yellow	Smooth, shiny	0.5	opaque	Entire	Flat	Circular
		Ce8	Cream	Smooth, dull	7	Opaque	Serrated	Raised	Irregular
		Ce9	Greyish	Smooth, shiny	0.2	Opaque	Entire	Flat	Circular
		Ce10	yellow	Smooth, shiny	0.1	opaque	Entire	Flat	Circular
Dangote Eleme	5	Ce11	white	Rough, dull	0.5	Opaque	Serrated	Flat	Irregular
		Ce12	Pale yellow	Smooth, shiny	0.5	opaque	entire	Flat	Circular
		Ce13	Orange	Smooth, shiny	0.4	Opaque	entire	Flat	circular
		Ce14	Cream	Rough, dull	7	Translucent	serrated	Flat	irregular
		Ce15	Greyish	Smooth, shiny	0.1	Transparent	entire	Flat	Circular
Dangote Eliozu	5	Ce16	Light pink	Smooth, shiny	0.3	Opaque	entire	Flat	Circular
		Ce17	White	Rough, dull	4	Opaque	serrated	Flat	Irregular
		Ce18	Cream	Rough, dull	0.2	Opaque	Entire	Flat	Circular
		Ce19	Yellow	Smooth, shiny	0.1	Opaque	Entire	Flat	Circular
		Ce20	Greyish	Smooth, shiny	0.1	Translucent	entire	flat	Circular
Control	2	Ce21	Cream	Smooth, shiny	5	Translucent	Serrated	Flat	Irregular
		Ce22	Pale yellow	Smooth, shiny	0.5	opaque	Entire	Flat	Circular

Table 3: Morphological Properties of Fungi Isolated from Air in the Vicinity of Cement Depots

Depot/Location Names	Macroscopy	Microscopy	Probable Genera
Lafarge Rukpokwu	White margin, green powdery mycelium, white and tinted red non-cracked reverse	Brush-like conidiophores with chains of conidia	<i>Penicillium sp.</i>
	Yellow or brown cracked reverse, circular colony, dense mycelia with black spores	Hyaline hyphae, conidiophore-bearing, large, globose, rough-walled black conidia	<i>Aspergillus niger</i>
	Greenish-yellow aerial mycelia, a fast-growing, circular colony with a white margin	Tree-like conidiophores with rough, globose conidia	<i>Aspergillus flavus</i>
	Green woolly mycelia, fast-growing, circular colony, white reverse	Branched conidiophores, clustered green conidia	<i>Trichoderma sp.</i>
Lafarge Iriebe	Yellow or brown cracked reverse, circular colony, dense mycelia with black spores	Hyaline hyphae, conidiophore-bearing, large, globose, rough-walled black conidia	<i>Aspergillus niger</i>
	White fluffy mycelia, fast-growing, white reverse, smooth mycelia	Branched, septate hyphae, sickle-shaped macroconidia	<i>Fusarium sp.</i>
	Orange-coloured fast-growing colony, dense aerial mycelia	Branched hyphae with large, multicellular, oblong conidia	<i>Neurospora sp.</i>
Dangote Eleme	Green woolly mycelia, fast-growing, circular colony, white reverse	Branched conidiophores, clustered green conidia	<i>Trichoderma sp.</i>
	Yellow or brown cracked reverse, circular colony, dense mycelia with black spores	Hyaline hyphae, conidiophores with large, globose, rough-walled black conidia	<i>Aspergillus niger</i>

Dangote Elioza	Yellow or brown cracked reverse, circular colony, dense mycelia with black spores	Hyaline hyphae, conidiophore-bearing, large, globose, rough-walled black conidia	<i>Aspergillus niger</i>
	Green woolly mycelia, fast-growing colony, white reverse, non-cracked	Branched conidiophores, clustered green conidia, and thick-walled septate hyphae	<i>Trichoderma sp.</i>
	White fluffy mycelia, fast-growing, white reverse, smooth mycelia	Thin hyaline septate hyphae, sickle-shaped macroconidia	<i>Fusarium sp.</i>
Control	Greenish-yellow aerial mycelia, a fast-growing, circular colony with a white margin	Tree-like conidiophores with rough, globose conidia	<i>Aspergillus flavus</i>

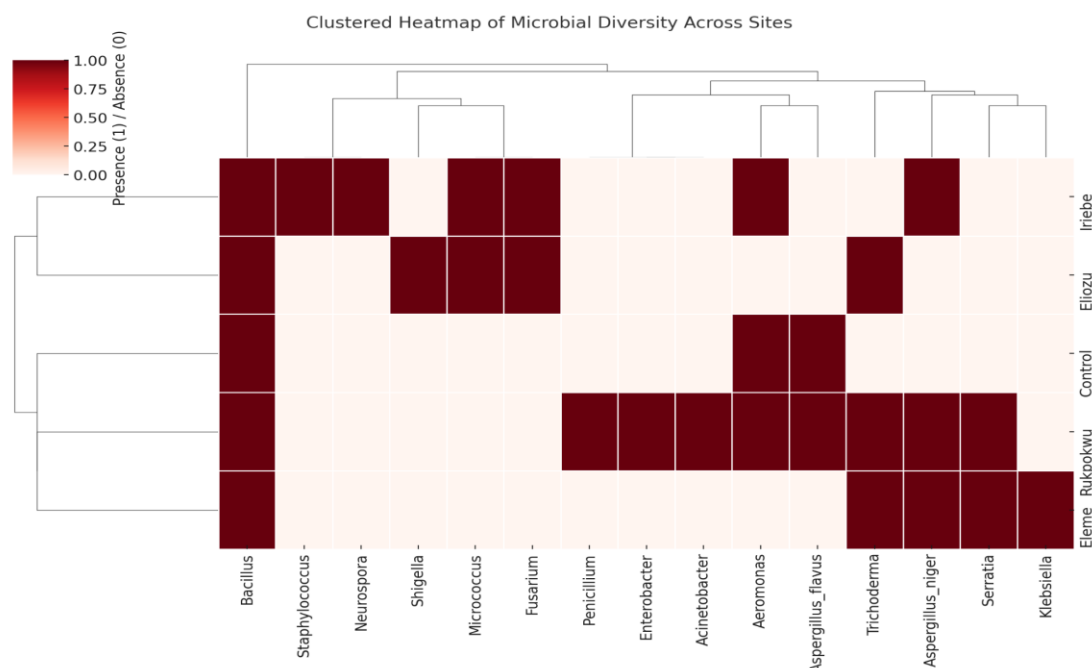


Figure 2: A clustered heatmap comparing microbial diversity across the five sites. It groups sites and microorganisms based on similarity, making it clear which depots share overlapping microbial profiles and which stand apart.

3.3 Air Quality Index (AQI) Across the Sites

Air quality index (AQI) assessment revealed significant variation across sites, as shown in Table 4. At Lafarge Cement Depot, Rukpokwu, AQI values for $PM_{2.5}$ (166.0) and NO_x (124.3) exceeded 100, classifying the site as Unhealthy, while at Lafarge Cement Depot, Iriebe, NO_x (101.4) was the primary driver, placing the site in the Unhealthy for Sensitive Groups range. In contrast, Dangote Cement Depots showed substantially poorer air quality: Eleme recorded an AQI of 241.5, dominated by SO_x , while Elioza reached 261.9, the highest of all sites, also driven by SO_x exceedances. By comparison, the control site maintained an AQI of 33.3, consistently within the “Good” category and well below WHO 2021 thresholds.

Visual analyses further clarified these patterns. The condensed heatmap (Figure 3) highlighted Dangote Cement Depots at Eleme and Elioza as SO_x “hotspots,” while $PM_{2.5}$ mostly impacted Lafarge Cement Depot, Rukpokwu. Cluster analysis (Figure 4) grouped Eleme and Elioza due to severe SO_x pollution, while Rukpokwu and Iriebe clustered separately with elevated but less extreme $PM_{2.5}$, PM_{10} , and NO_x values. The composite AQI ranking (Figure 4) confirmed Elioza and Eleme as the most polluted sites, followed by Rukpokwu and Iriebe, with the control distinctly lower. Finally, analysis of the dominant pollutant across sites (Figure 6) showed SO_x ,

PM_{2.5}, and NO_x as the primary drivers at Dangote Cement Depots (at Eleme and Elioizu), Lafarge Cement Depot Rukpokwu, and Lafarge Cement Depot Iriebe, respectively. Collectively, these findings demonstrate that site-specific pollutant profiles influence air quality, with sulphur emissions at Dangote depots posing the greatest health concern.

Table 4: Comparative Air Quality Index (AQI) Across Cement Depots and Control Site

Parameter	WHO Limits, 2021b (24-hour mean)	Breakpoint 1	Breakpoint 2	Lafarge Cement Depot, Rukpokwu	Lafarge Cement Depot, Iriebe	Dangote Cement Depot, Eleme	Dangote Cement Depot, Elioze	Control (Non-Depot Site)	AQI Category Summary
PM _{2.5} (µg/m³)	15.0	15	40	166.0	92.0	130.0	74.0	33.3	Unhealthy (Rukpokwu), Moderate–Very Unhealthy (others), Good (Control)
PM ₁₀ (µg/m³)	45.0	45	75	113.0	86.7	161.7	55.0	24.4	Unhealthy (Eleme), Moderate (others), Good (Control)
NO _x (µg/m³)	25.0	25	75	124.3	101.4	127.1	87.1	24.0	Unhealthy (all depots), Good (Control)
SO _x (µg/m³)	40.0	40	80	0.01	54.9	241.5	261.9	0.01	Very Unhealthy (Eleme, Elioze), Moderate (Iriebe), Good (Rukpokwu & Control)
CO (mg/m³)	4.0	4	8	30.0	38.8	51.0	48.8	15.0	Moderate (all depots), Good (Control)

AQI Range for Breakpoint 1 = 0 – 50 (Good); AQI Range for Breakpoint 2 = 51 – 100 (Moderate); AQI Range > 100 (Unhealthy – Very Unhealthy)

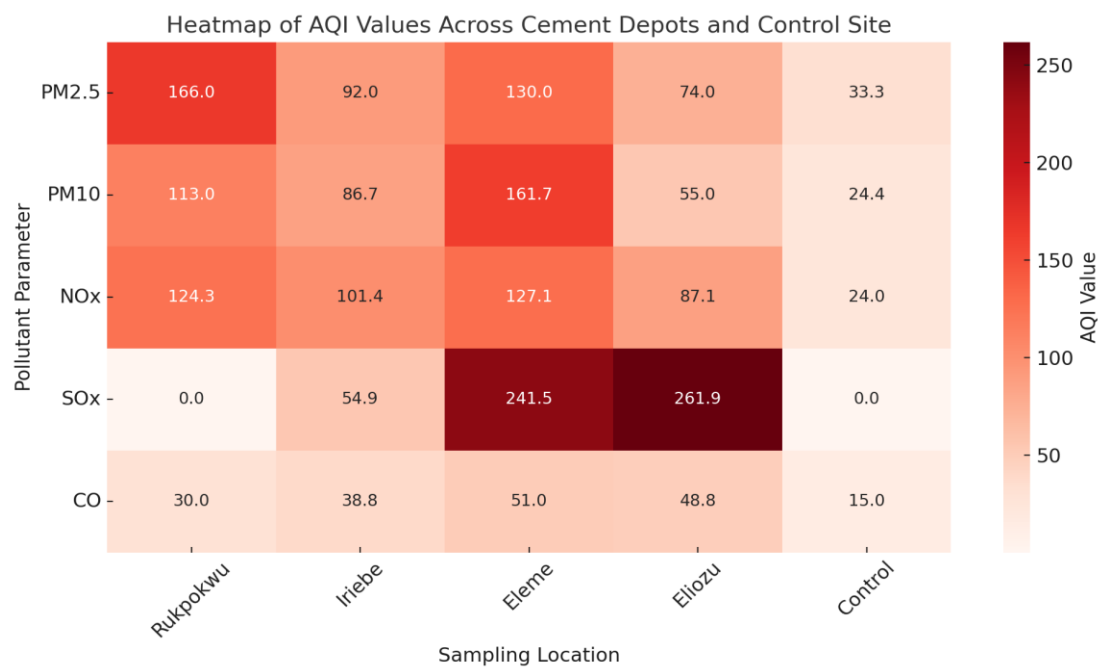


Figure 3: A condensed heatmap comparing AQI values across all cement depots and the control site. Darker red = higher AQI (worse pollution). Eleme and Elioze stand out with the highest SO_x-driven

pollution. Rukpokwu had the most severe PM_{2.5} impact. The control site stayed within the safe range across all pollutants.

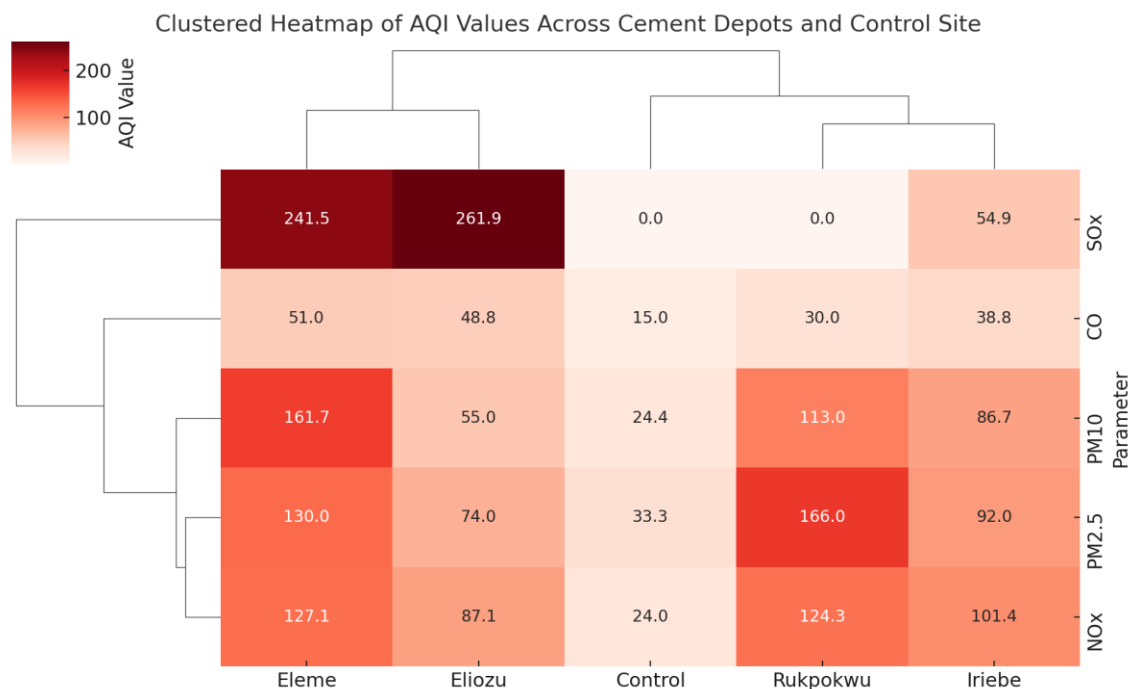


Figure 4: A clustered heatmap (clustermap). It groups both pollutants and sites based on similarity: Eleme and Elioizu cluster together, showing the worst SO_x-driven pollution. Rukpokwu and Iriebe form another cluster with elevated PM_{2.5}, PM₁₀, and NO_x levels, but less severe than those at the Dangote sites. The control site remains distinct, with consistently low AQI values across all pollutants.

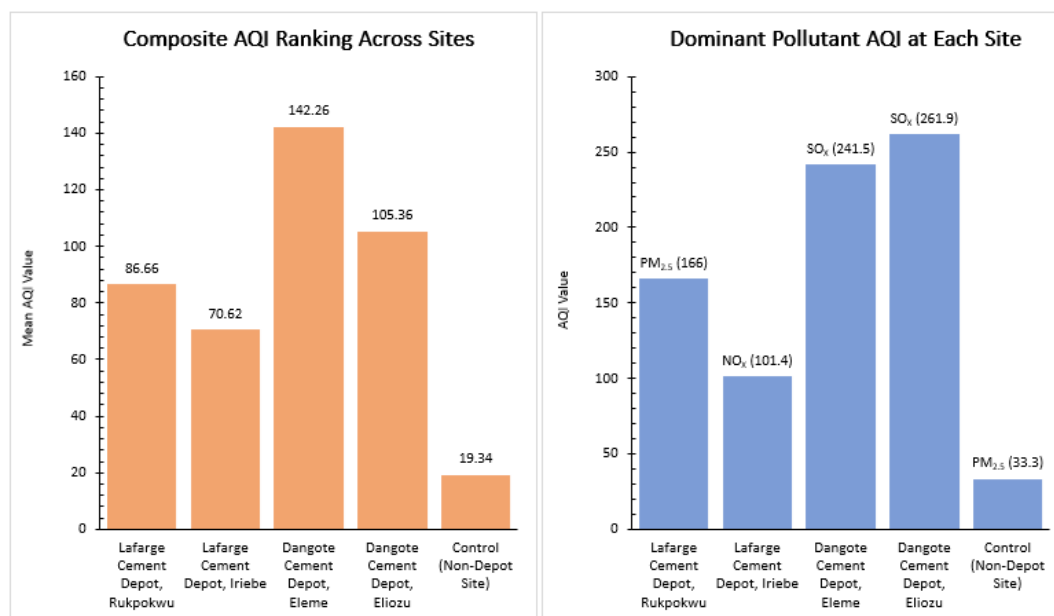


Figure 5

Figure 6

Figure 5: A composite AQI ranking chart. Elioizu and Eleme recorded the highest overall average AQI values, confirming them as the most polluted sites. Rukpokwu and Iriebe showed moderate but still unhealthy AQI levels. The control site was far below all depots, reflecting safe air quality. Figure 6: A Bar chart showing the dominant pollutant at each site with its AQI value

3.4 Statistical Analysis of Air Quality Index (AQI)

ANOVA confirmed variability in AQI among sites (Table 5), though overall differences were marginally non-significant ($p = 0.055$). Post-hoc comparisons revealed that only Dangote Cement Depot at Eleme differed significantly from the control ($p = 0.032$), with all other pairwise differences showing no statistical significance. This indicates that while AQI levels were elevated across all depots, the most significant deviation from background air quality occurred at Dangote Cement Depot, Eleme.

Table 5: ANOVA and Tukey HSD Pairwise Comparisons of AQI Across the Cement Depots and Control Site

Source	Sum of Squares	df	F-value	p-value
Cement Depot	40,537.25	4	2.773	0.0554
Residual	73,087.03	20	—	—
Total	113,624.28	24		

Group 1	Group 2	Mean Diff	p-value	95% CI Lower	95% CI Upper	Significant?
Dangote Cement Depot Eleme	Dangote Cement Depot Eliozu	-36.92	0.867 ^{ab}	-151.32	77.49	No
Dangote Cement Depot Eleme	Lafarge Cement Depot Iriebe	-67.52	0.419 ^{ab}	-181.93	46.89	No
Dangote Cement Depot Eleme	Lafarge Cement Depot Rukpokwu	-55.60	0.602 ^{ab}	-170.00	58.81	No
Dangote Cement Depot Eleme	Control Site	-122.90	0.032 ^a	-237.31	-8.50	Yes
Dangote Cement Depot Eliozu	Lafarge Cement Depot Iriebe	-30.61	0.927 ^{ab}	-145.01	83.80	No
Dangote Cement Depot Eliozu	Lafarge Cement Depot Rukpokwu	-18.68	0.988 ^{ab}	-133.09	95.73	No
Dangote Cement Depot Eliozu	Control Site	-85.99	0.203 ^{ab}	-200.39	28.42	No
Lafarge Cement Depot Iriebe	Lafarge Cement Depot Rukpokwu	11.93	0.998 ^{ab}	-102.48	126.33	No
Lafarge Cement Depot Iriebe	Control Site	-55.38	0.605 ^{ab}	-169.79	59.02	No
Lafarge Cement Depot Rukpokwu	Control Site	-67.31	0.422 ^{ab}	-181.71	47.10	No

4. DISCUSSION

This study assessed the physical, chemical, and microbial characteristics of ambient air around selected cement depots in Port Harcourt to determine their AQI. Particulate matter (PM_{2.5} and PM₁₀) consistently exceeded WHO thresholds, with Dangote Cement Depot Eleme recording the highest levels (55.0 µg/m³ and 112.0 µg/m³). SO_x peaked at 209.5 µg/m³ at Dangote Cement Depot Eliozu, while CO exceeded limits only at Eleme. Microbial loads were greatest at Lafarge Cement Depot Rukpokwu (233.0 CfU/m³ for bacteria, 35.0 CfU/m³ for fungi). By contrast, the control site remained within recommended limits. AQI values ranged from 101.4 at Iriebe to 261.9 at Eliozu, with the control (33.3) rated “Good.” Visual analyses revealed that Eleme and Eliozu clustered together due to severe SO_x-driven pollution, while Rukpokwu and Iriebe grouped separately, characterised by elevated particulates and NO_x. Composite AQI Ranking confirmed Eliozu and Eleme as the most polluted sites.

Air quality around the cement depots was degraded compared to the control. Emissions from Dangote Cement Depots were dominated by SO_x, while the Lafarge Cement Depots were more affected by particulates and microbes. Microbial diversity was highest at Lafarge Cement Depot Rukpokwu and Lafarge Cement Depot Iriebe, suggesting greater dust deposition and organic accumulation. However, Dangote Cement Depots at Eleme and Eliozu harboured fewer but

clinically relevant taxa. These gradients indicate distinct pollutant and microbial profiles, with Elioizu emerging as the most polluted site overall.

The results align with previous studies. Ajayi et al. (2024) and Nwogu et al. (2025) reported PM₁₀ levels of 70-130 µg/m³ around cement facilities in Ogun State, while Adeniran et al. (2019) and Awos et al. (2024) documented AQI values above 200 near cement warehouses, supporting the “Very Unhealthy” classification of Dangote depots. Microbial contamination mirrored findings by Adewale et al. (2021) and Sowunmi et al. (2020), who reported bacterial loads up to 300 CfU/m³. Unlike these studies, the inclusion of a control site and clustering analysis here revealed site-specific signatures, with Lafarge depots showing higher microbial diversity and Dangote depots marked by severe SO_x-driven pollution.

The implications are considerable. High AQI values from PM and SO_x elevate respiratory risks for workers and nearby residents, while microbial contamination increases potential for opportunistic infections. Opportunistic bacterial species belonging to genera such as *Bacillus*, *Enterobacter*, *Serratia*, *Acinetobacter*, and *Aeromonas* have been linked to respiratory disease and multidrug resistance (Fuehner et al., 2019; Gonzalez-Martin, 2019; Guillet et al., 2018; Rizi et al., 2021; Feng et al., 2022; Huang et al., 2018). Additionally, fungal species such as *Aspergillus niger*, *Aspergillus flavus*, and *Fusarium* spp. are associated with respiratory mycoses (Hashim et al., 2024; Satlin et al., 2019). Their abundance at Rukpokwu, Eleme, and Elioizu depots signals elevated occupational and community risks.

These findings underscore the need for routine microbial monitoring, stricter emission controls, and enforcement of occupational safety standards, while reinforcing the case for recognising bioaerosols in future air quality assessments.

5. CONCLUSIONS

Air quality around cement depots in Port Harcourt is substantially compromised, with PM_{2.5}, PM₁₀, NO_x, and SO_x consistently exceeded WHO limits. The most critical conditions were observed at Dangote Cement Depots at Eleme and Elioizu, where AQI values exceeded 240, classifying the air as “Very Unhealthy.” Microbial contamination was also pronounced, particularly at Lafarge Cement Depot Rukpokwu, reflecting the combined effects of dust and organic matter accumulation. Collectively, these findings point to inadequate dust suppression and emission control during routine depot operations.

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