

INTEGRATED SOIL QUALITY AND MICROBIAL RESPONSE TO CEMENT DEPOT EXPOSURE IN PORT HARCOURT, NIGERIA

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ABSTRACT	KEYWORDS
Cement depot operations pose ecological risks, yet integrated assessments combining physicochemical, microbial, and index-based approaches remain limited in sub-Saharan Africa. This study evaluated soils around four cement depots in Port Harcourt, Nigeria, to assess chemical alterations, microbial diversity, and overall soil quality. Composite topsoil samples (0-15 cm) were collected from Lafarge depots at Rukpokwu and Iriebe, and Dangote depots at Eleme and Elioizu, and a non-depot control. Physicochemical parameters, including pH, bulk density, nutrients, and heavy metals, were analysed using standard protocols. Microbial communities were quantified and identified by culture and biochemical/morphological tests. Soil Quality Index (SQI) was calculated using a weighted additive model, and ANOVA with Tukey’s post hoc test assessed variation across sites. Depot soils were consistently alkaline (pH 8.21-8.55) compared to the control (6.72), with higher bulk density and electrical conductivity. Heavy metals were elevated at depots, especially Eleme, where Pb reached 13.58 mg/kg, Cd 8.18 mg/kg, Cr 26.63 mg/kg, and As 8.25 mg/kg, compared to the control values of 1.62, 0.73, 5.12, and 0.44 mg/kg, respectively. Microbial biomass and viable counts were lower in depot soils, with community shifting toward Serratia, Bacillus, Pseudomonas, Aspergillus, and Fusarium. SQI ranged from 0.565 (Eleme) to 0.606 (Elioizu), all moderate, while the control scored 0.878. ANOVA showed no significant SQI differences (p = 0.431). Cement depot soils are characterised by alkalinity, heavy metal accumulation, and reduced microbial diversity, but retain moderate SQI values due to organic matter and microbial activity. The higher SQI around the control site highlights ecological stress around the depots, with long-term risks if metal buildup persists.	Cement depots; Soil contamination; Soil quality index (SQI); Heavy metals; Microbial diversity.

Introduction

Soil health is central to ecosystem stability, agricultural productivity, and community well-being. It is shaped by a balance of physical, chemical, and biological processes that together sustain nutrient cycling, microbial diversity, and pollutant buffering (Friedrichsen et al., 2025; Kumar et al., 2025; Usharani et al., 2019; Xing et al., 2025). Industrialisation, however, increasingly disrupts these balances. Among key contributors is the cement industry, which generates alkaline dust and heavy metal residues that accumulate in soil and alter its quality (Agbede et al., 2024; Yitagesu & Bekele, 2019).

Cement production and storage release particulate matter enriched with trace metals, such as lead (Pb), cadmium (Cd), arsenic (As), chromium (Cr), and mercury (Hg) (Birgül, 2024; Gupta et al., 2012; Ogunbileje et al., 2013). When deposited in soils, these elements may impair fertility, disturb microbial functions, and introduce long-term ecological risks (Bilen et al., 2025; Helepiciuc et al., 2017; Iqbal et al., 2024; Miltan, 2023). For instance, Pb and Cd are widely documented for their toxicity, even at low concentrations, with reported soil levels near cement depots exceeding global safety thresholds (Das et al., 2023; Ismail et al., 2023; Ogunkunle & Fatoba, 2014). These pollutants can persist in soils, bioaccumulate, and ultimately, threaten groundwater, crops, and human health (Bouida et al., 2022; Raj & Maiti, 2020).

Microbial communities act as sensitive bioindicators of such disturbances. Shifts from diverse, functionally balanced communities to stress-tolerant or opportunistic taxa often accompany contamination and chemical imbalance (Martins et al., 2024; Stanley et al., 2014). Studies have linked cement-related soils to reductions in microbial biomass, richness, and functional diversity, while favouring resilient genera such as *Serratia*, *Pseudomonas*, *Fusarium*, and *Aspergillus* (Sowunmi et al., 2020; 2021). This microbial restructuring not only signals ecological stress but may also elevate occupational and community health risks, as several of these taxa may include opportunistic pathogens (Mltan, 2023).

To integrate such complex soil responses, composite indices such as the Soil Quality Index (SQI) have been developed. SQI condenses multiple physicochemical and biological parameters into a single score, enabling cross-site comparisons and clearer ecological interpretation (Aravindh et al., 2019; Serri et al., 2022). While widely applied in agricultural and environmental studies, few investigations have used SQI to assess soils exposed to cement storage and depot activities in sub-Saharan Africa. This represents a critical knowledge gap, given the region's expanding cement sector and the proximity of storage depots to residential and agricultural zones.

This study, therefore, evaluates soil around major cement depots in Port Harcourt, Nigeria, comparing Lafarge depots at Rukpokwu and Iriebe, and Dangote depots at Eleme and Eliozu, with an undisturbed control site. By combining physicochemical analysis, microbial diversity profiling, and SQI assessment, the study critically examines the extent of soil alteration associated with cement depot activities. The objective is to document chemical and microbial impacts and contextualise these within an integrative soil quality framework to offer insights into ecological risks, resilience, and management needs.

2. MATERIALS AND METHODS

2.1 Study Area

The research was conducted in Port Harcourt, Rivers State, Nigeria (Figure 1). Four cement depots were selected: 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 Elioze ($4^{\circ}52'57.63''\text{N}$, $7^{\circ}0'43.13''\text{E}$). A non-depot site served as control. These locations were chosen for their high vehicular and industrial activity, which increases the likelihood of pollutant emissions.

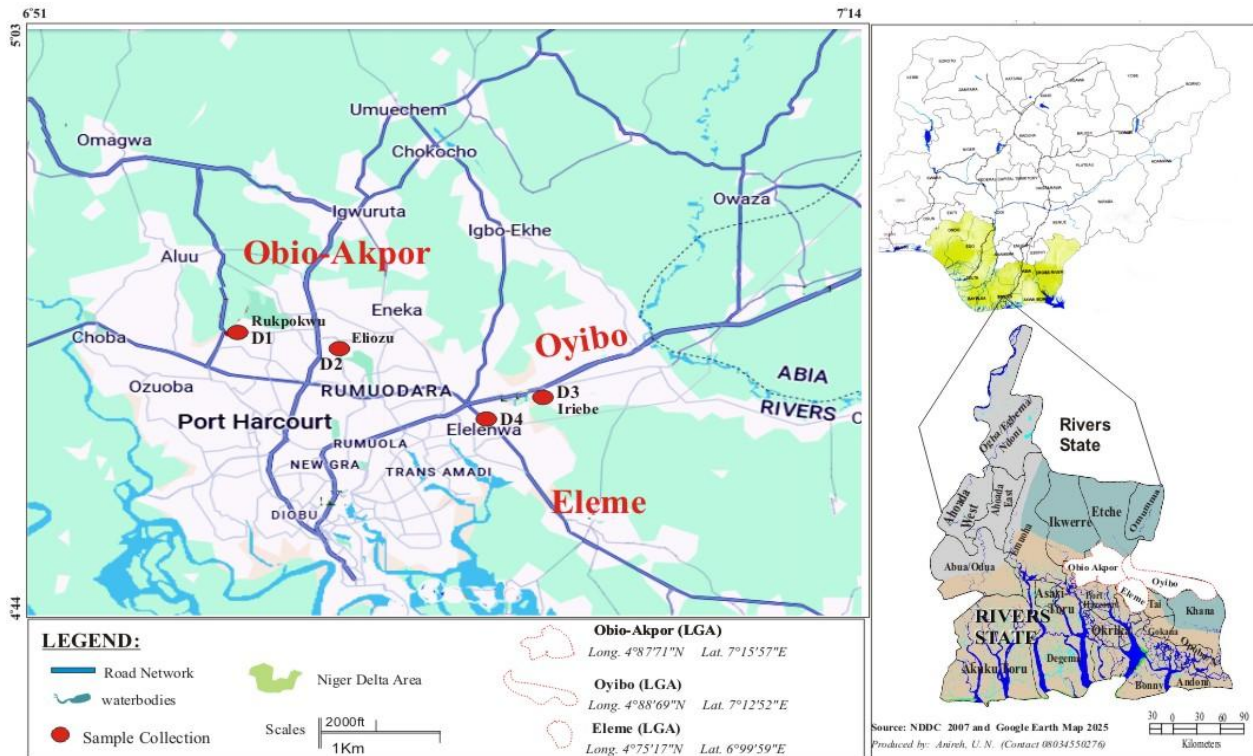


Figure 1: A map showing the study area.

2.2 Soil Sampling and Preparation

Soil samples (0-15 cm depth) were collected from upwind and downwind directions at each depot using sterile augers, following Agbede et al. (2024), Egbe et al. (2019), and Lamare and Singh (2020). Samples were stored in sterile polyethene bags, transported in cool boxes, and cement dust was collected for comparison. In the laboratory, samples were air-dried ($25 \pm 2^{\circ}\text{C}$, 3-5 days), homogenised, sieved (2 mm for physicochemical; 0.5 mm for chemical analyses), and stored under sterile conditions. All tools were sterilised with 70% ethanol before and after use (Pérez-Sierra et al., 2023).

2.3 Physicochemical Analyses

Soil texture was determined using the Bouyoucos hydrometer method (Orhan & Kılınc, 2020), and bulk density by the core method (Jabro et al., 2020). Soil pH and electrical conductivity (EC) were measured in a 1:2.5 soil–water suspension with a calibrated HANNA HI9811-5 meter (Awad et al., 2022). Total organic matter (TOM) was quantified by the Loss on Ignition method at 550°C (Hoogsteen et al., 2018). Nitrogen content was determined using the micro-Kjeldahl method (Trikilidou et al., 2022), while available phosphorus was assessed via Bray-1 extraction and

spectrophotometry at 882 nm (Mustapha et al., 2022). Calcium was extracted with 1 M ammonium acetate and analysed by Atomic Absorption Spectrophotometry (AAS) (Sharma et al., 2018). Heavy metals (Pb, Cd, Cr, Cu, Co, Ni, As, Hg) were quantified following acid digestion (Kinuthia et al., 2020) using AAS; Hg was measured by cold vapour AAS. Duplicate and blank samples ensured quality control.

2.4 Microbiological Analyses

Microbial counts were estimated by serial dilution and spread plating (Bartelme et al., 2020; Olatunde et al., 2021). Heterotrophic bacteria were cultured on Nutrient Agar, while fungi were grown on Potato Dextrose Agar with chloramphenicol. Plates were incubated at 37°C for bacteria (24-48 h) and 28°C for fungi (3-5 days), with counts expressed as CFU/g soil. Bacterial isolates were identified using morphological, Gram staining, and biochemical tests (Ogodo et al., 2022; Da Silva et al., 2018), compared with Bergey's Manual (Holt et al., 1994). Fungal isolates were identified by macro- and micromorphology using lactophenol cotton blue staining and standard taxonomic references (Barnett & Hunter, 1998; Larone, 2011).

2.5 Soil Quality Index (SQI)

The SQI was computed using the weighted additive method (Li et al., 2020; Yu et al., 2023). Sub-Indices (SI) were calculated depending on whether parameters had a maximum permissible value (Equation 1), a minimum desirable value (Equation 2), or range-bound values (Equation 3). SI values were normalised (0–1), weighted according to ecological importance, and summed to obtain SQI scores (Equation 4). Standards were based on the Food and Agriculture Organisation FAO (2017) guidelines for soil health and pollution.

$$SI_{\text{MAXP}} = (V_{\text{actual}} / V_{\text{standard}}) \quad (\text{Eq. 1})$$

$$SI_{\text{MIND}} = (V_{\text{actual}} / V_{\text{standard}}) \quad (\text{Eq. 2})$$

$$SI_{\text{RNB}} = 1 - [(V_{\text{actual}} - V_{\text{ideal}}) / (V_{\text{standard}} - V_{\text{ideal}})] \quad (\text{Eq. 3})$$

$$SQI = \sum (\text{Weight} \times SI) \quad (\text{Eq. 4})$$

3. RESULTS

3.1 Physicochemical and Microbiological Properties of Soils

Soils around the cement depots showed distinct alterations compared to the control (Table 1). Depot soils were consistently alkaline (pH > 8.2), while the control site remained near neutral (pH 6.7). Bulk density was higher in depot soils, peaking at Elioze, whereas the control site had the lowest value. Electrical conductivity followed a similar pattern, with Eleme showing the highest salinity and the control site the lowest.

Organic matter and nutrient levels varied, with Elioze soils exhibiting the greatest organic enrichment, while Rukpokwu had the lowest. Nitrogen and phosphorus were consistently higher at the control site than at most depots. Calcium was also greatest at the control site, suggesting less depletion relative to the depot environments.

Heavy metal concentrations were markedly elevated at the depots, especially Eleme, where Pb, Cd, Cr, and As were substantially higher than background levels. In contrast, the control soils contained only trace concentrations of these metals.

Microbiological indicators mirrored these trends. Microbial biomass and viable bacterial and fungal counts were consistently reduced in depot soils compared to the control, with Elioizu showing the sharpest decline.

Table 1: Physicochemical and Microbiological Profile of Soil in Four Cement Depots

Parameter (Unit)	Lafarge Rukpokwu	Lafarge Iriebe	Dangote Eleme	Dangote Elioizu	Control Site (Non-Depot Area)
Sand (%)	64.5	61.3	58.2	55.6	67.8
Silt (%)	20.1	22.6	24.3	25.9	19.6
Clay (%)	15.4	16.1	17.5	18.5	12.6
Bulk Density (g/cm ³)	1.38	1.41	1.48	1.53	1.27
pH	8.21	8.27	8.22	8.55	6.72
E.C. (μS/cm)	177.2	202.8	227.4	174.1	93.5
Total Organic Matter (%)	3.94	4.51	5.92	7.38	5.41
Nitrogen (mg/kg)	0.17	0.21	0.27	0.31	0.34
Phosphorus (mg/kg)	15.5	18.3	21.7	25.4	27.6
Ca (mg/kg)	136.29	154.43	178.05	164.96	182.4
Pb (mg/kg)	8.96	6.78	13.58	10.48	1.62
Cd (mg/kg)	3.10	5.07	8.18	4.97	0.12
Cr (mg/kg)	14.06	19.64	26.63	21.58	4.23
Cu (mg/kg)	8.97	11.57	14.72	9.32	5.76
Co (mg/kg)	5.07	3.14	7.10	5.58	1.88
Ni (mg/kg)	3.68	6.89	9.42	11.43	2.17
As (mg/kg)	2.34	4.08	8.25	6.15	0.28
Hg (mg/kg)	0.87	0.32	1.24	0.06	0.03
Microbial Biomass (μg C/g soil)	456.2	387.5	332.1	295.3	562.3
Total Heterotrophic Bacteria Count (10 ³ Cfu/g)	68.5	37.5	45.0	33.0	88.7
Total Fungi Count (10 ² Cfu/g)	6.5	5.5	4.0	2.5	9.3

3.2 Diversity of Soil-Borne Bacterial and Fungal Diversity Across Sites

Bacterial communities varied across locations (Tables 2a, 2b). *Serratia spp* dominated the soil around Lafarge Cement Depots at Rukpokwu and Iriebe. However, the soil in Dangote Cement Depots at Eleme and Elioizu harboured *Corynebacterium sp.* and *Pseudomonas sp.*, and *Serratia marcescens* and *Bacillus sp.*, respectively. The control site supported the greatest diversity, including *Bacillus spp.*, *Pseudomonas sp.*, and *Streptomyces sp.*.

Fungal distribution also differed among sites (Table 3). The soil around Lafarge Cement Depot harboured *Penicillium sp.*, *Fusarium sp.*, and *Aspergillus niger* at Rukpokwu and *Aspergillus flavus* and *Trichoderma sp.* at Iriebe. The soil in the vicinity of Dangote Cement Depots at Eleme and Elioizu was dominated by *Aspergillus glaucus*, *Penicillium sp.*, and *Trichoderma sp.*, and *Trichoderma sp.*, and *Fusarium sp.*, respectively. The control site exhibited the highest richness, with the presence of *Penicillium sp.*, *Rhizopus sp.*, *Fusarium sp.*, and *Aspergillus niger*.

The clustered heatmap (Figure 2) demonstrated clear grouping of sites based on microbial profiles. Rukpokwu and Iriebe clustered together, reflecting their dominance by *Serratia spp.* with occasional

presence of *Providencia sp.* or *Acinetobacter sp.*. Eleme and Elioze formed a separate cluster characterised by *Bacillus spp.*, *Trichoderma spp.*, and *Pseudomonas spp.*. The control site was distinct, hosting a broader diversity, including *Bacillus spp.*, *Streptomyces sp.* and *Rhizopus sp.*. Collectively, the patterns show that cement exposure may reduce microbial richness.

Table 2a: Morphological properties of bacteria isolated from soil in the vicinity of cement depots

Depot / Location	No. of Isolates	Isolate ID	Colour	Surface	Size (cm)	Opacity	Edge	Elevation	Shape
Lafarge Rukpokwu	4	CE1	Greyish	Smooth, shiny	0.2	Transparent	Entire	Flat	Circular
		CE2	Cream	Smooth, shiny	0.3	Opaque	Entire	Raised	Circular
		CE3	Yellow	Rough, dull	0.3	Opaque	Entire	Raised	Circular
		CE4	Yellow	Smooth, shiny	0.3	Translucent	Entire	Flat	Circular
Lafarge Iriebe	3	CE5	Orange	Smooth, shiny	0.4	Opaque	Entire	Flat	Circular
		CE6	Cream	Smooth, shiny	0.7	Translucent	Serrated	Flat	Irregular
		CE7	Greyish	Smooth, shiny	0.2	Transparent	Entire	Flat	Circular
Dangote Eleme	3	CE8	Cream	Smooth, shiny	0.5	Opaque	Entire	Flat	Circular
		CE9	Bluish	Smooth, shiny	0.3	Opaque	Entire	Flat	Circular
		CE10	Creamy white	Wrinkled / rough ¹	0.2	Opaque	Serrated	Flat	Irregular ³
Dangote Elioze	2	CE11	Yellow	Rough, dull	0.3	Opaque	Entire	Raised	Circular
		CE12	Yellow	Smooth, shiny	0.3	Translucent	Entire	Flat	Circular
Control Site	6	CE13	White	Rough, dull	5.0	Opaque	Serrated	Flat	Irregular
		CE14	Cream	Smooth, shiny	0.3	Opaque	Serrated	Flat	Circular
		CE15	Creamy white	Wrinkled / rough ¹	0.2	Opaque	Serrated	Flat	Irregular ³
		CE16	White to green ⁴	Smooth, shiny ⁴	0.3	Opaque	Entire	Flat	Circular
		CE17	Powdery grey ⁵	Filamentous margins	0.3	Opaque	Filamentous	Raised ⁵	Filamentous

Table 2b: Biochemical properties of probable bacteria isolated from soil around cement depots

Depot / Location	No. of Isolates	Isolate ID	Catalase	Citrate	Glucose	Lactose	Indole	Motility	Starch	MR	VP	TSIA	H ₂ S	Gram Reaction	Possible Bacteria
Lafarge Rukpokwu	4	CE1	+	-	+	-	-	+	+	-	-	AB	-	- rod	<i>Serratia sp.</i>
		CE2	+	+	-	-	+	+	-	+	+	AB	-	- rod	<i>Providencia sp.</i>
		CE3	+	-	-	+	-	+	+	-	+	AB	-	- rod	<i>Serratia marcescens</i>
		CE4	+	+	-	-	+	-	+	+	-	AB	-	+ rod	<i>Bacillus sp.</i>
Lafarge Iriebe	3	CE5	+	+	-	-	-	+	+	-	-	AB	-	- rod	<i>Serratia sp</i>
		CE6	+	-	+	-	-	-	-	-	+	AB	-	- rod	<i>Acinetobacter sp.</i>
		CE7	+	-	+	-	-	+	+	-	-	AB	-	- rod	<i>Serratia sp.</i>
Dangote Eleme	3	CE8	+	-	+	-	-	+	+	+	+	AA	-	+ rod	<i>Corynebacterium sp.</i>
		CE9	+	+	-	-	+	+	+	-	-	BB	-	- rod	<i>Pseudomonas sp.</i>
		CE10	+	+	+	-	-	+	+	-	+	AB	-	+ rod	<i>Bacillus subtilis</i>
Dangote Eliozu	2	CE11	+	-	-	+	-	+	+	-	+	AB	-	- rod	<i>Serratia marcescens</i>
		CE12	+	+	-	-	+	-	+	+	-	AB	-	+ rod	<i>Bacillus sp.</i>
Control Site	5	CE13	+	+	+	-	-	+	+	+	+	AB	-	+ rod	<i>Bacillus sp.</i>
		CE14	+	-	+	-	-	+	+	-	+	AB	-	+ rod	<i>Bacillus sp.</i>
		CE15	+	+	+	-	-	+	+	-	+	AB	-	+ rod	<i>Bacillus subtilis</i>
		CE16	+	+	-	-	+	+	+	-	-	BB	-	- rod	<i>Pseudomonas sp.</i>
		CE17	+	+	-	-	-	+	+	+	-	AB	-	Filaments	<i>Streptomyces sp.</i>

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

Cement Depot/Location Names	Macroscopy	Microscopy	Probable Genera
Lafarge, Rukpokwu	Raised, dry, rough mycelia, blue-green folded surface with white margin	Long hyaline hyphae with brush-like conidiophores bearing conidia	<i>Penicillium sp.</i>
	White fluffy mycelia, fast-growing, white reverse, smooth mycelia	Thin hyaline septate hyphae, sickle-shaped macroconidia	<i>Fusarium 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>
Lafarge, Iriebe	Greenish powdery dense mycelium, white margin, non-cracked reverse	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>
Dangote, Eleme	White margin, yellow powdery mycelia, spiral yellow reverse	Branched conidiophores with round conidia in chains, septate hyphae	<i>Aspergillus glaucus</i>
	Green powdery mycelia, white margin, non-cracked reverse	Brush-like conidiophores with chains of conidia	<i>Penicillium sp.</i>
	Green woolly mycelia, fast-growing, circular colony, white reverse	Branched conidiophores, clustered green conidia	<i>Trichoderma sp.</i>
Dangote, Eliozu	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 Site	Raised, dry, rough mycelia, blue-green folded surface with white margin	Long hyaline hyphae with brush-like conidiophores bearing conidia	<i>Penicillium sp.</i>
	Black spore-producing, cottony aerial mycelia	Sporangia on sporangiophores, branched, dark greyish-brown hyphae	<i>Rhizopus sp.</i>
	White fluffy mycelia, fast-growing, white reverse, smooth mycelia	Thin hyaline septate hyphae, sickle-shaped macroconidia	<i>Fusarium 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>

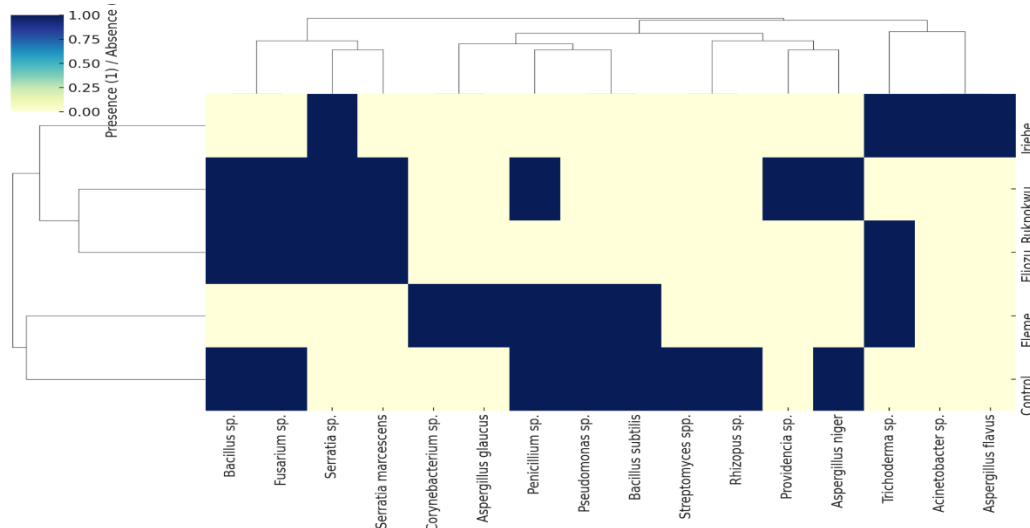


Figure 2: Clustered heatmap of microbial diversity across sites. The control site stood apart with broader richness, while Rukpokwu–Iriebe (Serratia-dominated) and Eleme–Ellozu (Bacillus, Trichoderma, opportunistic taxa) formed distinct clusters

3.3 Soil Quality Index (SQI) Across the Sites

Soil quality varied across locations (Tables 4-8). All cement depot sites fell within the moderate SQI range (0.565-0.606), while the control site achieved a substantially higher score (0.878), as shown in Figure 3, indicating undisturbed soils supported healthier ecological function.

Among the depots, Ellozu (0.606) and Iriebe (0.604) ranked highest, both sustained by strong organic matter, nutrient availability, and microbial biomass. Rukpokwu (0.601) showed similar values, while Eleme (0.565) lagged, driven by elevated cadmium and arsenic and reduced pH suitability. Across all depots, alkaline pH and toxic metals (Cd, As) were persistent limiting factors, offsetting otherwise favourable indicators such as organic matter and microbial activity.

The control site contrasted sharply with the depots, maintaining optimal pH, low contamination, and the highest microbial biomass, which together underpinned its markedly superior SQI.

Table 4: SQI in Soil in Lafarge Cement Depot, Rukpokwu

Parameter	Actual Value	Permissible Limit (FAO, 2017)	Method	Weight	Normalisation	Sub-Indices (SI)	Weight × SI
Bulk Density (g/cm ³)	1.38	< 1.6	Max	0.05	1 - (1.38 / 1.6)	0.1375	0.0069
pH	8.21	(6.0–7.5)	Range	0.08	1 - ((8.21 - 7.0) / (7.5 - 7.0))	0.0000	0.0000
E.C. (μS/cm)	177.2	400	Max	0.06	1 - (177.2 / 400)	0.5570	0.0334
Total Organic Matter (%)	3.94	≥ 2	Min	0.08	3.94 / 2	1.0000	0.0800
Nitrogen (mg/kg)	0.17	≥ 0.15	Min	0.06	0.17 / 0.15	1.0000	0.0600
Phosphorus (mg/kg)	15.5	≥ 15	Min	0.06	15.5 / 15	1.0000	0.0600
Pb (mg/kg)	8.96	200	Max	0.07	1 - (8.96 / 200)	0.9552	0.0669
Cd (mg/kg)	3.10	1	Max	0.09	1 - (3.10 / 1)	0.0000	0.0000
Cr (mg/kg)	14.06	100	Max	0.07	1 - (14.06 / 100)	0.8594	0.0602
Cu (mg/kg)	8.97	200	Max	0.06	1 - (8.97 / 200)	0.9551	0.0573
Ni (mg/kg)	3.68	100	Max	0.06	1 - (3.68 / 100)	0.9632	0.0578
As (mg/kg)	2.34	1	Max	0.09	1 - (2.34 / 1)	0.0000	0.0000
Hg (mg/kg)	0.87	2	Max	0.05	1 - (0.87 / 2)	0.5650	0.0282
Microbial Biomass (μg C/g soil)	456.2	≥ 122.15	Min	0.09	456.2 / 122.15	1.0000	0.0900
SQI = $\sum (\text{Weight} \times \text{SI}) =$							0.6007

Key Notes: SI values are clamped between 0 and 1 to keep scoring consistent; normalisation formulas clearly show how each score was derived; and the Final Soil Quality Index (SQI) = 0.6007, indicating moderate quality.

Table 5: SQI in Soil in Lafarge Cement Depot, Iriebe

Parameter	Actual Value	Permissible Limit (FAO, 2017)	Method	Weight	Normalisation	Sub-Indices (SI)	Weight × SI
Bulk Density (g/cm ³)	1.41	< 1.6	Max	0.05	1 - (1.41 / 1.6)	0.1188	0.0059
pH	8.27	(6.0–7.5)	Range	0.08	1 - ((8.27 - 7.0) / (7.5 - 7.0))	0.0000	0.0000
E.C. (μS/cm)	202.8	400	Max	0.06	1 - (202.8 / 400)	0.4930	0.0296
Total Organic Matter (%)	4.51	≥ 2	Min	0.08	4.51 / 2	1.0000	0.0800
Nitrogen (mg/kg)	0.21	≥ 0.15	Min	0.06	0.21 / 0.15	1.0000	0.0600
Phosphorus (mg/kg)	18.3	≥ 15	Min	0.06	18.3 / 15	1.0000	0.0600
Pb (mg/kg)	6.78	200	Max	0.07	1 - (6.78 / 200)	0.9661	0.0676
Cd (mg/kg)	5.07	1	Max	0.09	1 - (5.07 / 1)	0.0000	0.0000
Cr (mg/kg)	19.64	100	Max	0.07	1 - (19.64 / 100)	0.8036	0.0563
Cu (mg/kg)	11.57	200	Max	0.06	1 - (11.57 / 200)	0.9422	0.0565
Ni (mg/kg)	6.89	100	Max	0.06	1 - (6.89 / 100)	0.9311	0.0559
As (mg/kg)	4.08	1	Max	0.09	1 - (4.08 / 1)	0.0000	0.0000
Hg (mg/kg)	0.32	2	Max	0.05	1 - (0.32 / 2)	0.8400	0.0420
Microbial Biomass (μg C/g soil)	387.5	≥ 122.15	Min	0.09	387.5 / 122.15	1.0000	0.0900
SQI = ∑ (Weight × SI) =							0.6038

Key Notes: Final SQI = 0.6038 → indicates moderate soil quality, slightly higher than Rukpokwu (0.6007); Strengths: High microbial biomass, organic matter, and nutrient content; Weaknesses: Strongly alkaline pH and elevated cadmium and arsenic levels.

Table 6: SQI in Soil in Dangote Cement Depot, Eleme

Parameter	Vactual	Permissible Limit (FAO, 2017)	Method	Weight	Normalisation	Sub-Indices (SI)	Weight × SI
Bulk Density (g/cm ³)	1.48	< 1.6	Max	0.05	1 - (1.48 / 1.6)	0.0750	0.0038
pH	8.22	(6.0–7.5)	Range	0.08	1 - ((8.22 - 7.0) / (7.5 - 7.0))	0.0000	0.0000
E.C. (μS/cm)	227.4	400	Max	0.06	1 - (227.4 / 400)	0.4315	0.0259
Total Organic Matter (%)	5.92	≥ 2	Min	0.08	5.92 / 2	1.0000	0.0800
Nitrogen (mg/kg)	0.27	≥ 0.15	Min	0.06	0.27 / 0.15	1.0000	0.0600
Phosphorus (mg/kg)	21.7	≥ 15	Min	0.06	21.7 / 15	1.0000	0.0600
Pb (mg/kg)	13.58	200	Max	0.07	1 - (13.58 / 200)	0.9321	0.0652
Cd (mg/kg)	8.18	1	Max	0.09	1 - (8.18 / 1)	0.0000	0.0000
Cr (mg/kg)	26.63	100	Max	0.07	1 - (26.63 / 100)	0.7337	0.0514
Cu (mg/kg)	14.72	200	Max	0.06	1 - (14.72 / 200)	0.9264	0.0556
Ni (mg/kg)	9.42	100	Max	0.06	1 - (9.42 / 100)	0.9058	0.0543
As (mg/kg)	8.25	1	Max	0.09	1 - (8.25 / 1)	0.0000	0.0000
Hg (mg/kg)	1.24	2	Max	0.05	1 - (1.24 / 2)	0.3800	0.0190
Microbial Biomass (μg C/g soil)	332.1	≥ 122.15	Min	0.09	332.1 / 122.15	1.0000	0.0900
SQI = ∑ (Weight × SI) =							0.5652

Key Notes: Total SQI = 0.5652 – this reflects moderate soil quality at the Eleme depot; Key weaknesses: high cadmium and arsenic levels, alkaline pH; Strengths: high organic matter, nitrogen, and microbial biomass.

Table 7: SQI in Soil in Dangote Cement Depot, Elioju

Parameter	Actual Value	Permissible Limit (FAO, 2017)	Method	Weight	Normalisation	Sub-Indices (SI)	Weight × SI
Bulk Density (g/cm ³)	1.53	< 1.6	Max	0.05	1 - (1.53 / 1.6)	0.0438	0.0022
pH	8.55	(6.0–7.5)	Range	0.08	1 - ((8.55 - 7.0) / (7.5 - 7.0))	0.0000	0.0000
E.C. (μS/cm)	174.1	400	Max	0.06	1 - (174.1 / 400)	0.5648	0.0339
Total Organic Matter (%)	7.38	≥ 2	Min	0.08	7.38 / 2	1.0000	0.0800
Nitrogen (mg/kg)	0.31	≥ 0.15	Min	0.06	0.31 / 0.15	1.0000	0.0600
Phosphorus (mg/kg)	25.4	≥ 15	Min	0.06	25.4 / 15	1.0000	0.0600
Pb (mg/kg)	10.48	200	Max	0.07	1 - (10.48 / 200)	0.9476	0.0663
Cd (mg/kg)	4.97	1	Max	0.09	1 - (4.97 / 1)	0.0000	0.0000
Cr (mg/kg)	21.58	100	Max	0.07	1 - (21.58 / 100)	0.7842	0.0549
Cu (mg/kg)	9.32	200	Max	0.06	1 - (9.32 / 200)	0.9534	0.0572
Ni (mg/kg)	11.43	100	Max	0.06	1 - (11.43 / 100)	0.8857	0.0531
As (mg/kg)	6.15	1	Max	0.09	1 - (6.15 / 1)	0.0000	0.0000
Hg (mg/kg)	0.06	2	Max	0.05	1 - (0.06 / 2)	0.9700	0.0485
Microbial Biomass (μg C/g soil)	295.3	≥ 122.15	Min	0.09	295.3 / 122.15	1.0000	0.0900
SQI = ∑ (Weight × SI) =							0.6061

Key Notes: Total SQI = 0.6061 – the highest among the four cement depots; Strengths: Excellent organic matter, nutrient content, and microbial biomass; Limitations: Excessively alkaline pH and high cadmium and arsenic levels

Table 8: SQI in Soil in Control Site (Non-depot Area)

Parameter	Actual Value	Permissible Limit (FAO, 2017)	Method	Weight	Normalisation	Sub-Indices (SI)	Weight × SI
Bulk Density (g/cm ³)	1.27	< 1.6	Max	0.05	1 - (1.27 / 1.6)	0.2063	0.0103
pH	6.72	(6.0–7.5)	Range	0.08	1 - (6.72 - 6.0) / (7.5 - 6.0)	0.4800	0.0384
E.C. (μS/cm)	93.5	400	Max	0.06	1 - (93.5 / 400)	0.7663	0.0460
Total Organic Matter (%)	5.41	≥ 2	Min	0.08	5.41 / 2	1.0000	0.0800
Nitrogen (mg/kg)	0.34	≥ 0.15	Min	0.06	0.34 / 0.15	1.0000	0.0600
Phosphorus (mg/kg)	27.6	≥ 15	Min	0.06	27.6 / 15	1.0000	0.0600
Pb (mg/kg)	1.62	200	Max	0.07	1 - (1.62 / 200)	0.9919	0.0694
Cd (mg/kg)	0.12	1	Max	0.09	1 - (0.12 / 1)	0.8800	0.0792
Cr (mg/kg)	4.23	100	Max	0.07	1 - (4.23 / 100)	0.9577	0.0670
Cu (mg/kg)	5.76	200	Max	0.06	1 - (5.76 / 200)	0.9712	0.0583
Ni (mg/kg)	2.17	100	Max	0.06	1 - (2.17 / 100)	0.9783	0.0587
As (mg/kg)	0.28	1	Max	0.09	1 - (0.28 / 1)	0.7200	0.0648
Hg (mg/kg)	0.03	2	Max	0.05	1 - (0.03 / 2)	0.9850	0.0493
Microbial Biomass (μg C/g soil)	562.3	≥ 122.15	Min	0.09	562.3 / 122.15	1.0000	0.0900
SQI = ∑ (Weight × SI) =							0.8782

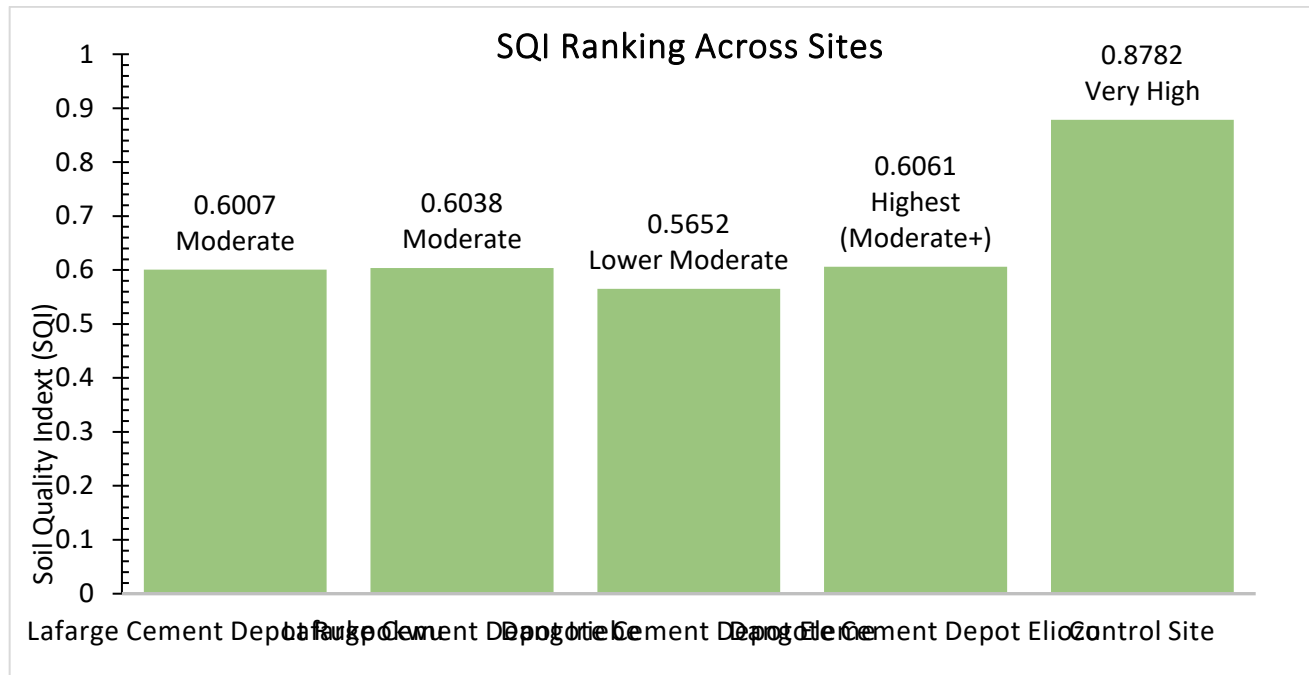


Figure 3: A visual representation of the SQI across the cement depots and the control site

3.4 Statistical Analysis of SQI

ANOVA confirmed that SQI differences between sites were not statistically significant ($p = 0.431$), as shown in Table 9. Tukey's post hoc tests showed no significant pairwise contrasts, even between the lowest-quality site (Eleme) and the control. Although not statistically distinct, the consistent trend of lower SQI values in cement-exposed soils relative to the control underscores the cumulative ecological stress imposed by cement storage activities.

Table 9: ANOVA and Tukey HSD Pairwise Comparisons of Soil Quality Index Across the Sites

Source	Sum of Squares	df	F-value	p-value
Cement Depot	0.003302	4	0.968	0.431
Residual	0.055403	65	—	—
Total	0.058705	69		

Group 1	Group 2	Mean Diff	p-value	95% CI Lower	95% CI Upper	Significant?
Dangote Cement Depot Eleme	Dangote Cement Depot Eliozu	0.0029	0.999 ^a	-0.0280	0.0339	No
Dangote Cement Depot Eleme	Lafarge Cement Depot Iriebe	0.0028	0.999 ^a	-0.0282	0.0337	No
Dangote Cement Depot Eleme	Lafarge Cement Depot Rukpokwu	0.0025	0.999 ^a	-0.0284	0.0335	No
Dangote Cement Depot Eleme	Control Site	0.0190	0.427 ^a	-0.0119	0.0500	No
Dangote Cement Depot Eliozu	Lafarge Cement Depot Iriebe	-0.0002	1.000 ^a	-0.0311	0.0308	No
Dangote Cement Depot Eliozu	Lafarge Cement Depot Rukpokwu	-0.0004	1.000 ^a	-0.0313	0.0306	No
Dangote Cement Depot Eliozu	Control Site	0.0161	0.593 ^a	-0.0149	0.0471	No
Lafarge Cement Depot Iriebe	Lafarge Cement Depot Rukpokwu	-0.0002	1.000 ^a	-0.0312	0.0307	No
Lafarge Cement Depot Iriebe	Control Site	0.0163	0.583 ^a	-0.0147	0.0472	No
Lafarge Cement Depot Rukpokwu	Control Site	0.0165	0.571 ^a	-0.0145	0.0474	No

4. DISCUSSION

This study evaluated the physicochemical and microbial characteristics of soils surrounding four cement depots and compared them with a non-depot control site, using the Soil Quality Index (SQI) as an integrative measure of soil health.

Depot soils were consistently alkaline ($\text{pH} > 8.2$), which contrasted with the near-neutral pH of the control soil. Electrical conductivity and bulk density were also elevated around depots, reflecting chemical enrichment and compaction. Although organic matter and nutrients were moderate to high in most depot soils, heavy metals such as cadmium and arsenic were consistently above permissible limits, especially at Eleme. These chemical stresses coincided with reduced microbial biomass and viable counts compared to the control.

Microbial community composition also shifted due to cement exposure. *Serratia* and *Acinetobacter* dominated Lafarge depots, while *Bacillus*, *Corynebacterium*, and *Pseudomonas* were more common at Dangote depots. Fungal assemblages were likewise skewed toward resilient taxa, including *Aspergillus*, *Fusarium*, and *Trichoderma*. The control soil, by contrast, maintained broader richness with *Streptomyces*, *Rhizopus*, and diverse *Bacillus* species. Heatmap clustering further confirmed the grouping of depot soils by their shared dominance of stress-tolerant taxa, while the control site stood apart, with its richer community.

The results reveal that cement storage activities may impose alkaline stress, heavy metal enrichment, and microbial depletion, consistent with other reports around cement facilities (Meme & Nwadukwe, 2016; Ogunkunle & Fatoba, 2014). Although microbial biomass at the control site ($> 560 \mu\text{g C/g}$) aligns with values reported for undisturbed soils (Benbi et al., 2015; Stevenson et al., 2014), depots consistently showed lower biomass and counts, suggesting functional impairment. The qualitative shifts toward opportunistic bacteria such as *Serratia* (Trinh et al., 2024) and stress-tolerant fungi, including *Aspergillus* and *Fusarium* (Sowunmi et al., 2020), further highlight ecological disturbances and potential occupational exposure risks.

Despite these alterations, depot soils retained moderate SQI values (0.565-0.606), mainly sustained by organic matter and microbial activity. The control site's higher SQI (0.878) underscores the buffering role of balanced pH, low contamination, and high microbial biomass. The absence of statistically significant differences in SQI among sites ($p = 0.431$) may reflect compensatory processes such as organic matter inputs, microbial resilience, or differences in depot operations.

These findings suggest that cement depot soils remain partially functional but under environmental stress. The persistent accumulation of heavy metals, particularly cadmium and arsenic, at Eleme, presents ecological and potential groundwater risks, necessitating monitoring and remediation. Moreover, over-reliance on SQI alone may mask site-specific vulnerabilities. Integrating microbial diversity metrics and contaminant-specific risk assessments could provide a more sensitive evaluation framework. The results also reaffirm the utility of SQI as a multidimensional assessment tool but highlight its limitations when moderate values coexist with clear evidence of microbial and chemical stress.

5. CONCLUSION

Cement depot soils showed clear changes compared to the control. They were more alkaline, moderately saline, and contained higher levels of heavy metals, especially cadmium and arsenic, at Eleme. Microbial biomass and viable counts were lower, with communities shifting toward stress-tolerant taxa such as *Serratia*, *Aspergillus*, and *Fusarium*. Despite these stresses, depot soils maintained moderate SQI values, reinforced by organic matter and microbial activity. The control site scored higher, reflecting balanced pH, low contamination, and diverse microbial communities. Generally, depot soils remain partly functional but are under ecological stress, with long-term risks if heavy metal buildup continues.

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