Journal of Toxicological Studies 2025, 3(1), 2187.
https://doi.org/10.59400/jts2187

Article

Tracking heavy metal pollution and potential ecological threats in soils around Mfamosing cement plant, Nigeria

Udiba U. Udiba[1,*], Blossom U. Ejah[1], Abo I. Nta[1], John Ama[1], Amah J. Etim[2], Ekom R. Akpan[3], Ekpo E. Antai[3]

[1] Department of Zoology and Environmental Biology, University of Calabar, Calabar 540271, Nigeria
[2] Department of Geography and Environmental Science, University of Calabar, Calabar 540271, Nigeria
[3] Institute of Oceanography, University of Calabar, Calabar 540271, Nigeria
*** Corresponding author:** Udiba U. Udiba, udiba.udiba@yahoo.com, udibaudiba@unical.edu.ng

CITATION

Udiba UU, Ejah BU, Nta AI, et al. Tracking heavy metal pollution and potential ecological threats in soils around Mfamosing cement plant, Nigeria. Journal of Toxicological Studies. 2025; 3(1): 2187. https://doi.org/10.59400/jts2187

ARTICLE INFO

Received: 2 December 2024
Accepted: 13 January 2025
Available online: 10 March 2025

Abstract: This study, conducted from June to December 2022 around the Mfamosing cement plant in Akamkpa, Nigeria, evaluated soil pollution status and potential ecological risks posed by heavy metals using an Atomic Absorption Spectrophotometer (Model AA-6800, Japan) after wet digestion. The ranges of lead, cadmium, mercury, arsenic and chromium concentrations (mg/kg) were: 9.11–84.73, 0.21–9.94, 0.64–0.78, 4.63–5.92, 8.25–37.23 respectively. The mean soil metals concentrations were below US-EPA maximum permissible limits and Dutch soil intervention values, cadmium being the only exception. The high spatial variations reflecting decreased metal levels with increasing distance from the cement plant suggest the cement plant may be responsible for the elevated soil metal concentrations. Metals contamination factors correspond to contamination status ranging from low contamination to very high contamination. Index of geo-accumulation (Igeo), revealed that Farms 1, 2, 3, and 4 ranged from unpolluted to strongly polluted. Ecological risk factor revealed that the metals pose a range of low to high potential ecological risk to other components of the environment. Given these findings, metal speciation analysis is strongly recommended to better understand the mobility, bioavailability, and toxicity of the contaminants. This would provide essential insights into potential uptake by crops, ecological transfer, and leaching risks, thereby guiding more targeted environmental management and remediation strategies.

Keywords: cement dust; soil; heavy metals; ecological risk; pollution status

1. Introduction

Ecological or environmental toxicology focuses on studying the detrimental effects of substances released by human activities or natural occurrences in diverse environmental elements (air, water, soil, and food) exposed to man and other living organisms [1]. To evaluate the potential risks and adverse effects on ecological communities resulting from exposure to physical, biological, or chemical stressors, ecological risk assessment is employed. This scientific approach aims to safeguard and manage the environment by assessing the ecological impacts of human activities [2].

With the increasing global industrialization and urbanization, substantial amounts of dust, particulate matter, and pollutants are continuously being produced, posing threats to human and environmental health [3]. Since the demand for cement, according to Mishra and Siddiqui [4], is directly correlated with economic growth, developing economies' sincere pursuit of rapid infrastructure expansion over time has been a stimulus for the enormous rise in cement production. The cement industry, crucial for economic growth and infrastructure development, generates significant amounts of gaseous and particulate emissions during its production process. However, the increase in cement production has raised environmental concerns and sustainability issues. Sustainable development calls for meeting present needs while preserving the environment for future generations. Cement production is associated with a range of environmental impacts, ranging from landscape damage during raw material extraction to the emission of gaseous and particulate matter, which poses health and safety concerns [5].

Dust and contaminants released by cement industries can be transported over considerable distances, affecting areas surrounding the factories with higher concentrations and gradually decreasing with distance [6]. Heavy metals that are known to have detrimental effects on both human health and the environment, such as iron, manganese, nickel, cobalt, zinc, chromium, lead, mercury, and cadmium, are commonly found in these emissions [5]. Heavy metals are particularly unsafe due to their toxic and persistent nature, as they can be transformed into different chemical forms depending on environmental conditions. The presence of heavy metals in the soil is of great concern as it can lead to their uptake by organisms within the ecosystem [7]. Given the significance of soil as both a geochemical sink for contaminants and a natural buffer that influences the movement of chemical elements within the environment, understanding the chemo-dynamics of heavy metals is essential [8]. Organisms in an ecosystem are interconnected, making ecological exposure to heavy metals possible when these elements reach locations within organisms in bioavailable forms [9]. The global scale of heavy metal contamination and pollution has raised concerns due to their multiple sources and widespread distribution, impacting ecosystems adversely [10,11].

Mfamosing cement plant was originally established in 2002 and inaugurated for production on 12 May 2009, as United Cement Company, Nigeria (UNICEM) Limited, following the acquisition of the assets of Calabar Cement Company (CalCemCo), with an initial install capacity of 2.5 million tons per annum. It is currently the single largest cement production site for Lafarge Africa Plc, having been upgraded to 5 million tons per annum and inaugurated for production in 2016 after its affiliate, Nigerian Cement Holdings (NCH) completed a 100% acquisition of the United Cement Company Nigeria (UNICEM) Limited. Given that, about 0.07 kg of dust is released into the atmosphere for every 1 kg of cement produced [12], an estimated 3.325 million tonnes of dust rich in heavy metals may have been discharged into the Mfamosing ecological geochemical environment between 2009 and 2022 by the Mfamosing, cement plant [12].

Despite being a major contributor to economic growth, the cement industry faces controversies and politics, especially regarding corporate social responsibility (CSR) investments in host communities. CSR emphasizes the responsibility of organizations for their impact on society and the environment, aiming to balance economic interests with environmental conservation and sustainable livelihoods [13]. However, deficiencies in monitoring environmental performance compliance have allowed some plant operators to exploit host communities, leading to environmental degradation [14]. Communities near cement production plants often face adverse effects on soil, air, water, and agriculture, but a lack of scientific data has left them voiceless and unable to ascertain the extent and severity of these impacts [12–15]. This study aims to assess the lead, cadmium, mercury, arsenic and chromium pollution status and the potential risks of soils in the vicinity of the Mfamosing cement plant, Nigeria. Though the plant is a modern plant and the amount of cement dust estimated may not have been discharged, periodic assessment of the ecological risk posed is absolutely necessary to safeguard both human and environmental health.

2. Materials and methods

2.1. Study area

The Mfamosing Cement plant is located in the Cross River limestone belt in Mfamosing, Akamkpa Local Government Area of Nigeria, about 30 km northeast of Calabar. This plant is part of the Lafarge cement concession area, under a mining lease to Lafarge Holcim, and is situated in the rural AbiMfam community [16]. It is positioned between latitudes 4°53′ N and 5°05′ N and longitudes 8°15′ E and 8°27′ E (**Figure 1**). The area is characterized by limited infrastructure and a tropical climate with prominent rainforest vegetation. The annual rainfall averages around 1600 mm, and temperatures range from 26 °C to 36 °C. Calabar experiences two distinct seasons: A wet season from April to October and a dry season from November to March. There is a brief drought period, called the "August break", in August and September during the wet season. Additionally, the region experiences harmattan conditions with very low night temperatures from December to February [17]. The primary occupation of the local population is farming, with cassava being the most widely grown crop and the main staple food.

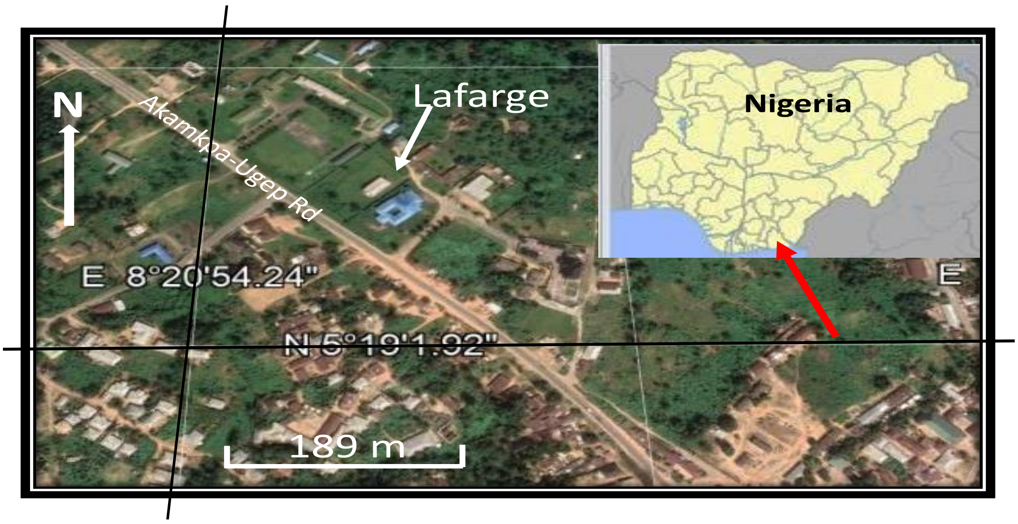

Figure 1. Map of study area showing Mfamosing cement plant, Akamkpa local government area, Nigeria.

2.2. Sample collection and preservation

The procedure followed the methodology outlined by Abida [12], which was used in the collection and preservation of the sample. The study area consisted of fertile agricultural soil, with cassava farms located on both sides of the road leading from the factory gate. Four specific cassava farms were selected for the study. Farm 1 was situated directly opposite the factory gate (zero meters); farm 2 was 500 m away from the gate, farm 3 was 1000 m away, and farm 4 was 1500 m away from the factory gate. Each farm was divided into three sections, labelled as sampling points 1, 2, and 3. Soil samples were collected at a depth of 1–10 cm using a soil auger and then combined into a composite sample representing the entire farm. For proper identification and preservation, the composite samples were kept in black polyethylene bags with labels. Three cassava farms in Atimbo Village, which is 30 km from the study region, provided control samples. As with the farm samples, the control samples were also composite samples made by mixing soil samples from the different farms in Atimbo village. After that, all samples were brought to Lab 249 at the University of Calabar's Department of Zoology and Environmental Biology for processing.

2.3. Sample preparation

A standardized process was used to prepare the soil samples for analysis [18]. Each farm's soil samples were carefully combined. to ensure uniformity, and then air-dried for five days to remove moisture. To obtain a fine particle size, the dry materials were ground up and sieved using a 2 mm mesh. With a 3:1:1 ratio of concentrated nitric acid, perchloric acid, and hydrofluoric acid, one gram of the homogenized and sieved sample was digested in a 250 mL glass beaker on a hot plate. Following near-total evaporation, 20 mL of 2% nitric acid were added and filtered into a 50 mL volumetric flask. The final volume was then adjusted to the 50 ml mark with deionized, distilled water [19,20].

2.4. Sample analysis

Metal concentrations in the digested samples were determined with a Shimadzu Atomic Absorption Spectrophotometer (model AA-6800, Japan), utilizing Zeeman background correction and a graphite furnace for enhanced accuracy. This analytical procedure was carried out at the National Research Institute for Chemical Technology (NARICT) located in Zaria, Nigeria.

2.5. Analytical quality assurance

To ensure result accuracy and dependability, strict quality control protocols were followed throughout the study. Samples were managed with care to prevent any potential cross-contamination. All glassware was meticulously cleaned, and deionized distilled water was consistently used. High-purity, analytical-grade reagents—including HNO_3 (Riedel-deHaen, Germany), HF (Sigma Aldrich, Germany), and $HClO_4$ (British Drug House Chemicals Limited, England)—were applied in the analysis. Each sample batch included a blank and a set of mixed standards to check for background contamination and maintain consistency. Additionally, the accuracy was confirmed by processing Standard Reference Materials (Lichens coded IAEA-336) under the same digestion and analysis methods and comparing the results with the certified values for the target elements.

2.6. Statistical analysis

Statistical analyses were carried out using IBM SPSS software version 23.0 for Windows. To determine if there were significant variations between the control group and the four study farms (Farms 1, 2, 3, and 4), an Analysis of Variance (ANOVA) was conducted. Seasonal differences in soil heavy metal concentrations were analyzed with an independent t-test, and a significance threshold of $p < 0.05$ was applied to both tests. The relationship between metal concentrations in cassava farms and cassava tissues was assessed using the correlation coefficient at $\alpha = 0.05$. Correlation strength was categorized as follows: strong negative (−0.8 to −1.0), moderate negative (−0.5 to −0.8), weak negative (−0.2 to −0.5), no association (−0.2 to +0.2), weak positive (+0.2 to +0.5), moderate positive (+0.5 to +0.8), and strong positive (+0.8 to +1.0).

2.7. Evaluation of potential ecological risk

The levels of metal contamination and their potential risks were analyzed using multiple quantitative indices, such as the contamination factor, degree of contamination, ecological risk factor, geo-accumulation index, and pollution load index [21,22].

2.7.1. Contamination factor (CF)

The Contamination Factor (CF), defined by Equation (1), measures soil contamination by comparing the average metal content in soil from sampling sites (Cs) with the pre-industrial reference level for that metal (Cp).

$$\mathrm{CF} = \frac{\mathrm{Cs}}{\mathrm{Cp}} \tag{1}$$

2.7.2. Contamination degree (CD)

The Contamination Degree (CD), represented by Equation (2), indicates the overall contamination level in soil from a specific farm. It is calculated by summing all the contamination factors for each metal at the site.

$$CD = \sum_{i=1}^{n} \mathrm{CF} \tag{2}$$

2.7.3. Ecological risk factor

Using Equation (3), the Ecological Risk Factor (Er) was calculated to assess the potential threat posed by each metal. This factor incorporates both the contamination factor (CF) and the toxic-response factor (Tr) of the relevant metal.

$$\mathrm{Er} = \mathrm{Tr} \times \mathrm{CF} \tag{3}$$

2.7.4. Index of geo-accumulation

The Index of Geo-accumulation (Igeo), calculated using Equation (4), evaluates metal contamination levels in soil by comparing present heavy metal concentrations (Cl) to those from pre-industrial times (Crl). To accommodate variations in background values and slight human impacts, a correction factor of 1.5 is applied.

$$I_{\mathrm{geo}} = \log_2 [C_{\mathrm{l}} / (1.5 C_{rl})] \tag{4}$$

2.7.5. Pollution load index (PLI)

Pollution load index evaluates the level of heavy metal pollution in the study area, as shown in Equation 5. This index provides a straightforward method to compare the pollution quality of the site based on the contamination factors (CF1 to CFn) of all the metals studied [23].

$$PLI = n\sqrt{(CF1 \times CF2 \times CF3 \times \ldots CFn)} \quad (5)$$

These indices collectively offer valuable insights into the potential ecological risks and contamination levels of heavy metals in the soil around the cement plant.

3. Results and discussion

3.1. Analytical quality assurance

The evaluation of the standard reference material (Lichen IAEA-336), processed and analyzed in the same way as the soil samples, revealed that the results were within the certified reference values for the elements analyzed (**Table 1**). This indicates that the analytical approach utilized in this study is both accurate and reliable.

Table 1. Analyzed values of reference materials (Lichen IAEA-336) compared to certified reference values (mg/kg).

Elements (mg/kg)	Lead	Cadmium	Mercury	Arsenic	Chromium
Analyzed values	4.98	0.121	0.19	0.68	1.07
Reference values	4.3–5.5	0.10–0.134	0.16–0.24	0.55–0.71	0.89–1.23

3.2. Total heavy metal concentration in soil across cassava farms

The heavy metal concentrations result in soils across cassava farms within the vicinity of the Mfamosing Cement plant, Nigeria for both the dry and wet seasons are presented in **Table 2**. A comparison of the heavy metal concentration in soil across the cassava farms for the dry and wet seasons can be found in **Figures 2** and **3**.

The average lead concentrations in the soil for both the dry and wet seasons were as follows: 59.41 ± 3.94 and 81.61 ± 3.67 for farm 1, 47.01 ± 4.07 and 76.45 ± 3.14 for farm 2, 40.04 ± 3.15 and 63.67 ± 6.61 for farm 3, 22.67 ± 2.78 and 29.56 ± 3.39 for farm 4, and 9.12 ± 0.01 and 9.13 ± 0.01 for the control station (**Table 2**). The highest concentration of lead (84.73 mg/kg) was recorded in December at farm 1, while the lowest (9.11 mg/kg) was recorded at the control station in July.

Soil quality significantly impacts the production and safety of food [24,25]. The mean concentration of lead in the soil was measured to be below the 400 mg/kg threshold established by the United States Environmental Protection Agency (US-EPA) for lead levels in soil [26]. In the absence of specific metal concentration standards for soil in Nigeria, the Department of Petroleum Resources (DPR) references the Dutch standards as part of its Environmental Guidelines and Standards for the Petroleum Industry (EGASPIN). The Dutch soil remediation policy sets target values to monitor and manage potential environmental hazards.

The remediation intervention threshold for lead is established at 530 mg/kg, reflecting the concentration at which the soil's capacity to sustain human, animal, and plant life is significantly compromised. This value marks the threshold above which soil is considered seriously contaminated. A lead level of 85 mg/kg is identified as the target value, indicating a level below which sustainable soil quality is attained, allowing for the complete restoration of all functional properties essential for human, animal, and plant life [27].

This research demonstrated that soil lead levels were lower than both the Dutch target and intervention levels, suggesting that the soil's functional properties remain unaffected by lead contamination. Nevertheless, the highest lead level recorded in December at farm 1 was 84.73 mg/kg, nearly reaching the target value. This farm is located opposite the factory gate, raising concerns about potential toxicological risks depending on the chemical form of lead and soil conditions. There is a possibility of plant uptake of mobilized lead or leaching into groundwater, which warrants attention.

Table 2. Total heavy metal concentration mg/kg in soil across cassava farm within the vicinity of Mfamosing cement plant, Nigeria.

Farms	Metals	Dry Season					Wet Season				
		June	July	August	Mean ± SD	Range	October	November	December	Mean ± SD	Range
1	Pb	53.84	62.12	62.26	59.41 ± 3.94^{a}	53.84–62.26	76.46	83.64	84.73	81.61 ± 3.67^{b}	76.46–84.73
	Cd	7.34	7.33	7.84	7.50 ± 0.24^{a}	7.33–7.84	8.28	8.94	9.87	9.03 ± 0.65^{b}	8.28–9.94
	Hg	0.73	0.72	0.73	0.73 ± 0.01^{a}	0.72–0.73	0.71	0.74	0.76	0.74 ± 0.02^{a}	0.71–0.76
	As	5.43	5.51	5.55	5.50 ± 0.05^{a}	5.43–5.55	5.65	5.64	5.61	5.63 ± 0.02^{a}	5.61–5.65
	Cr	31.25	32.13	34.21	32.53 ± 1.24^{a}	31.25–34.21	34.56	35.16	37.23	35.65 ± 1.14^{a}	34.46–37.23
2	Pb	41.73	47.64	51.65	47.01 ± 4.07^{a}	41.73–51.65	72.56	76.56	80.24	76.45 ± 3.14^{b}	72.56–80.24
	Cd	6.86	6.98	7.04	6.96 ± 0.07^{a}	6.86–7.04	7.21	7.34	8.03	7.53 ± 0.36^{a}	7.21–8.03
	Hg	0.72	0.74	0.72	0.73 ± 0.01^{a}	0.72–0.74	0.73	0.72	0.75	0.73 ± 0.01^{a}	0.012472
	As	5.21	5.32	5.33	5.29 ± 0.05^{a}	5.21–5.33	5.21	5.67	5.92	5.60 ± 0.29^{a}	5.21–5.92
	Cr	25.23	24.87	26.12	25.41 ± 0.53^{a}	24.87–26.12	26.87	26.95	27.01	26.94 ± 0.06^{b}	24.87–27.01
3	Pb	35.87	40.77	43.47	40.04 ± 3.15^{a}	35.87–43.47	54.32	68.35	68.34	63.67 ± 6.61^{b}	54.32–68.65
	Cd	4.72	4.85	5.36	4.98 ± 0.28^{a}	4.72–5.36	5.54	5.62	5.81	5.66 ± 0.11^{b}	5.54–5.81
	Hg	0.67	0.64	0.74	0.68 ± 0.04^{a}	0.64–0.74	0.77	0.78	0.77	0.77 ± 0.01^{a}	0.77–0.78
	As	5.03	5.05	5.12	5.07 ± 0.04^{a}	5.03–5.12	5.32	5.64	5.63	5.53 ± 0.15^{a}	5.32–5.64
	Cr	15.51	16.36	16.23	16.03 ± 0.37^{a}	15.51–16.36	16.75	16.76	16.89	16.80 ± 0.06^{a}	16.75–16.89
4	Pb	20.12	21.34	26.54	22.67 ± 2.78^{a}	20.12–26.58	27.11	27.23	34.35	29.56 ± 3.39^{a}	27.11–34.35
	Cd	2.46	2.56	3.65	2.89 ± 0.54^{a}	2.46–3.65	2.78	2.88	2.97	2.88 ± 0.08^{a}	2.78–2.97
	Hg	0.69	0.71	0.73	0.71 ± 0.02^{a}	0.69–0.73	0.71	0.71	0.72	0.71 ± 0.01^{a}	0.71–0.72
	As	4.63	5.42	5.02	5.02 ± 0.32^{a}	4.63–5.42	5.02	5.48	5.51	5.34 ± 0.22^{a}	5.02–5.51
	Cr	10.47	10.23	10.43	10.38 ± 0.10^{a}	10.23–10.47	10.87	11.12	11.25	11.08 ± 0.16^{b}	10.87–11.25
Contrl	Pb	9.12	9.11	9.13	9.12 ± 0.01^{a}	0.008165	9.13	9.14	9.13	9.13 ± 0.01^{a}	9.13–9.14
	Cd	0.21	0.23	0.21	0.22 ± 0.09^{a}	0.21–0.223	0.24	0.21	0.23	0.23 ± 0.01^{a}	0.21–0.24
	Hg	0.69	0.68	0.69	0.69 ± 0.01^{a}	0.68–0.69	0.67	0.71	0.73	0.70 ± 0.02^{a}	0.67–073
	As	4.98	4.89	5.14	5.00 ± 0.10^{a}	4.98–5.14	5.01	5.46	5.55	5.34 ± 0.23^{a}	5.01–5.55
	Cr	8.25	8.26	8.45	8.32 ± 0.09^{a}	8.25–8.45	8.45	8.26	8.34	8.35 ± 0.08^{a}	8.26–8.45

Means with the different superscripts across the row indicates significant ($p < 0.05$, ANOVA) difference in metals concentration.

Soil lead levels were also assessed using Soil Guideline Values (SGVs). In accordance with UK regulations, SGVs serve as benchmarks for assessing the potential risks to human health associated with prolonged exposure to chemical contaminants in soil [28]. The mean soil lead concentrations in this study were found to be lower than the SGVs for lead in residential areas with homegrown plant produce, which is set at 200 mg/kg [29]. Soils around cement factories have been previously reported to show high concentrations of heavy metals, especially lead, zinc, and cadmium, particularly in the top 0–10 cm of soil [30]. Similar mean soil lead levels were reported for other cement factories in different regions, with the highest concentrations found near the plant and decreasing with increasing distance [12,31,32]. The production process in the cement industry, which involves burning fossil fuels, may contribute to the presence of lead in the environment through impurities or additives in fossil fuels and dust and particulate matter emitted during cement production [31]. Lead has adverse effects on plants, interfering with important enzymes and inhibiting seed germination. It can also affect the photosynthetic process, growth, development, and overall morphology of plants [33]. Certain plant species, such as Senna obtusifolia, can phytoextract lead from the soil and transport it to the above-ground parts, posing significant health risks to humans and animals [34].

The average concentrations of cadmium in the soil were found to be 7.50 ± 0.24 and 9.03 ± 0.65 mg/kg for farm 1, 6.96 ± 0.07 and 7.53 ± 0.36 mg/kg for farm 2, 4.98 ± 0.28 and 5.66 ± 0.11 mg/kg for farm 3, 2.89 ± 0.54 and 2.88 ± 0.08 mg/kg for farm 4, and 0.22 ± 0.09 and 0.23 ± 0.0 mg/kg for the control station during the dry and wet seasons, respectively. The highest cadmium concentration (9.94 mg/kg) was recorded in November at farm 1, while the lowest concentration (0.21 mg/kg) was found at the control station in June, July, and November. Cadmium has a low crustal abundance and is slightly soluble in water, making it more mobile in soil and readily bioavailable. The recorded cadmium concentrations exceeded the US-EPA and European Union limits for cadmium in soil (3 mg/kg), indicating potential contamination in farms 1, 2, and 3. However, the concentrations were below the Dutch remediation intervention value (12 mg/kg) and the soil guideline values for cadmium in residential areas with homegrown plants (10 mg/kg), suggesting that the soil quality may still be sustainable but requires further investigation. Given cadmium's mobility and bioavailability, there is a risk of plant uptake or leaching into groundwater, potentially leading to cumulative toxicity and risks to organisms higher up the food chain. Cadmium levels at farms 1, 2, and 3 were higher than the average of 5.24 mg/kg reported by Mandal and Voutchkov, but lower than the range of 0.12 ± 0.00 to 0.74 ± 0.04 mg/kg reported by Olowoyo et al.

For mercury, the mean concentrations were 0.73 ± 0.01 and 0.74 ± 0.02 mg/kg for farm 1, 0.73 ± 0.01 and 0.73 ± 0.01 mg/kg for farm 2, 0.68 ± 0.04 and 0.77 ± 0.01 mg/kg for farm 3, 0.71 ± 0.02 and 0.71 ± 0.01 mg/kg for farm 4, and 0.69 ± 0.01 and 0.70 ± 0.02 mg/kg for the control station during the dry and wet seasons, respectively. The highest mercury concentration (0.78 mg/kg) was recorded in November at farm 3, while the lowest concentration (0.64 mg/kg) was found at farm 3 in July. Mercury occurs naturally in various forms, and its concentration and toxicity depend on the chemical form, soil sorption, pH, and soil chemistry. The mercury concentrations in all cassava farms were above the Dutch target value (0.3 mg/kg) but below the intervention value (10 mg/kg) and the Environment Agency soil guideline values for residential areas with homegrown plants (11 mg/kg for methyl mercury compounds and 170 mg/kg for inorganic mercury). There was no significant variation in mercury concentration across the farms. Elevated mercury levels can cause phytotoxic effects, including physiological disorders, oxidative stress, and interference with plant activities.

For chromium, the mean concentrations were 32.53 ± 1.24 and 35.65 ± 1.14 mg/kg for farm 1, 25.41 ± 0.53 and 26.94 ± 0.06 mg/kg for farm 2, 16.03 ± 0.37 and 16.80 ± 0.06 mg/kg for farm 3, 10.38 ± 0.10 and 11.08 ± 0.16 mg/kg for farm 4, and 8.32 ± 0.09 and 8.35 ± 0.08 mg/kg for the control station at Atimbo during the dry and wet seasons, respectively. The highest chromium concentration (37.23 mg/kg) was recorded in December at farm 1, while the lowest concentration (8.25 mg/kg) was found at the control station in June. The chromium concentrations in the soil were below the WHO guidelines for soil chromium levels (300 mg/kg), the European Union Regulatory Standards for chromium in soil, and the FAO guidelines for soil chromium levels (100 mg/kg). Chromium was not identified as posing a toxicological risk to the environment. Previous studies have reported different mean chromium concentrations in the soil around cement factories, with values ranging from 35.60 mg/kg to 138.67 mg/kg. Chromium can induce oxidative stress in plants, causing cell membrane damage, degradation of photosynthetic pigments, and inhibition of growth and development.

Table 2 indicates that the mean concentrations (mg/kg) of arsenic in soil for both dry and wet seasons were 5.50 ± 0.05 and 5.63 ± 0.02 for farm 1, 5.29 ± 0.05 and 5.60 ± 0.29 for farm 2, 5.07 ± 0.04 and 5.53 ± 0.15 for farm 3, 5.02 ± 0.32 and 5.34 ± 0.22 for farm 4, and 5.00 ± 0.10 and 5.34 ± 0.23 for the control station at Atimbo. The highest concentration of arsenic in soil across cassava farms (5.92 mg/kg) was recorded in December at farm 2, and the lowest (4.63 mg/kg) at farm 4 in June. Naturally, arsenic occurs in the environment, but increased levels are linked to anthropogenic activities [35]. Arsenic is very soluble in its inorganic form. Excessive arsenic uptake by plants interferes with enzyme function and phosphate movement in the plant system. The soil guideline value (SGV) for arsenic is 32 mg/kg [36]. The target and intervention values for arsenic in soil are 29 and 55 mg/kg, respectively [27]. The arsenic concentrations in this study were below the SGVs and Dutch target and intervention values. Arsenic concentrations ranging from 3.43 ± 0.15 to 8.84 ± 0.06 Mg/kg have been reported for soils around cement factories [12]. A mean value of 7.6 Mg/kg was recorded in topsoil near the cement plant [37]. Arsenic is highly phototoxic. It causes stunted growth, chlorosis, wilting, reduced fruit yield, and reduced leaf area and dry matter production [33].

3.3. Relationship between heavy metal in soil across cassava farms

3.3.1. Spatial variation of heavy metal in soil across cassava farms

Spatial variation of metal content in soil across cassava farms showed significant differences in the concentrations of lead, cadmium, and chromium with increasing distance from the cement factory. Lead concentrations followed the trend: Farm 1 > Farm 2 = Farm 3 > Farm 4. For cadmium, the trend was: Farm 1 = Farm 2 > Farm 3 >

Farm 4, and for chromium: Farm 1 > Farm 2 > Farm 3 > Farm 4. These results align with other studies. Semhi et al. [38] indicated that proximity to industrial sources, such as cement factories, can result in higher concentrations of heavy metals in the surrounding soil. The significant differences in metal concentrations between the study area and the control station suggest a strong influence of human activities, particularly the cement plant, on metal levels in the area. In contrast, mercury and arsenic concentrations did not show significant variations across the farms or between the study area and the control station, indicating that their presence may be attributed to natural sources. These findings imply that topsoil can be a valuable tool for monitoring the impact of anthropogenic activities on the environment.

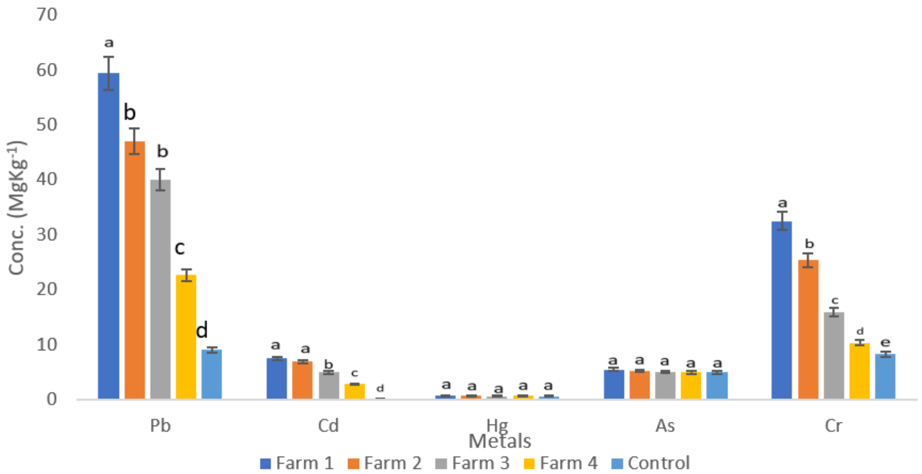

Figure 2. Comparison of metal concentration in soil across cassava farms for dry season.

Bars with different superscript for a given metal indicates significant difference (ANOVA, $p < 0.05$) in the mean concentration of the metal.

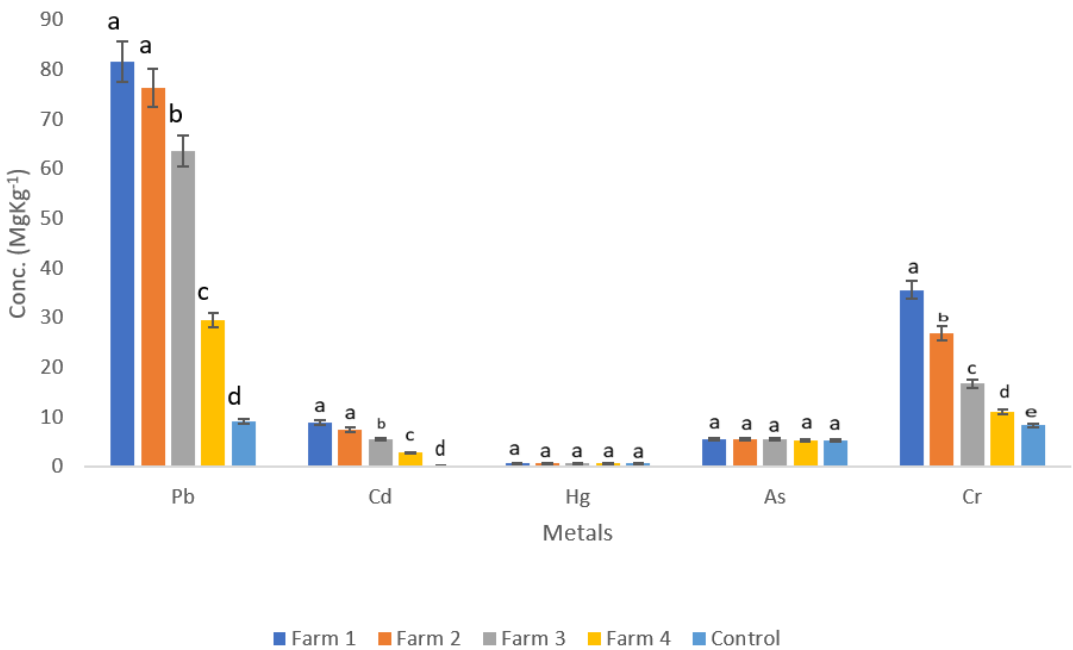

Figure 3. A Comparison of soil metal concentrations across cassava farms during the wet season.

Bars with different superscript for a given metal indicates significant difference (ANOVA, $p < 0.05$) in the mean concentration of the metal.

3.3.2. Seasonal variation of heavy metal in soil across cassava farms

Seasonal variations in soil heavy metal concentrations across cassava farms within the vicinity of the Mfamosing Cement plant in Nigeria were observed. The differences in lead concentrations between wet and dry seasons were significant ($p < 0.05$) for farms 1, 2, and 3, while cadmium concentrations showed significant ($p < 0.05$) differences for farms 1 and 3, and chromium concentrations for farms 2 and 4 (**Table 2**). Concentrations of the metals during the wet season were found to be significantly higher compared to the dry season. The observed higher wet season metal concentrations may be attributed to increased moisture during the wet season which may have led to the dissolution of cement dust and subsequent release of more metals into the soil. Additionally, the wet conditions may facilitate the mobilization of metals, depending on the soil chemistry. Various factors, such as the chemical form of the metals, soil pH, and cation exchange capacity, can influence the availability of heavy metals, affecting their solubility, adsorption, retention, and movement within the soil. Soil moisture content plays a crucial role in enhancing these factors [39].

3.3.3. The relationship between heavy metals in soil across cassava farms

Table 3 illustrates the relationships between heavy metals in the soil of cassava farms near the Mfamosing Cement plant in Nigeria. The data reveals significant ($p < 0.01$) positive correlations between various metal pairs. A very strong positive correlation was observed between lead and cadmium ($r = 0.944$), lead and chromium ($r = 0.871$), and cadmium and chromium ($r = 0.936$). Additionally, moderately strong correlations were found between lead and mercury ($r = 0.596$) and lead and arsenic (r = 0.657). The correlations between cadmium and mercury ($r = 0.514$), cadmium and arsenic ($r = 0.541$), mercury and arsenic ($r = 0.626$), and arsenic and chromium ($r = 0.552$) were also significant ($p < 0.01$) and moderately strong. These positive correlations suggest that an increase in the concentration of one metal is associated with a corresponding increase in the concentration of the other. The very strong positive correlations between lead, cadmium, and chromium at a 99% confidence level indicate that these metals may originate from the same source. Conversely, the moderate positive correlations between arsenic, mercury, and the other metals suggest a lower probability that they share the same source as lead, cadmium, and chromium.

Table 3. Correlations showing association between heavy metals concentrations in soil.

		Lead	**Cadmium**	**Mercury**	**Arsenic**	**Chromium**
Lead	Pearson Correlation	1				
	Sig. (2-tailed)					
	N	30				
Cadmium	Pearson Correlation	0.944**	1			
	Sig. (2-tailed)	0.000				
	N	30	30			
Mercury	Pearson Correlation	0.596**	0.514**	1		
	Sig. (2-tailed)	0.001	0.004			
	N	30	30	30		

Table 3. (*Continued*).

		Lead	Cadmium	Mercury	Arsenic	Chromium
Arsenic	Pearson Correlation	0.657**	0.541**	0.626**	1	
	Sig. (2-tailed)	0.000	0.002	0.000		
	N	30	30	30	30	
Chromium	Pearson Correlation	0.871**	0.936**	0.397*	0.552**	1
	Sig. (2-tailed)	0.000	0.000	0.030	0.002	
	N	30	30	30	30	30

**. Correlation is significant at the 0.01 level. *. Correlation is significant at the 0.05 level.

3.4. Evaluation of potential ecological risk posed by some heavy metals

This study assessed the potential ecological risks of cadmium, lead, mercury, arsenic, and chromium in the soil near the Mfamosing Cement plant in Nigeria. For this evaluation, pre-industrial reference levels and toxic response factors determined by Hakanson [21] (see **Table 4**) were used to calculate the contamination and ecological risk factors. The results of these ecological risk assessments are detailed in **Tables 5–8**.

Table 4. Pre-industrial reference level (μgg^{-1}) and toxic-response factor.

Elements	Hg	Cd	As	Pb	Cr
Pre-industrial reference level	0.25	1.0	15	7.0	90
Toxic-response factor	40	30	10	5	2

Source: [21].

3.4.1. Contamination factor and contamination degree

The contamination factor and contamination degree were utilized to assess the soil contamination status. The average contamination factors for both dry and wet seasons were as follows: 6.04 and 8.98 for lead, 5.58 and 6.28 for cadmium, 2.87 and 2.96 for mercury, 0.35 and 0.37 for arsenic, and 0.22 and 0.25 for chromium (**Table 5**). Lead had the highest contamination factor (11.66) recorded at farm 1 during the wet season, while chromium had the lowest contamination factor (0.09) recorded at the control station (Atimbo) in both wet and dry seasons. The interpretation of the contamination factors followed specific criteria: $Cf < 1$ indicated low contamination, $1 \leq Cf < 3$ suggested moderate contamination, $3 \leq Cf < 6$ represented considerable contamination, and $Cf \geq 6$ indicated very high contamination [22]. Based on these criteria, the lead contamination status for both dry and wet seasons corresponded to very high contamination. Cadmium showed contamination status ranging from considerable contamination to very high contamination, while chromium corresponded to moderate contamination. On the other hand, mercury and arsenic in the study were associated with low contamination (**Table 5**). The high contamination factor for lead, cadmium and chromium suggests significant anthropogenic contribution, while the low contamination factor for mercury and arsenic suggests minimal anthropogenic contribution.

Table 5. Contamination factor (CF) and contamination degree (CD).

Sampling Station	Dry Season						Wet Season					
	Contamination Factor (CF)					Contamination degree (CD)	Contamination Factor (CF)					Contamination degree (CD)
	Pb	Cd	Hg	As	Cr		Pb	Cd	Hg	As	Cr	
Farm 1	8.49	7.50	2.95	0.37	0.31	19.62	11.66	9.03	2.96	0.38	0.40	24.43
Farm 2	6.72	6.96	2.95	0.35	0.28	17.26	10.92	7.53	2.95	0.37	0.30	22.07
Farm 3	5.72	4.98	2.72	0.34	0.18	13.94	9.10	5.66	3.08	0.37	0.19	18.40
Farm 4	3.24	2.89	2.84	0.33	0.12	9.42	4.22	2.88	2.84	0.36	0.12	10.42
Average	6.04	5.58	2.87	0.35	0.22	15.06	8.98	6.28	2.96	0.37	0.25	18.83
Control	1.30	0.22	2.76	0.33	0.09	4.70	1.30	0.23	2.80	0.36	0.09	4.78

The contamination degree values for both dry and wet seasons were as follows: 19.62 and 24.43 for farm 1, 17.26 and 22.07 for farm 2, 13.94 and 18.40 for farm 3, 9.42 and 10.42 for farm 4, and 4.70 and 4.78 for the control station (**Table 5**). To interpret the contamination degree, the following criteria were employed: Cd < 7 indicated a low degree of contamination, 7 ≤ Cd < 14 represented a moderate degree of contamination, 14 ≤ Cd < 21 indicated a high degree of contamination, and Cd > 21 suggested a very high degree of contamination. Based on these criteria, the contamination degree for farm 1 and farm 2 corresponded to a range from high contamination to very high contamination. Farm 3 displayed a contamination degree ranging from moderate contamination to high contamination. Farm 4 had a contamination degree corresponding to moderate contamination, while the control station exhibited a low contamination degree.

3.4.2. Ecological risk factor (EC)

The ecological risk factor (EC) in this study serves as an indicator of the potential ecological risk associated with the presence of heavy metals in the soil. It helps to assess the vulnerability of various biological communities to metal contamination. The average values of ecological risk factors for both dry and wet seasons were as follows: 30.21 and 44.88 for lead, 167.48 and 188.25 for cadmium, 114.60 and 118.30 for mercury, 3.48 and 3.70 for arsenic, and 0.45 and 0.51 for chromium (**Table 6**). Among the metals studied, cadmium exhibited the highest ecological risk factor, with a value of 270.90 recorded at cassava farm 1 during the wet season, while chromium had the lowest ecological risk factor, with a value of 0.18 recorded at the control station (Atimbo) in both wet and dry seasons. The ecological risk factors for each metal followed the trend of Cd > Hg > Pb > As > Cr in both the dry and wet seasons. The ecological risk factor was categorized into different levels to interpret its implications: Er < 40 represented low potential ecological risk, 40 ≤ Er < 80 indicated moderate potential ecological risk, 80 ≤ Er < 160 signified considerable potential ecological risk, 160 ≤ Er < 320 suggested high potential ecological risk, and Er ≥ 320 indicated very high potential ecological risk [22]. Based on these criteria, lead was found to pose a range of low to moderate ecological risks to the surrounding environment. Cadmium exhibited a high potential ecological risk, indicating a greater concern for its impact on the ecosystem. Mercury posed a considerable ecological risk, while chromium and arsenic were associated with low potential ecological risk to the surrounding geochemical environment.

Table 6. Ecological risk factor (EC).

Sampling Station	Dry Season					Wet Season				
	Pb	**Cd**	**Hg**	**As**	**Cr**	**Pb**	**Cd**	**Hg**	**As**	**Cr**
Farm 1	42.45	225.00	118.00	3.70	0.62	58.30	270.90	118.40	3.80	0.80
Farm 2	33.60	208.80	118.00	3.50	0.56	54.60	225.90	118.00	3.70	0.60
Farm 3	28.60	149.40	108.80	3.40	0.36	45.50	169.80	123.20	3.70	0.38
Farm 4	16.20	86.70	113.60	3.30	0.24	21.10	86.40	113.60	3.60	0.24
Average	30.21	167.48	114.60	3.48	0.45	44.88	188.25	118.30	3.70	0.51
Control	6.50	6.60	110.40	3.30	0.18	6.50	6.90	112.00	3.60	0.18

3.4.3. Index of Geo-accumulation (I_{geo})

The Index of Geo-accumulation (Igeo) was employed to evaluate and classify the levels of metal contamination in the soil by comparing present concentrations with historical "pre-industrial" levels. Muller's method was used to categorize the Igeo into seven distinct classes [22]: $I_{geo} \leq 0$, class 0, indicating an unpolluted state; $0 < I_{geo} \leq 1$, class 1, representing a range from unpolluted to moderately polluted; $1 < I_{geo} \leq 2$, class 2, indicating a moderately polluted state; $2 < I_{geo} \leq 3$, class 3, representing a range from moderately polluted to strongly polluted; $3 < I_{geo} \leq 4$, class 4, indicating a strongly polluted state; $4 < I_{geo} \leq 5$, class 5, representing a range from strongly polluted to extremely polluted; and $I_{geo} > 5$, class 6, indicating an extremely polluted state. **Table 7** shows that the average I_{geo} values for both dry and wet seasons were as follows: 1.93 and 2.48 for lead, 1.80 and 1.94 for cadmium, 0.93 and 1.94 for mercury, −2.11 and -2.03 for arsenic, and −2.81 and −2.72 for chromium. The index of geo-accumulation values followed the trend Pb > Cd > Hg > As > Cr for both dry and wet seasons. Based on the computed I_{geo} values in this study, it was determined that Farms 1, 2, and 3 ranged from moderately polluted to strongly polluted with respect to lead, moderately polluted with respect to cadmium, and from unpolluted to moderately polluted with respect to mercury.

Table 7. Index of geo-accumulation (I_{geo}).

Sampling Station	Dry Season					Wet Season				
	Pb	**Cd**	**Hg**	**As**	**Cr**	**Pb**	**Cd**	**Hg**	**As**	**Cr**
Farm 1	2.50	2.32	0.97	−2.03	−2.05	2.96	2.55	0.98	−2.00	−1.92
Farm 2	2.16	2.21	0.97	−2.09	−2.40	2.86	2.33	0.97	−2.01	−2.33
Farm 3	1.93	1.73	0.86	−2.15	−3.07	2.60	1.91	1.36	−2.02	−3.01
Farm 4	1.11	0.95	0.92	−2.16	−3.70	1.49	0.94	0.92	−2.08	−3.61
Average	1.93	1.80	0.93	−2.11	−2.81	2.48	1.94	1.06	−2.03	−2.72
Control	−0.20	−0.83	0.88	−2.17	−4.02	−0.20	−2.75	0.88	−2.08	−4.01

3.4.4. Pollution load index (PLI)

In this investigation, the Pollution Load Index (PLI) was applied to determine the pollution status of soils located around the United Cement Company in Mfamosing, Nigeria. The PLI provides a measure of the overall pollution quality of the soil based on the presence and concentrations of various pollutants. The following interpretations were used to explain the Pollution Load Index (PLI): PLI > 1 indicates a polluted state; PLI = 1 suggests pollutants are present at baseline levels; and PLI < 1 indicates a non-polluted state. The average values of the pollution load index were determined as 2.00, 1.81, 1.50, 1.04, and 0.62 for cassava farms 1, 2, 3, 4, and the control station, respectively (**Table 8**). Consequently, the PLI values followed the trend in the following order: Cassava farm 1 > Cassava farm 2 > Cassava farm 3 > Cassava farm 4 > control station.

Table 8. Pollution Load Index (PLI).

Seasons	Farm 1	Farm 2	Farm 3	Farm 4	Control
Dry Season	1.85	1.68	1.37	1.00	0.75
Wet Season	2.14	1.93	1.62	1.08	0.49
Average	2.00	1.81	1.50	1.04	0.62

According to the Pollution Load Index (PLI) results, farms 1, 2, 3, and 4 were found to be polluted, whereas the control station was identified as unpolluted. The PLI values displayed the following pattern: Cassava farm 1 had the highest pollution load index, followed by Cassava farm 2, Cassava farm 3, Cassava farm 4, and finally, the control station. This ranking indicates that farm 1 had the highest pollution level among all the sites, while the control station exhibited the least pollution.

4. Conclusion

This study revealed that the mean concentrations of soil metals within 0–2km of the Mfamosing cement plant were below the guidelines set by the United States Environmental Protection Agency (US-EPA), Dutch intervention values, and European Union Regulatory Standards (EURS), except cadmium. A significant decrease in lead, cadmium, and chromium concentrations was observed with increasing distance from the factory to the control station, indicating that cement production activities may be responsible for the higher metal concentrations in the soil. The contamination factor for lead indicated very high contamination, cadmium ranged from substantial to very high contamination, and chromium indicated moderate contamination. Mercury and arsenic indicated low contamination levels. The ecological risk factor showed that lead poses moderate risks to the environment, cadmium poses a high potential ecological risk, mercury poses a considerable ecological risk, and chromium and arsenic pose low potential ecological risks. The geo-accumulation index (Igeo) revealed that Farms 1, 2, 3, and 4 ranged from moderately to strongly polluted with lead, moderately polluted with cadmium, from unpolluted to moderately polluted with mercury, and unpolluted with chromium and arsenic. The pollution load index indicated that Farms 1, 2, 3, and 4 are polluted, while the control station is unpolluted. The pollution load index followed the sequence:

Cassava Farm 1 > Cassava Farm 2 > Cassava Farm 3 > Cassava Farm 4 > Control Station.

Author contributions: Conceptualization, UUU, AIN, BUE, ERA and EEA; methodology, UUU, BUE, ERA, JA and AIN; software, AJE, UUU; validation, ERA, EEA and UUU; formal analysis, UUU, AIN, BUE, ERA, JA and EEA; investigation, All authors; resources, UUU, BUE, AIN, JA, AJE, ERA and EEA; data curation, UUU; writing—original draft preparation, UUU, BUE, AIN, JA, AJE, ERA and EEA; writing—review and editing, UUU, BUE, AIN, JA, AJE, ERA and EEA; supervision, UUU and AIN; project administration, BUE; funding acquisition, UUU, BUE, AIN, JA, AJE, ERA and EEA. All authors have read and agreed to the published version of the manuscript.

Acknowledgments: The authors wish to express their sincere gratitude to the Department of Zoology and Environmental Biology, University of Calabar for making their laboratory available for this work. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sector.

Conflict of interest: The authors declare no conflict of interest.

References

1. Hodgson E. A Textbook on Modern Toxicology. John Willey and Sons Inc., Hoboken, New Jersey; 2004. pp. 74–154.
2. Tavakoly Sany SB, Salleh A, Halim Sulaiman A, et al. Distribution characteristics and ecological risk of heavy metals in surface sediments of West Port, Malaysia. Environment Protection Engineering. 2012; 38(4). doi: 10.37190/epe120412
3. Rai PK. Biomonitoring of particulates through magnetic properties of roadside plant leaves in Tiwari. Advances in Environmental Chemistry. India: Mizoram University; 2011.
4. Mishra S, Siddiqui NA. A Review on Environmental and Health Impacts of Cement. International Journal of Geology, Agriculture and Environmental Sciences. 2014; 2(3): 26–31.
5. Oran SA, Hamad MF, Zahra A. Impact of the cement dust emitted from the South Cement Factory in Tafila/Jordan on plant diversity of the surrousnding area. International Journal of biodiversity and conservation. 2014; 5(6): 400–414.
6. Naeini FY, Azimzadeh H, Arani AM, et al. Ecological risk assessment of heavy metals from cement factory dust', Environmental Health Engineering and Management Journal. 2019; 6(2): 129–137.
7. Udiba UU, Akpan ER, Antai EE. Assessment of Lead (Pb) Uptake and Hazard Potentials of Cassava Plant (Manihot esculentus cranz), Dareta Village, Zamfara, Nigeria'. International Research Journal of Public and Environmental Health. 2019; 6(6): 115–126.
8. Moreno M, Invernizzi R, Pla R, Pignata ML. Heavy metal pollution in top soils near a cement plant: The role of organic matter and distance to the source to predict total and HCl-extracted heavy metal concentrations. Chemosphere. 2010; 78(2010): 375–381.
9. NGCERA. Navy Guidance for Conducting Ecological Risk Assessment: Fundamentals of Ecology and Ecotoxicology, Ecorisk Fundamentals. 1999; 1(1999): 1–30.
10. Nriagu JO. Global metal pollution: poisoning the atmosphere. Environment. 1990; 7: 87– 93.
11. Uwah EI, Ndahi NP, Ogugbuaja VO. Study of the levels of some agricultural pollutants in soils and water leaf (Talinum triangulare) Obtained in Maiduguri, Nigeria. Journal of Applied Sciences in Environmental Sanitation. 2009; 4(2): 71–78.
12. Olowoyo JO, Mugivhisa LL, Busa NG. Trace Metals in Soil and Plants around a Cement Factory in Pretoria, South Africa Pol. J. Environ. Stud. 2015; 24(5): 56–65.
13. Okojie LO. Cement Production and Sustainable Rural Farming Livelihood in Nigeria: Striking a Sensible Balance through Environmental Legislation and Enforcement. European Journal of Sustainable Development. 2014; 3(3): 251–262.
14. Oguntoke O, Awanu AE, Annegarn HJ. 'Impact of cement factory operations on air quality and human health in Ewekoro Local Government Area, South-Western Nigeria', International Journal of Environmental. 2012; 15.

15. Edet EO, Udoe PO, Isong IA, Abiam NE. Based Farmers, Health and Production Efficiency within Lafarge Cement Concession Area in Mfamosing, Cross River State, Nigeria', World News of Natural Sciences. 2019; 23: 182–199.
16. Lafarge. Lafarge Africa Plc at a Glance. Available online: https://www.lafarge.com.ng/lafarge-africa-plc-a-glance (accessed on 4 June 2024).
17. UniCem. UniCem: Jonathan to inaugurate a 2.5 metric tonnes cement line. Available online: https://nairametrics.com/2014/09/02/unicem (accessed on 4 June 2024).
18. Abida BM, Ramaiah H, Khan I, Veena K. Analysis of heavy metals concentration in soil and lichens from various localities of Hosur road, Bangalore. Indian E-journal of Chemistry. 2009; 1: 13–22.
19. Baker DE, Amacher MC. Nickel, Copper, Zinc, and Cadmium. Methods of Soil Analysis. Agron. Monogr; 1982. pp. 323–336. doi: 10.2134/agronmonogr9.2.2ed.c19
20. Udiba UU, Ogabiela EE, Hammuel C,et al. Post remediation assessment of contaminant levels in soil, Dareta Village, Zamfara. Journal of Trends in Advanced Science and Engineering Tase. 2012; 4(1): 70-79.
21. Hakanson L. An ecological risk index for aquatic pollution control: a sedimentological approach. Journal of Water Research. 1980; 14(8): 75–1001.
22. Gong Q, Jun D, Xia Y, Wang Q, et al.Calculating Pollution Indices by Heavy Metals in Ecological Geochemistry Assessment; A Case Study in Parks of Beijing. Journal of China University of Geosciences. 2008; 19(3): 230–241.
23. Thomilson DC, Wilson DJ, Harris CR, Jeffrey DW. A problem in Heavy metals in estuaries and the formation of a pollution index. Helgol Wissmeeresunlter. 1980; 33(1–4): 566–575.
24. Singh A, Sharma RK, Agrawal M, et al. Risk assessment of heavy metal toxicity through contaminated vegetables from wastewater irrigated area of Varanasi, India. Tropical Ecology. 2010; 51: 375–387.
25. Laniyan TA, Adewumi AJ. Evaluation of Contamination and Ecological Risk of Heavy Metals Associated with Cement Production in Ewekoro, Southwest Nigeria. J Health Pollution. 2020; 25: 200306.
26. UNICEF. Programme Cooperation Agreement 'Environmental remediation—lead poisoning in Zamfara FINAL REPORT September 2010–March 2011'. Available online: www.blacksmithinstitute.org (accessed on 4 June 2024).
27. Dutch Target and Intervention Values. Available online: http://esdat.net/Environmental%20 Standards/Dutch/annexS_I2000Dutch%20 (accessed on 4 Juen 2024).
28. DEFRA and the Environment Agency. CLR11 Model Procedures for the Management of land contamination. Available online: https://www.stroud.gov.uk/media/2297/contaminated_development.pdf (accessed on 4 June 2024).
29. Claire C. Soil generic assessment criteria for human health risk assessment. Buckinghamshire: Chiltern House, Haddenham Business Centre; 2010.
30. Khashman OA, Shawabkeh RA. Metal Distribution in Soils around the Cement Factory in Southern Jor-dan. Environmental Pollution. 2006; 140: 387–394.
31. Mandal A, Voutchkov M. Heavy Metals in Soils around the Cement Factory in Rockfort, Kingston, Jamaica. International Journal of Geosciences. 2011; 2: 48–54.
32. El-Sherbiny MM, Ismail AI, EL-Hefnawy ME. A preliminary assessment of potential ecological risk and soil contamination by heavy metals around a cement factory, in western Saudi Arabia. Open Chem. 2011; 17: 671–684.
33. Asati A, Pichhode M, Nikhil K. Effect of Heavy Metals on Plants: An Overview. International Journal of Application or Innovation in Engineering & Management. 2016; 5(3): 1–12.
34. Udiba UU, Akpan ER, Antai EE. Assessment of Lead (Pb) Remediation Potentials of Senna obtusifolia, Dareta Village, Zamfara Nigeria. International Research Journal of Public and Environmental Health. 2019; 6(6): 115–126.
35. Daniel ES, Musa JJ, Akos MP, et al. Assessment of Heavy Metal Pollution in Some Nigerian Soils: A Review. In: Proceedings of the 37th Annual Conference and Annual General Meeting of Nigerian Institution of Agricultural Engineers; 2016.
36. Environment Agency. Human Health Toxicological Assessment of Contaminants in Soil. Available online: https://webarchive.nationalarchives.gov.uk/20140328160926/http:/cdn.environmentagency.gov.uk/scho0804bibr-e-e.pdf (accessed on 4 June 2024).
37. Bermudez GMA, Moreno M, Invernizzi R, et al. Heavy metal pollution in topsoils near a cement plant: The role of organic matter and distance to the source to predict total and HCl-extracted heavy metal concentrations. Chemosphere. 2010; 78: 375–381.

38. Semhi K, Khirbash SA, Abdalla O, et al. Dry Atmospheric Contribution to the Plant-Soil System around a Cement Factory: Spatial Variations and Sources—A Case Study from Oman. Water Air and Soil Pollution. 2010; 205: 343–357. doi:10.1007/s11270-009-0079-8
39. Chibuike S, Obiora SC. Heavy Metal Polluted Soils: Effect on Plants and Bioremediation Methods. Applied and Environmental Soil Science. 2014.