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Original Research Article

Industrial Emissions and Toxic Metals Bioaccumulation in Cassava Cultivated around Mfamosing Cement Plant, Akamkpa: A Toxicological Risk Evaluation for Consumers

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ABSTRACT

Industrial emissions from cement production are significant sources of environmental contamination, raising concerns about the safety of food crops cultivated near such facilities. This study evaluated the concentrations of toxic metals (lead, cadmium, mercury, arsenic, and chromium) and assessed the associated health risks from consuming edible cassava tissues harvested from areas surrounding the Mfamosing Cement Plant, Nigeria, between June and December 2023. Cassava samples were systematically collected at varying distances from the cement plant and analyzed using an atomic absorption spectrophotometer (Model 6800, Japan) after wet digestion. Health risk assessments were conducted following the US-EPA models, using Estimated Daily Intake (EDI), Target Hazard Quotient (THQ), Hazard Index (HI), Incremental Lifetime Cancer Risk (ILCR), and Cumulative Cancer Risk (CCR). Results showed that the total heavy metal concentrations (mg/kg) were of the ranges: lead (0.07–1.11), cadmium (0.05–0.61), mercury (0.01–0.05), arsenic (0.01–0.05), and chromium (0.01–0.06 mg/kg). The mean concentrations of Pb, Cd, and Hg in cassava tissues exceeded FAO/WHO and EU permissible limits, with EDI values surpassing the Recommended Daily Intake (RDI) and Tolerable Upper Intake Levels (UL). While the individual THQ remained below unity, HI exceeded unity at the site closest to the cement plant, indicating possible non-carcinogenic risks. Notably, the ILCR and CCR values for Pb, Cd, As, and Cr exceeded the regulatory safety thresholds (10^{-4}), indicating significant carcinogenic risks to consumers. The study concludes that consuming cassava cultivated near the Mfamosing Cement Plant poses both carcinogenic and non-carcinogenic health risks to local communities.

Keywords: Safety evaluation, health risk, heavy metals, cassava tissues, Mfamosing cement plant, Nigeria.

Introduction

Cement production industries are a major source of environmental degradation due to the discharge of particulate matter and gases rich in toxic chemicals such as methane, heavy metals, and oxides of carbon, nitrogen and Sulphur.[1] One of the possible sources of toxic metals like lead, mercury, cadmium zinc, and chromium is cement dust.[2] Particulate deposition reduces with increasing distance from the factories.[1] Studies around cement factories in Jamaica revealed elevated metal levels.[3] These metals have a propensity for bioaccumulation in plants and other biota, making them a "chemical time bomb". Even at minimal concentrations, several heavy metals are proven to be harmful.[4] Olowoyo *et al.*,[1] documented moderate soil pollution around a cement factory in South Africa, noting that Panicum maximum plants in the area accumulated metals exceeding the maximum permissible limits for human and animal consumption. Cement dust deposition on plants can lead to adverse effects, including reduced energy storage, stomata closure, and decreased photosynthesis and plant growth.[1] Detrimental effects of contaminated dust deposition on plant are most times irreversible and the severity may depend on such factors as; grain size, composition, quantity and timing of release. The uptake of contaminants from the soil to plants on the other hand, depends on various factors, including metal solubility, soil pH, plant growth stages, and general soil chemistry.[5] This has led to heightened apprehension about food crops exceeding statutory and advisory standards for chemical contaminants like toxic metals. The sustainability of host communities whose livelihoods are largely dependent on food crop production is therefore, seriously threatened. Most communities hosting cement producing plants have witnessed deterioration in the quality soils, air and water as well as decreased in agricultural production and productivity. Human health impacts including morbidity and mortality have been reported.[6] The Mfamosing Cement plant, is the largest cement production site for Lafarge Africa Plc in Nigeria, yet there is no published data on its environmental impact on food crops in the area. This study seeks to assess the safety and potential health risks linked to the consumption of edible cassava tissues cultivated near the cement plant

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Sixth in importance among food crops, cassava plays a significant role in the diets of more than 80 million people worldwide. After maize and rice, it is said to be the third-largest source of carbohydrates. Of all known crops, fresh cassava tubers have the highest starch output per unit area, with an average starch concentration of 30%.[7] Though with a very low protein content, cassava contains numerous minerals, vitamins and Phyto-nutraceuticals useful in animal feed and human diet. Such mineral elements include; iron, phosphorus, calcium and vitamin C.[7] Nutritional potentials of cassava leaves abound. On a dry matter basis, tender cassava leaf has been reported to contain up to 25% protein. The protein amino acid profile is similar to that present in hen's egg and is superior to legumes such as soya bean.[8] Cassava leaf is also a rich source of calcium, iron and vitamin A and C_3. The rich protein and iron content makes it useful in the improvement of haematological indices while calcium content enhances bone calcification.[9] Essential natural anti-oxidant and phyto-chemicals have also been linked to cassava leaves. Despite this significant potential, the leaves are yet to be fully incorporated into the food system as a leafy vegetable. While some communities harvest and consume tender cassava leaves, others only recognise it as a source protein for monogastric animals and ruminants.[8] In Nigeria (especially in the southern and north central regions), cassava with an average daily intake of 226.93g/person/day is one of the major staple foods.[10] It is valued for its contribution to food security, eradicating poverty, and providing raw materials for agro-allied industries. Based on these, it is the cardinal crops, focussed upon by the Nigerian government in an effort to guarantee the general public access to food.[11] Cassava is one of the most commonly cultivated crops around Mfamosing Cement plant, Nigeria. Owing to proximity of these farms to the cement manufacturing plant, there is possibility of the crop being contaminated by heavy metals from the gaseous and particulate emissions. Since soil to plant transfer is the primary mechanism by which hazardous metals are ingested by humans through the food chain, an excessive build-up of pollutants in agricultural soils that promote uptake by food crops is extremely concerning. While previous studies have reported heavy metal contamination in soil and crops, none have conducted a comprehensive health risk assessment specific to cassava consumers. This study aimed at quantifying heavy metal levels (Pb, Cd, Hg, As, Cr), comparing them to FAO/WHO and EU food safety standards, estimating daily intake (EDI), and assessing health risks using Target Hazard Quotient (THQ), Hazard Index (HI), Incremental Lifetime Cancer Risk (ILCR), and Cumulative Cancer Risk (CCR), while also examining spatial and seasonal trends. The study provides a comprehensive health risk assessment of cassava tissues grown near one of Nigeria's largest cement facilities, integrating multi-metal profiling, advanced risk modeling, and spatial gradient analysis. The research methods—systematic spatial sampling, atomic absorption spectrophotometry, standardized US-EPA health risk models, and statistical analysis—are relevant and appropriate, providing critical data for public health decision-making and proposed evidence-based policy recommendations for crop safety.

Materials and Methods

Study Location

Mfamosing Cement Plant, located within the Cross River limestone belt in Mfamosing, Akamkpa Local Government Area, Nigeria, is about 30 kilometres northeast of Calabar city. The plant falls within the Lafarge cement concession area, which is a mining lease available to Lafarge Holcim, and is located in the rural community of AbiMfam. It lies between latitude 40 53' N and 50 05' and longitude 80 15' E and 80 27' E. The region has limited infrastructure.[6, 12, 13] The climate is tropical, characterized by prominent tropical rainforest vegetation. The average annual rainfall in the area is around 1600 mm, with a temperature that ranges between 26^{o}C and 36^{o}C.[2] The two distinct seasons in Calabar are the wet season (April to October) and the dry season (November to March). The "August break," a short time of drought, occurs during the wet season between August and September. Moreover, from December to February, the region experiences harmattan weather, characterized by very low night temperatures. Farming is the primary occupation of the local population, with cassava being the most commonly cultivated crop, serving as the main staple food for the people.

Collection and Preservation of Sample

The procedure used for collecting, preserving, and preparing the samples adhered to the methods described by Abida *et al*.,[14] Sampling took place between June and December 2023. Four specific cassava farms (100 m x 50 m each) were selected for the study. Farm 1 was located directly opposite the factory gate (zero meters), farm 2 was 500 meters away from the gate, farm 3 was 1000 meters away, and Farm 4 was 1500 meters away from the factory gate. Each of the farms was divided into ten strata and numbered 1-10. Mature cassava tubers and leaves were harvested from three randomly selected strata within a farm. Samples from the three strata of each farm were combined to form a composite sample representing that specific farm. Control samples were collected from cassava farms around Atimbo in Calabar Municipal Local Government Area. Collected samples were transported Zoology Laboratory, University of Calabar for preparation.

Sample Preparation

Cassava leaves and tubers collected were carefully washed to get rid of adhered soils and other dirt. The leaves were chopped into pieces and the tubers were peeled and sliced. After five days of air drying, the samples were oven-dried for four hours at 103°C, ground into a powder and passed through a 1 mm mesh screen. 1g of the sieved powder was then digested using concentrated nitric acid.[11]

Sample Analysis

The concentrations of selected heavy metals—lead (Pb), cadmium (Cd), mercury (Hg), arsenic (As), and chromium (Cr)—were measured in the digested cassava samples using a Shimadzu AA-6800 atomic absorption spectrophotometer (Japan).

Analytical Quality Assurance

To guarantee the reliability and accuracy of analytical results, rigorous quality control procedures were followed. Precautions were taken to avoid cross-contamination during sample processing. Only high-purity (analytical-grade) nitric acid was used for digestion. Each batch of samples included blank controls and calibration standards to assess consistency and detect background interference. Additionally, Standard Reference Material (SRM) labeled IAEA-336 (Lichen) underwent the same digestion and analysis protocol to confirm the validity of the method employed.[15]

Statistical Analysis

Data obtained from the analysis were statistically examined using IBM SPSS software, version 23.0, for the Windows operating system.

Dietary Intake and Health Risk Assessment

To evaluate potential health risks from consuming cassava tubers and leaves, both carcinogenic and non-carcinogenic risks linked to Pb, Cd, Hg, As, and Cr were assessed using the United States Environmental Protection Agency (US-EPA) health risk assessment model.[16] This evaluation was based on the assumption that all metals present in the cassava tissues are fully ingested and absorbed by consumers and that their concentrations remain unchanged during food preparation or cooking.[17]

Non-Carcinogenic Risk

Finding each metal's Estimated Daily Intake (EDI) was the initial step in estimating the level of exposure in order to evaluate the non-carcinogenic health risk. Several factors were used in the EDI calculation (Equation 1), including average exposure frequency (EF), exposure duration (ED), average daily vegetable intake (DIV), metal concentration in peeled cassava tubers and cassava leaves (Cm), average adult body weight (WAB), and average exposure time-age (AT).[11, 18 19, 20]

$$EDI = \frac{EF \times ED \times DIV \; x \; Cm}{WAB \times AT} \quad \ldots\ldots (1)$$

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To maintain consistency between the concentration data and the averag e daily vegetable intake, the concentrations of metals measured in dry weights were converted to wet weights using specific factors such as th e dry weight concentration (Cdw) and the average moisture content of cassava leaves and peeled cassava tubers (W).[21-23] This conversion pro cess, as described in Equation 2, ensured that the units used for the ave rage daily vegetable intake were aligned with the concentration data. B y doing so, the estimated daily intake of metals via the consumption of cassava tubers and leaves remained consistent and accurate in the healt h risk assessment.

$$Cww = Cdw[\frac{100-W}{100}] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

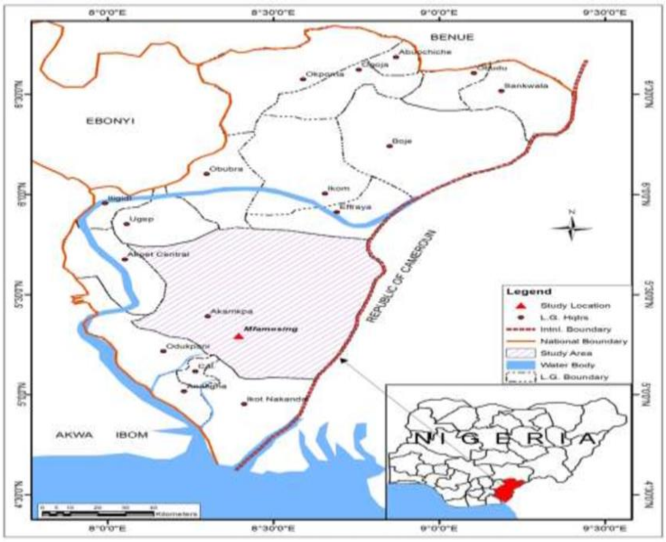

Figure 1: Map of study area showing Mfamosing Cement plant, Akamkpa, Cross River State, Nigeria

Target hazard Quotient (THQ)
Each metal's target hazard quotient (THQ), which indicates the element's systematic toxicity or non-carcinogenic danger, was subsequently calculated using equation 3. For each metal, the THQ levels were compared to the oral reference dose (RfD), which is an estimation of the daily intake that does not cause harmful outcomes over a lifetime. Reliable sources provided the RfD values used in this investigation.[24, 25]

$$\text{THQ} = \frac{\text{EF} \times \text{ED} \times \text{FIR} \times \text{Cm}}{RfD \times \text{WAB} \times AT} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Hazard Index (HI)
The THQ values of each heavy metal under analysis were added up to determine the Hazard Index (HI) (equation 4). It reflects the potential non-carcinogenic risk associated with exposure to multiple metals through cassava tubers and leaves consumption.[24]

$$HI = \sum THQ = THQ\text{Pb} + \text{THQCd} + \text{THQHg} + \text{THQAs} + \text{QCr}\ldots\ldots(4)$$

Carcinogenic Risk
The carcinogenic health risk was assessed by calculating the Incremental Lifetime Cancer Risk (ILCR) and cumulative cancer risk. The ILCR estimates the probability of an individual developing cancer from exposure to carcinogenic or potentially carcinogenic metals.[25]

Incremental Lifetime Cancer Risk (ILCR)
Equation 5 was utilized to calculate the ILCR values, taking into account, the cancer slope factor-oral (CSF-oral) and the estimated daily intake (EDI) for each metal.[26]

$$ILCR = EDI \ x \ CSF\_0ral \ldots\ldots\ldots (5)$$

Cumulative Cancer Risk (CCR)
The Cumulative Cancer Risk (CCR) was calculated to evaluate the cumulative carcinogenic risk brought on by exposure to certain carcinogenic metals.[27] The CCR was computed using Equation 6 and is the sum of an individual's metal-specific ILCR values.[27]

$$CCR = \sum ILCR = ILCRPb + ILCRCd + ILCR\ Hg + ILCRAs + ILCRCr \ldots\ldots\ldots\ldots\ldots (6)$$

Results and Discussions

Analytical Quality Assurance
The certified reference material (Lichen IAEA-336), prepared and analyzed under identical conditions as the samples, yielded values that were within the acceptable ranges for the determined elements (Table 1). This result affirms the dependability and validity of the analytical method applied.

Total Heavy Metal Concentration in Peeled Cassava Tubers across Cassava Farm within the Vicinity of Mfamosing Cement plant, Nigeria
The results obtained from the analysis of metals contents of peeled cassava tubers during both the dry and wet seasons are presented in Table 2. Figures 2 and 3 illustrate the comparison of heavy metal concentrations in peeled cassava tubers across different farms for both seasons.

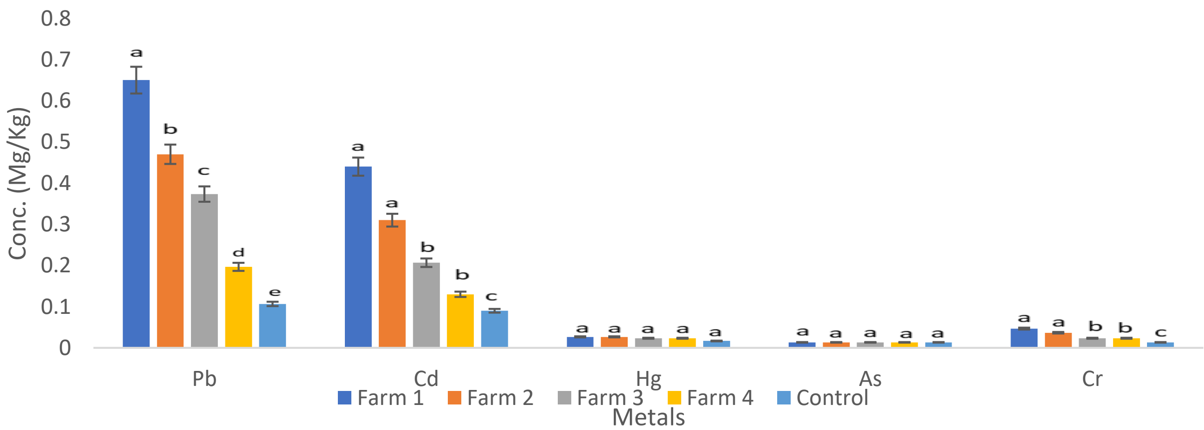

Figure 2: Comparison of metal Concentrations in Peeled Cassava tubers across farms for the dry season.
Bars with different superscript for a given metal indicates significant difference (ANOVA, $p < 0.05$) in the mean concentration of the metal

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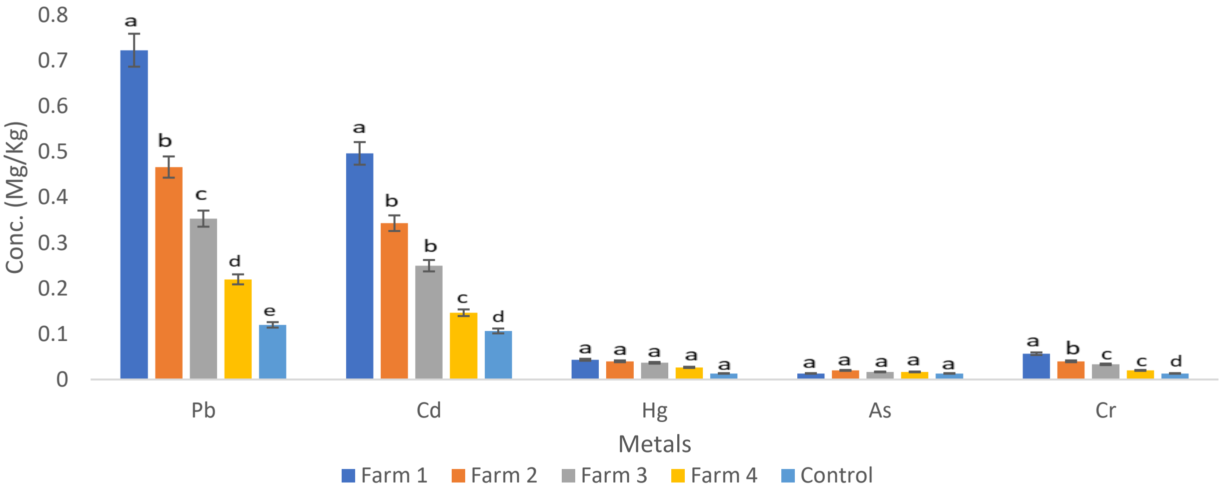

Figure 3: Comparison of metal Concentrations in Peeled Cassava Tubers across Farms for the Wet season.
Bars with different superscript for a given metal indicates significant difference (ANOVA, $p < 0.05$) in the mean concentration of the metal

Table 2 shows the concentration ranges (Mg/kg) of the metals as follows: Pb (0.09 - 0.75), Cd (0.07 - 0.52), Hg (0.01 – 0.05), As (0.01 - 0.03), and Cr (0.01 – 0.06). It was observed that the mean lead, cadmium, and mercury contents of peeled cassava tubers exceeded the acceptable levels for contaminants and toxins set by FAO/WHO for metals in roots and tuber vegetables, which is 1.0 Mg/kg.[28] Similarly, the concentration of lead and cadmium surpassed the maximum levels set by the European communities, which are 0.1 Mg/kg and the mercury level exceeded the limit of 0.01 Mg/kg for vegetables.[29, 30] However, the concentration of arsenic in peeled cassava tubers were below both the FAO/WHO standards and the European communities' maximum levels for arsenic in vegetables, which is 0.50 Mg/kg.[28, 30] For chromium, its concentration in peeled cassava tubers was lower than the Tolerable Daily Intake (TDI) of 0.3 mg/kg body weight per day, as established by the European Food Safety Authority. This TDI equates to 18.21 mg/day for an average adult weighing 60.7 kg, the reference weight used in this study. It follows therefore that, the consumption of peeled cassava tubers harvested from farms near the Mfamosing Cement facility in Nigeria presents a considerable toxicological threat, particularly in relation to lead, cadmium, and mercury exposure. Lead exposure can cause adverse effects in various organs and systems, even at low doses, leading to cardiovascular, kidney, and reproductive issues. Cadmium is an extremely toxic metal with a long biological half-life and is associated with carcinogenesis in multiple organs. Mercury is also toxic to the nervous system, particularly the brain, and can negatively affect organs such as the muscles, kidneys, and nerves. Arsenic is classified as a human carcinogen and has been linked to gastrointestinal issues and brain-related disorders like encephalopathy.[30-32]

The analysis of variance (ANOVA) indicated statistically significant differences in heavy metal concentrations among the peeled cassava tubers collected from the various farms. Specifically, levels of lead, cadmium, and mercury showed a notable decline ($p \leq 0.05$) as the distance from the cement manufacturing facility increased, suggesting a potential link to emissions from the plant (see Figures 2 and 3). In contrast, the concentrations of mercury and arsenic did not differ significantly ($p \geq 0.05$) between the sampled farms and the control site. Seasonal comparison revealed no significant variation in metal levels between the dry and wet seasons ($p \geq 0.05$), except for lead, which was significantly elevated ($p \leq 0.05$) during the wet season at both farm 1 and farm 2.

Comparisons with previous studies highlighted variations in heavy metal concentrations in cassava tubers from various regions,[33] thus, highlighting the importance of considering regional variations and potential sources of contamination. Edori *et al.*,[34] reported lower mean concentrations of 0.377±0.341 Mg/kg and 0.019±0.019 Mg/kg for Pb and Cd in cassava tubers from Gakona, Nigeria, and 0.1167±0.0833 for Cd in cassava gathered from farms along highways in Owerri, Nigeria was also recorded [30]. Furthermore, cassava tubers from Otukpo, Ohimini, and Kastina-Ala were found to contain higher average lead concentrations of 0.840 ± 0.230 mg/kg, 0.850 ± 0.270 mg/kg, and 0.870 ± 0.250 mg/kg, respectively.[11] Previous studies have also found a comparable mean arsenic concentration of 0.11 Mg/kg in cassava tubers from farms in Namibia.[8]

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	0.210	0.79	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

Evaluation of Potential Health Risk via Consumption of Peeled Cassava Tubers

Non-Carcinogenic Risk

To assess the potential non-carcinogenic health effects associated with consuming peeled cassava tubers, this study employed three key indicators: Estimated Daily Intake (EDI), Target Hazard Quotient (THQ), and Hazard Index (HI).

Estimated Daily Intake

In this study, the Recommended Daily Intake (RDI) and tolerated upper intake levels for each metal are compared to the Estimated Daily Intake (EDI), which calculates the amount of the metals of interest consumed daily through the eating of edible cassava tissues.[24] Findings revealed that the average EDI values for lead, cadmium, and mercury in peeled cassava tubers exceeded their respective RDIs.

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Table 2: Total Heavy Metal Concentration in Peeled Cassava Tuber across Cassava Farm aound Mfamosing Cement plant, Nigeria

Farms	Metals	Dry Season					Wet Season				
		June	July	August	Mean±SD	Range	Oct.	Nov.	Dec.	Mean±SD	Range
1	Pb	0.64	0.67	0.64	0.65±0.01 [a]	0.64-0.67	0.69	0.73	0.75	0.72±0.02 [b]	0.69-0.75
	Cd	0.47	0.41	0.44	0.44±0.02 [a]	0.41-0.47	0.48	0.52	0.49	0.50±0.02[a]	0.48-0.52
	Hg	0.02	0.02	0.04	0.03±0.01 [a]	0.02-0.04	0.04	0.04	0.05	0.04±0.01[a]	0.04-0.05
	As	0.01	0.01	0.02	0.01±0.01[a]	0.01-0.02	0.02	0.01	0.01	0.01±0.01 [a]	0.01-0.02
	Cr	0.05	0.04	0.05	0.05±0.01 [a]	0.04-0.05	0.05	0.06	0.06	0.06±0.01 [a]	0.05-0.06
2	Pb	0.43	0.53	0.45	0.47±0.04 [a]	0.43-0.53	0.45	0.43	0.52	0.47±0.04 [b]	0.43-0.52
	Cd	0.28	0.32	0.33	0.31±1.11 [a]	0.28-0.33	0.33	0.35	0.35	0.34±0.01 [a]	0.33-0.35
	Hg	0.03	0.02	0.03	0.03±0.01 [a]	0.02-0.03	0.03	0.05	0.04	0.04±0.01 [a]	0.03-0.05
	As	0.02	0.01	0.01	0.01±0.01 [a]	0.01-0.02	0.03	0.02	0.01	0.02±0.01 [a]	0.01-0.03
	Cr	0.04	0.04	0.03	0.04±0.01 [a]	0.03-0.04	0.03	0.04	0.05	0.04±0.01 [a]	0.03-0.05
3	Pb	0.34	0.37	0.41	0.37±0.02 [a]	0.34-0.41	0.31	0.36	0.39	0.35±0.03 [a]	0.31-0.39
	Cd	0.18	0.23	0.21	0.21±0.02 [a]	0.18-0.23	0.24	0.27	0.24	0.25±0.01 [a]	0.24-0.27
	Hg	0.01	0.03	0.03	0.02±0.01 [a]	0.01-0.03	0.03	0.04	0.04	0.04±0.01 [a]	0.03-0.04
	As	0.02	0.01	0.01	0.01±0.01 [a]	0.01-0.02	0.01	0.02	0.02	0.02±0.01 [a]	0.01-0.02
	Cr	0.02	0.02	0.3	0.11±0.11 [a]	0.02-0.03	0.03	0.03	0.04	0.03±0.03 [a]	0.03-0.04
4	Pb	0.21	0.19	0.19	0.20±0.01 [a]	0.19-0.21	0.21	0.24	0.21	0.22±0.01 [a]	0.21-0.24
	Cd	0.12	0.14	0.13	0.13±0.01 [a]	0.12-0.14	0.15	0.14	0.15	0.15±0.01 [a]	0.14-0.15
	Hg	0.02	0.02	0.03	0.02±0.01 [a]	0.02-0.03	0.03	0.02	0.03	0.03±0.01 [a]	0.02-0.03
	As	0.01	0.01	0.02	0.01±0.01 [a]	0.01-0.02	0.01	0.02	0.02	0.02±0.01 [a]	0.01-0.02
	Cr	0.02	0.03	0.02	0.02±0.01 [a]	0.02-0.03	0.02	0.02	0.02	0.02±0.00 [a]	0.02
Control	Pb	0.09	0.12	0.11	0.11±0.01 [a]	0.09-0.11	0.11	0.13	0.12	0.12±0.01 [a]	0.11-0.13
	Cd	0.07	0.08	0.12	0.09±0.02 [a]	0.07-0.12	0.09	0.11	0.12	0.11±0.01 [a]	0.09-0.12
	Hg	0.02	0.01	0.02	0.02±0.01 [a]	0.01-0.02	0.01	0.02	0.01	0.01±0.01 [a]	0.01-0.02
	As	0.01	0.01	0.02	0.01±0.01 [a]	0.01-0.02	0.02	0.01	0.01	0.01±0.01 [a]	0.01-0.02
	Cr	0.01	0.01	0.02	0.01±0.01 [a]	0.01-0.02	0.01	0.02	0.01	0.01±0.01 [a]	0.01-0.02

Means with the different superscripts across the row indicates significant difference in metals concentration between dry and wet season

For instance, considering an average adult with a body weight of 60.7 kg, the average daily intake of lead (as an example) across the farms during the dry and wet seasons (0.59 and 0.44 Mg/kg bw/day, respectively) translates to 35.81 mg/day and 26.71 mg/day, respectively. These EDI values (Table 3) suggest that prolonged consumption of peeled cassava tubers from the study area may lead to health risks for consumers, on the assumption that cooking processes does not have significant influence on the metal levels. The results of this study is consistent with findings by Addo *et al*.[18] in Ghana, who reported elevated EDI values for Pb and Cd in cassava near cement factories, attributing it to industrial emissions. Similarly, Adedokun *et al.*[20] in Lagos, Nigeria, observed EDI values for Cd and Pb in vegetables exceeding FAO/WHO limits, raising public health concerns. Abah *et al*.[11] in Benue, Nigeria, also reported high EDI levels in cassava roots from agrochemical-exposed areas. These findings underscore that cassava grown in industrial zones in Africa can accumulate metals at levels that pose chronic exposure risks. Internationally, Jaishankar *et al*.[32] emphasized that consumption of food crops from contaminated sites can lead to long-term toxic accumulation, especially when EDI exceeds oral intake limits.

Target Hazard Quotient (THQ)

The Target Hazard Quotient (THQ) was employed to assess the potential health risks posed by exposure to individual metals through the consumption of peeled cassava tubers.[24] THQ is defined as the ratio of the estimated exposure to a metal relative to its reference oral dose. The average THQ values for all metals analyzed were below unity across cassava farms in both dry and wet seasons (Table 4). A THQ value below one indicates negligible non-carcinogenic risk, whereas a value above one implies a significant risk. This evaluation considered exposure exclusively through the consumption of peeled cassava tubers, excluding other potential exposure pathways. However, Edori *et al*.[34] reported that THQ values for Cd and Pb in cassava from oil-polluted soils in Rivers State, Nigeria, approached or exceeded unity, especially in highly contaminated locations. Njoku-Tony *et al*.[9] found THQ values exceeding 1 in fluted pumpkin near oil-contaminated areas in Nigeria, highlighting metal-specific toxicity risks. A comparative study in Kenya by Onyari *et al.*[35] also noted THQ values for Pb in root crops near industrial sites were close to unity, suggesting similar risk levels across African industrial zones. These findings reinforce the caution that even sub-threshold THQs may contribute to risk over time, especially under cumulative exposure.

Hazard Index (HI)

The Hazard Index (HI) was used to assess the combined potential health risks associated with all the studied metals.[24] It is calculated as the sum of the Target Hazard Quotients (THQs) for all analyzed heavy metals, based on the assumption that their harmful effects are additive and proportional to cumulative exposure.

The findings revealed that the HI for peeled cassava tubers from the study area was below unity for an average adult weighing 60.7 kg, except for farm 1 (Table 4). An HI exceeding one indicates a potential health risk, and farm 1 demonstrated significant risk.

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Table 3: Estimated Daily Intake (Mg/kg b.w/day) of metals Due to Consumption of Peeled Cassava Tubers Cassava from Farms around Mfamosing Cement plant, Nigeria

Sampling Station	**Dry Season**					**Wet Season**				
	Pb	Cd	Hg	As	Cr	Pb	Cd	Hg	As	Cr
Farm 1	0.91	0.59	0.03	0.01	0.07	0.084	0.7	0.07	0.01	0.07
Farm 2	0.65	0.42	0.03	0.01	0.07	0.66	0.45	0.07	0.02	0.07
Farm 3	0.52	0.28	0.02	0.01	0.02	0.49	0.35	0.07	0.02	0.03
Farm 4	0.28	0.17	0.02	0.01	0.02	0.51	0.21	0.03	0.02	0.02
Average	**0.59**	**0.365**	**0.025**	**0.01**	**0.045**	**0.436**	**0.4275**	**0.06**	**0.0175**	**0.0475**
Control	0.14	0.14	0.02	0.01	0.01	0.17	0.14	0.14	0.14	0.14
UL (mg/day)	0.240	0.064	ND	1-3	0.130	0.240	0.064	ND	1-3	0.130
RDI (mg/day)	0.00	0.00	0.00	0.5-1	0.03(0.02)	0.00	0.00	0.00	0.5-1	0.03(0.02)

Table 4: Target Hazard Quotient (THQ) and Hazard Index (HI) of metals due to Consumption of Peeled Cassava Tubers Cassava from Farms within the Vicinity of Mfamosing Cement plant, Nigeria

Sampling Station	Dry Season						Wet Season					
	Target Hazard Quotient (THQ)					Hazard Index (HI)	Target Hazard Quotient (THQ)					Hazard Index (HI)
	Pb	Cd	Hg	As	Cr		Pb	Cd	Hg	As	Cr	
Farm 1	0.255	0.607	0.136	0.049	0.0003	1.047	0.241	0.691	0.185	0.094	0.0007	1.212
Farm 2	0.185	0.429	0.136	0.049	0.0003	0.799	0.185	0.468	0.185	0.084	0.0003	0.922
Farm 3	0.143	0.293	0.087	0.049	0.0017	0.574	0.136	0.346	0.185	0.084	0.0024	0.753
Farm 4	0.077	0.178	0.087	0.049	0.0017	0.393	0.087	0.206	0.136	0.084	0.0017	0.515
Average	**0.165**	**0.377**	**0.112**	**0.049**	**0.001**	**0.704**	**0.163**	**0.428**	**0.173**	**0.087**	**0.0013**	**0.851**
Control	0.042	0.122	0.087	0.049	0.0017	0.302	0.042	0.15	0.049	0.049	0.0017	0.292

Additionally, the HI values decreased with increasing distance from the cement plant, indicating reduced health risks for other farms. The average contributions of lead, cadmium, mercury, arsenic, and chromium to the overall risk were analyzed for both wet and dry seasons (Table 4). However, Udiba *et al*.[36] documented HI values >1 for multiple metals in Zamfara, Nigeria, due to environmental mining activities. Similarly, Abba *et al*.[26] found HI >1 in vegetables from industrial areas of Kano, confirming cumulative risks where metal exposure is additive. Guerra *et al*.[24] also stressed globally that HI values above 1 are critical indicators of long-term health concerns in populations consuming metal-contaminated produce.

Carcinogenic Health Risk Assessment

Incremental Lifetime Cancer Risk (ILCR)

The Incremental Lifetime Cancer Risk (ILCR) was determined to evaluate the potential cancer risks linked to the consumption of peeled cassava tubers. The average ILCR values for the dry and wet seasons were 4.89 x10^{-3} and 4.9 x10^{-3} for lead, 5.51 and 6.42 for cadmium, 7.3x10^{-2} and 3.4 x10^{-2} for arsenic, and 2.4 x10^{-2} and 2.4 x10^{-2} for chromium, respectively (Table 5). These ILCR values for lead, cadmium, arsenic, and chromium surpassed the acceptable regulatory threshold for carcinogenic risks (10^{-4}). Cadmium, chromium, and arsenic are confirmed human carcinogens, while lead is classified as a probable human carcinogen.[31] The results suggest that long-term consumption of peeled cassava tubers may present cancer risks due to exposure to lead, cadmium, arsenic, and chromium. This aligns with OKereke *et al*.[33] reported similarly high ILCR values for cassava from roadside farms in Owerri, Nigeria. IARC[28] confirms that As, Cd, and Cr are Group 1 carcinogens, and Pb is a probable human carcinogen

Cumulative Cancer Risk (CCR)

The Cumulative Cancer Risk (CCR) was assessed to determine the total cancer risk from exposure to all the metals studied through the consumption of peeled cassava tubers (Table 5). The findings revealed that the cumulative cancer risks for cadmium, lead, and arsenic in the farms surpassed the acceptable regulatory limit for carcinogens (10^{-4}), suggesting a potential cancer risk. This underscores the need to address heavy metal contamination in agricultural products to protect public health. Maina *et al.*[3] reported elevated CCR values in crops near Ashaka Cement Factory, Nigeria, associating these with particulate emissions and cement dust. Bilewu and Ogunlana[22] also found elevated cumulative risks in cassava leaves from southwestern Nigeria. These studies highlight the need for integrative cancer risk modeling in dietary exposure assessments, especially in industrially impacted regions

Total Heavy Metal Concentration in Cassava Leaves across Cassava Farms

Table 6 presents the heavy metal concentrations found in cassava leaves from the farms during both the dry and wet seasons. Figures 4 and 5 provide a comparison of the heavy metal levels in cassava leaves across various farms for each season.

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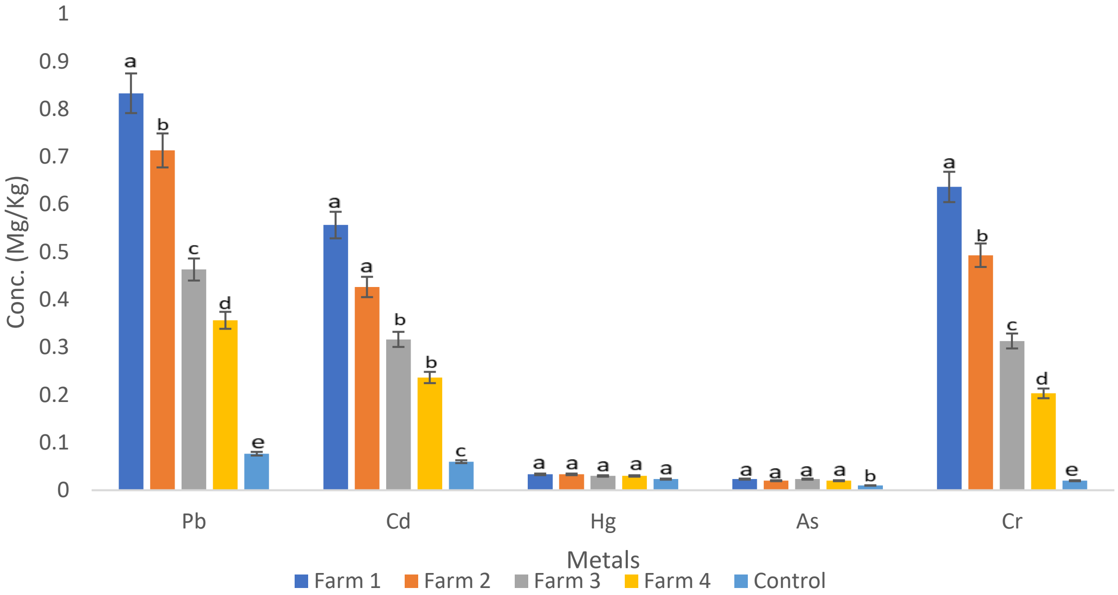

Figure 4: Comparison of metal Concentrations in Cassava leaves across farms for the dry season.
Bars with different superscript for a given metal indicates significant difference (ANOVA, p < 0.05) in the mean concentration of the metal

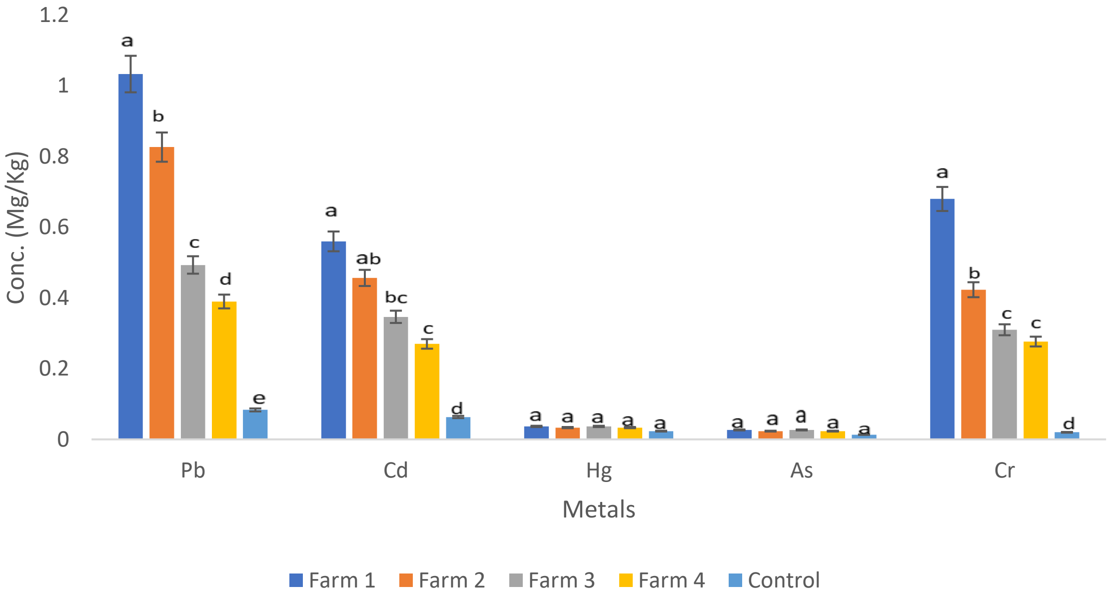

Figure 5: Comparison of metal Concentrations in Cassava leaves across Farms for Wet season.
Bars with different superscript for a given metal indicates significant difference (ANOVA, p < 0.05) in the mean concentration of the metal

Table 6 shows the ranges of metals concentrations (Mg/kg) in cassava leaves, which were as follows: Pb (0.07 - 1.11), Cd (0.05 - 0.61), Hg (0.02 – 0.04), As (0.01 - 0.03), and Cr (0.02 – 0.72). The mean concentrations of lead and cadmium in cassava leaves were found to exceed the maximum levels set by the European Communities and the permissible limits established by the food and agricultural organization, and world health organization for leafy vegetables (0.03 Mg/kg for lead and 0.2 Mg/kg for cadmium).[28-31] Additionally, the concentration of chromium in cassava leaves was below the tolerable daily intake (TDI) of 0.3 Mg/kg bw per day established by EFSA,[37] which corresponds to 18.21 mg/day for an average adult with a body weight of 60.7 kg considered in this study. Notably, the recommended health criteria value and estimated adult tolerable daily intake for inorganic and methyl mercury were 2 µg/kg bw/day and 0.2 µg/kg bw/day, respectively. Similarly, the recommended health criteria value for inorganic arsenic was 0.30 µg/kg bw/day. Based on the metals concentrations observed in cassava leaves from the study area, there is a possibility of toxicological risk associated with lead and cadmium intoxication via consumption of these leaves. In Gokana, Rivers State, Nigeria, concentrations ranging from 1.297±0.124 to 1.943±0.214 for lead and 0.127±0.110 to 0.181±0.101 for cadmium were reported.[34] In Owerri, Nigeria, concentrations of 0.713±0.2829-0.95±0.3904 for lead and 0.0763±0.0068-0.158±0.0327 for cadmium were recorded in cassava leaves along highways.[33]

As observed with peeled cassava tubers, the levels of lead, cadmium, and chromium in cassava leaves varied significantly among the sampled farms and the control site.

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Table 6: Total Heavy Metal Concentration in Cassava Leaves across Cassava Farm within around Mfamosing Cement plant, Nigeria

Farms	Metals	Dry Season					Wet Season				
		June	July	August	Mean±SD	Range	October	November	December	Mean±SD	Range
1	Pb	0.82	0.74	0.94	0.83±0.08 [a]	0.74-0.94	0.96	1.03	1.11	1.03±0.06 [a]	0.96-1.11
	Cd	0.52	0.54	0.61	0.56±0.04 [a]	0.52-0.61	0.59	0.54	0.55	0.56±0.02 [a]	0.54-0.57
	Hg	0.03	0.03	0.04	0.03±0.01 [a]	0.03-0.04	0.03	0.04	0.04	0.04±0.01 [a]	0.03-0.04
	As	0.02	0.02	0.03	0.02±0.01 [a]	0.02-0.03	0.03	0.02	0.03	0.03±0.01 [a]	0.02-0.03
	Cr	0.62	0.62	0.67	0.64±0.02[a]	0.62-0.67	0.72	0.69	0.63	0.68±0.04 [a]	0.63-0.72
2	Pb	0.65	0.76	0.73	0.71±0.05 [a]	0.65-0.76	0.78	0.83	0.87	0.83±0.04 [a]	0.78-0.87
	Cd	0.42	0.43	0.43	0.43±0.01 [a]	0.42-0.43	0.51	0.43	0.43	0.46±0.04 [a]	0.43-0.51
	Hg	0.03	0.03	0.04	0.03±0.01 [a]	0.03-0.04	0.03	0.03	0.04	0.03±0.01 [a]	0.03-0.04
	As	0.02	0.02	0.02	0.02±0.00 [a]	0.00	0.02	0.03	0.02	0.02±0.01 [a]	0.02-0.03
	Cr	0.52	0.47	0.49	0.49±0.02 [a]	0.47-0.52	0.41	0.39	0.47	0.42±0.03 [a]	0.39-0.47
3	Pb	0.43	0.47	0.49	0.46±0.02 [a]	0.43-0.49	0.48	0.51	0.49	0.49±0.01 [a]	0.48-0.51
	Cd	0.32	0.29	0.34	0.32±0.02 [a]	0.29-0.32	0.36	0.32	0.36	0.35±0.02 [a]	0.32-0.36
	Hg	0.04	0.02	0.03	0.03±0.01 [a]	0.02-0.04	0.03	0.04	0.04	0.04±0.01 [a]	0.03-0.4
	As	0.02	0.02	0.03	0.02±0.01 [a]	0.02-0.03	0.03	0.03	0.02	0.03±0.01 [a]	0.02-0.03
	Cr	0.29	0.32	0.33	0.30±0.02 [a]	0.29-0.33	0.28	0.34	0.31	0.31±0.02 [a]	0.28-0.31
4	Pb	0.37	0.37	0.33	0.36±0.02 [a]	0.33-0.37	0.36	0.42	0.39	0.39±0.02 [a]	0.36-0.42
	Cd	0.26	0.22	0.23	0.24±0.02 [a]	0.22-0.26	0.27	0.26	0.28	0.27±0.01 [a]	0.26-0.28
	Hg	0.03	0.02	0.04	0.03±0.01 [a]	0.02-0.04	0.03	0.04	0.03	0.03±0.01 [a]	0.03-0.04
	As	0.02	0.02	0.02	0.02±0.00 [a]	0.00	0.02	0.03	0.02	0.02±0.01 [a]	0.02-0.03
	Cr	0.21	0.18	0.22	0.20±0.02 [a]	0.18-0.22	0.24	0.31	0.28	0.28±0.03 [b]	0.24-0.31
Control	Pb	0.08	0.08	0.07	0.08±0.01 [a]	0.07-0.08	0.09	0.08	0.08	0.08±0.01 [a]	0.08-0.09
	Cd	0.06	0.07	0.05	0.06±0.01 [a]	0.05-0.07	0.06	0.07	0.06	0.06±0.01 [a]	0.06-0.07
	Hg	0.02	0.03	0.02	0.02±0.01 [a]	0.02-0.03	0.02	0.02	0.03	0.02±0.01 [a]	0.02-0.03
	As	0.01	0.01	0.01	0.01±0.00 [a]	0.00	0.01	0.02	0.01	0.01±0.01 [a]	0.01-0.02
	Cr	0.02	0.02	0.02	0.02±0.00 [a]	0.00	0.02	0.02	0.02	0.02±0.00 [a]	0.00

Means with the different superscripts across the row indicate significant differences in metals concentration between dry and wet season

A clear downward trend in metal concentrations was noted with increasing distance from the cement plant during both the wet and dry seasons (see Figures 4 and 5), suggesting that emissions from cement production may contribute to elevated metal levels in nearby vegetation. In contrast, mercury and arsenic levels did not show any significant variation between the farms and the control. Additionally, seasonal differences in metal concentrations within cassava leaves were not statistically significant for any of the analyzed elements. These findings emphasize the influence of proximity to industrial activity on the contamination of food crops and raise public health concerns regarding the safety of consuming cassava grown in the vicinity of the cement facility.

Evaluation of Potential health Risk via Consumption of Cassava leaves
Non-carcinogenic Risk
Estimated Daily Intake
Average values of estimated daily intake values (mg/kg b.w./day) for Pb, Cd, Hg, As, and Cr through consuming cassava leaves obtained from the studied farms during the dry and wet seasons were 0.56 and 0.67, 0.37 and 0.39, 0.03 and 0.04, 0.02 and 0.03, and 0.39 and 0.35, respectively (Table 7). These EDI values indicated that the average intake of lead, cadmium, mercury, and chromium were higher than the recommended daily intake for these metals. Furthermore, the average EDI for lead, cadmium, and chromium exceeded the tolerable upper intake levels, suggesting that prolonged consumption of cassava leaves from this area could lead to significant adverse effects on consumers' well-being.

Target Hazard Quotient
Average target hazard quotient values for Pb, Cd, As, and Cr during both the dry and wet seasons were 0.161 and 0.174, 0.370 and 0.392, 0.107 and 0.125, 0.071 and 0.089, and 0.003 and 0.003, respectively (Table 8). These THQ values were all below unity, suggesting that there were no appreciable non-carcinogenic health hazards connected to the metals from eating cassava leaves for those eating at or below the average daily vegetable intake level.

Hazard Index
The average hazard index (HI) for both the dry and wet seasons were 0.94 and 1.02 for farm 1, 0.79 and 0.85 for farm 2, 0.61 and 0.72 for farm 3, 0.51 and 0.54 for farm 4, and 0.18 and 0.9 for the control group (Table 8). For an adult with a body weight of 60.7 kg (considered in this study), the hazard index resulting from the consumption of cassava leaves was below unity for all farms, except for lead in the wet season. The percentage contribution of lead, cadmium, mercury, arsenic, and chromium to the aggregate risk was 22.64%, 52.04%, 15.05%, 9.99%, and 0.35% for the dry season, and 22.25%, 50.13%, 15.98%, 11.38%, and 0.38% for the wet season.

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Table 7: Estimated Daily Intake (mg/kg b.w/day) of metals Due to Consumption of Cassava leaves obtained from Farms around Mfamosing Cement plant, Nigeria

Sampling Station	Dry Season					Wet Season				
	Pb	Cd	Hg	As	Cr	Pb	Cd	Hg	As	Cr
Farm 1	0.79	0.53	0.03	0.02	0.61	1.05	0.54	0.04	0.03	0.65
Farm 2	0.68	0.41	0.03	0.02	0.47	0.79	0.44	0.03	0.02	0.40
Farm 3	0.44	0.31	0.03	0.02	0.29	0.47	0.33	0.04	0.03	0.30
Farm 4	0.34	0.23	0.03	0.02	0.19	0.37	0.26	0.03	0.02	0.03
Average	0.563	0.37	0.03	0.02	0.39	0.67	0.39	0.04	0.03	0.35
Control	0.08	0.06	0.02	0.01	0.02	0.08	0.006	0.02	0.01	0.02
UL (mg/day)	0.240	0.064	ND	1-3	0.130	0.240	0.064	ND	1-3	0.130
RDI (mg/day)	0.00	0.00	0.00	0.5-1	0.03(0.02)	0.00	0.00	0.00	0.5-1	0.03(0.02)

Assessment of Carcinogenic Risk

Incremental life-time Cancer Risk

Average values of incremental life-time cancer risk for lead, cadmium, arsenic, and chromium from consuming cassava leaves in both the dry and wet seasons were 4.8×10^{-3} and 5.78×10^{-3}, 5.55 and 5.89, 3.0×10^{-2} and 3.8×10^{-2}, and 2.0×10^{-2} and 1.73×10^{-1}, respectively (Table 9). These ILCR values exceeded the acceptable regulatory limit for carcinogenic risks (10-4), indicating that consuming cassava leaves poses substantial cancer risks. These results highlight the importance of evaluating the health risks associated with cassava leaves from farms near the cement plant, particularly concerning heavy metal contamination, and emphasize the need for actions to mitigate these risks to protect public health.

Table 8: Target Hazard Quotient (THQ) and Hazard Index (HI) of Metals through to Consumption of Cassava leaves obtained from Farms around Mfamosing Cement plant, Nigeria

Sampling Station	Dry Season						Wet Season					
	Target Hazard Quotient (THQ)					Hazard Index (HI)	Target Hazard Quotient (THQ)					Hazard Index (HI)
	Pb	Cd	Hg	As	Cr		Pb	Cd	Hg	As	Cr	
Farm 1	0.226	0.534	0.107	0.071	0.004	0.942	0.229	0.535	0.142	0.107	0.004	1.017
Farm 2	0.193	0.410	0.107	0.071	0.003	0.784	0.226	0.439	0.107	0.071	0.003	0.846
Farm 3	0.125	0.305	0.107	0.071	0.002	0.61	0.133	0.334	0.142	0.107	0.002	0.718
Farm 4	0.099	0.229	0.107	0.071	0.001	0.507	0.106	0.258	0.107	0.071	0.002	0.544
Average	0.161	0.370	0.107	0.071	0.0025	0.71075	0.174	0.392	0.125	0.089	0.003	0.782
Control	0.021	0.056	0.071	0.035	0.001	0.184	0.021	0.064	0.071	0.035	0.001	0.192

Table 9: Incremental Lifetime Cancer Risk (ILCR) and Cumulative Cancer Risk (CCR) of metals in Cassava Leaves from Farms Within the Vicinity of Lafarge African Plc, Mfamosing Cement plant, Nigeria

Sampling Station	Dry Season						Wet Season					
	Incremental Lifetime Cancer Risk					Cumulative Cancer Risk	Incremental Lifetime Cancer Risk					Cumulative Cancer Risk
	Pb	Cd	Hg	As	Cr		Pb	Cd	Hg	As	Cr	
Farm 1	$6.7x10^{-3}$	7.95	-	$3.0 \text{ x}10^{-2}$	$3.1 \text{ x}10^{-1}$	8.29	$8.9 \text{ x}10^{-3}$	8.10	-	$4.5 \text{ x}10^{-2}$	$3.3 \text{ x}10^{-1}$	8.48
Farm 2	$5.9 \text{ x}10^{-3}$	6.15	-	$3.0x10^{-2}$	$2.4 \text{ x}10^{-1}$	6.42	$6.7 \text{ x}10^{-3}$	6.60	-	$3.0 \text{ x}10^{-2}$	$2.0 \text{ x}10^{-1}$	6.84
Farm 3	$3.7 \text{ x}10^{-3}$	4.65	-	$3.0x10^{-2}$	$1.5 \text{ x}10^{-1}$	4.83	$4.0 \text{ x}10^{-3}$	4.95	-	$4.5 \text{ x}10^{-2}$	$1.5 \text{ x}10^{-1}$	5.15
Farm 4	$2.9 \text{ x}10^{-3}$	3.45	-	$3.0x10^{-2}$	$9.5 \text{ x}10^{-2}$	3.58	$3.1 \text{ x}10^{-3}$	3.90	-	$3.0 \text{ x}10^{-2}$	$1.5 \text{ x}10^{-2}$	3.95
Average	$4.8 \text{ x}10^{-3}$	5.55	-	$3.0x10^{-2}$	$2.0 \text{ x}10^{-2}$	5.78	$5.7 \text{ x}10^{-3}$	5.89	-	$3.8 \text{ x}10^{-2}$	$1.73 \text{ x}10^{-1}$	6.10
Control	$6.8 \text{ x}10^{-3}$	0.90	-	$1.5x10^{-2}$	$1.0x10^{-2}$	0.93	$6.8 \text{ x}10^{-4}$	0.09	-	$1.5 \text{ x}10^{-2}$	$1.0 \text{ x}10^{-2}$	0.12

Conclusion

This study demonstrates that cassava cultivated around the Mfamosing Cement Plant bioaccumulates toxic metals, notably lead, cadmium, and mercury, at concentrations exceeding international safety standards. Health risk assessments revealed that, while non-carcinogenic risks remain low in most sites, carcinogenic risk indicators for lead, cadmium, arsenic, and chromium surpass regulatory thresholds, indicating significant cancer risks from prolonged consumption. The spatial analysis confirms a clear gradient of metal contamination decreasing with distance from the cement facility. These findings highlight a clear influence of industrial emissions on metal bioaccumulation in cassava plants and underscore the vulnerability of communities reliant on agriculture near the facility and the importance of enforcing emission control measures at cement production facilities to safeguard food safety and public health.

Conflicts of Interest

The authors declare no conflicts of interest.

Author's Declaration

The authors hereby declare that the work presented in this article is original and that any liability for claims relating to the content of this article will be borne by them.

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