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Research paper

Quantitative Assessment of Heavy Metal Contamination and Health Risk in Fruits from Agricultural Farmlands Of Dakasoye, Kano State, Nigeria

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Abstract

Heavy metal contamination in food crops presents potential environmental and public health risks. This study assessed the concentrations of Pb, Cd, Zn, Cu, Fe, and Mn in fruits cultivated on Dakasoye farmlands, Kano State, Nigeria, using Atomic Absorption Spectrophotometry (AAS). Most metals were found within FAO/WHO permissible limits, indicating generally low contamination levels. However, elevated Pb concentrations in some fruit samples suggest localized contamination concerns. Significant differences in metal levels among fruit types were observed ($p < 0.05$). Estimated daily intakes (EDI) and associated health-risk indices (HQ, HI, CF, PLI, and CR) were largely within acceptable thresholds, implying minimal health risks, though continued monitoring of Pb is recommended.

Keywords: *Assessment; Contamination; Fruits; Heavy metals; Health risk; Spectrophotometry.*

1. Introduction

The contamination of agricultural products by heavy metals poses a significant environmental and public health concern, driven by both geochemical processes and anthropogenic activities. While trace metals such as zinc (Zn) and copper (Cu) are essential micronutrients required for plant growth and human metabolism, excessive accumulation can result in toxicity. Furthermore, non-essential metals, including lead (Pb), cadmium (Cd), chromium (Cr), arsenic (As), nickel (Ni), and mercury (Hg), are inherently toxic and environmentally persistent due to their non-biodegradable nature and strong affinity for soil and water matrices [1]. Chronic dietary exposure to these metals has been linked to neurotoxicity, nephrotoxicity, cardiovascular disorders, and carcinogenic effects [2].

Fruits are important dietary components, providing vitamins, minerals, and dietary fiber, yet their frequent raw consumption and minimal processing make them effective pathways for heavy-metal transfer to humans [3]. Consequently, the presence of heavy metals in fruits has become a growing food safety concern. Studies worldwide have reported detectable levels of toxic metals in fruits cultivated in areas affected by industrial and agricultural activities. A recent meta-analysis demonstrated substantial variability in As, Cd, and Pb concentrations in fruits, with the highest levels observed in several African and Eastern Mediterranean regions, where rapid industrialization, poor waste management, and intensive farming practices prevail [4].

Country-specific studies further highlighted this issue. In Bangladesh, fruits such as mango (Mangifera indica), guava (Psidium guajava), banana (Musa spp.), papaya (Carica papaya), and pineapple (Ananas comosus) were reported to occasionally exceed FAO/WHO permissible limits for As, Cd, and Pb, with carcinogenic risk indices for As, Cd, Cr, and Ni surpassing acceptable thresholds [5]. In Zambia, Siame [6] observed elevated concentrations of Cu, Ni, Zn, Co, Pb, and Fe in fruits and leafy vegetables from mining-impacted areas, largely attributed to industrial and mining emissions. Similar contamination patterns have been reported in Algeria, India, and China, where irrigation with untreated wastewater and proximity to industrial zones have resulted in increased Pb, Cd, and Cr levels in agricultural produce [7].

Geochemically, heavy-metal accumulation in fruits reflects the combined influence of geogenic and anthropogenic sources. Natural inputs arise from the weathering of metal-bearing rocks and atmospheric deposition, whereas anthropogenic contributions include industrial discharges, vehicular emissions, agrochemical application, and improper waste management [8]. The presence of toxic metals in agricultural products is increasingly recognized as an indicator of environmental degradation and unsustainable land-use practices, with implications for food safety and ecosystem integrity [9].

In Nigeria, particularly in Kano State, heavy-metal contamination of agricultural products requires targeted investigation. Kano State is a major agricultural and industrial center in northern Nigeria, where urban expansion, industrial effluents, and vehicular emissions constitute potential sources of metal pollution. The Dakasoye farmlands, characterized by intensive fruit cultivation, are situated within this environment and may be vulnerable to contamination, raising concerns about food safety and public health [10].

Accordingly, this study determines the concentrations of selected heavy metals (Pb, Cd, Cr, Zn, Cu, and Ni) in fruits cultivated on the Dakasoye farmlands, Kano State, Nigeria. The measured levels are compared with FAO/WHO food safety limits to evaluate potential health risks associated with fruit consumption. The findings provide site-specific data on the geochemical quality of edible fruits and contribute to understanding the influence of regional industrial and environmental dynamics on food safety in sub-Saharan Africa.

2. Materials and Methods

In the preparation of reagents, only analytical-grade chemicals and deionized water were used to maintain the accuracy and reliability of the analyses. All glasswares were carefully washed with liquid detergent, rinsed thoroughly with distilled water, and then dried in an oven at 105 °C to avoid contamination. Sample weights were measured using an analytical balance (Model FA), while metal concentrations were determined using an Agilent Atomic Absorption Spectrophotometer (AAS) following standard analytical procedures [11].

2.1. Sample collection

The fruit samples collected were first washed thoroughly with tap water to remove any dirt or surface impurities, and then rinsed with distilled water to clear away any remaining contaminants. After cleaning, the fruits were cut into small pieces and dried in a hot-air oven at 100 °C for 48 hours to ensure that all moisture was completely removed. Once dried, the samples were ground into a fine powder using a mechanical grinder and passed through a 1 mm sieve to achieve a uniform texture. Each powdered fruit sample was then labeled and stored in airtight plastic containers under dry conditions until further analysis [12].

2.2. Sample digestion

Digestion of Fruit Samples
To prepare the samples for analysis, 0.5 g of each dried fruit sample was digested with a mixture of nitric acid (HNO_3) and perchloric acid ($HClO_4$) in a 5:1 ratio, following the method recommended by the World Health Organization and the Food and Agriculture Organization (WHO/FAO). The mixture was gently heated until the solution became clear and transparent, indicating that all the organic matter had been completely broken down. The digested samples were then filtered using Whatman No. 42 filter paper and diluted to a final volume of 25 mL with distilled water. Finally, the concentrations of heavy metals were measured using an Atomic Absorption Spectrophotometer (AAS) [13].

2.3. Description of the study area

Dakasoye is a village located near the boundary between Kura and Garun Malam local governments in Kano state, Nigeria. Geographically, Dakasoye village is located at a latitude 11.7071° north of the equator and longitude 8.4406 ° east of the Greenwich meridian with an elevation of about 473m above the sea level(Figure1). The village is situated close to localities such as Turedasu, Takanawa, Shifawa, and Yadakwari [14]. The area is well known for Rice farming and vegetable cultivation.

2.4. Sampling locations

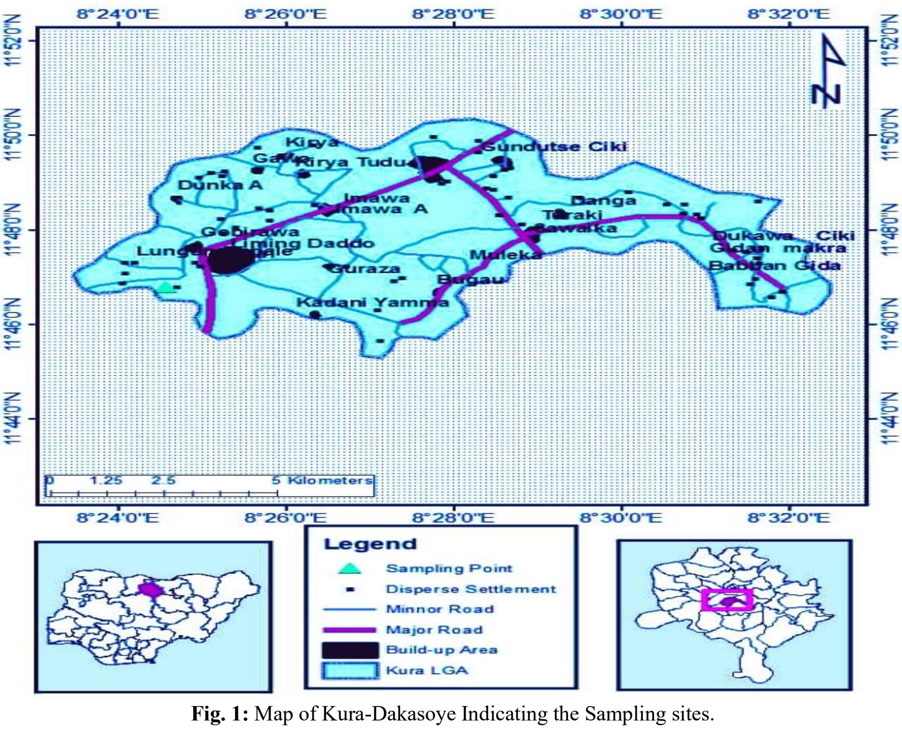

Fig. 1: Map of Kura-Dakasoye Indicating the Sampling sites.

Source: GIS Unit, Department of Geography, Bayero University Kano.

2.6. Instrumentation

Heavy metals (Cd, Cr, Mn, Pb, and Zn) were determined by an Agilent Atomic Absorption spectrophotometer (AAS), after appropriate digestion of samples to extract the metals. Standard solutions with known concentrations and blanks are prepared. A calibration curve is created from the standards. The absorbance of the Fruit samples was measured and compared to the calibration curve to determine the concentration of the heavy metals. A blank is used to correct for background interference[15].

3. Statistical analysis of heavy metal concentrations in fruits from Dakasoye farmlands

The mean concentrations of selected heavy metals— Zinc (Zn), Cadmium (Cd), Chromium (Cr), Lead (Pb), and Manganese (Mn) in Fruit samples collected from Dakasoye farmlands were statistically analyzed using IBM SPSS Statistics version 23.0. To determine whether there were statistically significant differences in heavy metal concentrations among fruit samples, Analysis of Variance (ANOVA) was performed. The results of the statistical Analysis in Table1 below indicated a significant difference as the p-value was found to be less than 0.05.

Table 1: Results of Statistical Analysis (ANOVA)

Between Groups. 72.275663. 4 18.068916 43.50 1.6×10^{-12} 2.69
Within Groups. 12.460071. 30 0.415332.
Total. 84.735734. 34

Sources of variations SS. df. MS. F. P-value. Fcrit.

3.1. Results

The results of the Fruits from the Kura-Dakasoye Agricultural area are presented in Table 1 below.

Table 2: The Mean Concentrations (mg/kg) of Heavy Metals in the Samples Analysed

Fruits	Zn	Mn	Cr	Cd	Pb
Banana(Musa Spp)	5.292	1.294	0.312	0.038	0.278
Guava(Psidium Guajava)	4.132	1.078	0.152	0.036	0.248
Lemon (Citrus lemon)	3.910	1.028	0.164	0.032	0.308
Orange (Citrus sinensis)	0.896	1.502	0.168	0.034	0.27
Mango (Mangifera indica)	4.372	1.042	0.278	0.040	0.44
Pawpaw(Carica papaya)	4.698	1.082	0.226	0.036	0.224
Watermelon (Citrullus lanatus)	3.818	0.554	0.106	0.023	0.158
FAO/WHO [16]	99.4	5.0	1.30	0.2	0.3

3.2. Discussion

Discussion

As shown in Table 2, Zn concentrations ranged from 0.896 mg/kg in orange to 5.292 mg/kg in banana, all well below the [13] permissible limit of 99.5 mg/kg. These values indicated that Zn levels in the analyzed fruits pose no toxicological concern. The relatively higher Zn concentrations in banana and pawpaw may originate from their deeper and more fibrous root systems, which enhance micronutrient uptake. Conversely, the lower value in orange likely results from limited Zn mobility and species-specific uptake mechanisms.

Zinc is an essential element involved in enzymatic activity, protein synthesis, and growth regulation. Plants regulate Zn homeostasis through ZIP and HMA transporter families [16].

The observed zinc (Zn) concentrations are comparable to those previously reported in fruits from Nigeria (3.2–6.8 mg/kg; [17]) and Bangladesh (1.7–9.4 mg/kg; [18]). Similar Zn ranges have also been reported in fruits cultivated in northern Nigeria, where concentrations between 2.5 and 8.9 mg/kg were reported, reflecting moderate environmental exposure and effective plant regulation mechanisms [19]. Similar results have been reported in other studies from Nigeria, such as Zn levels of 3.99 mg/kg in watermelon from Lagos, 7.71 mg/kg in pawpaw, and 6.60 mg/kg in pineapple from Lagos markets [20], and a wider range of 1.42–13.88 mg/kg in fruits from Enugu State [21]. Higher Zn values, ranging from 8.82 to 34.91 mg/kg, were reported in indigenous fruits from Ikwo, Ebonyi State [22]. Comparable Zn concentrations have also been reported in fruits from other parts of the world, including China, where bananas, starfruit, and grapes contained 5.28, 7.26, and 1.22 mg/kg Zn, respectively [23]. In Bangladesh, Zn concentrations up to 134 mg/kg have been observed in certain fruit samples, particularly banana [24]. Collectively, these studies suggest that Zn accumulation in fruits is generally within a physiologically regulated and environmentally safe range, though regional and species variations occur.

Manganese (Mn)

Manganese (Mn) concentrations in the analyzed fruits (Table 2) were determined to be between 0.554 mg/kg in watermelon and 1.502 mg/kg in orange, substantially below the [13] permissible limit of 5.0 mg/kg [13]. These low concentrations are consistent with the known biological behavior of Mn, which, although an essential micronutrient, exhibits limited phloem mobility and is predominantly sequestered in leaves, where it contributes to photosynthetic and enzymatic functions [25].

The Mn concentrations reported in this study correspond with values from other regions, including Ethiopia (0.85–2.4 mg/kg; [26]) and India (1.1–3.7 mg/kg; [27]; 1.1–6.16 mg/kg; [28]). Comparable levels have also been recorded in Nigeria, where fruits such as avocado, orange, pawpaw, and pineapple contained Mn at 0.01–12.6 mg/kg, reflecting variations in soil properties and agronomic practices [29]. Lower baseline Mn concentrations (0.26–2.42 mg/kg) have been recorded in irrigated vegetables from Maiduguri, Nigeria [30], whereas relatively elevated concentrations (~6.2 mg/kg) were found in wild fruits [31].

Furthermore, markedly elevated Mn concentrations have been obtained in environments impacted by anthropogenic contamination, including fruit samples from Bangladesh (up to 570 mg/kg; [18]and mangoes from Portugal (4.44–11.0 mg/kg; [32] The moderate Mn concentrations quantified in the present study likely reflect neutral to slightly alkaline soil conditions, which limit Mn solubility and bioavailability [8]. Collectively, these findings indicate that the fruits were cultivated in soils devoid of significant Mn contamination and suggest that Mn accumulation is predominantly regulated by soil chemistry and intrinsic plant biological mechanisms.

Chromium (Cr)

Chromium (Cr) concentrations in the analyzed fruits (Table 2) were observed to be between 0.106 mg/kg in watermelon and 0.312 mg/kg in banana, remaining well below the FAO/WHO permissible limit of 1.3 mg/kg [13]. These low Cr concentrations indicate minimal contamination and are consistent with previous reports from similar agro-ecological environments. In Nigeria, Cr levels in fruits have been reported to range from 0.10–0.51 mg/kg [33], 0.04–0.12 mg/kg in sliced watermelon [32], and 0.01–0.07 mg/kg in fruits sampled from Lagos markets [34].

International studies likewise report low Cr concentrations in fruits. According to [35], tropical fruits consumed in South Korea exhibited a mean Cr concentration of 0.0258 mg/kg fresh weight, with values between 0.0155 and 0.0567 mg/kg. Slightly elevated concentrations (up to 0.22 mg/kg) have been reported in fruits and vegetables marketed in industrialized regions of Algeria, an observation attributed to localized anthropogenic inputs such as traffic emissions and industrial activities [36] Higher Cr levels have also been reported in fruit skins; for example, mango and guava peels in Nigeria contained Cr concentrations of up to 0.9 mg/kg, while corresponding pulp samples showed substantially lower levels [37].

The generally low Cr concentrations recorded in the present study can be attributed to both environmental and physiological factors. In plants, chromium predominantly occurs as trivalent Cr(III), a poorly soluble and weakly mobile form that tends to accumulate in root tissues or be sequestered in vacuoles, thereby limiting translocation to edible fruit tissues [38]. Overall, the findings suggest that the fruits were cultivated in uncontaminated soils and that chromium uptake is physiologically regulated, minimizing potential dietary exposure.

Cadmium (Cd)

As presented in Table 2, Cd concentrations ranged from 0.023 mg/kg in watermelon to 0.040 mg/kg in mango, all below the [13] limit of 0.30 mg/kg. Cd is a non-essential and toxic metal associated with renal and skeletal damage at high exposure levels. The current results agree with previous studies in Nigeria (0.02–0.08 mg/kg; [39] and Ethiopia, where cadmium (Cd) concentrations in fruits were reported to range from 0.10 to 0.30 mg/kg dry weight [40].

Similar low Cd concentrations have been reported in other regions of Nigeria, with fruit samples ranging from 0.003–0.090 mg/kg [41] and up to 0.24 mg/kg in markets of Enugu [42] In Ethiopia, mango fruits were found to contain approximately 0.193 mg/kg Cd [43] In Bangladesh, tropical fruits from industrial areas showed Cd concentrations ranging from 0.001 to 0.64 mg/kg [44] Collectively, these studies indicate that fruits cultivated under non-polluted conditions generally show low Cd accumulation, supporting the conclusion that the present samples pose minimal risk of dietary Cd exposure.

Low Cd accumulation can be attributed to restricted mobility at higher soil pH, competition with Zn at uptake sites, and limited xylem translocation to fruits [45]. These factors collectively contribute to the safe Cd levels observed in the analyzed fruits.

Lead (Pb)

Lead (Pb) concentrations in the analyzed fruits (Table 2) ranged from 0.158 mg/kg in watermelon to 0.440 mg/kg in mango, representing the highest levels among the toxic metals investigated. Except for watermelon, all samples exceeded the FAO/WHO permissible limit of 0.20 mg/kg [13], indicating environmental contamination. Pb is a non-essential, highly toxic element capable of inducing neurotoxicity, anemia, and renal impairment [46].

Although Pb uptake by plant roots is generally limited due to strong binding within root tissues, the elevated concentrations observed in fruits point to external contamination pathways such as atmospheric deposition, vehicular emissions, and polluted irrigation water [47]. Fruit morphology and exposure duration appear to influence Pb retention, with rough or exposed fruits (e.g., mango and banana) accumulating more dust-borne Pb than smoother fruits like watermelon.

The Pb concentrations observed are comparable to those reported in Nigeria (0.27–0.89 mg/kg; [48]) and Iran (up to 2.1 mg/kg in urban and industrialized areas; [49]), suggesting moderate but potentially unsafe exposure through chronic consumption. Higher Pb levels have been documented in broader Nigerian surveys (up to 4.23 mg/kg; [50]), whereas lower concentrations were reported in fruits from China (0.03–0.28 mg/kg; [51]), Iraq (0.02–0.29 mg/kg; [52]), Turkey (0.277–0.520 mg/kg in and Colombia (up to 0.61 mg/kg in tropical fruits; [54]).

The trend of heavy metal concentrations in the fruit samples followed Zn > Mn > Cr > Cd > Pb (Table 2), reflecting typical physiological uptake patterns. Essential micronutrients (Zn, Mn) were absorbed and regulated efficiently, while non-essential and toxic elements (Cr, Cd, Pb) remained at relatively low concentrations due to limited translocation mechanisms [55]. However, Pb levels exceeding permissible limits highlight a public health concern, likely stemming from anthropogenic sources such as vehicular emissions, industrial activities, or residual Pb in soils and irrigation water. Chronic Pb exposure has been associated with neurological, cardiovascular, and renal disorders [44], emphasizing the need for ongoing monitoring and mitigation to minimize dietary risk.

3.3. Contamination factors (CF)

The contamination factor (CF) evaluates the relative degree of metal contamination by comparing measured concentrations to reference or permissible limits [56].

Contamination Factor (CF) evaluates the degree of metal enrichment:

CF = \frac{C_{sample}}{C_{reference}}

Interpretation:

CF < 1 = low contamination;

1 ≤ CF < 3 = moderate contamination;

3 ≤ CF < 6 = considerable contamination;

CF ≥ 6 = very high contamination.

CF = \frac{C_{sample}}{C_{reference}

Table 3: Contamination Factors and Pollution Load Index of Fruits Analyzed

Metal	Mean conc	FAO/WHO	CF Level. Pollution load index	Mg/kg
Zn	3.88	99.4	0.19	Low. 0.32
Mn	1.08	5.0	0.01	Low
Cr	0.20	5.00	0.04	Low
Cd	0.035	0.30	0.12	Low
Pb	0.278	0.20	1.39	Moderate

As shown in Table 3, the calculated contamination factor (CF) values indicate that all analyzed metals, with the exception of Pb, fall within acceptable limits, suggesting minimal contamination and a generally unpolluted environment. The low CF values for Zn, Mn, Cr, and Cd confirmed that these elements primarily originated from natural geochemical sources, consistent with background levels typical of uncontaminated agricultural soils[57].

Their presence likely reflects normal lithogenic contributions and essential micronutrient cycling rather than anthropogenic influence.

Furthermore, Pb showed a moderate CF value of 1.39, signifying slight enrichment and potential input from anthropogenic activities. Possible contributors include vehicular emissions, Pb-based agrochemicals, and atmospheric deposition, which are responsible for high Pb concentrations in surface soils and crop tissues [48]. This moderate enrichment pattern is comparable to findings reported in Tanzania, where similar trends of trace metal accumulation in fruits and soils were observed [58]. Similar moderate Pb enrichment in soils and crops near major roadways in Ibadan, Nigeria, while fruits from mining-influenced regions of Osun State also showed elevated Pb relative to background levels [59]. Conversely, fruits from relatively uncontaminated Nigerian markets such as Enugu and Lafia recorded Pb concentrations well below permissible limits, corresponding to CF < 1 [60].

Comparable international observations have been reported in Bangladesh, where [18] and [24] found markedly higher Pb contamination factors (CF > 6) in vegetables cultivated near industrial zones and high-traffic corridors, while Zn, Mn, and Cr remained within natural background levels. Similarly, a recent assessment in Spain and the United Arab Emirates identified Pb as the dominant anthropogenic contaminant, in contrast to essential metals such as Zn and Mn, which typically reflect geogenic sources [61]. These regional and international parallels support the inference that Pb is a sensitive indicator of anthropogenic impact in agricultural environments, whereas other essential micronutrients generally remain within their natural biogeochemical range.

3.4. Pollution load index (PLI)

The Pollution Load Index (PLI) provides an integrated measure of the overall pollution status of a sampling area [62].

$$PLI = (CF_1 \times CF_2 \times CF_3 \times CF_4 \times CF_5)^{1/n}$$

$$PLI = (0.19 \times 0.01 \times 0.04 \times 0.12 \times 1.39)^{1/5} = 0.32$$

Interpretation: PLI < 1 denotes no pollution, = 1 indicates baseline levels, and >1 implies contamination.

As shown in Table 3, the computed Pollution Load Index (PLI) value of 0.32 indicates that the analyzed fruits originated from an unpolluted environment. This finding is consistent with the interpretation criteria of [62], where PLI < 1 signifies no pollution and values near unity indicate emerging contamination. The low PLI recorded in this study confirmed that the examined fruits are produced under minimal anthropogenic influence.

These observations agreed with results from [17], who reported PLI values below 0.5 for fruits cultivated in agricultural zones of southwestern Nigeria, attributing such low pollution indices to the absence of major industrial activities and the predominance of natural lithogenic metal sources. Similarly, [60] found PLI values ranging from 0.28 to 0.46 for mango, cucumber, and pawpaw fruits from markets in Lafia, Nasarawa State, indicating a non-polluted status comparable to that shown in Table 3.

Comparable results have been reported in other parts of Nigeria, such as the study by [46], where edible plants grown in peri-urban areas around Pretoria and Abuja showed PLI < 1, confirming low cumulative contamination. Likewise, [63] observed negligible heavy-metal pollution (PLI = 0.34–0.47) in fruits sold in Enugu Metropolis, suggesting that agricultural products from relatively rural or less industrialized zones in Nigeria typically fall within the unpolluted range, consistent with the present study.

Internationally, similar trends have been reported. For instance, [18] in Bangladesh and [56] in the United Arab Emirates both found PLI < 1 for crops and fruits cultivated in low-impact agricultural environments, indicating background or lithogenic metal contributions rather than industrial pollution. In contrast, [5] reported elevated PLI values (>1.5) for vegetables and fruits grown near industrial and high-traffic areas in Dhaka, Bangladesh, and [64] found moderate pollution (PLI = 1.1–1.6) in certain Mediterranean agricultural soils influenced by atmospheric deposition.

Therefore, the PLI value of 0.32 (Table 3) in the present study aligns with the lowest category of contamination, comparable to findings from unpolluted agricultural regions in Nigeria and abroad. The low index underscores the dominance of natural geochemical sources and minimal anthropogenic metal input, further corroborating the low CF and E_{ri} values for most elements in Table 3.

The Geoaccumulation Index (Igeo), introduced by [65], is used to assess the contamination level of a sample by comparing measured concentrations to background (reference) values.

$$I_{geo} = \log_2 \left(\frac{C_n}{1.5 \times B_n} \right)$$

Where:

= measured concentration of the metal in the sample (mg/kg)

= background concentration of the metal (usually from literature or natural baseline)

1.5 = background matrix correction factor for lithologic variability

Table 4: Computed Geoaccumulation Index (Igeo)

Fruit.	Zn.	Mn	Cr	Cd	Pb
Banana (Musa spp)	0.82	0.79	2.06	0.34	1.8
Guava (Psidium guajava)	0.46	0.52	1.69	0.26	1.72
Lemon (Citrus lemon)	0.38	0.45	1.79	0.09	1.87
Orange (Citrus sinensis)	-1.08	0.67	1.83	0.18	1.85
Mango (Mangifera indica)	0.55	0.48	2.06	0.42	2.22
Pawpaw (Carica papaya)	0.64	0.53	1.94	0.26	1.58
Watermelon (Citrullus lanatus)	0.35	-0.44.	1.17	-0.38	1.41

Step 4. Interpretation of Igeo [65]

Igeo Class	Value Range	Contamination Level
0	≤ 0	Uncontaminated
1	0–1	Uncontaminated to moderately contaminated
2	1–2	Moderately contaminated
3	2–3	Moderately to strongly contaminated
4	3–4	Strongly contaminated
5	4–5	Strongly to extremely contaminated
6	> 5	Extremely contaminated

The calculated Geoaccumulation Index (Igeo) values for fruits cultivated on the Dakasoye farmlands (Table 4) ranged from –1.08 to 2.22, indicating contamination levels varying from uncontaminated to moderately to strongly contaminated. According to [65] classification, chromium (Cr) exhibited moderate contamination across all fruit species (Igeo ≈ 1.2–2.1), while lead (Pb) recorded the highest contamination levels, ranging from moderate to strong (1.4–2.2). Zinc (Zn) and manganese (Mn) fell within the uncontaminated to moderately contaminated range, whereas cadmium (Cd) showed the lowest contamination (Igeo < 0.5), suggesting limited anthropogenic input. Among the fruits, orange and watermelon displayed the lowest overall Igeo values.

The dominance of Pb and Cr contamination implies significant anthropogenic influence, likely originating from industrial discharge, vehicular emissions, and atmospheric deposition typical of the Dakasoye environment. The moderate Zn and Mn indices reflect a combination of natural geochemical background levels and minor anthropogenic enrichment, consistent with their roles as essential trace elements in plant systems.

When compared with related studies across Nigeria, the Dakasoye Igeo results are consistent with previously reported moderate contamination trends[66] and [67] obtained similar Pb and Cr contamination levels (Igeo = 1.2–2.3) in fruits from Enugu and Ibadan, respectively, while [68] observed comparable values (Igeo = 1.4–2.2) in Maiduguri, attributing them to vehicular and industrial emissions. International comparisons further corroborate these findings. In Zambia,[6] reported Igeo values of 1.3–2.4 for Pb and Cr in fruits from mining regions, while [5] recorded global mean values of 1.1–2.5 for Pb and 1.0–2.3 for Cr in fruits grown in industrialized areas of South Asia. Comparable contamination levels (Igeo ≈ 1.5–2.2) have also been reported in India [28] and Egypt [69].

The Igeo distribution pattern in Dakasoye fruits mirrors those observed in other industrial and urban agricultural zones of Africa and Asia.

3.6 Estimated daily intake (EDI)

The Estimated Daily Intake (EDI) assesses potential exposure through fruit consumption [70].

EDI = \frac{C_{metal} \times IR}{BW}

Where C= concentration of the metal in fruits, IR= Ingestion rate, and BW = Body weight.
Adopted parameters:
Adult ingestion rate (IR) = 0.345 kg/day; body weight (BW) = 70 kg
Child ingestion rate = 0.232 kg/day; BW = 15 kg

Table 5: Estimated Daily Intakes(Mg/Kg-Day)of the Analyzed Fruits

Metal	EDI (Adults) (mg/kg-day)	EDI (Children) (mg/kg-day)
Zn	0.0191	0.0060.
Mn	0.0053	0.0017
Cr	0.0010	0.00031
Cd	0.00017	0.000054
Pb	0.00137	0.00043

As presented in Table 5, all Estimated Daily Intake (EDI) values for the analyzed metals were found to be below [13] permissible daily intake limits, indicating low dietary exposure risk from the consumption of the studied fruits. This implies that the intake of these metals through regular fruit consumption poses no immediate health concern for consumers.

Among the metals, zinc (Zn) recorded the highest EDI, reflecting its natural abundance in edible plant tissues and its physiological significance in enzyme activation, protein synthesis, and chlorophyll formation [8]. The relatively higher Zn intake is consistent with its essential micronutrient status and regulated plant uptake mechanisms that maintain homeostasis even under varying soil metal concentrations.

Conversely, cadmium (Cd) and lead (Pb) exhibited the lowest EDI values, indicating minimal translocation from soil to fruit tissues. This limited accumulation may be attributed to root sequestration, restricted xylem transport, and low phloem mobility, which collectively reduce bioavailability within edible portions [16]. The low EDI for Cd and Pb underscores the limited anthropogenic influence in the study area, in agreement with the low CF and PLI values reported earlier (Tables 3–4).

Comparable results have been reported locally in Nigeria. [17] observed that EDI values for Zn, Cu, and Mn in fruits from southwestern Nigeria were below the WHO limits, with Cd and Pb either undetectable or negligible, confirming low dietary risk. Similarly, [60] assessed fruits from Lafia, Nasarawa State, and reported EDI values for Zn (0.008–0.017 mg/kg bw/day) and Pb (0.0003–0.001 mg/kg bw/day), both well below guideline levels, indicating safe exposure for consumers. In another Nigerian study, [63] found comparable trends in fruits sold in Enugu Metropolis, where all metal EDIs were within tolerable limits, further supporting the current findings in Table 4.

In other African contexts,[26] reported similar EDI ranges for tropical fruits in Ghana, concluding that dietary exposure from fruit consumption was below acceptable daily intake thresholds for all analyzed metals. Likewise,[31] found EDI values for essential (Zn, Mn) and non-essential (Cd, Pb) metals in fruits from Ethiopia to be within safe limits, reflecting low environmental contamination. Comparable findings were reported in Kenya, where [71] observed that heavy-metal EDIs in mangoes, oranges, and bananas grown in non-industrial regions were well below hazard thresholds, indicating low health risk.

Internationally, studies in Bangladesh [18], Turkey [53], and India [72]Lead (Pb) concentrations in the analyzed fruits (Table 2) were found to be between 0.158 mg/kg in watermelon and 0.440 mg/kg in mango, representing the highest levels among the toxic metals. Except for watermelon, all samples exceeded the FAO/WHO permissible limit of 0.20 mg/kg [13], indicating potential environmental contamination. Pb is a non-essential, highly toxic element capable of inducing neurotoxicity, anemia, and renal impairment [46]

3.7. Hazard quotient (HQ)

The Hazard Quotient (HQ) evaluates potential non-carcinogenic health risks associated with ingestion:

HQ = \frac{EDI}{RfD}
EDI= Estimated daily intakes, RFD= Oral reference dose.

Table 6: Hazard Quotients of the Analyzed Fruits

Metal	HQ (Adults)	HQ (Children)	Risk Interpretation
Zn	0.064	0.020	Safe
Mn	0.038.	0.012	Safe
Cr	0.333	0.103.	Slight concern
Cd	0.170	0.054	Low risk
Pb	0.391	0.123	Slight concern

As shown in Table 6, all calculated Hazard Quotient (HQ) values for the studied metals were less than 1, indicating that exposure through fruit consumption poses no immediate non-carcinogenic health risk to consumers. This outcome demonstrates that the estimated daily intake of each metal remains well within the tolerable limits established by international health guidelines [70].

Among the metals assessed, chromium (Cr) and lead (Pb) recorded comparatively higher HQ values, implying a possible risk of chronic health effects with long-term or excessive consumption. The elevated Pb HQ presented in Table 5 supports earlier findings by [18] in Bangladesh and [37] in Nigeria, who both highlighted lead as a major contributor to non-carcinogenic health risks in fruits and vegetables cultivated near industrial and high-traffic areas.

Similar patterns have been observed across Nigeria. For instance, [60] found that fruits from Lafia, Nasarawa State had safe levels of Zn, Mn, Cu, and Cr (HQ < 1), but lead (Pb) showed slightly higher HQ values (0.56–0.78), likely reflecting pollution from vehicle emissions or other human activities. Likewise, [63] reported that while Pb and Cd levels in fruits sold in Enugu posed little non-carcinogenic risk (HQ < 1), Pb still stood out as the most elevated metal. In southwestern Nigeria, [17] also noted low HQ values for essential metals, yet Pb again contributed the most to the overall hazard index (HI), echoing the moderate Pb HQ observed in Table 5.

Comparable results have been reported elsewhere in Africa. In Ghana,[26] observed HQ < 1 for all metals in fruits irrigated with wastewater but noted that Pb had the highest relative HQ contribution, reinforcing its global significance as a toxicant of concern. In Ethiopia, [31] found HQ values ranging from 0.002 to 0.41 for fruits and vegetables, indicating negligible risk yet advising continued environmental surveillance due to Pb persistence in soils. Similarly, [71] in Kenya reported low HQ and total hazard index (THI) values (< 1) for mangoes, bananas, and oranges, confirming that fruits grown in non-industrial areas are generally safe for consumption.

3.8. Cancer risk (CR)

Carcinogenic risk (CR) estimates the probability of developing cancer over a lifetime due to metal exposure:

CR = EDI \times CSF

EDI= Estimated daily intakes, CSF= Cancer slope factor.

Table 7: Cancer Risks of the Analyzed Fruits

Metal	CR (Adults)	CR (Children)	Acceptable Range (10^{-6}–10^{-4})
Cr	5.0×10^{-4}	1.6×10^{-4}	Slightly above safe
Cd	1.0×10^{-3}	3.3×10^{-4}	Moderate cancer risk
Pb	1.2×10^{-5}	3.7×10^{-6}	Within safe range

As presented in Table 7, the combined carcinogenic risk ($\sum CR \approx 1.6 \times 10^{-3}$) for the analyzed metals falls within the tolerable risk range (10^{-4}–10^{-3}) established by the United States Environmental Protection Agency [70]. This indicates a low to moderate potential cancer risk associated with the long-term consumption of the studied fruits. Although the cumulative carcinogenic risk remains within the globally accepted safety threshold, the slightly elevated values observed for cadmium (Cd) and chromium (Cr) suggest possible chronic exposure effects under prolonged or high-level intake scenarios.

The slightly higher risk values linked to cadmium (Cd) and chromium (Cr) reflect their well-known toxic properties, including persistence in the environment, tendency to accumulate in the body, and potential to cause oxidative stress, DNA damage, and disruptions in cellular repair mechanisms [47] Similar observations have been made by [5] and [26] who reported that Cd and Cr were the main contributors to carcinogenic risks in fruits and vegetables grown in industrial and peri-urban areas of Bangladesh and Ghana, respectively.

Comparable outcomes have been reported locally in Nigeria [60], found ∑CR values ranging between 1.2×10^{-4} and 2.8×10^{-3} in fruits sold in Lafia markets, attributing the slightly elevated Cd and Cr risks to the use of contaminated irrigation water and atmospheric deposition from vehicular emissions. Similarly, [37]reported that Cd and Cr contributed more than 70% of the total CR in soils and crops collected near a cement production site in southwestern Nigeria, reflecting their persistence and anthropogenic enrichment. In another Nigerian study, [63] observed low but non-negligible CR values for Cd and Cr in fruits sold in Enugu Metropolis, further confirming their dominance among the trace metals of concern.

Similar patterns of carcinogenic risk have been observed across Africa and Asia. For example, in Ethiopia, [31] reported cumulative cancer risk (CR) values ranging from 1.0×10^{-4} to 2.0×10^{-3} for metals in fruits grown near agricultural soils, which aligns with the moderate risk levels shown in Table 6. In Kenya,[71] found total CR values below 10^{-3} for fruits from non-industrial areas, with cadmium (Cd) contributing most to lifetime cancer risk. In India, 72] observed similar CR levels in vegetables and fruits, with Cd and chromium (Cr) posing slightly higher risks than other metals. Likewise, [53] reported cumulative CR values between 1.3×10^{-3} and 1.9×10^{-3} in Turkish agricultural products, again highlighting Cd and Cr as the metals with the greatest carcinogenic potential.

Collectively, the results in Table 7, and supporting evidence from Nigeria and other regions indicated that although the cumulative carcinogenic risk (∑CR) remains within the acceptable global threshold, Cd and Cr require continued monitoring due to their genotoxic potential.

4. Conclusion

The results indicate that concentrations of zinc (Zn), manganese (Mn), chromium (Cr), and cadmium (Cd) in the analyzed fruits were within FAO/WHO permissible limits, reflecting generally low levels of contamination. In contrast, lead (Pb) concentrations exceeded the recommended threshold in most fruit types, suggesting localized anthropogenic inputs, a pattern consistent with reports identifying Pb as a persistent contaminant in fruits from many developing regions.

Despite this, the estimated daily intake (EDI) values for all assessed metals were below their respective oral reference doses, and the calculated hazard quotient (HQ), hazard index (HI), contamination factor (CF), and pollution load index (PLI) remained within acceptable limits. These findings indicate a low likelihood of immediate non-carcinogenic health effects from fruit consumption. Similarly, carcinogenic risk (CR) values were below established safety benchmarks, suggesting a negligible lifetime cancer risk. However, while the fruits pose generally low health risk to consumers, the elevated Pb levels highlight the need for site-specific monitoring and targeted mitigation to prevent potential long-term exposure.

4.1. Recommendations

Based on the findings of this study, several actions are hereby recommended to ensure the continued safety of agricultural produce and to mitigate potential heavy metal contamination risks:

1) Regular environmental monitoring programs should be instituted by relevant environmental and agricultural agencies to continuously assess heavy metal concentrations in agricultural soils, irrigation water, and edible crops.
2) Enforcement of environmental regulations should be strengthened to ensure that industrial emissions, vehicular exhaust, and waste disposal are properly managed, thereby reducing the deposition of toxic metals such as lead (Pb), cadmium (Cd), and chromium (Cr) into agricultural ecosystems.
3) Use of contaminated water sources for irrigation should be discouraged, and periodic testing of irrigation water should be mandated to ensure compliance with WHO and FAO quality standards.
4) Good Agricultural Practices (GAPs) should be promoted among farmers through agricultural extension services. The adoption of soil amendments, organic fertilizers, and phytoremediation crops should be encouraged to minimize metal uptake by edible plants.
5) Periodic screening of fruits and vegetables sold in markets should be carried out by food safety authorities to ensure that heavy metal levels remain within permissible limits and to identify contamination hotspots early.
6) Public awareness campaigns should be conducted to educate farmers, traders, and consumers on safe cultivation, handling, and consumption practices—such as proper washing, peeling, and sourcing of produce from clean environments.
7) Research and data-sharing platforms should be established to facilitate collaboration among universities, environmental agencies, and public health institutions for continuous assessment of metal contamination trends and their health implications.
8) Policy frameworks and legislation related to environmental protection, agricultural safety, and food quality control should be periodically reviewed and updated to incorporate recent scientific evidence and international best practices.

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