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Assessment of human health risks associated with trace metal exposure through the consumption of *Amaranthus viridis* and *Manihot esculenta* grown in the Kimwenza gare area of Mont-Ngafula (Kinshasa, DRC)

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ABSTRACT

Introduction
Human populations are exposed to trace metal contamination through foodstuffs, particularly leafy vegetables.

Purpose
This study assessed the human health risks associated with consumption of vegetables grown in the Kimwenza gare agroecosystem. It focused on the vegetables most commonly consumed by populations relying on this production area.

Methods
Surveys were conducted among residents living near the agroecosystem to identify the vegetables most frequently prepared and to collect data on consumption habits. Two vegetable species were selected for chemical analysis using an energy-dispersive X-ray fluorescence spectrometer (ED- XRF). The daily exposure dose and hazard quotient were calculated for cadmium (Cd) and lead (Pb). Pearson correlation analysis was performed using RStudio (version 4.5.1).

Results
Trace metal concentrations were determined with a 95% confidence interval. Lead concentrations were low, whereas cadmium concentrations exceeded the WHO/FAO permissible limit in five samples (0.129 ± 0.012, 0.164 ± 0.123, 0.133 ± 0.012, 0.291 ± 0.026, and 0.420 ± 0.028 mg/kg, compared with the limit of 0.10 mg/kg). Statistical analysis indicated that both vegetables accumulated trace metals proportionally ($r = 0.967$ to $r = 0.995$). Hazard quotient values calculated from the daily exposure dose were > 1 for cadmium, indicating a potential risk of non-carcinogenic health effects among consumers, with children being the most vulnerable group.

Conclusion
Consumption of vegetables grown in the Kimwenza gare agroecosystem may expose consumers to health risks, as indicated by hazard quotient values. Raising awareness among market gardeners and implementing periodic monitoring of trace metal concentrations could help reduce this risk.

INTRODUCTION

In many parts of the world, agricultural areas are increasingly exposed to pollution from road, rail, and air traffic. These impacts manifest as air pollution, soil degradation, reduced agricultural productivity, and crop contamination. Vegetables are essential sources of vitamin C, folic acid, minerals, niacin, thiamine, and pyridoxine due to their biochemical roles (Siegel et al., 2014). They also contain antioxidants and dietary fiber that support normal physiological functioning. Regular vegetable consumption is necessary to reduce the risk of several diseases (Azi et al., 2018; Boeing et al., 2012; FAO/WHO, 2013; Ngweme et al., 2020, 2021).

The agricultural sector has become increasingly dependent on fertilizers and pesticides to improve yields and meet food and economic demands. Phosphate fertilizers are known sources of metallic and radioactive contaminants, mainly derived from phosphate bedrock (Nziguheba & Smolders, 2008; Yamaguchi et al., 2009). Their excessive use may contaminate soils and crops with trace metals. Exposed vegetables can accumulate significant concentrations, thereby posing risks to human health (Ametepey et al., 2018; Naser et al., 2011). Consumer exposure is of concern because physicochemical changes in the environment can influence metal bioavailability and uptake by cultivated vegetables (Amoah et al., 2006; Mpundu et al., 2013). The health risk associated with vegetable consumption depends on the quantity of contaminated vegetables consumed and the body weight of the exposed individual. Prolonged ingestion of small amounts of trace metals increases the risk of disease, with effects often becoming apparent only after several years (Bortey-Sam et al., 2015). The city of Kinshasa, capital of the Democratic Republic of the Congo, contains several agricultural production sites, including the Kimwenza gare site in the municipality of Mont-Ngafula, located in southwestern Kinshasa. Most of these sites are directly influenced by urban and peri-urban activities. Market gardeners commonly use mineral and organic fertilizers, as well as pesticides, to achieve high yields. Previous studies conducted in Kinshasa have reported elevated concentrations of trace metals, such as cadmium and lead, in cultivated vegetables (Falasi, 2017; Mukeba et al., 2023).

To date, no studies have been conducted in Kimwenza gare to assess human health risks and hazard quotients associated with vegetable consumption. These indicators allow for more accurate estimation of poisoning risk from pollutant ingestion by incorporating contaminant concentrations, exposure levels, and the physiology of exposed individuals.

This study aimed to assess the health risks associated with consumption of vegetables grown in Kimwenza gare by determining the estimated daily intake (EDI) and hazard quotient (HQ). Specifically, the study sought to (i) quantify trace metal concentrations, (ii) estimate dietary exposure, and (iii) assess non-carcinogenic health risks among adults and children.

METHODS

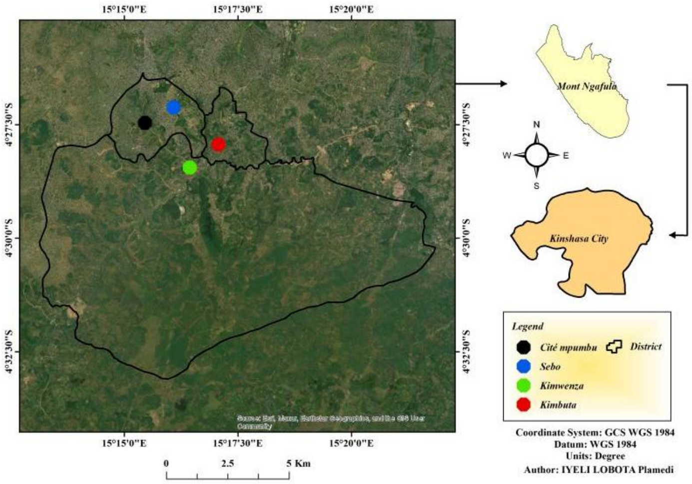
Study Area Overview

The study was conducted at Kimwenza gare, located in the Kimwenza district of the municipality of Mont-Ngafula, southwest of the city of Kinshasa **(Figure 1)**. The area is characterized by intensive agricultural activity along several waterways, the most important being the Lukaya River. The site also has significant commercial activity, with various products sold, including leafy and fruit vegetables.

In addition, the area experiences substantial road and railway traffic. These activities generate aerosols and other pollutants that may settle on soils and cultivated vegetables depending on climatic conditions. This proximity directly exposes crops and indirectly exposes consumers.

The local environment is characterized by sandy soils developed on Kalahari sands, with low clay content (less than 20%) to a depth of at least 100 cm and low organic matter content. To compensate for low soil fertility, market gardeners use mineral fertilizers and organic amendments such as animal manure. Vegetables produced in this area are sold in local markets and in nearby districts, including Kimbuta, Sebo, and Cité Mpumbu.

Figure 1:
Esri world imagery of the sampling site. (a) Municipality of Mont-Ngafula, (b) City of Kinshasa.



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Study Population and Sampling Strategy

The target population consisted of individuals consuming leafy and fruit vegetables produced in Kimwenza gare, particularly in the districts of Kimwenza, Kimbuta, Sebo, and Cité Mpumbu. Survey participants included both adults and children selected through random sampling to obtain a representative sample. Amaranth (*Amaranthus viridis*) and cassava leaves (*Manihot esculenta*) were identified as the vegetables most frequently prepared in households within these districts. Survey data were collected using KoboToolbox software.

Vegetable samples were collected in November during the rainy season. Both vegetable species were analyzed to quantify accumulated trace metal concentrations. Due to the large size of the agricultural site and financial constraints, composite sampling was adopted. The site was subdivided into three sectors based on irrigation water sources, since irrigation water may transport pollutants **(Table 1)**. The three sectors were Lukaya, Ma Valley, and Melo.

Vegetable samples were collected from two market gardeners in each sector, yielding a total of six market gardeners (n = 6). Approximately 1 kg of *A. viridis* and 1 kg of *M. esculenta* leaves were purchased from each market gardener.

Samples from the two market gardeners within each sector were combined to form one composite sample per vegetable species per sector. This resulted in three composite samples of amaranth (n = 3) and three composite samples of cassava leaves (n = 3). Samples were packaged and transported on the same day to the Central Analysis Laboratory (LCA) of the General Commission for Atomic Energy/Nuclear Research Center in Kinshasa (CGEA/CREN-K).

Table 1:
Distribution of Vegetable Samples by Sector

Vegetable species	Lukaya	Melo	Ma Valley
Amaranthus viridis	A1, A2	A3, A4	A5, A6
Manihot esculenta	FM1, FM2	FM3, FM4	FM5, FM6

Note. Composite samples were formed as follows: A1 + A2 = first amaranth sample; A3 + A4 = second amaranth sample; A5 + A6 = third amaranth sample; FM1 + FM2 = first cassava leaf sample; FM3 + FM4 = second cassava leaf sample; FM5 + FM6 = third cassava leaf sample.

Laboratory Analysis

Vegetable samples were first washed with tap water to remove soil and sand particles, then rinsed with distilled water. Samples were air-dried for three days and subsequently dried in an oven at 40°C for three additional days. After drying, the samples were crushed and sieved using a 60 µm mesh.

A 5 g subsample of the resulting powder was mixed with 1 g of Fluxana binder to form pellets using a mold and hydraulic press. Pellets were analyzed using an energy-dispersive X-ray fluorescence spectrometer (ED-XRF). All analyses were performed in triplicate to ensure reproducibility and reliability.

Trace elements were quantified using a XEPOS III ED-XRF spectrometer with the “FP-Pellet CGEA” and “TQ-Pellets Fast” methods. The ED-XRF is a multi-element analytical technique using four secondary targets: molybdenum (39.76 kV, 0.88 mA), aluminum oxide (49.15 kV, 0.70 mA), cobalt (35.79 kV, 1.00 mA), and HOPG Bragg crystal (17.40 kV, 1.99 mA), using a palladium anode. Samples were irradiated with an X-ray beam, causing atoms to emit characteristic fluorescent X-rays. The resulting energy spectrum displays peaks corresponding to specific elements, allowing quantification of their concentrations.

Statistical Analysis

Statistical analysis was performed using RStudio (version 4.5.1). Pearson correlation coefficients were calculated to evaluate relationships between trace metal concentrations in vegetable samples from different sectors, allowing assessment of accumulation patterns.

Health Risk Assessment

Hazard identification enables selection of substances to be included in quantitative health risk assessment (QHRA) and allows identification of potential adverse effects, including acute, subchronic, chronic, threshold, and non-threshold effects. In this study, the assessment focused on two trace metals: cadmium (Cd) and lead (Pb).

The methodology included the following components:

- **Dose–response assessment**, which establishes a quantitative relationship between administered or absorbed dose and the incidence of effects, resulting in toxicological reference values such as the reference dose (RfD).
- **Exposure assessment**, which identifies pathways of contaminant transfer from source to human receptor and estimates exposure frequency, duration, and intensity. This step allows calculation of the estimated daily intake (EDI).

The EDI for trace metals through vegetable consumption was calculated using Equation (1):

$$EDI = C \times Q \times F / P \qquad (1)$$

where:

- **EDI** = estimated daily intake (mg/kg/day)
- **C** = concentration of the contaminant (mg/kg)
- **Q** = daily vegetable consumption rate (kg/day)
- **F** = exposure frequency (unitless)
- **P** = body weight (kg)

In this study, the mean adult body weight was derived from survey data. The weekly consumption frequency was 2 for amaranth and 3 for cassava leaves. Survey data were also used to quantify the amount of vegetables consumed, using a precision scale. The container weight was measured alone and then measured again with prepared vegetables; the difference represented the weight of vegetables consumed.

Risk characterization estimates the likelihood and severity of adverse effects that may occur in a population exposed to contaminants. For threshold effects, risk characterization is expressed as the hazard quotient (HQ), calculated for oral exposure using Equation (2):

$$HQ = EDI / RfD \qquad (2)$$

where:

- **EDI** = estimated daily intake (mg/kg/day)
- **RfD** = reference dose (mg/kg/day)

The RfD values used in this study were 0.0040 mg/kg/day for lead and 0.0010 mg/kg/day for cadmium. Interpretation of HQ values was as follows:

- If **HQ < 1**, toxic effects are unlikely.
- If **HQ > 1**, toxic effects cannot be ruled out.

This approach evaluates each contaminant individually and does not account for combined effects from exposure to mixtures.

Ethical Considerations

Participation in the survey was voluntary, and information from residents of the four neighborhoods was collected without coercion. Authorization was obtained from local authorities and the university prior to conducting the survey.

RESULTS

Survey Results

Depending on respondent availability, we surveyed 73 households across four districts. Body weight data were collected for all participants (adults and children). The mean body weight of adults was 71 kg, while that of children was 43 kg **(Table 2)**. Standard weights established by ASTEE (70 kg for adults and 28 kg for children) were not used because most children in our sample weighed more than 30 kg, with a maximum of 55 kg.

The quantity of vegetables prepared per meal was generally equivalent to two bunches for both vegetable species. However, this quantity varied depending on stem size, leaf density, and vendor practices. Based on measurements and calculations, the average quantity of vegetables consumed was estimated at 0.508 kg.

Table 2:
Body Weight of Survey Participants

Category	Age group	Mean body weight (kg)
Children	< 18 years	43
Adults	≥ 18 years	71

Note. Body weight values were obtained from survey data (n = 73 households).

Trace Metal Concentrations in Vegetables

All six vegetable samples analyzed contained trace metals. However, only essential trace elements (Cu, Fe, and Zn) and non-essential trace metals potentially harmful to human health were considered in this study.

Table 3 presents trace metal concentrations in cassava leaves (*Manihot esculenta*) collected from the three sectors. Cadmium (Cd) was detected in all samples at concentrations exceeding the WHO/FAO permissible limit of 0.10 mg/kg dry weight (0.129 ± 0.012, 0.164 ± 0.123, and 0.133 ± 0.012 mg/kg). Chromium (Cr) and lead (Pb) were also detected, although at low concentrations.

Table 4 presents trace metal concentrations in amaranth (*Amaranthus viridis*). Lead was not detected in samples from the Melo and Lukaya sectors, possibly due to its absence or concentrations below the detection limit of the instrument. A similar observation was made for nickel (Ni) in the Lukaya sector. Cadmium concentrations exceeded the permissible limit in Melo and Lukaya samples.

Figure 2 shows correlations between trace metal concentrations in both vegetable species. Strong positive correlations were observed across the three sectors (r = 0.967, r = 0.995, and r = 0.979), indicating proportional accumulation of trace metals in both vegetables despite differences in absolute concentrations. Overall, vegetables from the Lukaya sector showed the highest trace metal concentrations.

Table 3:
Trace Metal Concentrations in *Manihot esculenta* Samples and WHO/FAO Permissible Limits (WHO, 2014)

Sector	Trace metal	Unit	Concentration (mg/kg)	Permissible limit (mg/kg)
Melo	Cu	mg/kg	7.180 ± 0.406	73
	Ni	mg/kg	1.056 ± 0.010	67
	Fe	mg/kg	77.219 ± 4.063	–
	Zn	mg/kg	29.253 ± 1.523	100
	Cd	mg/kg	0.129 ± 0.012	0.10
	Cr	mg/kg	0.711 ± 0.053	2.3
Lukaya	Cu	mg/kg	5.601 ± 0.483	73
	Ni	mg/kg	1.242 ± 0.135	67
	Fe	mg/kg	249.936 ± 22.282	–
	Zn	mg/kg	46.460 ± 3.128	100
	Cd	mg/kg	0.164 ± 0.123	0.10
	Cr	mg/kg	0.396 ± 0.030	2.3
	Pb	mg/kg	0.096 ± 0.007	0.30
Ma Valley	Cu	mg/kg	7.603 ± 0.613	73
	Ni	mg/kg	2.217 ± 0.158	67
	Fe	mg/kg	160.680 ± 15.183	–
	Zn	mg/kg	62.190 ± 4.864	100
	Cd	mg/kg	0.133 ± 0.012	0.10
	Cr	mg/kg	0.735 ± 0.055	2.3
	Pb	mg/kg	0.035 ± 0.002	0.30

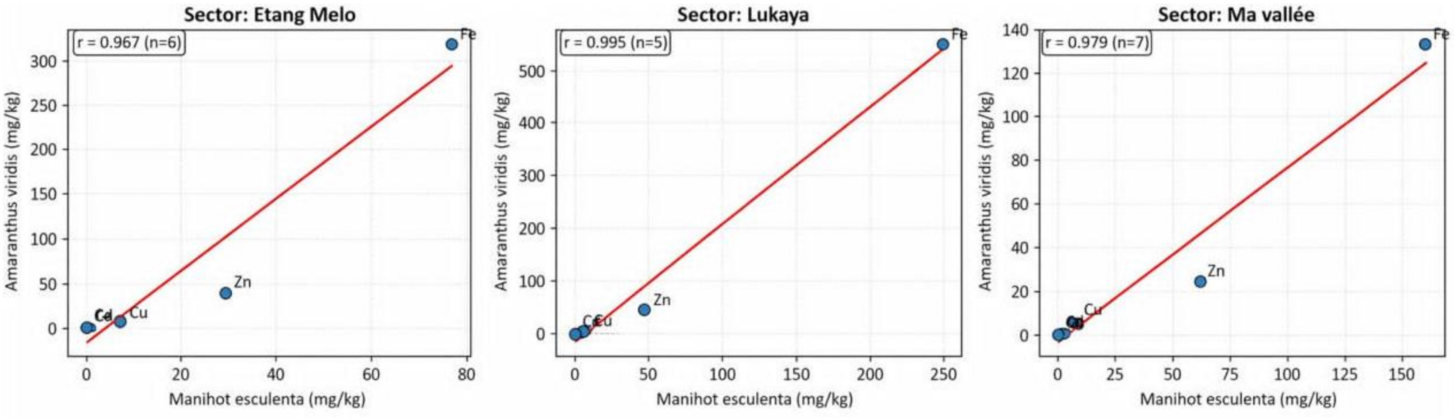
Note: Concentrations are expressed as mean ± standard deviation (n = 3).

Table 4:
Trace Metal Concentrations in *Amaranthus viridis* Samples and WHO/FAO Permissible Limits (WHO, 2014)

Sector	Trace metal	Unit	Concentration (mg/kg)	Permissible limit (mg/kg)
Melo	Cu	mg/kg	7.031 ± 0.532	73
	Ni	mg/kg	1.354 ± 0.011	67
	Fe	mg/kg	320.328 ± 30.383	–
	Zn	mg/kg	38.337 ± 2.404	100
	Cd	mg/kg	0.291 ± 0.026	0.10
	Cr	mg/kg	1.540 ± 0.937	2.3
Lukaya	Cu	mg/kg	6.384 ± 0.479	73
	Fe	mg/kg	550.475 ± 35.921	–
	Zn	mg/kg	46.111 ± 3.250	100
	Cd	mg/kg	0.420 ± 0.028	0.10
	Cr	mg/kg	0.942 ± 0.122	2.3
Ma Valley	Cu	mg/kg	6.180 ± 0.492	73
	Ni	mg/kg	0.637 ± 0.056	67
	Fe	mg/kg	133.678 ± 12.614	–
	Zn	mg/kg	24.430 ± 2.170	100
	Cd	mg/kg	0.052 ± 0.039	0.10
	Cr	mg/kg	0.240 ± 0.018	2.3
	Pb	mg/kg	0.151 ± 0.013	0.30

Note: Concentrations are expressed as mean ± standard deviation (n = 3). Pb was not detected in Melo and Lukaya samples.

Figure 2:
Correlation of trace metal concentrations between the two vegetable species



Estimated Daily Intake (EDI) and Hazard Quotient (HQ)

For calculation of the estimated daily intake (EDI) and hazard quotient (HQ), only two non-essential trace metals detected in the vegetables were considered: cadmium (Cd) and lead (Pb). **Figure 3** compares the concentrations of these two metals across the three sectors. Cadmium generally accumulated at higher concentrations than lead, except in amaranth from the Ma Valley sector, where Pb concentrations exceeded Cd concentrations.

The calculated EDI and HQ values are presented in **Table 5**. Hazard quotients were computed using the mean body weights of adults and children, the average quantity of vegetables consumed, weekly consumption frequency, and measured concentrations of Cd and Pb. An HQ < 1 indicates low immediate risk, whereas HQ > 1 suggests that adverse non-carcinogenic health effects cannot be excluded.

Cadmium HQ values exceeded 1 across all sectors, indicating a high likelihood of cadmium-related non-carcinogenic health effects, particularly among children. In contrast, lead HQ values were consistently below 1, suggesting that immediate risks associated with lead exposure are unlikely.

Figure 3:
Comparison of Pb and Cd concentrations in vegetables from the three sectors

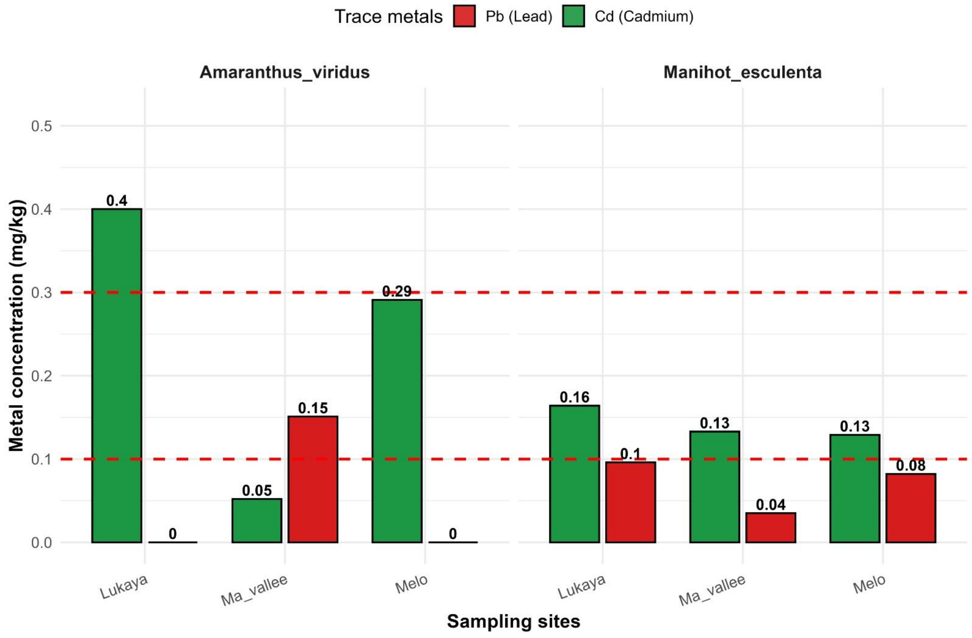


Table 5:
Estimated Daily Intake (EDI) and Hazard Quotient (HQ) for Lead and Cadmium in Adults and Children

Sector	Vegetable species	Pb EDI (children)	Pb EDI (adults)	Pb HQ (children)	Pb HQ (adults)	Cd EDI (children)	Cd EDI (adults)	Cd HQ (children)	Cd HQ (adults)
Melo	*Manihot esculenta*	0.003	0.002	0.75	0.50	0.004	0.002	4.0	2.0
	Amaranthus viridis	–	–	–	–	0.006	0.004	6.0	4.0
Lukaya	*Manihot esculenta*	0.003	0.002	0.75	0.50	0.005	0.003	5.0	3.0
	Amaranthus viridis	–	–	–	–	0.009	0.005	9.0	5.0
Ma Valley	*Manihot esculenta*	0.001	0.0007	0.25	0.175	0.004	0.002	4.0	2.0
	Amaranthus viridis	0.003	0.002	0.75	0.50	0.001	0.0007	1.0	0.7

Note: EDI is expressed in mg/kg/day. HQ values were calculated using RfD = 0.0040 mg/kg/day for Pb and RfD = 0.0010 mg/kg/day for Cd. "–" indicates Pb was not detected.

DISCUSSION

Trace Metals in Vegetables

All analyzed samples of the two vegetable species contained trace metal elements. The same trace metals were detected in amaranth samples across the three sectors. Among the seven elements identified, cadmium concentrations exceeded the permissible limit of 0.10 mg/kg dry weight (0.129 ± 0.012, 0.164 ± 0.123, and 0.133 ± 0.012 mg/kg), indicating contamination. Potential sources include phosphate fertilizers (Nziguheba & Smolders, 2008) and other contaminated agricultural inputs used by market gardeners. Although lead and chromium concentrations were low, their presence indicates environmental contamination.

Cassava leaf samples also contained trace metals, with variation in accumulation across sectors. All trace metals identified in amaranth were detected only in samples from the Ma Valley sector. Lead was not detected in samples from Melo and Lukaya, and nickel was not detected in Lukaya samples. Cadmium exceeded the permissible limit in Melo and Lukaya samples (0.291 ± 0.026 mg/kg and 0.420 ± 0.028 mg/kg dry weight, respectively). Pearson correlation analysis showed a strong positive association between trace metal concentrations in the two vegetable species, with correlation coefficients close to 1 (r = 0.967, r = 0.995, and r = 0.979 for Melo, Lukaya, and Ma Valley, respectively).

Estimated Daily Intake (EDI) and Hazard Quotient (HQ)

Although seven trace metals were detected, only Cd and Pb were considered in HQ calculations. Cadmium concentrations exceeded the permissible limit in most amaranth samples, confirming that consumers are exposed to cadmium-related health effects. However, contaminant concentration alone does not fully indicate risk, since risk depends on factors such as body weight, consumption frequency, and quantity consumed.

Hazard quotient values indicated a high probability of non-carcinogenic health effects associated with cadmium exposure, since most HQ values exceeded 1, with the exception of one adult value (HQ = 0.7) for amaranth from the Ma Valley sector. These findings suggest that consumers may be at risk of kidney damage (including tubular nephropathy and chronic renal failure), bone diseases such as osteoporosis and osteomalacia, and reproductive disorders. Children were found to be more vulnerable, as their HQ values were consistently higher than those of adults. Although lead HQ values were below 1, they remain of concern due to lead's tendency to bioaccumulate.

Mukeba et al. (2023) reported high concentrations of lead and cadmium in vegetables collected from four markets in Kinshasa (Camp Kokolo, Bandalungwa, Kitambo, and Bayaka/Ngiri-Ngiri). In that study, cancer risk coefficients were greater than 1 for both elements in amaranth from three markets, although the calculation procedure was not clearly described and did not differentiate between exposure groups or consumption patterns.

In Loumbila, Burkina Faso, Bambara et al. (2023) detected elevated lead concentrations in leafy vegetables and fruits (carrots, onion leaves, onions, lettuce, green beans, and bell peppers). However, HQ values exceeded 1 only for carrots and lettuce, where lead concentrations (27.02 mg/kg and 15.44 mg/kg dry weight) were substantially above the permissible limit of 0.30 mg/kg. Similarly, in

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Ghana, Ametepey et al. (2018) reported HQ values above 1 for cadmium, chromium, and manganese in cabbage, carrots, green peppers, onions, and tomatoes.

These findings support the influence of agricultural inputs (fertilizers, pesticides, and irrigation water) on vegetable quality. Road and rail transport may also contribute to lead contamination through atmospheric deposition. Overall, the results indicate a potential risk of cadmium-related non-carcinogenic diseases among adults and children consuming amaranth and cassava leaves grown in Kimwenza gare. Although lead HQ values were below 1, chronic exposure may still pose long-term health risks due to accumulation in the body.

CONCLUSION

Kinshasa has several agricultural sites where vegetables are produced and sold for consumption by the local population. Residents rely heavily on these vegetables, and market gardeners increasingly depend on fertilizers and pesticides to improve yields. However, the use of mineral fertilizers and pesticides can introduce trace metals that may expose consumers to health risks.

This study quantified trace metals accumulated in amaranth (*Amaranthus viridis*) and cassava leaves (*Manihot esculenta*) grown in the Kimwenza gare agroecosystem. It also estimated dietary exposure to cadmium and lead in order to assess non-carcinogenic health risks among adults and children in four districts where these vegetables are commonly consumed. Hazard quotient values greater than 1 for cadmium suggest that consumers may be at risk of cadmium-related non-carcinogenic diseases, including kidney and bone disorders.

Risk reduction strategies should aim to limit trace metal accumulation in foods that are essential for public health. Raising awareness among market gardeners regarding the use of less-polluting organic fertilizers (e.g., green manure) and implementing periodic monitoring of soil and vegetable quality may help reduce food contamination risks.

The main limitation of this study is the small number of analyzed samples and the lack of additional health risk indices such as cancer risk (CR) and target cancer risk (TCR). Including these indices would allow estimation of carcinogenic risks associated with consumption of trace metal-contaminated vegetables. Expanding this research to other agroecosystems and incorporating medical data would improve understanding of the extent and health impacts of this issue.

Author Contributions: I.L.P. designed the study and defined the objectives. T.M.D. collected the vegetable samples and survey data. K.B.P. performed the statistical analysis. T.T.T. and B.M.E. contributed to critical review and supervision of the study.

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Ethical Approval: Authorization was obtained from local authorities and the University prior to conducting the survey.

Conflicts of Interest: None declared.

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