OPEN ACCESS

Orapuh Journal

ORIGINAL ARTICLE *Journal of Oral & Public Health*

Evaluation of the impacts of trace metals on market gardening consumers: The case of Kimwenza-Gare

Iyeli, L. P.[1,2], Kanjinga, N. A.[1,2], & Tangou, T. T.[1,2,3]

[1]*CBRN Centre of Excellence, Ministry of Higher Education, University, Scientific Research and Innovation, Democratic Republic of the Congo*
[2]*Department of Environmental Sciences, Faculty of Science and Technology, University of Kinshasa, Kinshasa, Democratic Republic of the Congo*
[3]*Commissariat Général à l'Énergie Atomique (CGEA), Ministry of Higher Education, University, Scientific Research and Innovation, Democratic Republic of the Congo*

ARTICLE INFO

Received: *30 January 2026*
Accepted: *21 February 2026*
Published: *07 April 2026*

Keywords:
Environment, trace metals, leafy vegetables, Kimwenza-Gare, Mont-Ngafula

Peer-Review: *Externally peer-reviewed*

Correspondence to:
Plamedi Iyeli Lobota
plamedi.iyeli@unikin.ac.cd

To cite:
Iyeli, L. P., Kanjinga, N. A., & Tangou, T. T. (2026). Evaluation of the impacts of trace metals on market gardening consumers: The case of Kimwenza-Gare. *Orapuh Journal, 7*(3), e1421
https://dx.doi.org/10.4314/orapj.v7i3.21

ISSN: *2644-3740*

Published by Orapuh, Inc. (info@orapuh.org)

Editor-in-Chief: Prof. V. E. Adamu
Orapuh, F. Gaye R., Sukuta, Greater Banjul, The Gambia, editor@orapuh.org.

ABSTRACT

Introduction

The reliance of agriculture on mineral fertilizers and pesticides has raised concern for decades. In Kinshasa, market gardening contributes substantially to feeding the local population.

Purpose

This study assesses the impacts of trace metals accumulated in leafy vegetables cultivated in Kimwenza-Gare (Mont-Ngafula Commune), with a particular focus on potential risks to consumer health.

Methods

A survey of market gardeners was conducted to identify the most frequently sold vegetables throughout the year and to document the agricultural inputs used for soil fertilization and pest control. Six vegetable samples and three soil samples were analyzed for ionic composition using an energy-dispersive X-ray fluorescence spectrometer (ED-XRF). Statistical analyses included Student's *t*-test, as well as Spearman and Pearson correlation coefficients, performed using RStudio (version 4.3). Results were compared with World Health Organization (WHO) standards.

Results

Trace elements were detected in all vegetable samples at a 95% confidence interval. Chromium (Cr) concentrations exceeded the WHO guideline value (2.3 mg/kg dry weight) in all *Amaranthus viridis* samples from the Lukaya sector, reaching a maximum concentration of 9.46 ± 1.26 mg/kg. Lead (Pb) concentrations also exceeded the guideline value (0.30 mg/kg) in this vegetable, with the highest level recorded in the same sector (0.67 ± 0.01 mg/kg). Cadmium (Cd) was detected but remained below the detection limit. Overall, vegetables accumulated heavy metals present in the soil, particularly *Amaranthus viridis* in the Lukaya sector ($\rho = 1$).

Conclusion

Although the overall concentrations of trace metals were relatively low, consumers remain exposed to potential risks of chronic poisoning. Preventive measures, including awareness campaigns targeting market gardeners, should be implemented.

INTRODUCTION

Contamination of food products by trace metals has significant consequences for ecosystems and human health. Among anthropogenic activities that represent potential sources of trace metals is agriculture. Because trace metals are non-biodegradable by nature, they are highly ecotoxic and may cause numerous diseases (Touaihia, 2021). In many parts of the world, the use of mineral fertilizers has become necessary in recent decades to increase agricultural production by improving crop quality through nutrient inputs. This practice is also intended to expand agricultural activities to soils considered infertile (Chen et al., 2007, as cited in Azzi, 2016).

Several studies in sub-Saharan Africa have investigated contamination in peri-urban agroecosystems (Hodomihou et al., 2016; Niyomutoni, 2025; Traoré, 2021). Other studies have focused on the contribution of phosphate fertilizers to trace metal inputs in acidic soils under humid climatic conditions, as well as their mobility in soils and transfer to plants (François et al., 2009; Sayyad et al., 2010). Once present in the soil, trace metals may accumulate in food crops consumed by local populations (Bakhoum et al., 2025; Smith et al., 2008).

In the Democratic Republic of the Congo, in the municipality of Masina (Kinshasa), lead (Pb) concentrations exceeding recommended limits were reported in amaranth vegetables (Falasi, 2017). However, a large proportion of the population depends on agricultural products grown in these peri-urban agroecosystems.

Very few studies have been conducted in the southwestern part of Kinshasa. Existing studies have mainly focused on farming practices and the identification of metallic contaminants in vegetables. Agricultural inputs used in these areas include phosphate-based chemical fertilizers, compost, sewage sludge, plant protection products, as well as pollution from industrial activities and transportation (Traoré, 2021).

At Kimwenza-Gare, in the municipality of Mont-Ngafula, market gardeners use both chemical and biological inputs for crop production. However, to date, no studies have specifically investigated trace metal contamination in crops grown in this area. Therefore, the main objective of this study is to assess the impacts of trace metals accumulated in market garden crops, particularly with regard to potential effects on human health.

The specific objectives were as follows: (1) to identify the two leafy vegetables most commonly grown by market gardeners; (2) to conduct a quantitative chemical analysis of trace metals available in the soil and accumulated in these vegetables; and (3) to assess the impacts on the environment and, in particular, on human health. This assessment does not include a quantitative health risk calculation.

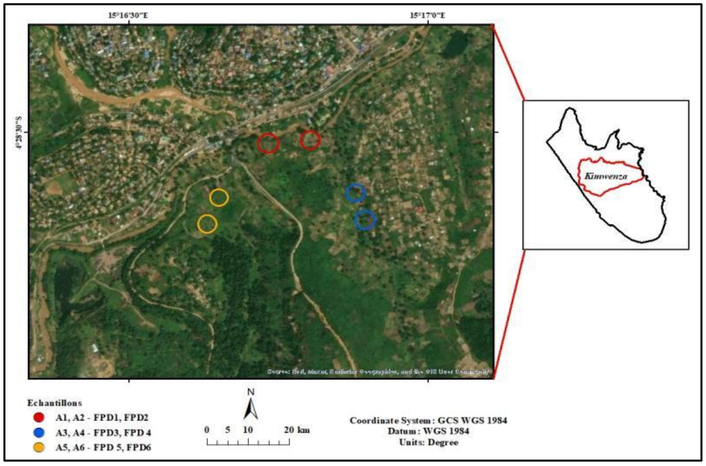
METHODS

Study Area Overview

Kimwenza is a neighborhood located in the municipality of Mont-Ngafula, in the southern part of Kinshasa Province. It is situated on a plateau overlooking the city at an altitude of approximately 493 m within the Lukaya River watershed. The area has a humid tropical climate classified as AW4 according to the Köppen classification, with an average annual rainfall of approximately 1,500 mm and an average temperature of 24°C.

The study area, located in a peri-urban zone, is one of the most active agricultural areas in Kinshasa. Market gardeners cultivate leafy vegetables and fruit crops, and livestock activities (poultry, sheep, and pigs) are also present.

Figure 1:
Study area and sample collection sites



Study Design

This study aimed to assess the potential impacts of trace metals on consumers exposed through the consumption of market garden crops. It is primarily focused on the human environmental component, with consideration of public health aspects.

Study Population and Sampling Strategy

The study population consisted of Mont-Ngafula municipality, which is divided into several districts, including Kimwenza and Kimbuta, among others, that rely on vegetables produced in Kimwenza-Gare.

The study samples consisted of vegetables cultivated at Kimwenza-Gare, particularly those most frequently sold by market gardeners and resold by local traders. Soil samples were also collected. Following interviews with market gardeners, the two most frequently sold leafy vegetables were identified as amaranth (*Amaranthus viridis*) and sweet potato leaves (*Ipomoea batatas*).

The sampling campaign was conducted in June, during the dry season. Samples were collected to quantify accumulated trace metals and to assess their potential implications for consumers. Because the study area is extensive and financial resources were limited, a composite sampling approach was adopted.

The market gardening area was subdivided into three sectors based on irrigation water sources: (1) Lukaya River, (2) Kolopan River, and (3) irrigation water from the lake in the “Ma Vallée” area. This subdivision was based on the assumption that each water source could influence the quality of vegetables produced.

Two market gardeners were randomly selected in each sector, for a total of six market gardeners across the entire area (n = 6). Approximately 1 kg of each vegetable was collected from each market gardener. Soil samples were also collected from the plots where each vegetable was harvested.

This resulted in a total of six raw samples for amaranth, six raw samples for sweet potato leaves, and six raw soil samples. Before laboratory analysis, two samples of the same vegetable species from the same sector were combined to form composite samples. This resulted in six vegetable composite samples (n = 6) for analysis. Soil samples were treated similarly, yielding three composite soil samples (n = 3).

Table 1:
Distribution of Vegetable Samples by Sector

Vegetable species	Lukaya	Kolopan	Ma Vallée
Amaranthus viridis	A1, A2	A3, A4	A5, A6
Ipomoea batatas	FPD1, FPD2	FPD3, FPD4	FPD5, FPD6

Note: Composite samples were prepared as follows: A1 + A2 = A1.2 (first amaranth composite sample); A3 + A4 = A3.4 (second composite sample); A5 + A6 = A5.6 (third composite sample). Similarly, FPD1 + FPD2 = FPD1.2 (first composite sample of sweet potato leaves); FPD3 + FPD4 = FPD3.4 (second composite sample); FPD5 + FPD6 = FPD5.6 (third composite sample).

After collection, vegetable and soil samples were placed in plastic bags 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).

Vegetable samples were washed first with tap water and then with distilled water to remove dust and surface residues. Samples were air-dried in the laboratory for three days, then oven-dried at 40°C for an additional three days. After drying, samples were shredded and sieved (60 µm mesh) to obtain a fine powder. For pellet preparation, 5 g of powdered sample were mixed with 1 g of Fluxana binder and pressed into pellets using a mold and hydraulic press.

Laboratory Analysis

All samples were analyzed using the internal method “TQ-Pellets Fast.” Soil samples were air-dried for three days and sieved using a Retsch sieve (60 µm mesh). After grinding, 5 g of each soil sample were mixed with 1 g of Fluxana binder, homogenized, and pressed into pellets using a hydraulic press prior to analysis.

Elemental concentrations were determined using a XEPOS III energy-dispersive X-ray fluorescence (ED-XRF) spectrometer, following the “FP-Pellet CGEA” and “TQ-Pellets Fast” methods. The standards ISE870, ISE890, ISE919, ISE961, and SOIL-7 were used for calibration.

The ED-XRF method is a multi-element 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 (17.4 kV; 1.99 mA) from a palladium anode.

In principle, the sample pellet is exposed to an X-ray beam. Under irradiation, the sample emits characteristic

https://dx.doi.org/10.4314/orapj.v7i3.21

secondary X-rays through fluorescence. The resulting energy spectrum displays peaks corresponding to the elements present, while peak intensity is proportional to elemental concentration. Concentrations were determined through external calibration using normalized spectrometer intensities. The Kα1 peak (3.313 keV) of potassium (K) was used in the calculation, and the HOPG Bragg crystal target provided normalized peak areas relative to coherent and incoherent scattering peaks.

Results are reported with a confidence interval based on Student's *t*-test at $\alpha = 0.95$.

Like many analytical methods, ED-XRF has limitations and strengths. Elements with an atomic number lower than carbon cannot be detected. Detection limits depend on the excitation source and analytical conditions; they are approximately 10 ppm for elements such as Zn, Cu, and Pb, and may reach 100–500 ppm for lighter elements.

Accuracy depends on sample mass, the elements of interest, and the matrix composition. Sensitivity is influenced by sample preparation and varies among chemical elements; it may approach µg/g when analyzing undiluted samples of approximately one gram.

Statistical Analysis

Statistical analyses were conducted using RStudio (version 4.3). Data were compiled and processed through scripted coding to generate the study database. Pearson correlation coefficients were used to assess linear relationships between trace metal concentrations in soils and vegetables. Spearman correlation coefficients were used to evaluate monotonic relationships and to assess the direction and ranking of trace metal accumulation patterns.

Impact Assessment Methodology

Trace metal concentrations measured in amaranth and sweet potato leaves were compared with international guideline values for trace metals in vegetables. Standards published by the World Health Organization (WHO) and the Food and Agriculture Organization (FAO) were used as reference values.

Environmental impact assessment was based on five criteria: nature, intensity, duration, extent, and significance of impacts.

- **Nature** refers to whether the impact is positive or negative.
- **Intensity (magnitude)** refers to the degree of disturbance affecting the environment and depends on the vulnerability of the affected component (high, medium, or low).
- **Duration** refers to the period over which the impact manifests (permanent, temporary, or momentary).
- **Extent** refers to the spatial scale of the impact (regional, local, or localized).
- **Significance** reflects the magnitude of change affecting the environmental component and depends on duration, extent, and intensity.

Three disruption levels were used:

- **High**, when the impact permanently alters environmental quality or restricts use of the affected component;
- **Medium**, when the impact partially compromises use, integrity, or quality;
- **Low**, when the impact does not noticeably alter quality or use.

The importance of impacts was calculated using the following formula:

Importance = Intensity + Extent + Duration (1)

The impact receptors considered were physical, biological, and human environmental components.

Ethical Considerations

This study used information obtained from market gardeners with their informed consent. Interviews were conducted with members of the Kimwenza Market Gardeners Association (UGMK) after obtaining authorization from the association's leaders and the relevant local authorities. Formal approval from an ethics committee was not required.

RESULTS

Trace Metal (TM) Concentrations

Trace Metals in Soils

Table 2 presents the concentrations of trace metals measured in soils from the three sectors. Several metals were detected; however, the present study focuses primarily on elements generally considered priority environmental micropollutants, namely As, Cd, Cr, Cu, Hg, Ni, Pb, and Zn.

Overall, the concentrations of the investigated elements were below the WHO permissible limits for soils. Cadmium (Cd) concentrations were below the detection limit in all soil samples. In addition to the elements detected in the Lukaya soil, tin (Sn) was detected only in the Kolopan sector.

Table 2:
Trace Metal Concentrations (mg/kg Dry Weight) in Soil Samples and WHO Permissible Limits (WHO, 2014)

Element (mg/kg DW)	Lukaya	Kolopan	Ma Vallée	WHO permissible limit
Cr	25.01 ± 2.87	29.97 ± 3.79	35.56 ± 4.09	100
Cu	15.41 ± 3.54	8.16 ± 0.75	17.56 ± 4.04	100
Zn	49.35 ± 6.57	35.47 ± 1.99	101.32 ± 13.48	300
As	1.61 ± 0.24	1.79 ± 0.13	2.89 ± 0.43	20
Cd	< 0.40	< 0.40	< 0.40	3
Sn	ND	3.40 ± 0.25	ND	–
Pb	7.94 ± 0.49	9.25 ± 1.03	17.72 ± 1.10	100

Note. Values are presented as mean ± confidence interval (α = 0.95). ND = not detected. DW = dry weight. WHO = World Health Organization.

Trace Metals in Vegetables

Table 3 presents trace metal concentrations in *Amaranthus viridis* (amaranth) and *Ipomoea batatas* (sweet potato leaves) from the three sectors. Chromium (Cr) and lead (Pb) concentrations exceeded WHO permissible levels in several vegetable samples.

Tin (Sn) was not detected in sweet potato leaves (*Ipomoea batatas*) from the Lukaya and Ma Vallée sectors. Lead (Pb) was not detected in *Ipomoea batatas* from the Lukaya sector.

Table 3:
Trace Metal Concentrations (mg/kg Dry Weight) in Vegetable Samples and WHO Permissible Limits (WHO, 2014)

	A. viridis			*I. batatas*			
Element (mg/kg DW)	**Lukaya**	**Kolopan**	**Ma Vallée**	**Lukaya**	**Kolopan**	**Ma Vallée**	**WHO permissible limit**
Cr	9.46 ± 1.26	6.52 ± 0.87	5.47 ± 0.73	3.52 ± 0.47	2.11 ± 0.28	2.90 ± 0.39	2.3
Ni	2.52 ± 0.11	2.19 ± 0.10	3.11 ± 0.14	2.57 ± 0.11	1.58 ± 0.07	2.42 ± 0.11	67
Cu	6.83 ± 0.40	7.78 ± 0.45	8.71 ± 0.51	13.14 ± 1.77	6.32 ± 0.37	12.69 ± 1.75	73
Zn	35.32 ± 1.37	51.89 ± 2.01	33.70 ± 1.30	32.28 ± 1.25	21.45 ± 0.83	31.32 ± 1.21	100
Cd	< 0.48	< 0.48	< 0.48	< 0.48	< 0.48	< 0.48	0.10
Sn	0.00	< 0.80	< 0.80	0.00	< 0.80	0.00	–
Pb	0.67 ± 0.01	0.62 ± 0.01	0.62 ± 0.01	ND	0.69 ± 0.01	< 0.46	0.30

Note: Values are presented as mean ± confidence interval (α = 0.95). ND = not detected. DW = dry weight. WHO = World Health Organization.

Soil-to-Plant Transfer Factors

Soil-to-plant transfer factors were calculated to estimate the ability of vegetables to accumulate trace elements from soils **(Tables 4 and 5)**. Only trace metals detected in both soil and vegetable samples at measurable concentrations were included.

In *Amaranthus viridis*, Zn and Cu showed the highest transfer factors in the Kolopan sector (1.46 and 0.95, respectively) **(Table 4)**. In *Ipomoea batatas*, Cu and Zn exhibited relatively high transfer factors in all sectors, except for Zn in the Ma Vallée sector **(Table 5)**.

Figure 1 shows correlation coefficients among trace metals in soils and indicates strong positive correlations between Pb and Zn (r = 0.948) and between Cr and As (r = 0.936). The heat map also indicates a very strong positive correlation between the Lukaya and Ma Vallée sectors (r = 0.98).

Figure 2 shows that the correlation between trace metal concentrations measured in *Amaranthus viridis* and

Ipomoea batatas was strong and positive (Pearson's r ≈ 0.96–0.99), suggesting that metals with higher concentrations in one vegetable tended to be higher in the other.

Soil–vegetable correlations were positive in all three sectors, indicating that higher soil concentrations generally corresponded to higher concentrations in plant tissues **(Figure 3)**. The strongest association was observed in Lukaya, with a perfect Spearman correlation for *Amaranthus viridis* (ρ = 1) and a high correlation for *Ipomoea batatas* (ρ ≈ 0.84), indicating strong agreement in the ranking of trace metal concentrations between soil and vegetables in this sector **(Figure 4)**.

Table 4:
Soil-to-Plant Transfer Factors for *Amaranthus viridis*

Element	Lukaya	Kolopan	Ma Vallée
Cr	0.38	0.22	0.15
Cu	0.44	0.95	0.50
Zn	0.72	1.46	0.33
Pb	0.08	0.07	0.03

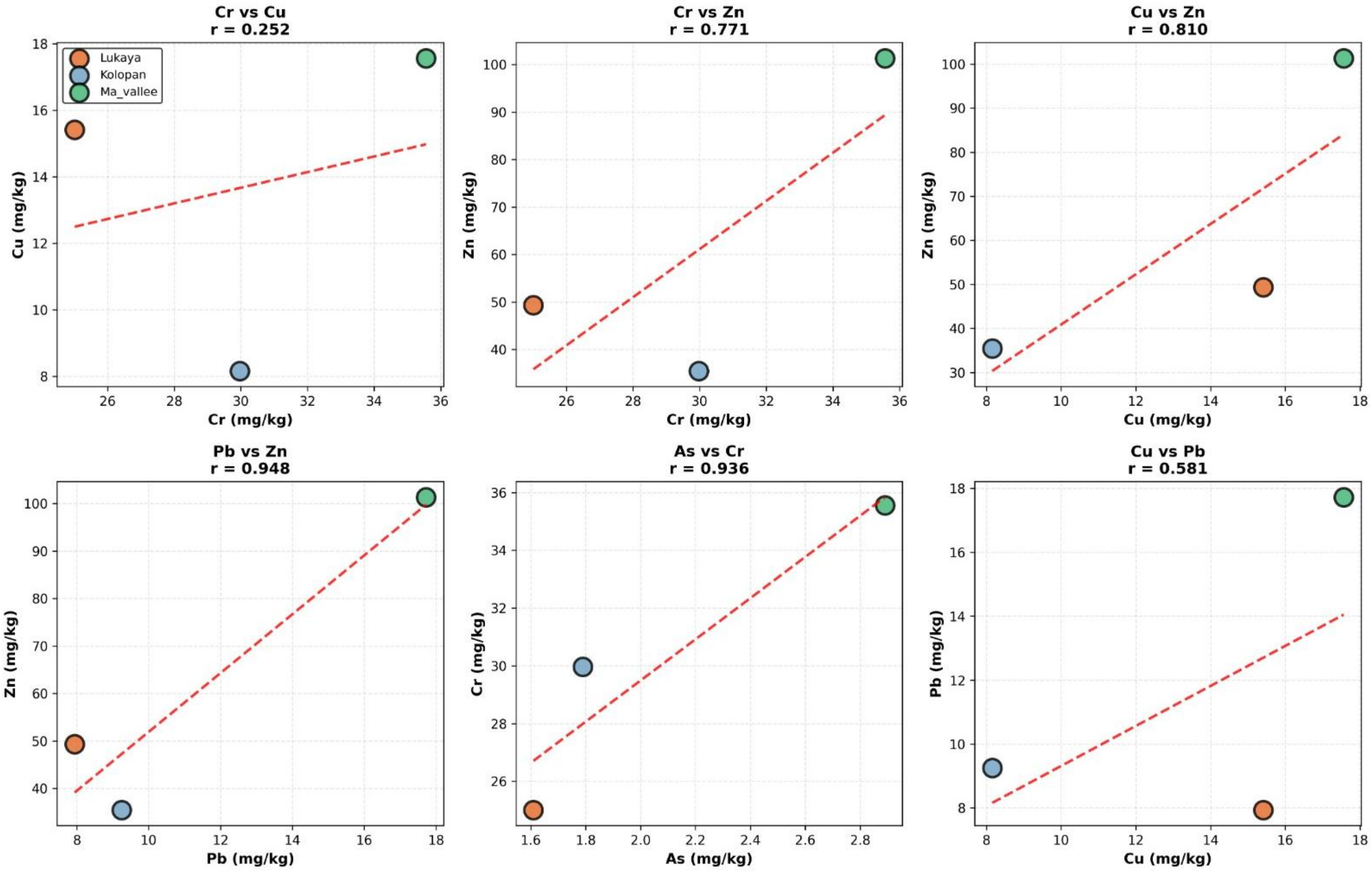
Table 5:
Soil-to-Plant Transfer Factors for *Ipomoea batatas*

Element	Lukaya	Kolopan	Ma Vallée
Cr	0.14	0.07	0.08
Cu	0.85	0.77	0.72
Zn	0.65	0.60	0.31
Pb	ND	0.07	ND

Note: ND = not detected.

Figure 1 (a & b):
Correlation coefficients of trace metals in soils

a)



b)

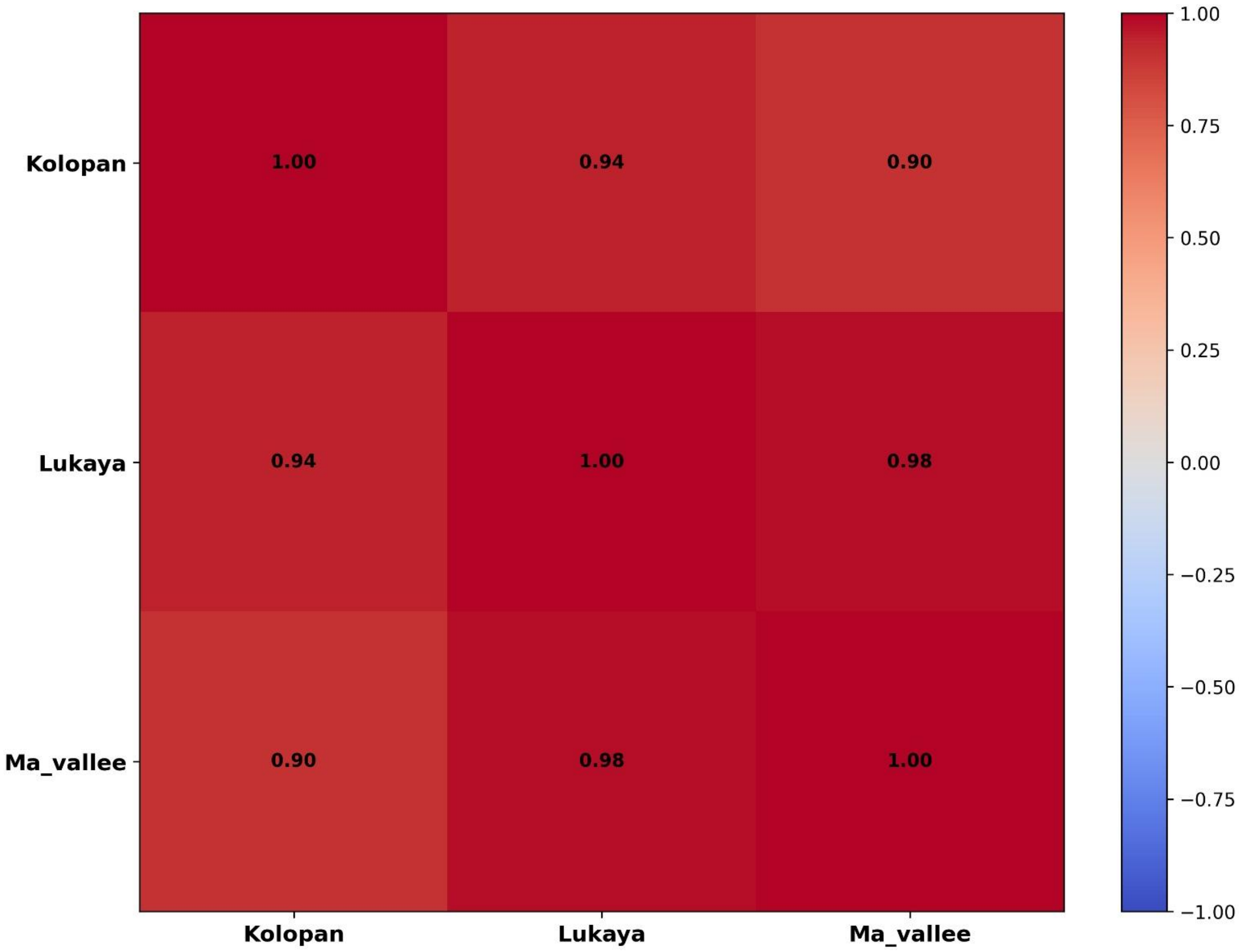


Figure 2:
Correlations between trace metal profiles in *Amaranthus viridis* and *Ipomoea batatas*.

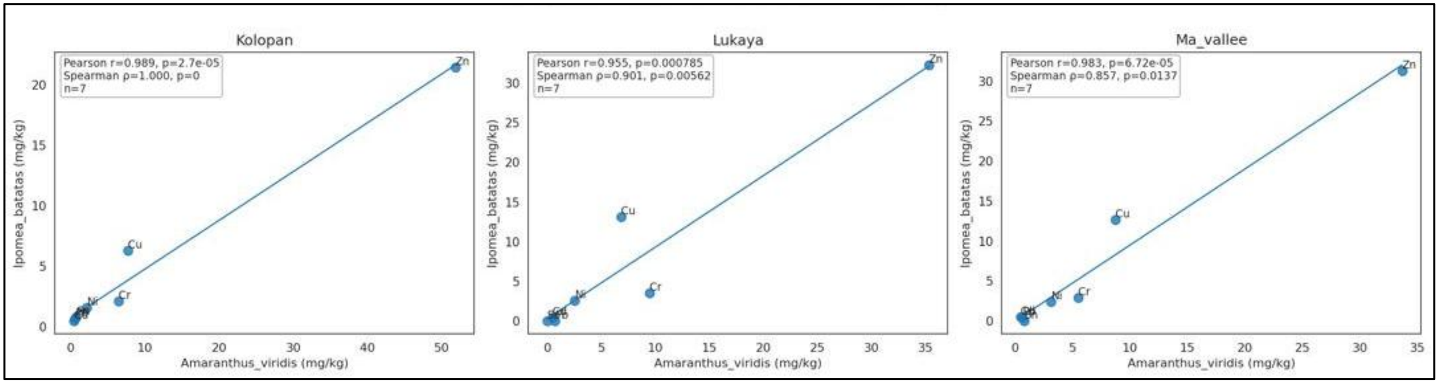


Figure 3:
Correlation coefficients between trace metals in soils and vegetables.

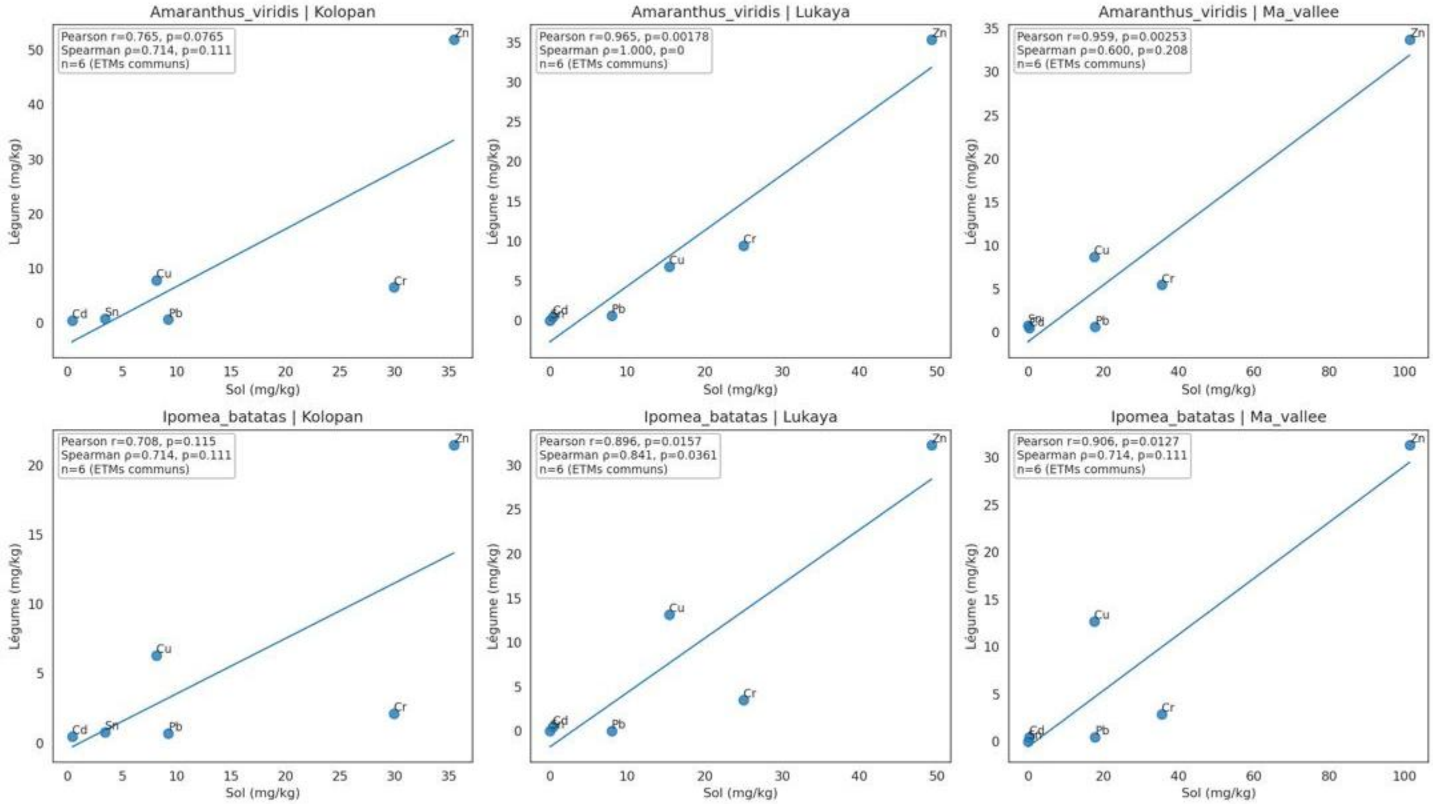
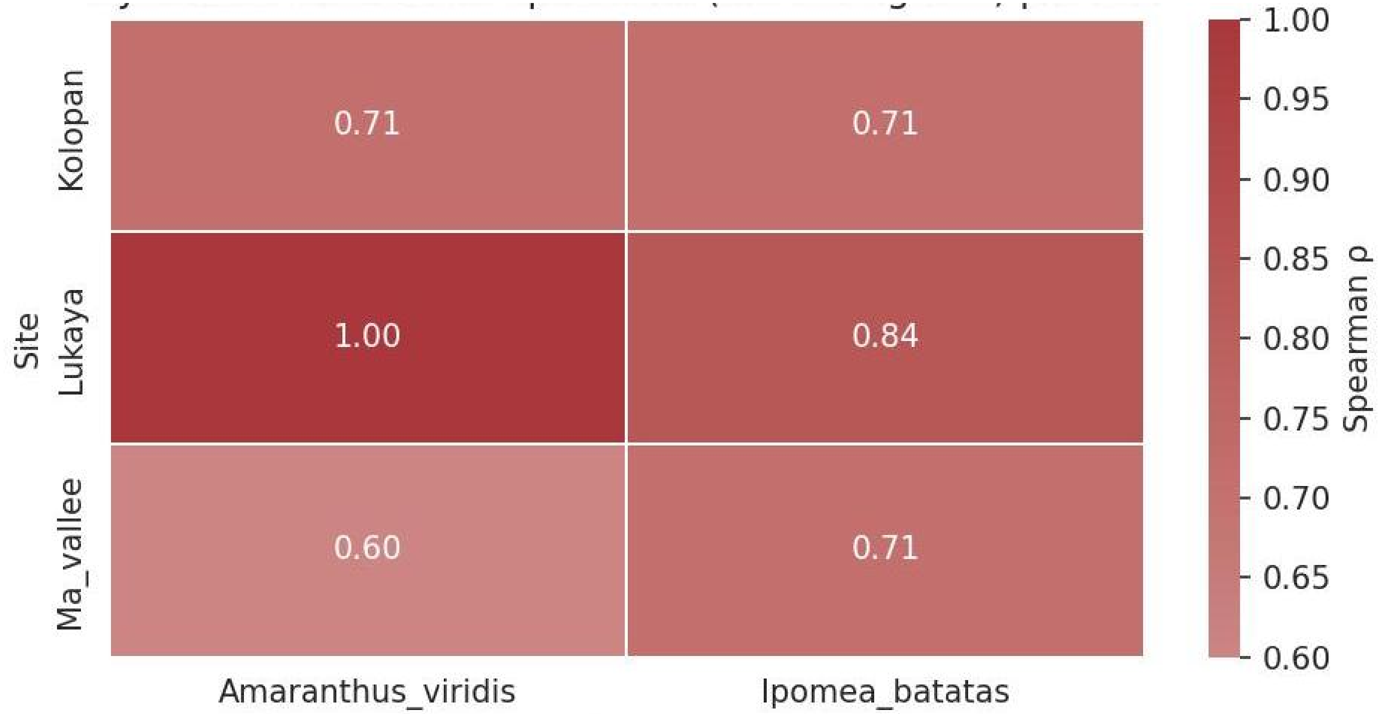


Figure 4:
Summary of soil–vegetable correlations for trace metals.



Potential Impacts of Trace Metals (TMEs)

Table 6 presents the potential impacts of market gardening activities on environmental components. The main activities identified as potential impact sources were soil amendment using mineral and organic fertilizers, pesticide application, and irrigation using water of questionable quality. **Table 7** summarizes the positive and negative impacts associated with these activities across the different environmental components.

Table 6:
Identification of Potential Impacts of Market Gardening in Kimwenza-Gare

Impact-generating activity	Air	Water	Soil	Fauna	Flora	Human health and economy
Amendment with chemical fertilizers	×	×	×	×	×	×
Pesticide application	×	×	×	×	×	×
Irrigation with polluted water	–	×	×	×	×	×

Note: × = potential impact; – = no direct impact identified.

Table 7:
Summary of Positive and Negative Impacts of Market Gardening in Kimwenza-Gare

Impact-generating activity	Positive impacts	Negative impacts
Amendment with chemical fertilizers	Good yields; rapid crop growth; lower production costs; economic gains for market gardeners; job creation.	Destruction of nitrogen-fixing bacteria at high concentrations; soil contamination by trace metals; contamination of surface water and groundwater; air pollution due to volatilization of certain compounds; public health risks.
Pesticide application	Pest control; improved yields; improved crop health; job creation.	Soil, water, and air contamination by trace metals; crop contamination; public health risks.
Irrigation with polluted water	Ensures water availability for crops; job creation.	Crop contamination; soil pollution; groundwater contamination; public health risks.

Impact Significance Assessment

Table 8 presents the results of the impact significance assessment of market gardening practices on environmental components, with emphasis on implications for human health. The values assigned to the assessment criteria were based on the trace metal concentrations measured in soil and vegetable samples.

The low intensity of impacts was attributed to the relatively low trace metal concentrations observed, which were generally below tolerance thresholds in soils. The local extent of airborne contamination is explained by the physical mobility of trace metals, which may disperse beyond the study site depending on meteorological conditions. Because trace metals are non-biodegradable and bioaccumulative, their persistence in receiving environments is long-term; therefore, duration was considered permanent.

The combined criteria (intensity, extent, and duration) resulted in an overall classification of impact significance as medium. Although concentrations were generally low, trace metals may pose chronic health risks at the consumer trophic level. Potential health effects include lead poisoning, neurological disorders, cardiovascular diseases, and reduced fertility in the case of Pb exposure. Total chromium is recognized as carcinogenic and may cause respiratory disorders and gastrointestinal damage.

Table 8:
Impact Significance Assessment Matrix for Market Gardening in Kimwenza-Gare

Impact-generating activity	Component	Identified impact	Nature	Intensity	Extent	Duration	Importance
Amendment with chemical fertilizers / pesticide application	Air	Air pollution due to volatilization of certain compounds	Negative	Low	Local	Permanent	Medium
Amendment with chemical fertilizers / pesticide application	Water	Contamination of surface water and groundwater	Negative	Low	Local	Permanent	Medium
Amendment with chemical fertilizers / pesticide application	Soil	Soil contamination and pollution	Negative	Low	Local	Permanent	Medium
Amendment with chemical fertilizers / pesticide application	Fauna and flora	Destruction of nitrogen-fixing bacteria at high concentrations; crop	Negative	Low	Local	Permanent	Medium

		contamination					
Amendment with chemical fertilizers / pesticide application	Human health	Diseases and public health risks	Negative	Low	Local	Permanent	Medium
Irrigation with polluted water	Air	Air pollution due to volatilization of certain compounds	Negative	Low	Local	Permanent	Medium
Irrigation with polluted water	Water	Contamination of surface water and groundwater	Negative	Low	Local	Permanent	Medium
Irrigation with polluted water	Soil	Soil contamination and pollution	Negative	Low	Local	Permanent	Medium
Irrigation with polluted water	Fauna and flora	Contamination	Negative	Low	Local	Permanent	Medium
Irrigation with polluted water	Human health	Contamination via inhalation, ingestion, and dermal contact	Negative	Low	Local	Permanent	Medium
Pesticide application	Fauna and flora	Contamination of living organisms	Negative	Low	Local	Permanent	Medium
Pesticide application	Soil	Contamination and pollution	Negative	Low	Local	Permanent	Medium
Pesticide application	Human health	Diseases and public health risks	Negative	Low	Local	Permanent	Medium

Note: Importance was calculated as: Importance = Intensity + Extent + Duration.

DISCUSSION

Trace Metals in Soils

Trace metals (TM) were detected in soil samples collected from the Kimwenza-Gare market gardening site, which was divided into three sectors based on irrigation water sources. The elements detected by ED-XRF were ranked in decreasing order of concentration as follows: Zn, Cr, Cu, Pb, As, Sn, and Cd.

Arsenic (As), lead (Pb), zinc (Zn), and copper (Cu) are among the substances widely dispersed in soils and potentially hazardous at elevated concentrations. This ranking is comparable to the findings of Wuana and Okieimen (2011), who reported that Zn is among the most abundant trace metals in soils (150–5,000 mg/kg), whereas Cd is typically among the least abundant (0.10–345 mg/kg) in contaminated environments.

The presence of Cu, Zn, Cd, and Pb may be associated with the application of poultry and cattle manure rich in organic matter, as well as the use of contaminated irrigation water from the three sources identified in this study. Cadmium inputs may also originate from phosphate fertilizers frequently used by market gardeners. Similar findings have been reported in other studies (Hodomihou et al., 2016).

Road traffic is another potential source of Pb contamination in surface soils. Lead was historically added to gasoline as an anti-knock agent, contributing significantly to particulate emissions from exhaust gases (Miquel, 2001). Chromium (Cr) and tin (Sn) may also originate from anthropogenic sources, including agricultural inputs and other local activities.

In addition, interactions among trace metals, combined with soil physicochemical characteristics (particularly pH), influence metal mobility, adsorption, and accumulation. This may explain why the concentrations measured in the soils remained below WHO guideline values. However, continuous monitoring of trace metal accumulation in this site is recommended, as long-term irrigation and repeated input application can progressively increase soil contamination. For example, in soils irrigated over several years in Nigeria, pseudo-total Cd concentrations were reported to exceed the permissible threshold (4 mg/kg compared to a limit of 3 mg/kg) (Abdu, 2010; Falasi, 2017).

Trace Metals in Vegetables

In vegetable samples, the ranking of detected trace metals differed from that observed in soils. In *Amaranthus viridis*, the order was Zn > Cu > Cr > Ni > Pb > Cd > Sn. In a similar study, Noubissie (2015) reported that such variations may depend on soil physicochemical properties and plant-specific accumulation capacity. Factors influencing accumulation include the availability of metals in soil (e.g., Pb bound to organic matter), plant uptake efficiency, reductions in Zn and Cu during plant growth, and competitive uptake interactions between Cu and Zn (Reichman, 2002, as cited in Falasi, 2017).

Chromium (Cr) concentrations exceeded the maximum permissible level established by the WHO (2014) in all *Amaranthus viridis* samples, with a peak concentration of 9.46 ± 1.26 mg/kg dry weight recorded in the Lukaya sector **(Table 3)**. Chromium was also detected in *Ipomoea batatas*, exceeding the permissible limit in the Lukaya and Ma Vallée sectors. Elevated Cr concentrations may pose a risk to consumer health. However, it should be noted that ED-XRF measures total chromium and does not distinguish between Cr(III) and the more toxic Cr(VI).

Lead (Pb) concentrations exceeded the WHO guideline value in *Amaranthus viridis* across all three sectors and in *Ipomoea batatas* from the Kolopan sector **(Table 3)**. Exposure to Pb may cause lead poisoning and physiological and neurological disorders, as well as kidney, reproductive, liver, and bone dysfunction, which may lead to severe health outcomes (Niyomutoni, 2025; Parui et al., 2023).

Transfer factor calculations revealed high accumulation of Zn (1.46) and Cu (0.95) in *Amaranthus viridis* from the Kolopan sector **(Table 4)**. In *Ipomoea batatas*, Cu showed high accumulation in all three sectors, while Zn accumulation was high in Lukaya and Kolopan **(Table 5)**. Nickel (Ni) was detected in vegetables but not detected in soils, whereas arsenic (As) was detected in soils but was absent in all vegetable samples. This observation may reflect the limited capacity of many vegetables to accumulate arsenic from soils. Phaneuf et al. (2012), in a study conducted in Quebec, reported that edible plant parts generally do not accumulate As at concentrations likely to cause adverse effects on human health.

Although toxic elements such as Cd, Pb, and Ni were detected at relatively low concentrations, the risks should not be underestimated because these metals are bioaccumulative and non-biodegradable.
Consumers exposed through vegetable consumption may therefore face long-term health risks. Preventive strategies should be considered to reduce potential public health impacts in the region.

Statistical analyses revealed strong positive correlations between Pb and Zn (r = 0.948) and between Cr and As (r = 0.936), as well as a strong correlation between Cu and Zn (r = 0.810). These relationships suggest common pollution sources and/or similar geochemical behavior under the soil conditions of the study area. Among the three sectors, Ma Vallée consistently showed the highest concentrations of most trace metals measured.

The correlation between trace metal concentrations measured in *Amaranthus viridis* and *Ipomoea batatas* was very strong and positive (Pearson's r ≈ 0.96–0.99), indicating a strong linear association. The generally weak Spearman correlation coefficients (except for *Amaranthus viridis* in Lukaya, where ρ = 1) suggest that the ranking of trace metals at low concentrations is not always consistent. In contrast, the Kolopan sector showed near-perfect agreement (Spearman's ρ = 1), indicating identical ranking of trace metals between the two plant species.

The Lukaya sector exhibited the strongest soil-to-vegetable transfer relationships. This may be explained by environmental characteristics such as soil pH and organic matter content, combined with plant-specific uptake capacities. Overall, both vegetables accumulated trace metals present in soils, but *Amaranthus viridis* showed the highest accumulation capacity. These vegetables may therefore act as effective bioaccumulators of pollutants present in the environment, potentially increasing consumer exposure.

This study was limited by the relatively small number of composite samples, which provides only a preliminary assessment of vegetable quality. Future studies using larger sample sizes are recommended. Sampling campaigns conducted during both rainy and dry seasons would also provide better insight into seasonal dynamics of trace metals and their transfer to vegetables. Finally, future health risk assessments should incorporate consumption frequency, exposure duration, and consumer physiological characteristics (e.g., body weight).

CONCLUSION

Market gardening is one of the most active agricultural sectors in Kinshasa and represents a potential pathway for trace metals to enter the food chain through chemical fertilizers, irrigation water, and pesticide use. This study evaluated the quality of two widely consumed leafy vegetables sold at Kimwenza-Gare (Mont-Ngafula municipality) in order to assess environmental impacts and potential implications for consumer health.

Results showed that trace metals present in soils across the three sectors were accumulated by both vegetables, with the exception of arsenic (As), which was not detected in plant tissues. In addition to essential trace elements such as Cu and Zn, the vegetables accumulated potentially toxic metals such as Cd, Pb, and Cr. The main potential sources of contamination include agricultural inputs (particularly mineral fertilizers, sewage sludge, and pesticides), as well as transportation-related emissions.

Excessive concentrations of Cr and Pb in vegetable samples, exceeding WHO guideline values, indicate a potential risk of poisoning. Although Cd concentrations were low, its detection is concerning because of its bioaccumulative and non-biodegradable nature, which may contribute to long-term health effects depending on chronic exposure.

These findings highlight the need for urgent preventive measures to reduce the risk of food-related poisoning. Recommended actions include: (1) raising awareness among market gardeners regarding controlled input supply and the quality of fertilizers and pesticides; (2) establishing periodic monitoring of vegetable quality and irrigation water; and (3) promoting the use of compost rich in organic matter to enhance metal complexation and reduce mobility.

Such measures could reduce the presence of toxic trace metals in the environment, limit their bioavailability to crops, and ultimately reduce dietary exposure among consumers.

Author Contributions: P.I.L. designed the study, conducted the surveys, collected samples, and developed the database and map. A.K.N. and T.T.T. contributed to critical review of the study and manuscript.

Acknowledgments: The authors thank the market gardeners of Kimwenza-Gare for their availability and cooperation during data collection. The authors are also grateful to Mr. Mabiala Philipe and Mr. Solo Kuanda Thomas, researchers in the Physical Sciences Division, Central Analysis Laboratory Department, CGEA/CREN-K, for their technical support..

Ethical Approval: Nil required.

Conflicts of Interest: None declared.

ORCID iDs:

Iyeli, L. P.[1,2]:	https://orcid.org/0009-0003-3533-8167
Kanjinga, N. A.[1,2]:	https://orcid.org/0009-0007-3220-1471
Tangou, T. T.[1,2,3]:	https://orcid.org/0009-0003-6788-9684

REFERENCES

Abdu, N. (2010). *Availability, transfer, and balances of heavy metals in urban agriculture in West Africa* (Doctoral dissertation). University of Kassel.

Azzi, V. (2016). *Contributions of trace metals from phosphate chemical fertilizers in Lebanese soils: Investigation into their fate and transfer* (Doctoral dissertation, Paul Sabatier University–Toulouse III & Lebanese University). TEL Archives. https://tel.archives-ouvertes.fr/tel-01535848

Bakhoum, M., Ndiolene, A., Ndiaye, N., Diallo, M. A., & Diop, T. (2025). Evaluation of the level of contamination by trace metals in leafy vegetables grown near the Mbeubeuss urban landfill (Dakar). *Journal of Applied Biosciences*. https://doi.org/10.3579/JABs.205.4

Chen, W., Chang, A. C., & Wu, L. (2007). Assessing long-term environmental risks of trace elements in phosphate fertilizers. *Ecotoxicology and Environmental Safety*, *67*(1), 48–58. https://doi.org/10.1016/j.ecoenv.2006.12.013

Falasi, N. J. R. (2017). *Pollution of the N'djili River and soil management constraints around the Malebo Pool (Case study of the Masina Rail1/Kinshasa agricultural site)* [Master's thesis, University of Liège]. Matheo

Repository. https://matheo.uliege.be/bitstream/2268.2/5571/5/TFE%20MS%20SGE%20FALASI%20NITU%20JOSEPH%202017-2018.pdf

Food and Agriculture Organization of the United Nations, & World Health Organization. (2014). *Evaluation of certain food additives and contaminants: Seventy-seventh report of the Joint FAO/WHO Expert Committee on Food Additives* (WHO Technical Report Series No. 995). World Health Organization.

François, M., Grant, C., Lambert, R., & Sauvé, S. (2009). Prediction of cadmium and zinc concentration in wheat grain from soils affected by the application of phosphate fertilizers varying in Cd concentration. *Nutrient Cycling in Agroecosystems, 83*, 125–133. https://doi.org/10.1007/s10705-008-9204-0

Hodomihou, N. R., Feder, F., Masse, D., Agbossou, K. E., Amadji, G. L., Badiane, Y. N., & Doelsch, E. (2016). Diagnosis of contamination of peri-urban agrosystems in Dakar by trace metals. *Biotechnology, Agronomy, Society and Environment, 20*(3). https://doi.org/10.25518/1780-4507.13035

Miquel, G. (2001). *Les effets des métaux lourds sur l'environnement et la santé* (Rapport parlementaire; Assemblée nationale No. 2979; Sénat No. 261). Parlement français.

Niyomutoni, A. (2025). *Impact of irrigation on heavy metal concentrations in irrigated amaranth in the city of Bujumbura: The case of copper, zinc, and lead* [Thesis]. University of Burundi Repository. https://repository.ub.edu.bi/handle/123456789/2203

Noubissie, E. (2015). *Speciation of organometallic compounds (Hg, Sn, Pb) in vegetable crop soils and in three species of cultivated plants in Ngaoundéré (Cameroon)* (Doctoral dissertation). https://www.theses.fr/2015PAUU3006/document

Parui, R., Nongthombam, G. S., Hossain, M., Adil, L. R., Gogoi, R., Bhowmik, S., & Iyer, P. K. (2023). Impact of heavy metals on human health. In *Remediation of heavy metals: Sustainable technologies and recent advances* (pp. 47–81). Wiley. https://doi.org/10.1002/9781119853589.ch4

Phaneuf, D., Belleville, D., Normandin, L., & Bourgault, M.-H. (2012). *Étude sur la présence de résidus chimiques dans les aliments consommés au Québec*. Institut national de santé publique du Québec. http://www.inspq.qc.ca

Reichman, S. M. (2002). *The responses of plants to metal toxicity: A review focusing on copper, manganese and zinc* (Occasional Paper No. 14). The Australian Minerals & Energy Environment Foundation.

Sayyad, G., Afyuni, M., Mousavi, S., Abbaspour, K. C., Richards, B. K., & Schulin, R. (2010). Transport of Cd, Cu, Pb, and Zn in a calcareous soil under wheat and safflower cultivation: A column study. *Geoderma, 154*(3–4), 311–320. https://doi.org/10.1016/j.geoderma.2009.10.019

Smith, S. E., & Read, D. J. (2008). *Mycorrhizal symbiosis*. Academic Press. https://doi.org/10.1016/B978-0-12-370526-6.X5001-6

Touaihia, S. (2021). *Effect of certain heavy metals on the germination and growth of Atriplex halimus L. seedlings* (Master's thesis). University of Laarbi Tébessi–Tébessa.

Traoré, K.D. (2021). *Assessment of health risks associated with the ingestion of heavy metals (As, Cd, Cr, Hg, Ni, Pb, Zn) contained in vegetable crops in the city of Daloa (Côte d'Ivoire).* Master's degree in Applied Physical Chemistry, specialising in the environment. Jean Lorougnon Guede University. Republic of Côte d'Ivoire.

Wuana, R. A., & Okieimen, F. E. (2011). Heavy metals in contaminated soils: A review of sources, chemistry, risks, and best available strategies for remediation. *ISRN Ecology, 2011*, Article 402647.