

# Heavy metals contamination and health risk assessment in food samples from the Democratic Republic of the Congo: A systematic review

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## ABSTRACT

Heavy metal contamination in food poses significant risks to food safety and human health. Chronic exposure can lead to serious health issues, with the impact of contaminated foods influenced by factors such as exposure level, body mass, age, and gender. Vulnerable populations, including pregnant women and children, are particularly at risk. Long-term exposure to heavy metals is associated with various disorders, including metabolic diseases like diabetes and obesity, as well as reproductive system disruptions and cancers. This review synthesizes available data on heavy metal contamination in foods within the Democratic Republic of the Congo (DRC) and provides recommendations for enhancing heavy metal risk assessment. A comprehensive search of PubMed/MedLine, Google Scholar, ScienceDirect, and EMBASE yielded ten relevant studies published between 2011 and 2021. The distribution of studies included five from Kinshasa (50%), three from Katanga (30%), and two from Kongo Central (20%). Seventy percent of the studies focused on vegetable samples, with additional analyses of fish (30%), beef (10%), and aquatic invertebrates (10%). Risk assessment metrics, including Estimated Daily Intake (EDI), Target Hazard Quotient (THQ), Metal Pollution Index (MPI), and Hazard Index (HI), were employed in five studies (50%). The findings highlight the urgent need for comprehensive monitoring of heavy metals in diverse food sources throughout the DRC to accurately assess associated health risks and inform public health interventions.

## INTRODUCTION

The increase in industrial, agricultural, and urban activities in the Democratic Republic of the Congo (DRC)

has led to a concerning rise in heavy metal contamination in food, which poses significant risks to human health. Unlike many organic compounds, heavy metals are not

biodegradable and tend to accumulate in the environment (Bourrelrier & Berthelin, 1998). Globally, there is an increasing risk of heavy metal (HM) contamination (Luo et al., 2021; Rizwan et al., 2021).

Food provides essential nutrients for the human body, including vitamins, minerals, proteins, and carbohydrates. However, the presence of heavy metals in food is raising concerns about food safety and quality. The long half-lives of heavy metals in soil and their complex metabolism post-ingestion make them particularly harmful (Tang et al., 2016; Ekhtator et al., 2017). According to Gollenberg et al. (2010), prepubescent girls experienced disturbances in reproductive hormones, resulting in decreased fertility upon reaching reproductive age (Chang et al., 2006), marked by irregular menstruation (Tang & Zhu, 2003). Eating food, including plants for energy intake and animals for protein intake, is one of the main ways that metal pollutants enter the human body (Radwan & Salama, 2006). Most of the world's population consumes fruits and vegetables, and the World Health Organization (1990) recommends a daily intake of 400 g or more of fruits and vegetables (Oyebode et al., 2014).

The degree to which an animal is exposed to heavy metals during its growth depends on its environment and, in particular, on the food it eats. As a result, the animal may absorb heavy metals, which, depending on their concentrations and chemical speciations, may eventually accumulate in the animal's body, undergoing varying degrees of degradation. The Japanese Minamata disease, caused by mercury poisoning of fish and subsequent human exposure to mercury, exemplifies bioaccumulation through the food chain. A primary concern with heavy metals is their persistence in the environment, which promotes bioaccumulation in various target organs, including the liver and kidneys.

This principle also applies to plants: based on their growth environment, they accumulate metals present in the soil or nearby atmosphere (Shahid et al., 2013b; Mombo et al., 2015a). According to Huff (2007) and Andujar (2010), these metals can rapidly accumulate in metabolic organs such as the liver and kidney, leading to a range of toxic symptoms. Metals can damage the kidneys, bones, liver, brain, and other organs by interfering with various biochemical

processes. In the DRC, these metals (Cu, Pb, Ni) and certain metalloids such as arsenic are naturally present in the soil in highly variable concentrations, particularly in volcanic regions, where rocks contain high concentrations of Cu, Ni, and Pb. Given the added impact of industrial and agricultural pollution, these metals can ultimately enter the human food chain, causing multiple public health problems. This study was conducted to provide verifiable scientific data and to alert sectoral authorities, encouraging them to establish normative guidelines to manage the affected areas effectively. The bioavailability and toxicity of metals upon consumption are influenced by their chemical speciation and compartmentation within the target organism, whether plant or animal. Ultimately, the pollution intake amount, bioavailability, and concentration within the food matrix determine the level of human exposure, integrating these factors in quantitative health risk assessments.

## METHODS

### *Search Strategy*

This study is based on a comprehensive review of the literature, screening approximately 250 research papers in general and 42 articles specifically focused on the Democratic Republic of the Congo (DRC) documenting contamination levels of heavy metals in food. A systematic search and review were conducted using four keywords ("Heavy metals," "Contamination," "Risk assessment," and "Vegetable samples") across PubMed/MedLine, Google Scholar, ScienceDirect, and EMBASE, which are accredited and indexed databases. Articles from January 2011 to December 2021 were included, with a focus on heavy metals, soil and vegetable contamination, and associated health risks. Additionally, relevant articles published by ScienceDirect and Google Scholar between January 2013 and December 2021 addressing heavy metal contamination and impact were screened and included as references in this review.

### *Data Collection*

Eligibility criteria were applied when evaluating full texts and abstracts, which included studies on heavy metal contamination published in reputable scientific journals that measured heavy metal concentrations in food. Articles were classified based on publication year, location, food of interest, analytes (study year), analytical methods, and

mean (min-max) concentrations of heavy metals. Studies failing to meet these criteria were excluded.

For each article, data such as publication year, location, food of interest, analytes (research year), analytical methods, and mean (min-max) concentrations of heavy metals were extracted (Tables 1 and 2). The results from the DRC were compared to permissible values established in the literature and similar research.

**Table 1:**  
Heavy Metal Contaminant Analysis Using Advanced Analytical Tools

Author	Location	Vegetable samples	Analytical methods	Analyte study year	Trace metals investigated
Mpumbu 2013	Former Katanga	Amaranthus hybridus and Spinacia oleracea	AAS	-	Cu, Co, Cd, Pb and Zn
Mudimbu 2015	Former Katanga	Manihot esculanta, Amaranthus hybridus and Psidium guajava L.	ICP-MS	-	Mg, Al, Cr, Fe, Co, Ni, Cu, Zn, Cd, Pb and U
Nuapia 2017	Kinshasa	Cabbage, beans, fish and beef from markets	ICP-MS, ICP-OES and Mercury analyseur	From July till October 2016	Al, As, Cd, Cr, Cu, Hg, Mn, Pb, Se, Zn
Suami 2018	Kongo Central	Fishes from Atlantic Coast	ICP-MS and AAS	August 2016	Cr, Cu, Zn, Ni, Sb, Cd, Pb, Se and Hg
Suami 2019	Kongo Central	Oysters and Shrimp	ICP-MS and AAS	November 2017	Hg, Cr, Ni, Cu, Zn, Se, Cd, Sb, Pb, Mn, Co and Fe
Ngweme 2020	Kinshasa	Amaranthus viridis from gardens	ICP-MS and AAS	July 2018	Cr, Co, Cu, Zn, As, Cd, Pb and Hg
Mata 2020	Kinshasa	Ledermanniella schlechteri	ICP-MS and AAS	March 2019	Cr, Ni, Cu, Zn, As, Cd, Pb and Hg
Ngweme 2021	Kinshasa	Amaranthus viridis from markets	ICP-MS and AAS	In February 2019 and August 2019	Cr, Co, Cu, Zn, As, Cd, Pb and Hg
Ambayeba 2021	Former Katanga	Amaranthus hybridus, Cucurbita maxima, Manihot esculanta, Ipomea batatas, Lycopersicon esculentum and Phaseolus vulgaris.	CP-MS and ICP-OES	-	Mn, Co, Ni, Cu, Zn, As, Cd, Pb and U

## RESULTS

A total of 10 studies on food contamination by heavy metals (HMs) conducted between 2011 and 2021 were examined (Table 1). The earliest study, from 2013, was conducted in Katanga, and the most recent study, in 2021, was in Kinshasa. The majority of these studies (50%) were conducted in Kinshasa. Among the studies that reported HM levels, 70% focused on vegetables, 30% on fish, 10% on beef, and 10% on aquatic invertebrate samples. The cumulative percentage exceeded 100% as one of the studies assessed HMs in a combination of vegetables, beef, and fish. Amaranthus species was the most commonly studied vegetable (71.42%). All studies investigated contamination by trace elements, but only 50% included a risk assessment.

Inductively Coupled Plasma Mass Spectrometry (ICP-MS) was the primary method used for detecting HMs, while Atomic Absorption Spectrophotometry (AAS) was used specifically for mercury (Hg) determination and, in one study, for all metals. The concentration of HMs in vegetable samples decreased in the following order: Cu, Cd, Pb, and Zn < As < Co, Cr < Ni < Hg, Mn, U < Al < Mg, Fe. In fish and aquatic invertebrate samples, the order was Cu, Cr, Cd, Pb, Se, Hg, and Zn < Ni, Sb and Mn < Al, As, Fe, and Co.

### Heavy Metals in Vegetables

#### Amaranthus Species

Mpumbu reported the presence of copper (Cu), cobalt (Co), cadmium (Cd), lead (Pb), and zinc (Zn) in *Amaranthus hybridus*, with concentrations of 21.9 (Cu), 1.2 (Co), 1.2 (Cd), 1.72 (Pb), and 101.33 mg/kg (Zn). In every market, the copper content in vegetables exceeded the standard limit of 10 mg/kg. However, certain markets did not meet the permissible limits for lead (Pb: 3 mg/kg) and cadmium (Cd: 2 mg/kg) set by France (Mpumbu et al., 2013).

Kalonda et al. (2015) found that *A. hybridus* contained concentrations of magnesium (Mg), aluminium (Al), chromium (Cr), iron (Fe), Co, nickel (Ni), Cu, Zn, Cd, Pb, and uranium (U) ranging from 20290 to 23000 (Mg), 5173 to 8919 (Al), 5.666 to 18.51 (Cr), 112.7 to 1642 (Fe), 11.71 to 116.2 (Co), 0 to 5.863 (Ni), 45.69 to 516.2 (Cu), 370.5 to 497.1 (Zn), 1.295 to 7.717 (Cd), 5.352 to 10.25 (Pb), and 0.302 to 0.534 (U) (Mudimbu et al., 2015).

**Table 2:**  
Heavy Metal Analytical Results from Foods Control

Food	Year	Heavy metals concentrations (Means or ranging) in mgkg <sup>-1</sup> or µg g <sup>-1</sup>															
		Cu	As	Hg	Fe	Mg	Mn	Se	Ni	U	Al	Co	Pb	Cd	Cr	Zn	Sb
Amaranthus	2013	21.9	-	-	-	-	-	-	-	-	-	1.2	1.72	1.2	-	101.33	-
	2015	45-516	-	-	622.7	22513.3	-	-	3.78	0.44	7326.7	68.5	7.71	3.66	10.01	426.3	-
	2020	16.11	0.1	0.1	-	-	-	-	12.3	-	-	1.73	8.91	1.62	2.97	652.91	-
	2021a	7.4-11.3	1.7	0.2	-	-	-	-	-	-	-	1.5	18.3	1.5	3.6	348.2	-
	2021b	139	-	-	-	-	15.8-2606	-	2.2-119	0.1-3.2	-	21-2624	1.3-354	0.42	-	8.3-482	-
Spinach	2013	24.3	-	-	-	-	-	-	-	-	1.49	0.72	1.49	-	94.24	-	
Cabbage	2017	3.8	3.33	ND	-	-	5.34	0.64	-	-	52.1	-	2.14	2.93	3.07	27.93	-
Beans	2017	3.3	1.62	ND	-	-	-	0.18	-	-	22.56	-	1.98	1.13	1.63	19.05	-
Manihot	2015	52.1	-	-	245.13	4902.7	-	-	0	0.2	7128.7	33.46	4.07	0.835	4.58	383.26	-
Psidium	2015	102.9	-	-	457.33	5789.7	-	-	6.39	0.33	5823	35.19	5.074	0.09	3.48	321.13	-
Ledermaniella	2020	5.5-78.4	.08-0.15	.02-0.07	-	-	-	-	0.1-0.6	-	-	-	0.4-2.07	0.2-0.48	0.4-0.74	336-596.7	-
Fish/Atlantic	2018	0.02-0.5	-	1.21	-	-	-	1.05	4.25	-	-	-	0.09	0.59	1.00	29.9	0.0-0.01
Oysters	2019	4.2-37.2	-	0.2	457.3	-	1.87	1.89	0	-	-	0.52	0.08	0.03	0.12	46.36	0.0-0.01
Shrimp	2019	16-60.5	-	.05-0.26	14.3-95	-	1.1-3.6	0.6-2.5	0.06	-	-	0.04	0.2-0.18	.03-0.13	.03-0.08	47-55.9	<LD-
Fish/market	2017	6.53	3.48	1.53	-	-	10.51	0.12	-	-	9.1	-	0.39	0.64	0.37	14.17	0.01
Beef	2017	0.69	1.62	ND	-	-	7.18	0.29	-	-	11.93	-	0.16	0.16	0.58	5.47	-
Fishes/Congo River	2019	.09-2.7	-	0-072	-	-	-	.12-1.5	-	-	-	-	0.2-4.96	.01-0.05	0-1.21	2.8-59.72	-
Permissible level mg/kg		73 <sup>a</sup>	1.00 <sup>**</sup>	0.001 <sup>***</sup>	425		500 <sup>*</sup>		70 <sup>d</sup>	0.36 <sup>*****</sup>	12-	50 <sup>****</sup>	0.3 <sup>*</sup>	0.2 <sup>*</sup>	1.3 <sup>*</sup>	99.4 <sup>*</sup>	
		30 <sup>e</sup>		1 <sup>b</sup>							71 <sup>**</sup>		0.5 <sup>e</sup>	1 <sup>b</sup>	12 <sup>c</sup>	50 <sup>f</sup>	
													0.2 <sup>b</sup>	0.1 <sup>i</sup>			

Ngweme analyzed *A. viridis* from various sources and reported Cr, Co, Cu, Zn, arsenic (As), Cd, Pb, and Hg. The concentrations in Kinshasa gardens reached 2.97 (Cr), 1.73 (Co), 12.30 (Ni), 16.11 (Cu), 652.91 (Zn), 0.10 (As), 1.62 (Cd), 8.91 (Pb), and 0.1 mg/kg (Hg). The estimated daily intake (EDI) and weekly intake (EWI) for Cd in Cecomaf and Lemba-Imbu leaves, as well as Pb in Cecomaf, Riffilaert, and Lemba-Imbu leaves, surpassed the recommended limits. However, EDI and EWI values for Cu, Zn, As, and Hg were below the recommended limits. Except for As at Lemba-Imbu, the calculated target hazard quotient (THQ) values exceeded suggested limits (Ngweme et al., 2020).

In another study, Ngweme found high concentrations of hazardous metals in leafy vegetables during both dry and wet seasons, with values reaching 3.6 (Cr), 1.5 (Co), 29.7 (Cu), 348.2 (Zn), 1.7 (As), 1.5 (Cd), 18.3 (Pb), and 0.2 mg/kg (Hg). The concentrations of metals, excluding Cu, exceeded permissible levels established by the FAO/WHO for human consumption (Ngweme et al., 2021).

Ambayeba's study showed that *A. hybridus* was contaminated with manganese (Mn), Co, Ni, Cu, Zn, As, Cd, Pb, and U, with concentrations (in µg/g) ranging from 39.4 to 128 (Mn), 1.63 to 16.4 (Co), 4.9 to 17.9 (Ni), 24.8 to

166 (Cu), 59.5 to 324 (Zn), 0.800 to 2.60 (As), 0.359 to 2.25 (Cd), 1.11 to 10.4 (Pb), and 1.47 to 5.79 (U). The levels of Cd and Pb exceeded international standards. Similar results were found for other vegetables, including pumpkins, cassava, sweet potatoes, tomatoes, and common beans (Ambayeba et al., 2021).

Permissible limits were notably exceeded for certain metals such as Hg, with a threshold of 0.001 mg/kg; concentrations found in *A. viridis* species were as high as 0.2 mg/kg. Lead and cadmium also surpassed acceptable limits, with detected concentrations of 1.2 to 1.5 mg/kg for Cd and 1.72 to 10.25 mg/kg for Pb, exceeding the permissible levels of 0.3 and 0.2 mg/kg, respectively.

#### Other Vegetables

Mpumbu (2013) stated that *Spinacia oleracea* is contaminated with copper (Cu), cobalt (Co), cadmium (Cd), lead (Pb), and zinc (Zn), with metal concentrations greater than 24.32 mg kg<sup>-1</sup> for Cu, 1.49 mg kg<sup>-1</sup> for Co, 1.49 mg kg<sup>-1</sup> for Cd, 0.72 mg kg<sup>-1</sup> for Pb, and 94.24 mg kg<sup>-1</sup> for Zn.

Kalonda (2015) indicated that *Manihot esculenta* and *Psidium guajava* L. are contaminated with magnesium (Mg),

aluminium (Al), chromium (Cr), iron (Fe), cobalt (Co), nickel (Ni), copper (Cu), zinc (Zn), cadmium (Cd), lead (Pb), and uranium (U). The metal concentrations (in mg kg<sup>-1</sup>) for *Manihot esculenta* ranged between 4045-5867 (Mg), 6719-7835 (Al), 3.357-6.604 (Cr), 222.1-257.8 (Fe), 11.79-54.87 (Co), 0 (Ni), 30.28-67.24 (Cu), 418.9-717 (Zn), 0.102-1.621 (Cd), 3.331-5.21 (Pb), and 0.169-0.22 (U). For *Psidium guajava*, the values (in mg kg<sup>-1</sup>) ranged between 3958-6929 (Mg), 6580-7524 (Al), 2.620-4.455 (Cr), 218.1-900.2 (Fe), 4.653-76.84 (Co), 0-19.19 (Ni), 200.1 (Cu), 279.3-393.2 (Zn), 0.059-0.139 (Cd), 4.089-5.797 (Pb), and 0.222-0.452 (U) (Mudimbu et al., 2015).

Nuapia (2017) reported that both beans (*Phaseolus vulgaris*) and cabbage (*Brassica oleracea*) are contaminated with aluminium (Al), cadmium (Cd), chromium (Cr), copper (Cu), mercury (Hg), manganese (Mn), lead (Pb), zinc (Zn), arsenic (As), and selenium (Se). The mean microelement concentrations in the cabbage and bean samples were in this order: Al > Zn > Mn > Cu > As > Cr > Cd > Pb > Se. The majority of the metals tested in raw foods exceeded the maximum permissible limit set by the Joint FAO/WHO Expert Committee on Food. The estimated daily intake for each food exceeded the WHO/FAO (2000) upper tolerable limit (UL); however, As, Cd, Cr, Hg, and Se were all above the UL level. All of the combined total hazard quotient (THQ) values exceeded one.

Mata (2019) claimed that the aquatic plant *Ledermaniniella schlechteri* is contaminated with chromium (Cr), nickel (Ni), copper (Cu), zinc (Zn), arsenic (As), cadmium (Cd), lead (Pb), and mercury (Hg). The metal concentrations (in mg kg<sup>-1</sup>) varied dramatically between sampling sites, with typical values ranging from 0.44 to 9.1 for Cr, 0.14 to 4.52 for Ni, 5.5 to 78.4 for Cu, 336.14 to 1520.91 for Zn, 0.08 to 0.9 for As, 0.21 to 0.78 for Cd, 0.44 to 11.81 for Pb, and 0.02 to 0.24 for Hg. The average content of Zn, As, Cd, and Hg in plant samples from all sampling sites exceeded what the FAO and WHO considered safe for human consumption. According to FAO/WHO regulations and computed values, the impact on human health is expected to occur.

#### Heavy Metals in Fish

According to Nuapia (2018), the heavy metals with the highest mean concentrations in fish muscle were Zn, Mn, Al, Cu, As, Hg, Cd, Pb, Cr, and Se. The majority of the

metals tested in raw foods exceeded the maximum permissible limit set by the Joint FAO/WHO Expert Committee on Food. The estimated daily intake for each food exceeded the acceptable limit set by WHO/FAO (2000). Al, Cu, Mn, Pb, and Zn had lower estimated daily intakes from raw food, whereas As, Cd, Cr, Hg, and Se had estimates that exceeded the upper tolerable daily limit (UL). Both male and female food samples had total THQ values greater than one overall.

Suami (2018) discovered significant differences in heavy metal concentrations in fish muscle tissues across sites and species ( $p < 0.05$ ), with maximum values (in mg kg<sup>-1</sup> wet weight) of 1.00 for Cr, 2.69 for Cu, 29.90 for Zn, 4.25 for Ni, 0.09 for Sb, 0.59 for Cd, 0.09 for Pb, 1.05 for Se, and 1.21 for Hg. The Food and Agriculture Organization (FAO), European Union, and World Health Organization (WHO) determined that the levels of metals in fish were safe for human consumption, with the exception of mercury.

Mata (2019) found that the concentrations of hazardous metals (measured in mg kg<sup>-1</sup> wet weight) in fish muscle tissues ranged from 0.00 to 1.21 for Cr, 2.80 to 59.72 for Zn, 0.12 to 1.53 for Se, 0.01 to 0.05 for Cd, 0.22 to 4.96 for Pb, 0.00 to 0.72 for Hg, and 0.09 to 2.65 for Cu. *M. moorii* and *D. fasciolatus* had the highest concentrations of Pb (4.96 mg kg<sup>-1</sup>) and Zn (59.71 mg kg<sup>-1</sup>) among the fish species studied. Similarly, *B. ubangensis* (0.72 mg kg<sup>-1</sup>), *D. fasciolatus* (0.53 mg kg<sup>-1</sup>), and *M. moorii* had the highest levels of Hg (0.70 mg kg<sup>-1</sup>). These concentrations exceeded the reference limits for human consumption set by FAO/WHO (0.53 mg kg<sup>-1</sup> wet weight). In general, all fish species had Cd, Cr, and Cu concentrations that were acceptable.

#### Heavy Metals in Invertebrates

This study provides the first metal measurements in four major seafood species from Muanda's Atlantic Coast: oysters (*Egeria congica*) and prawns (*Macrobrachium spp.*, *Parapenaeus spp.*, and *Penaeus spp.*). Suami (2019) discovered significant differences in metal accumulation between oyster and sand shrimp species, including Hg, Cr, Cu, Sb, Mn, Co, and Fe, but not Ni, Zn, Se, Cd, or Pb. Except for the levels of Cu and Pb in a few samples of *Macrobrachium spp.* and *Egeria congica*, all tested samples (both oyster and prawn species) contained metal amounts

below those that would raise concerns about seafood safety.

#### Heavy Metals in Beef

According to Nuapia (2017), cabbage and beans are contaminated with Al, Cd, Cr, Cu, Hg, Mn, Pb, Zn, As, and Se. Metal levels in beef samples were quantified in the following sequence: Al, Mn, Zn, As, Cu, Cr, Se, Cd, and Pb. Most of the metals studied in raw foods exceeded the recommended maximum acceptable limit set by the Joint FAO/WHO Expert Committee on Food. The upper tolerable limits for estimated daily intake for each food were established by WHO/FAO (2000). The estimated daily intake of raw food was lower for Al, Cu, Mn, Pb, and Zn, whereas As, Cd, Cr, Hg, and Se exceeded the upper tolerable daily limit (UL). All food samples had combined THQ values greater than one, for both male and female samples.

#### DISCUSSION

Ten studies indicated that food samples are contaminated with copper (Cu), antimony (Sb), arsenic (As), mercury (Hg), iron (Fe), magnesium (Mg), manganese (Mn), selenium (Se), nickel (Ni), uranium (U), aluminum (Al), cobalt (Co), lead (Pb), cadmium (Cd), chromium (Cr), and zinc (Zn). Four trace elements—Cu, Pb, Cd, and Zn—accounted for 25% of all the samples collected. Among the most prevalent heavy metals are lead and cadmium, both of which are extremely hazardous. Cadmium is released into the atmosphere due to natural or human activities, and people can be exposed to cadmium through food ingestion, inhalation of contaminated air, or consumption of water rich in the metal. Lead, a non-biodegradable metal, is found in nature (Radwan & Salama, 2006; Afshin et al., 2008; Mitra et al., 2022). Copper and zinc are vital for biochemical and physiological processes necessary for maintaining health (Prentice, 1993; ATSDR, 1994; Linder & Azam, 1996).

The Pb concentration ranged from 0.08 to 354 mg/kg, with *Amaranthus hybridus* from the former Katanga region exhibiting the highest value. The Pb content in vegetable samples exceeded the levels permitted by the Food and Agriculture Organization (FAO) for human consumption. Other foods, such as fish, ocean invertebrates, and beef, fell below the permissible values. It is noteworthy that the

concentration of Pb in fish marketed in Kinshasa was 4.33 times higher than in fish from the Atlantic coast. The Cd concentration ranged from 0.03 to 3.66 mg/kg, with the highest concentration found in *Amaranthus hybridus* from the former Katanga region. With the exception of *Psidium guajava* from the former Katanga, the Cd content in vegetable samples exceeded the FAO's allowable limits for human consumption. Other items, including fish, marine invertebrates, and cattle, had amounts below the allowable limit. An excessive intake of these metals is linked to various illnesses, including those affecting the neurological, skeletal, cardiovascular, and renal systems (WHO, 1992, 1995, 2019; Steenland & Boffetta, 2000; Jarup, 2003). Furthermore, these heavy metals are associated with teratogenesis, mutagenesis, and carcinogenesis (Radwan & Salama, 2006).

The copper content of vegetables in the studies reviewed ranged from 3.3 to 3416 mg/kg. The spinach from the old Katanga region had the highest copper concentration (3416 mg/kg), followed by *Amaranthus viridis* from a garden in Kinshasa (516.2 mg/kg) and *Ledermaniella* from Kinshasa (102.9 mg/kg). These values exceeded the FAO's permitted limit of 73 mg/kg. The highest concentration in invertebrates from the Atlantic coast was found in the shrimp species *Macrobrachium spp.* (60.46 mg/kg), surpassing the FAO limit of 30 mg/kg (wet weight). In fish samples, the concentrations of Cu were well below the permissible value of 30 mg/kg (wet weight). Samples from fish marketed in South Africa exhibited higher average concentrations than those from Kinshasa (Nuapia et al., 2018), with fish marketed in Kinshasa being 12.74 times higher than fish samples from the Atlantic coast of Muanda. The Zn concentration ranged from 5.47 to 652.91 mg/kg, with the highest concentration in *Amaranthus viridis* from former Kinshasa's gardens. With the exception of spinach and cabbage, Zn concentrations in vegetable samples were above those allowed by the FAO for human consumption. Other items, including fish, marine invertebrates, and cattle, had amounts below the allowable limit. The Zn concentrations in fish samples from Kinshasa were less than the Canadian Food Inspection Agency's (CFIA) (2011) limit of 50 mg/kg. However, samples from Johannesburg and Nigeria exceeded the upper limit (Nuapia et al., 2017; Wangboje et al., 2018). In rare cases, various disorders can lead to a buildup of zinc and copper

in bodily tissues. While Zn and Cu rarely cause toxicity in the human body, they can do so at elevated concentrations (Anderson et al., 2004; Chan et al., 2004). Zinc can lower levels of high-density lipoproteins and immunological responses (Harmanescu et al., 2011). Prolonged exposure to high copper levels can lead to numerous adverse health effects, including liver and kidney damage, anemia, immunotoxicity, and developmental toxicity. Many of these outcomes are consistent with oxidative damage to membranes or macromolecules. Several enzymes, including glutathione reductase and glucose-6-phosphatase, can have their sulfhydryl groups bound by copper, inhibiting their ability to protect cells from free radical damage. If accumulated excessively, copper can cause gastrointestinal distress, liver damage, immune system dysfunction, neurological system impairment, and reproductive harm (Schümann et al., 2002; ATSDR, 2022). Gastrointestinal distress is one of the most frequently reported adverse effects of copper on health (Yalçın Tepe, 2014).

Only samples from Kongo Central were used to determine Sb, while samples exclusively from the old Katanga region were used to assess Mg and U. The primary concern with uranium is the release of radon, one of its gaseous decay products, in confined areas, such as poorly ventilated homes or mines (Keith et al., 2015; WHO, 2010). Uranium is also nephrotoxic and may affect other organs (Ma et al., 2020). Iron was not detected in any vegetable samples from Kinshasa, whereas As, Hg, and Se were absent from samples from the old Katanga region.

The arsenic content in this review ranged from 0.1 to 3.48 mg/kg. The highest levels of As were found in fish sold in Kinshasa (3.48 mg/kg), followed by cabbage (3.33 mg/kg), *Amaranthus viridis* (1.7 mg/kg), and beans and beef (1.62 mg/kg each) sold in Kinshasa. These amounts exceeded the FAO permitted limit of 1 mg/kg. Oliveira et al. (2017) reported that the concentration of arsenic in *Tilapia* sold in the Indonesian market was lower than that found in *Amaranthus viridis* samples marketed in Kinshasa, which were at least 17 times higher than those from Kinshasa gardens. It is also important to highlight that the concentration of arsenic in fish marketed in Kinshasa was significantly elevated. An increasing body of research suggests that long-term exposure to inorganic arsenic (iAs)

may raise the risk of keratosis, hyperpigmentation, and cardiometabolic illnesses, such as diabetes mellitus and cardiovascular diseases (EPA, 2002; Kuo et al., 2013; Maull et al., 2012; Moon et al., 2012; Mohammad et al., 2015).

The mercury content ranged from 0.02 to 1.53 mg/kg. Fish samples from the Atlantic coast (1.21 mg/kg), *Amaranthus viridis* sold in Kinshasa (0.2 mg/kg), *Amaranthus viridis* from Kinshasa's garden (0.1 mg/kg), and *Ledermaniella* from the Congo River had lower mercury levels than the fish marketed in Kinshasa (1.53 mg/kg). The FAO, European Union (EU), and World Health Organization (WHO) have established permissible thresholds for vegetables (0.001 mg/kg) and fish for human consumption (1 mg/kg). The fish samples from Kinshasa had lower Hg concentrations than those from Johannesburg and higher levels than those found in fish marketed in Palestine (Nuapia et al., 2017). Mohamed et al. (2012) reported cabbage (0.011 mg/kg) and beans (0.024 mg/kg) contamination in Saudi Arabia, while Zvezdana et al. (2016) reported cabbage (0.0097 mg/kg) and beans (0.013 mg/kg) contamination in Croatia, indicating that the cabbage and beans from Kinshasa were not contaminated with Hg. The toxicity of methyl mercury (MeHg) is greater than that of inorganic mercury, and the effects of mercury on human health are closely related to its form. Methylmercury is the primary stable organic form of mercury absorbed by the body from food and is well known to be neurotoxic (Garcia-Bravo et al., 2010, 2011; Suami et al., 2019).

Aluminum content ranged from 9.1 to 7,326.7 mg/kg. The highest levels of aluminum were found in vegetables from the old Katanga region, with *Amaranthus hybridus* showing a concentration of 7,326.7 mg/kg, followed by *Manihot esculenta* at 7,128.7 mg/kg and *Psidium guajava* at 5,823 mg/kg. These concentrations were significantly higher than those found in vegetables from Kinshasa and far exceeded the Food and Agriculture Organization's (FAO) permitted levels for human consumption. For example, the concentration of *Amaranthus hybridus* was 140.6 times higher than that of cabbage and 324.7 times higher than that of beans. Aluminum (Al) is considered a potentially harmful element with no known biological function in the body. While Al can be toxic at elevated concentrations, it is significantly less harmful than mercury (Hg) or lead (Pb).

High levels of aluminum exposure have been linked to various health issues, including osteomalacia, Parkinson's disease, Alzheimer's disease, autism, and autoimmune disorders (Shaw et al., 2013; Ekhatior et al., 2017).

Chromium concentrations ranged from 0.03 to 10.1 mg/kg, with *Amaranthus hybridus* from the former Katanga exhibiting the highest concentration. Except for *Ledermanniella*, chromium levels in the vegetable samples exceeded the FAO's recommended limits for safe human consumption. Other food items, including fish, marine invertebrates, and cattle, had chromium levels below the allowable limit. Suami et al. (2019) reported a significant difference ( $p < 0.05$ ) between oyster and shrimp samples; however, the chromium concentrations in both were below the permitted limit of 12 mg/kg established by the [Food and Drug Administration Guidance Document for Chromium in Shellfish \(US FDA, 1993a\)](#). Oysters were found to accumulate more chromium than shrimp, based on average chromium concentrations. Chromium (III) is an essential nutrient that facilitates insulin binding to its receptor sites, playing a critical role in glucose, lipid, and protein metabolism in both humans and animals (Anderson, 1997). While chromium may inhibit certain enzyme systems or interact with organic molecules at high levels, it is less toxic. Conversely, chromium (VI) is a potent oxidant that can damage cells, with exposure primarily occurring through dietary consumption and household emissions. It is associated with allergic reactions and poses a lung cancer risk when inhaled (Merzenich et al., 2001; Costa & Klein, 2006; IARC, 1990).

Of the studies focused on heavy metal contamination in food, only five (50%) assessed potential health risks associated with the consumption of specific foods by calculating the Estimated Daily Intake (EDI) (Mpumbu et al., 2013; Nuapia et al., 2018; Mata et al., 2019; Ngweme et al., 2020) or the Target Hazard Quotient (THQ) (Nuapia et al., 2018; Mata et al., 2019). The EDI was estimated based on daily food intake in grams and the concentration of each heavy metal in the diet. Mpumbu and Ngweme's analysis of EDI values indicated that consuming *Amaranthus* sp. leafy vegetables could pose health risks to humans. Nuapia's research showed that the estimated daily intake of raw food from Kinshasa was low for aluminum, copper, manganese, lead, and zinc, while the

estimated daily intake of arsenic, cadmium, chromium, mercury, and selenium exceeded the acceptable limits.

## CONCLUSION

The current study is the first review of heavy metals in food in the Democratic Republic of the Congo (DRC) and found that the overall level of trace metal contamination in the environment was higher in the former Katanga region than in Kinshasa. Some heavy metal concentrations in food samples exceeded the permissible levels for human consumption established by the Food and Agriculture Organization (FAO), the European Union (EU), JECFA, and the World Health Organization (WHO). Regular consumption of these foods may seriously endanger people's health. The main sources of heavy metal contamination include vegetable production on polluted soil, wastewater irrigation, pesticides used to treat and prevent vegetable diseases, and atmospheric deposition in areas with contaminated air.

There have been few studies on food, primarily focusing on vegetables (especially *Amaranthus* spp.) and conducted in only three provinces: Kinshasa, former Katanga, and Kongo Central. The authors concluded that, to accurately assess the hazards to human health, more thorough and periodic studies should be conducted to monitor the levels of heavy metals in various foods from all regions of the DRC.

As a recommendation, we urge state and sector authorities to regulate mineral exploitation throughout the country, particularly in the regions covered by our study, especially in the Katanga region. This can be achieved by producing guidelines for mineral exploitation and establishing a national reference document for the permanent monitoring of heavy metal levels in all products that may become contaminated. We also advocate for this study to be extended to other provinces not involved in the current research and for a comprehensive analytical study to be carried out to produce more detailed figures and statistical data reflecting the reality of this issue throughout the country.

**Ethics Approval:** Nil required.

**Conflicts of Interest:** None declared.

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