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Research Article

Determination of some heavy metals and their potential risk in selected vegetables on sale within Kaduna Metropolis, Kaduna State, Nigeria

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Highlights/Key Messages

- High heavy metals content were detected in the vegetables
- Adults and children face notable non-carcinogenic and cancer risks
- Contaminated Kaduna river irrigation is the major pollution source

Background
Heavy metals in food, such as vegetables, may pose a serious health danger, making their consumption a public concern.

Objective
The purpose of this study was to evaluate the dietary intake of heavy metals and their potential health risks in some vegetables consumed in Kaduna Metropolis.

Methods
Commonly consumed vegetable samples were purchased from five markets in Metropolis using random systematic sampling. These samples were rinsed, air dried, pulverised, and allowed to pass through a British Standard (BS) mesh (BS 125mm). The same vegetable types (5) from the same market were composed by the coning and quartering method, which was eventually analysed using a non-disruptive Energy Dispersive X-ray Fluorescence (ED-XRF) spectrophotometric method for heavy metal content.

Results
Estimated Maximum Daily Intake (EMDI), hazard quotient (HQ), hazard index (HI), and incremental lifetime cancer risk (ILCR) for both adults and children were used to quantify the potential public health risk posed by the consumption of these vegetables. The total average concentrations of the heavy metals and their EMDI were ranked as follows: iron > copper > zinc > manganese > molybdenum > chromium > cobalt > nickel. With a few exceptions, the non-carcinogenic risk (HQ and HI values) for the majority of the vegetables was excessive (> 1) for both adults and children. Both adults and children show moderate to high carcinogenic health risks for three of the heavy metals (Cr, Cu, and Ni) examined for carcinogenic health risk (ILCR), with the exception of a few vegetables.

Conclusion
This study gave an insight into possible potential high risk of both non-carcinogenic and carcinogenic health risks from the consumption of vegetables on sale in Kaduna metropolis. Consequently, there is need for prompt action to control heavy metals sources in the environment as well as vegetables to protect public health.

Keywords: **heavy metal, vegetables, contaminated environment, Kaduna metropolis, human health, health risks, dietary intake**

Introduction

The availability of safe, fresh food, especially vegetables, is a basic need for public health. When cultivated in contaminated environments or irrigated with contaminated water, leafy vegetables are more vulnerable to contamination by higher concentrations of harmful components (Hou et al., 2013). These metals can be incorporated into plants, including vegetables, and subsequently move up the food chain (Singh et al., 2010), impacting both animal and human consumption. One of the most crucial components of food quality assurance and management is the control of heavy metal contamination (Khan et al., 2008).

Human health can be seriously endangered by certain metals, especially when concentrations exceed the extremely low levels required by the body (Tomori, 2018). They can impede the normal operations of many organs, leading to a variety of health problems (Adedokun et al., 2016; Yahaya et al., 2023). Iron, manganese, copper, zinc, and selenium are examples of heavy metals that are useful to the body at appropriate levels, while mercury, arsenic, aluminium, and cadmium are examples of metals that are commonly hazardous. Although essential metals are necessary for metabolic, enzymatic, and biochemical processes, excessive intake can be harmful (Argun, 2025). Additionally, a variety of mineral-to-mineral interactions occur, including those between calcium and zinc, copper and molybdenum, calcium and manganese, and selenium and mercury; high concentrations of one element may impair the availability of another (Peter, 2024). To protect humans from the harmful effects of ingesting excess metals, FAO and WHO have established upper limits of tolerance (FAO/WHO, 2011).

Risk assessment is a means of determining the likelihood that a specific number of negative consequences will occur during a given time period (Emmanuel et al., 2022). Provisional maximum tolerated weekly intakes (PMTWI) and provisional maximum tolerable daily intakes (PMTDI) are harmfulness values set by WHO to protect humans from the negative consequences of consuming excess metals. For pollutants without cumulative features, PMTDI is the endpoint; for food contaminants, PMTWI is the endpoint. An element is considered to be harmful if its estimated daily intake is higher than its given PMTDI (FAO/WHO, 2011). In addition to defining the process for estimating their possible risks, health risk assessment categorises substances as either carcinogenic or non-carcinogenic (Ekere et al., 2020). The hazard index (HI) estimates the total health risk from all contaminants/pollutants; the hazard quotient (HQ) evaluates the non-carcinogenic health risk from a metal through consumption; and the estimated daily intake evaluates the daily dietary contributions of a specific contaminant or nutrient. Incremental lifetime cancer risk (ILCR) is the probability that a population will develop cancer due to exposure to pollutants over its lifetime (Chamon, 2023).

Soil plays an integral role in agricultural resources and environmental sustainability because it is the stockpile for nutrients and ecosystem supports, and thus provides an avenue on which healthy plants and crops could grow. It can be contaminated with heavy metals through emissions from industrial areas, mining activities, wastewater disposal, fertilizer applications, sewage sludge disposal, atmospheric deposition, etc. (Liu et al., 2018; Jiang et al., 2018). Heavy metals in soil are persistent and non-biodegradable, entering the food chain through root systems, accumulating in food, and becoming a dietary concern (Kenny et al., 2020). Food safety and the assessment of possible health concerns depend on the EMDI of metals in food. It helps determine the average daily exposure to metals from food consumption and allows for comparison with established safety limits, aiding in public health risk assessment and informing dietary recommendations (Ogungbemi and Owoade, 2023).

Heavy metal concentrations in vegetables and the health risks they entail have been the subject of numerous studies conducted in a variety of settings (Doherty et al., 2012; Ugbidye et al., 2024). However, there were relatively few studies that explicitly measured the levels of heavy metals and the health risks they pose in the vegetables grown in many parts of Nigeria. Therefore, we investigated the dietary contributions of heavy metals from vegetables on sale at five marketplaces in Kaduna Metropolis and estimated the public health risks associated with their ingestion.

Materials and Methods

Sample Collection and Authentication

Twelve vegetable types (carrots, sweet potatoes, celery, lettuce, spinach, cabbage, broccoli, cauliflower, eggplant, avocado, peas, and beans) were collected from five different markets (Sabo, Central, Tudun Wada, Kawo, and Mando markets) in the Kaduna metropolis. Five samples of each type of vegetable from the same market (different vendors) were gathered. After being appropriately tagged and safely wrapped in nylon bags, the samples were brought to the lab. Authentication of the vegetable samples was done in the Botanical unit of the Department of Biological Science, Nigeria Defence Academy (NDA), and they were assigned voucher numbers.

Sample Preparation and Preservation

Vegetables were gathered, destalked where required, cleaned thoroughly with tap water to remove dust contamination, then rinsed with distilled water and drained. These samples were chopped with a stainless knife and oven-dried at 105 °C until crisply dried. Dried vegetable samples were pulverized into a fine powder using an agate mortar and pestle, then sieved through a mesh (BS 125mm). The same powdered and sieved samples from the same markets were combined to form a composite for each market that represents a vegetable type within each market in the Metropolis, using the coning and quartering method (Noli and Tsamos, 2016), from which a laboratory sample was taken for analysis. The composite samples were stored in a well-labelled, air-tight container for further analysis.

Quantitative Analysis of Heavy Metals in Vegetable Samples

The vegetable samples were ground manually to a grain size of less than 1.25 mm using an agate mortar and pestle. Pellets of 19 mm diameter were prepared from 0.5g of powder mixed with three drops of an organic liquid binder and were pressed at 10 tons with a hydraulic press. Each sample was loaded into the spectrometer's sample chamber, and a spectrum was acquired for 1000 seconds. Measurements were performed using an annular 25 mCi 109Cd as the excitation source, which emits Ag-K X-rays (22.1 keV), at the maximum power of 9W. The system furthermore consists of a Si-(Li) detector equipped with a thin beryllium (Be) window, with a resolution of 170 eV for the 5.90 keV line, coupled to a computer-controlled ADC card. Quantitative analysis of the samples was carried out using the Emission-Transmission (E-T) method. Accurate elemental identification and x-ray intensity determination, essential for determining the sample composition, were carried out using Bruker remote control software and later quantified using Bruker instrument tool software (Dehayem-Kamadjeu and Okonda, 2019).

Human Health Risk Indices

Non-cancerous risk estimates, using the heavy metal EMDI, hazard quotient (HQ), and hazard index (HI), and their cancer risks in adults and children, were used to evaluate the health risks associated with heavy metal consumption from vegetables.

Estimated maximum daily intake (EMDI)

The EMDI estimates the quantity of harmful metals that can be safely eaten daily over a lifetime without posing a significant danger to health (Gupta et al., 2019). The estimated maximum daily intake of toxic metals from vegetable consumption was calculated using the following equation (Chary et al., 2008).

$$EMDI = \frac{Cm \times Cr}{BW}$$

Where, Cm= the concentration of toxic metals in vegetables (mg/ kg). The consumption rate (Cr) of vegetables in Nigeria, according to FAO (2021), is 2.3 mg/kg/day. Adult and children (Toddler 1-2 years old) average body weights were estimated to be 60 kg and 10 kg, respectively (Sarkar et al., 2016).

Hazard quotient

According to Singh et al. (2010), the Hazard Quotient is a measure of the health risk posed by ongoing exposure to hazardous metals, which can also cause chronic hazards. Each leafy vegetable's HQ was determined using the following formula (Antoine et al., 2017).

$$HQ = \frac{EDI}{RfD}$$

Oral reference dosage (mg/kg/day) values for each metal of concern are known as RfD, while the population's estimated daily consumption of hazardous metals, measured in mg/day/kg body weight, is known as EMDI. According to the US EPA (2020), the RfD values for Cr, Mn, Fe, Co, Ni, Cu, Mo, and Zn were 0.005, 0.14, 0.007, 0.0003, 0.002, 0.04, 0.005, and 0.3 mg/kg/day, respectively. It is generally thought that the risk of noncarcinogenic effects is negligible when the HQ is less than 1; if the HQ is greater than 1, it is assumed that the risk of noncarcinogenic effects increases with HQ (Sultana et al., 2017).

Hazard Index

A hazard index (HI) was developed to assess potential risks to human health from multiple chemical contaminants (Guerra et al., 2012). It is a dynamic measure that assesses the total potential consequences of exposure to multiple contaminants. The cumulative effect of any pollutant is likely to cause noticeable health effects when the HI value exceeds 1 (Li P et al., 2009; Goumenou and Tsatsakis, 2019).

$$HI = \sum HQ = HQ_{Cr} + HQ_{Mn} + HQ_{Ni} + HQ_{Zn}$$

where HI is the sum of various metal hazards quotients.

Cancer risk

Carcinogenic risk (CR) is a person's likelihood of having cancer throughout their life due to exposure to toxic metals. In this study, only the elements Cr, Ni, and Cu were considered. The assessment of carcinogenic health risk can be carried out using the equation below.

$$CR = EDI * CSF$$

where CR = cancer risk over a lifetime by individual toxic metal. EMDI = estimated daily intake in mg/day/kg, CSF = oral cancer slope factor in (mg/kg/day). The CSF values for Cr, Ni, and Cu were 0.5, 0.91, and 1.7 mg/kg/day, respectively (Gebeyehu and Bayissa, 2020). For a single carcinogenic and multicarcinogenic metal, the acceptable values are < 10−6 and < 10−4, respectively (Tepanosyan et al., 2017). The New York State Department of Health (NYSDOH) states that a CR value of ⩽ 10-6 indicates low carcinogenic risks, a value of 10-5 to 10-3 indicates moderate risks, and a value of 10-3 to 10-1 indicates high risks (Li X et al., 2013; Tchounwou et al., 2014; Ashraf et al., 2021).

Results and Discussion

Heavy metal contents of selected vegetables and their dietary contribution

The content of heavy metals in the vegetables selected from Kaduna Metropolis markets are presented in Table 1. Iron had the highest total concentration, followed by copper, zinc, manganese, molybdenum, chromium, cobalt, and nickel. Generally, these vegetables had high concentrations of iron, copper, zinc, and manganese.

The EMDI of metals from the selected vegetables for adults and children is presented in Table 2. The orders of heavy metal load in the investigated vegetables are as follows:
Avocado>Cabbage>Beans>Potato>Celery>Lettuce>Spinach>Eggplant>Pea>Carrot>Cauliflower>Broccoli.
The range of EMDI of these metals (mg/kg.b.w/day) for adults and children respectively are Cr (0-0.16; 0-0.97), Mn (0.12-0.56; 0.32-3.36); Fe (0.34-4.09; 2.02-24.51); Ni (0-0.01; 0-0.41); Zn (0.14-0.92; 0.86-5.53); Co (0-0.12; 0-0.72); Cu (0.2-1.32; 0.76-7.91) and Mo (0-0.26; 0.02-1.56) (Table 2). The dietary contributions (EMDI) of heavy metals from different vegetables for children were on the same order of magnitude as for adults (Table 1).

Table 1. Heavy Metal Content of Selected Vegetables (mg/kg)

7	Cr	Mn	Fe	Co	Ni	Cu	Mo	Zn
Avocado	28.2±2.64	203±115	1485±148	0.00±0.00	17.3±1.73	283±48.4	34.7±3.47	125±12.5
Beans	58.8±4.94	174.6±34.4	765±76.5	28.7±2.46	0.00±0.00	479±79.2	51.3±5.13	288±28.8
Broccoli	6.3±0.4	19.5±1.22	122±12.2	8.85±0.83	2.33±0.20	46.1±7.77	1.33±0.14	33.7±3.38
Cabbage	19.3±1.7	170±11.1	870.8±87.08	37.6±1.91	12.6±1.32	424±77.04	63.3±6.33	335±33.5
Carrot	0.00±0.00	45.4±2.94	164±16.4	7.30±0.04	2.36±0.24	112±11.6	45.3±4.53	125±12.5
Cauliflower	12.1±0.72	50.8±2.97	217±21.7	8.38±1.28	0.00±0.00	71.1±12.6	16.0±1.60	52.2±5.22
Celery	10.3±0.92	81.1±5.09	862±86.2	4.55±0.59	0.79±0.08	144±8.59	24.0±2.40	190±19.05
Eggplant	19.2±1.92	66.7±4.7	308±30.8	6.65±0.59	6.31±0.66	179±17.9	37.3±3.74	66.7±6.67
Lettuce	2.8±0.26	163±16.2	680±68.1	13.3±0.99	17.6±2.18	134±41.7	19.3±1.93	98.8±9.88
Pea	28.8±2.73	118±9.21	213±21.3	26.4±2.65	0.00±0.00	197±33.5	23.3±2.34	75.5±7.55
Potato	59.1±5.57	97.0±10.2	691±69.2	43.9±0.21	24.7±2.95	470±65.2	94.6±9.47	86.8±8.68
Spinach	2.8±0.26	59.6±4.13	816±81.6	5.9±0.6	0.79±0.08	99.2±11.04	29.3±2.94	72.3±7.23

Cr is found in the soil, the atmosphere, construction materials, household goods, and even food (Vincent and Lukaski, 2018). The primary sources of this pollution are tanneries, textile manufacturing, printing and dyeing, food processing equipment, and packaging (Yan et al., 2023). We found an upper limit of 59.1 mg/kg Cr content in potatoes. Though Cr plays an important role in cholesterol, fat, and glucose metabolism and helps maintain blood sugar levels (Wen et al., 2024), continuous accumulation at high levels in tissues can result in cumulative poisoning, carcinogenicity, and genotoxicity in humans (Yan et al., 2023). All selected vegetable samples in this study, except carrots, had Cr concentrations (EMDI) that exceeded the EU permissible limit (0.3 mg/kg) (EU, 2006), which should be a source of concern. Osaili et al. (2016) have reported Cr concentrations in lettuce (2.00 mg/kg) and spinach (8.90 mg/kg), which are lower than the values obtained in this study.

Manganese (Mn) is an essential metal that is involved in bone formation and the metabolism of carbohydrates, cholesterol, and amino acids. According to Dey et al. (2023), the main human-caused sources of Mn include burning fossil fuels, metallurgical processes, sewage sludge, wastewater discharges, and emissions from combustion of fuel additives. The highest Mn content of our selected vegetable samples was in avocado at 203 mg/kg. The EMDI for Mn in this study is 0.56mg and 3.36mg for adults and children, respectively (Table 2); this value is lower than 2 mg for adults but higher than 0.3–1.00 mg and 1.5 mg for infants and children, respectively, as reported by Unaiza and Audra (2022). Although there is no official recommended dietary allowance (RDA) for manganese (Renthlei et al., 2016), the US National Research Council has determined that individuals should consume 2–5 mg of the mineral daily. The results obtained in this study were comparable to those of Babra et al. (2020), who reported Mn content of 204.99–249.13 mg/kg in vegetables. Many publications have found foliar manganese levels of 2000–4000 mg/kg (Paschke, 2005). The actual amount of Mn consumed, its molecular form, and the availability of other dietary metals, such as copper and iron (Fe), all affect how quickly Mn is absorbed. Mn is a trace metal essential to life, but if it builds up, it may become toxic and cause complications.

As a cofactor for several enzymes, iron is an essential nutrient for humans. It is involved in numerous metabolic processes that are vital to life, such as electron transport, oxygen transport, and the creation of deoxyribonucleic acid (DNA) (Kumar et al., 2022). The lower limit of iron concentration in this study is 122 mg/kg in broccoli and 1485 mg/kg in avocado. The safe limit of 425 mg/kg (FAO/WHO, 2011) has been established for iron content in vegetable samples. There have been multiplekg) inried concentration of iron reported in the literature; A lower level of Fe was reported by Chiroma et al., (2014) in food crops (883 mg/kg) in Yola, (Nigeria) while Oladebeye (2017) recorded much higher iron concentrations (2354.96 to 29950.57 mg/kg) in vegetables than those reported in this study. While iron is essential for many bodily functions, including oxygen transport and immune response, both deficiency and excess can be detrimental. Excessive iron intake can lead to health concerns like liver damage, diabetes, and cardiovascular disease, as well as oxidative stress and tissue damage (Akhtar et al., 2022).

For humans, animals, and prokaryotes, Co is a necessary trace element. It is an essential element of vitamin B12 (cobalamin), which contributes to metabolism by promoting haematopoiesis, boosting immunity, and exhibiting antimicrobial properties (Ugonna et al., 2020; Genchi et al., 2023). Meat, oysters, liver, fish, eggs, clams, and milk are the primary sources of cobalamin; humans can also obtain it by inhaling ambient air and by consuming drinking water that contains Co components (Khan et al., 2023). The Co content in the selected vegetable samples has an upper limit of 43.9 mg/kg in potatoes. The amount of Co that humans consume through their diet ranges from 5 to 50 g per day, with the majority of that being inorganic. Just a small portion of oral Co is vitamin B12. Adults should consume 2.4 g of vitamin B12 per day, which includes 0.1 g of Co, according to the recommended daily dietary allowance (RDA). These results exceeded the EMDI values for several vegetables considered. Human food and drink provide a potentially active route for exposure to both nutritionally necessary and harmful Co elements (Chishti et al., 2011). Therefore, it is essential to monitor and determine the Co concentration in various foods to safeguard public health.

Because nickel is a trace metal that many animal species, microbes, and plants require for sustenance, signs of toxicity or insufficiency may appear when either too little or too much Ni is absorbed (Cempel & Nikel, 2006). The general public can consume nickel orally, primarily through food and water, as a water pollutant, or as a food ingredient and contaminant (Gopal et al.,2014). With an upper limit of 24.69 mg/kg for potatoes, the Ni concentration in the chosen crops is below the FAO/WHO (2011) permitted level of 67.9 mg/kg. No clear evidence of a need for nickel in humans has been found. Nickel consumption from food varies greatly, according to scattered studies, although in most countries, the average daily intake of this metal is between 100 and 300 µg (Genchi et al., 2020). The findings of this study are lower than those of Kumari et al. (2018), who reported that vegetables had a very high Ni concentration (300 mg/kg). Numerous clinical consequences could result from human exposure to heavily contaminated environments. These include respiratory tract cancer, skin allergy, lung fibrosis, and iatrogenic nickel poisoning. The long-term application of pesticides and fertilizers, industrial wastewater, atmospheric deposition, etc are some of the reasons adduced as sources of Ni in the agricultural soil-plants-animal interaction, including humans (Ahmed et al., 2021).

Copper is a micronutrient necessary for several physiological processes, including oxidation, photosynthesis, protein and carbohydrate metabolism, cell wall metabolism, and symbiotic N2 fixation (Quartacci et al., 2000; Kabata-Pendias, 2010). Cu must be kept at a low concentration in cells, though, since too much of copper might disrupt DNA, cell membrane integrity, respiration, photosynthesis, and enzyme activity, which could stunt plant development and jeopardise plant survival (Zvezdanović et al., 2007; Chaffai et al., 2007; Zhao et al., 2010). The copper (Cu) content in the selected vegetable samples has an upper limit of 479 mg/kg in beans, which is far above the acceptable limit of 2.0 mg/kg stipulated by the FAO/WHO for copper. The Cu concentration in this study was far higher than those of Liu et al. (2004), Divrikli et al. (2006), and Ozcan (2004); however, Sayo et al. (2020) also reported values that exceeded these acceptable limits (39.42–64.78) but to a lesser degree when compared to this study. Humans rarely experience acute copper toxicity, which typically results from the following: children accidentally consuming copper salts, suicide attempts involving several grammes of copper salts, drinking water from tainted water sources, or consuming acidic food or drinks that were kept in copper containers (Araya et al., 2001).

Molybdenum is a trace element required by four enzymes: sulphite oxidase, xanthine oxidase, aldehyde oxidase, and the human mitochondrial amidoxime-reducing component. Molybdenum is found in many foods, but its concentration in plant foods is mostly influenced by regional soil richness, and its concentration in meat is influenced by the animals' feed (Novotny, 2011). The reported molybdenum content in the vegetable samples was highest in potatoes (94.6 mg/kg). There have been several average stipulated Mo requirements across the globe (EFSA, 2013); by Food and Nutrition Board of the United States Institute of Medicine (45 mg/d), World Health Organization (WHO) (100 to 300 mg/d), Food and Nutrition Board (2 mg/d), others like Health and Consumer Protection Directorate General of the European Commission (600 mg/d) and Expert Group on Vitamins and Minerals of the United Kingdom (230 mg/d). All these recommendations were far higher than all the EMDI results obtained for the vegetable samples in this study (Table 2). Although molybdenum can be extremely toxic to certain animals, especially ruminants, the levels we found, ranging from estimated daily intakes of 76 mg/d to 275 mg/d across various countries, do not appear to pose a toxicity risk to people (Novotny, 2011).

Skin, kidney, testis, epididymis, eye, hair, blood, bone, liver, prostate, and nearly every other organ or tissue in the human body contains zinc, an essential nutrient. It is essential for more than 300 enzymes and plays a critical role in cellular metabolic processes such as protein synthesis, immune system function, and gene expression regulation, even though it makes up only 0.003% (1.4–2.3 g) of a healthy adult human body. Acute zinc poisoning, on the other hand, can result from excessive zinc intake and is characterized by symptoms such as fever, diarrhoea, vomiting, and nausea (Mai et al., 2024). Zn content of our vegetable samples ranges from 33.7 mg/kg for broccoli to 335 mg/kg for cabbage. Zinc concentrations in all selected vegetables exceeded the permissible limit of 60 mg/kg (WHO, 2007), except for broccoli and cauliflower. The present results were higher than those of Farooq et al. (2008) for lettuce (1.893 mg/kg) and cabbage (0.678 mg/kg) and also the average reported by Akubugwo et al. (2012) in vegetables (1.74 mg/kg). The daily requirement is 15 mg/d for adults, 5 mg/d for infants, and 10-15 mg/d for children (Kexin et al., 2023), all of which are higher than the levels currently observed in the vegetables under investigation (Table 2). Higher dietary Zn exposure is dangerous for public health; therefore, its presence in the food chain should be a concern not only from a beneficial point but also due to its toxicity.

It has been argued from several literatures (Mahre et al., 2007; Yusuf et al., 2008; Abui et al., 2017; Butu et al., 2019) that River Kaduna has received untreated wastewater over a long period of time, and this has progressively undermined its quality. The major polluting industries are the Kaduna refinery, textile, food and beverages industries, ceramic, fertilizer, and paper industries that constantly discharge their untreated wastewater into the river. The river naturally floods during raining season, naturally enriching the river bank with heavy metals, thus increasing the possibility of transfer into planted vegetables. During the dry season, many farmers along Kaduna River used the river as irrigation water for vegetable farming, which may also have contributed to the observed high levels of various heavy metals in the vegetables. Therefore, anthropogenic sources of the various heavy metals under investigation are implicated as direct contaminants in the investigated vegetables.

Non-Carcinogenic and Carcinogenic Health Risk Estimate of Selected Vegetables

Tables 3 and 4 present the carcinogenic and non-carcinogenic risk estimates for the selected vegetables, respectively. To determine whether eating vegetables could pose a non-carcinogenic health risk, HQ and HI values were calculated. The results are displayed in Table 3 for both adults and children. The findings showed that HQ values for adults and children of most of the metals were excessive (>1) except for Cr in carrots, Ni in cauliflower, pea, and beans, and Co in avocado, for adults and children; the highest HQ was observed in Fe in avocado. When the HQ value of a metal in

Table 2. Estimated Maximum Daily Intake (mg/kg.b.w/day) of metals from the selected vegetables for adults and children

	Cr_{Ad}	Cr_{Ch}	Mn_{Ad}	Mn_{Ch}	Fe_{Ad}	Fe_{Ch}	Ni_{Ad}	Ni_{Ch}	Zn_{Ad}	Zn_{Ch}	Co_{Ad}	Co_{Ch}	Cu_{Ad}	Cu_{Ch}	Mo_{Ad}	Mo_{Ch}
Avocado	0.08	0.46	0.56	3.36	4.09	24.51	0.05	0.29	0.34	2.07	0	0	0.78	4.67	0.1	0.57
Beans	0.16	0.97	0.48	2.88	2.1	12.61	0	0	0.79	4.75	0.08	0.47	1.32	7.91	0.14	0.85
Broccoli	0.02	0.10	0.05	0.32	0.34	2.02	0.01	0.04	0.09	0.56	0.02	0.15	0.13	0.76	0	0.02
Cabbage	0.05	0.32	0.47	2.82	2.39	14.37	0.03	0.21	0.92	5.53	0.1	0.62	1.17	7.01	0.17	1.04
Carrot	0	0	0.12	0.75	0.45	2.7	0.01	0.04	0.34	2.07	0.02	0.12	0.31	1.84	0.12	0.75
Cauliflower	0.03	0.2	0.14	0.84	0.6	3.58	0	0	0.14	0.86	0.02	0.14	0.2	1.17	0.04	0.26
Celery	0.03	0.17	0.22	1.34	2.37	14.23	0	0.01	0.52	3.14	0.01	0.08	0.4	2.37	0.07	0.4
Eggplant	0.05	0.32	0.18	1.1	0.85	5.08	0.02	0.1	0.18	1.1	0.02	0.11	0.49	2.95	0.1	0.62
Lettuce	0.01	0.05	0.45	2.7	1.87	11.23	0.05	0.29	0.27	1.63	0.04	0.22	0.37	2.21	0.05	0.32
Peas	0.08	0.48	0.33	1.95	0.59	3.52	0	0	0.21	1.25	0.07	0.44	0.54	3.25	0.06	0.38
Potato	0.16	0.97	0.27	1.6	1.9	11.41	0.07	0.41	0.24	1.43	0.12	0.72	1.29	7.76	0.26	1.56
Spinach	0.01	0.05	0.16	0.98	2.24	13.47	0	0.01	0.2	1.19	0.02	0.1	0.27	1.64	0.08	0.48
PMTDI	0.20-0.3	0.20-0.30	2.0-5.0	2.0-5.0	17.0	17.0	0.3	0.3	20.0	20.0	0.0016	0.0016	2.0	2.0	0.01	0.01

Key: Ad=Adult, Ch=children

Table 3. Hazard quotients (HQ) and Hazard index (HI) (mg/kg/ day) of metals from the selected vegetables for adults and children

		Cauliflower	Carrot	Avocado	Cabbage	Celery	Potato	Pea	Lettuce	Spinach	Beans	Broccoli	Eggplant
HQ_{Cr}	Ad	**6.7**	0.0	15.5	10.6	5.7	32.5	15.9	1.5	1.5	32.3	3.5	10.5
	Ch	**39.9**	0.0	92.9	63.6	34.1	194	95.1	9.1	9.1	193	20.9	63.2
HQ_{Mn}	Ad	**1.0**	0.9	4.0	3.4	1.6	1.9	2.3	3.2	1.2	3.4	0.4	1.3
	Ch	**6.0**	5.4	24.0	20.1	9.6	11.4	13.9	19.3	7.0	20.6	2.3	7.9
HQ_{Fe}	Ad	**85.2**	64.3	583	342	339	272	83.8	267	321	300	48.1	121
	Ch	**511**	386	3502	2052	2031	1631	503	1604	1924	1801	289	725
HQ_{Co}	Ad	**76.8**	66.9	0.0	345	41.7	402	242	122	53.8	263	81.1	61.0
	Ch	**461**	402	0.0	2068	250	2414	1454	729	323	1580	487	366
HQ_{Ni}	Ad	**0.0**	3.3	23.8	17.4	1.1	34.0	0.0	24.2	1.1	0.0	3.2	8.7
	Ch	**0.0**	19.5	143.0	104	6.5	204	0.0	145	6.5	0.0	19.2	52.1
HQ_{Cu}	Ad	**4.9**	7.7	19.5	29.2	9.9	32.3	13.6	9.2	6.8	32.9	3.2	12.3
	Ch	**29.3**	46.0	117	175	59.4	194	81.3	55.3	40.9	198	19.0	73.8
HQ_{Zn}	Ad	**0.5**	1.2	1.2	3.1	1.8	0.8	0.7	0.9	0.7	2.6	0.3	0.6
	Ch	**2.9**	6.9	6.9	18.4	10.5	4.8	4.2	5.4	4.0	15.8	1.9	3.7
HQ_{Mo}	Ad	**8.8**	24.9	19.1	34.8	13.2	52.1	12.8	10.6	16.1	28.2	0.7	20.5
	Ch	**52.8**	149	114	209	79.2	312	77.0	63.8	96.8	169	4.4	123
HI	Ad	**184**	169	666	785	414	828	371	439	402	663	141	236
	Ch	**1102**	1015	3999	4710	2482	4966	2228	2632	2411	3979	843	1415

Key: Ad=Adult, Ch=children

the selected vegetables is likely to have significant non-carcinogenic health effects on consumers, as the values were substantially higher than 1. The most likely reason for this observation in this study is that most vegetable farmers in Kaduna Metropolis rely on River Kaduna for irrigation, and this river has been repeatedly found to be contaminated with heavy metals (Isah et al., 2025). Lower HQ for metals was reported by Adedokun et al. (2016) in vegetables, despite being grown with wastewater irrigation. Our children had higher HQ values in all cases. Our values were in tandem with Mahfuza et al. (2017), Michael et al. (2015), and Liu et al. (2013), who also reported higher values for children. The HI values for the selected vegetable samples collected from five different markets are presented in Table 3. HI for adults ranged from 140 mg/kg in broccoli to 828 mg/kg in potatoes, while HI for children ranged from 843 mg/kg in broccoli to 4966 mg/kg in potatoes. The results for both adults and children in Table 3 indicate that the HI values obtained were greater than 1, indicating that eating vegetables that contain metals or their mixtures poses serious health risks (USEPA, 2020).

The values obtained for the assessment of some of the investigated heavy metal carcinogenic risk were presented in Table 4, and for Cr, it ranges from 0.00 – 0.08, 0.00 - 0.1, for Cu, 0.22-2.20, 0.69- 7.19, and for Ni, 0.00-0.06, 0.00- 0.69, respectively, for adults and children. The lowest detectable value recorded in this study was 0.01 mg/kg (observed in Chromium and Nickel concentrations for Broccoli, Celery, and Carrot. A CR value of < 10-6 is linked to low carcinogenic hazards, a value between 10-5 and 10-3 to moderate risks, and a value between 10-3 and 10-1 to high risks, according to the New York State Department of Health (Li et al., 2013). For the three evaluated heavy metals (Cr, Cu, and Ni), the carcinogenic health risk index (CR) for both adults and children indicate moderate to high carcinogenic health risks except for Cr in carrot, lettuce, and spinach, and Ni in beans, cauliflower, and peas, where no or low risk is observed. These risk values for the others indicate that consumption of these selected vegetables may result in cancer cases (USEPA 2007). Cu is the most dominant carcinogen in the selected vegetables. People who are exposed to multiple hazardous elements are thought to experience either combined or interactive negative effects (Balali-Mood et al., 2021).

Using vegetable consumption rates to estimate health risks (especially heavy metal exposure) in Nigeria faces significant limitations due to a lack of updated data (which often do not reflect current consumption patterns), high consumption variability, data inaccuracies, and regional-specific information. Reliable, nationally representative data on food intake are scarce, leading to reliance on outdated or localized studies. Reported vegetable intake in Nigeria is low (27 to 114 kg/capita/year), below the WHO/FAO recommendation of 146 kg/capita/year (Chubike et al., 2013), potentially leading to underestimation of risks from contaminated sources. Interpretations of the outcome of this work should thus be made with caution. However, possible risks that consumption of contaminated vegetables irrigated with contaminated river water can pose to population health should be taken seriously.

Table 4. Cancer risk (CR) of Cr, Cu and Ni (mg/kg /day) from selected vegetables for adults and children

	Cr		Cu		Ni	
	Adult	Children	Adult	Children	Adult	Children
Avocado	0.04	0.23	1.32	4.25	0.04	0.48
Beans	0.08	0.48	2.24	7.19	0.00	0.00
Broccoli	0.01	0.05	0.22	0.69	0.01	0.07
Cabbage	0.03	0.16	1.99	6.38	0.03	0.35
Carrot	0.00	0.00	0.52	1.67	0.01	0.07
Cauliflower	0.02	0.10	0.33	1.07	0.00	0.00
Celery	0.01	0.09	0.67	2.16	0.00	0.02
Eggplant	0.03	0.16	0.84	2.69	0.00	0.18
Lettuce	0.00	0.02	0.63	2.01	0.04	0.49
Pea	0.04	0.24	0.92	2.96	0.00	0.00
Potato	0.08	0.49	2.24	7.06	0.06	0.69
Spinach	0.00	0.02	0.46	1.49	0.00	0.02

The lowest detectable value recorded in this study was 0.01 mg/kg (observed in Chromium and Nickel concentrations for Broccoli, Celery, and Carrot). Values recorded as 0.00 indicate concentrations that were below the machine's Limit of Detection (LOD).

Conclusions

We found that the heavy metal content of the vegetables we measured was, in many cases, high. The highest content was found to be iron (Fe) in avocado, and the lowest was cobalt (Co) in avocado, nickel (Ni) in beans, cauliflower, and peas, and chromium (Cr) in carrot, which were below our detection level. The EMDI of the selected vegetables (based on somewhat outdated estimates of intakes for the entire country) was moderately high for both adults and children, especially for children. We also found that HQ (and HI) values of most metals for adults and children were >1. This signifies the possibility of non-carcinogenic risk from selected vegetables. Both adults and children have extremely high ILCRs for Cr, Cu, and Ni after eating certain plants, with children showing particularly high ILCRs. The development of cancer is likely to result from prolonged exposure to a particular carcinogen, and the risk rises with the amount consumed. This study provided information on the probable elevated non-carcinogenic and carcinogenic health risks associated with eating the vegetables under investigation sold in the city of Kaduna. This clearly indicates the need for prompt action to control sources of heavy metals in the environment, in general, and in vegetables in particular. Treatment of industrial wastewater should be mandated to limit human exposure to excessive accumulation of heavy metals. Most of the vegetables consumed in the metropolis relied on the Kaduna River for irrigation: during the rainy season, from overflowing river water; and during the dry season, from river water (Butu et al., 2019). This river was reported (Abui et al., 2017) to be heavily contaminated with heavy metals, with values exceeding NIS and WHO limits.

Author Contributions

COI: Conception, data analysis, manuscript preparation. WBT: Experimental Design, manuscript preparation and revision. WAO: laboratory work, manuscript preparation and revision. PEU: Manuscript preparation and revision. All authors have read and approved the final version of the paper and its submission and have given consent for publication.

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Data Availability Statement

All relevant data are available within the manuscript

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Conflict of Interest

The authors declare that they have no conflicts of interest.

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