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Research article

Heavy metal pollution and evaluation of health risk of amaranth around Don Bosco wastewater treatment plant, Iringa, Tanzania

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A B S T R A C T

One of the world's most significant sources of environmental pollution is heavy metals contamination of soil, water, and agricultural products. Liver cancer, kidney damage, anaemia, coma, hypertension and sporadic fever are among the illnesses that might result from consuming plants contaminated with heavy metals. This study assesses heavy metals (Cu, Mn, Cd, Cr, Ni and Pb) contamination and associated human health risks in amaranth (*Amaranthus hybridus*) grown near Don Bosco wastewater treatment plant in Iringa municipal, Tanzania. The study measured the concentration of heavy metals in amaranth vegetables using AAS. The level of Mn in the vegetables ranged between 67.90 and 493.44 mg/kg. The mean concentration of Mn obtained was 280.67 mg/kg, lower than the permissible levels set by FAO/WHO but above the limit as set by TBS. The Cu levels in amaranth ranged between 6.37 and 7.90 mg/kg, with a mean concentration of 7.24 mg/kg lower than the permissible limits set by FAO/WHO and TBS. The Cd levels in amaranth ranged between 0.05 and 0.35 mg/kg, and the mean concentration was 0.20 mg/kg below the permissible limit set by FAO/WHO and TBS. The calculated daily intake consumption fell in the following sequence: Mn > Cu > Cd. The hazard quotient (HQ) for Mn and Cd is 261.66 and 6.45, respectively, higher than the allowed limit (HQ < 1), and the hazard index (HI) for all samples was HI > 1, which indicates the consumption of these veggies could pose a harm to one's health. Additionally, the assessment of cancer risks revealed that Mn and Cd levels exceeded the USEPA recommended threshold of 1E-04, indicating a risk of one additional cancer case for every 10,000 individuals consuming amaranth vegetables. Thus, regularly checking for heavy metal contamination in vegetables is critical to minimize health hazards.

1. Introduction

Heavy metals are a group of elements that have high atomic density and weight. The density of heavy metals typically ranges from approximately 4 to 22.5 g/cm^3 [1]. Heavy metals are divided into two groups: essential and toxic. Essential heavy metals are necessary for the proper functioning of the human body and play crucial roles in various physiological processes [2,3]. Examples of essential heavy metals include zinc (Zn), copper (Cu), iron (Fe) and manganese (Mn), etc. Toxic heavy metals are heavy metals that are considered harmful to living organisms, including humans, even at low concentrations. These elements include lead (Pb), mercury

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(Hg), chromium (Cr), cadmium (Cd) and arsenic (As) [4,5].

Heavy metals can enter the environment through both human activities and natural processes. Natural processes include volcanic eruptions and weathering of rocks. In contrast, human activities such as industrial processes, agriculture, mining and waste disposal contribute significantly to releasing heavy metals into the environment [6,7]. Agriculture activities such as modern farming, which use artificial fertilizers and pesticides, also add heavy metals to the soil. When heavy metals are present in the soil, they can be transferred to plants, including vegetables, through various mechanisms. One of the primary ways heavy metals are transferred from the soil to vegetables is through uptake by plants' roots. As plants absorb nutrients and water from the soil, they also absorb heavy metals [8,9]. The extent to which a plant absorbs heavy metals depends on several factors, including the type of plant, the concentration of heavy metals in the soil, the soil pH scale and other soil components [10]. Also, heavy metals are transferred from soil to vegetables through the air. Some heavy metals, such as Cd, can be absorbed by plant leaves when they come into contact with contaminated air. This process is known as atmospheric deposition. Additionally, dust particles carrying heavy metals can settle on the surface of leaves and eventually be absorbed by the plant [11]. The use of contaminated water for irrigation can also contribute to the transfer of heavy metals from soil to vegetables. If the water for irrigation contains heavy metals, these metals can be taken up by plants' roots and subsequently transferred to the edible parts of the plants [12]. Soil particles can also contribute to transferring heavy metals from soil to vegetables. When soil is disturbed, such as during tilling or construction activities, heavy metals can be released and become more accessible to plant roots. Moreover, soil erosion can transport heavy metals to new locations, potentially contaminating new land areas and the plants that grow there [13,14].

A serious problem that impacts public health, environmental sustainability, and food safety is heavy metal pollution in agricultural products. A green vegetable high in nutrients, amaranth is especially vulnerable to absorbing heavy metals from contaminated soil, water, or even the air. Ingesting heavy metals contaminated amaranth vegetables may lead to numerous serious human health dangers since they are non-biodegradable and can build up in plant tissues. Human bioaccumulation of heavy metals can have serious health effects, such as liver cancer, kidney damage, anaemia, coma, hypertension, sporadic fever cancer, developmental problems and neurotoxicity [15,16]. For example, Hg as well as Pb are known for their neurotoxicity effects, which can cause delay in children and neurological disorders in adults [17]. Certain heavy metals (such as Cd and As) are linked to an increased danger of cancer, including liver, bladder and lung cancer. Heavy metal exposure has been associated with reproductive health problems in both men and women, including infertility and congenital disabilities, organic damage, and chronic exposure to toxic heavy metals that can damage vital organs such as the kidney, liver and lungs, leading to organ dysfunction and failure [18].

The Don Bosco wastewater treatment plant handles wastewater from various sources in Iringa municipal. The waste may contain heavy metals that can contaminate the surrounding environment. Also, farmers use fertilizers and pesticides, increasing the level of heavy metals in amaranth. Additionally, the water sources used for irrigation are near the plant. Amaranth grown near the Don Bosco wastewater treatment plant is consumed by people both in the surrounding area and nearby areas. Therefore, it is essential to monitor and regulate heavy metal contamination in this vegetable. The accumulation of toxic metals in amaranth not only poses a serious risk to human health but also harms the ecosystem and reduces agricultural productivity. Controlling heavy metal pollution is critical for ensuring food safety, minimizing health risks, and promoting sustainable agricultural practices. Thus, this study assessed heavy metals and human health risks in amaranth (*Amaranthus hybridus,* known in Swahili as *mchicha*) vegetables grown near Don Bosco wastewater treatment plant.

2. Materials and methods

2.1. Study area

The Don Bosco wastewater treatment pond is found in Don Bosco, a suburb in the Iringa municipality in Tanzania. The Iringa region is about 500 and 260 km from Dar es Salaam and Dodoma Cities, respectively. Don Bosco is located at the coordinate of 8.3115° S latitudes and 35.0356°E longitudes.

2.2. Sample collection

Samples were collected in March 2024 from eight (8) sampling stations around the Don Bosco wastewater treatment area. The sampling station was the amaranth garden farms located near the plant. A fresh bunch of amaranth green leaves, consisting of 30–40 plants, was collected from a single garden. The leaves were randomly gathered from different locations across the farm. In total, 8 composite samples were collected, one from each garden farm. The amaranth vegetable samples were extracted from all the plants using a stainless-steel knife and subsequently labelled for identification purposes. The importance of labelling these samples for identification is emphasized. Each sample was packed and stored in polythene bags according to their types and brought to Mkwawa University College of Education (MUCE) for preparation.

2.3. Laboratory preparation of amaranth samples at MUCE

The amaranth vegetable samples underwent a series of preparation steps for analysis. First, they were washed with tap and distilled water to eliminate surface pollutants. To speed up the drying process, the cleaned samples were cut into little pieces using a plastic knife. All samples were air dried for 6 h to reduce moisture contents. The samples were then transferred using aluminium foils to an oven at 70^0C until constant weight was obtained. Following this, the dried samples were pulverized using an agate pestle and mortar and then sieved through a 0.5 mm mesh size sieve to achieve uniform particle size. Each vegetable sample was carefully labelled and stored in a dry plastic container pre-cleaned with concentrated ethanol to prevent metal contamination before analysis using AAS. The samples were then put in individual polythene bags and transported to the Sokoine University of Agriculture (SUA) laboratory for analysis.

2.4. Laboratory analysis and extraction of amaranth samples at SUA

The analysis of heavy metals in amaranth was done at SUA using Thermo Scientific iCE 3300 AAS. The 3300 AAS simplifies even the most complex analyses. Its advanced double-beam optics deliver exceptional performance, while the innovative hardware and software design make running samples, creating methods, and maintaining the instrument straightforward and efficient [19]. The metal analysis procedure of vegetable samples was extracted by employing the ashing method. EPA 3052 was used to extract the samples for metal analysis, and a microwave digester was used for the wet digestion process. Other procedures for amaranth vegetable samples extraction are the same as reported in the previous study [20].

2.5. Quality control and assurance

The minimum detection limit (MDL) of the AAS was established by running a blank solution, measuring the absorption three times with a 3-s integration period, and calculating the standard deviation (SD) from 10 consecutive readings. The AAS was calibrated using an external standard calibration method, with the response factor applied to check the linearity of the calibration. The correlation coefficient (r^2) was also determined. To assess the accuracy of the sample preparation process and detect any potential errors due to preparation or matrix effects, a spiked sample analysis was conducted. Additionally, a recovery study was performed to further evaluate the method's accuracy [20–23].

2.6. Determination of heavy metals in amaranth samples

The working standard solutions of metals were prepared from stock solutions of Pb, Cd, Cr, Ni, Cu and Mn. For all measurements, a standard air-acetylene flame was employed. The lamp current for Pb, Cd, Cr, Ni, Cu and Mn was 10, 10, 12, 10, 10 and 12 mA, respectively. The lamp current of each metal was set at 75 % and warmed for 30 min before analysis started. A wavelength set before analysis for Pb, Cd, Cr, Ni, Cu and Mn was 217, 228, 357, 232, 324.8 and 279 nm respectively. The analysis procedure involved first measuring the calibration standards, followed by the blank and the samples. Blank samples and reference standards were used to ensure the quality of the analysis (TZS, 2003). Table 1 provides a summary of the lamp currents, wavelengths, and detection limits for the heavy metals.Analysis started by reading calibration standards then followed by blank and samples [20].

2.7. Human health risk assessment

By calculating the hazard index (HI), hazard quotient (HQ), and predicted daily intake (EDI) from the obtained concentrations, the health hazards such as cancer risk (CR) related to the consumption of amaranth vegetables can be obtained. The following subsections will be dedicated to the evaluation of health risks.

2.7.1. Estimated daily intake of metals (EDI)

The estimated daily intake of metals (EDI) is a crucial parameter in assessing heavy metals in vegetables grown in areas affected by wastewater irrigation. In this context, the EDI refers to the amount of heavy metals an individual ingests daily by consuming contaminated vegetables. This measurement is essential for evaluating the potential health risks associated with the consumption of such vegetables and for formulating appropriate mitigation strategies. EDI was calculated as a product of equivalent to average lifetime (F_{IR}) average vegetable consumption (240 g/person/day), metal concentration C_M (mg/kg dry weight), a body weight of an adult B_W (70 kg) and 0.001 is a unit convectional factor [24] as shown in equation (1). Table 2 shows the summary of the parameters used to calculate EDI.

$$EDI = \frac{F_{IR} \times C_M}{B_W} \times 0.001 \quad (1)$$

Table 1
Wavelength, lamp current and detection limits of each heavy metal in the AAS analysis.

Element	Wavelength (nm)	Lamp current (A)	Detection limit (mg/kg)
Pb	217	10	0.013
Cd	228	10	0.0028
Cr	357	12	0.0054
Ni	232	10	0.008
Cu	324.8	10	0.0045
Mn	279	12	0.0016

Table 2
Parameters used to calculate EDI.

S/N		Unit	Child	Adult	References
01	Body weight (BW)	Kg	15	70	[24]
02	Exposure frequency (EF)	days/year	365	365	[3]
03	Exposure duration (ED)	years	6	65	[24]
04	Average exposure time (TA)	days	5475	23725	[24]
05	Average vegetable consumption (FIR)	g/day	240	240	[3]

2.7.2. Non-carcinogenic risk

Non-carcinogenic heavy metals are those that do not have a direct link to causing cancer in living organisms. In the context of amaranth vegetables, the primary non-carcinogenic risks are calculated by using the Hazard Index and Hazard Quotient**.**

2.7.3. Hazard quotient (HQ)

The hazard quotient (HQ) is a tool used to assess the potential health risks associated with exposure to heavy metals through food consumption. It is calculated by comparing the estimated daily intake (DIM) of a specific heavy metal from a particular food item (in this case, amaranth) to a reference dose (R_f D) established by regulatory agencies or health organizations. The reference dose represents the amount of a specific heavy metal that an individual can ingest daily over a lifetime without experiencing adverse health effects. The HQ is calculated using equation (2) [24,25].

$$HQ = \frac{EDI}{R_f D} \tag{2}$$

If the < 1 , the exposure is within or below the safe threshold, meaning there is no significant risk of harmful health effects. However, if the > 1 , the exposure exceeds the safe level, suggesting a potential risk of adverse health effects. For example if the HQ value for a particular heavy metal exceeds 1, it suggests that there may be potential health risks associated with consuming that metal through amaranth vegetables being assessed and if HQ is less than one, no potential health effects are expected from the exposure. The value of the Reference Dose of each heavy metal found in amaranth is shown in Table 3.

Suppose the HQ value for a particular heavy metal exceeds 1. In that case, it suggests that there may be potential health risks associated with consuming that metal through amaranth vegetables being assessed. If HQ is less than one, no potential health effects are expected from the exposure.

2.7.4. Hazard index (HI)

The HI is calculated by summing the ratios of the estimated daily intake (EDI) of each heavy metal to its corresponding reference dose (R_f D). The R_f D is an estimation of the daily exposure to a chemical that will probably not have a significant risk of negative consequences during a lifetime. The EDI is determined by multiplying the levels of every heavy metal in the vegetable by the average daily consumption rate. To calculate the hazard index for amaranth vegetables, researchers typically measure the concentrations of heavy metals in the edible portions of the plant and estimate the average daily intake based on local consumption patterns. These data are then compared to established reference doses for each heavy metal to determine the potential health risks of consuming amaranth. HI was calculated using equation (3) [3,26,27].

$$HI = \sum_{i=1}^{n} HQ = \left[\frac{EDI_{Pb}}{R_f D_{Pb}} + \frac{EDI_{Cr}}{R_f Cr} + \frac{EDI_{Cu}}{R_f Cu} + \frac{EDI_{Mn}}{R_f D_{Mn}} + \frac{EDI_{Cd}}{R_f D_{Cd}} + \frac{EDI_{Ni}}{R_f D_{Ni}}\right] \tag{3}$$

If the < 1 , the total exposure is considered within safe limits, indicating no significant risk of harmful health effects. However, if the $HI > 1$, the combined exposure from multiple sources surpasses safe levels, suggesting a potential risk of non-cancer health effects.

2.7.5. Carcinogenic effects

Carcinogenic heavy metals are those that have been found to cause cancer or have the potential to cause cancer in living organisms. The cancer risk (CR) presented to human health by individual potential carcinogenic metals was calculated depending on exposure dose from ingestion using equation (4) [3,27].

Table 3
Reference dose of heavy metals in amaranth vegetables.

Heavy metal	R_f D (mg/Kg/days)	References
Cd	0.0001	[24]
Cu	0.04	[24]
Ni	0.02	[24]
Pb	0.0035	[24]
Cr	0.003	[24]
Mn	0.003	[24]

$$CR = EDI \times C_{SF} \quad (4)$$

In this case, CR represents the lifetime cancer risk associated with a single heavy metal intake, EDI represents the population's estimated daily metal intake in mg/kg/day body weight, and CSF is the oral cancer slope factor in mg/kg/day.The United States Environmental Protection Agency (USEPA) has established an acceptable cancer risk range between 1E-06 and 1E-04. A risk of less than 1E-06 (one additional cancer case per 1,000,000 people) is typically not a cause for concern, while a risk greater than 1E-04 (one additional case per 10,000 people) is generally deemed unacceptable [28]. Table 4 shows Oral cancer slope factor for Cu, Cd and Mn.

3. Results and discussion

3.1. Concentration of heavy metals in amaranth samples

Table 5 shows the concentrations (mg/kg) of heavy metals (Cu, Mn, Cd, Cr, Ni and Pb) in amaranth vegetables from the Don Bosco wastewater treatment area, while Table 6 shows the comparison of metal concentration with other studies in vegetables from different countries. However, toxic heavy metals such as Pb and Cr were not detected in amaranth samples, whereas Ni was detected only in samples A7 and A8. The concentration of metals in the amaranth samples was mostly in the decreasing order of Mn > Cu > Cd. The range of Mn concentration in the amaranth sample was between 67.90 ± 1.42 (A8) and 493.44 ± 21.52 mg/kg (A1). The Mn concentration in this study was below the permissible limits of 500 mg/kg as set by FAO/WHO [31]. The Mn concentrations were above the allowable limits of 0.2 mg/kg as set by TBS [32]. One essential trace-heavy element found in the growth of plants and animals is manganese. Mammals that are lacking in it exhibit various skeletal and reproductive problems. Human lungs and brains are at risk from high Mn concentrations [33]. Excessive accumulation of Mn in the brain can lead to a neurological disorder that affects cognitive function, behavior, and motor skills [21]. The primary source of Mn in soil comes from the parent material of the soil itself, as Mn makes up around 0.1 % of the Earth's crust. Manganese can also be added to soil through atmospheric deposition, runoff from plants and other surfaces, leaching from plant tissues, and the breakdown of organic matter [34].The mean concentration of Mn in the present study was 280.67 ± 11.4 mg/kg higher compared to other studies from Bangladesh and Tanzania (Table 5).

The Cu levels in studies of amaranth from the Don Bosco wastewater treatment area ranged between 6.37 ± 0.30 (A5) and 7.90 ± 0.36 mg/kg (A8). The Cu concentration in this study was below the permissible limits of 40 mg/kg as set by FAO/WHO and TBS [24]. Cu is a necessary micronutrient that, along with Fe, acts as a biocatalyst for body pigmentation. It also keeps the central nervous system healthy, avoids anaemia, and is connected to the actions of Zn and Fe in the body. When the body has too much copper, it can cause organic disorders like gastroenteritis, which can cause nausea and intestinal irritations [24]. The mean concentration of Cu in the present study was 7.24 ± 0.33 mg/kg lower than in other studies, such as Tanzania, Burkina Faso, Qatar, and Bangladesh (Table 5). However, in this study, the mean concentration was higher than that of other studies from Iran and Tanzania (Table 5), and the lowest concentrations were 0.85, 0.25, and 0.25 mg/day, respectively.

The Cd levels in studies of amaranth from the Don Bosco wastewater treatment area ranged between 0.05 ± 0.02 (A4) and 0.35 ± 0.03 mg/kg (A5) observed in Don Bosco wastewater treatment. The value of Cd did not show any statistical difference, with a permissible limit of 0.2 mg/kg set by FAO/WHO and TBS [42]. Cd is one of the big three heavy metal poisons and is not known for any biological functioning. Cd has been shown to negatively impact several enzymes in the body, including those involved in protein reabsorption in kidney tubules. Thus, it is thought to cause renal damage, leading to proteinuria [33]. The mean concentration of Cd in the present study was 0.20 ± 0.03 mg/kg lower than other studies like Iran, Malaysia, China, and Tanzania, with concentrations of 0.03, 0.05, 0.05 and 0.03 mg/kg, respectively. However, in the present study, the mean concentration was higher than in other studies held in Pakistan, Qatar, and Bangladesh, with concentrations of 7.0, 0.90, 0.19 and 0.50 mg/kg, respectively.

3.2. Non-carcinogenic and carcinogenic human health risk assessment

Table 7 shows the calculated non-carcinogenic EDI, HQ and HI. The EDI of Cu, Mn, and Cd was computed based on each heavy metal's concentration in each vegetable and their corresponding consumption rates. Total estimated daily intakes of Cu, Mn and Cd were 2.53×10^{-4}, 0.785, and 6.45×10^{-4} (mg/person/day) respectively. The daily intake of Cu, Mn and Cd was less than the maximum tolerable daily intake (MTDI), so consuming amaranth vegetables cannot lead to health problems related to Cu, Mn and Cd. The EDI dropped in samples of veggies in the following order: Mn > Cd > Cu.

The results for calculated HQ of Cu was between the range of 0.0055 (A5) and 0.0068 (A8). The value of HQ for Mn ranged between 76.6 (A8) and 563.3 (A1), and Cd ranged between 2.74 (A1) and 12.0 (A5). The HI of heavy metals (Cu, Mn and Cd) in amaranth vegetables from Don Bosco wastewater treatment for all samples were above 1, as seen in Table 6. The findings of this study reveal that the HI > 1, suggests a possible health danger to individuals who eat these vegetables. An HI exceeding 1 for Cu suggests an increased

Table 4
Oral cancer slope factor.

Heavy metal	C_{SF} (mg/kg/day)	Reference
Cu	0.3	[24]
Cd	0.38	[29,30]
Mn	0.5	[27]

Table 5
Results of mean concentration of heavy metals with standard deviation.

Sample Name	Mean concentrations of Heavy Metals with Standard deviation in (*mg* /*kg*)					
	Cu	Mn	Cd	Cr	Ni	Pb
A_1	7.62 ± 0.19	493.44 ± 21.5	0.08 ± 0.04	ND	ND	ND
A_2	7.41 ± 0.12	219.42 ± 18.8	0.19 ± 0.02	ND	ND	ND
A_3	7.77 ± 0.76	263.57 ± 9.41	0.32 ± 0.04	ND	ND	ND
A_4	6.99 ± 0.01	115.71 ± 4.26	0.05 ± 0.02	ND	ND	ND
A_5	6.37 ± 0.30	378.45 ± 1.25	0.35 ± 0.03	ND	ND	ND
A_6	7.62 ± 0.74	388.90 ± 23.2	0.15 ± 0.02	ND	ND	ND
A_7	7.65 ± 0.34	204.35 ± 54.5	0.20 ± 0.03	ND	1.12 ± 0.61	ND
A_8	7.90 ± 0.36	67.90 ± 1.42	0.19 ± 0.02	ND	0.93 ± 0.12	ND
Minimum	6.37 ± 0.30	67.90 ± 1.42	0.05 ± 0.02	ND	0.93 ± 0.12	ND
Maximum	7.90 ± 0.36	493.44 ± 21.5	0.32 ± 0.03	ND	1.12 ± 0.61	ND
Mean	7.24 ± 0.33	280.67 ± 11.4	0.20 ± 0.03	ND	1.03 ± 0.37	ND

ND=Not detected.

Table 6
Comparison of heavy metals in vegetables in this study and other studies.

Country	Mean concentrations Heavy Metals with Standard deviation in (*mg* /*kg*)						
	Reference	Cu	Mn	Cd	Cr	Ni	Pb
Iran	[35]	0.85 ± 0.45	–	0.03 ± 0.03	ND	–	0.5 ± 0.31
Tanzania	[36]	55.75 ± 1.66	99.74 ± 6.7	–	ND	1.67 ± 0.26	4.82 ± 0.41
Burkina Faso	[24]	17.74	–	–	4.00	8.82	11.71
Pakistan	[37]		–	7.0 ± 0.10	–	–	5.40 ± 0.12
Qatar	[3]	13.04 ± 3.66	–	0.90 ± 0.5	6.41 ± 4.55	1.70 ± 2.39	6.36 ± 4.14
Bangladesh	[38]	9.98	134.15	0.50	2.23	0.73	0.67
Malaysia	[39]	–	–	0.05	–	–	0.10
China	[40]	–	–	0.05	0.19	–	0.07
Tanzania	[41]	10.1	151.8 ± 8	MDL	–	1.1 ± 0.09	0.9 ± 0.08
Tanzania	Present study	7.24 ± 0.33	280.67 ± 11.4	0.20 ± 0.03	ND	1.03 ± 0.37	ND

ND=Not detected.
MDL = Minimum detection limit.

Table 7
EDI, HQ and HI of heavy metals in vegetables.

Sample	Heavy metal (mg/Kg)			EDI (mg/person/day)			HQ (mg/Kg)			HI
	Cu	Mn	Cd	Cu	Mn	Cd	Cu	Mn	Cd	
A1	7.62 ± 0.19	493.44 ± 21.5	0.08 ± 0.04	2.6×10^{-4}	1.69	2.74×10^{-4}	6.5×10^{-3}	563.33	2.74	566.08
A2	7.41 ± 0.12	219.42 ± 18.8	0.190 ±0 .02	2.54×10^{-4}	0.75	6.51×10^{-4}	6.35×10^{-3}	250	6.51	256.52
A3	7.77 ± 0.7	263.57 ± 9.41	0.32 ± 0.04	2.66×10^{-4}	0.90	1.09×10^{-3}	6.65×10^{-3}	300	10.9	310.91
A4	6.99 ± 0.01	115.71 ± 4.26	0.05 ± 0.02	2.39×10^{-4}	0.39	1.71×10^{-4}	5.97×10^{-3}	130	1.71	131.72
A5	6.37 ± 0.30	378.45 ± 1.25	0.35 ± 0.03	2.18×10^{-4}	1.29	1.2×10^{-3}	5.45×10^{-3}	430	12.0	442.01
A6	7.62 ± 0.74	388.90 ± 23.	0.15 ± 0.02	2.61×10^{-4}	0.33	5.14×10^{-4}	6.52×10^{-3}	110	5.14	115.15
A7	7.65 ± 0.34	204.35 ± 54.5	0.20 ± 0.03	2.62×10^{-4}	0.70	6.06×10^{-4}	6.55×10^{-3}	233.3	6.06	239.37
A8	7.90 ± 0.36	67.90 ± 1.42	0.19 ± 0.02	2.71×10^{-4}	0.23	6.5×10^{-4}	6.77×10^{-3}	76.6	6.5	83.11
Mean	7.24 ± 0.33	280.67 ± 11.4	0.20 ± 0.03	2.53×10^{-4}	0.785	6.45×10^{-4}	5.5×10^{-3}	261.66	6.45	268.11

risk of cardiovascular diseases due to its role in promoting oxidative stress and inflammation, while Mn leads to neurological disorders such as parkinsonism and motor deficits.

Table 8 shows the carcinogenic Cancer Risk (CR) of heavy metals (Cu, Mn, and Cd) in amaranth vegetables from Don Bosco. The cancer risk values of Cu, Mn and Cd in the present study were 0.76, 410 and 2.2 ($\times 10^{-4}$) respectively. The values of Mn and Cd were higher than the 1×10^{-4} maximum threshold limit set by USEPA [24,28]. This shows that consumers have an extremely high chance of developing cancer related to Cd and Mn. According to USEPA, a cancer risk value above 1E-04 (1 in 10,000) suggests an elevated likelihood of developing cancer due to exposure to a carcinogen. This means there is one additional cancer case for every 10,000 people exposed. When the risk surpasses 1E-04, it is considered high and may raise public health concerns, as it exceeds the commonly accepted regulatory limits for acceptable risk levels. On the other hand, the cancer risk value for Cu was less than the threshold, indicating that consuming amaranth grown near Don Bosco wastewater treatment poses no danger of developing Cu-related cancer

Table 8
Estimated cancer risk for Cu, Mn and Cd in vegetable.

Element	CR ($\times 10^{-4}$)								
	A1	A2	A3	A4	A5	A6	A7	A8	Mean
Cu	0.78	0.76	0.798	0.72	0.65	0.78	0.786	0.81	0.76
Mn	8450	3750	4500	1950	6450	1650	3500	1115	31365
Cd	1.04	2.47	4.14	0.65	4.56	1.95	2.30	2.49	19.60
Mean	8451.82	3753.23	4504.94	1951.37	6455.21	1652.73	3503.086	1118.3	31390.68

4. Conclusion

This study evaluated heavy metal contamination in amaranth grown near the Don Bosco wastewater treatment area and its associated health risks. Results showed that while most heavy metal concentrations were below FAO/WHO limits, manganese levels exceeded those set by TBS. Additionally, HQ and HI values were above 1, indicating potential health risks from consuming these vegetables. Cancer risks from Cu, Cd, and Mn were also found to exceed the 1E-04 threshold set by USEPA, indicating a higher cancer risk for the local population. The study recommends regular monitoring of contamination levels and public awareness campaigns to educate people about the health risks of consuming vegetables grown in contaminated areas. It also urges stakeholders, including policymakers and local farmers, to collaborate on effective solutions to address the issue. Further research is needed to collect more samples from various vegetables, soil, and water to better evaluate contamination levels and provide clearer guidelines.

CRediT authorship contribution statement

Julius P. Mwakalukwa: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Antina Baton Mgimba:** Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Hassan Said Shaban:** Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Amos Vincent Ntarisa:** Writing – review & editing, Supervision, Project administration, Funding acquisition.

Data availability

Data will be made available on request.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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