frontiers | Frontiers in Water

TYPE Original Research
PUBLISHED 10 January 2025
DOI 10.3389/frwa.2024.1520923

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OPEN ACCESS

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RECEIVED 31 October 2024
ACCEPTED 27 December 2024
PUBLISHED 10 January 2025

CITATION
Addis T, Ketema S and Melaku A (2025) Uncontrolled urban vegetable farming poses public health risks in Ethiopia.
Front. Water 6:1520923.
doi: 10.3389/frwa.2024.1520923

Uncontrolled urban vegetable farming poses public health risks in Ethiopia

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Urban agriculture is increasingly recognized as a vital part of food security initiatives in cities worldwide, including Addis Ababa, Ethiopia. We studied trace metal levels in sediment, soil and irrigated vegetables from farms located along the Akaki River in Addis Ababa, Ethiopia's capital, and evaluated the associated public health risks. A total of 24 sediment and 36 soil samples, and edible parts of most widely cultivated vegetables were collected and analyzed for trace metals content using an Inductively Coupled Plasma Mass Spectrometry (ICP-MS). In sediment samples, the contents of As, Cr, Cu, Ni, Pb, and Zn were above the threshold effect level. Soil levels of As, Cr, Cu, Mn, and Zn levels exceeded typical values of world soils. Besides, Ni soil content at one farming site exceeded the limits set by the European Economic Community (EEC) for agricultural soils. Strikingly, the levels of As, Pb, and Zn in few vegetable samples were above the allowable limits of the World Health Organization (WHO) despite the fact that the levels of these metals in the soil samples were within the acceptable ranges for agricultural soils. Therefore, the allowable concentrations of trace elements in agricultural soils may need to be more stringent. Cadmium, a known cause for kidney, bone, and lung diseases including cancer, was the most accumulated in vegetables. Among the toxic metals, the levels of As, Cr, and Pb were higher in Swiss chard samples. The irrigation water quality and consumption of vegetables cultivated in such urban soils may also need to be restricted.

KEYWORDS

irrigation water, urban farming, health risk, risk assessment, Addis Ababa, heavy metals

1 Introduction

Trace and toxic metals occur naturally in the earth's crust just like other essential elements. However, most of these elements are extracted from the geological formation of the earth through anthropogenic processes and subsequently dispersed and being accessible to the living beings (Zovko and Romic, 2011). The extraction processes were practiced for hundreds of years without apparent negative effect. More pronounced environmental effects were started to emerge since the last quarter of 19th century, especially in areas close to mining sites and around industrial zones of big cities (van Straalen et al., 2001; Balarama Krishna et al., 2003; Imperato et al., 2003). Although, not as severe as industrialized regions, much of the factories in the developing countries are often located on the peripheries of cities along riverbanks where the population in the vicinity uses polluted river water for domestic purposes and cultivation of crops (Raschid-sally and Jayakody, 2008); and Ethiopia is no different (Alemayehu, 2001; Gebre and Van Rooijen, 2009).

As noted in various reports, the application of wastewater and sewage sludge to agricultural fields has been practiced since the second half of the 19th century in different parts of the world (Chang et al., 2001; Drechsel et al., 2010). Although, the majority of the first sewage irrigated farms appeared to be success stories, reports from various parts of the world claimed that such applications were disastrous as most of farmlands end up with accumulation of toxic elements (Kumar Sharma et al., 2007; Mapanda et al., 2005; Mireles et al., 2004; Muchuweti et al., 2006; Chang et al., 2001). It is apparent that plants can uptake toxic elements with other essential nutrients through absorption provided that these elements are available in the soils. As reported by various researchers (Itanna et al., 2008; Kumar Sharma et al., 2007; Muchuweti et al., 2006) and extensively compiled by Kabata-Pendias (2010), a wide range of elements were detected in plant tissues. Thus, it is possible to say that the use of sewage sludge and polluted river water for cultivation of vegetables and crops could be the main route of exposure to toxic elements for the human population.

To make things worse, the overall market share of vegetables produced from such lands and the total number of worldwide population supported by urban agriculture and farming is substantial (Drechsel et al., 2006; Ensink et al., 2004; Gebre and Van Rooijen, 2009; Weldesilassie et al., 2011). Specifically, in Addis Ababa such practices contribute for about 30% of vegetables (60–70% of leafy vegetables) consumed by the inhabitants of the City and its surroundings (CSA, 2007) and enjoyed support from the government as a strategical component of the poverty alleviation program (Gebremichael et al., 2014). Despite being a huge problem in the city and its vicinity, only Itanna (2002) attempted to investigate the concentrations of trace metals in soils and vegetables cultivated on farms in Addis Ababa, Ethiopia. Hence, this study aimed to determine the level of trace metals in soil, sediment, and vegetable samples taken from three different farming sites along the course of a severely polluted Little Akaki River in Addis Ababa, the capital of Ethiopia, and to evaluate its public health risks.

2 Materials and methods

2.1 Study area

Addis Ababa, the industrial, cultural, and political center of Ethiopia, is one of the largest cities in Africa. Based on the 2007 Ethiopian population and housing census (CSA, 2008) projection, it had about four million inhabitants. The United Nations estimates the population of Addis Ababa to be 5.7 million in 2024, higher than the 2007 census projection[1]. Addis Ababa City gets an average annual rainfall of 1,205 mm (Fazzini et al., 2015) and a mean temperature of 18°C (Abebe, 2017). Currently, the City Administration has managed to treat only about 30% of the wastewater generated while the rest 70% flows to the rivers without treatment. As a matter of fact, the rivers that pass through the City are used as dumping sites for both solid and liquid wastes. Though, a large portion of the City's wastewater is of domestic origin and believed to be less hazardous, toxic chemicals were also detected in the rivers (usually used for irrigation) as some factories release their wastes without treatment (Weldesilassie et al., 2011). The assessment conducted by Gebre and Van Rooijen (2009) revealed that the rivers in Addis Ababa were not safe for irrigation and can be classified as polluted rivers (Beyene et al., 2009). In this study, small scale vegetable farms situated along the course of Little Akaki River were selected as a case study. Soil, sediment, and plant samples were collected from three different vegetable farms located at Asko (upstream and industry free site), Mekanisa and Saris areas which were using the little Akaki River for irrigation (Figure 1).

2.2 Sample collection

From the three vegetable farming sites, we collected 36 soil samples; 12 samples from each farm (Figure 1). Sampling was conducted during the dry season where irrigation intensity and associated heavy metal exposure health risk is expected to be higher. During collection of these samples, general soil sampling procedures were employed (US-EPA, 1989; Zhang, 2007). These samples were collected from open spaces between lines of vegetables planted to minimize errors due to uptake of chemicals by plants. The first thing we did during collection was removing unwanted materials like log, leaves, and grasses from the soil surface, and then taking samples from the top (0–10 cm) soil with a Teflon spoon and transferred it into polyethylene bottles with minimal headspace for storage and transportation. Then, the bottles were properly labelled and stored in a refrigerator. During the sampling process, sample collectors wore natural latex rubber gloves to avoid unnecessary contamination.

Regarding sediments, benthic sediment samples were collected form Little Akaki River bordering the three farming sites. Two locations along the river at each farming site were selected to increase the number of samples and thereby to minimize bias. At each selected location, sediment samples were collected at four points across the river width at a place where the river flow is unruffled to minimize disturbance and in turn to avoid loss of fine materials. By doing so, eight samples from each site and a total of 24 sediment samples were collected. During sampling, Teflon spoon was used to take sediment samples from the river bed and to transfer into polyethylene bottles with minimal headspace. Sampling bottles were properly labelled for identification, transported, and stored just like soil samples.

In the same way, the most widely cultivated vegetables in Addis Ababa Swiss chards (*Beta vulgaris* L. var. *cicla*), collard greens (*Brassica oleracea var. viridis*) and carrot (*Daucus carota*) were collected. Only the healthy, matured/fully grown, and edible parts of leafy vegetables (Swiss chards and collard greens) and root vegetable (carrot) were considered. A total of 45 vegetable samples (five from each vegetable at each site) were collected. During the sampling process, the vegetable sample collectors wore natural latex rubber gloves to avoid contamination and transferred immediately into low-density polyethylene (LDPE) plastic bags and stored under refrigerated conditions.

2.3 Pre-treatment and preparation of samples

The first step of the laboratory analysis procedure was pre-treatment of samples. The sample pre-treatment and preparation activities were removal of stones (gravels) and other debris from soil and sediment samples, washing vegetable samples with distilled water to clean up the dust/soil particles and other external contaminants,

1 https://worldpopulationreview.com/cities/ethiopia/addis-ababa

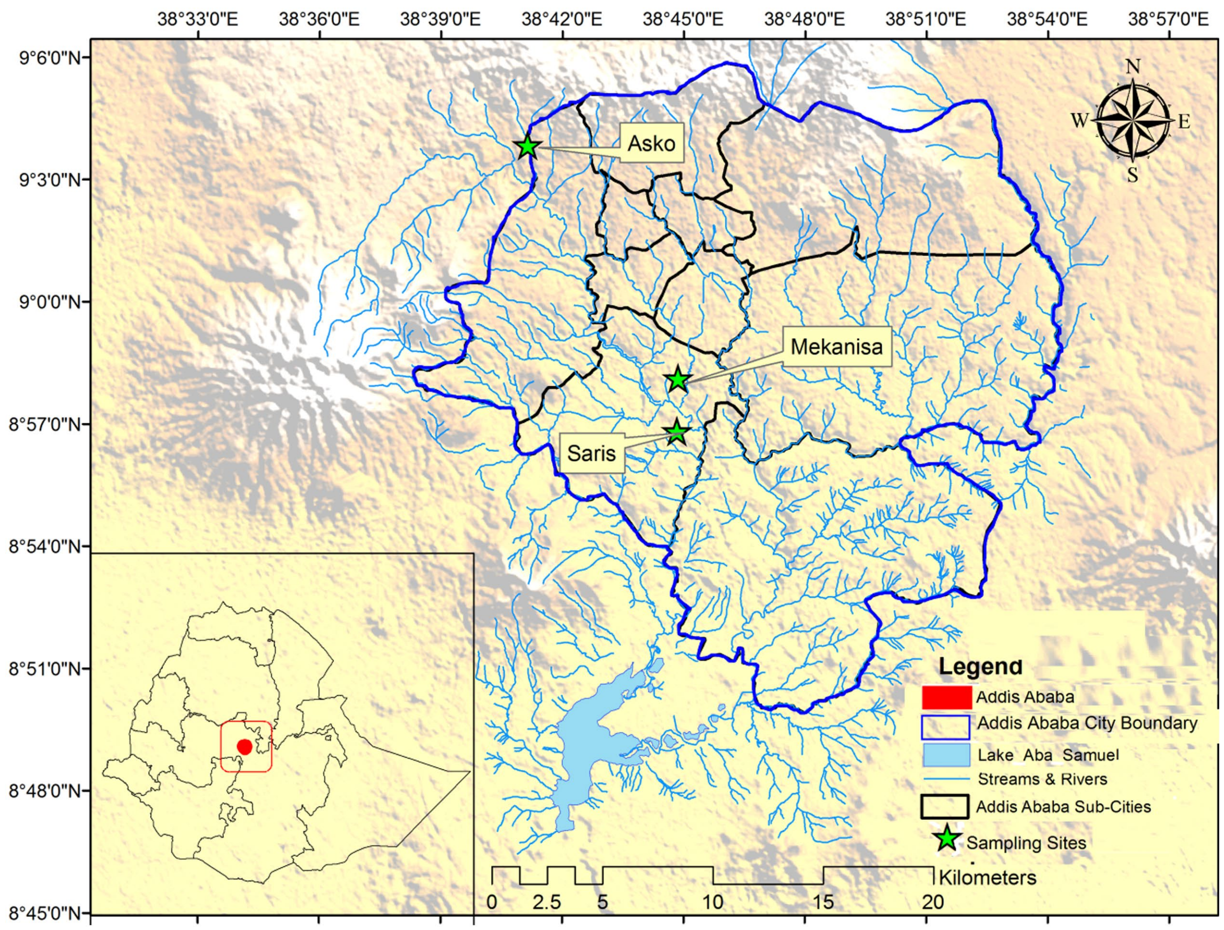

FIGURE 1
Map of the sampling sites in Addis Ababa, Ethiopia.

freeze-drying or lyophilisation (with LYOVAC GT2 freeze-dryer), and milling and homogenizing (with a German made, Type 0.2.102, Fritsch Puloerisette milling machine). Finally, we sieved the powder through 1-mm nylon sieve and kept with polyethylene bottles and prepared for digestion (Zhang, 2007).

2.4 Digestion of samples

All soil, sediment and plant samples were digested with CEM Mars 5 microwave digester (which is a pressure and temperature controlled equipment) using aqua regia (HCl: HNO_3, 3:1 v/v) for soil and sediment samples, and HNO_3 and H_2O_2 for plant samples (US-EPA, 2001). The first step in the digestion process was the cleaning step to make sure the vessels were free from any contaminant that can alter the result of the analysis. The cleaning process was as follows: the HP 500 digestion vessels first cleaned with 2% Extran; rinsed with Milli-Q® water; dried under laminar flow hood; filled with 10 mL HNO_3; and then the vessels were put in the microwave digester for pre-analysis cleaning. For the cleaning step the vessels were set at the temperature of 150°C and pressure of 150 psi for a total of 20 min (10 min ramp and another 10 min hold time). After the vessels got cooled, the acid in the vessels was emptied to the waste acid container, and the vessels rinsed with Milli-Q® water and again dried under a laminar flow hood. Then, the digestion step began by adding around 0.2 g of soil and sediment samples to the vessels. Again, 6 mL HCl and 2 mL HNO_3 were added to vessels. The rest of the procedure was the same as the cleaning step, except here the temperature was set at 180°C and pressure at 200 psi for a total of 30 min (15 ramp +15 hold time). The pressure and temperature in the vessels were monitored by a vessel in position1 that had the highest weight of soil or sediment samples in each run of digestions. After digestion, around 40 mL Milli-Q® water was added to the vessels and transferred to LDPE bottles and became ready for analysis using ICP-MS. The procedure used for plant samples was the same as that of soil and sediments. However, for plant samples 5 mL HNO_3 and 1 mL H_2O_2 were added to the vessels (Pradit et al., 2010; US-EPA, 2001).

2.5 Analysis of trace metals using ICP-MS

The whole samples (soil, sediment, and plant) were diluted ten times and then analyzed using a high resolution ICP-MS machine (ThermoFinnigan ELEMENT2). Prior to sample analysis, the ICP-MS machine was calibrated using multi-element standard solution (Trace Metal 1 ICM-411H which contains 5% Nitric Acid).

2.6 Accuracy and precision of laboratory procedures

The quality of analytical methods used in this study was asserted by analyzing blank samples and certified reference materials together with samples collected from the study areas in every batch of laboratory procedure. In addition to the blanks (twice distilled water), a certified reference material, LGC 6139 (from the Laboratory of the Government Chemist, UK) was used during the analysis of soil and sediment samples and a certified tissue reference material, TORT-2 for the analysis of plant samples (NRC, 1994). After completion of the laboratory works and analysis using an ICP-MS, the results of certified reference materials obtained were compared with the certified values. To check the precision of laboratory results four replicates were taken for all soil and sediment samples and mean ± 2SD (95% confidence limit) and relative standard deviation were calculated for each metal. Relative standard deviations (RSD) were generally less than 10%, which revealed the consistency of the procedure (Table 1). The analysis of certified reference material (LGC 6139) proved that the recoveries of As, Cd, Cr, Cu, Fe, Mn, Ni, Pb, and Zn were between 90 and 110% which is acceptable as it lay within the 95% confidence limit. Similarly, the recovery rates of trace elements for TORT-2 (Lobster-Hepatopancreas.homard) were considered acceptable.

2.7 Data analysis

Data were analyzed using MINITAB®17 statistical software package. The average concentrations (mg/kg), standard deviations (mg/kg), and relative standard deviation (%) of each metal in soil, sediment, and vegetable samples from all the three sites are presented in tables. A relative standard deviation below 20% was considered as a reasonably good precision (McFarren et al., 1970). The average result of each metal at each site (for soil and vegetable samples) was also compared with world average concentration and international acceptable standards. The mean plant to soil transfer factors of metals

TABLE 1 Average concentration of trace elements in soils at three different vegetable farms in Addis Ababa (mg/kg dry weight).

Metals	Sampling sites	Concentration, mean ± 2SD (RSD in %)	World soil average*	MAC**	European economic community limits***
As	Asko	10 ± 1.24 (6.3)	6.83	15–20	
	Mekanisa	4 ± 0.61 (7.7)			
	Saris	5 ± 0.63 (6.5)			
Cd	Asko	0.22 ± 0.02 (3.9)	0.41	1–5	1–3
	Mekanisa	0.24 ± 0.04 (7.5)			
	Saris	0.26 ± 0.04 (7.1)			
Cr	Asko	104 ± 8.6 (4.2)	59.5	50–200	50–150
	Mekanisa	75 ± 8.2 (5.6)			
	Saris	53 ± 5.9 (5.7)			
Cu	Asko	45 ± 6.4 (7.2)	38.9	60–150	50–140
	Mekanisa	25 ± 4.2 (8.5)			
	Saris	21 ± 3.3 (8.1)			
Fe	Asko	24,677 ± 207 (4.3)			
	Mekanisa	17,352 ± 128 (3.8)			
	Saris	14,110 ± 117 (4.2)			
Mn	Asko	1,500 ± 48 (5)	488		
	Mekanisa	1767 ± 176 (5.1)			
	Saris	3,119 ± 732 (6.2)			
Ni	Asko	94 ± 4.1 (2.2)	29	20–60	30–75
	Mekanisa	50 ± 6.9 (7.0)			
	Saris	44 ± 5.5 (6.4)			
Pb	Asko	23 ± 3.1 (6.9)	27	20–300	50–300
	Mekanisa	24 ± 3.5 (7.5)			
	Saris	26 ± 2.8 (5.4)			
Zn	Asko	173 ± 8.1 (2.3)	70	100–300	150–300
	Mekanisa	172 ± 8.6 (2.6)			
	Saris	191 ± 11 (2.9)			

* World-soil average compiled by Kabata-Pendias (2010). ** Ranges of maximum allowable concentrations (MAC) for trace metals in agricultural soils as compiled by Kabata-Pendias and Mukherjee (2007). *** The European Economic Community (Directive 86/278/EEC) limits (EEC, 1986).

were calculated by taking the ratio of the concentration of metal in plant samples to concentration of metal in soil samples.

3 Results

In this study a total of 36 soil samples (12 samples from each sampling site) and 24 sediment samples (8 samples from each sampling site) were collected from the three vegetable farms. As can be seen in Table 1, 2, the level of nine elements contained in the soil and sediment samples were quantified and presented as mean ± 2SD (mg/kg of dry weight).

The level of soil As, Cr, Cu, Fe and Ni were higher at Asko area compared to Mekanisa and Saris areas (Table 1). On the other hand, the values of Mn, Pb, and Zn were higher in downstream of Little Akaki River. And yet, it is possible to present metals in the order of their abundance in soil samples of all three sites (from high to low concentration) as: Fe > Mn > Zn > Cr > Ni > Cu > Pb > As > Cd (Table 1).

The sediment Cr, Cu, Fe, and Mn level were higher at Mekanisa area than the Asko and Saris (Table 2). The other trace elements like Ni, Pb, and Zn were found to be higher in Saris areas. Generally, the order of abundance of analyzed elements in sediment samples from high to low concentration was Fe > Mn > Zn > Cr > Ni > Pb > Cu > As > Cd (Table 2).

As shown in the Table 3, the levels of trace elements were quite varied among vegetable types even within the same site. For instance, Cd and Ni were found to be higher in the carrot samples. Whereas, the levels of As, Cr, Cu, Fe, Mn, Pb, and Zn were higher in Swiss chard samples. In general, in terms of abundance the top 5 trace metals in vegetable samples were Fe, Mn, Zn, Cu, and Ni.

When we look into the soil-to-plant transfer of trace elements, Cd was found to be the very highly absorbed element by vegetables (Table 4). Then, Zn and Cu were also the next elements with high plant/soil transfer factor, respectively. On the other hand, Cr and Fe can be considered as elements of low plant/soil transfer factor (Table 4).

TABLE 2 Sediment average heavy metals concentration along Little Akaki River close to vegetable farms in Addis Ababa (mg/kg dry weight).

Metals	Sampling sites	Mean ± 2SD	Threshold effect level *
As	Asko	7.3 ± 0.5	5.9
	Mekanisa	7.1 ± 0.5	
	Saris	7.2 ± 0.5	
Cd	Asko	0.23 ± 0.03	0.59
	Mekanisa	0.27 ± 0.03	
	Saris	0.27 ± 0.04	
Cr	Asko	94 ± 7	37.3
	Mekanisa	97 ± 6	
	Saris	79 ± 5	
Cu	Asko	26 ± 3.3	35.7
	Mekanisa	37 ± 3	
	Saris	34 ± 3	
Fe	Asko	5.5E+4	–
	Mekanisa	7E+4	
	Saris	6E+4	
Mn	Asko	2E+3	–
	Mekanisa	4E+3	
	Saris	3.6E+3	
Ni	Asko	60 ± 9	18
	Mekanisa	73 ± 9	
	Saris	75 ± 8	
Pb	Asko	36 ± 3	35
	Mekanisa	35 ± 3	
	Saris	59 ± 4	
Zn	Asko	128 ± 5	123
	Mekanisa	149 ± 10	
	Saris	167 ± 11	

*Threshold effect level represents the concentration below which adverse effects are expected to occur only rarely (MacDonald et al., 2000).

4 Discussion

4.1 Concentration of heavy metals in soil samples

The mean concentrations of As, Cd, and Cu in the soils of the three vegetable farming sites (Table 1) were found below the maximum allowable concentrations (MAC) for agricultural soils (Kabata-Pendias and Mukherjee, 2007). This finding was in agreement with the study conducted in south Addis Ababa (Itanna, 2002). Similarly, the mean values of Cd, Cu, and Pb were below the limits set by the European Economic Council (EEC, 1986). However, the content of Ni in Asko site (north Addis Ababa, a site where there is no industrial activity) was a bit higher than the MAC for agricultural soils, world soil average, and EEC limit (Table 1). Alemayehu (2001) also reported similar higher soil Ni concentration, 93.0 mg/kg, around Asko in Burayu area, north Addis Ababa. This higher concentration of Ni in Asko site could be due to the geological formation from which the soil derived (Giramy and Assefa, 1989). In addition to Ni, the concentrations of As, Cr, Fe, and Cu were also relatively higher in Asko (situated 2,572 meters above sea level at the border of the city where there are no industries) than Mekanisa and Saris which are located in industrial zones at the middle of the city in the downstream with an elevation of 344 and 373 meters lower than Asko, respectively. This finding is consistent with the results of Demie (2015) which compared heavy metal distribution in soils of the north (Burayu) and south (Akaki) Addis Ababa. As already mentioned, this might be because of higher contribution of the geological formations than industrial and municipality sources in the Asko area, north Addis Ababa compared with Mekanisa and Saris, south Addis Ababa.

On the other hand, soil samples in Saris site contained slightly higher amounts of Cd, Pb, Mn, and Zn than the other two sites. Itanna (2002) also reported similar findings for Cd and Pb. This could be explained by the higher contribution of pollution as this area is a

TABLE 3 Mean concentration of heavy metals in vegetables collected from three different sites in Addis Ababa (mg/kg dry weight).

Metals	Vegetable type	Range of values in vegetables from all sites	Typical and guideline values (mg/kg dry weight)
As	Carrot	0.02–0.04	0.020–0.250**, 0.1***
	Collard greens	0.03–0.25	
	Swiss chard	0.05–0.21	
Cd	Carrot	0.08–0.25	0.2***
	Collard greens	0.04–0.05	
	Swiss chard	0.06–0.1	
Cr	Carrot	0.10–0.18	2.3*
	Collard greens	0.13–1.7	
	Swiss chard	0.31–1.0	
Cu	Carrot	3.2–11	40*, 3.3–8.1**
	Collard greens	2.6–6.2	
	Swiss chard	5.3–7.5	
Fe	Carrot	68–128	16–130**
	Collard greens	145–781	
	Swiss chard	373–534	
Mn	Carrot	41–150	36–113**
	Collard greens	40–213	
	Swiss chard	53–165	
Ni	Carrot	3.6–4.8	0.26–3.3**
	Collard greens	1.1–2.1	
	Swiss chard	1.6–1.9	
Pb	Carrot	0.08–0.17	0.3***
	Collard greens	0.19–0.84	
	Swiss chard	0.49–6.0	
Zn	Carrot	19–32	60*, 10–44**
	Collard greens	18–32	
	Swiss chard	73–101	

* FAO/WHO (2001) guidelines. ** Range of typical values in vegetables (Kabata-Pendias and Pendias, 2001). *** FAO/WHO (2011) guidelines.

TABLE 4 The average plant/soil transfer factor of metals.

Metal	Average soil-to-plant TF in this study	Generalized values given by Kabata-Pendias (2010)
As	1.8E-2	1E-2
Cd	4.4E-1*	1E+1
Cr	5.4E-3	1E-2 to 1E-1
Cu	1.3E-1	1E-1
Fe	4.1E-3	1E-3
Mn	3.2E-2	1E-2
Ni	3.4E-2	1E-2
Pb	1.5E-2	1E-1
Zn	2.4E-1	

* All plant samples had a soil–plant TF of close to 1E-1, except for carrots (1.034).

site where industrial activity, sewage, solid waste dumping, automobile exhaust, auto-mechanical works and the like are so intensive. A study conducted in Shashemane City in southern Ethiopia, also revealed a strong correlation between the level of heavy metal contamination of soil and the presence of garages and auto-mechanical workshops (Demie, 2015), and might also be the case in Addis Ababa.

In fact, a number of studies from different corners of the world reported that the level of trace metals in agricultural soils is building up. An assessment conducted in Addis Ababa reported that the concentrations of Cr and Ni in soil and vegetable samples from two urban farms were higher than expected (Itanna et al., 2008). Another study from Mexico City as well reported potentially hazardous concentrations of metals like Cr, Co, and Cu in agricultural soils (Mireles et al., 2004). Similarly, a study done in Harare, Zimbabwe by Mapanda et al. (2005) stated that the concentration of trace elements in agricultural soils can be reached higher than the recommended limit (EEC, 1986) within 10 years of irrigation, particularly for Cd, Cu, and Zn depending on the severity of pollution of the water.

Despite determining natural background concentrations of trace metals in soils and compiling regional averages is debatable due to spatial variations of geological formations and contributions of anthropogenic causes since ancient times (Hamon et al., 2004). Therefore, this study used the quantities summarized by Kabata-Pendias (2010) just for the sake of comparison. The concentration of Mn was found 3, 4, and 6 times higher than the average values in world soils at Asko, Mekanisa, and Saris sites, respectively. Likewise, the mean concentrations of Cr in soils at Asko were twice the average values of world soils. The concentration of Ni was also 3 and 2 times higher than the average value in world soils at Asko and Mekanisa, respectively. The concentrations of Zn from all sampling sites were found to be 2.5 times higher than the average value in world soils. Generally, getting higher values of trace metals in the soils of this study area compared with the average values in world soils could not be a surprise as the soil formation of our study area is different and as it is derived from hydrothermally altered volcanic rocks weathering (Giramy and Assefa, 1989). Though Hamon et al. (2004) suggested the possibility of predicting the expected values of trace elements in top soils from the concentrations of semi-conservative elements, such as Fe, Al, and Mn, it is difficult to do such relationships using small data sets gathered in this assessment.

4.2 Concentration of heavy metals in sediment samples

Similarly, the results of sediment samples (Table 2) collected along the course of Little Akaki River (adjacent to each vegetable farming site) showed that the concentrations of As, Cr, Ni, and Zn (at all Sites), Cu (at Mekanisa), and Pb (at Asko and Saris) were found higher than the threshold effect level (a level that represents the concentration below which adverse effects are expected to occur only rarely) (MacDonald et al., 2000). The concentrations of Cr in sediments at Asko, Mekanisa, and Saris were 94, 97, and 79 mg/kg, respectively, which were much higher than the threshold effect levels of 37.3 mg/kg dry weight. In addition to this, the concentrations of Ni were also 60, 73, and 75 mg/kg dry weight at

Asko, Mekanisa, and Saris, respectively, as opposed to the threshold effect level of 18 mg/kg for river sediments. The levels of As and Zn were also a little bit higher than the threshold effect level at all three sites. Though unsaturated sediments could serve as a sink for trace metals in water, metals could also be released into the water column and subsequently pollute irrigated soils when the sediment surpass its adsorption and ion-exchanging capacity (Miranda et al., 2021). On the other hand, the concentration of each element in soil and sediment samples at each site showed no clear pattern. This might be due to the transport of metals through soil erosion from the topographically higher northern part of the city (Asko area) with a relatively higher concentration of most of the trace metal in the soil to the topographically lower southern part of the city (Mekanisa and Saris area) as well as gradual intensification of industrial and municipal waste pollution in the downstream (Alemayehu, 2006).

4.3 Concentrations of heavy metals in vegetables samples

As presented in Table 3, the levels of trace elements in vegetable samples were quite varied among vegetable types even within the same site. This difference might be due to the physiological differences between vegetables. Metals like Fe, Mn, Zn, Cu, and Ni were the most abundant elements in vegetable samples. The average levels of Fe, especially in the leafy vegetables – Swiss chard and collard greens – were ranged from 145 to 781 mg/kg (dry weight) at all three sites which were significantly higher than the typical range of values, i.e., 16–130 mg/kg of dry weight (Kabata-Pendias and Pendias, 2001). Similarly, carrot samples from Asko, collard greens from Saris, and Swiss chard samples from both Mekanisa and Saris contained higher Mn concentrations than the typical values. Likewise, the values of Ni in carrot samples were in the range between 3.6 mg/kg and 4.8 mg/kg of dry weight at all three sites contrary to the range of typical values which is between 0.26 and 3.3 mg/kg (Kabata-Pendias and Pendias, 2001). The possible explanation for the higher trace metals concentration in vegetables in this study area than the world typical value is due to pollution and geological formations (Giramy and Assefa, 1989). The mean levels of Zn in Swiss chard were between 73 and 101 mg/kg dry weight from all three sites which were well above 60 (mg/kg dry weight) recommended by FAO/WHO (2001).

In addition, the mean values of Pb in Swiss chard and collard greens samples were also 0.49 mg/kg and 0.84 mg/kg, respectively, that exceeded 0.3 mg/kg dry weight, the recommended guideline value of FAO/WHO (2011) in all sites, except collard greens at Asko containing 0.19 mg/kg dry weight. Concentrations higher than the typical values in vegetables were also registered for Cu in carrot at Mekanisa area (FAO/WHO, 2011). Among the most toxic elements, the concentration of As in Swiss chard samples at Asko and Saris sites, and collard greens at Mekanisa and Saris sites were higher than guideline values recommended by FAO/WHO (2011). Such differences might be due to combined effects of different soil properties such as pH, soil organic carbon and ion exchange capacity which in turn influence the bioavailability of metals (Alloway, 1994). Nevertheless, the levels were not out of the typical range values in vegetables compiled by Kabata-Pendias and Pendias (2001). Normally, arsenic does not tend to accumulate in vegetables grown in unpolluted environments. However, its uptake by vegetables could significantly be increased for plants grown in contaminated soils, which would result in the accumulation of arsenic inside plant tissues (Khan et al., 2009).

Swiss chard was the most accumulator of heavy metals among the vegetables studied. A previous study also identified Swiss chard as the highest accumulator of heavy metals, including arsenic (Cooper et al., 2020). Furthermore, Swiss chard was evaluated for its phytoremediation potential in heavy metal-contaminated soil in eastern Cameroon. The results of that study indicated that *Beta vulgaris* L. (Swiss chard) is a promising phytoremediation plant for restoring soil health and supporting sustainable agriculture (Arthur et al., 2022).

It is already an established fact that concentrations of trace elements in plants are often positively correlated with the abundance of these elements in soils (Kabata-Pendias and Mukherjee, 2007). In this assessment, it was found that the level of As, Pb, and Zn in the soil samples were within the acceptable limits for agricultural soils. However, the content of these metals in the vegetable samples were found above the guideline values set by FAO/WHO (2011). More toxic metals such as Cd, As, Pb and Cr could have both acute and chronic health effects at lower concentration. The health risk is expected to be more severe for vegetable farmers/families, pregnant women, children (Cooper et al., 2020). Farmers and their families might consume more vegetables that expose for higher heavy metal intake thereby more health risks. In such cases, it can be argued that setting trace element standards for agricultural soils may not ensure safe farming. Since soil–plant transfer of elements depend on a number of factors, it might be important to set regional standards by considering soil types, climate, and types of plants.

4.4 Soil-to-plant transfer factor (TF) of heavy metals

Regarding soil-to-plant transfer of heavy metals, the result obtained in this study (Table 4) exhibited similar trends in all types of vegetables collected for this particular assessment, with the exception of Cd. The average soil–plant TF of Cd was found to be 0.44. But, for carrots the value was around 1.034. The TF for carrots was in agreement with the typical TF of Cd (Kabata-Pendias and Pendias, 2001); that is 10. The level of Cd in carrot was also supported by Kabata-Pendias (2010) as some plants tend to accumulate extremely high levels of specific trace elements (Iskandar, 2000; Manahan, 2001). Even differences could be observed among vegetable types grown at the same site (Fytianos et al., 2001). Generally, the TF of metals other than Cd can be summarized as follows: Cu and Zn in the range of 1E-1; As, Mn, Pb, and Ni in the range of 1E-2; Cr and Fe in the range of 1E-3. The soil-to-plant TF of metals like Cd, Zn and Cu was found within the range of 1 to 10% of the metal content in the soil which was the highest. However, the transfer factor of Cr and Fe was found to be very low (between 0.1 and 1%).

From this and other studies, we understood that plants uptake metals at quite different rates. The concentration of trace elements in plants seems to depend on a number of factors like absorption and transport within the plant, concentration and form of occurrence in the soils, toxicity of the metals to plants, enzymatic processes, genetic differences, stages of maturity of plant, and seasonal influences (Alloway, 1994; Kabata-Pendias, 2010; Luo and Rimmer, 1995). And yet, it may be possible to envisage the chemical constituents in plants from the composition of agricultural soils and vice versa (Voutsa et al., 1996). Typically, the concentrations of metals in plants are lower than those respective soils wherein the plants cultivated. This indicates that only a fraction of metals in the soil is transferred to plants (Kabata-Pendias and Pendias, 2001). Hence, soil-to-plant TF is a suitable way of quantifying the relative differences of bioavailability of metals and thereby the public health risks through consumption. According to Kabata-Pendias (2010), the soil-to-plant transfer of trace elements follows some general trends which can be expressed as plant/soil TF. Kabata-Pendias (2010) revealed that Cd has the highest plant/soil TF of 10 followed by Co, Cu, Hg, Mo, Pb, and Zn with a value of 1E-1. Other elements which include As, Mn, Ni, Sb, Fe, V, and Ti are known to have the lowest TF which lies in the range between 1E-3 and 1E-2.

5 Conclusion

The concentrations of some of the metals in soil, sediment and vegetable samples collected along Little Akaki River in Addis Ababa were found substantially high. The concentrations of As, Cr, Cu, Mn, and Zn in most soil samples were higher than the typical values of world soils. Thus, it is safe to say that irrigation of farmlands with heavy metals polluted rivers might lead to the build-up of toxic metals in agricultural soils. In sediment samples, the concentrations of As, Cr, Cu, Ni, Pb, and Zn in sediment samples were above the threshold effect level – the level that requires immediate ameliorative measures. In some vegetables samples, the level of As, Pb and Zn were much higher than the allowable limits recommended by the FAO/WHO. Cadmium was the most accumulated heavy metal in vegetables. Swiss chard was the most accumulators for toxic metals mainly As, Cr, and Pb. This study revealed that complying soil As, Pb, and Zn acceptable limits for agricultural soils did not guarantee meeting FAO/WHO guideline value in vegetable samples. Hence, it is possible to say that setting trace element standards for agricultural soils might not be enough to ensure safe farming.

To curb heavy metals associated health risks with irrigated vegetables, national/international irrigation water quality and vegetables heavy metal standards should be enforced through regular water quality monitoring. The most feasible mitigation measures include identifying and controlling pollution sources, allocating buffer zones, applying natural wastewater purification methods such as wetlands, and soil phytoremediation for grossly contaminated farms. Besides, consumption of heavy metals contaminated vegetables should be reduced or if possible, avoided to minimize human health risks. Furthermore, public education including for farmers and women about health risks associate with eating heavy metal contaminated vegetables should be among the priority interventions.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

TA: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. SK: Conceptualization, Data curation, Formal analysis, Validation, Visualization, Writing – original draft, Writing – review & editing. AM: Conceptualization, Data curation, Formal analysis, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

Funding

The author(s) declare that no financial support was received for the research, authorship, and/or publication of this article.

Acknowledgments

The authors acknowledge Addis Ababa University for logistics support.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The authors declare that no Generative AI was used in the creation of this manuscript.

Publisher's note

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