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Heavy metals in vegetables grown in the vicinity of Hawassa industrial zone, Ethiopia: Estimation of possible human health risks

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Abstract

Concentration of heavy metals (Cr, Ni, Cu, Zn, As, Cd, Pb and Hg) in cabbages and potatoes were determined and the potential human health risks due to the consumption of the vegetables have been estimated. Mean concentrations of Zn (134.0 + 5.62 mg/kg), As (0.12 + 0.01 mg/kg) and Cd (0.32 + 0.01 mg/kg) in cabbages from Biological Lagoon area as well as Zn (103.0 + 8.34 mg/kg), As (0.14 + 0.01 mg/kg) and Cd (0.31 + 0.01 mg/kg) in cabbages from Boicha stream area were above the safety limits of FAO/WHO. Likewise, mean concentrations of As (0.24 + 0.03 mg/kg) in potatoes from Biological Lagoon area as well as As (0.35 + 0.07 mg/kg) and Pb (0.50 + 0.04 mg/kg) from Boicha stream area were also above safety limits. Assessment of Target Hazard Quotients (THQ) indicated no human health concern from consumption of both cabbages and potatoes grown in the areas except as through consumption of potatoes from Biological Lagoon and Boicha stream areas. However, effects of all the metals put together may affect human health as revealed by the high Hazard Index (HI > 1). Assessment of Target Cancer Risk (TCR) revealed human health concern from consumption of these vegetables for As and Cd. Overall, vegetables consumption from industrial zone is more risky than consuming vegetables from the Reference site indicating effluents from industries to be a potential sources of the heavy metals.

Keywords: *Health risk, Heavy metals, Vegetable consumption*

1. Introduction

Irrigation of agricultural land with wastewater is a common practice in industrial areas of many parts of the world that leads to accumulation of heavy metals in soils (Fawen *et al.*, 2020). Polluted irrigation water may not only result in soil contamination, but also affect food quality and safety (Fitsum and Abraha, 2018). Uptake of

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heavy metals from such contaminated soils in edible parts of the vegetables might reach quantities high enough to cause several clinical and physiological problems to human beings when consumed (Kashif *et al*., 2009). Heavy metals are non-biodegradable with long biological half-lives and potential to accumulate in different parts of the body and hence very harmful (Maseki *et al.,* 2017). In industrial areas of many underdeveloped countries, irrigation of agricultural land with wastewater that results in accumulation of heavy metals in soils and vegetables is a common practice (Fawen *et al.,* 2020). Most of the industries in Ethiopia discharge untreated or partially treated wastes into the nearby streams and rivers or farmlands (Zinabu and Zerihun, 2002). Likewise, the absence of proper waste disposal systems and scarcity of water predispose Ethiopian smallhold farmers to use industrial discharges for irrigation- a potential transfer of heavy metals to the crops.

A number of factories in Hawassa (Textile, Moha Soft Drink and Brewery-BGI) have been discharging effluents into streams in the neighborhood of the factories, which are used for irrigation to grow vegetables like Abyssinian cabbages (*Brassica carinata*) and potatoes (*Solanum tuberosum*), the most common vegetables that are grown during the dry season in the study area. Like in many Ethiopian urban areas, vegetables are widely consumed in Hawassa city (Lijalem, 2016). Although there are some studies on the concentrations of heavy metals in Ethiopian vegetables (Hintsa *et al*., 2016; Temesgen and Seyoum, 2017; and Fitsum and Abraha, 2018), potential health risks from human consumption of vegetables is, generally, not reported. Fast growing industry and human settlement as well as irrigation of vegetable farms for sale in Hawassa city (especially in the industrial zone), make it urgent to determine the health risk of eating vegetables. So far the levels of toxic metals in the industrial zone and assessment of human health risks due to the consumption of vegetables are not known. The aim of the present study was, therefore, to determine the concentrations of heavy metals in cabbages and potatoes (the most widely consumed vegetables in the study area) grown on wastewater irrigated soils, and to estimate the potential human health risks related to heavy metals ingested through these vegetables.

2. Materials and methods

2.1. Description of the study area

Hawassa industrial zone is located 275 km South of Addis Ababa (the capital city of Ethiopia) at an altitude of 1697-1742 m. a.s.l. at 7°06' N and 38°48' E. It has sub-humid climate and has bimodal rainfall distribution. The main rainy season generally extends from June to October with a maximum mean annual rainfall of about 1150 mm. The mean annual temperature of this area is 19.5 °C, with March and April having the highest (31.5 °C) and November and December having the lowest (15 °C) temperature (Gezahegn, 2017). Hawassa industrial zone has a cluster of factories such as Textile, Moha-Soft Drink and Brewery-BGI Factory. These factories discharge untreated and/or partially-treated wastewaters (Zinabu and Zerihun, 2002) into the nearby streams called Boga and Boicha that pass through the neighboring residential area before entering into “Tikur Wuha”, the only perennial river that flows into Lake Hawassa (Figure 1). The residents of the downstream areas of the Boicha stream use the effluent laden water for irrigation, washing and watering their cattle, especially during the dry season.

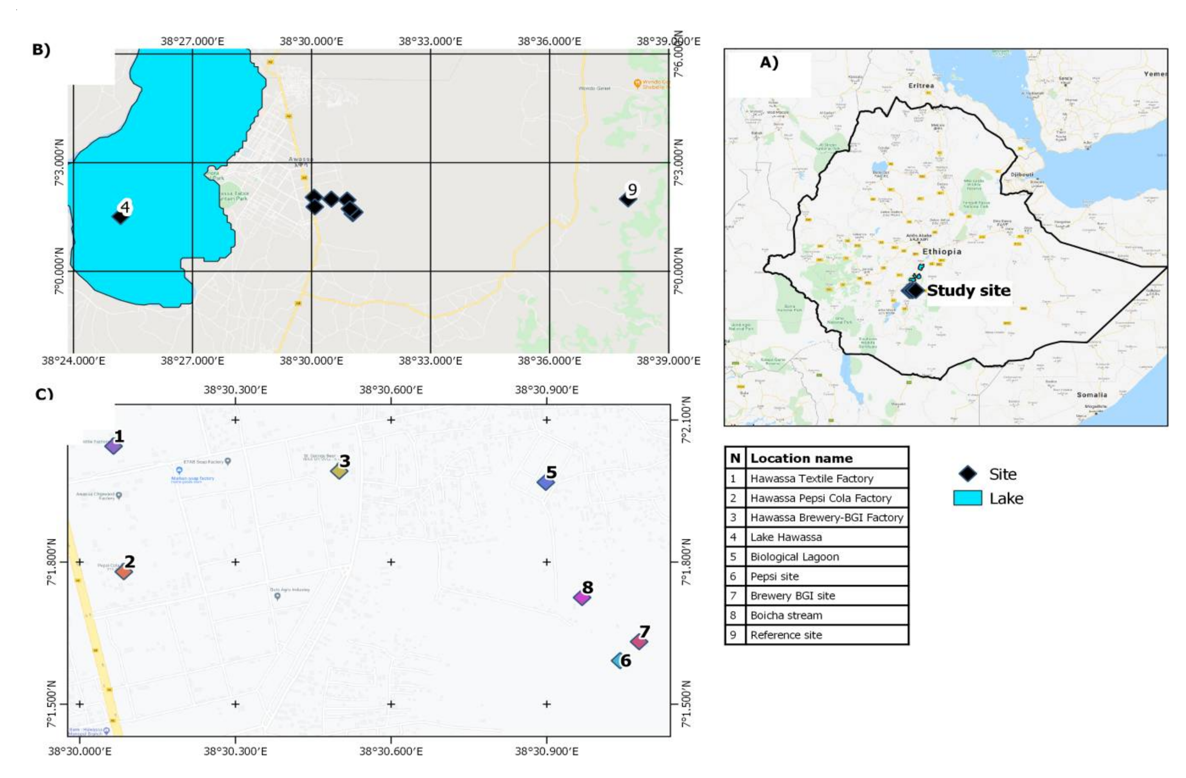
2.2. Sampling site selection

The sampling site was divided into three parts based on the effluent discharge routes. Sampling Site One was Biological Lagoon area that receives effluents from the textile factory after settling for a short time in the Biological Lagoon on its way downstream to Boicha stream. Sampling Site Two was Boicha stream area that is the area where effluents from textile, Moha Soft Drink and Brewery-BGI factories meet downstream and merge into Tikur Wuha River. Sampling Site Three was the Reference site, located 10 km from the industrial zone towards the north around Wondo Genet. It was selected as a Reference site or a benchmark, to compare changes taking place in the industrial zone. This site is assumed to be free from urban and industrial effluents and that there is relatively little influence from human activities (Figure 1).

2.3. Sample collection, preparation and analysis

2.3.1. Sample collection

Abyssinian cabbage (*Brassica carinata*) and potato (*Solanum tuberosum*) samples were collected randomly from the farmers land near the discharge routes of the effluent from the textile factory (Biological Lagoon area), from the farmers’ plot near Boicha stream routes (Boicha stream area) and from the farmers’ plot outside the industrial area (Reference site) (Figure 1). Ten heads of cabbage and 10 tubers of potatoes, at their consumption stages, were randomly collected from each sampling site. The leafy part (edible part) of the cabbage was picked by



N	Location name
1	Hawassa Textile Factory
2	Hawassa Pepsi Cola Factory
3	Hawassa Brewery-BGI Factory
4	Lake Hawassa
5	Biological Lagoon
6	Pepsi site
7	Brewery BGI site
8	Boicha stream
9	Reference site

Figure 1: Map of Hawassa industrial zone with sampling sites

hand. All the cabbage and potato samples were washed with tap water and then distilled water, and air dried for 5 h before they were separately sealed in polyethylene bags. The sealed samples were kept in the refrigerator at 4 ºC for three days before transporting to Norway. The samples were air transported, in icebox filled with ice, to the Soil and Water Laboratory of the Norwegian University of Life Sciences (NMBU) for analyses of heavy metal concentrations.

2.3.2. Sample preparation and analyses for heavy metals

Each cabbage and potato sample was washed with ultrapure water three times. After the water was evaporated, the cabbage and potato samples were freeze dried at app.–50 ºC at 180 m Torr. The samples were mechanically crushed into powder using pestles and mortal. Powdered samples (0.25 g) were weighed in Teflon vials and 2 ml deionized water and 5 ml ultrapure HNO_3 were added to the vials before they were digested in an UltraClave (Millestone) at 260 ºC for 1 h. The digested cabbage and potato samples were diluted with 50 ml deionized water (Barnstead, >18 $M\Omega\ cm^{-1}$) after cooling and analyzed for heavy metals (Cr, Ni, Cu, Zn, As, Cd and Pb), using ICP-MS (Agilent 8800 QQQ). About 250 μL of internal standard solution, 4 mg/L of rhodium (Rh), tellurium (Te), indium (In) and thallium (Th) were used to avoid interferences. According to Reference material (NIST1575) the recoveries were from 93-97%.

2.4. Data analysis

Data was analyzed using SPSS software version 20.0. One way analysis of variance (ANOVA) was used to compare site-wise differences in mean values of heavy metals at $\alpha = 0.05$ level of significance. Where significant difference were indicated, means were tested using Tukey's multiple comparisons test at $\alpha = 0.05$ significance level. Results were also compared with the standard limits of FAO/WHO (2011) in the diet of humans.

2.5. Potential human health risk assessment

The potential human health risk due to ingestion of heavy metals through the consumption of cabbages and potatoes was assessed as non-carcinogenic and carcinogenic health risks (see below).

2.5.1. Non-carcinogenic health risks

Target Hazard Quotient (THQ) and Hazard Index (HI) were used to estimate the potential non-carcinogenic health risks of heavy metals (USEPA, 2011). The THQ assesses health hazards for an individual heavy metal from vegetable consumption while, HI assesses health hazards for combined heavy metals, and was estimated as the sum of individual metals THQ (USEPA, 2011). THQ presumes a level of exposure below which it is improbable for even sensitive population to experience adverse health effects (Kawser *et al.*, 2016). The THQ and HI values were estimated using equation 1 and 2, respectively (USEPA, 2019). When the THQ and HI values are below 1.0 it means that the exposed population is safe in relation to the studied metal(s) or adverse non-carcinogenic health effects are unlikely to occur. If the THQ and HI values of metals are greater than 1.0, there are potential non-carcinogenic risks related to the heavy metal(s) analyzed (USEPA, 2019).

$$THQ = \frac{EF \times ED \times FIR \times C}{RFD \times WAB \times TA} \times 10^{-3} \qquad ...(1)$$

where:

- *THQ* is target hazard quotient.
- *EF* is the exposure frequency (from 365 days / year for people who eat vegetables seven times a week to 52 days / year for people who eat vegetables once a week-according to Food and Agriculture Organization (FAO, 2011).
- *ED* is the exposure duration equivalent to the average lifetime; average life expectancy in Ethiopia is 65 years according to the World Health Organization (WHO, 2015).
- *FIR* is the frequency of ingestion, i.e., average daily vegetable consumption rate (g / day / person) and *C* is the concentration of the metal (mg / kg) in the vegetables.
- *WAB* is the average body weight (kg), which was set by WHO (2010) to be 60 kg for adult Ethiopians.
- *TA* is the average exposure time for non-carcinogens (365 days / year x ED) (Kumar *et al.*, 2013).
- 10^{-3} is the unit conversion factor.
- *RFD* is the oral Reference dose obtained from Integrated Risk Information System database (USEPA, 2003) which was 0.003 mg / kg / day for Cr, 0.020 (Ni), 0.040 (Cu), 0.300 (Zn), 0.0003 (As), 0.001 (Cd) and 0.0035 for Pb.

The following is considered to calculate the THQ: According to FAO (2011), the daily average estimated consumption of vegetables in Ethiopia is 97.0 g per person per day.

$$HI = \Sigma THQ \qquad ...(2)$$

The THQ and HI were calculated for the people, who eat cabbages and potatoes one to seven days a week from Biological Lagoon, Boicha stream and the Reference areas.

Target Cancer Risks (TCRs): TCR were estimated as the incremental probability of an individual to develop cancer over a lifetime exposure to that potential carcinogen (USEPA, 2019). Acceptable risk levels for carcinogens range from 10^{-4} (risk of developing cancer over a human lifetime is 1 in 10,000) to 10^{-6} (risk of developing cancer over a human lifetime is 1 in 1,000,000). The equation used for estimating the TCR is as follows:

$$TCR = \frac{EF \times ED \times C \times CSFO}{WAB \times TA} \times 10^{-3} \qquad ...(3)$$

where:

- *TCR* is target cancer risk (lifetime cancer risk).
- *EF* is the exposure frequency (From 365 days / year for people who eat vegetable seven times a week to 52 days / year for people who eat vegetable once a week) (FAO, 2011).
- *ED* is the exposure duration equivalent to the average lifetime.
- *FIR* is the frequency of ingestion rate, i.e., average daily vegetable consumption rate (g / day / person).
- *C* is the measured metal concentration (mg / kg) in the vegetable.
- *CSFO* is the oral carcinogenic slope factor from integrated risk information system database (USEPA, 2010) which was 1.5 mg / kg / day for As, 1.7 (Ni), 0.5 (Cr), 15 (Cd) and 0.0085 mg kg $^{-1}$ / day for Pb. TCR was

estimated for Cr, Ni, Cd, As and Pb only since these elements may promote both non-carcinogenic and carcinogenic effects depending on the exposure dose. According to International Agency for Research on Cancer (USEPA, 2012), Cr, Ni, Cd and As are known as Group A carcinogens and Pb is known as Group B carcinogen.

- *WAB* is the average body weight (kg), which was set by World Health Organization (WHO, 2012) to be 60 kg for adult Ethiopians.
- *TA* is the average exposure time for non-carcinogens (365 days / year x ED) (Kumar *et al.*, 2013).
- 10^{-3} is the unit conversion factor.

3. Results and discussion

3.1. Concentration of heavy metals in cabbages and potatoes

Concentrations of heavy metals in the cabbages and potatoes are presented in Table 1. Mean concentrations of heavy metals in the cabbages generally followed the order: Zn > Cu > Ni > Cr > Cd > Pb > As and Zn > Cu > Ni > Cr > Pb > As > Cd in cabbages and potatoes, respectively. Mercury was below the detection limit in all samples. The maximum mean concentration of heavy metal obtained in cabbages was for Zn (134.0 + 5.62 mg / kg) from Biological Lagoon area and the minimum value was for As (0.05 + 0.002 mg / kg) from the Reference site. Similarly, the maximum mean concentration in potatoes was for Zn (27.50 + 0.62 mg / kg) from Boicha stream area and the minimum value was for Cd (0.04 + 0.001 mg / kg) from the Reference site.

Mean concentrations of all heavy metals, except Ni, were higher in the vegetables sampled from Biological Lagoon and Boicha stream areas than from the Reference site. It is reasonable to assume that the effluents discharged from industries and urban centers are enriched in heavy metals as the discharges are not treated at all or the treatments are inadequate when there was some kind of treatment. Industrial effluents from Hawassa textile factory are shown to contain enriched concentrations of heavy metals like Cr, Co, Cu, As, Cd, Hg, Ni, Se, Pb and Fe (Zinabu and Zerihun, 2002; and Berehanu *et al.,* 2015). Furthermore, application of agrochemicals on agricultural land can also contribute to high concentrations of heavy metals in vegetables (Raymond and Felix, 2011). Generally, lower concentrations of metals in vegetables from the Reference site compared to the Biological Lagoon and Boicha stream areas indicate that the Reference site is less impacted by anthropogenic supply of metals as it is located further away from the industrial and urban areas.

Although Hg was detected in fishes from Lake Hawassa (Zinabu and Pearce, 2003; Zinabu *et al.,* 2004; Zerihun *et al.,* 2006; Zerihun et al., 2008; and Ermias *et al.,* 2014), it was below the detection limit in all vegetables samples in the present study. This may be due to the physical-chemical form of Hg, as it is organo-mercury forms that bioaccumulate in lipids of fish (Environmental health and safety manual, 2000). Even from highly contaminated soils plants absorb only small amounts of Hg through their roots, where most of plant Hg is a result of surface contamination by Hg containing aerosols (Dudka and Miller, 1999). For instance, Zheng *et al.* (2007) reported that Hg concentration was only 0.004 mg / kg in edible parts of vegetable grown on the soils where the concentration of Hg was 1.28 mg / kg.

A higher concentration of Cr than the present study was reported in cabbages in Ethiopia by Temesgen and Seyoum (2017) Cr (1.33 mg / kg) from Koka and by Gebeyehu and Bayissa (2020) Cr (4. 63 mg / kg) from Mojo. Similarly, Yirgaalem *et al.* (2012) reported lower mean Ni concentration of 0.38 mg / kg in cabbages from Addis Ababa. The use of livestock manure for agricultural land, which is a common practice in the present study area, might have contributed to a high level of Ni in vegetables (Basta *et al.*, 2005), in addition to industrial effluents. Hintsa *et al*. (2016) and Temesgen and Seyoum (2017) also reported a lower Zn concentrations of 9.0 and 3.07 mg / kg in cabbages from Adwa and Addis Ababa, respectively. The higher values of Zn in vegetables in present study could be due to industrial effluents discharged from Hawassa Textile, Moha Soft Drink and Brewery-BGI factories.

The result of the present study revealed that the mean concentrations of Cu in vegetables were lower than the values reported by Yirgaalem *et al.* (2012), 0.99 mg / kg, in cabbages from Addis Ababa, Ethiopia and Mehrdad *et al*. (2013), 11.0 mg kg^{-1}, in potatoes from Iran. Hintsa *et al*. (2016) reported mean concentration of 0.16 mg / kg of Cd from Adwa, which is lower than 0.32 and 0.31 mg / kg obtained in this study from Biological Lagoon area and Boicha stream area, respectively. Gebeyehu and Bayissa (2020) reported mean concentration of 5.73 mg / kg of As in cabbages from Mojo, Ethiopia. This value is much higher than the values 0.12, 0.14 and 0.05 mg / kg from Biological Lagoon area, Boicha stream area and the Reference site, respectively obtained in this study. These differences could be attributed to differences in the level of heavy metal pollution of the areas through anthropogenic inputs. Moreover, as indicated by USEPA (1996), the differences in natural sources could also be the reason for the differences in heavy metals between the studies.

There were statistically significant ($p < 0.05$) site dependent differences in the mean concentrations of Zn, Cu and Pb in cabbages (with higher concentrations from Biological Lagoon area) and Cr, Ni, Cu and Pb in potatoes, with higher concentrations from Boicha stream area (Table 1). This suggests that there was difference in heavy metals pollution level between the sampling sites. Naser *et al.* (2012) noted that the concentrations of heavy metals in vegetables depends on factors such as concentrations of heavy metals in soils, type of the vegetables, solubility of the heavy metal, soil pH, organic matter content, and cation exchange capacity, etc. of the soil, and however, the authors indicated that the concentration of heavy metals in the soil dominates the other factors. Therefore, it is very likely that the concentrations obtained in this study are very much related to the concentrations in the soils which in turn are probably influenced by the concentrations of the metals in the effluents from the factories in the surrounding.

The concentration of Zn, As and Cd in cabbages and As concentration in potatoes from Biological Lagoon and Boicha stream areas, and Pb concentration in potatoes only from Boicha stream area are above the FAO / WHO (2011) maximum permissible limits (MPL) in the diet of humans (Table 1). This shows that it may not be safe to consume cabbages from both sites with regard to Zn, As and Cd and potatoes with respect to As and Pb toxicities. Therefore, high concentration and long time consumption of these vegetables grown in these study areas may cause toxic manifestation in humans. For example, according to Jordao *et al.* (2002) and Honda *et al.* (2006) excessive concentration of Zn in the diet is known to cause muscular pain and intestinal hemorrhage,

Table 1: Heavy metal concentrations (mg/kg, dry weight) in the cabbages and potatoes from the study sites (Mean ± SD, $n = 10$)

Vegetable	Heavy metal	Site			MPL
		Biological Lagoon area	Boicha stream area	Reference site	
Cabbages	Cr	0.48 ± 0.02^{a}	0.54 ± 0.02^{b}	0.47 ± 0.01^{a}	2.3
	Ni	0.54 ± 0.01^{a}	0.68 ± 0.04^{b}	0.58 ± 0.02^{a}	2.0
	Zn	**134.0 ± 5.62^{a}**	**103.0 ± 8.34^{b}**	40.40 ± 2.52^{c}	60.0
	Cu	4.57 ± 0.08^{a}	3.74 ± 0.14^{b}	2.66 ± 0.08^{c}	40.0
	As	**0.12 ± 0.01^{a}**	**0.14 ± 0.01^{a}**	0.05 ± 0.002^{b}	0.1
	Cd	**0.32 ± 0.01^{a}**	**0.31 ± 0.06^{a}**	0.08 ± 0.01^{b}	0.2
	Pb	0.23 ± 0.01^{a}	0.28 ± 0.01^{b}	0.12 ± 0.02^{c}	0.3
	Hg	ND	ND	ND	
Potatoes	Cr	0.48 ± 0.03^{a}	1.16 ± 0.08^{b}	0.13 ± 0.01^{c}	2.3
	Ni	0.52 ± 0.04^{a}	1.23 ± 0.08^{b}	0.13 ± 0.02^{c}	2.0
	Zn	25.30 ± 0.88^{a}	27.50 ± 0.62^{a}	22.70 ± 0.58^{b}	60.0
	Cu	4.82 ± 0.17^{a}	3.78 ± 0.43^{b}	0.42 ± 0.03^{c}	40.0
	As	**0.24 ± 0.03^{a}**	**0.35 ± 0.07^{a}**	0.01 ± 0.001^{b}	0.1
	Cd	0.06 ± 0.003^{a}	0.06 ± 0.004^{a}	0.04 ± 0.001^{b}	0.2
	Pb	0.27 ± 0.01^{a}	**0.50 ± 0.04^{b}**	0.02 ± 0.003^{c}	0.3
	Hg	ND	ND	ND	

Note: Mean values with different superscript letters in a row are significantly different from each other ($\alpha = 0.05$). Values in bold are those above the maximum permissible limits (MPL) in the diet of humans according to the FAO/WHO 2011 standards; and ND = Not Detected, MPL = Maximum Permissible Limit.

even though it is required to maintain the functioning of the immune system its. Gbaruko *et al.* (2010) indicated that long-term exposure of humans to As may cause several health problems including skin lesions, blackfoot disease, circulatory disorders, diabetes and cancers of the bladder, skin, lung, kidney, and liver. Other sensitive endpoints of prolonged exposure to As are peripheral neuropathy, cardiovascular disease, and in exposed children neurobehavioral effects (Nurchi *et al.*, 2020). Chronic exposure to Cd causes nephrotoxicity, pulmonary toxicity and musculoskeletal toxicity (Sarah and Christy, 2017).

3.2. Health risks associated with vegetable consumption

3.2.1. Target Hazard Quotient (THQ)

The results of THQ through consumption of cabbages and potatoes from the study sites for people who eat these vegetables one to seven times a week are shown in Tables 2 and 3. The THQ values for metals from consumption of cabbages followed the order: Zn > As > Cd > Cr > Cu > Pb > Ni, As > Zn > Cd > Cr > Cu > Pb > Ni and As > Cr > Zn > Cd > Cu > Pb > Ni from Biological Lagoon area, Boicha stream area and the Reference site, respectively (Table 2). Likewise, the order of values from consumption of potatoes was As > Cr > Cu > Zn > Pb > Cd > Ni, As > Cr > Pb > Cu > Zn > Ni > Cd and Zn > Cd > Cr > As > Cu > Ni > Pb Biological Lagoon area, Boicha stream area and the Reference site, respectively (Table 3). The THQ values from consumption of cabbages from Boicha stream area for Cr, Ni, As and Pb ranged 0.041-0.285, 0.008-0.054, 0.104-0.722 and 0.018-0.126, respectively. In the same way, THQ values from consumption of potatoes from Boicha stream ranged from 0.089-0.618 for Cr, 0.014-0.098 (Ni), 0.021-0.146 (Zn), 0.267-1.850 (As) and 0.033-0.228 (Pb). These ranges of values were highest in both vegetables from Boicha stream than those from Biological Lagoon area and the Reference site (Tables 2 and 3). Temesgen and Seyoum (2017) reported lower THQ values than present study

Table 2: Target Hazard Quotient (THQ) and Hazard Index (HI) of heavy metals from consumption of cabbages from the study sites at different levels (days per week) of exposure

Site	Levels of exposure (d/w)	Target Hazard Quotient (THQ)							Hazard Index (HI)
		Cr	Ni	Zn	Cu	As	Cd	Pb	
Biological Lagoon area	1	0.037	0.006	0.103	0.026	0.094	0.074	0.015	0.355
	2	0.074	0.012	0.206	0.053	0.187	0.148	0.030	0.710
	3	0.111	0.019	0.309	0.079	0.281	0.222	0.044	**1.065**
	5	0.185	0.031	0.514	0.132	0.468	0.371	0.074	**1.775**
	7	0.256	0.043	0.712	0.182	0.648	0.513	0.103	**2.457**
Boicha stream area	1	0.041	0.008	0.079	0.022	0.104	0.074	0.018	0.346
	2	0.082	0.016	0.159	0.043	0.209	0.148	0.036	0.693
	3	0.123	0.023	0.237	0.064	0.313	0.221	0.055	**1.036**
	5	0.206	0.039	0.395	0.108	0.522	0.370	0.091	**1.731**
	7	0.285	0.054	0.547	0.149	0.722	0.511	0.126	**2.394**
Reference site	1	0.036	0.007	0.031	0.015	0.036	0.019	0.008	0.152
	2	0.072	0.013	0.061	0.031	0.072	0.038	0.016	0.303
	3	0.108	0.020	0.092	0.046	0.108	0.057	0.024	0.455
	5	0.180	0.034	0.154	0.077	0.180	0.096	0.040	0.761
	7	0.249	0.046	0.213	0.106	0.250	0.132	0.056	**1.052**

Note: Values in bold (>1) indicate potential non-carcinogenic health risk for humans.

Table 3: Target Hazard Quotient (THQ) and Hazard Index (HI) of heavy metals from consumption of potatoes from the study sites at different levels (days per week) of exposure

Site	Levels of exposure (d/w)	Target Hazard Quotient (THQ)							Hazard Index (HI)
		Cr	Ni	Zn	Cu	As	Cd	Pb	
Biological Lagoon area	1	0.037	0.006	0.019	0.028	0.180	0.015	0.018	0.303
	2	0.073	0.012	0.039	0.056	0.361	0.029	0.036	0.606
	3	0.110	0.018	0.058	0.083	0.541	0.044	0.053	0.907
	5	0.183	0.030	0.097	0.139	0.902	0.072	0.089	**1.512**
	7	0.253	0.042	0.134	0.192	**1.249**	0.100	0.123	**2.093**
Boicha stream area	1	0.089	0.014	0.021	0.022	0.267	0.014	0.033	0.460
	2	0.178	0.028	0.042	0.044	0.534	0.027	0.066	0.919
	3	0.268	0.042	0.063	0.065	0.802	0.041	0.099	**1.380**
	5	0.446	0.071	0.106	0.109	**1.336**	0.068	0.165	**2.301**
	7	0.618	0.098	0.146	0.151	**1.850**	0.094	0.228	**3.185**
Reference site	1	0.010	0.001	0.017	0.002	0.006	0.010	0.001	0.047
	2	0.020	0.003	0.035	0.005	0.012	0.020	0.002	0.097
	3	0.030	0.004	0.052	0.007	0.018	0.030	0.003	0.144
	5	0.050	0.007	0.087	0.012	0.031	0.050	0.005	0.242
	7	0.069	0.010	0.121	0.017	0.043	0.069	0.007	0.336

Note: Values in bold (>1) indicate potential non-carcinogenic health risk for humans.

for Cr (0.00008), Ni (0.005), Zn (0.005), Cd (0.044) and Pb (0.013) through every day consumption of cabbages from Koka farm, Ethiopia. This difference might be due to pollution levels difference between the study areas. Another study in Ghana (Samuel *et al.*, 2018) reported lower THQ value for Zn (0.01) from every day consumption of cabbages for adults.

A statistical analysis showed significant differences ($p < 0.05$) in THQ values for Cr, Ni, Zn, Cu and As through the consumption of cabbages and potatoes among the study sites. The difference in THQ values of the heavy metals might probably be due to a high level of heavy metal pollution in Boicha stream area than in the Biological Lagoon area and the Reference sites. This is very likely given that the Boicha stream directly receives effluents from the industries in the area. Results of this study (Tables 2 and 3) showed that there is a highest probability of non-carcinogenic health risks from ingestion of Cr, Ni, As and Pb individually in cabbages from Boicha stream area compared to that from Biological Lagoon area and the Reference site. Likewise, there is a highest probability of non-carcinogenic health risks from ingestion of Cr, Ni, Zn, As and Pb individually in potatoes from Boicha stream area compared to that from Biological Lagoon area and the Reference site at all levels of exposure.

The fact that the THQ values for all heavy metals, except As, through consumption of cabbages and potatoes from the study sites were less than unity is an indication that there is potentially little non-carcinogenic health risks from ingestion of Cr, Ni, Zn, Cu, Cd and Pb individually through consumption of cabbages and potatoes from the study sites. The THQ values for As through consumption of potatoes from Biological Lagoon and Boicha stream areas were greater than unity; therefore there are potential non-carcinogenic health risks from ingestion of As through consumption of potatoes every day from Biological Lagoon area, and five or more days a week from Boicha stream area. Therefore, farmers and their families around the study areas as well as those who consume potatoes are expected to be victims of As intoxication.

The THQ values for Cu, As, Cd and Pb from consumption of potatoes from all sites were higher than those from consumption of cabbages (Tables 2 and 3). This suggests that consumption of potatoes is potentially more risky than that of cabbages with respect to toxicities from these metals. On the other hand, the THQ values for Cr, Ni and Zn from consumption of cabbages from all sites were higher than those from consumption of potatoes indicating consumption of cabbages is potentially more risky than potatoes with respect to the toxicities of the metals.

Table 4: Carcinogenic (TCR) health risks of heavy metals due to consumption of cabbages from the study sites

Site	Levels of exposure (d/w)	Target Cancer Risk (TCR)				
		Cr	Ni	As	Cd	Pb
Biological Lagoon area	1	1.54E-05	2.11E-05	3.21E-05	5.5E-05	4.42E-07
	2	3.96E-05	4.21E-05	7.43E-05	8.22E-05	8.85E-07
	3	5.66E-05	6.32E-05	9.26E-05	**2.33E-04**	1.33E-06
	5	7.77E-05	8.05E-05	**2.11E-04**	**5.56E-04**	2.21E-06
	7	9.83E-05	9.46E-05	**3.92E-04**	**8.70E-04**	3.06E-06
Boicha stream area	1	1.17E-05	1.66E-05	4.70E-05	9.11E-05	5.42E-07
	2	3.23E-05	3.32E-05	9.40E-05	**3.22E-04**	1.08E-06
	3	5.85E-05	5.98E-05	**1.41E-04**	**7.33E-04**	1.63E-06
	5	7.09E-05	7.33E-05	**2.35E-04**	**1.54E-03**	2.71E-06
	7	9.27E-05	8.84E-05	**3.25E-04**	**6.68E-03**	3.75E-06
Reference site	1	1.40E-05	2.28E-06	1.62E-05	1.87E-05	2.39E-07
	2	4.08E-05	4.56E-06	3.25E-05	3.73E-05	4.78E-07
	3	6.62E-05	6.84E-06	4.87E-05	5.60E-05	7.17E-07
	5	7.70E-05	8.14E-06	7.12E-05	7.43E-05	1.19E-06
	7	9.74E-05	1.59E-05	9.12E-05	8.99E-05	1.65E-06

Note: Values in bold indicate TCR above acceptable limit (10^{-4}).

Table 5 Carcinogenic (TCR) health risks of heavy metals due to consumption of potatoes from the study sites

Site	Levels of exposure (d/w)	Target Cancer Risk (TCR)				
		Cr	Ni	As	Cd	Pb
Biological Lagoon area	1	1.48E-05	2.04E-05	8.12E-05	4.18E-05	5.29E-07
	2	3.10E-05	4.08E-05	**1.62E-04**	7.35E-05	1.06E-06
	3	5.64E-05	5.52E-05	**3.44E-04**	**1.53E-04**	1.59E-06
	5	7.74E-05	7.02E-05	**5.06E-04**	**5.09E-04**	2.64E-06
	7	9.79E-05	9.41E-04	**7.62E-04**	**9.51E-04**	3.66E-06

Table 5 (Cont.)

Site	Levels of exposure (d/w)	Target Cancer Risk (TCR)				
		Cr	Ni	As	Cd	Pb
Boicha stream area	1	1.34E-05	1.82E-05	7.20E-05	3.04E-05	9.79E-07
	2	3.68E-05	3.63E-05	9.40E-05	6.08E-05	1.96E-06
	3	5.01E-05	5.45E-05	**3.61E-04**	9.11E-05	2.94E-06
	5	7.69E-05	7.41E-05	**6.01E-04**	**1.09E-04**	4.89E-06
	7	9.26E-05	9.33E-05	**8.32E-04**	**3.41E-04**	6.78E-06
Reference site	1	1.49E-05	1.01E-05	2.76E-06	1.49E-05	3.13E-08
	2	2.97E-05	3.0E-05	5.53E-06	2.97E-05	6.26E-08
	3	4.46E-05	5.50E-05	8.29E-06	4.46E-05	9.40E-08
	5	7.43E-05	7.51E-05	1.38E-05	6.02E-05	1.57E-07
	7	1.03E-04	9.47E-05	1.91E-05	8.03E-05	2.17E-07

Note: Values in bold indicate TCR above acceptable limit (10^{-4}).

3.2.2. Hazard Index (HI)

The HI values from the consumption of cabbages and potatoes, one to seven times a week, are shown in Tables 2 and 3. The HI values through consumption of cabbages from Biological Lagoon area, Boicha stream area and the Reference site ranged from 0.355 to 2.457, 0. 346 to 2.394 and 0.152 to 1.052, respectively (Table 2) while those through consumption of potatoes were in the ranges of 0.303 to 2.093, 0.460 to 3.185 and 0.047 to 0.336 for Biological Lagoon area, Boicha stream area and the Reference site, respectively (Table 3). The result of the present study revealed that the HI values through consumption of cabbages were lower than the value reported by Samuel *et al*. (2018) HI (6.51) from Ghana. The HI values through consumption of cabbages for three or more days a week, from Biological Lagoon and Boicha stream areas, and every day from the Reference site were greater than unity. This suggests the presence of a potential non-carcinogenic health risk from ingestion of all the heavy metals collectively considered under this study through consumption of the cabbages at aforementioned exposure levels from each site. The HI values through consumption of potatoes were similar to those mentioned above for cabbages except that the exposure levels were five or more days a week for Biological Lagoon and Boicha stream areas. These results show that there is a higher potential non-carcinogenic health risks from the consumption of the vegetables from Biological Lagoon and Boicha stream areas compared to consumption of these vegetables from the Reference site. Therefore, families of farmers around the study areas and other people who consume these vegetables nearly every day are more vulnerable to the heavy metals toxicities.

3.2.3. Target Carcinogenic Risks (TCRs)

The TCR from exposure to Cr, Ni, As, Cd and Pb due to consumption of cabbages and potatoes for one to seven days a week from the three sampling sites are presented in Table 4 and 5. The highest TCR value for exposure of seven days a week obtained in this study was 6.68E-03 (for Cd) through consumption of cabbages from Boicha stream area, while the lowest was 2.17E-07 (for Pb) through consumption of potatoes from the Reference site. In the present study, the TCR values for Cr, Ni and Pb were below the acceptable range ($<10^{-6}$-10^{-4}) for all levels of exposure. This indicates that there is no potential carcinogenic health risk from ingestion of Cr, Ni and Pb through the consumption of cabbages and potatoes for all levels of exposure from the three sampling sites. However, the TCR values for As were above the acceptable range ($>10^{-6}$-10^{-4}) for consumption of cabbages five or more days a week from Biological Lagoon area and three or more days per week from Boicha stream area. Similar result was obtained for Cd through consumption of cabbages three or more days per week from

Biological Lagoon area and two or more days per week from Boicha stream area. Likewise, the TCR values for As from consumption of potatoes from Biological Lagoon area and Boicha stream area were above the acceptable range for exposure of two or more days a week and three or more days a week, respectively. In the same way, the TCR values for Cd from consumption of potatoes from Biological Lagoon area and Boicha stream area were above the acceptable range for exposure three or more days per week and five days per week, respectively. Therefore, it can be inferred that there is a potential carcinogenic health risk from ingestion of As and Cd through the consumption of cabbages and potatoes from Biological Lagoon and Boicha stream areas for the above-mentioned exposure levels.

4. Conclusion

This study has revealed that consumption of cabbages and potatoes from Biological Lagoon and Boicha stream areas at different levels (days per week) of exposure could be unsafe with respect to toxicities of Zn, As and Cd. Based on the results from the three study sites, it is possible to infer that consumption of cabbages and potatoes from Biological Lagoon and Boicha stream areas is more risky than consuming vegetables from the Reference site—indicating that the Biological Lagoon and Boicha stream areas are more polluted with heavy metals than the Reference site. Effluents from industries and urban wastes in the Hawassa Industrial Zone are assumed to be the sources of the heavy metals in the soils from where the vegetables were sampled for this study. Farmers and their families, who are likely to consume vegetables much more frequently than other communities, are the forefront risk group whose health must be protected. Therefore, it is important to create awareness among stakeholders and also put into effect sound waste disposal and monitoring policy interventions to protect the health of the ecosystem and the public.

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