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Review on Heavy Metal Contamination in Vegetables Grown in Ethiopia and Its Economic Welfare Implications

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Abstract
Urbanization is occurring rapidly throughout Ethiopia, as populations are increasingly migrating from rural areas to major cities. Vegetables constitute an important part of the human diet since they contain carbohydrates, proteins, vitamins, minerals and fibers required for human health. However, these plants contain both essential and toxic metals over a wide range of concentrations. Heavy metal contamination of the food items is one of the most important aspects of food quality assurance. The most common heavy metal contaminants are Cd, Cr, Cu, Hg, Pb, and Zn. Metals are natural components in soil. Some of these metals are micronutrients necessary for plant growth, such as Zn, Cu, Mn, Ni, and Co, while others have unknown biological function, such as Cd, Pb, and Hg. There is a strong link between micronutrient nutrition of plants, animals and humans and the uptake and impact of contaminants in these organisms. The content of essential elements in plants is conditional, the content being affected by the characteristics of the soil and the ability of plants to selectively accumulate some metals. They are also known to have effect on plant growth, ground cover and have a negative impact on soil. The uptake and bioaccumulation of heavy metals in vegetables is influenced by many factors such as climate, atmospheric depositions, the concentrations of heavy metals in soils, the nature of soil and the degree of maturity of the plants at the time of the harvest. Water pollution by heavy metals is mainly caused by point source emissions from mining activities and a wide variety of industries. The studies undertake to determine the concentration of heavy metals in soils, as well as on the vegetable grown in the vicinity of industrial areas and contaminated irrigation water in Ethiopia indicated that Vegetables grown in such lands, contaminated with heavy metals and unsafe for consumption. Prolonged human consumption of unsafe concentrations of heavy metals in food stuffs may lead to the disruption of numerous biological and biochemical processes in the human body, the chronic accumulation of heavy metals in the kidney and liver of humans causing disruption of numerous biochemical processes, leading to cardiovascular, nervous, and kidney and bone diseases. Heavy metals have greatest health risk to both adult and children consumers of vegetables grown in contaminated soil and water.
Keywords: Heavy metals, Waste water, Vegetables, Health risk

1. Introduction

Rapid population growth, agricultural activities, urbanization and industrial development have been adversely degrading the environment, and moreover pollution has reached alarming proportions. The major consequences of man's activities on the environment are habitat degradation, water pollution, and the resultant deterioration of the aquatic ecosystem (Baye, 2006). Urbanization is occurring rapidly throughout Ethiopia, as populations are increasingly migrating from rural areas to major cities. Over the past decade, the country has experienced dramatic demographic changes, including increased rural-to-urban migration and a "youth bulge". About 48% of the current population is under the age of 15 (USAID, 2010).

Vegetables constitute an important part of the human diet since they contain carbohydrates, proteins, vitamins, minerals and fibers required for human health. They also act as neutralizing agents for acidic substances formed during digestion. They are made up of chiefly cellulose, hemi-cellulose and pectin substances that give them their texture and firmness (Sobukola and Dairo, 2007). They are very important protective food and useful for the maintenance of health and the prevention and treatment of various diseases (D'Mello, 2003). However, these plants contain both essential and toxic metals over a wide range of concentrations (Radwan and Salama, 2006).

As human activities increases, especially with the application of modern technologies, pollution and contamination of the human food chain has become inevitable. Heavy metals uptake by plants grown in polluted soils has been studied to a considerable extent (Yusuf *et al*., 2003). Heavy metal contamination of the food items is one of the most important aspects of food quality assurance (Khan *et al*., 2008). International and national regulations on food quality have lowered the maximum permissible levels of toxic metals in food items due to an increased awareness of the risk, these metals pose to food chain contamination (Radwan and Salama, 2006).

The term heavy metal refers to any elements with metallic properties and an atomic number >20. The most common heavy metal contaminants are Cd, Cr, Cu, Hg, Pb, and Zn. Metals are natural components in soil. Some of these metals are micronutrients necessary for plant growth, such as Zn, Cu, Mn, Ni, and Co, while others have unknown biological function, such as Cd, Pb, and Hg (Jarup, 2003) ; (Lenntech, 2004) but the collective term now includes arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), nickel (Ni), manganese (Mn), iron (Fe), cobalt (Co), zinc (Zn) and selenium (Se) is toxic or poisonous at low concentrations. Living organisms require trace amounts of some heavy metals, but excessive levels can be detrimental to the organism (Farlex, 2005).)

Of the nonessential metals, mercury (Hg), lead (Pb), cadmium (Cd), and arsenic (As) are recognized as health hazardous and all have caused major health problems as a result of environmental pollution (Duffus, 2002). Physiologic roles are known for iron (haemmoeties of heamoglobin and cytochromes), copper (amine oxidases, dopamine hydrolase and collagen synthesis), manganese (superoxide dismutase) and zinc (protein synthesis, stabilization of DNA and RNA) with low requirements of chromium (glucose homeostasis). Other heavy metal ions are not believed to be essential to health even in trace amounts (Suruchi and Jilani, 2011).

The heavy metals cadmium, lead and mercury are common air pollutants, being emitted mainly as a result of various industrial activities. Although the atmospheric levels are low, they contribute to the deposition and build-up in soils. Heavy metals are persistent in the environment and are subject to bioaccumulation in food-chains. In general, most heavy metals are not biodegradable, have long biological half-lives and have the potential for accumulation in the different body organs leading to unwanted side effects (Jarup, 2003; Sathawara *et al*., 2004). There is a strong link between micronutrient nutrition of plants, animals and humans and the uptake and impact of contaminants in these organisms (Yaman *et al*., 2005). The content of essential elements in plants is conditional, the content being affected by the characteristics of the soil and the ability of plants to selectively accumulate some metals (Sobukola *et al*., 2010). Thus the objective of this paper is to review the heavy metal concentration load in vegetables grown in contaminated areas of under urban settings.

2. Heavy Metals Effect in the Environment

Metal pollution has harmful effect on biological systems and does not undergo biodegradation. Toxic heavy metals such as Pb, Co, Cd can be differentiated from other pollutants, since they cannot be biodegraded but can be accumulated in living organisms, thus causing various diseases and disorders even in relatively lower concentrations (Pehlivan and Adholeya, 2009). Heavy metals, with soil residence times of thousands of years, pose numerous health dangers to higher organisms. They are also known to have effect on plant growth, ground cover and have a negative impact on soil microflora. It is well known that heavy metals cannot be chemically degraded and need to be physically removed or be transformed into nontoxic compounds (Gaur and Adholeya, 2004).

2.1 Arsenic (As) - Arsenic is a semi metallic element, odorless and tasteless. Arsenic can combine with other elements to form inorganic and organic arsenicals (National Ground Water Association). Arsenic exists in the -3, 0, +3, and +5 valence oxidation states (Mohan and Pittman, 2007) and in a variety of chemical forms in natural waters and sediments. It is one of the contaminants found in the environment which is notoriously toxic to man and other living organisms (Chutia *et al*, 2009). It is a highly toxic element that exists in various species, and the toxicity of arsenic depends on its species. The pH, redox conditions, surrounding mineral composition, and microbial activities affect the form (inorganic or organic) and the oxidation state of arsenic. It is generally accepted that the inorganic species, arsenite [As^{3+}] and arsenate [As^{5+}], are the predominant species in most environments, although the organic ones might also be present (Andrianisa *et al*, 2008).

2.2. Lead (Pb) - exists in many forms in the natural sources throughout the world and is now one of the most widely and evenly distributed trace metals. Soil and plants can be contaminated by lead from car exhaust, dust, and gases from various industrial sources. Pb^{2+} was found to be acute toxic to human beings when present in high amounts. Since Pb^{2+} is not biodegradable, once soil has become contaminated, it remains a long-term source of Pb^{2+} exposure. Metal pollution has a harmful effect on biological systems and does not undergo biodegradation (Pehlivan and Adholeya, 2009). In the environment, lead is known to be toxic to plants, animals, and microorganisms. Lead contamination in the environment exists as an insoluble form, and the toxic metals pose serious human health problem brain damage and retardation (Cho-Ruk *et al.*, 2006).

2.3. Mercury (Hg) - is a persistent environmental pollutant with bioaccumulation ability in fish, animals, and human beings (Chang *et al.*, 2006). Mercury salts and organomercury compounds are among the most poisonous substances in our environment. The mechanism and extent of toxicity depend strongly on the type of compound and the redox state of mercury. Environmental contamination due to mercury is caused by several industries, petrochemicals, minings, painting, and also by agricultural sources such as fertilizer and fungicidal sprays (Resaee *et al.*, 2005).

3. Sources of Heavy Metal Pollution in Vegetables

Rapid and unorganized industrialization and urbanization have contributed to the elevated levels of heavy metals in the urban environment of the developing countries (Wong *et al*., 2003; Khillare *et al*., 2004; Sharma *et al*., 2008). Heavy metals are non-biodegradable and persistent environmental contaminants which may be deposited on the surfaces and then adsorbed into the tissues of the vegetables. The uptake and bioaccumulation of heavy metals in vegetables is influenced by many factors such as climate, atmospheric depositions, the concentrations of heavy metals in soils, the nature of soil and the degree of maturity of the plants at the time of the harvest.

3.1. Soil - It has been established that heavy metals in soil are associated with various chemical forms that relate to their solubility which directly bear on their mobility and biological availability. Heavy metals in soluble form have high relation to their uptake by plants. Vegetables can absorb metals from soil as well as from deposits on the parts of the vegetables exposed to the air from polluted environments (Haiyan and Stuanes, 2003). Toxicity from heavy metals can directly affect plant physiology, growth and many cases of toxicity from heavy metals have been reported. Jorgensen *et al*., (2005) show that, intensive horticultural systems in urban areas may be threatened by soil toxicity through trace elements such as Zn, Cu, As and Pb.

3.2 Waste Water - Water contamination by heavy metals in some areas is practically inevitable due to natural process (weathering of rocks) and anthropogenic activities (industrial, agricultural and domestic effluents). Waste water from the industries of mining, electroplating, paint or chemical laboratories often contains high concentrations of heavy metals, including cadmium (Cd), copper (Cu) and lead (Pb). Heavy metal contamination of agricultural soils from wastewater irrigation is of serious concern since it has implications on human health. A study carried out by Mensah *et al*. (2008) in Ghana using water to which Cd and Pb had been added to irrigate cabbage, carrots and lettuce revealed that Cd and Pb concentrations increased with irrigation water concentrations significantly. In many developing countries it is a common practice to grow vegetables along banks of rivers passing through urban centers. Waters of such rivers have often been reported to be polluted by heavy metals (Othman, 2001). The extent of absorption of the elements by the plant depends on among other things, the nature of the plant, and chemical constitution of the pollutant, concentration of the element in the soil, pH and the interaction with other metals.

Many studies have shown that waste water irrigation has elevated the levels of heavy metals in receiving soils (Singh *et al*., 2004; Mapanda *et al*., 2005; Sharma *et al*., 2006). The accumulation of heavy metals in edible portions of vegetables has serious adverse effects in edible portions of vegetables has serious adverse effects on human health and plants (Wenzel and Jockwer, 1999). According to Fisseha, 2003, the Ethiopian metal tools factory is the major source of pollution of rivers which is used to irrigate part of vegetable farms. In addition to that the author reported that waste from garage, hospitals, gas station as well as households also discharged into these rivers. This had impact on concentration of heavy metals such as Cu, Zn, Pb, Cd and Cr were exceeding the maximum limits recommended by FAO/WHO in the vegetables produced by irrigating these contaminated rivers.

3.3. Vegetable - Vegetables contain carbohydrate, proteins, vitamins and metals important for life. They assimilate metals from the soil they grow on and from the water they irrigated with. Of the total amount of ions associated with plant root, only part of them is absorbed into cells (Last, 2000). Difference in metal concentration in vegetables seems to imply that different types of vegetables have different abilities to accumulate the metals. In spite of the mechanism involved in the element uptake by root, plants are known to respond to the amounts of readily mobile type of metals in soil. The orders of toxic heavy metal contaminations in vegetables are vary with toxic metals. Different vegetable species accumulate different metals depending on environmental conditions, metal species and plant available forms of heavy metals (Lokeshwari and Chandrappa, 2006). Genetic differences in tolerance and co-tolerance to heavy metals are well known in some species and ecotypes of natural vegetation (Marschner, 1997). A study on metal contents of vegetables from Addis Ababa market showed that lettuce contained the highest Cd whereas cabbage accumulate the least (Rahlenbeck *et al*., 1999). Similar trends of higher accumulation of metals in Swiss chard and low accumulation in cabbage were observed in vegetables from Akaki farm, which was irrigated with industrial effluent (Fisseha and Olsson, 2004).

3.4. Anthropogenic - Anthropogenic sources of heavy metals include the addition of manures, sewage sludge, fertilizers and pesticides which may affect the uptake of heavy metals by modifying the physico-chemical properties of the soil such as pH, organic matter, bioavailability of heavy metals in the soil (Yusuf and Osibanjo, 2006). Whatmuff (2002) and McBride (2003) found that, increasing concentrations of heavy metals in soil increased the crop uptake. Cultivation areas near highways are also exposed to atmospheric pollution in the form of metal containing aerosols. These aerosols can be deposited on soil and absorbed by the vegetables or alternatively deposited on the leaves and fruits and then absorbed. Emission of heavy metals from the industries and vehicles may be deposited on the vegetable surfaces during their production, transport and marketing.

4. Heavy Metal Contamination in Vegetables Grown in Ethiopia

4.1 Concentration of Heavy Metals in Irrigated Water

Water pollution by heavy metals is mainly caused by point source emissions from mining activities and a wide variety of industries (Nazif *et al*, 2006). Tamiru *et al*. (2010) reported the highest concentrations of metals in soil samples for Zn (113 mg/kg), Cr (47.8 mg/kg), Pb (17.7 mg/kg), and Cd (0.250 mg/kg) farms of Ziway, Burau and Addis Ababa. The highest concentration of the metals was obtained from farms found at Addis Ababa as compared to the Ziway area. This shows that vegetable farms are operating in an area where metals are concentrated due to geogenic sources (Alemayehu, 2006).

Table 1. Heavy metals in soils of different vegetable farms

Metals (mg kg^{-1})	Ziway Kentola	Ziway Ethioflora	Burayu	Kuskuam Upper	Kuskuam Lower	Rec.Max. Lev. in soil
Cd	0.180	0.220	0.140	0.250	0.190	3
Cr	3.0	8.44	47.78	31.24	32.6	100
Pb	6.02	7.12	17.66	16.38	11.17	100
Zn	49.98	68.42	88.47	112.7	78.02	300

Source; (Tamiru *et al*., 2010)

The studies conducted to assess the level of heavy metal contamination in soil samples collected from Bulbul, Kebena and Akaki sites in The percentage contamination rate was significantly different among samples collected for in the level of heavy metal contents (Ermias and Tigist, 2017). They also report that the soil collected from Kebena site had the highest level of Cr (178.1 mg/kg, 81.9mg/kg soil), Cu (99.2 mg/kg, 107.6 mg/kg soil), Pb (56.7 mg/kg, 61.3 mg/kg soil) and Zn (25.93 mg/kg, 27.61 mg/kg soil) from 0-15 and 15-30 cm soil depth compared to Bulbul and Akaki sites. In addition to that Kebena site soil registered the highest levels of Cr (178.1 mg/kg soil) than Cd, Cu, Pb and Zn in the samples collected from the top soil depth (0-15 cm). However, this site had the highest levels of Cu (107.6 mg/kg soil) in the samples collected from the bottom soil depth (15-30 cm). The lowest level of Cd (<0.01 mg/kg soil) contamination was registered in Kebena; Bulbul and Akaki sites. The Cr contents in all sites are highest than Cd, Cu, Pb and Zn (Ermias and Tigist, 2017).

Table 2. Heavy metal concentration of irrigation water of Addis Ababa vegetable farming sites

Site	Total concentration		
	Cd	Co	Cr
Sora Amba	0.43	3.68	17.7
Lekuanda	0.8	14.6	29.3
Peacok-Urael	0.37	7.28	8.53
Peacok-Bole	0.17	5.48	3.09
Kera	2.82	16.3	44.2
Mekanissa	0.81	8.73	19.8
Lafto	1.48	21.6	14.2
Hana Mariam	1.05	23.7	35.1
Akaki 08	0.57	3.38	24.4
Akaki	0.33	5.57	14.8
RML(microg/L)	10	50	100

Source; Woldetsadik *et al.*, 2017 RML- Recommended maximum Limit for irrigation water by FAO

Table 3. Concentrations of some trace elements found in Bulbula and Kera rivers and soils of adjacent farms, Ethiopia

Element	**Bulbula**		**Kera**		Recommended max. Levels in		
	river (µg/L)	**Soil (total)**	**river (µg/L)**	**Soil (total)**	**Irrig. Water**	**Soil (total)**	**Vegetables(mg/kg)**
As	1.7	5.19	<1.00	6.8	100	20	0.2
Cd	0.07	0.71	<1.00	0.44	10	3	0.2
Co	2.69	27.95	<5.00	43	50	50	0.3
Cr	-	81	7.4	115	550	100	2.3
Cu	12.4	38.96	39	55	17	100	73.3
Fe	-	163.86	4290	79.7	500	50000	425.5
Ni	2.26	74.13	8.9	115	1400	50	67.9
Pb	14.1	46.74	33	110	65	100	2.65
Se	-	0.09	0.08	0.02	20	10	-
Zn	50.37	2985.5	193	263	2000	300	99.4

Source; (CAC, 2001, Itanna, 2002, Eslami *et al.*, 2007)

4.2. Concentration of Heavy metals in soils

Woldetsadik *et al.*, (2017) has conducted a research on physico-chemical parameters on wastewater irrigated soils in urban vegetable farming sites of Addis Ababa and reported that across the vegetable farming sites, the mean values of soil pH varied from 5.99 to 7.16. The mean organic matter content is highest at Sore Amba (4.6%) followed by Lekunda (4.1%), Mekanissa (3.8%) and lowest in soils from Akaki (2.6%).The CEC value is highest in soils of Akaki 08 (54.5). As compared to other vegetable farming sites, the lowest CEC value (34.9) was exhibited from soils of Peacock- Urael. Weldegebriel *et al.* (2012) also reported highest Cation Exchsnge Capacity in soils of Akaki.

Sewage-irrigated site (Lafto) has greater levels of metals than those sites having no specific application of sewage (Woldetsadik *et al*, 2017). But even the upper limits of the metal concentrations (Co, Cr, Cu and Ni) are below the maximum threshold levels. The mean levels of Cd, Co, Cu, Ni, Pb and Zn recorded by desta etal, 2017 is comparable or slightly higher than those reported (Itanna 1998, 2002; Weldegebriel *et al.* 2012; Aschale *et al.* 2015).

According to Deribachew *et al.*, (2015) assessed heavy metal concentration on the soils of Haramya university, Awadey, and Harer sites. They have found that High Cr concentration (41.45 mg kg^{-1}) was observed for the Haramya University site and the least concentration (25.71 mg kg^{-1}) was recorded for the Aweday site. However, Cr concentration in soils of Haramaya and Harar sites were 29.52 mg kg^{-1} and 37.62 mg kg^{-1}, respectively. The concentration of Cd in the soil samples was found to be 0.79, 1.38, 1.43 and 2.56 mg kg^{-1} for Haramaya, Harar, Aweday and Haramya University sites, respectively. Similarly, the author also indicated that the soil from which the vegetables originated revealed high Co concentration (23.59 mg kg^{-1}) from the Haramya University site. This was closely followed by the Co concentration collected from Harar and Aweday sites, which amounted to 17.69 mg kg-1 and 20.65 mg kg-1, respectively. The lowest Co concentration (17.69 mg kg^{-1}) was observed for the Haramaya site. The soil sample from HU site contained high Pb concentration (47.29 mg kg^{-1}) followed by soil from Aweday site (31.25 mg $kg^{-1).}$ The lowest and comparable Pb concentration (26.04 mg kg^{-1}) was recorded in soil samples of Haramaya and Harar towns. Among the targeted heavy metal analytes, Cr was found to be the highest in concentration followed by Pb and Co. The concentration of Cd was found to be the lowest in the soil samples from all the sampling sites.

4.3 Heavy Metal Concentration in different Vegetables

Amare (2007) carried out a study to determine the levels of heavy metals, in six vegetables Potato, Carrot, Cabbage, Lettuce, Kale and Swiss chard grown by Akaki, Peacok and Kera Rivers in Addis Ababa. The results showed that, in vegetables grown with industrial and municipal wastes, in Akaki, the highest concentrations of cobalt were observed in potato followed by Lettuce and Swiss chard. Lettuce from Kera accumulated the highest concentrations of Cr and Fe; whereas kale from the same place accumulated highest amounts of Cu, Ni, and Zn. Swiss chard and carrot from Akaki contained the highest Mn and Pb, respectively. The author concludes that lettuce; Swiss chard and Kale seem to be major metal accumulating vegetables in Addis Ababa. The problems of heavy metal contamination in the vegetable farms of Addis Ababa and their accumulation on the vegetables have been well recorded by (Fisseha, 2002; Fisseha and Olsson, 2004). A comparative study conducted by Tamiru (2006) indicates that a geogenic source from deeper crust or mantle in the form of hydrothermal activity which affected the chemical composition of volcanic rocks seems to be responsible for the heavy metal concentrations in the urban environment of Addis Ababa.

Deribachew *et al.* (2015) determined quantitatively the concentrations of the metals (Cr, Co, Cd and Pb) in

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vegetables at three sites. The result indicated that the heavy metals, Cd, Cr and Pb in the cabbage, potato, and khat samples, respectively. The metal concentrations (mg kg^{-1}) in cabbage samples were found to be <MDL(method detection limit –17.13, 5.72–9.72, 1.15-2.46 and 5.48-11.95 for Cr, Co, Cd and Pb, respectively. The concentrations (mg kg^{-1}) of heavy metals in potato samples from Aweday and the vicinity of Haramya University (HU)sites ranged from 11.96-14.21, 5.15 -8.72, 1.22-1.46, and 5.43-7.78 for Cr, Co, Cd and Pb, respectively. The metal concentrations (mg kg^{-1}) in khat samples were found to be 9.04–14.54, <MDL–8.87, 0.38-3.22, and 4.49-10.95 for Cr, Co, Cd and Pb, respectively.

Table 4. Comparison of Lead and Cadmium in vegetables from different parts of world

Vegetables	Nigeria[a]		Egypt[b]		Pakistan[c]		India[d]		Tanzania[e]		Greek[f]	
	Pb	Cd	Pb	Cd	Pb	Cd	Pb	Cd	Pb	Cd	Pb	Cd
Spinach	0.56	0.03	0.34	0.11	-	-	1.44	1.96	0.30	0.05	0.05	
Lettuce	0.07	0.01	0.58	0.07	-	-	-	-	0.37	0.04	0.05	
Tomato	-	-	0.26	0.01	1.56	0.33	-	-	-	-	0.01	
Onion	-	-	0.14	0.02	0.06	0.07	-	-	-	-	0.03	
Cauliflower	-	-	-	-	-	-	1.56	2.57	-	-	-	
Lady's finger	-	-	-	-	-	-	1.03	1.41	-	-	-	

Source; ([a]Onianwa *et al.*, 2001), ([b]Radwan and Salama, 2006), ([c]Farooq *et al.*, 2008), ([d]Sharma *et al.*, 2009), ([e]Dogheim *et al.*, 2004) and ([f]Bahemuka and Mubofu, 1999)

Table 4. Continued

Vegetables	Addis Ababa		Gonder	
	Pb	Cd	Pb	Cd
Lettuce	0.25	4.99	1.78	0.17
Cabbage	0.82	0.03	0.38	0.03
Kale	0.7	0.66	0.77	0.11
Carrot	0.64	0.04	0.09	0.11

Source; (Rahlenbeck *et al.*, 1999)

According to Deribachew *et al.* (2015), Except for cabbage samples collected from Haramaya site (<MDL), the concentrations of Cr detected in all of the vegetables analyzed in this study were higher than the limit levels in food by FAO/WHO guidelines (Kihampa, 2011). Deribachew *et al.* (2015) also reported that the concentration of Cr was observed to be the highest for cabbage samples collected from HU site and it was below method detection limit in cabbage samples from Haramaya site. Among the investigated vegetables, cabbage was found to be more Cr-loaded than potato and khat. Higher concentration of this heavy metal was obtained in vegetables from HU site which might be due to sewage sludge discharged to the environment from It is concluded that amongst the investigated vegetables, cabbage was found to be more cobalt-loaded than potato and khat, and high concentration of the heavy metal was obtained from vegetable samples collected from the vicinity of Haramaya University.

Table 5. Concentrations of trace metals in leaves of some vegetables grown with industrial and municipal wastes in Addis Ababa

Crop	Metal / Metalloid Concentration										
	Farm	As	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn
		(µg/kg)			(mg/kg)						
Cabbage	Kera	<1000	<50	62	0.89	3.03	73	29	0.8	0.21	31.8
	Peacock	<1000	<50	133	1.71	3.3	173	25	0.91	0.29	31.81
	Akaki	<1000	<50	131	0.68	2.5	219	30	1.37	0.37	32.49
Swiss C.	Kera	1210	78	681	2.05	8.06	527	37.5	2.10	1.79	56.19
	Peacock	<1000	<50	317	1.04	7.88	4.61	67	0.89	0.61	48.91
	Akaki	1020	193	532	0.9	14.95	555	218	1.81	1.63	81
Carrot	Mekanisa	<1000	59	130	0.82	7.68	403	53	2.44	0.91	44.87
	Peacock	<1000	<50	84	0.28	7.79	205	29	0.98	0.54	29.9
	Akaki	<1000	84	256	0.82	8.99	469	57	1.66	2.15	59.03
Kale	Kera	<1000	130	308	0.99	9.92	331	126	4.64	0.53	63.71
	Akaki	<1000	<50	187	1.1	3.05	173	30.5	1.31	0.37	35.08
Potato	Kera	<1000	78	256	0.7	9.66	364.5	66	1.4	1.8	28.25
	Akaki	1205	159	882	1.35	13.15	816	69.5	2	2.02	64.7
Lettuce	Kera	1040	126	757	9.47	6.62	1345	106	1.86	1.59	48.63
	Bulbula	<1000	75	165	1.21	6.24	351	54	0.71	0.39	47.8
Rec.Leve (mg/kg)		0.43	0.2	-	2.3	-	425.5	-	67.9	0.3	99.4

Source; (Amare, 2007)

According to Weldegebriel *et al.,* (2012) in the urban farms of Addis Ababa and analyzes the concentrations of Cd, Co and Cu in Akaki, Kera and Peacock farms for vegetables Ethiopian kale, Swiss chard, lettuce, cauliflower and cabbage were assessed for their metal accumulations. The results indicated that, Cd in all except Swiss chard and lettuce in Peacock and cabbage in Akaki, and Pb in all of the vegetables except lettuce and cauliflower in Peacock farm surpassed the maximum limit. In these cases, consuming the vegetables may pose health risk due to the high Cd and Pb concentrations (Codex Alimentarius Commission, 2001). From the vegetables studied (mg metal kg^{-1}): Ethiopian kale (1.13) from Kera was the highest and Swiss chard (0.12) from Peacock was the least accumulators. The average Cd concentration (mg kg^{-1}) trend by vegetables was Ethiopian kale (0.79) cauliflower leaves (0.74) cauliflower (0.56) lettuce (0.39) Swiss chard (0.27) cabbage (0.18) and by farm was Goffa Kera Akaki Peacock. This trend could be ascribed to the high Cd concentration present in the studied soils. On average, the accumulation of lead in vegetables was highest in Ethiopian kale collected from Gofa and Kera farms and the lowest in cauliflower collected from Peacock farm.

Table 6. Total metal content in vegetables irrigated with Akaki River

Vegetables	Total metal content(μg g^{-1})						
	Cd	Cr	Cu	Zn	Mn	Fe	Ni
Beet	0.254±0.08	10.28±1.94	32.25±3.0	90.3±5.8	161.0±6.02	566.20±8.4	7.57±1.06
Potato	0.281±0.14	7.18±1.06	35.13±3.1	105.00±6.2	148.05±5.8	634.04±9.4	5.99±1.68
Carrot	0.198±0.06	8.05±1.08	22.18±2.6	80.12±5.2	95.10±6.2	426.01±8.8	4.51±1.08
Onion	0.271±0.12	8.58±1.6	25.13±2.4	65.9±4.2	107.9±8.06	578.0±9.4	3.67±1.02
Tomato	0.115±0.06	4.91±1.4	13.21±1.8	45.11±3.8	69.17±4.08	322.3±8.4	2.21±0.08
Pepper.	0.180±0.08	5.55±1.6	17.21±2.6	49.15±3.8	56.29±2.6	429.26±8.8	5.38±1.02
Head cabbage	0.101±0.04	4.11±108	14.20±1.8	48.47±3.6	45.4±3.8	245.2±6.4	1.95±0.06
Greenbeen	0.199±0.04	6.12±1.2	12.52±1.6	62.54±6.6	86.25±6.04	251.54±6.2	2.1±0.08
Lettuce	0.345±0.18	24.11±2.4	24.25±2.4	108.94±8.8	145.6±6.02	511.27±8.2	2.95±0.08
Maximum Limits for vegetables	0.2	2.3	-	99.4	-	425.5	67.9

Source; (Prabu, 2008)

Alemayehu, (2001) reported that vegetables from farms irrigated with the more polluted Little Akaki River (Goffa and Kera farms) were higher accumulators of metals than those irrigated with the less polluted Big Akaki River (Peacock farm) .

Four vegetable farms (Akaki, Goffa, Kera and Peacock) in Addis Ababa were irrigated with contaminated waters exhibited increased concentrations of metals both in the soils and the vegetables grown on them. But, it was noticed that different vegetables accumulate and translocate variable amounts of metals from the soil into their tissues. Without regard to bioavailability, the vegetables Ethiopian kale, Swiss chard, lettuce and cauliflower grown in these farms showed Cd and Pb at levels that could raise health risk concerns to consumers. However, cabbage in Akaki farm contained relatively lower amounts of these toxic metals (Weldegebriel *et al*., 2012) Simlar results reported by Girmay ., (2014) on vegetables grown at melka Hida and Wonji Gefrsa farms.

Tamiru *et al*., (2010) reported that, the concentration of Cd, Cr and Zn were the highest in lettuce at Kuskuam farm (utilizes tap water from public water supply) than the other farms and followed by Burayu farm (utilizes water from the Gefersa River). On the other hand, Burayu farm contains higher concentration of Pb as compared to other farms, but Ethioflora from Ziway (water from Lake Ziway) has the least concentration for all the metals. Lettuce has the highest mean concentration of Pb from Burayu farm followed by lettuce from Kuskuam and Ethiopian kale from Burayu farms. In more acidic environmental condition, which could be attained during rainfall, vegetables can pick up metals into their system. The concentration of Pb was not significantly different in all the vegetables at different farms. Vegetables containing lead may contribute to increased Pb levels in blood with increased risk of anemia and neurological disorders.

Table 7. Percentage of metal accumulations in vegetables tissue from the Soil

Vegetables	Metals	Vegetable farms		
		Kuskuam	Burayu	Ziway Ethioflora
Lettuce	Cd	28%	36%	14%
	Cr	3%	2%	9%
	Pb	7%	7%	7%
	Zn	41%	42%	30%
Ethiopian Kale	Cd	47%	42%	11%
	Cr	2%	2%	19%
	Pb	3%	4%	9%
	Zn	44%	37%	35%
Swiss chard	Cd	26%	2%	-
	Cr	1%	39%	-
	Pb	36%	1%	-
	Zn	2%	36%	-

Source; (Tamiru *et al*., 2010)

Fisseha (1998) conducted research on two vegetable farms, Peacock farm irrigated with Bulbula River and kera farm irrigated with Kebena River. The Autors' result indicated that cabbage was the least accumulator of metals. Lettuce and Swiss chard grown at kera had higher concentrations of metals compared to those grown at the peacock farm. In afew cases , As, Cr, Fe and Pb in these vegetables have surpassed maximum permitted concentrations,while Cu deficiency was observed in cabbage. In general, vegetables are among the plants that assimilate heavy metals to their metabolic need depending on their genetic makeup, from the soil they are grown and the water they are irrigated with. The variations in heavy metal concentration among vegetables were attributed to the self-selectivity of the vegetable for particular metal.

Table 8. Metal concentration in leafy vegetables from Kera and Peacock farms, Addis Abeba, Ethiopia

Elements (mg/kg)	Cabbage		Lettuce		Swisschard		Recom.Max.level for vegetables [a]
	Kera	Peacock	Kera	Peacock	Kera	Peacock	
As	0.13	0.11	1.04	0.31	1.21	0.34	0.43
Cd	0.02	0.01	0.13	0.08	0.08	0.04	0.2[b]
Co	0.06	0.13	0.76	0.17	0.68	0.32	50[c]
Cr	0.89	1.61	9.47	1.21	2.05	1.04	2.3
Cu	3.03	3.3	6.62	6.24	0.06	7.88	-
Fe	73	173	1345	351	527	461	425.5
Mn	29	25	106	54	37.5	67	500[c]
Ni	0.8	0.91	1.86	0.71	2.1	0.89	67.9
Pb	0.21	0.29	1.59	0.39	1.79	0.61	0.3[b]
Zn	31.8	31.81	48.63	47.8	56.19	48.91	99.4

Source: (Weight, 1991a, FAO/WHO-Codex Alimentarius Commission, 2001b, Pendias and Pendias, 1992c)

Ermiyas and Tigest (2017) in Swisschard vegetable cultivated in the vicinity of Addis on three vegetable growing farms (Bulbul, Kebena and Akaki) to monitor their heavy metal loads and reported that, Heavy metals in vegetable Mean Cd concentrations were highest in vegetables harvested from Kera and Lafto farming sites. Highest concentration of Cu and Zn were detected in Swiss chard leaf harvested from Bulbul, Kebena and Akaki sites than Cd, Pb and Cr. Besides, the higher concentration of Cu and Zn were registered from Bulbul and Kebena sites compared to Akaki site. On the other hand Swiss chard leaf harvested from Kebena site showed higher Zn content than Bulbul and Akaki farms.

Deribachew *et al*. (2015) assessed the levels of metal concentration in the vegetables (cabbage, potato and khat) grown at Harar Haramaya University (HU) and Aweday site. The result indicated that all samples contained Cd concentration above the maximum permissible limit. Among the sampling sites, the samples from the HU site contained higher Cd concentration which might be attributed to the sewage sludge discharge from the University's laboratories, student dormitories, garage and cafeterias. Leafy vegetables (khat and cabbage) contained the highest levels of Cd which shows higher accumulation of this metal in the aerial parts of the plants than the roots. It has been reported that Cd is a highly mobile metal, easily absorbed by the plants through root surface and moves to wood tissue and transfers to upper parts of plants (Mohsen and Mohsen, 2008).

4.3. Heavy Metal Concentration in Washed Vegetables

Yonas, (2015) assessed the concentrations of Pb, Cr and Cd in washing water of the green vegetables grown around old Saris Alcohol Factory (Kebele 58) area vegetable farm of Southern Addis Ababa. The result shows that the Ethiopian Kale accumulates more Cd in root part than other parts. Lettuce accumulates more Cr in root part than other parts. On the other hand the leaf of swisschard accumulates more Cr in than other parts. The root of lettuce accumulates more Pb than other parts that the stem of Chard accumulates more Pb than other parts around old Saris Alcohol Factory (Kebele 58). the author conclude that Pb is the major heavy metal pollutant accumulated in leaf vegetables grown in agricultural soils around old Saris Alcohol Factory (Kebele 58) area which exceeds maximum limit in leaf and root of Ethiopia kale and root and stem part of Swiss chard. Due to this reason if the vegetable is not properly washed additional heavy metal can be consumed from the surface above the permissible limit because of the sum of the accumulation in the part and on the surface of the vegetable part (example Cd in Swiss chard leaf and washing water). The surface contamination can be caused by air, irrigation water or dust during collection and transportation.

Yusuf and Oluwole (2009) reported that, variations in the magnitude of reductions in heavy metal contamination due to washings of vegetables also depicted variations in heavy metal deposition at various market sites. They further suggested that to reduce the health risk, vegetables should be washed properly before consumption as washing can remove a significant amount of aerial contamination from the vegetable surfaces.

Al-Jassir *et al*. (2005) assessed the deposition of heavy metals on green leafy vegetables sold on road sides of Riyadh city, Saudi Arabia. In this study the levels of lead, cadmium, copper and zinc were determined in washed and unwashed green leafy vegetable samples. The result of this study in comparison with PTDI values indicates that intake of heavy metals through leafy vegetables would not mean a health hazard for consumers but gets significance in the light of reported daily intake of Cd and Pb through diet in the country. A comparison was made with some reported test vegetables from different countries, showing the concentration of heavy metals in them.

4.4. Heavy Metal Concentration in Transportation and Marketing Vegetables

The studies conducted to assess the level of contamination of fruits and vegetables in jimma Town the Result Indicated that the samples were collected from four different local markets in Jimma Town. The results of the study showed that samples collected from “Hirmata Merkato” (29.8%) had high contamination rate followed by samples collected from “Bishishe” (28.4%), “Agip” (22.1%), and “Kochi” (19.7%) markets. The percentage contamination rate was significantly different among samples collected from the different markets (= 0.003). The habit of eating raw vegetables like salad and tomato is commonly practiced in the study area. Hence, the findings of the present study are of public health importance, requiring an appropriate intervention to prevent transmission of parasitic diseases that can be acquired through consumption of contaminated fruits and vegetables (Tamrat, *et al*., 2014 cited in Tadele and Derebew, 2015). This variation among the produces might be due to the fact that salad, cabbage, carrot, and lettuce have uneven surfaces which make the parasitic stages attach more easily to the surface of these vegetables. The smooth surface of green pepper, tomato, and mango might reduce the rate of parasitic attachment hence had lower contamination rate (Tamrat, *et al*., 2014)

Sharma *et al*. (2008) have generated data on heavy metal pollution in and around Varanasi city of India and associated health risk assessment for the consumer’s exposure to the heavy metals. They proposed the hypothesis that the transportation and marketing of vegetables in contaminated environment may elevate the levels of heavy metals in vegetables through surface deposition has been proved through this study. The consumption of vegetables directly from production areas might be less hazardous to human health in comparison to those from polluted open market areas. Heavy metals have a toxic impact but detrimental impacts become apparent only when long-term consumption of contaminated vegetables occurs. It was suggested that regular monitoring of heavy metals in vegetables and other food items should be performed in order to prevent excessive buildup of these heavy metals in the human food chain. Appropriate precautions should also be taken at the time of transportation and marketing of vegetables.

High accumulation of lead, chromium and cadmium in leafy vegetables due to atmospheric deposition has been reported by De Nicola *et al*. (2008). The levels of heavy metals (zinc, manganese, copper and lead) in vegetables collected from dump sites of Nigeria were found to be high due to vehicular emission. Okunola *et al*. (2008) reported that, automobiles are a major source of these metals along the road side environment. The magnitude of heavy metal deposition on vegetable surfaces varied with morphophysiological nature of vegetables (Singh and Kumar, 2006).

4.5. Heavy Metal Concentration in Boiled Vegetables

In Boiled vegetables heavy metal contents reduced significantly. In cauliflower purchased from Gariahat, Maniktala, VIP Market, Shyambazar and Brinjal purchased from Gariahat, Maniktala, Shyambazar, content of Cd reached below safe value after boiling in water for 15 minutes. Cauliflower collected from Lake Market and VIP market showed Cd content slightly above the recommended value even after boiling. But even after washing and boiling, Pb content of all the vegetables remain higher than the recommended value. Cu content in unwashed Brinjal (Lake Market, Maniktala), Indian Spinach (VIP market, Shyambazar) exceeds safe value. But in boiled vegetables Cu content did not exceed the safe value. Cr content in brinjal, Indian spinach in a few samples was found to exceed the safe value. After washing only one sample Red Indian spinach purchased from Maniktala showed higher amount of Cr. Pb content in all vegetables (Washed, Unwashed and Boiled) exceed safe value (0.2 mg/Kg) (Banerjee *et al.*, 2011).

5 Production and Consumption trend of Leafy Vegetables in Addis Ababa

Currently, there are numerous local outlets that distribute fresh produce in Addis Ababa. The major sources of vegetables are farms in different parts of the city which use heavily contaminated water for irrigation. Various undesirable microorganisms may be present at the time of purchase in grocery stores. This becomes particularly important in salad vegetables which are prepared and consumed without heat treatment (Aberra *et al.,* 1991). Until recently, vegetables did not constitute a major part of the Ethiopian diet, except during the fasting period. However, since recent years their consumption is increasing gradually, particularly among the urban communities. This is due to increased awareness on the food value of vegetables, as a result of exposure to other cultures and acquiring proper education. Vegetables grown in Addis Ababa include: potato (*Solanum tuberosum* L.), swiss chard (*Beta vulgaris* L. var. *cicla*), carrot (*Daucus carota* L.), cabbage (*Brassica oleracea* L. var. *capitata*), Ethiopian kale (*Brassica carinata* A. Br.), lettuce (*Lactuca sativa* L. longifolia), spinach (*Beta vulgaris* var. *cicla*), cauliflower (*Brassica oleracea* L. var. b*otrytis*) and red beet (*Beta vulgaris* L. var. *vulgaris*). These are often grown on the embankments along the major rivers within Addis Ababa and the neighboring towns of Akaki, Alem Gena, and Sebeta (Mogessie, 1989).

The vegetable farms at Akaki and the Peacock Park are among the biggest farms in the capital, where a substantial amount of vegetables is being produced seasonally. These farms are irrigated with the wastewater from rivers Akaki and Bulbula. Before several decades, the water from the rivers in the capital was clean. However, with the increase in the urban population and industrialization, the water has now become contaminated with various pollutants, among which are heavy metals (Fisseha, 1998). Vegetables grown at contaminated sites could take up and accumulate metals at concentrations that are toxic. In addition, they could be contaminated as farmers wash vegetables with wastewater before bringing them to market (Fisseha, 2002). If fruits and vegetables are to be washed or irrigated in processing plants or farm lands, respectively, with contaminated water, this should therefore be well sanitized to prevent food borne illnesses (Weigert, 1991).

The average amount of vegetables consumed per day by a person in Addis Ababa is 5g in contrast to the international daily average of 50g for leafy vegetables (Fisseha, 2002). It is because of this, that the intake of metals from the studied vegetables constitutes much less than the theoretical maximum daily intake (TMDI) or the provisional tolerable weekly intake (PWTI), which are used to express the exposure of consumers and associated health risk. A recent study on leafy vegetables bought from Addis Ababa market also confirms this (Prabu, 2008). However, with increase in vegetable consumption this situation could easily change. For instance, it has been reported that through the introduction of bio-intensive gardening in some households in Addis Ababa the daily vegetable intake per person has risen from 5g to 161g (Fisseha, 2002).

6. Predicted Health Risk from Metal Contaminated Vegetables

The contamination of agricultural products with heavy metals has become an important concern throughout the world due to the potential adverse effects of heavy metals on human health. Heavy metals are very harmful because of their non-biodegradable nature, long biological half lives and their potential to accumulate in different body parts. They are one of a range of important types of contaminants that can be found on the surface and in the tissues of fresh vegetables. Most of the heavy metals are extremely toxic because of their solubility in water. Now a day's heavy metals are ubiquitous because of their excessive use in industries. Factors associated with the possible health effects of exposure to cadmium, lead and mercury have been investigated over many years in occupational settings, using experimental animals and humans exposed to environmental pollution. The types of adverse health effect are known to a great extent but, because of the very strong influence of confounding factors, it is very difficult or almost impossible to find thresholds for some outcomes such as impairment of cognitive functions in children exposed to lead or mercury (Suruchi and Pankaj, 2011). Chronic low level intakes of heavy metals have adverse effects on human beings and other animals due to the fact that there is no effective mechanism for their elimination from the body. Metals such as lead, mercury, cadmium and copper are cumulative poisons. These metals cause environmental hazards and are reported to be exceptionally toxic (Chove *et al.*, 2006).

Prolonged human consumption of unsafe concentrations of heavy metals in food stuffs may lead to the disruption of numerous biological and biochemical processes in the human body, the chronic accumulation of heavy metals in the kidney and liver of humans causing disruption of numerous biochemical processes, leading to cardiovascular, nervous, kidney and bone diseases (Steenland and Boffetta, 2000; WHO, 2001; Jarup, 2003). Mercury (Hg) and lead (Pb) are associated with the development of abnormalities in children. Suruchi and Pankaj (2011) have reported that long term intake of Cd caused renal, prostrate and ovarian cancers. Cadmium has also been identified as a potential human carcinogen, causing lung cancer, kidney and bone damage. Food is the main source of cadmium exposure in the general population (representing >90% of the total intake in non-smokers). Cadmium is accumulating in soils and catchments under certain environmental conditions, thus increasing the risk of future exposure through food. These heavy metals are also implicated in carcinogenesis, mutagenesis and teratogenesis (Radwan and Salama, 2006). Lead exposures have developmental and neurobehavioral effects on fetuses, infants and children and elevate blood pressure in adults. Other metals, such as copper and zinc are essential for important biochemical and physiological functions and necessary for maintaining health throughout life (Linder and Azam, 1996).

The potential health risk to Addis Ababa residents associated with vegetable consumption was assessed by Yonaes, (2015) with the THQ. Of the three heavy metals, Pb posed the greatest health risk to both adult and children consumers of vegetables grown in study areas especially Swiss chard, followed by Ethiopian Kale. For both adults and children the THQs of all three heavy metals in the three leaf vegetables was less than 1.0, indicating that the residents in the Addis Ababa are not exposed to significant health risks associated with consumption of green leafy vegetables grown around old.

Intestinal parasitic infections are widely distributed throughout the world causing substantial intimidation to the public health, economy, and physical and cognitive development particularly among children in developing countries like Ethiopia. The consumption of fruits and vegetables helps in protecting human body from a number of diseases. Eating unclean, raw, or undercooked fruits and vegetables is one of the means by which the transmission of intestinal parasitic infections is propagated. Despite the fact that intestinal parasitosis is common in Jimma Town (Tadele and Derbew, 2015).

Economic cost Impact of water pollution

According to *Gebre G.& Van Rooijen D., 2017.* Polluted water can be a cause for two kinds of economic costs. The first one, it reduces the given total amount of adequate water available for household consumption or agricultural and industrial usage. Thus it leads to extra cost incur to get back the required water to be consumed by the households from the suppliers. Secondly, costs incurred due to the use of this polluted water for the household consumption and production purpose in many aspects. Both quantity and quality of products decreased due to using contaminated water and cost is going to be incurred in this aspect as well. Contaminated water also a cause for loosing many aquatic species and ecosystem and there are many costs associated with recovering or importing this species back for consumption or production purpose.

Table 9. Types of vegetables grown and Income generated derived from irrigated agriculture at Addis Ababa

Vegetables	**Plot size/ha**	**Market price/birr/kg**	**Net income biirr/ha**	**Total net income birr/year**	**Average farmers income birr/month**
Lettuce	**55**	**2**	**24,279**	2,666,805	141.2
Swiss Chard	**49**	**2.00**	**21,810**	**1,060,620**	**56.2**
Carrot	46	1.00	14,854	363,597	1, 72.2
Cabbage	**33**	**1.00**	**24,425**	**1,591,045**	**84.2**
Kale	**39**	**2.00**	**9,269**	**724,094**	**38.3**
Potato	**49**	**1.00**	**11,915**	**1,160,521**	**61.4**
Beetroot	**25**	**1.00**	**22,010**	**1,113,706**	**59.0**
Tomato	**15**	**1.25**	**14,735**	**442,919**	**23.5**
Onion	**7**	**2.00**	**12,960**	**181,440**	**9.6**
Cucumber (Zukuni)	**10**	**2.00**	**65,660**	**1,353,909**	**71.7**
Cauliflower	27	3.00	14,070	747,398	39.6

Source: Bureau of Agriculture Addis Ababa, 2003

Summary and Conclusion

Vegetables constitute an important part of the human diet since they contain carbohydrates, proteins, vitamins, minerals and fibers required for human health. They also act as neutralizing agents for acidic substances formed during digestion. As human activities increases, especially with the application of modern technologies, pollution and contamination of the human food chain has become inevitable. Heavy metals uptake by plants grown in polluted soils has been studied to a considerable extent.

Heavy metal contamination of the food items is one of the most important aspects of food quality assurance. International and national regulations on food quality have lowered the maximum permissible levels of toxic metals in food items due to an increased awareness of the risk, these metals pose to food chain contamination.

In general, most heavy metals are not biodegradable, have long biological half-lives and have the potential for accumulation in the different body organs leading to unwanted side effects. There is a strong link between micronutrient nutrition of plants, animals and humans and the uptake and impact of contaminants in these organisms. The content of essential elements in plants is conditional, the content being affected by the characteristics of the soil and the ability of plants to selectively accumulate some metals.

The contamination of heavy metals to the environment, i.e., soil, water, plant and air is of great concern due to its potential impact on human and animal health. Cheaper and effective technologies are needed to protect the precious natural resources and biological lives. Substantial efforts have been made in identifying plant species and their mechanisms of uptake and hyper accumulation of heavy metals in the last decade. The contamination of heavy metals to the environment, i.e., soil, water, plant and air is of great concern due to its potential impact on human and animal health. Cheaper and effective technologies are needed to protect the precious natural resources and biological lives.

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