

Chapter

Heavy Metal Contamination in Vegetables and Their Toxic Effects on Human Health

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Abstract

Vegetables are a prevalent nutrition for people all over the world because they are high in important nutrients, antioxidants, and metabolites that function as buffers for acidic compounds created during digestion. Vegetables, on the other hand, absorbed both vital and poisonous substances through the soil. Possible human health concerns, including as cancer and renal damage, have been linked to the consumption of heavy metal-contaminated vegetables (HMs). Heavy metals like Cr, Mn, Fe, Ni, Cu, Zn, Cd, Pb, and Hg were found in high concentrations in popular vegetables such as *Amaranthus tricolour* L., *Chenopodium album* L., *Spinacia oleracea*, *Coriandrum sativum*, *Solanum lycopersicum*, and *Solanum melongena*. The toxicity, fortification, health hazard, and heavy metals sources grown in soil are detailed in this review study.

Keywords: vegetables, heavy metals, toxic effects, human health, contamination

1. Introduction

Heavy metals, which are a major environmental problem, have a natural residency in the continental mantle. In general, a heavy metal is nothing but any chemical element which is metallic with a comparatively higher density that is poisonous above a tolerable range, such as mercury (Hg), cadmium (Cd), chromium (Cr), nickel (Ni), lead (Pb), and so on [1–3]. Contaminated heavy metal is a key cause of pollution and a possible increasing environmental and human health hazard all over the world, resulting in disorders in people and animals by consuming polluted vegetables. Heavy metals have damaged soil and water eco-systems worldwide. Heavy metals have been discharging into the environment through a variety of practises, including irrigation with polluted water, the use of chemical-based fertilisers, the dumping of industrial effluents into bodies of water, volcanic eruptions, forest fires, and so on [4]. Metals may seep into the ground, ground water, and eventually agricultural plants. Heavy metals can have serious consequences for human health when vegetables polluted with these metals are ingested. Although trace levels of copper (Cu), iron (Fe),

manganese (Mn), nickel (Ni), and zinc (Zn) are needed in plants, excessive quantities of these metals can be hazardous [5, 6]. Metals including aluminium (Al), arsenic (As), cadmium (Cd), lead (Pb), and mercury (Hg) are not essential for regular human function and can cause toxicity promptly [7].

Vegetables are an integral portion of the normal diet because they contain nutritionally vital substances that are necessary for human existence. They also act as protective foods by contributing in the avoidance of disorders in people. Vegetables grown in areas polluted with dangerous metals or nearby sources of heavy metal pollution may gather greater amounts of heavy metals than other vegetables. Heavy metals are taken through the roots of plants from polluted soils and environmental wastes, entering the edible sections of plant tissues or accumulating on the surface of vegetables. Protracted irrigation of heavy metals with polluted garbage water raises heavy metal concentrations over the allowable limit [8].

The sensitivity, supplementation, potential dangers, and heavy metals sources grown in soil are all reviewed in this review study. Vegetables absorbed both essential and toxic chemicals from the soil. The consumption of heavy metal-contaminated vegetables has been related to potential human health issues such as cancer and kidney impairment (HMs). Heavy metals including Cr, Mn, Fe, Ni, Cu, Zn, Cd, Pb, and Hg were discovered in high amounts in common vegetables such *Amaranthus tricolour* L., *Chenopodium album* L., *Spinacia oleracea*, *Coriandrum sativum*, *Solanum lycopersicum*, and *Solanum melongena*.

2. Accumulation of heavy metals in vegetables

Mechanical, biochemical, and biological processes, as well as doings of human, could releases heavy metal into the environment and may cause heavy metal contaminants to accumulate inside living creatures in the food chain [9, 10]. HMs diffuse into the soil, air, as well as water bodies, wherever they could be had or eaten by crops/plants, bio-accumulating into upper consumers, and then biomagnified [11–13]. HMs cannot be easily removed from the top of the food chain once they have entered it, and they are thus cycled throughout the entire food web. Numerous hyperaccumulated plants provide nourishment for both humans as well as animals. As a result, the rotation from soil to humans thru plants and back into the soil following the expiry of upper consumers provides a pathway for HMs to persist in the environment for extended time periods, causing a variety of negative impacts. Ingestion vegetables containing HMs may provide potentially harmful health risks to lifeforms [14, 15] (**Figure 1**).

Heavy metals come in the food chain from a variety of sources. Cd, for example, took up from the soil by the roots and transferred to the body of plant. In the instance of Pb, the heavy metal is absorbing by plants through air pollution, whereas As and Hg can be received from dirt water. Some heavy metals having a capacity to accumulate in the tissues (liver, feathers, muscles, kidney, and other organs) of upper customers during the transit from one segment of the food chain to the next. Metal are liberated into the soil, water, and air from their parental material. These HMs are found in soil in decipherable, non-soluble, and moderately soluble forms, with the soluble forms being most harmful since they are quickly captivated by plants through roots before spreading all over the whole plant organs. Metal toxicity is caused through the disruption of cellular metabolic processes [16–19]. Hazardous metals are changed to persistent oxidation states in the acid standard and combine with particular proteins and enzymes when they reach the stomach from contaminated foods. The stabilised



Figure 1.
 Vegetables get contaminated through various ways.

metal compounds interact with cysteine's sulphydryl groups ($-SH$) as well as methionine's sulphur atoms ($-SCH_3$), causing protein molecules to breakdown [18, 20].

3. Impact of heavy metals on the quality of vegetables

Vegetation sensitivity to nutrition and metal concentrations varies, and their reactions can be seen in variations in stain concentration, liquid content, dehydrated weight, as well as development [21–23]. All of these variations in plant properties lead to different light absorption as well as reflectivity characteristics, which can be utilised to determine soil pollution and plant physiological condition. A few research findings have shown that metal and nutritional anxiety in plants contribute to differences in the supernatural reflectivity of the undergrowth [24–26], which may end up causing numerous biological effects in the plants and thus contribute to nutritional availability in veggies increasing or decreasing. Toxicity of metals in plants causes high germination inhibition, significant reductions in rates of growth, variations in photosynthetic efficiency, respiration, and transpiration, as well as changes in nutrient homeostasis and Mn, K, Mg. [27, 28] discovered distinctive leaf symptoms in *Raphanus* and *Phaseolus*, as well as a decrease in the root: shoot ratio and ratio of biomass. Higher levels of HM as well as cytochemical localization of Zn in *Raphanus* and *Pha-seolus*, which may cause stress, defence, and detoxification, are attributable to Zn's direct actions and the combined indirect effects of heavy metal (Table 1).

Sr. No.	Heavy metals	Vegetables	Observations	Area	References
1	Pb, Cd	<i>Spinacia oleracea</i> and <i>Solanum lycopersicum</i>	The concentration of the HMs increased than allowable limit	Amba nalla in Amravati city, Maharashtra	[29]
2	Pb, Cd, Cu, Zn, and As	<i>Raphanus sativus</i> L., <i>Daucus carota</i> L., <i>Ipomoea batatas</i> L., <i>Brassica parachinensis</i> , <i>Brassica campestris</i> L., <i>Solanum melongena</i> L., <i>Capsicum annuum</i> Linn, <i>Lycopersicum esculentum</i> Mill, <i>Momordica charantia</i> Linn, <i>Luffa cylindrical</i> , <i>Cucumis sativus</i> , <i>Cucurbita moschata</i> Duch, <i>Ipomoea aquatica</i> Forsk, <i>Amaranthus tricolor</i> , <i>Brassica oleracea</i> , <i>Brassica Chinensis</i> Linn, <i>Brassica pekinensis</i> , <i>S. oleracea</i> , <i>Coriandrum sativum</i> , <i>Lactuca sativa</i> , <i>Vigna unguiculata</i> , and <i>Phaseolus vulgaris</i>	Observing health problems	Shizhuyuan area in China	[30]
3	Cr, Ni, Cu, Zn, As, Cd, and Pb	<i>S. lycopersicum</i> , <i>Lagenaria siceraria</i> , <i>Solanum melongena</i> , <i>Cucurbita maxima</i> , <i>Amaranthus viridis</i> L., <i>Amaranthus paniculatus</i> L., and <i>Capsicum annuum</i> L.	Health risks of Cr, Cu, As, Cd, and Pb should be of great concern	Dhaka city, Bangladesh	[31]
4	As, Cd, Cr, Pb and Zn	<i>Lepidium sativum</i> , <i>Foeniculum vulgare</i> , <i>C. sativum</i> , and <i>Spinacea oleracea</i>	Pb and Cd levels exceeded the maximum permissible limits set by FAO/WHO for human consumption	Market sites of Kathmandu	[32]
5	Cd, Cu, Pb and Zn	<i>Lactuca sativa</i> L., <i>Spinacia Oleracea</i> L., <i>Allium ampeloprasum</i> , <i>Mentha</i> , and <i>Petroselinum crispum</i> L.	Cd and Pb levels exceeding the maximum level (ML) set by the Australian and New Zealand Food Authority	Port Kembla and Boolaroo, Australia	[33]
6	Fe, Zn, Cu, Pb, Cd, Mn, and Cr	<i>S. oleracea</i> L., <i>B. oleracea</i> L. var. <i>capitata</i> Linn., <i>B. oleracea</i> L., <i>S. melongena</i> , <i>Abelmoschus esculentus</i> , <i>Lycopersicum esculentum</i> Mill, and <i>R. sativus</i> L.	High level of pollution along cement factories of Rewa, India	J.P. Cement (Rewa)	[34]
7	Cu, Cd, Zn and Pb	<i>Beta vulgaris</i> L., <i>A. esculentus</i> L. and <i>B. oleracea</i> L.	The concentration of the HMs increased than allowable limit	Market sites of India	[35]

Table 1.
Heavy metals impacted vegetables from different areas.

Growth of plant was inhibited in both treatments of Cd, i.e. leaf chlorosis symptoms at 10 M Cd and necrotic patches at 100 M Cd, according to [36, 37], and browning of root was detected in both treatments. In root extracts of Cd-exposed plants, the action of phosphoenolpyruvate carboxylase, which is involved in the anaplerotic fixation of CO₂ into organic acids, increased. At 100 M Cd, citrate synthase, isocitrate dehydrogenase, and malate dehydrogenase activities increased significantly in leaf extracts, although fumarase activity declined. Membrane damage, electron transport disturbances, enzyme inhibition/activation, and interactions with nucleic acids are among known effects of metal toxicity [38, 39]. The production of oxidative stress and the substitution of critical cofactors of numerous enzymes, like Zn, Fe, and Mn, are two plausible causes for the development of these illnesses. Various researchers have associated oxidative stress with introduction to high heavy metal concentrations [40, 41]. Heavy metals' influence on plants, according to [42–44], growth suppression, physical harm, and a decay in physical, biological, and plant function are all consequences. Heavy metal toxicity disrupts cell and organelle membrane integrity by blocking enzymes, polynucleotides, and important nutrient and ion transport systems, displacing and/or substituting essential ions from cellular locations, denaturing and inactivating enzymes, and denaturing and inactivating enzymes. At supra-optimal absorptions, heavy metals as Cd, Pb, Hg, Cu, Zn, and Ni impede plant development, growth, and yield.

Interspecies distinctions in metal and nutrient uptake, as well as differences caused by therapeutic interventions within the similar plant, are minor and could be due to plant biomass and root exudes into the soils. The availability of metals and nutrients for plant absorption will be affected when plants develop and roots grow in soil due to biogeochemical interactions of organic acids generated by root exudes. This method may explain why tomato (*Solanum lycopersicum*) and pepper (*Piper nigrum*) plants absorb more Cu as well as Zn than other crops. According to [45, 46], Zn & Cu create organometallic compounds with organic acids found in root exudes, resulting in enhanced plant absorption. Excessive Zn in the growth media was shown to be hazardous to all 3 vegetable crops. Chlorosis in early leaves, searing of coralloid roots, and severe suppression of plant development were all signs of toxicity. With rising Zn concentrations, shoot fresh weight (FW) dropped.

Cu had a negative effect on seed germination in Chinese cabbage, according to [47]. (*Brassica pekinensis*). The germination rate was significantly lowered by the 0.5 mmol L⁻¹ Cu treatment, with a median fatal dosage of 0.348 mmol L⁻¹. In early seedlings, Cu lowered root and shoot lengths, however the 0.008 mmol L⁻¹ treatment resulted in stimulatory elongation of the shoots. The aluminium coagulators had a toxic outcome on the plant growth of vegetable seeds at the tested concentrations. Furthermore, excessive copper levels in growing media harmed all 3 vegetable crops, causing chlorosis in new leaves, brown, stunted, coralloid roots, as well as plant development inhibition [48, 49].

Lin et al. [40] find that under higher Cd concentrations, the content of protein of desolate carrot (*Daucus carota*) and common sunflower (*Helianthus annuus*) decreased. Increased Zn concentrations reduced the content of protein of algae and Rapeseed (*Brassica napus*), according to [50]. The reduce in content of protein has been linked to increased protease activity speeding up protein breakdown [51, 52] or heavy metals interfering with nitrogen metabolism. Heavy metals, according to [53], may disrupt nitrogen metabolism, reducing protein synthesis in vegetables, and are also reason for a decrease in photosynthesis, which affects protein synthesis [40]. Cd

could impair the absorption of Fe, potassium, Mn & calcium [54], and the toxicity amount had been observed to be higher in the case of specific heavy metals.

4. Intake of heavy metal in human body through vegetables

The industries are growing day by day in our country. The waste chemical contaminated water from these industries is directly thrown in river, sea, etc. Also the wastes, garbage from city is thrown in the water. This is the major reason behind the contamination of water. This water is used in many purposes like drinking, agriculture, etc. The contaminated water used in agriculture is absorbed by various vegetables. Resulting the vegetables become contaminated. We the humans use these contaminated vegetables in eating purpose. Once it is ingested in digestive system, it shows poisonous effects on the body as described in **Figure 2**. Heavy metal exposure typically follows this outline: from industries to air, soil, water, and foods, and then to people [55–59]. This heavy metals are existing in a amount of formats. Heavy metals like lead, cadmium, manganese, as well as arsenic could arrive the body by the gastrointestinal system or the entrance of digestive system while eating, drinking, or eating fruits and vegetables. The bulk of bodily heavy metals are transferred from blood to tissues [60, 61]. Red blood cells passes lead to not only the liver but also kidneys, where it is subsequently re-assigned as phosphate salt to the teeth, bone as well as hair [62–64]. Cadmium firstly fixes to blood cells & albumin, formerly to metallothionein in the kidney as well as liver. Later being carried through the blood to the lungs, vapour of manganese disperses over the membrane of lung to the central nervous system (CNS). Water solvable inorganic manganese ions are dispersed in the plasma as well as kidney for renal removal, whereas fat solvable manganese salts are diffused in the colon for faecal removal. Accumulation of Arsenic in the heart, lungs, liver, kidney, muscle, and neural tissues, as well as the skin, nails, and hair, afterward being passed by the circulation.

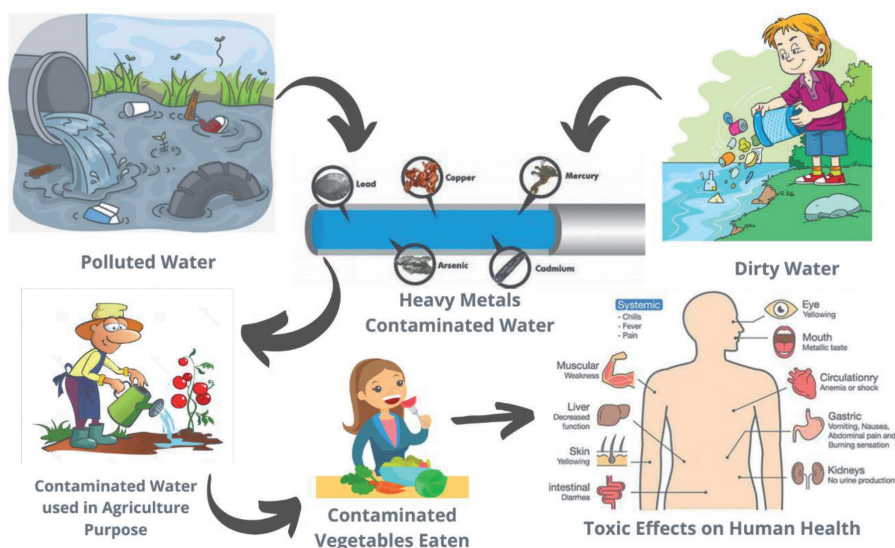


Figure 2.
Cyclic explanation of how vegetables contaminated and its toxic effects on humans.

Free radicals are known to be produced by some heavy metals, which can cause oxidative stressing as well as other cellular damaging. The method by which free radicals are generated is unique to heavy metal. Heavy metals are acetified by the acid medium of stomach when they are consumed through food or drink. They oxidised to several oxidative states (Zn^{2+} , Cd^{2+} , Pb^{2+} , As^{2+} , As^{3+} , Ag^{+} , Hg^{2+} , etc.) in this acidic media, which can quickly fix to biological molecules like proteins as well as enzymes to create persistent and strong connections. The thio groups are the most prevalent functional groups that heavy metals fixes to (SH group of cysteine and SCH₃ group of methionine). Cadmium had shown to bind to cysteine remains in the catalytic surface of human thiol transfers in vitro, consisting thioredoxin reductase, glutathione reductase, as well as thioredoxin [65–70].

Heavy metal-bounded proteins might be able to be useful as a substratum by some enzymes. The heavy metal-bounded protein has an enzyme-substrate complex in a specific pattern, which prevents the enzyme through absorbing any more substrates till it is release. Resulting of the enzyme being inhibited, the product of substratum is not formed, and the heavy metal becomes embedded in the tissue, producing dysfunctions, abnormalities, and damage. Constraining thiol transferases reasons an rise in oxidative pressure and cell damaging. Poisonous arsenic, which can be there in fungicides, herbicides, and insecticides, can damage enzymes' –SH groups, preventing them from catalysing reactions.

As arsenite-inducing protein clustering was found and proved to be concentration-dependending, heavy metals may cause proteins to aggregate. The clusters also comprised a diverse ranging of proteins with roles linked to metabolism, protein portable, synthesis of protein, and protein stability [71–75]. After exposing to equi-toxic quantities of cadmium, arsenite, as well as chromium (Cr(VI)), *Saccharomyces cerevisiae* (budding yeast) cells gathered aggregated proteins, and the outcome of heavy metals on protein aggregation was altered in this direction: arsenic > cadmium > chromium [76–80]. The effectiveness of this agents' cellular uptake/export, as well as their different modalities of biological action, are likely to determine their in vivo potency to cause protein aggregation.

5. Heavy metal hazardous effects on human health

Heavy metals in soil, air, as well as water are a severe concerned since they will have a detrimental impact on food sustainability and human health. Eating of heavy metal-contaminating vegetables can result in a variety of ailments in consumers. Vegetable eating is the primary route for heavy metals to infect humans. Heavy metal pollution in food may produce heavy metal buildup in humans' kidneys and livers, disrupting a variety of biochemical processes that can lead to cardiovascular, neurological, renal, and bone illnesses [35, 81–84]. The biotoxic effects of high are determined by their concentrations and oxidation states, deposition mechanism, chemical composition of plants, physical characterisation, and rate of intake (**Table 2**) [1].

Cd had being discovered to have deleterious effects on a number of essential enzymes. The negative repercussions might include everything from a painful bone condition called ostemalacia to red blood cell disintegration and renal issues. High lead in the blood can induce hypertension, nephritis, and cardiovascular illness, as well as affecting children's cognitive development [61, 93, 94]. Cu as well as Zn can lead to acute stomach and bowel issues as well as liver damage [95–97]. Arsenic exposurance is linked to angiosarcoma and skin cancer [98, 99]. Zn, on

Heavy metal	Applications	Health effects	References
Chromium	paints pigment, fungicide, Pesticide	Cancer, nephritis and ulceration	[16]
Lead	Plastic, batteries, Auto exhaust, gasoline	Risk of cardiovascular disease and neurotoxic diseases	[85]
Cadmium	Pigments Fertiliser, plastic	Endocrine disrupter Carcinogenic, Alter calcium regulation in biological systems mutagenic, lung damage, fragile bones	[86, 87]
Zinc	Fertilisers	Dizziness, fatigue, vomiting, renal damage, decreased Immune function	[88, 89]
Nickle	Electroplating	Lung cancer, Immuno-toxic Allergic disease, neurotoxic, genotoxic, Infertility	[90]
Copper	Electronics, wood preservative, Architecture	Brain damage, Chronic anaemia, Kidney damage, Intestine irritation, Liver cirrhosis, Spontaneous abortions and gestational diabetes	[91]
Arsenic	Pesticides, Wood products & herbicides	Immunological, Reproductive and Developmental alterations and causing cancer	[92]
Mercury	Catalysts, Electric Switches, rectifiers, CFLs	Neurological and immune disorders, fatal to kidney and lungs	[27]

Table 2.

Various heavy metals, their application areas/industries, and probable harmful health consequences on humans produced by these heavy metals are shown.

the different side, can impair immunological function and raise stages of higher-density lipoproteins [99].

Due to higher heavy metal concentrations in the soil, fruit, as well as vegetables, the Vanregion of Turkey has a higher incidence of greater gastrointestinal cancer rates. Eating of heavymetal-contaminating food can depletes some vital bodily nutrients, resulting in lowered immune defences, altered physico-social behaviour, intrauterine growing retardation, and problems linked with malnourishment [100, 101]. Metal poisoning has also been linked to neurotoxic, carcinogenic, mutagenic, or teratogenic consequences, which might be acute, chronic, or sub-chronic. Some employees also stated having problems with their kidneys [102, 103].

The link between heavy metal exposure during pregnancy and foetal development has been widely established. Heavy metals have the potential to harm the reproductive system of female by causing damage to the ovary and hormone production and release [104, 105]. [106] found that heavy metals can causing alterations in the structure and role of the ovary, as well as embryonic development, when they were researched on the female reproductive system. In vivo and in vitro investigations have confirmed the depositing of heavy metals in the ovary. Pb in the body of the host has been linked to lower birth weightiness, preterm birthing, stillbirths, spontaneous abortions, as well as hypertension [107], while Ar in the body of the host has been linked to foetal loss, stillbirths, spontaneous abortions, and impaired growth as well as development [107, 108]. While Cd exposure is linked to low birth weight, AS exposure has been linked to spontaneous abortions and neurotoxic consequences. Cu poisoning is linked to lower birth weightiness, spontaneous abortions, and gestational diabetes [109]. [110] found women who had miscarriages had high methylmercury

levels, albeit the link among methyl mercury exposure and spontaneous abortion has yet to be shown [110]. Stillbirths, miscarriages, and foetal development problems have described as a effect of mercury toxicity.

6. Future prospects and conclusion

Pollutants in the environment, food safety and security, and human health are all intricately intertwined. Heavy metal concentrations in the environment have risen rapidly in recent years. Heavy metal sources in vegetables differ across the developing and industrialised worlds. The principal contamination causes in soil–crop systems in industrialised nations are the deposition of PM on food plants and the use of industrial effluents and sewage sludge as fertilisers. However, in underdeveloped nations, irrigation with untreated sewage or sludge is the primary cause of contamination for food crops. Heavy metal transmission from soil to crop systems is complicated and employs a variety of methods. To establish the true metal toxicity of multi-metal toxicity in vegetables, special care must be used. Human health hazards have been extensively investigated on a universal basis, but only a handful of these findings employed suitable epidemiological methodology. Existing control methods focus on decreasing heavy metal concentrations in soil and the food chain to decrease health hazards. To minimise the passage of metallic pollutants into the food chain and to develop appropriate remediation techniques, soil pollution must be mapped quickly and precisely. For temperately contaminating soils, biological remediation, such as phytoremediation and PGPR, could be a cost-effective and environmentally friendly alternative. With specific financial assurances, eco-friendly technical advancements such as nano-tools and farmer knowledge might benefit local economies and livelihoods.

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