Journal of Science and Engineering Papers
Volume: 01, Issue: 01 (January), 2024, page: 40-48
Journal homepage: www.jsciengpap.com
https://doi.org/10.62275/josep.24.1000001
ISSN: 3006-3191 (online)

Heavy Metal Contamination in Soil and Vegetables: A Review with Health Risk Assessments

Sha Md. Shahan Shahriar*, Md. Sarwar Hossain, Sumaiya Dipti, and Sayed M A Salam

Department of Applied Chemistry and Chemical Engineering, University of Rajshahi, Rajshahi-6205, Bangladesh.

*Corresponding author: e-mail address: shahan@ru.ac.bd; ORCID: https://orcid.org/0000-0003-3956-2409

ARTICLE INFO

Received: 06th November, 2023
Revised: 04th December, 2023
Accepted: 15th December, 2023

Keywords:
contamination
food web
health risk
heavy metal
soil
vegetable

ABSTRACT

Since the dawn of time, plant-based foodstuffs have been an indispensable component of human nutrition. This hasn't evolved, but the heavy metal contamination of soil and edible vegetable portions is currently a global grave threat to the environment. One of the predominant components contributing to agricultural contamination includes heavy metals. Anthropogenic activities and rapid industrialization can introduce dangerous and invisible heavy metals throughout the soil, water, air, and plants, among other environmental components. In addition to being critical for plants to flourish consistently, heavy metals also play substantial functions in basic nucleic acid metabolisms, electron transfer, redox reactions, and as direct participants in several enzymes. It is crucial that these vital metals be present in growth media at a certain concentration, yet an excess of them might have detrimental consequences ranging from deadly ailments. The article reviewed the existing understanding of how those released toxic heavy metals penetrate the food chain, biomagnify into cells when they are consumed as vegetables, and cause potentially catastrophic consequences to health. These harmful metals have a significantly higher propensity to bioaccumulate and turn deadly in human beings.

1. Introduction

Over the past 200 years, urbanization and industrialization have grown at a rapid rate, resulting in significant levels of air, water, and soil pollution. Because of their toxicity, persistence, and capacity to build up in the biota, trace metals in the environment continue to pose a hazard even if persistent organic contaminants and greenhouse gases have received more attention [1]. Cadmium (Cd), Chromium (Cr), mercury (Hg), arsenic (As), lead (Pb), and other metalloids having a density of greater than 5 g/cm^3 are examples of heavy metals. Besides polluting the environment, heavy metals can seriously injure humans by building up in bodily organs and other living things via the food chain [2, 3]. Exposure to heavy metals in soil primarily occurs via inhalation, oral consumption, and skin touch, constituting the three main routes of human contact [4, 5]. The main causes of heavy-metal pollution include milling, industrialization, burning fossil fuels, agrochemicals, and mining which release a range of HHMs into agricultural soils and water bodies, including Pb, Cr, Co, Cd, Zn, As, Ni, Cu and Hg [6-8]. Because they include essential nutrients that humans need to survive, vegetables are a vital part of a typical diet. Additionally, they serve as protective meals by helping people prevent disorders. Vegetables may gather greater concentrations of hazardous heavy metal when cultivated near heavy metal pollution sources [9]. The accumulation of heavy metals in vegetables as well as crops that are edible in contaminated soils eventually poses a major risk to the human body as well as animal health as a result of the detrimental and irreversible effects of metals [10]. Few heavy metals such as Co [11], Mn [12], Zn [13], Cu [14] and Ni [15] are key components at certain levels in humans yet they become toxic when exposed to higher doses. Heavy metals pose significant health risks, particularly Pb along with Cd, which can cause damage for example malformations and bone fractures, along with hypertension, kidney failure, cardiovascular problems and other severe nervous system, immune system, lung and liver diseases [16-18]. Memory loss, heart problems, digestive disorders, and genotoxicity are among the negative consequences of mercury poisoning [19]. Many analytical methods and instruments use mercury (Hg), such as barometers and thermometers, blood pressure monitors with fluorescent illumination, amalgam for dental restoration, and fluorescent lighting [20]. Heavy metal accumulation at chronic level in the liver, kidney and bones of humans can result in kidney, cardiovascular, neurological, and bone illnesses. This buildup can be caused by long-term ingestion of high quantities of heavy metals through contaminated food. These days, as more people become aware of the health dangers linked with heavy metal exposure, risk assessment has become a global hot subject [21].

2. Heavy metal sources causing soil and vegetable contamination

Plant food contamination can result from air pollution or by coming into touch with polluted soil. Heavy metals from various sources can deteriorate the soil, which is essential to the growth of food crops. Anthropogenic activities related to agriculture and industry are the main causes of soil pollution with heavy metals worldwide [22-24]. Soil-crop ecosystems are impacted by sewage from industries, irrigation, agricultural practices, and mining activities in highly populated and developing nations [25]. The use of specific inorganic and organic fertilisers, insecticides, herbicides, and organic manure that contain heavy metals can potentially boost heavy metal content in soils [26, 27]. The swift advancement of industrialization around the globe has led to a notable rise in the likelihood of heavy metal pollution in the environment. Toxic materials build up in the soil, air, water as a consequence of rapid industrialization, chaotic urbanisation, and long-term heavy fertiliser and pesticide usage [28, 29]. In part because of the higher concentrations of heavy metals and metalloids in leachates from municipal solid waste dumps, inadequate garbage disposal methods can also affect soil-crop systems [30]. The amount of heavy metals in food is directly impacted by soil contamination since samples of plant food taken from contaminated soils have been shown to accumulate these hazardous elements. [31-33]. Different origins of those heavy metals and their injurious proliferation on vegetables as well as crops are given in **Table 1**.

3. Heavy metal contamination in soil

Heavy metal accumulation in soil is the most significant. Heavy metals, which include chromium (Cr), arsenic (As), copper (Cu), cadmium (Cd), mercury (Hg), zinc (Zn), nickel (Ni), and lead (Pb) are often found contaminants in soil environments. This kind of pollution is pervasive, long-lasting, and physiologically hazardous in the soil environment [44]. A vital component of any ecosystem is soil. Because of its capacity to both absorb and emit, soil may get contaminated from various sources [45]. The weathering of rocks, volcanic activity, and erosion are the primary natural sources of the incorporation of heavy metals into soils. Anthropogenic sources include smelting, ore mining operations, landfills, industry effluents, electroplating, military training and warfare, use of phosphate fertiliser and pesticides, biosolids utilisation (such as fertilisers, animal manure, and municipal effluent), and atmospheric deposition [46, 47]. The excess soil contamination scale is 16.1%, with the highest over-standard concentrations of heavy metals being Pb, Cd, Hg, As, and Cr at 1.50%, 7.0%, 1.60%, 2.70%, and 1.10%, respectively [48]. The overall state of the soil in agricultural settings can serve as a marker for heavy metal pollution brought on by farming practices [49]. The soil has already begun to absorb the majority of these heavy metals. On the contrary, long-term exposure to heavy metals can cause bone fractures and lung cancer in humans [50, 51]. Remediation methods for heavy metal-polluted soil have been extensively studied. These methods include ex-situ remediation methods (soil washing, landfilling, vitrification, solidification) and in-situ methods (electrokinetic process of extraction, encapsulation, surface capping, chemical immobilisation, phytoremediation, soil flushing, and bioremediation) [52-54].

4. Mechanism of toxic heavy metals accumulation in vegetables

Notwithstanding the mass amount of heavy metals in aerial tissues and excluders, different plants as well as vegetables serve as accumulators and evidence of survival. Plants that successfully undergo biodegradation or biotransformation of pollutants into innocuous arrangements inside their tissues have higher rates of survival [62]. Plants accumulate hazardous heavy metals through various mechanisms, including absorption by root, xylem loading, heavy metal mobilisation, root-to-shoot transit, cellular compartmentation, and sequestration. The bioaccumulations of heavy metals in different organs of vegetables are given in **Table 2**. Almost all heavy metals are found in soil in an insoluble form which is not bioavailable to plants. Different root exudates that plants release can change the rhizosphere's pH along with enhancing the solubility of heavy metals, hence increasing their bioavailability [63, 64].

Vegetables absorb the heavy metals found in soil organic matter, and when they connect to short carbon atom chains, they transform into crucial cations [65]. In root hairs, heavy metals are actively transferred to the root cell plasma membrane from the apoplast or the soil. Upward movement, vacuoles, and barriers in the xylem as well as phloem are crucial for the translocation of the absorbed metals to the shoot [66]. The bioavailable metal penetrates the cell wall to access the root cells after being absorbed at the root surface. The two main pathways by which heavy metals are taken by

https://doi.org/10.62275/josep.24.1000007

roots are the symplastic pathway (active transport against electrochemical potential gradients and concentration across the plasma membrane) and the apoplastic pathway (passive diffusion) [67].

this is insufficient to initiate the methylation of As in plants [68]. As is catalyzed by specific enzymes, which includes Sadenosylmethionine-dependent arsenite methyltransferase, which is also crucial for the biogeochemical pathway of As [69]. Numerous metal transporters are involved in the mobilisation along with the transfer of metals from one compartment of cells and plant organs to another, including OsHMA2, OsHMA3, OsNramp5, Lsi1, NIP, Lsi2, MMA, HAC, ABC, DMA, and PT [70].

Table 1. Different origins of heavy metals and their toxic contamination of vegetable /crops

Source of Heavy Metals	Heavy Metal Present	Contamination	Vegetable/crop	Region	Reference
Industries	Cd, Co, Cr, Cu, Fe, Mg, Mn, Pb, Zn	Leafy vegetables	*Lactuca sativa, Raphanus sativus, Mentha piperita, Petroselinum crispum, Eruca Sativa*	Jazan, Saudi Arabia	[34]
Soil	Pb, Hg, Cd, As	Vegetable and fruit	*Daucus carota, Trigonella foenum-graecum, Allium sativum, Zingiber officinale, Solanum tuberosum, Raphanus sativus, Allium cepa etc*	Maharashtra, India	[35]
Soil	Cr, Cd, Pb, Ni, Cu, Zn, Fe, Mn	Leafy and root vegetables	*Beta vulgaris L, Raphanus sativus L, Daucus carota, Brassica rapa, Brassica nigra, Brassica oleracea, Spinacia oleracea L., Coriandrum sativum, Mentha*	Dhaka, Bangladesh	[36]
Contaminated waterbody	As, Zn, Cd, Pb, Cu, Hg, Co	Vegetables and soil	*Brassica oleracea, Solanum lycopersicum*	Koka area of central Ethiopia	[37]
Soil	Cu, Ni, Fe, Zn, Cd, Pb, As, Mn, N, P	Vegetable	*Solanum tuberosum, Cucumis sativus, Solanum lycopersicum, Daucus carota, Lactuca sativa , Spinacia oleracea*	Isfahan, Iran	[38]
Wastewater	Cd, Cu, Zn, Al, Cr, Co, Mn, Fe, Pb, V, Mo	Soils and vegetables	*Avena sativa L., Cynara scholymus L., Medicago sativa L., Corchorus olitorius L., Cynodon dactylon L.*	Asmara, Eritrea	[39]
Wastewater treatment plant	Pb, Cd, Zn, Cu	Water, soil, crops	*Triticum turgidum, Eruca. Sativa, Malus sylvestris, Vicia faba, Triticum aestivum, Madia sativa* and *Urtica dioica*	Marrakech, Morocco	[31]
Wastewater of Shitalakhya River	Cu, Ni, Cd, Cr, Pb, Zn	Vegetables, Soil	*Cucurbita moschata, Spinacia oleracea, Amaranthus lividus, Basella alba*, and *Trichosanthes cucumerina*	Narayangonj, Bangladesh	[40]
Soil	Hg	Vegetables	*Phaseolus vulgaris, Raphanus raphanistrum, Brassica rapa, Brassica oleracea, Spinacia oleracea, Solnum melongena, and Piper nigru*	China	[41]
Region Impacted by Mine	Pb, As, Cd, Cu	Vegetables, Soil	*Piper nigrum, Amaranthus dubius, , Phaseolus vulgaris Solanum melongena, Ipomoea batatas, Solanum lycopersicum, and Ipomoea aquatic*	Daye, China	[42]
Commercial and municipality sewage water	Ni, Zn, Pb, Cd	Crops, Soil	*Oryza sativa*	Lenjan, Iran	[43]

soil pH, dissolved cations and anions, chemical pesticides, and species of vegetation, fertilisers, and soil type all affect how much hazardous metal is taken up from the soil [62]. In the rhizosphere, bacteria generate DMA (dimethyl arsenic acid) and MMA (monomethyl arsenic acid), nevertheless, Heavy metal ions have a tendency to combine with a variety of chelators, including organic acids, after they have entered root cells. These complexes, which include phosphate precipitate, sulphate, and carbonate, are subsequently immobilised in either the intracellular (symplastic compartments, including vacuoles) or extracellular (apoplastic cellular walls) [71]. Through the root symplasm, the metal ions contained inside the vacuoles may travel into the stele as well as the xylem stream [72]. Heavy metals are mostly accumulated in leaves by xylem-loading absorption, and in seeds and fruits through phloem-loading [73] are then transported by xylem vessels to the shoots. They are carried and dispersed throughout leaves by apoplast or symplast, where they are confined in extracellular compartments (cell walls) or plant vacuoles, preventing the buildup of free metal ions in the cytosol [74]. Metal ion transporters and complexing agents are two of the many molecules that mediate the uptake and translocation of heavy metals in plants. The absorption of heavy metal ions from soil depends on these specialised transporters, channel proteins, also known as H+-coupled carrier proteins, which are present in the plasma membrane of root cells. In addition to mediating the influx-efflux of metal translocation from roots to shoots, they are capable of moving certain metals across cellular membranes [75]. Several heavy metal ions, for example, Fe^{2+}, Co^{2+}, Cd^{2+}, Mn^{2+}, and Cu^{2+} are also transported by the naturally resistant associated macrophage proteins (NRAMPs) [76, 77]. In addition to metal ion transporters, amino acids as well as organic acids, which are complexing agents, function as metal ligands to contribute to the chelation of heavy metal ions. For instance, in the xylem, citrate also is a significant chelator for Ni and Fe [67, 71, 78]. The bioaccumulations of heavy metals in different organs of vegetables are presented in Table 2.

5. Health risk assessment

A human health risk assessment (HRA) is the method of determining the kind along probability of adverse health outcomes in individuals who could be subjected to chemicals or other potentially dangerous substances in the environment. An HRA is a type of health inquiry designed to evaluate a person's health risks and quality of life [16]. This section describes some of the parameters found in the literature used to calculate the HRA.

5.1 Bio-concentration factor (BCF)

BCF is an essential term in health risk assessment since it provides quantifiable information on a contaminant's capacity to be taken up by organisms. It is frequently employed as a preliminary screening measure for bioaccumulative, hazardous, and persistent chemicals. The BCF of heavy metals in soils and vegetables was calculated by dividing the concentration of each heavy metal in the edible parts of the vegetables by the concentration of the heavy metal in the soil sample. A lower BCF score indicates less heavy metal transport from soil to crops. BCF values larger than one, on the other hand, indicate that the investigated plants absorb more heavy metals from the soil [79]. The bioconcentration factor is assessed by following Eq. 1

$$BCf = \frac{Cv}{Cs} \quad (1)$$

Where, Cs = heavy metals in soil samples (ppm), Cv = heavy metals in vegetables on a dry weight (DW) basis (ppm),

5.2 Estimated daily intake (EDI)

Daily intake is determined by both metal content in food and daily food consumption. Furthermore, the human body weight can impact contamination tolerance. The EDI is a notion that was developed to account for these concerns. Eq. 2 is used to calculate the anticipated daily intake for each element. The EDI value of each metal may be used to calculate the health risk of a vegetable.

$$EDI = \frac{E_f \times E_D \times F_{IR} \times C_M \times C_f}{B_W \times T_A} \times 10^{-3} \quad (2)$$

Where E_f denotes exposure frequency (365 days/year); E_D means exposure duration, equivalent to average lifetime; F_{IR} is equal to average food (vegetable) consumption; C_M denotes metal concentration (ppm dry weight); C_f is equal to 0.085 which is concentration conversion factor; B_w denotes reference body weight for an adult; T_A means the average exposure time in 65 years (23,725 days) and 10^{-3} is unit conversion factor [80-82].

5.3 Target hazard quotient (THQ)

The target hazard quotient (THQ) is the ratio of hazardous element exposure to the reference dosage, which is the greatest amount at which no adverse health consequences are predicted. The THQ method is used to assess the non-carcinogenic danger of eating infected crops [83].

$$THQ = \frac{EDI}{RfD} \quad (3)$$

Where RfD is the oral reference dose (mg/kg/day). If THQ is less than 1, the exposed population is unlikely to suffer visibly adverse repercussions. When THQ is equal to or more than 1, there is a potential health concern, and proper preventative measures and steps should be taken.

5.4 The carcinogenic risk index (CRI)

The carcinogenic risk index determines a human's lifetime risk of acquiring cancer. CRI is used to assess the potential human health risk of recognised carcinogens. The CRI is computed by multiplying the EDI by the oral cancer slope factor (CSF) for the heavy metals in question [84]. The following formula is used to calculate the CRI.

$$CRI = EDI \times CSF \quad (4)$$

When the CRI is larger than, the exposed people are at a major carcinogenic risk; but, when the CRI is less than, the exposed populations are not at a significant carcinogenic risk. Furthermore, if TR and/or TCR levels are between 10^{-4} and 10^{-6}, the exposed populations are at high risk of cancer [84].

another exciting field that can remediate heavy metal-containing wastewater before it is released into the environment. By using these technologies, heavy metal content in the soil may be decreased, and as a result, the bioaccumulation of heavy metals in vegetables can be reduced as well. Heavy metal removal technologies comprise electrolytic recovery, membrane filtration, ion exchange, adsorption, precipitation, and more. It is indispensable that further research be conducted to develop more pocket friendly, sophisticated, and ecologically conscious versions of them to fulfil the prerequisites for the removal of heavy metals from our soil as well as food web.

Table 2. Bioaccumulation of heavy metals in different organs of vegetables

Scientific name of the vegetables	Organ of accumulation	Heavy metal concentration, mg/kg	Location	Reference
Peri-urban vegetable	Edibe parts	Cd- 0.30; Hg- 0.26; As- 0.37; Pb- 0.54; Cr- 1.17; Cu- 6.17; Ni- 1.96; Zn- 18.56	*China*	[55]
Coriandrum sativum, Allium cepa, Solanum lycopersicum	Edible parts	Cd- 0.13-0.23; Pb- 0.46-2.12; Ni- 0.54-0.89; Co- 0.22-0.47; Zn- 16.77-36.65; Cu- 14.46-21.65	Jhansi, India	[56]
Lepidium sativum, Coriandrum sativum, Spinacia olarecea	Leaves	Pb- 0.2-4.7; Zn- 1.7-6.7; Cd- 0.02-0.52; Cu- 0.59-2.23; Ni- 0.04-0.81; As- 0.018-0.126; Co- 0.005-0.21; Cr- 0.1-1.87	Tehran, Iran	[57]
Spinacia oleracea, Solanum melongena, Cucumis melo	Edible parts	Mn- 18.7-137; Cu- 22.2-65; Ni- 1.8-5.05; Zn- 19.5-41; Cd- 0.05-0.39; Fe-129-968; Cr- 2.7-3.7; Pb- BDL	Pakistan	[58]
Lactuca sativa, Raphanus sativus, Mentha piperita, Petroselinum crispum, Eruca Sativa	edible portions of leafy vegetable	Cd- 0.242–1.249; Co- 0.457–0.764; Cr-1.10–3.534; Cu- 5.36-9.18; Fe- 355.4-1195.9; Mn- 31.90-132.63; Pb- 0.858-1.175; Zn- 18.20-36.72	*Saudi Arabia*	[34]
Brassica oleracea, Beta vulgaris, Lactuca sativa, Solanum lycopersicum	Edible parts	Pb- 0.061-0.741; Cr- 0.136-1.141; Cd-0.028-0.477; Zn- 0.012-8.72	Ethiopia	[59]
Amaranthus hybridus, Ipomoea batatas, Abelmoschus esculentus, Solanum melongena	Edible parts	Zn- 2.64-10.29, Fe- 4.84-13.64 Pb- 0.32-2.46; Cu - 0.55-1.04	Tanzania	[60]
Solanum lycopersicum, Solanum cepa, Capsicum annuum	Edible parts	Pb- 0.02-0.03; Ni- 0.02-0.48; Cr- 0.001-0.02; Fe- 0.74-4.37; Cd- 0.001-0.004; Zn- 0.50-1.16; Cu- 0.14-0.25	Turkey	[61]

5. Conclusion:

Food supply chain contamination is one of the noteworthy approaches that heavy metals penetrate human body. It is potentially dangerous to human beings and impedes the worldwide supply of food. The main causes of food chain contamination are inadequate effluent management, lax enforcement of standards and laws, a lack of research evidence on sustainable management, and low public consciousness. In the end, food safety is concealed by these constraints. This review has uncovered the root causes of heavy metal pollution, how they contaminate food chains, how plants carry metals, and the way our bodies absorb them. Transportation of heavy metals into plants, including fruits and vegetables, is mostly due to soil pollution. For this reason, attaining food safety and security on a global scale is hampered by the buildup of heavy metal(loid)s in agricultural soils. Although bioremediation is a potential natural remedy for heavy metal(loid) pollution, several problems require to be resolved before it can be used more widely. Accelerating global soil mapping and developing regional models capable of accurately predicting pollutant distributions and pinpointing contamination sources will be advantageous. Biosorbents offer appealing prospects as an inexpensive way to prevent pollution in the environment. Nanotechnology is

Reference

1. Ali, H., Khan, E., and Ilahi, I., (2019). Environmental chemistry and ecotoxicology of hazardous heavy metals: environmental persistence, toxicity, and bioaccumulation. *Journal of Chemistry*, 2019, 1–14. https://doi.org/10.1155/2019/6730305
2. Sun, R., Yang, J., Xia, P., Wu, S., Lin, T., and Yi, Y., (2020). Contamination features and ecological risks of heavy metals in the farmland along shoreline of Caohai plateau wetland, China. *Chemosphere*, 254: 126828. https://doi.org/10.1016/j.chemosphere.2020.126828.
3. Dong, J., Yang, Q. W., Sun, L. N., Zeng, Q., Liu, S. J., Pan, J., and Liu, X. L., (2011). Assessing the concentration and potential dietary risk of heavy metals in vegetables at a Pb/Zn mine site, China. *Environmental*

Earth Sciences, 64(5): 1317–1321. https://doi.org/10.1007/s12665-011-0992-1.

4. Shahriar, S. M. S., Akther, S., Akter, F., Morshed, S., Alam, M. K., Saha, I., Halim M. A., and Hassan M. M., (2014). Concentration of copper and lead in market milk and milk products of Bangladesh. *International Letters of Chemistry, Physics and Astronomy*, 8: 56-63. https://doi.org/10.56431/p-25obfk
5. Kolo, M. T., Khandaker, M. U., Amin, Y. M., Abdullah, W. H. B., Bradley, D. A., and Alzimami, K. S., (2018). Assessment of health risk due to the exposure of heavy metals in soil around mega coal-fired cement factory in Nigeria. *Results in Physics*, 11: 755–762. https://doi.org/10.1016/j.rinp.2018.10.003.
6. Kumar, V., Thakur, R. K., and Kumar, P., (2019). Assessment of heavy metals uptake by cauliflower (Brassica oleracea var. botrytis) grown in integrated industrial effluent irrigated soils: A prediction modeling study. *Scientia Horticulturae*, 257: 108682. https://doi.org/10.1016/ j.scienta.2019.108682.
7. Shahriar, S. M. S., Munshi, M., Zakir, H. M., Islam, M. J., Mollah, M. M. A., and Salam, S. M. A., (2023). Assessment of heavy metal pollution in irrigation water of Rajshahi city, Bangladesh. *Environmental and Earth Sciences Research Journal*, 10(3): 100-110. https://doi.org/10.18280/eesrj. 100303
8. Kumar, S., Prasad, S., and Yadav, K. K., (2019). Utilization of air pollutants by plants: need for present and future scrutiny. *Journal of Agricultural and Food Chemistry*, 67(10): 2741–2742. https://doi.org/10.1021/ acs.jafc.9b00921.
9. Christou, A., Eliadou, E., Michael, C., Hapeshi, E., and Fatta-Kassinos, D., (2014). Assessment of long-term wastewater irrigation impacts on the soil geochemical properties and the bioaccumulation of heavy metals to the agricultural products. *Environmental Monitoring and Assessment*, 186(8): 4857–4870. https://doi.org/10.1007/ s10661-014-3743-4.
10. Malik, A., (2004). Metal bioremediation through growing cells. *Environment International*, 30(2): 261–278. https://doi.org/10.1016/j.envint.2003.08.001.
11. Moukadiri, H., Noukrati, H., Ben Youcef, H., Iraola, I., Trabadelo, V., Oukarroum, A., Malka, G., and Barroug, A., (2023). Impact and toxicity of heavy metals on human health and latest trends in removal process from aquatic media. *International Journal of Environmental Science and Technology*, https://doi.org/10.1007/s13762-023-05275-z
12. Flora, S. J., (2014). Metals. *Biomarkers in Toxicology*, 485–519. https://doi.org/10.1016/b978-0-12-404630-6.00029-4
13. Shahriar, S. M. S., Islam, M. J., Hanif, M. A., and Salam, S. M. A., (2022). Level of chromium and zinc in groundwater and cows' raw milk in Rajshahi, Bangladesh. *International Journal of All Research Education and Scientific Methods*, 10(2): 2153- 2158.
14. Wuana, R. A., and Okieimen, F. E., (2011). Heavy metals in contaminated soils: a review of sources, chemistry, risks and best available strategies for remediation. *ISRN Ecology*, 2011: 1–20. https://doi.org/10.5402/2011/402647
15. Ihedioha, J. N., Okoye, C. O. B., and Onyechi, U. A., (2014). Health risk assessment of zinc, chromium, and nickel from cow meat consumption in an urban Nigerian population. *International Journal of Occupational and Environmental Health*, 20(4): 281–288. https://doi.org/10.1179/2049396714y.0000000075
16. Shahriar, S. M. S., Munshi, M., Hossain, M. S., Zakir, H. M., and Salam. S. M. A., (2023). Risk assessment of selected heavy metals contamination in rice grains in the Rajshahi City of Bangladesh. *Journal of Engineering Science*, 14(1): 29–41. https://doi.org/10.3329/ jes.v14i1.67633
17. Mollah, M. M. A., Rabbany, M. G., Nurunnabi, M., Shahriar, S. M. S., and Salam, S. M. A., (2022). Health risk assessment of heavy metals through six common spices of mohanpur upazila of Rajshahi District, Bangladesh. *Global Journal of Nutrition & Food Science*, 3(5): 1-8.
18. Genchi, G., Sinicropi, M. S., Lauria, G., Carocci, A., and Catalano, A., (2020). The effects of cadmium toxicity. *International Journal of Environmental Research and Public Health*, 17(11): 3782. https://doi.org/10.3390/ijerph17113782
19. Andreoli, V., and Sprovieri, F. (2017). Genetic aspects of susceptibility to mercury toxicity: an overview. *International Journal of Environmental Research and Public Health*, 14(1): 93. https://doi.org/10.3390/ijerph14010093
20. Beckers, F., and Rinklebe, J. (2017). Cycling of mercury in the environment: sources, fate, and human health implications: a review. *Critical Reviews in Environmental Science and Technology*, 47(9): 693–794. https://doi.org/10.1080/10643389.2017.1326277
21. Anwar, S., Nawaz, M. F., Gul, S., Rizwan, M., Ali, S., and Kareem, A., (2016). Uptake and distribution of minerals and heavy metals in commonly grown leafy vegetable species irrigated with sewage water. *Environmental Monitoring and Assessment*, 188: 541. https://doi.org/10.1007/s10661-016-5560-4
22. Li, Y., Mei, L., Zhou, S., Jia, Z., Wang, J., Li, B., Wang, C., and Wu, S., (2018). Analysis of historical sources of heavy metals in lake taihu based on the positive matrix factorization model. International Journal of Environmental *Research and Public Health*, 15(7): 1540. https://doi.org/10.3390/ijerph15071540
23. Yan, X., Liu, M., Zhong, J., Guo, J., and Wu, W., (2018). How human activities affect heavy metal contamination of soil and sediment in a long-term reclaimed area of the Liaohe River Delta, North China. *Sustainability*, 10(2): 338. https://doi.org/10.3390/su10020338

24. Antoniadis, V., Golia, E. E., Liu, Y. T., Wang, S. L., Shaheen, S. M., and Rinklebe, J., (2019). Soil and maize contamination by trace elements and associated health risk assessment in the industrial area of Volos, Greece. *Environment International*, 124: 79-88. https://doi.org/10.1016/j.envint.2018.12.053
25. Afonne, O. J., and Ifediba, E. C., (2020). Heavy metals risks in plant foods – need to step up precautionary measures. *Current Opinion in Toxicology*, 22: 1–6. https://doi.org/10.1016/j.cotox.2019.12.006
26. Reboredo, F., Simões, M., Jorge, C., Mancuso, M., Martinez, J., Guerra, M., Ramalho, J. C., Pessoa, M. F., and Lidon, F., (2018). Metal content in edible crops and agricultural soils due to intensive use of fertilizers and pesticides in Terras da Costa de Caparica (Portugal). *Environmental Science and Pollution Research*, 26(3): 2512–2522. https://doi.org/10.1007/s11356-018-3625-3
27. Dharma-wardana, M. W. C., (2018). Fertilizer usage and cadmium in soils, crops and food. *Environmental Geochemistry and Health*, 40(6): 2739–2759. https://doi.org/10.1007/s10653-018-0140-x
28. Zwolak, A., Sarzyńska, M., Szpyrka, E., and Stawarczyk, K., (2019). Sources of soil pollution by heavy metals and their accumulation in vegetables: a review. *Water, Air, & Soil Pollution*, 230: 164. https://doi.org/10.1007/s11270-019-4221-y
29. Rodrigues, A. A. Z., De Queiroz, M. E. L. R., De Oliveira, A. F., Neves, A. A., Heleno, F. F., Zambolim, L., Freitas, J. F., and Morais, E. H. C., (2017). Pesticide residue removal in classic domestic processing of tomato and its effects on product quality. *Journal of Environmental Science and Health*, Part B, 52(12): 850–857. https://doi.org/10.1080/03601234.2017.1359049
30. Vongdala, N., Tran, H. D., Xuan, T., Teschke, R., and Khanh, T., (2018). Heavy metal accumulation in water, soil, and plants of municipal solid waste landfill in Vientiane, Laos. *International Journal of Environmental Research and Public Health*, 16(1): 22. https://doi.org/10.3390/ijerph16010022
31. Chaoua, S., Boussaa, S., El Gharmali, A., and Boumezzough, A., (2019). Impact of irrigation with wastewater on accumulation of heavy metals in soil and crops in the region of Marrakech in Morocco. *Journal of the Saudi Society of Agricultural Sciences*, 18(4): 429–436. https://doi.org/10.1016/j.jssas.2018.02.003
32. Barmao, K. J., Cherutoi, J. K., Mitei, C. Y., Were, M. L., Kiprop, A., and Achieng', O. G., (2019). Assessment of fluoride and selected heavy metals in food chain around Fluorspar mining Plant, Kenya. *Greener Journal of Environmental Management and Public Safety*, 8(1): 15–24. https://doi.org/10.15580/gjemps.2019.1.020919029
33. Liang, G., Gong, W., Li, B., Zuo, J., Pan, L., and Liu, X., (2019). Analysis of Heavy Metals in Foodstuffs and an Assessment of the health risks to the general public via consumption in Beijing, China. *International Journal of Environmental Research and Public Health*, 16(6): 909. https://doi.org/10.3390/ijerph16060909
34. Najmi, A., Albratty, M., Al-Rajab, A. J., Alhazmi, H. A., Javed, S. A., Ahsan, W., Hassani, R., and Alqahtani, S. S., (2023). Heavy metal contamination in leafy vegetables grown in Jazan region of Saudi Arabia: assessment of possible human health hazards. *International Journal of Environmental Research and Public Health*, 20(4): 2984. https://doi.org/10.3390/ijerph20042984
35. Mawari, G., Kumar, N., Sarkar, S., Daga, M. K., Singh, M. M., Joshi, T. K., and Khan, N. A., (2022). Heavy metal accumulation in fruits and vegetables and human health risk assessment: findings from Maharashtra, *India. Environmental Health Insights*, 16: 117863022211191. https://doi.org/10.1177/11786302221119151
36. Sultana, R., Tanvir, R. U., Hussain, K. A., Chamon, A. S., and Mondol, M. N., (2022). Heavy metals in commonly consumed root and leafy vegetables in Dhaka City, Bangladesh, and assessment of associated public health risks. *Environmental Systems Research*, 11: 15. https://doi.org/10.1186/s40068-022-00261-9
37. Bayissa, L. D., and Gebeyehu, H. R., (2021). Vegetables contamination by heavy metals and associated health risk to the population in Koka area of central Ethiopia. *Plos One*, 16(7), e0254236. https://doi.org/10.1371/journal.pone. 0254236
38. Dabbagh Moghadam, A., and Shahmoradi, A., (2021). Heavy metals accumulation and health risk consumption in some vegetables, Isfahan, Iran. *Annals of Military and Health Sciences Research*, 19(1), e101311. https://doi.org/10.5812/amh.101311
39. Kfle, G., Asgedom, G., Goje, T., Abbebe, F., Habtom, L., and Hanes, H., (2020). The level of heavy metal contamination in selected vegetables and animal feed grasses grown in wastewater irrigated area, around Asmara, Eritrea. *Journal of Chemistry*, 2020: 1359710. https://doi.org/10.1155/2020/1359710
40. Ratul, A. K., Hassan, M., Uddin, M. K., Sultana, M. S., Akbor, Ahedul, M. and Ahsan, M., (2018). Potential health risk of heavy metals accumulation in vegetables irrigated with polluted river water. International *Food Research Journal*, 25: 329-338.
41. Yu, H., Li, J., and Luan, Y., (2018). Meta-analysis of soil mercury accumulation by vegetables. *Scientific Reports*, 8: 1261. https://doi.org/10.1038/s41598-018-19519-3
42. Yang, J., Ma, S., Zhou, J., Song, Y., and Li, F., (2018). Heavy metal contamination in soils and vegetables and health risk assessment of inhabitants in Daye, China. *Journal of International Medical Research*, 46(8): 3374–3387. https://doi.org/10.1177/0300060518758585
43. Rahimi, G., Kolahchi, Z., and Charkhabi, A., (2017). Uptake and Translocation of some heavy metals by rice crop (*Oryza sativa*) in paddy soils. *Agriculture*

(Pol'nohospodárstvo), 63(4): 163–175. https://doi.org/10.1515/agri-2017-0016
44. Ma, C. Y., Cai, D. J. and Yan, H., (2013). Soil Cd pollution and research progress of treatment techniques. *Henan Chemical Industry*, 30(16): 17–22 (2013).
45. Kumari, S., and Mishra, A., (2021). Heavy metal contamination: Soil contamination - threats and sustainable solutions. https://doi.org/10.5772/intechopen.93412
46. Herrero, M., Rovira, J., Nadal, M., Domingo, J. L., (2019). Risk assessment due to dermal exposure of trace elements and indigo dye in jeans: Migration to artificial sweat. *Environmental Research*, 172: 310-318.
47. Fulekar, M., Singh, A., and Bhaduri, A. M., (2009). Genetic engineering strategies for enhancing phytoremediation of heavy metals. *African Journal of Biotechnology*, 8: 529–535.
48. MEEC (Ministry of Ecology and Environment of China). National Soil Pollution Survey Bulletin (2019). http://www.zhb.gov.cn/gkml/hbb/qt/201404/t20140417_270670.html
49. Liu, Z., Gu, C., Chen, F., Yang, D., Wu, K., Chen, S., Jiang, J., and Zhang, Z., (2012). Heterologous expression of a Nelumbo nucifera phytochelatin synthase gene enhances cadmium tolerance in Arabidopsis thaliana. *Applied Biochemistry and Biotechnology*, 166: 722-734.
50. Rai, P. K., Lee, S. S., Zhang, M., Tsang, Y. F., and Kim, K. H., (2019). Heavy metals in food crops: Health risks, fate, mechanisms, and management. *Environment International*, 125: 365–385. https://doi.org/10.1016/j.envint. 2019.01.067
51. Salvatore Gallicchio, V., and Harper, J., (2021). Role of Heavy Metals in the Incidence of Human Cancers. Heavy Metals - Their Environmental Impacts and Mitigation. https://doi.org/10.5772/intechopen.98259
52. Khan, S., Naushad, M., Lima, E. C., Zhang, S., Shaheen, S. M., and Rinklebe, J., (2021). Global soil pollution by toxic elements: Current status and future perspectives on the risk assessment and remediation strategies - A review. *Journal of Hazardous Materials*, 417: 126039. https://doi.org/10.1016/j.jhazmat.2021.126039
53. Li, H., Liu, Y., Zhou, Y., Zhang, J., Mao, Q., Yang, Y., Huang, H. Liu, Z., Qinghui Peng Luo, L., (2018). Effects of red mud based passivator on the transformation of Cd fraction in acidic Cd-polluted paddy soil and Cd absorption in rice. *Science of the Total Environment*, 640–641: 736–745. https://doi.org/10.1016/j.scitotenv.2018.05.327
54. Hou, D., O'Connor, D., Igalavithana, A. D., Alessi, D. S., Luo, J., Tsang, D. C. W., . . . Ok, Y. S., (2020). Metal contamination and bioremediation of agricultural soils for food safety and sustainability. *Nature Reviews Earth and Environment*, 1(7): 366–381. https://doi.org/10.1038/s43017-020-0061-y
55. Hu, N. W., Yu, H. W., Deng, B. L., Hu, B., Zhu, G. P., Yang, X. T., Wang, T.-Y., Zeng, Y., and Wang, Q. Y., (2023). Levels of heavy metal in soil and vegetable and associated health risk in peri-urban areas across China. *Ecotoxicology and Environmental Safety*, 259, 115037. https://doi.org/10.1016/j.ecoenv.2023.115037
56. Gupta, N., Yadav, K. K., Kumar, V., Prasad, S., Cabral-Pinto, M. M. S., Jeon, B.-H., Kumar, S., Abdellattif, M. H., and Alsukaibia, A. K. D., (2022). Investigation of heavy metal accumulation in vegetables and health risk to humans from their consumption. *Frontiers in Environmental Science*, 10. https://doi.org/10.3389/fenvs.2022.791052
57. Souri, M. K., Alipanahi, N., Hatamian, M., Ahmadi, M., and Tesfamariam, T., (2018). Elemental profile of heavy metals in garden cress, coriander, lettuce and spinach, commonly cultivated in Kahrizak, South of Tehran-Iran. *Open Agriculture*. 3: 32-37. https://doi.org/10.1515/opag-2018-0004
58. Latif, A., Bilal, M., Asghar, W., Azeem, M., and Ahmad, M.I., (2018). Heavy metal accumulation in vegetables and assessment of their potential health risk. *International Journal of Environmental Analytical Chemistry*, 5: 234. https://doi.org/10.4172/2380-2391.1000234
59. Lemessa, F., Simane, B., Seyoum, A., and Gebresenbet, G., (2022). Analysis of the concentration of heavy metals in soil, vegetables and water around the bole Lemi industry park, Ethiopia. *Heliyon*, 8:12. https://doi.org/10.1016/j.heliyon.2022.e12429
60. Kacholi, D. S., and Sahu, M., (2018). Levels and health risk assessment of heavy metals in soil, water, and vegetables of Dar es Salaam, Tanzania. *Journal of Chemistry*, 2018:1–9. https://doi.org/10.1155/2018/1402674
61. Zeliha, L. and Kar, M., (2018). Accumulation of heavy metals in vegetables irrigated with different water sources and their daily intake in Nevsehir. *Journal of Agricultural Science and Technology*, 20:401-41
62. Kumar, S., Prasad, S., Yadav, K. K., Shrivastava, M., Gupta, N., Nagar, S., Bach Q. V., Kamyab H., Khan S. A., Yadav S., and Malav, L. C., (2019). Hazardous heavy metals contamination of vegetables and food chain: Role of sustainable remediation approaches - A review. *Environmental Research*, 179:108792. https://doi.org/10.1016/j.envres.2019.108792
63. Dalvi, A., and Bhalerao, S., (2013). Response of plants towards heavy metal toxicity: An overview of avoidance, tolerance and uptake mechanism. *Annals of Plant Sciences*, 2(09): 362-368. https://www.annalsofplantsciences.com/index.php/aps/article/view/87
64. Clemens, S., and Ma, J. F., (2016). Toxic heavy metal and metalloid accumulation in crop plants and foods. *Annual review of plant biology*, 67: 489–512. https://doi.org/10.1146/annurev-arplant-043015-112301

65. Manzoor, J., Sharma, M., and Wani, K. A., (2018). Heavy metals in vegetables and their impact on the nutrient quality of vegetables: A review. *Journal of Plant Nutrition*, 41(13): 1744–1763. https://doi.org/10.1080/01904167.2018.1462382
66. Meng, B., Feng, X., Qiu, G., Liang, P., Li, P., Chen, C., and Shang, L., (2011). The process of methylmercury accumulation in rice (*Oryza sativa L.*). *Environmental science & technology*, 45(7): 2711–2717. https://doi.org/10.1021/es103384v
67. Yan, A., Wang, Y., Tan, S. N., Mohd Yusof, M. L., Ghosh, S., and Chen, Z., (2020). Phytoremediation: A promising approach for revegetation of heavy metal-polluted land. *Frontiers in Plant Science*, 11:2020. https://doi.org/10.3389/fpls.2020.00359
68. Zhao, F. J., Harris, E., Yan, J., Ma, J., Wu, L., Liu, W., McGrath, S. P., Zhou, J., and Zhu, Y. G., (2013). Arsenic Methylation in Soils and Its Relationship with Microbial arsM Abundance and Diversity, and As Speciation in Rice. *Environmental Science & Technology*, 47(13): 7147–7154. https://doi.org/10.1021/es304977m
69. Huang, K., Xu, Y., Packianathan, C., Gao, F., Chen, C., Zhang, J., Shen, Q., Rosen, B. P., and Zhao, F., (2017). Arsenic methylation by a novel ArsM As (III) S adenosylmethionine methyltransferase that requires only two conserved cysteine residues. *Molecular Microbiology*, 107(2): 265–276. https://doi.org/10.1111/mmi.13882
70. Zhao, F. J., Tang, Z., Song, J. J., Huang, X. Y., and Wang, P., (2022). Toxic metals and metalloids: Uptake, transport, detoxification, phytoremediation, and crop improvement for safer food. *Molecular Plant*, 15(1): 27–44. https://doi.org/10.1016/j.molp.2021.09.016
71. Pasricha, S., Mathur, V., Garg, A., Lenka, S., Verma, K., and Agarwal, S., (2021). Molecular mechanisms underlying heavy metal uptake, translocation and tolerance in hyperaccumulators-an analysis. *Environmental Challenges*, 4: 100197. https://doi.org/10.1016/j.envc.2021.100197
72. Thakur, S., Singh, L., Wahid, Z. A., Siddiqui, M. F., Atnaw, S. M., and Din, M. F. M., (2016). Plant-driven removal of heavy metals from soil: uptake, translocation, tolerance mechanism, challenges, and future perspectives. *Environmental Monitoring and Assessment*, 188(4): 206. https://doi.org/10.1007/s10661-016-5211-9
73. Khan, M. A., Castro-Guerrero, N., and Mendoza-Cozatl, D. G., (2014). Moving toward a precise nutrition: preferential loading of seeds with essential nutrients over non-essential toxic elements. *Frontiers in Plant Science*, 5: 2014. https://doi.org/10.3389/fpls.2014.00051
74. Hlihor, R. M., Roșca, M., Hagiu-Zaleschi, L., Simion, I. M., Daraban, G. M., and Stoleru, V., (2022). Medicinal plant growth in heavy metals contaminated soils: Responses to metal stress and induced risks to human health. *Toxics*, 10(9): 499. https://doi.org/10.3390/toxics10090499
75. DalCorso, G., Fasani, E., Manara, A., Visioli, G., and Furini, A., (2019). Heavy metal pollutions: State of the art and innovation in phytoremediation. *International Journal of Molecular Sciences*, 20(14): 3412. https://doi.org/10.3390/ijms20143412
76. Ray, S., Berry, S. P., Wilson, E. A., Zhang, C. H., Shekhar, M., Singharoy, A., and Gaudet, R., (2023). High-resolution structures with bound Mn2+ and Cd2+ map the metal import pathway in an Nramp transporter. *eLife*, 12: e84006 https://doi.org/10.7554/elife.84006
77. Bastow, E. L., Garcia de la Torre, V. S., Maclean, A. E., Green, R. T., Merlot, S., Thomine, S., and Balk, J., (2018). Vacuolar iron stores gated by NRAMP3 and NRAMP4 are the primary source of iron in germinating seeds. *Plant Physiology*, 177(3): 1267–1276. https://doi.org/10.1104/pp.18.00478
78. Krämer, U., Pickering, I. J., Prince, R. C., Raskin, I., and Salt, D. E., (2000). Subcellular localization and speciation of nickel in hyperaccumulator and non-accumulator thlaspispecies. *Plant Physiology*, 122(4): 1343–1354. https://doi.org/10.1104/pp.122.4.1343
79. Sharma, S., Nagpal, A. K., and Kaur, I., (2018). Heavy metal contamination in soil, food crops and associated health risks for residents of Ropar wetland, Punjab, India and its environs. *Food Chemistry*, 255: 15–22. https://doi.org/10.1016/j.foodchem.2018.02.037
80. Gebeyehu, H. R. and Bayissa, L.D., (2020). Levels of heavy metals in soil and vegetables and associated health risks in Mojo area, Ethiopia. *PLOS ONE*, 15: e0227883.https://doi.org/10.1371/journal.pone.0227883
81. Miranzadeh Mahabadi, H., Ramroudi, M., Asgharipour, M. R., Rahmani, H. R., and Afyuni, M., (2020). Assessment of heavy metals contamination and the risk of target hazard quotient in some vegetables in Isfahan. *Pollution*, 6(1): 69-78. https://doi.org/10.22059/poll.2019.285113.645
82. Alipour, H. and Banagar, G. R., (2018). Health risk assessment of selected heavy metals in some edible fishes from Gorgan Bay, Iran. *Iranian Journal of Fisheries Sciences*, 17: 21-34. https://doi.org/10.22092/IJFS.2018.11558 2
83. Mao, Y., Wang, M., Wei, H., Gong, N., Wang, F., and Zhu, C., (2023). Heavy metal pollution and risk assessment of vegetables and soil in Jinhua City of China. *Sustainability*, 15(5): 4241. https://doi.org/10.3390/su15054241
84. Liu X. M., Gu S. B., Yang S. Y., Deng J. S., and Xu J. M., (2021). Heavy metals in soil vegetable system around E-waste site and the health risk assessment. *Science of The Total Environment*, 779: 146438. https://doi.org/10.1016/j.scitotenv.2021.146438