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Heavy Metals Contamination in Vegetables Grown in Polluted Soils and Their Health Implications for Humans in South Asia: A Systematic Review

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A B S T R A C T

Background: This review aimed to investigate vegetable contamination with heavy metals and their associated health impacts on humans.
Methods: Data was collected from websites, journals, and published reports on heavy metals contamination in vegetables over the last 30 years using various search engines, including Google Scholar, ResearchGate, Scopus, Google Scholar, DOAJ, PLOS ONE, etc.
Results: The analysis results illustrated that heavy metal concentrations in common vegetables, such as tomatoes, eggplants (brinjal), spinach, red spinach, carrots, and radishes, of different countries often exceeded the permissible limits of the World Health Organization (WHO), the Codex Alimentarius Commission, China' s Ministry of Health, and the State Environmental Protection Administration (SEPA) standards. This review showed that the higher concentrations of heavy metals, especially cadmium, copper, chromium, lead, and manganese, are linked to numerous health disorders in humans, including cardiovascular diseases, low birth weight, spontaneous abortions, gastrointestinal issues, liver damage, and renal dysfunction.
Conclusion: The excessive use of chemical fertilizer and irrigation with contaminated groundwater and industrial discharge wastewater are the causes of higher levels of heavy metal accumulation in vegetables. Thus, relevant authorities must take initiatives to monitor industrial effluent discharge, ensure compliance with regulatory frameworks, and build public awareness for food safety, soil, water, and environmental sustainability.

1. Introduction

The importance of a balanced diet in preventing the development of chronic diseases has become increasingly apparent to consumers in recent decades (Mazzoni et al., 2021). It is estimated that 97% of people rely on groundwater as a reliable drinking water source, while 70% of irrigation water comes from groundwater (Islam & Mostafa, 2024). Tomatoes, brinjal, spinach, amaranth, carrots, and radishes are popular vegetables throughout the world for their nutritional value and availability. Tomatoes contain lycopene and bioflavonoids (cancer-fighting agents), which can decrease the risk of conditions such as cancer, osteoporosis, and cardiovascular disease and make people healthier (Bhowmik et al., 2012). Brinjal contains low calories and various macro-and micro-minerals like potassium, magnesium, calcium, and iron, which are useful for the human body (Sahu et al., 2022). It is cultivated extensively in warm countries like China, India, Pakistan, Bangladesh, the Philippines, the United States, France, and Italy (Singh et al., 2020). Spinach is highly valued as a leafy vegetable for both its dietary food and medical properties. It has been shown to scavenge reactive oxygen species, prevent macromolecular oxidative damage, and regulate the expression and activity of genes involved in metabolism, proliferation, inflammation, and antioxidant defense (Roughani & Miri,

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2019). Similarly, amaranthus is considered a promising plant genus as it provides unsaturated oil, high-quality protein, and other valuable constituents (Narwade & Pinto, 2018). Carrots are a natural source of antioxidants and are consumed in various forms, including raw, processed, and manufactured products (Sharma & Sharma, 2020). Radishes, known for their high vitamin C content mineral diversity, are a fast-growing and short-duration crops that can be cultivated in both temperate and tropical climates (Satari et al., 2020). However, the presence of heavy metals in these commonly consumed vegetables has become a significant concern due to their ubiquity, toxicity, bioaccumulation, and non-biodegradability. This review is mainly focused on the evaluation of heavy metal concentrations in popular vegetables and their negative effects on human health.

2. Materials and Methods

2.1 Data sources and search strategy

In many cases, the systematic reviews and meta-analysis methods are significant as they permit finding research questions derived from findings across various contexts, highlight research gaps for further investigation, and propel advancements among scholars in the field (Akuno et al., 2019; Littell et al., 2009). A systematic review was used to address the research questions related to the objective of this study. This review encompasses several processes, such as the identification of eligible articles, data extraction, data selection, study area, and statistical methods. The literature search was conducted using keywords such as "heavy metal", "contamination", "diseases", "concentration", "vegetables", "impact", and "human health" through multiple databases, including PubMed, Scopus, Google other Scholar, and Web of Science, covering publications from and databases for from the past 35 years (1989-2024).

2.2 Sampling: Inclusion and exclusion criteria

Figure 1 presents a flow diagram illustrating the criteria used to select the papers included in the systematic review and meta-analysis. A key criterion for preliminary selection was the available data relevant to the research topic. The majority of papers were excluded due to the lack of relevance. The study faced significant challenges in finding the appropriate and homogeneous literature specific to the selected country. Figure 1 displays that a total of 1,036 published papers were initially identified from four database sources: Google Scholar (243), PubMed (356), Scopus (257), and Web of Science (180). Finally, 34 articles were qualified for systematic review and meta-analysis.

2.3 Study area

In Asia, Bangladesh, India, and Pakistan due to their similar climatic and environmental conditions, including temperature, humidity, and rainfall. In Europe, the Banat area and Southern Carpathians of Romania were chosen for their continental Mediterranean climate and diverse soil types, such as urbic regosols, regosols, mixic entiantrosols (the R area and the M area), and reddish-brown soils. In Africa, the Tamale Metropolis in Ghana was selected, comprising 115 communities, many of which are rural and characterized by extensive agricultural land. These rural areas serve as the agricultural hub for the Metropolis, which functions as a central market for local goods from agricultural and commercial sectors within the region. Additionally, the markets attract goods from neighboring West African countries such as Burkina Faso, Niger, Mali, and northern Togo.

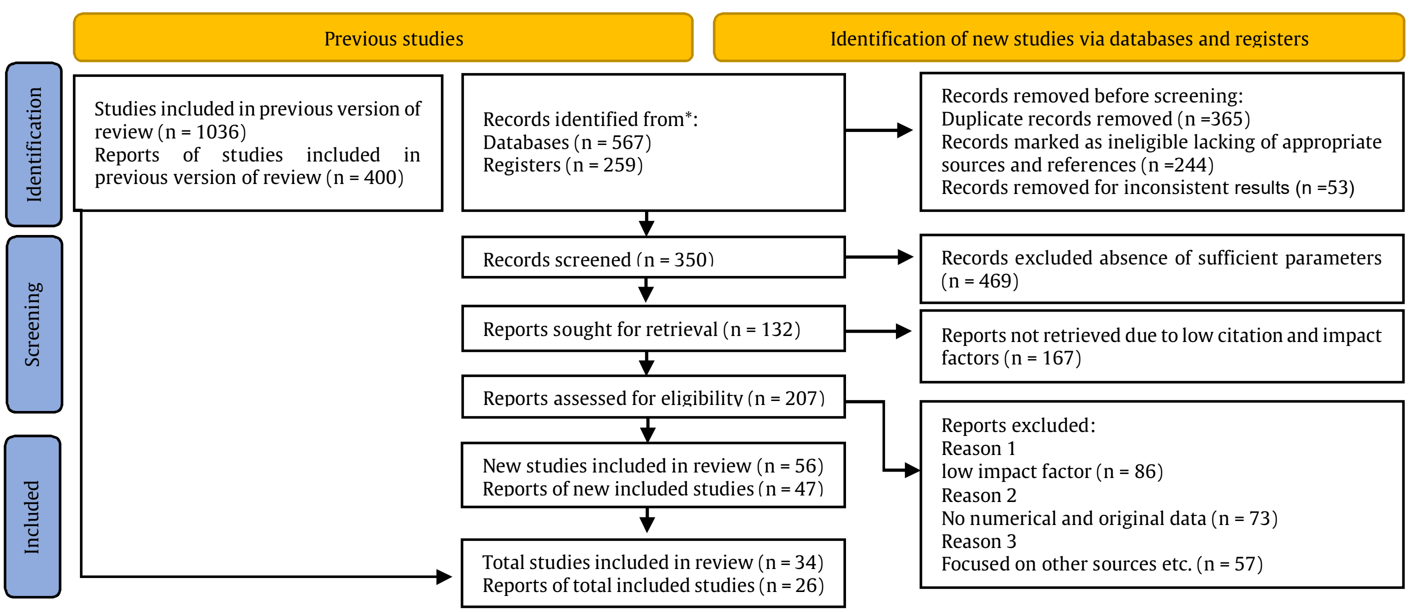

Figure 1. PRISMA flow diagram on the identification of eligible studies to final inclusion (Page et al., 2021)

2.4 Data extraction and statistical analysis

The data extracted from the 34 included articles are summarized in Figure 1. The preliminary variables extracted from the studies included the authors′ names, publication year, study areas with geological formations, country names, and other relevant details.

3. Results and Discussion

3.1 Popular selected vegetables in different countries

Various types of vegetables are grown around the world. This review focuses on six vegetables-tomato, eggplant, spinach, red amaranth, carrot, and radish–selected based on their taste, nutritional value, and availability. The scientific and family names of these vegetables are listed in Table 1.

Table 1. Selected commonly consumed vegetables, and their local and English names

Vegetable type	Local name	English name	Scientific name	Family
Fruit	Tomato	Tomato	*Lycopersicon esculentum*	Solanaceae
	Begun	Eggplant	*Solanum melongena*	Solanaceae
Leafy	Palong shak	Spinach	*Spinacia oleracea*	Solanaceae
	Laal shak	Red amaranth	*Amaranthus gangeticus*	Amaranthaceae
Root	Gajor	Carrot	*Daucus carota*	Apiaceae
	Mula	Radish	*Raphanus sativus*	Brassicaceae

A brief description of the selected vegetables is provided in Table 1. Tomatoes are grown worldwide, particularly in Europe (Italy and Spain), Asia (China, India, Turkey, Iran), Africa (Nigeria, Egypt), and the United States (Sekara et al., 2019). This fruit can be eaten raw or used as an ingredient in various dishes, sauces, and beverages (Ganesan et al., 2012). Eggplant is among the most prevalent, widely consumed, and economically important vegetable crops (Arivazhagan et al., 2018). It ranks fifth in terms of vegetable production across Asia and the Mediterranean region (Younas et al., 2022). Spinach is a commonly used leafy vegetable valued for its vitamins and phytonutrients (Nayik & Gull, 2020). Red amaranth is considered a predominant leafy vegetable due to its nutritional benefits and is grown year-round in tropical and subtropical regions (Ali et al., 2022). Carrot, a widely cultivated short-duration vegetable crop, is an affordable source of fiber, minerals, and vitamins (Muhie & Yimer, 2023). Radish, an underground-modified root vegetable, is widely grown in temperate, tropical, and subtropical regions (Ali et al., 2023). These vegetables are known to accumulate heavy metals from irrigation water, posing potential health threats to humans.

3.2 Heavy metals in vegetables

3.2.1 Safe limit of heavy metals in the selected vegetables

The permissible limits for heavy metal concentrations in soil have been established by various organizations, including the World Health Organization (WHO), the Codex Alimentarious Commission, the Ministry of Health in China, and the State Environmental Protection Administration (SEPA). These values are presented in Table 2. Table 2 shows the allowable limits of heavy metals in vegetables set by these organizations. While the values are largely consistent, with a few exceptions, the WHO (2012) has set lower permissible limits for most of the nine heavy metals, except for chromium (Cr), copper (Cu), and zinc (Zn), where the limits are comparatively higher.

Table 2. The safe limit of heavy metals in vegetables for human consumption

Organizations	Heavy metals (mg/kg)									References
	As	Cd	Cr	Cu	Fe	Mn	Ni	Pb	Zn	
WHO/FAO, 2012	0.5	0.2	2.3	73	425	0.2	0.1	0.3	99	Atta et al., 2023
Codex Alimentarious commission, 2011	-	0.05	2.3	-	-	-	10	0.1	40	Amuri et al., 2017
Ministry of Health, China. 2005	-	0.2	0.5	20	-	-	10	9	-	Zhuang et al., 2009
SEPA, 2005	-	0.2	0.5	20	-	-	10	9	100	Ahmed et al., 2019

*WHO-World Health Organization *FAO-Food and Agriculture Organization *SEPA-Scottish Environment Protection Agency

3.3 Heavy metals in fruit vegetables

The reported data indicated that Cr, Mn, and Ni levels in tomatoes and eggplant exceeded the permissible limits, while As, Cd, Cu, Fe, Pb, and Zn were below the permissible limits. However, in the Gazipur area of Bangladesh, an exception was observed, where all these heavy metals exceeded the permissible limits, suggesting that they are harmful to human consumption. Gazipur, being an industrial zone, contributes to severe heavy metal pollution due to the discharge of untreated effluents and improper disposal of solid waste. Notably, the highest concentrations of heavy metals in tomatoes were recorded in this region.

3.4 Heavy metals in tomato

Table 3 presents the concentrations of heavy metals in tomatoes and eggplants, revealing significant variations across different regions.

3.4.1 Dera Ghazi Khan, Punjab, Pakistan

In this region located between the Indus-River and Koh-e-Sulaiman range, Cr, Mn, and Ni exceeded the permissible limits set by WHO/FAO (2012). Mn and Ni concentrations were 23 and 12 times higher, respectively, than the limits. The trend in heavy metal concentrations was: Fe > Zn > Cu >

Mn > Cr > Ni > Pb > Cd > As. Irrigation in this area relied on contaminated water mixed with municipal sewage and industrial effluent (Atta et al., 2023).

3.4.2 Jhansi, Uttar Pradesh, India

In this region in this region, cadmium (Cd), copper (Cu), lead (Pb), and zinc (Zn) concentrations in tomatoes were within tolerable limits, while manganese (Mn) concentrations (3.83-22.76 mg/kg) exceeded the permissible limit. The trend in heavy metal concentrations was: Zn > Mn > Ni > Cu > Pb > Cd. The proximity of agricultural fields to highways and industrial areas contributed to the contamination (Gupta et al., 2022).

3.4.3 Gazipur, Bangladesh

In the Mokesh Beel area, Cd, Cr, Pb, and Zn exceeded permissible limits with As, Cd, and Pb significantly higher than all standards. The trend of concentration of heavy metals was Zn > Fe > Mn > Pb > Cu > Cr > Ni > As > Cd. These data were collected from the agricultural area around Mokesh Beel, near the industrial area of Gazipur district in Bangladesh. This area was oriented toward pharmaceutical, cement-klinker, battery, ceramic, glass, textile, and dyeing industries, poultry farms, etc. These industries discharge their waste directly through a drain into surface water bodies (Islam & Mostafa, 2022) the water. The highest level of heavy metals was found in water during the pre-monsoon season due to the lower dilution effect of water (Islam et al., 2015; Mohiuddin et al., 2012). The people around Mokesh Beel areas used the polluted water for irrigation purposes during the winter season and produced heavy metal-contaminated vegetables (Ahmed et al., 2019). 3.1.6 Heavy metals in eggplants The concentrations of heavy metals in eggplants are also presented in Table 3, demonstrating variation across regions.

3.5.1 Dera Ghazi Khan, Punjab, Pakistan

In eggplant from Dera Ghazi Khan concentrations of As, Cd, Cu, Fe, and Pb were within tolerable limits. However, Cr levels (4.61mg/kg) exceeded the permissible limits set by WHO/FAO, the Codex Alimentarious Commission, and SEPA. Mn (11.3 mg/kg) and Ni (1.08 mg/kg) were also above WHO/FAO limits. Specifically, Cr was two times higher than WHO/FAO/SEPA limits and nine times higher than Codex Alimentarious thresholds, while Mn and Ni were 56 and 10 times higher, respectively. The heavy metal concentration trend was Fe > Zn > Cu > Mn > Cr > Ni > Pb > Cd > As. Agricultural fields in this region rely on contaminated water sourced from Manka municipal sewage and industrial effluents for irrigation (Atta et al., 2023).

3.5.2 Satkhira, Khulna Division, Bangladesh

In eggplant from Satkhira and Khulna, Cd concentrations (0.10-0.38 mg/kg) were slightly higher, while Cu, Fe, Pb, and Zn levels were within tolerable limits. However, Mn (4.04-49.12 mg/kg) concentrations significantly exceeded the permissible limit of the WHO/FAO. Mn was 20-245 times higher than WHO/FAO. The trend in the concentration of heavy metal content was Fe > Zn > Mn > Cu > Pb > Cd. Vegetables in this area might be contaminated because of household activities, geographical position, excessive fertilizer use, and industrialization (Uddin et al., 2019).

3.5.3 Turag River, Dhaka, Bangladesh

In eggplant from the agricultural area near the Turagriver in Dhaka, concentrations of As, Cr, Cu, Pb, and Zn were within permissible levels. However, Cd levels were slightly elevated, and Ni (3.42-5.73 mg/kg) exceeded WHO/FAO thresholds but remained below limits set by other organizations. The trend of concentrations of the heavy metal trend was Zn > Cu > Ni > Cr > Cd > Pb > As. Industrial activities, including leather, pharmaceuticals, battery manufacturing, electronic goods, and textile manufacturing, discharge industrial effluents into the Turag River, contributing to contamination (Islam et al., 2014). Table 3 shows that the concentration of heavy metals in tomatoes and eggplants largely depended on location and irrigation water quality.

Table 3. Heavy metal concentrations in fruit vegetables (tomato and eggplant)

Vegetable Name	Heavy metal (mg/kg)									Location	References
	As	Cd	Cr	Cu	Fe	Mn	Ni	Pb	Zn		
Tomato	0.0002	0.12	3.02	10.6	69.4	4.6	1.23	0.15	26	Dera Ghazi Khan, Pakistan	Atta et al., 2023
		0.02-0.35		0.39-9.83		3.83-22.76	0.13-11.88	0.03-2.30	7.81-23.92	Jhansi, India	Gupta et al., 2022
	1.16	1.29	8.7	18.42	738.17	28.57	4.34	19.87	3184.55	Gazipur, Bangladesh	Ahmed et al., 2019
Eggplant	0.001	0.18	4.61	21.5	252.1	11.3	1.08	0.33	23.4	Dera Ghazi Khan, Pakistan	Atta et al., 2023
		0.10-0.38		3.62-18.43	99.5-1144.27	4.04-49.12		0.49-4.25	13.27-44.35	Satkhira, Bangladesh	Uddin et al., 2019
	0.03-0.04	0.17-0.30	0.68-1.35	13.57-19.90			3.42-5.73	0.06-0.10	16.29-21.50	Dhaka City, Bangladesh	Islam & Hoque, 2014

3.6 Heavy metal concentration in leafy vegetables

3.6.1 Heavy metals in spinach

Table 4 summarizes the concentrations of heavy metals in spinach, highlighting regional variations and their potential sources of contamination.

3.6.1.1 Dera Ghazi Khan, Punjab, Pakistan

In spinach collected from the Dera Ghazi Khan district, Punjab, Pakistan, cadmium (Cd) concentration (0.14 mg/kg) exceeded the limit set by the Codex Alimentarius Commission (2011) but remained within permissible limits established by WHO/FAO, SEPA, and the Ministry of Health, China. Cr (4.17 mg/kg), Cu (33.5 mg/kg), Mn (18.8 mg/kg), and Ni (1.53 mg/kg) were above the permissible limits. Notably, Mn levels were 94 times higher than the WHO/FAO threshold, while Cr levels were eight times higher than the limits set by SEPA and the Ministry of Health, China. In contrast, As, Fe, Pb, and Zn concentrations were below WHO/FAO safe limits. The heavy metal concentration trend was Fe > Cu > Mn > Zn > Cr > Ni > Cd > Pb. Spinach grown in this region is irrigated with water contaminated by municipal sewage and industrial effluent, leading to heavy metal accumulation in crops (Atta et al., 2023).

3.6.1.2 Dhaka, Bangladesh

Spinach samples collected from Karwan Bazar, the largest fresh produce market in Dhaka, were grown in districts such as Manikganj, Tangail, Narsingdi, Munshiganj, Savar, Keraniganj, and Dhamrai. Cd concentrations (0-0.90 mg/kg) exceeded the limits set by WHO/FAO, SEPA, and the Ministry of Health, China. Mn (33.4-194.7 mg/kg) and Zn (125.38-233.82 mg/kg) were significantly above permissible limits. Mn levels were 167-970 times higher than WHO/FAO limits, while Zn levels were three to five times higher than the Codex Alimentarius Commission threshold. Other heavy metals were within tolerable limits. The concentration trend of heavy metals in spinach was Fe > Zn > Mn > Cu > Cr > Pb > Cd (Sultana et al., 2022).

3.6.1.3 Satkhira, Khulna Division, Bangladesh

Spinach from Satkhira, Khulna Division, exhibited Cd levels (0.44-0.85 mg/kg) exceeding permissible limits set by WHO/FAO, SEPA, the Ministry of Health, China, and the Codex Alimentarius Commission. Fe (105.24-1211.8 mg/kg) and lead (Pb, 5.13-18.17 mg/kg) concentrations were also above WHO/FAO limits. However, Cu, Mn, and Zn concentrations were within tolerable ranges. The heavy metal concentration trend was Fe > Zn > Mn > Pb > Cu > Cd. Vegetables in this region are likely contaminated due to factors such as household waste, geographical conditions, excessive fertilizer use, and industrial activities (Uddin et al., 2019).

3.6.2 Heavy metals in red amaranth

Table 4 outlines the concentrations of heavy metals in red amaranth, showing significant variations across regions due to diverse environmental and industrial influences.

Table 4. Heavy metal concentrations in leafy vegetables (spinach and red amaranth)

Vegetable name	Heavy metal (mg/kg)										References
	As	Cd	Cr	Cu	Fe	Mn	Ni	Pb	Zn	Location	
Spinach		0.14	4.17	33.5	329.8	18.8	1.53	0.09	14.2	Dera Ghazi Khan, Punjab, Pakistanp.5 t2	Atta et al., 2023
		0-0.90	1.40-3.30	4.0-14.40	177.10-920.90	33.4-194.7	0-1.7	0-2.0	125.38-233.82	Dhaka City, Bangladesh	Sultana et al., 2022
		0.44-0.85		0.89-22.28	105.24-1211.8	10.19-99.02		5.13-18.17	19.72-95.54	Satkhira, Bangladesh.	Uddin et al., 2019
Red Amaranth	1.33	0.83	20.04	23.27	1615.71	57.91	9.29	497.99	818.35	Mokesh beel, Gazipur, Dhaka	Ahmed et al., 2019
		0.20-0.99		4.61.52.34	219.7-1126.5	9.10-44.14		6.20-18.11	11.82-52.68	Satkhira, Bangladesh,	Uddin et al., 2019
	0.11-0.19	0.60-1.05	1.42-2.84	15.41-22.60			4.35-7.30	1.51-2.70	90.47-119.42	Dhaka City, Bangladesh,	Islam & Hoque, 2014

3.6.2.1 Mokesh Beel, Gazipur, Bangladesh

In red amaranth collected from the agricultural area near the industrial area around Mokesh Beel, Gazipur, As concentration (1.33 mg/kg) exceeded the permissible limit set by WHO/FAO. Cd (0.83 mg/kg), Cr (20.04 mg/kg), Fe (1615.71 mg/kg), Pb (497.99 mg/kg), and Zn (818.35 mg/kg) were significantly higher than the permissible limits established by all referenced organizations. Notably, Cr levels were eight times higher than WHO/FAO and the Codex Alimentarius Commission standards, and 40 times higher than the limits set by SEPA and the Ministry of Health, China. Pb levels were 1659 times higher than WHO/FAO limits, while Zn concentrations were eight times higher than thresholds set by WHO, FAO, and SEPA. In contrast, Cu, Mn, and Ni concentrations were within tolerable limits. The heavy metal concentration trend was Fe > Zn > Pb > Mn > Cu > Cr > Ni > As > Cd. The contamination in this area is attributed to waste discharges from industries such as pharmaceuticals, cement, batteries, glass, poultry, and textiles. These industries release untreated waste directly into water bodies, leading to heavy metal accumulation in agricultural soils and crops (Ahmed et al., 2019).

3.6.2.2 Satkhira, Khulna Division, Bangladesh

In the Satkhira region of Khulna Division, cadmium (Cd), lead (Pb), and zinc (Zn) levels were within safe limits.

However, iron (Fe, 219.7-1126.5 mg/kg) exceeded permissible limits set by WHO/FAO, the Codex Alimentarius Commission, SEPA, and the Ministry of Health, China. Copper (Cu, 4.61-52.34 mg/kg) and manganese (Mn, 9.10-44.14 mg/kg) were also above the permissible limits established by WHO/FAO and other organizations. The concentration trend of heavy metals in red amaranth was Fe > Zn > Mn > Pb > Cu > Cd. The contamination in this region is likely caused by household activities, excessive use of fertilizers, industrial discharges, and geographical factors. These factors contribute to heavy metal accumulation in agricultural soils, adversely affecting crop quality (Uddin et al., 2019).

3.6.3 Cd concentrations (0.60-1.05 mg/kg) exceeded the permissible limits set by WHO/FAO, the Codex Alimentarius Commission, the Ministry of Health, China, and SEPA

In contrast, the concentrations of other heavy metals were below the permissible limits established by these organizations. The observed trend in heavy metal concentrations (mg/kg) was Zn > Cu > Ni > Pb > Cr > Cd > As. These data were collected from agricultural areas near the Turag River in Dhaka City, Bangladesh, which is surrounded by various industries, including leather processing, pharmaceuticals, battery manufacturing, electronic goods production, and textile manufacturing. Vegetables cultivated near the Turag River were irrigated with industrial effluents and untreated domestic sewage, contributing to heavy metal contamination in the crops (Islam et al., 2014).

3.7 Heavy metal concentration in root vegetables

3.7.1 Heavy metals in carrot

3.7.1.1 Banat, Southern Carpathians, Romania

In carrots from the Banat area of the Southern Carpathians, Romania, the concentration of Cd, Cu, Fe, Mn, Ni, and Zn showed tolerable limits. However, Pb concentrations (2.11 mg/kg) showed a higher value than that set by WHO/FAO and the Codex Alimentarius Commission but were lower than that of the Ministry of Health, China, and SEPA. The observed trend in heavy metal concentrations was Fe > Zn > Mn > Pb > Cu > Ni > Cd. This region features a continental Mediterranean climate and a combination of urbic regosols, mixic enthiantrosols, and reddish-brown soils (Manea et al., 2020).

3.7.1.2 Dhaka, Bangladesh

Carrots collected from the Karwan Bazar vegetable market in Dhaka city-the central supply hub for vegetables-showed manganese (Mn) concentrations (10.3-21.0 mg/kg) that exceeded permissible limits set by WHO/FAO. These Mn levels were 51.5-105 times higher than the recommended threshold. Other heavy metals, including Cd, chromium (Cr), Cu, Fe, nickel (Ni), Pb, and Zn, were found to be within tolerable limits. The trend of heavy metal concentrations was Fe > Zn > Mn > Pb > Cu > Cd. These carrots were grown in the agricultural zones surrounding Dhaka, including the districts of Manikganj, Tangail, Narsingdi, Munshiganj, Savar, Keraniganj, and Dhamrai (Sultana et al., 2022).

3.7.1.3 Tamale, Ghana

Carrots from the Central and Abaoba markets in Tamale, the capital city of the Northern Region of Ghana, exhibited heavy metal concentrations below permissible limits established by WHO/FAO, the Ministry of Health, China, the Codex Alimentarius Commission, and SEPA. The trend of heavy metal concentrations was Fe > Cr > Mn > Zn > Cd. Vegetables in this area were often cultivated using wastewater or graywater, which could contribute to the presence of heavy metals (Ametepy et al., 2018).

Table 5. Heavy metal concentration (mg/kg) in root vegetables (carrot and radish)

Vegetable name	Heavy metal								Location	References
	As	Cd	Cr	Cu	Fe	Mn	Ni	Pb	Zn		
Carrot		0.08		1.53	29.97	3.07	0.18	2.11	4.93	Banat area, Southern Carpathians	Manea et al., 2020
		0.00-0.50	0.50-2.20	2.80-4.20	47.90-149.30	10.3-21.0	0.00-0.90	0.00-3.00	7.28-17.55	Dhaka City, Bangladesh.	Sultana et al., 2022
		0.04	0.40	0.07	4.06	0.30			0.12	Tamale Metropolis, Ghana.	Ametepy et al., 2018
Radish		0.22-0.84		1.12-14.81	132.27-644.54	11.45-69.96		0.53-14.05	23.46-59.46	Satkhira, Bangladesh.	Uddin et al., 2019
		0.17-0.62	0.34-0.56		11.31-14.3	6.92-7.54	0.98-1.64	1.89-3.12	0.99-1.92	Peshawar, Khyber Pakhtunkhwa province of Pakistan.	Khan et al., 2015
		6		29			10	3	67	Research Farm, Indian Agricultural Research Institute	Singh et al., 2012

3.7.2 Heavy metals in radish

3.7.2.1 Satkhira, Khulna Division, Bangladesh

In Radish samples Satkhira, Khulna Division (Table 5), cadmium (Cd), copper (Cu), lead (Pb), and zinc (Zn) concentrations were within tolerable limits, while manganese (Mn, 11.45-69.99 mg/kg) exceeded the permissible limit set by WHO/FAO. The trend of heavy metal concentrations in radish was Fe > Zn > Mn > Cu > Pb > Cd. The vegetables in this area might be contaminated due to factors such as geographical position, household activities, excessive fertilizer use, and industrialization (Uddin et al., 2019).

3.7.2.2 Peshawar, Khyber Pakhtunkhwa, Pakistan

In radish samples from Peshawar, manganese (Mn, 6.92-7.54 mg/kg) showed higher values than the permissible limit, while cadmium (Cd, 0.17-0.62 mg/kg) and chromium (Cr, 0.34-0.56 mg/kg) showed slightly higher values compared to the permissible limit set by WHO/FAO. Other metals were within tolerable limits. The trend of heavy metal concentrations in radish was Fe > Mn > Pb > Zn > Cr > Cd. Peshawar, the capital city of Khyber Pakhtunkhwa province, is known for its suburban vegetable and forage crop cultivation. These crops are irrigated from canals originating from the Shalam River, which receives industrial effluents and household wastewater, contributing to contamination risks (Khan et al., 2015). Cd (6 mg/kg) and Cu (29 mg/kg) concentrations in radish were found to be significantly higher than the permissible limits set by WHO/FAO, the Codex Alimentarius Commission, the Ministry of Health, China, and SEPA. Cd was 30 times higher than the limit set by WHO/FAO, the Ministry of Health, China, and SEPA, and 120 times higher than the Codex Alimentarius Commission's limit. The trend of heavy metal concentrations was Zn > Cu > Ni > Cd > Pb (Singh et al., 2012).

3.8 Heavy metals consumption by humans

The health impacts of heavy metal consumption due to the transfer of contaminants to the human body may be assessed through the concept of average daily intake (ADI). ADI is the average daily intake of heavy metals per individual measured in mg per day (mg/person). Data for this assessment were collected from different relevant published articles. For tomato consumption, the levels of Cd, Cu, and Zn showed a lower limit than the limit set by WHO/FAO. However, Pb concentrations showed the highest limit (4.24E-04 mg/person), likely due to cultivation in a farmer's field near the national highway (Table 6). For eggplant consumption, the detected heavy metal levels remained within permissible limits, attributable to irrigation practices utilizing wastewater. In the case of spinach, while Cd, Cu, and Zn levels were within acceptable ranges, Pb concentrations exceeded permissible limits, also as a consequence of wastewater irrigation. Regarding amaranth, Cd levels were observed to be marginally above the acceptable limit, and Pb levels were significantly elevated, indicating contamination from cultivation in proximity to industrial areas. For carrot consumption, both Cd and Cu concentrations were found to be elevated. Similarly, radish samples exhibited the highest levels of Cu, which were collected from fresh vegetables at Karwan Bazar.

3.9 Effects of heavy metal consumption

Table 7 describes the effects of heavy metal consumption. The majority of heavy metals are found in the biosphere, which includes rocks, soils, and water. They are also released into the environment by anthropogenic activities, primarily those used in commerce and industry. When human bodies get overexposed to microscopic heavy metal molecules, it can lead to heavy metal toxicity. If treatment is not received, the symptoms that heavy metals create could be fatal because they bind to cells and stop their functions.

Table 6. Daily intake of heavy metals from vegetables (mg/person/day)

Vegetable	Heavy metal								References
	As	Cd	Cr	Cu	Fe	Mn	Ni	Pb	Zn	
Tomato		1.29E-04		4.43E-03		1.34E-02	8.25E-04	4.24E-04	1.56E-02	Gupta et al., 2022
Eggplant	0.00000012	0.0002	0.005	0.02	0.26	0.01	0.001	0.0003	0.02	Atta et al., 2023
Spinach		0.0001	0.004	0.03	0.34	0.091	0.002	9.2E-05	0.01	Atta et al., 2023
Amaranth	0.0004	0.0023	0.01	0.05			0.02	0.0055	0.29	Islam et al., 2014
Carrot		0.006	0.031	0.073	1.871	0.280	0.007	0.015	1.758	Sultana et al., 2022
Radish		0.002	0.012	0.053	1.288	0.239	0.012		2.627	Sultana et al., 2022
FAO/WHO (2019)		2.00E-01		5.00E-02-5.00E-01				3.00E-01	3.00E-01-1.00E+00	Gupta et al., 2022

Table 7. Health effects of heavy metal consumption

Heavy metal	Health effects	References
As	affects the pulmonary, nervous system, and skin. It is associated with respiratory tract cancers, peripheral neuropathy, and nasal septum perforation. May cause involve nausea, vomiting, and cardiac rhythm abnormalities. Long-term low-level exposure can lead to skin darkening skin and the formation of small corns or warts on the palms, soles, and torso.	Islam & Mostafa, 2024; Manzoor et al., 2018; Jolly et al., 2016; Mahurpawar, 2015; Martin & Griswold, 2015; Hartley & Lepp, 2008; Zhou et al., 2008; WHO, 1997; WHO, 1996; WHO, 1989.
Cd	proteinuria, Glucosuria, Aminoaciduria, emphaysemia, Ostemalacia	Engwa et al., 2019; Ametepey et al., 2018; Mahurpawar, 2015; Martin & Griswold, 2015; Guera et al., 2012; Suruchi & Pankaj, 2011; Sobha et al., 2017; Fu et al., 2008; Garcia & Milkan, 1998; De Flora et al., 1997.
Cr	affects lung health, causing lung ulcers. This can lead to perforation of the nasal septum. Crucial for insulin activity. Important for deoxyribonucleic acid (DNA) transcription.	Ametepey et al., 2018; Mahurpawar, 2015; Guerra et al., 2012; Zhuang et al., 2009.
Cu	low birth weight, spontaneous abortions, gestational diabetes, acute intestine and stomach aches, and liver damage.	Ametepey et al., 2018; Khanna, 2011; Manzoor et al., 2018; Rahman et al., 2014; Basu et al., 2014; Singh et al., 2012.
Fe	excess ingestion of Fe results in the deposition of Fe in tissues (siderosis). Affects the adrenal glands, liver, pancreas, thyroid, and pituitary gland.	Ametepey et al., 2018; Codex, 2011.
Mn	attacks the nervous system, causing central and peripheral neuropathies. Results in muscle weakness in different parts of the body. Damages sperm and leads to loss of sex drive. Increases the risk of pneumonia.	Monira & Mostafa, 2023; Jolly et al., 2016; Mahurpawar, 2015; Islam & Mostafa, 2024.
Ni	attacks the nervous and pulmonary systems, causing visual defects. Leads to EEG changes. Causes pneumoconiosis, an interstitial lung disease.	Jolly et al., 2016; Mahurpawar, 2015.
Pb	attacks the nervous system, leading to encephalopathy. Alters the brain function or structure. Causes anemia. Results in kidney damage.	Monira & Mostafa, 2023; Manzoor et al., 2018; Mahurpawar, 2015; Martin & Griswold, 2015; Grant et al., 2013; Navas-Acien et al., 2007; Ekong et al., 2006; Mahira & Fevaro., 2006; Shobha & Kalshetty, 2017.
Zn	acute stomach and intestine disorders, liver damage, decreased immune function, and levels of high-density lipoproteins.	Ametepy et al., 2018; Manzoor et al., 2018; Rahman et al., 2014; Harmanescu et al., 2011.

4. Conclusion

This review highlights elevated concentrations of heavy metals in various vegetables grown in industrially contaminated areas, exceeding the permissible limits set by WHO and other regulatory organizations. This review showed that the concentrations of heavy metals, including, Cu (18.42), Fe (738.17), Mn (28.57), Pb (19.87), and Zn (3184.55), For instance, in tomatoes cultivated in Gazipur, Bangladesh, the concentrations of Cd (1.29 mg/kg), Cr (8.7 mg/kg), Cu (18.42 mg/kg), Fe (99.2-1144.27 mg/kg), Mn (28.57 mg/kg), Pb (19.87 mg/kg), and Zn (3184.55 mg/kg) were significantly above standard thresholds. Similarly, Fe concentration in eggplant from the Satkhira district of Bangladesh was higher than the permissible limits, with similar findings reported for eggplant from Dera Ghazi Khan in Pakistan and Jhansi in India. Excessive Cd exposure causes proteinuria and emphysema in humans, while elevated Fe levels are associated with siderosis in the adrenals, liver, pancreas, thyroid, and pituitary. Spinach from Dera Ghazi Khan, Pakistan, irrigated with municipal sewage and industrial effluents, showed Mn (18.8 mg/kg) levels over 90 times higher than WHO/FAO limits, with Ni (1.53 mg/kg) and Cr levels exceeding the limits set by SEPA and the Chinese Ministry of Health by eight times. Red amaranth samples Mokesh Beel, Gazipur and Dahaka City exhibited Cd (0.83 mg/kg), Cr (20.04 mg/kg), and Pb (497.99 mg/kg) concentrations above the permissible limits, reflecting the influence of waste discharge from above the permissible limits. In carrots, Mn concentrations (10.3-21.0 mg/kg) were found to exceed the maximum limits set by the WHO/FAO and were associated with cultivation in industrially contaminated areas. Excess Cr was noted to adversely affect lung function and insulin activity, while elevated Pb levels were linked to brain function impairment, anemia, and kidney damage. These vegetables were predominantly sourced from the Karwan Bazar vegetable market in Dhaka City, suggesting they were cultivated in areas with significant industrial influence. Radish samples from the Satkhira district of Bangladesh exhibited Mn concentrations (11.45-69.9 mg/kg) above permissible limits, likely due to geogenic contamination. Excessive Mn in humans may disrupt the nervous system, causing muscle weakness. This review underscores that heavy metal contamination in vegetables arises primarily from irrigation with industrially contaminated water, geogenic sources, domestic sewage, household waste, and excessive use of chemical fertilizers.

4.1 Control policy

The government should take initiatives for awareness-building programs and establish necessary rules and regulations, as well as execute properly for irrigation water for the production of vegetables. Additionally, individuals involved in agricultural practices should exercise caution when selecting and using irrigation water to minimize contamination risks.

Authors' Contributions

Serajam Monira: Conceptualization; Writing-review & editing; Data curation; Investigation; Writing-original draft. **Golam Mostafa:** Conceptualization; Investigation; Project administration; Supervision; Writing-review & editing.

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Conflicts of Interest

The authors have declared no competing interests.

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Ethical considerations

There were no ethical considerations to be considered in this research.

Using artificial intelligence

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