Environmental Health Engineering and Management Journal 2024, 11(3), 349-359
http://ehemj.com
doi 10.34172/EHEM.2024.34

Environmental Health Engineering and Management Journal

Original Article

Open Access Publish Free

Health risk assessment of heavy metals in vegetables consumed in the central part of Mazandaran province

Abdoliman Amouei[1,2*], **Elham Falahati Naghibi**[3], **Hourieh Fallah**[1,2], **Hosseinali Asgharnia**[1,2], **Asieh Khalilpour**[1,3], **Hajar Tabarinia**[3]

[1]Environmental Health Research Center (EHRC), Health Research Institute, Babol University of Medical Sciences, Babol, Iran
[2]Social Determinants of Health Research Center, Health Research Institute, Babol University of Medical Sciences, Babol, Iran
[3]Department of Environmental Health, Public Health Faculty, Babol University of Medical Sciences, Babol, Iran

Abstract

Background: Heavy metals (HMs) in the environment threaten food safety and human health. In this study, the health risks of HMs caused by the consumption of commonly consumed vegetables in the central part of Mazandaran province were evaluated.

Methods: In this study, 42 vegetable samples were analyzed for concentration of HMs, and estimated daily intake (EDI), target hazard quotients (THQ), hazard index (HI), and target carcinogenic risk (TCR) were calculated.

Results: The mean content of lead (Pb), cadmium (Cd), and zinc (Zn) in the studied areas were obtained 28.45, 0.26, and 79.20 mg/kg, respectively. The concentration of Pb, Cd, and Zn in the studied vegetables was found to be 1.76 ± 0.2, 0.09 ± 0.07, and 11.53 ± 1.20 mg/kg, respectively. The EDI average of Pb, Cd, and Zn in adults was 0.0064, 0.0003, and 0.0412 mg/kg day^{-1}; and in children were 0.0099, 0.0005, and 0.0686 mg/kg day^{-1}, respectively. The present study showed that the THQ for Pb in all vegetables consumed by children faces much higher risks than adults. The TCR for Pb in total vegetables was less than 10^{-4} and for Cd was identified as more than 10^{-4} in some vegetables in the adults and the children's population.

Conclusion: The concentration of Cd and Zn in the soil and related vegetables is less than the permissible limit, but the amount of Pb in the vegetables is higher than the permissible limit. Therefore, continuous care and monitoring of agricultural soils in these areas, such as the proper use of chemical fertilizers, pesticides, and treated wastewater sludge, is necessary.

Keywords: Heavy metals, Vegetables, Adult, Children, Soil

Citation: Amouei A, Falahati Naghibi E, Fallah H, Asgharnia H, Khalilpour A, Tabarinia H. Health risk assessment of heavy metals in vegetables consumed in the central part of Mazandaran province. Environmental Health Engineering and Management Journal 2024; 11(3): 349-359 doi: 10.34172/EHEM.2024.34.

Article History:
Received: 14 April 2024
Accepted: 20 May 2024
ePublished: 22 June 2024

***Correspondence to:**
Abdoliman Amouei,
Email: iamouei1966@gmail.com

Introduction

Heavy metal (HM) pollution has spread broadly over the globe and has disrupted the environment and posed health hazards to humans and other living things. Despite HMs are natural components of the Earth's crust and can be released by natural processes, but often, anthropogenic activities (e.g., the rapid growth of urbanization, land use changes, mining, application of fertilizers and pesticides, and industrialization) are responsible for the majority of HM pollution (1-4).

Soil is the primary source of HMs in the atmosphere, hydrosphere, and other living organisms, and therefore, plays an essential role in the cycle of metals in nature. HMs in the soil are potential threats to the environment and living organisms, which can damage human health and the environment through different pathways such as direct digestion, dermal contact, inhalation, and oral intake (5,6).

Vegetables play important roles in the human diet, due to having a variety of useful materials and nutrients such as proteins, carbohydrates, vitamins, and antioxidants (7,8). However, various human activities such as industrial processing like smelting, mining, automobile exhausts, pesticides and fertilization, especially excessive consumption of inorganic chemical fertilizers in agricultural places are causing HM contamination in the world (9-11). Vegetables take up HMs by uptaking them from contaminated soils, as well as from deposits on parts of the vegetables exposed to the air from polluted environments (12).

Chemical effects of HMs on soil include changes in pH (e.g., metals such as cadmium [Cd] and aluminum can reduce soil pH, making it more acidic, and like nickel and chromium can increase soil pH, making it more alkaline), nutrient imbalance, degradation of soil organic matter, and impact on redox reactions (13). HMs impact the physiological and biochemical functions of plants, triggering adverse effects on photosynthesis by diminishing chlorophyll production, disrupting enzyme activity, and impeding nutrient absorption (14). This results in halted plant growth, stunted development, and diminished product yield. Moreover, HMs induce oxidative stress in plants, generating reactive oxygen species that harm cellular structures, disrupt metabolic functions, and lead to cell membrane damage, protein degradation, and DNA alterations, ultimately, affecting plant growth and crop productivity (13).

Long-term intake of HMs in humans and other living organisms causes serious damage to them. For example, chromium, copper, and Zn cause non-cancerous diseases such as neurologic conflict, headache, and liver disease, when the HMs contents are higher than their safe threshold values (15). There is also clear evidence that long-term exposure to low doses of HMs can cause various cancers. For example, Park et al found an increased lifetime risk of dust and mists containing hexavalent chromium (16). Daily intake of Cd through the consumption of rice and other foods obtained from contaminated soils has been associated with the occurrence of a type of breast cancer (17). Cd and Pb are the most toxic metals for humans (18). Laˇcˇtuşu et al reported that in people who lived in areas with soil and vegetables contaminated with Pb and Cd in a place of Romania, life expectancy decreased by 9 to 10 years (19). Exposure to high concentrations of Pb can cause elevated arterial pressure, behavioral issues, and long-term impairment of the brain and kidneys (20). On the other hand, extreme exposure to Cd may cause skeletal difficulties, respiratory system, cardiac, and renal complications (2,3). Hu et al analyzed the levels of HMs in soil and vegetables and evaluated the associated health risks in suburban areas across China (21). Heshmati et al investigated the concentration and health risks of Pb and Cd in vegetable and grain consumption in western Iran (22). In addition, Amouei et al examined the concentration of Pb, Cd, and Zn in the soil of different agricultural areas of Mazandaran province along with their potential impact on human health (23).

Babol city is located in the central part of Mazandaran province and is one of the most populous cities in northern Iran. The Babol River passes through this city and flows into the Caspian Sea. This city has a lot of vegetable fields, the area under vegetable cultivation is 6,438 hectares and the annual production is 104 300 tons, and every year, large quantities of vegetables are sent to all parts of Iran. Therefore, this study aimed to determine the concentration of HMs (Pb, Cd, and Zn) in the agricultural soils and some vegetables consumed and to assess their potential human health risks in the residents of Babol city.

Materials and Methods

Soil and vegetable sampling

In this study, soil and vegetable samples were collected from four areas of Babol city including L_1 = Mooziraj, L_2 = Tork Mahalle, L_3 = Gorji Abad, and L_4 = Bala Baziar (Figure 1). In each agricultural area, 15 soil samples

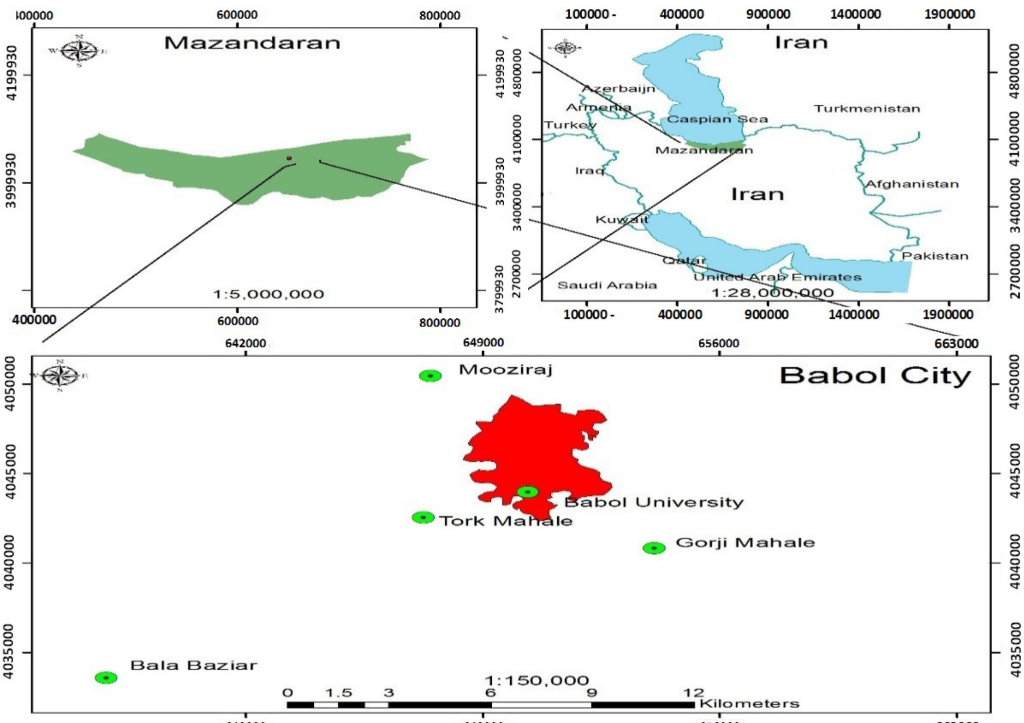

Figure 1. Soil and vegetable sampling locations in the investigated areas of central Mazandaran province (Babol city)

related to the studied vegetables (approximately 1 kg in each sample) were randomly taken from a surface area of 20 cm × 20 cm at 5 and 15 cm depth and transferred to the laboratory using polyethylene bags. The soil samples were first air-dried at room temperature for one week and passed through 2-mm and 0.15-mm sieves, respectively (23). Sixty samples from 6 commonly consumed vegetable types such as cress, radish, parsley, leek, coriander, and lettuce were collected from four regions of vegetable fields. The vegetable samples were thoroughly cleaned by washing away any dust particles with de-ionized distilled water, followed by drying in an oven at 70-80 °C for 24-48 hours. Subsequently, the dried samples were ground up, crushed, and stored in sealed containers until the digestion and analysis stages (24,25).

Soil and vegetable samples digestion

One gram of dried soil samples was digested in a digestion system (21 mL HNO_3 + 7 ml HCl) for 1 hour at a temperature of 80 °C. The digestion samples were filtered through Whatman paper No. 42 and deionized water was added to reach 50 mL. Then, they were transferred to 100 mL polyethylene containers and kept in the refrigerator at 4 °C for HMs analysis (26). For chemical digestion of vegetable samples, 1 g of each sample was subjected to digestion using a mixture of three acids including HNO_3 (Nitric acid 65%, Merck), $HClO_4$ (Perchloric acid 60%, Merck), and H_2SO_4 (Sulfuric acid 98%, Merck), in the proportion of 5:1:1. The digestion process took place at a temperature of 100 °C until clearing of solution. After digestion, the samples were filtered through Whatman paper No. 42 and diluted to 50 mL with distilled water (24,27).

Determination of HMs in soil and vegetable samples

Vegetables and soil samples were collected after the preparation steps (digestion, acidification, and filtering). They were stored in polyethylene bottles. The metal content of samples was measured by flame-atomic absorption spectrophotometer (PG-instrument Company, 990 model, UK). The concentration of Pb, Cd, and Zn in each sample was measured at specific wavelengths (Pb = 2383.5 nm, Cd = 288.8 nm, and Zn = 13.29 nm). To control the quality of the analyses, three blank samples were prepared along with other samples. Stock standard solutions of Cd, Zn, and Pb were provided at a concentration of 1000 mg L^{-1} in a solution containing 0.5 mol HNO_3 (ultrapure) supplied by Merck company. The analytical detection limit was 0.0028, 0.012, and 0.003 (mg/L) for Cd, Pb, and Zn, respectively. The sensitivity, standard deviation (SD), and precision of analytical conditions were evaluated. Five-eight-point calibration curves were prepared for each element with the aspiration of the standard solutions (1-1.5 mL). Each sample was analyzed three times with an integration time of 3 s to obtain a relatively standard deviation of 5% or less within the calibration range. Working standard solutions for Zn (0.00, 0.5, 1, 2, 4, and 6 mg/L), Pb (0.00, 0.312, 0.625, 1.25, 2.5, 5, and 10 mg/L), and Cd (0.00, 0.018, 0.039, 0.078, 0156, 0.312, 0.625, and 1.25 mg/L) were prepared from stock standards 1000 mg/L purchased from Merck company. Only deionized water was used to prepare analysis solutions. The final dilution of standards was done in a solution of 2% HNO_3 (from HNO_3 65%). The calibration curve was established using the standard solutions.

Health risk assessment

Estimated daily intake

The daily intake of metals depends on the daily food consumption rate (24). The daily intake of HMs through vegetables was evaluated by USEPA methods and determined using Eq. (1). Estimations were made for two groups: children, as a sensitive group, and adults, as the general population.

$$\mathrm{EDI} = \frac{C_M \times I_R \times E_F \times E_D}{B_W \times A_T} \tag{1}$$

Where *EDI* is the estimated daily intake of the HM through ingestion (mg/kg day^{-1}), C_m is the concentration of HM in the edible part of vegetable (mg/kg), I_R is the ingestion rate of vegetable or vegetable consumption per capita (kg/person/day), E_F is the exposure frequency to the HM (day/year), E_D is the average exposure duration based on the average lifespan (year), B_w is average body weight (kg), and A_T is the time duration of human exposure as day (24,28). The parameters for calculating the EDI are presented in Table 1.

Non-carcinogenic risks

Target hazard quotient (THQ)

The THQ is used to determine the non-carcinogenic risk level due to pollutant exposure (32). The THQ is the ratio of exposure to a toxic element to the reference dose (Eq. 2). This index describes the non-carcinogenic health risk from exposure to a specific toxic element as follows: If the THQ is < 1, non-carcinogenic health effects are not expected, but if it is > 1, there is a possibility of adverse health effects (33-35).

$$\mathrm{THQ} = \frac{\mathrm{EDI}}{\mathrm{RfD}} \tag{2}$$

Table 1. Parameters for calculating estimated daily intake (EDI)

Parameter	Value	Reference
I_R	0.125 kg day^{-1} for children and 0.25 kg day^{-1} for adults	(29,30)
E_F	365 day $year^{-1}$	(24)
$_ED$	6 years for children and 70 years for adults	(3,24)
B_W	21 kg for children and 70 kg for adults	(7,24)
A_T	365 × E_D = 2190 days for children and 25550 days for adults	(31)

Table 2. Reference dose (RfD) and cancer slope factor (CSF) for heavy metals

Heavy metal	RfD (mg/kg day^{-1})	CSF (mg/kg day^{-1})	Reference
Pb	0.0035	0.0085	(34, 35)
Cd	0.001	0.38	(24, 35)
Zn	0.3	-	(37)

Where *RfD* (reference dose) is the maximum tolerable daily intake (MTDI) of a specific metal (mg/kg day^{-1}) (36,37). RfD for the various HMs is presented in Table 2.

Hazard index (HI)

The HI refers to the non-carcinogenic health risk associated with several HMs in the exposure pathway. When HI is less than 1, it indicates that the exposed HMs (through the consumption of vegetables) do not have significant non-carcinogenic adverse effects. However, when HI is greater than 1, it means that there are non-carcinogenic risks associated with the exposed HMs (38,39). The HI is calculated using Eq. (3):

$$HI = \sum_{1}^{n} THQ = THQ_{Pb} + THQ_{Cd} + THQ_{zn} \quad (3)$$

Target carcinogenic risk (TCR)

TCR is a measure used to assess the potential risk of developing cancer from consuming foods that contain HMs (40,41). Instead of an oral reference dose, as is used for the determination of THQ, an oral slope factor is utilized. This factor determines, along with the dose of the carcinogen, the probability of excess cancer risk over the lifetime of the exposed individual (33,42). The cancer slope factor is an estimate of the probability that an individual will develop cancer if exposed to a chemical substance for a lifetime of 70 years (40). TCR is determined by Eq. (4):

$$\mathrm{TCR} = EDI \times CSF \quad (4)$$

Where *EDI* is the estimated daily intake of HMs through ingestion (mg/kg/d) and *CSF* is the cancer slope factor for HMs (mg/kg/d). Cancer risk values ranging from 10^{-6} to 10^{-4} are considered to pose a tolerable risk. Risk values lower than 10^{-6} can be disregarded, while values exceeding 10^{-4} are deemed unacceptable in terms of potential health impact (15,43).

Results

Concentration of metals in soil

According to Table 3, the mean content of Pb, Cd, and Zn in the studied areas were 28.45, 0.26, and 79.18 mg/kg. The highest amount of Pb in the soil (34.40 mg/kg) was observed in the L_4 area, the highest amount of Cd and Zn (0.31 and 84 mg/kg, respectively) were observed in the L_3 area, and the lowest concentration of Pb, Cd, and Zn in the soil samples was obtained in the L_1 area.

Table 3. Descriptive statistical analysis mean values of the heavy metals concentrations in the soil (mg/kg)

Location of Sampling	Heavy Metal			THM
	Pb±SE	Cd±SE	Zn±SE	
L_1 (Mooziraj)	21.30±5	0.18±0.07	72.80±24	94.28±9.69
L_2 (Tork Mahalle)	24.60±4.80	0.23±0.06	76.50±16.50	101.33±7.12
L_3 (Gorji Mahalle)	33.50±4.50	0.31±0.10	84.00±21.50	117.81±8.7
L_4 (Bala Baziar)	34.40±5	0.30±0.10	83.40±12.80	118.10±5.97
Mean	28.45±4.83	0.26±0.08	79.18±18.70	107.88
Max	34.40±5	0.31±0.10	84.00±21.50	118.10
Min	21.30±2	0.18±0.07	72.80±24	94.28
-	35 [a]	0.35 [a]	90 [a]	-
-	100 [b]	3 [b]	300 [b]	-

THM: Total heavy metals.
[a] Background level of heavy metals in the world soils (42).
[b] Maximum permissible values of heavy metals concentrations in soils (43).

Concentration of metals in vegetables

The concentrations of HMs (Pb, Cd, and Zn) in the six types of vegetables studied are detailed in Table 4. In this study, the maximum concentration of Pb (2.04 mg/kg) was observed in coriander, and the lowest one (1.59 mg/kg) was reported in lettuce. The maximum amount of Cd (0.16 mg/kg) was obtained in lettuce and the minimum one (0.03 mg/kg) in leek. In this study, the maximum Zn concentration (14.90 mg/kg) was reported in cress, and the minimum one (8.52 mg/kg) in leek.

Estimated daily intake

As previously mentioned, the EDI refers to the quantity of HM ingested per kilogram of body weight per day. The EDI values for the metals under investigation in two population groups— adults (A) and children (B) (as the sensitive group)— are presented in Table 5. According to this table, the EDI of Pb, Cd, and Zn related to all vegetables was higher in children than in adults. The average EDI of Pb for children and adults in this study was 0.0106 and 0.0064 mg/kg/d, respectively. The highest EDI values for Pb in both children and adults (0.0121 and 0.0073 mg/kg/d) were related to coriander. The maximum values of EDI related to Cd and Zn in children and adults were 0.0010 and 0.006 mg/kg/d in lettuce and 0.0888 and 0.0533 mg/kg/d in garden cress, respectively.

Target hazard quotient and hazard index

The non-carcinogenic risk of HMs through vegetable consumption is calculated using criteria such as THQ and HI. THQ and HI values for adults (A) and children (B) population are presented in Table 6. According to this table, the amount of THQ of Pb in all studied vegetables was higher than one. Also, the average THQ of this metal was higher in children (3.02) than in adults (1.82). In this study, the maximum THQ of Pb (3.47) was obtained in coriander and the minimum one (1.62)

Table 4. Mean value of the heavy metals concentrations in vegetables (mg/kg)

Number	Vegetable	Scientific Name	Heavy metal			THM
			Pb±SE	Cd±SE	Zn±SE	
1	Cress	*Lepidium sativum*	1.74±0.24	0.09±0.004	14.91±1.36	16.74
2	Radish	*Raphanus sativus*	1.96±0.23	0.09±0.008	12.15±1.61	14.20
3	Parsley	*Petroselinum crispum*	1.73±0.21	0.04±0.006	9.66±0.40	11.43
4	Leek	*Allium ampeloprasum*	1.61±0.25	0.03±0.006	8.52±1.04	10.16
5	Coriander	*Coriandrum sativum*	2.04±0.18	0.11±0.007	12.13±0.99	14.28
6	Lettuce	*Lactuca sativa*	1.59±0.27	0.16±0.009	11.81±1.60	13.56
Average vegetable	-	-	1.78±0.23	0.09±0.007	11.53±1.20	12.71
Max	-	-	2.04±0.18	0.16±0.009	14.91±1.36	13.40
Min	-	-	1.59±0.27	0.03±0.006	8.52±1.04	10.16
The FAO/WHO maximum permissible values (41)			0.3	0.2	99.4	-

THM: Total heavy metals.

in lettuce. In this study, the order of THQ of the studied HMs caused by vegetable consumption was as follows: Pb > Cd > Zn, and the THQ order of Pb as a vegetable was as coriander > radish > cress > parsley > leek > lettuce. Also, the THQ order of Cd and Zn as vegetables was as lettuce > coriander > cress > radish > parsley > leek; and cress > radish > coriander > lettuce > parsley > leek, respectively. In this study, the THQ of Cd was less than one in all studied vegetables in children and adults. The maximum of this element in children (0.95) and adults (0.57) was related to lettuce. The maximum THQ of Zn in children (0.30) and adults (0.18) was related to cress plant. According to Table 6, the HI level in all the investigated vegetables in children and adults was higher than one. The maximum HI produced due to the studied HMs in adults (2.61) and children (4.36) was related to coriander and the lowest one (1.85) was related to leek.

Target carcinogenic risk (TCR)

According to Table 6, the average TCR of Pb and Cd in the studied vegetables was calculated as 5.4×10^{-5} and 9.3×10^{-5} in adults, and 9.00×10^{-5} and 1.96×10^{-4} in children, respectively. The maximum TCR of Pb in children (1.3×10^{-4}) and adults (6.2×10^{-5}) was related to coriander. The maximum TCR of Cd in children (3.6×10^{-4}) and adults (2.2×10^{-4}) was attributed to lettuce. In this study, the lowest TCR of Pb in children (8×10^{-5}) and adults (4.8×10^{-5}) was related to lettuce. Also, the minimum TCR of Cd was obtained in adults (4.1×10^{-5}) and children (6.8×10^{-5}) in leek.

Table 5. Estimated daily intake (mg/kg/d) for adults (A) and children (B) in Babol city, Mazandaran province

Vegetable	Scientific name	EDI		
		Pb	Cd	Zn
A: Adults				
Cress	*Lepidium sativum*	0.0062	0.0003	0.0533
Radish	*Raphanus sativus*	0.0070	0.0003	0.0434
Parsley	*Petroselinum crispum*	0.0062	0.0001	0.0345
Leek	*Allium ampeloprasum*	0.0058	0.0001	0.0304
Coriander	*Coriandrum sativum*	0.0073	0.0004	0.0433
Lettuce	*Lactuca sativa*	0.0057	0.0006	0.0422
Mean veg.		0.0064	0.0003	0.0412
Max		0.0073	0.0006	0.0533
Min		0.0057	0.0001	0.0304
MTDI		0.0035	0.0010	0.300
B: Children				
Cress	*Lepidium sativum*	0.0104	0.0005	0.0888
Radish	*Raphanus sativus*	0.0117	0.0005	0.0723
Parsley	*Petroselinum crispum*	0.0103	0.0002	0.0575
Leek	*Allium ampeloprasum*	0.0096	0.0002	0.0507
Coriander	*Coriandrum sativum*	0.0121	0.0007	0.0722
Lettuce	*Lactuca sativa*	0.0095	0.0010	0.0703
Mean veg.		0.0099	0.0005	0.0686
Max		0.0121	0.0010	0.0888
Min		0.0095	0.0002	0.0507
MTDI		0.0035	0.0010	0.300

MTDI: Maximum tolerable daily intake.

Discussion

The central part of Mazandaran province is located near the Caspian Sea, which includes agricultural areas where some agricultural products such as rice and many vegetables and fruits are produced. Every year, large amounts of agricultural and horticultural products from these areas are sent to other cities in Iran. The occupations of most people in these areas are agriculture, horticulture, animal husbandry, and honey breeding. Therefore, the control and protection of the environment, including the agricultural soils of these areas, will be very important to provide and maintain the health of food, and also, the health of the consumers of agricultural products in these areas.

Concentration of heavy metals in soil samples

Table 6. Target hazard quotient (THQ), hazard index (HI), and target cancer risk (TCR) for adults and children

Vegetable	Scientific Name	THQ			HI	TCR	
		Pb	Cd	Zn		Pb	Cd
A: Adult							
Cress	*Lepidium sativum*	1.78	0.32	0.18	2.28	5.28×10^{-5}	1.22×10^{-4}
Radish	*Raphanus sativus*	2.00	0.32	0.16	2.46	5.95×10^{-5}	1.22×10^{-4}
Parsley	*Petroselinum crispum*	1.77	0.14	0.12	2.03	5.25×10^{-5}	5.43×10^{-5}
Leek	*Allium ampeloprasum*	1.64	0.11	0.10	1.85	4.89×10^{-5}	4.07×10^{-5}
Coriander	*Coriandrum sativum*	2.08	0.39	0.15	2.61	6.19×10^{-5}	1.49×10^{-4}
Lettuce	*Lactuca sativa*	1.62	0.57	0.14	2.33	4.83×10^{-5}	2.17×10^{-4}
Mean	-	1.82	0.31	0.14	2.26	5.40×10^{-5}	9.27×10^{-5}
Max	-	2.08	0.57	0.18	2.61	6.19×10^{-5}	2.17×10^{-4}
Min	-	1.62	0.11	0.10	1.85	4.83×10^{-5}	4.07×10^{-5}
B: Children							
Cress	*Lepidium sativum*	2.96	0.58	0.30	3.80	8.80×10^{-5}	2.04×10^{-4}
Radish	*Raphanus sativus*	3.33	0.54	0.24	4.11	9.92×10^{-5}	2.04×10^{-4}
Parsley	*Petroselinum crispum*	2.94	0.24	0.19	3.37	8.75×10^{-5}	9.05×10^{-5}
Leek	*Allium ampeloprasum*	2.74	0.18	0.17	3.09	8.15×10^{-5}	6.79×10^{-5}
Coriander	*Coriandrum sativum*	3.47	0.65	0.24	4.36	1.03×10^{-4}	2.49×10^{-4}
Lettuce	*Lactuca sativa*	2.70	0.95	0.23	3.88	8.04×10^{-5}	3.62×10^{-4}
Mean	-	3.02	0.52	0.23	3.77	9.00×10^{-5}	1.96×10^{-4}
Max	-	3.47	0.95	0.30	4.36	1.03×10^{-4}	3.62×10^{-4}
Min	-	2.70	0.18	0.17	3.09	8.04×10^{-5}	6.79×10^{-5}

One of the most important ways to ensure and maintain the health of agricultural products of an area is to investigate and determine the concentration of HMs in the soil and vegetables used in it (23). In this study, the concentration ranges of Pb, Cd, and Zn in the soil of the studied areas were obtained as 28.5 ± 4.8, 0.26 ± 0.08, and 79.2 ± 18.7 mg/kg, respectively. According to the background concentration of Pb, Cd, and Zn in the soil of the world including 35, 0.35, and 90 mg/kg, respectively, as well as the maximum permissible amounts of these metals according to the recommendations of the Environmental Protection Agency (EPA) (37), the obtained data of Pb, Cd, and Zn in the soil of the studied areas is acceptable. In the study of Hu et al in the vegetable growing areas of China, the concentration of Pb, Cd, and Zn in the soil of these areas was found to be 41.94, 0.5, and 75.38 mg/kg, respectively (21). In another study, the average Cd and Zn concentrations in the around area of Marrakech city were 9.94 and 85.69 mg/kg, respectively (42). The reasons for the difference in the concentrations of Pb, Cd, and Zn in the soil of the agricultural areas around the cities can be attributed to the disposal of municipal sludges and solid wastes, the natural and geological characteristics of the soil, the irrigation of agricultural lands with untreated sewage, and the excessive consumption of chemical fertilizers, and contaminated organic (44,45). For example, in the suburban areas of northern Algeria, the main source of HMs was long-term wastewater irrigation, which might lead to the accumulation of Cd and Zn in soil (45). Luo et al have estimated that 6.6% of the HMs added to the soil annually came from wastewater irrigation in China (46). According to the data from the National Bureau of Statistics of China, the Cd content in agricultural soils is significantly correlated with the Cd concentration in the phosphate fertilizers and livestock manure applied (47). Moreover, the application of pesticides could also lead to the accumulation of Cd in soil (41).

Concentration of heavy metals in vegetables samples

In this study, the maximum and minimum concentration of Pb was obtained in coriander (2.04 ± 0.2 mg/kg) and lettuce (1.6 ± 0.3 mg/kg), respectively. In this study, cress and leek had the highest and lowest Zn concentrations (14.9 ± 1.4 and 8.5 ± 1 mg/kg), respectively. In the literature, the oldest study related to the analysis of Pb in cress in Iran is related to the study of Shariatpanahi and Anderson, which reported a mean concentration of 0.8 mg/kg for Pb (48). In cress, the highest Pb concentration (17.00 mg/kg) is related to the study of Jalali and Meyari (49), and subsequently, to the study of Maleki et al 13.11 mg/kg (26). In the present study, the mean concentration of Pb for parsley obtained was 1.73 mg/kg. For parsley, a mean concentration of 0.2 mg/kg was found by Tajdar-Oranj et al (50). Many differences between the results of different articles can be caused by the difference in extraction methods and analysis methods. In addition, it should be related to different geographical areas and the physical and chemical properties of the soil of different regions, such as the difference in the pH and Total organic carbon (TOC) percentage of soils (44,46,51). In this study, the average concentration of Pb was found as follows coriander > radish > cress > parsley > leek > lettuce . In the present study, the average concentration of Cd in total vegetable samples was 0.09 mg/kg. Also, the maximum Cd concentration (0.16 ± 0.01 mg/kg) was in lettuce and the minimum one was (0.03 ± 0.006 mg/kg) in leek. Many studies have revealed that leaf vegetables have strong capabilities to take up Cd compared to other vegetable varieties, which is consistent with the results of the present study (49). The rank order of mean concentration of Cd was lettuce > coriander > radish > cress > parsley > leek. Jalali and Meyari reported an average Cd concentration of 1.46 mg/kg in coriander (49). In another study by Khajeh et al, a mean Cd concentration of 0.06 mg/kg was obtained (52). The highest mean concentration of Cd in Iran for dill vegetables was reported 2.5 mg/kg in the study by Jalali and Meyari (49). In the study by Bahrami et al, the mean Cd concentration of 0.07 mg/kg was determined in some vegetable samples (53), which is consistent with the results of the present study. In this study, the mean concentration of Cd in parsley was 0.4 mg/kg. In the studies by Seid-Mohammadi et al (54) and Derakhshan et al (55), the mean concentrations of Cd in parsley were reported 0.02 and 0.05 mg/kg, respectively. Various parameters such as the geographical area from where the samples were gathered or the number of samples and the analysis method can play a role in the heterogeneity of the results (43,45).

Non-carcinogenic and carcinogenic indexes in health risk assessment

In this study, the average EDI of Pb in children and adults through consumption of studied vegetables was 0.0106 and 0.0064 mg/kg/d, respectively. Also, the average EDI of Cd and Zn in children and adults through consumption of the studied vegetables were 0.0005 and 0.0686 mg/kg/d; 0.0003 and 0.0412 mg/kg/d, respectively. According to the MTDI of Pb, Cd, and Zn set by the World Health Organization (WHO) (0.0035, 0.0010, and 0.3 mg/kg/d) (40), it is clear that the Pb EDI obtained in this study is higher than the guideline of the WHO, but the values related to Cd and Zn are lower than the limit.

Since the THQ for Pb metal was shown to be higher than 1 in all the vegetables studied, the HI values for all the vegetables were higher than 1, which means that consumption of all the vegetables studied poses non-carcinogenic risks for both populations. As shown, coriander has the highest non-carcinogenic risk values with HI = 4.36 and HI = 2.62 for children (B) and adults (A) populations, respectively. Su et al assessed the health risks associated with the human intake of vegetables in South China. In their study, Cd, As, Hg, Cu, Ni, Pb, Zn, and Cr in soil and vegetables were evaluated for contamination. They showed that the total non-cancer risk (HI) of HMs ingested through vegetables was 2.3 for children and 0.96 for adults (56) that like the present study, the non-carcinogenic risk in children is almost twice that of adults. Singh et al found that chromium, nickel, copper, and Pb in Indian vegetables had THQ > 1 for both children and adults. Their study revealed contamination of these HMs in vegetables, posing health risks to local residents, except for Zn (57). Abuzed Sadee et al determined HMs in some vegetables consumed in Erbil city of Iraq and HQ caused by HMs. They reported that the HQ of Cd and Pb were in the range of 0.60-3.32 and 0.83-2.23, respectively. The findings of their study revealed that there would be a non-carcinogenic health risk to the population of Erbil city by both metals (Pb and Cd), unlike the present study (only Pb) (4). Long-term exposure to high concentrations of HMs through contaminated food can cause chronic HM deposition in humans' liver, kidneys, and bones, which can result in renal, cardiovascular, neurological, and bone issues (13).

The consumption of HM-contaminated dietary stuff for long-term exposure throughout life daily is considered to be carcinogenic effects (cancer in different parts of the body). The US EPA stated that if cancer risk values lie between 10^{-6} to 10^{-4}, it causes tolerable risk, but if it is less than 10^{-6} it can be ignored, and while TCR values more than 10^{-4} is unacceptable (58-61). The assessment of carcinogenic risk associated with lead exposure through vegetable consumption revealed that in the adult population (A), the risk falls within the range of 10^{-6} to 10^{-4} for all vegetables studied. This suggests a tolerable level of risk from lead exposure in this population. However, in the children population (B), the carcinogenic risk from lead in coriander exceeds 10^{-4} (1.03×10^{-4}), indicating a risk of carcinogenesis associated with lead exposure through the consumption of this vegetable among children in this city (Table 6). Moreover, carcinogenic risks associated with Cd were noted in the adult and children populations from the consumption of some these vegetables (cress, radish, coriander, and lettuce). Many studies have investigated the health risk including non-carcinogenic and carcinogenic risks of consuming vegetables contaminated with HMs (62-66). For example, Osae et al showed that the HI for adults (0.46–41.16) and children (3.88–384.12) were high for all vegetables tested and was associated with cancer risk due to high levels of chromium and Pb. They concluded that vegetables grown in the Coral Lagoon catchment are unsuitable for consumption due to associated adverse health effects (3). In the study of Mizan et al, the TCR exceeded the acceptable value (1×10^{-6}) and showed greater risks to children than adults, especially for Cr in soil (67). In the study of Su et al, the total cancer risk for children was 2.54×10^{-2} and 1.07×10^{-2} for adults, both of which exceeded acceptable levels. They reported that children are more susceptible to health risks due to the consumption of contaminated vegetables than adults, which is consistent with the findings of the present study (56). Due to the rising cancer incidence, the carcinogenic risk connected with HMs is a global concern (3). Some studies reported management practices to avoid health risks associated with the consumption of HM-polluted vegetables. Wang et al evaluated the effects of some foliar fertilizers (fortified zinc fertilizer ($ZnSO_4$ + silicon surfactant); Nano-silicon fertilizer (SINA); fortified silicon-zinc (Na_2SiO_3 + $ZnSO_4$); and compound fertilizer) on vegetable production, promoted nutrient values, and mitigated Cd transport to edible parts in pepper and eggplant, as well as their effects on the health risk indexes like HI and CR. The results concluded that the application of composed foliar fertilizers was most effective, and could be a promising alternative for the improvement of vegetable production and decreasing of vegetable accumulation in the studied vegetables and human health risks (68). In the study of Saman et al, the application of EDTA in the mitigation of HMs stress in different varieties of Brassica juncea was investigated. It was deduced that the application of EDTA had significantly decreased the translocation of Pb in the soil through to the Brassica juncea roots, shoots, and food chain (69). In another study, the effects of foliar utilization of mineral elements such as Si, Se, and Zn on HMs contents in wheat grains were investigated. This study showed that foliar application with Si could significantly increase the production and plant height, and reduce the content of arsenic and Pb in wheat grains. Furthermore, foliar application with selenium and Zn can significantly reduce Cd, arsenic, and Pb (70). Guo et al evaluated the effectiveness of four soil amendments containing sepiolite (SE), single super phosphate, triple super phosphate, and calcium magnesium phosphate in combination with one foliar fertilizer zinc sulfate ($Zn SO_4$) on Cd and Pb immobilization in contaminated soils. The results indicated that the application of these amendments and foliar fertilizer significantly decreased Cd availability in soils and Cd accumulation in wheat ($P < 0.05$); however, the soil amendments plus Zn fertilizer did not significantly decrease Cd and Pb concentrations in wheat (71). In another study, Augustsson et al reported that washing vegetables with water can remove 56% of Pb and Co, 55% of Cr, 45% of As, and 7% of Cd, as well as Zn–rich particles on vegetables (72).

Conclusion

In general, the concentration of Pb, Cd, and Zn in the soil of different agricultural areas in this study was lower than the permissible limit of the WHO. While the amount of Cd in all consumed vegetables was lower than the permissible limit, this amount of Pb was higher than its permissible limit in vegetables. The THQ of Pb in all vegetable samples was more than 1, indicating that there is a possibility of adverse health effects in the adults and children population of these locations. While this type of risk has not been assessed in any of the studied vegetables by Cd and Zn. In this study, the cancer risk (TCR) of Cd in some vegetables of total locations has been observed in both children and adults. Various methods can be proposed to reduce the entry of HMs into the human body, and also, to reduce the values of health risk indexes. Regarding HMs with high accessibility and dissolution in the soil like Cd, to reduce their transfer into vegetables, soil protection measures such as not using chemical fertilizers, pesticides, and sewage sludge, and also, using chemical compounds that stabilize HMs such as amendments and foliar fertilizers like calcium magnesium phosphate, triple phosphate, and zinc sulfate in combination is suitable. Concerning HMs with low solubility and potential availability such as Pb, cobalt, and arsenic, significant amounts of these metals can be removed by washing contaminated vegetables with water. Also, the choice of cultivated vegetables can be a good strategy to manage urban agriculture under high HM foliar deposition, and the transfer and consumption of vegetables with little availability potential to HMs are recommended.

Acknowledgments

The authors are grateful to the Deputy of Research and Technology of Babol University of Medical Sciences for the financial support.

Authors' contributions

Conceptualization: Abdoliman Amouei, Elham Falahati Naghibi.
Data curation: Abdoliman Amouei.
Formal analysis: Hourieh Fallah, Hosseinali Asgharnia, Asieh Khalilpour.
Funding acquisition: Abdoliman Amouei.
Investigation: Abdoliman Amouei, Elham Falahati Naghibi.
Methodology: Abdoliman Amouei, Hajar Tabarinia.
Project administration: Abdoliman Amouei.
Resources: Abdoliman Amouei.
Software: Elham Falahati Naghibi.
Supervision: Abdoliman Amouei.
Validation: Abdoliman Amouei, Elham Falahati Naghibi.
Visualization: Abdoliman Amouei, Elham Falahati Naghibi.
Writing–original draft: Elham Falahati Naghibi.
Writing–review and editing: Abdoliman Amouei.

Competing interests

The authors declare that they have no conflict of interests.

Ethical issues

The authors certify that all data collected during the study are as stated in the manuscript, and no data from the study has been or will be published separately elsewhere. Ethical approval was obtained from Babol University of Medical Sciences, Babol, Iran (Ethical code: IR.MUBABOL.REC.1400.125).

Funding

This research was funded by the Vice-Chancellor for Research and Technology of Babol University of Medical Sciences.

References

1. Tchounwou PB, Yedjou CG, Patlolla AK, Sutton DJ. Heavy metal toxicity and the environment. Exp Suppl. 2012;101:133-64. doi: 10.1007/978-3-7643-8340-4_6.
2. Rai PK, Lee SS, Zhang M, Tsang YF, Kim KH. Heavy metals in food crops: health risks, fate, mechanisms, and management. Environ Int. 2019;125:365-85. doi: 10.1016/j.envint.2019.01.067.
3. Osae R, Nukpezah D, Darko DA, Koranteng SS, Mensah A. Accumulation of heavy metals and human health risk assessment of vegetable consumption from a farm within the Korle lagoon catchment. Heliyon. 2023;9(5):e16005. doi: 10.1016/j.heliyon.2023.e16005.
4. Abuzed Sadee B, Jameel Ali R. Determination of heavy metals in edible vegetables and a human health risk assessment. Environ Nanotechnol Monit Manag. 2023;19:100761. doi: 10.1016/j.enmm.2022.100761.
5. Bhat SA, Bashir O, Ul Haq SA, Amin T, Rafiq A, Ali M, et al. Phytoremediation of heavy metals in soil and water: an eco-friendly, sustainable and multidisciplinary approach. Chemosphere. 2022;303(Pt 1):134788. doi: 10.1016/j.chemosphere.2022.134788.
6. Rashid A, Schutte BJ, Ulery A, Deyholos MK, Sanogo S, Lehnhoff EA, et al. Heavy metal contamination in agricultural soil: environmental pollutants affecting crop health. Agronomy. 2023;13(6):1521. doi: 10.3390/agronomy13061521.
7. Orellana Mendoza E, Cuadrado W, Yallico L, Zárate R, Quispe-Melgar HR, Limaymanta CH, et al. Heavy metals in soils and edible tissues of *Lepidium meyenii* (maca) and health risk assessment in areas influenced by mining activity in the central region of Peru. Toxicol Rep. 2021;8:1461-70. doi: 10.1016/j.toxrep.2021.07.016.
8. Mizan A, Juel MA, Alam MS, Pichtel J, Ahmed T. Environmental and health risks of metal-contaminated soil in the former tannery area of Hazaribagh, Dhaka. SN Appl Sci. 2020;2(11):1915. doi: 10.1007/s42452-020-03680-4.
9. Pipoyan D, Stepanyan S, Beglaryan M, Stepanyan S, Mendelsohn R, Deziel NC. Health risks of heavy metals in food and their economic burden in Armenia. Environ Int. 2023;172:107794. doi: 10.1016/j.envint.2023.107794.
10. Jaishankar M, Tseten T, Anbalagan N, Mathew BB, Beeregowda KN. Toxicity, mechanism and health effects of some heavy metals. Interdiscip Toxicol. 2014;7(2):60-72. doi: 10.2478/intox-2014-0009.
11. Affum AO, Osae SD, Kwaansa-Ansah EE, Miyittah MK. Quality assessment and potential health risk of heavy metals in leafy and non-leafy vegetables irrigated with groundwater and municipal-waste-dominated stream in the Western region, Ghana. Heliyon. 2020;6(12):e05829. doi: 10.1016/j.heliyon.2020.e05829.
12. Liang H, Wu WL, Zhang YH, Zhou SJ, Long CY, Wen J, et al. Levels, temporal trend and health risk assessment of five heavy metals in fresh vegetables marketed in Guangdong province of China during 2014-2017. Food Control. 2018;92:107-20. doi: 10.1016/j.foodcont.2018.04.051.
13. Angon PB, Islam MS, Kc S, Das A, Anjum N, Poudel A, et al. Sources, effects and present perspectives of heavy metals contamination: soil, plants and human food chain. Heliyon. 2024;10(7):e28357. doi: 10.1016/j.heliyon.2024.e28357.
14. Rai R, Agrawal M, Agrawal SB. Impact of heavy metals on physiological processes of plants: with special reference to photosynthetic system. In: Singh A, Prasad SM, Singh RP, eds. Plant Responses to Xenobiotics. Singapore: Springer; 2016. p. 127-40. doi: 10.1007/978-981-10-2860-1_6.
15. US Environmental Protection Agency (EPA). Exposure Factors Handbook 2011 Edition (Final Report). Washington, DC: EPA; 2011.
16. Park RM, Bena JF, Stayner LT, Smith RJ, Gibb HJ, Lees PS. Hexavalent chromium and lung cancer in the chromate industry: a quantitative risk assessment. Risk Anal. 2004;24(5):1099-108. doi: 10.1111/j.0272-4332.2004.00512.x.
17. Liu X, Song Q, Tang Y, Li W, Xu J, Wu J, et al. Human health risk assessment of heavy metals in soil-vegetable system: a multi-medium analysis. Sci Total Environ. 2013;463-464:530-40. doi: 10.1016/j.scitotenv.2013.06.064.
18. Guerra F, Trevizam AR, Muraoka T, Marcante NC, Canniatti-Brazaca SG. Heavy metals in vegetables and potential risk for human health. Sci Agric. 2012;69(1):54-60. doi: 10.1590/s0103-90162012000100008.
19. Laˇcˇtuşu R, Răuţă C, Cârstea S, Ghelase I. Soil-plant-man relationships in heavy metal polluted areas in Romania. Appl Geochem. 1996;11(1):105-7. doi: 10.1016/0883-2927(95)00101-8.
20. Chang CY, Yu HY, Chen JJ, Li FB, Zhang HH, Liu CP. Accumulation of heavy metals in leaf vegetables from agricultural soils and associated potential health risks in the Pearl River Delta, South China. Environ Monit Assess. 2014;186(3):1547-60. doi: 10.1007/s10661-013-3472-0.
21. Hu NW, Yu HW, Deng BL, Hu B, Zhu GP, Yang XT, et al. Levels of heavy metal in soil and vegetable and associated health risk in peri-urban areas across China. Ecotoxicol Environ Saf. 2023;259:115037. doi: 10.1016/j.ecoenv.2023.115037.
22. Heshmati A, Mehri F, Karami-Momtaz J, Mousavi Khaneghah A. Concentration and risk assessment of potentially toxic elements, lead and cadmium, in vegetables and cereals consumed in Western Iran. J Food Prot. 2020;83(1):101-7. doi: 10.4315/0362-028x.jfp-19-312.
23. Amouei A, Cherati A, Naghipour D. Heavy metals contamination and risk assessment of surface soils of Babol in northern Iran. Health Scope. 2018;7(1):e62423. doi: 10.5812/jhealthscope.62423.
24. Hussain N, Shafiq Ahmed K, Asmatullah, Shafiq Ahmed M, Makhdoom Hussain S, Javid A. Potential health risks assessment cognate with selected heavy metals contents in some vegetables grown with four different irrigation sources near Lahore, Pakistan. Saudi J Biol Sci. 2022;29(3):1813-24. doi: 10.1016/j.sjbs.2021.10.043.
25. Margenat A, Matamoros V, Díez S, Cañameras N, Comas J, Bayona JM. Occurrence and human health implications of chemical contaminants in vegetables grown in peri-urban agriculture. Environ Int. 2019;124:49-57. doi: 10.1016/j.envint.2018.12.013.

26. Maleki A, Alasvand Zarasvand M. Heavy metals in selected edible vegetables and estimation of their daily intake in Sanandaj, Iran. Southeast Asian J Trop Med Public Health. 2008;39(2):335-40.
27. Mahmood A, Malik RN. Human health risk assessment of heavy metals via consumption of contaminated vegetables collected from different irrigation sources in Lahore, Pakistan. Arab J Chem. 2014;7(1):91-9. doi: 10.1016/j.arabjc.2013.07.002.
28. Mengistu DA. Public health implications of heavy metals in foods and drinking water in Ethiopia (2016 to 2020): systematic review. BMC Public Health. 2021;21(1):2114. doi: 10.1186/s12889-021-12189-3.
29. Mmaduakor EC, Umeh CT, Morah JE, Omokpariola DO, Ekwuofu AA, Onwuegbuokwu SS. Pollution status, health risk assessment of potentially toxic elements in soil and their uptake by *Gongronema latifolium* in peri-urban of Ora-Eri, south-eastern Nigeria. Heliyon. 2022;8(8):e10362. doi: 10.1016/j.heliyon.2022.e10362.
30. Lemessa F, Simane B, Seyoum A, Gebresenbet G. Analysis of the concentration of heavy metals in soil, vegetables and water around the bole Lemi industry park, Ethiopia. Heliyon. 2022;8(12):e12429. doi: 10.1016/j.heliyon.2022.e12429.
31. Parker GH, Gillie CE, Miller JV, Badger DE, Kreider ML. Human health risk assessment of arsenic, cadmium, lead, and mercury ingestion from baby foods. Toxicol Rep. 2022;9:238-49. doi: 10.1016/j.toxrep.2022.02.001.
32. Sarkar T, Alam MM, Parvin N, Fardous Z, Chowdhury AZ, Hossain S, et al. Assessment of heavy metals contamination and human health risk in shrimp collected from different farms and rivers at Khulna-Satkhira region, Bangladesh. Toxicol Rep. 2016;3:346-50. doi: 10.1016/j.toxrep.2016.03.003.
33. Antoine JMR, Fung LAH, Grant CN. Assessment of the potential health risks associated with the aluminium, arsenic, cadmium and lead content in selected fruits and vegetables grown in Jamaica. Toxicol Rep. 2017;4:181-7. doi: 10.1016/j.toxrep.2017.03.006.
34. Nag R, Cummins E. Human health risk assessment of lead (Pb) through the environmental-food pathway. Sci Total Environ. 2022;810:151168. doi: 10.1016/j.scitotenv.2021.151168.
35. Yousefi Z, Batabi R, Ziaei Hezarjaribi H, Mousavi Nasab N. Survey on the quality of outlet biosolids and sludge heavy metals in the wastewater treatment plants of Mazandaran province. Environ Health Eng Manag. 2023;10(3):281-91. doi: 10.34172/ehem.2023.32.
36. Baghaie AH, Fereydoni M. The potential risk of heavy metals on human health due to the daily consumption of vegetables. Environ Health Eng Manag. 2019;6(1):11-6. doi: 10.15171/ehem.2019.02.
37. US Environmental Protection Agency (EPA). International Decontamination Research and Development Conference. Washington, DC: EPA; 2015.
38. Haque MM, Niloy NM, Khirul MA, Alam MF, Tareq SM. Appraisal of probabilistic human health risks of heavy metals in vegetables from industrial, non-industrial and arsenic contaminated areas of Bangladesh. Heliyon. 2021;7(2):e06309. doi: 10.1016/j.heliyon.2021.e06309.
39. Mohammadi AA, Zarei A, Majidi S, Ghaderpoury A, Hashempour Y, Saghi MH, et al. Carcinogenic and non-carcinogenic health risk assessment of heavy metals in drinking water of Khorramabad, Iran. MethodsX. 2019;6:1642-51. doi: 10.1016/j.mex.2019.07.017.
40. Hussain A, Farris FF, Ray SD. Cancer potency factor. In: Wexler P, ed. Encyclopedia of Toxicology. 4th ed. Oxford: Academic Press; 2024. p. 447-53.
41. Demissie S, Mekonen S, Awoke T, Teshome B, Mengistie B. Examining carcinogenic and noncarcinogenic health risks related to arsenic exposure in Ethiopia: a longitudinal study. Toxicol Rep. 2024;12:100-10. doi: 10.1016/j.toxrep.2024.01.001.
42. Sayadi MH, Sayyed MR. Comparative assessment of baseline concentration of the heavy metals in the soils of Tehran (Iran) with the comprisable reference data. Environ Earth Sci. 2011;63(6):1179-88. doi: 10.1007/s12665-010-0792-z.
43. Mensah E, Kyei-Baffour N, Ofori E, Obeng G. Influence of human activities and land use on heavy metal concentrations in irrigated vegetables in Ghana and their health implications. In: Yanful EK, ed. Appropriate Technologies for Environmental Protection in the Developing World. Dordrecht: Springer; 2009. p. 9-14. doi: 10.1007/978-1-4020-9139-1_2.
44. Oubane M, Khadra A, Ezzariai A, Kouisni L, Hafidi M. Heavy metal accumulation and genotoxic effect of long-term wastewater irrigated peri-urban agricultural soils in semiarid climate. Sci Total Environ. 2021;794:148611. doi: 10.1016/j.scitotenv.2021.148611.
45. Napoletano P, Guezgouz N, Di Iorio E, Colombo C, Guerriero G, De Marco A. Anthropic impact on soil heavy metal contamination in riparian ecosystems of northern Algeria. Chemosphere. 2023;313:137522. doi: 10.1016/j.chemosphere.2022.137522.
46. Luo L, Ma Y, Zhang S, Wei D, Zhu YG. An inventory of trace element inputs to agricultural soils in China. J Environ Manage. 2009;90(8):2524-30. doi: 10.1016/j.jenvman.2009.01.011.
47. Liu WR, Zeng D, She L, Su WX, He DC, Wu GY, et al. Comparisons of pollution characteristics, emission situations, and mass loads for heavy metals in the manures of different livestock and poultry in China. Sci Total Environ. 2020;734:139023. doi: 10.1016/j.scitotenv.2020.139023.
48. Shariatpanahi M, Anderson AC. Accumulation of cadmium, mercury and lead by vegetables following long-term land application of wastewater. Sci Total Environ. 1986;52(1-2):41-7. doi: 10.1016/0048-9697(86)90103-8.
49. Jalali M, Meyari A. Heavy metal contents, soil-to-plant transfer factors, and associated health risks in vegetables grown in western Iran. J Food Compost Anal. 2022;106:104316. doi: 10.1016/j.jfca.2021.104316.
50. Tajdar-Oranj B, Javanmardi F, Parastouei K, Taghdir M, Fathi M, Abbaszadeh S. Health risk assessment of lead, cadmium, and arsenic in leafy vegetables in Tehran, Iran: the concentration data study. Biol Trace Elem Res. 2024;202(2):800-10. doi: 10.1007/s12011-023-03707-y.
51. Fang H, Li W, Tu S, Ding Y, Wang R, Rensing C, et al. Differences in cadmium absorption by 71 leaf vegetable varieties from different families and genera and their health risk assessment. Ecotoxicol Environ Saf. 2019;184:109593. doi: 10.1016/j.ecoenv.2019.109593.
52. Khajeh M, Saravani F, Ghaffari-Moghaddam M, Bohlooli M. Flotation-assisted homogenous liquid–liquid microextraction for determination of cadmium in vegetables. Int J Veg Sci. 2016;22(3):266-73. doi:

10.1080/19315260.2015.1039744.
53. Bahrami S, Moore F, Keshavarzi B. Evaluation, source apportionment and health risk assessment of heavy metal and polycyclic aromatic hydrocarbons in soil and vegetable of Ahvaz metropolis. Hum Ecol Risk Assess. 2021;27(1):71-100. doi: 10.1080/10807039.2019.1692300.
54. Seid-Mohammadi A, Roshanaei G, Asgari G. Heavy metals concentration in vegetables irrigated with contaminated and fresh water and estimation of their daily intakes in suburb areas of Hamadan, Iran. J Res Health Sci. 2014;14(1):69-74.
55. Derakhshan Z, Faramarzian M, Mahvi AH, Hosseini MS, Miri M. Assessment of heavy metals residue in edible vegetables distributed in Shiraz, Iran. J Food Qual Hazards Control. 2016;3(1):25-9.
56. Su C, Wang J, Chen Z, Meng J, Yin G, Zhou Y, et al. Sources and health risks of heavy metals in soils and vegetables from intensive human intervention areas in South China. Sci Total Environ. 2023;857(Pt 1):159389. doi: 10.1016/j.scitotenv.2022.159389.
57. Singh R, Singh PK, Madheshiya P, Khare AK, Tiwari S. Heavy metal contamination in the wastewater irrigated soil and bioaccumulation in cultivated vegetables: assessment of human health risk. J Food Compost Anal. 2024;128:106054. doi: 10.1016/j.jfca.2024.106054.
58. Bello O, Naidu R, Rahman MM, Liu Y, Dong Z. Lead concentration in the blood of the general population living near a lead-zinc mine site, Nigeria: exposure pathways. Sci Total Environ. 2016;542(Pt A):908-14. doi: 10.1016/j.scitotenv.2015.10.143.
59. Habte G, Mekonen N, Desse G, Kassa G. Heavy metal contamination and health risk assessment of horticultural crops in two sub-cities of Addis Ababa, Ethiopia. Toxicol Rep. 2023;11:420-32. doi: 10.1016/j.toxrep.2023.09.002.
60. Olmedo P, Pla A, Hernández AF, Barbier F, Ayouni L, Gil F. Determination of toxic elements (mercury, cadmium, lead, tin and arsenic) in fish and shellfish samples. Risk assessment for the consumers. Environ Int. 2013;59:63-72. doi: 10.1016/j.envint.2013.05.005.
61. Tusher TR, Sarker ME, Nasrin S, Kormoker T, Proshad R, Islam MS, et al. Contamination of toxic metals and polycyclic aromatic hydrocarbons (PAHs) in rooftop vegetables and human health risks in Bangladesh. Toxin Rev. 2021;40(4):736-51. doi: 10.1080/15569543.2020.1767650.
62. Etsuyankpa MB, Ahmad AS, Mustapha S, Baba NM, Ndamitso MM, Elabor R. Levels of selected heavy metals in blood and urine of workers of Alkali Kongo Plaza GSM Market within Lafia metropolis, Nasarawa state, Nigeria. Environ Chall (Amst). 2022;9:100649. doi: 10.1016/j.envc.2022.100649.
63. Quispe N, Zanabria D, Chavez E, Cuadros F, Carling G, Paredes B. Health risk assessment of heavy metals (Hg, Pb, Cd, Cr and As) via consumption of vegetables cultured in agricultural sites in Arequipa, Peru. Chem Data Coll. 2021;33:100723. doi: 10.1016/j.cdc.2021.100723.
64. Sawut R, Kasim N, Maihemuti B, Hu L, Abliz A, Abdujappar A, et al. Pollution characteristics and health risk assessment of heavy metals in the vegetable bases of northwest China. Sci Total Environ. 2018;642:864-78. doi: 10.1016/j.scitotenv.2018.06.034.
65. Tongprung S, Wibuloutai J, Dechakhamphu A, Samaneein K. Health risk assessment associated with consumption of heavy metal-contaminated vegetables: a case study in the southern area of Northeast Thailand. Environ Chall (Amst). 2024;14:100845. doi: 10.1016/j.envc.2024.100845.
66. Amouei A, Fallah H, Asgharnia H, Mousapour A, Parsian H, Hajiahmadi M, et al. Comparison of heavy metals contamination and ecological risk between soils enriched with compost and chemical fertilizers in the north of Iran and ecological risk assessment. Environ Health Eng Manag. 2020;7(1):7-14. doi: 10.34172/ehem.2020.02.
67. Mizan A, Mamun MA, Islam MS. Metal contamination in soil and vegetables around Savar tannery area, Dhaka, Bangladesh: a preliminary study for risk assessment. Heliyon. 2023;9(3):e13856. doi: 10.1016/j.heliyon.2023.e13856.
68. Wang Q, Zhou Q, Feng Y, Yang X. Foliar application protected vegetable against poisonous element cadmium and mitigated human health risks. Sci Total Environ. 2024;926:171915. doi: 10.1016/j.scitotenv.2024.171915.
69. Saman RU, Shahbaz M, Maqsood MF, Lili N, Zulfiqar U, Haider FU, et al. Foliar application of ethylenediamine tetraacetic acid (EDTA) improves the growth and yield of brown mustard (*Brassica juncea*) by modulating photosynthetic pigments, antioxidant defense, and osmolyte production under lead (Pb) stress. Plants. 2022;12(1):115. doi: 10.3390/plants12010115.
70. Gu X, Wen X, Yi N, Liu Y, Wu J, Li H, et al. Effect of foliar application of silicon, selenium and zinc on heavy metal accumulation in wheat grains in field studies. Environ Pollut Bioavailab. 2022;34(1):246-52. doi: 10.1080/26395940.2022.2085630.
71. Guo G, Lei M, Chen T, Yang J. Evaluation of different amendments and foliar fertilizer for immobilization of heavy metals in contaminated soils. J Soils Sediments. 2018;18(1):239-47. doi: 10.1007/s11368-017-1752-y.
72. Augustsson A, Lundgren M, Qvarforth A, Hough R, Engström E, Paulukat C, et al. Managing health risks in urban agriculture: the effect of vegetable washing for reducing exposure to metal contaminants. Sci Total Environ. 2023;863:160996. doi: 10.1016/j.scitotenv.2022.160996.