Environmental Health Engineering and Management Journal 2024, 11(3), 327-336
http://ehemj.com
doi 10.34172/EHEM.2024.32
Environmental Health Engineering and Management Journal
Original Article
Open Access Publish Free

Investigation of heavy metal concentrations (lead, cadmium, and arsenic) in vegetables irrigated with synthetic effluent and well water: Risk assessment of carcinogenicity and non-carcinogenicity

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Abstract

Background: The growing use of treated wastewater in farming has raised concerns about the potential impacts on public health.

Methods: This study assessed the levels of the heavy metals lead (Pb), cadmium (Cd), and arsenic (As) in plants watered in greenhouse settings using both well water and synthetic wastewater. Synthetic wastewater with As at concentrations of 0.1, 0.2, and 0.4 mg/L, Pb at 1, 3, and 5 mg/L, and Cd at 0.01, 0.03, and 0.05 mg/L, as well as well water were used to irrigate radish, coriander, and grass. In the end, 144 vegetable samples were gathered, and inductively coupled plasma-optical emission spectrometry (ICP-OES) was used to determine the heavy metal concentrations in the samples. Risk assessment for consumers was determined based on the measured levels of heavy metals in the vegetables.

Results: Even though the concentrations of heavy metals in the wastewater were within the limits for irrigation, the risk assessment showed that consumption of vegetables irrigated with treatment wastewater could pose risks to individuals' health. The maximum concentration of Pb in radish leaves was observed at the Pb concentration of 5 mg/L, and the maximum concentration of As in cress irrigated with As effluent at the As concentration of 0.02 mg/L.

Conclusion: The consumption of vegetables containing Pb can pose a significant non-carcinogenic risk to consumers. However, well water may also be dangerous in the long run. Therefore, it is important to ensure about food safety when using treated wastewater for irrigation.

Keywords: Arsenic, Lead, Vegetables, Wastewater, Risk assessment

Citation: Parmoozeh Z, Reza Mostafaii G, Rabbani D, Akbari H, Salem A, Miranzadeh MB. Investigation of heavy metal concentrations (lead, cadmium, and arsenic) in vegetables irrigated with synthetic effluent and well water: risk assessment of carcinogenicity and non-carcinogenicity. Environmental Health Engineering and Management Journal 2024; 11(3): 327-336 doi: 10.34172/EHEM.2024.32.

Article History:
Received: 15 March 2024
Accepted: 3 August 2024
ePublished: 19 August 2024

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Introduction

Continuous population growth, industrialization, and climate change have led to increased water demand, and consequently, increasing wastewater production worldwide (1,2). Given the limited freshwater resources (3), wastewater reuse is considered a suitable solution to overcome the problem of water shortage (4,5). Wastewater reuse has potential economic and environmental benefits (6), which can solve the problem of water scarcity, wastewater disposal, and the return of organic and inorganic nutrient levels to the soil simultaneously (7). Heavy metals are one of the most important environmental pollutants (8,9) and are present in the effluent as a solution (10). Cadmium (Cd), lead (Pb), mercury (Hg), nickel (Ni), iron (Fe), hexavalent chromium)Cr), manganese (Mn), cobalt (Co), molybdenum (Mo), copper (Cu), zinc (Zn), selenium (Se) and arsenic (As) are among the most important heavy metals (11,12). They can accumulate at toxic and dangerous levels in soil and crops by continuously using the effluents for irrigation (13). The transfer of heavy metals from soil to plants is the main way for human exposure (14). The effects of heavy metals on human health are carcinogenicity, mutagenicity, fetal abnormalities, endocrine disorders, immune system disorders (15), renal, pulmonary, nervous, and skeletal system injuries (16). Thus, the entry of pollutants through the food chain and the accumulation of heavy metals in soil and plants has become a vital issue for human health

(17). The World Health Organization (WHO) and the Food and Agriculture Organization (FAO) have set the standard concentration of heavy metals in the effluent for irrigation in agriculture for different metals; the standard of toxic metals such as Pb, Cd, and As in effluent for irrigation is 5, 0.01, and 0.1 mg/L, respectively. This is done to control the content of heavy metals transferred from the effluent to agricultural products (18). In different countries, according to climatic conditions, consumption of agricultural products, access to water resources, and the reuse of wastewater in agriculture, various standards for heavy metals in wastewater for irrigation have been developed. According to the Environmental Protection Agency of Iran (IRNDOE), the standard concentration of toxic metals Pb, Cd, and As for irrigation is 1, 0.01, and 0.1 mg/L, respectively (19). Measuring the concentration of heavy metals is carried out using highly precise devices such as atomic absorption spectrophotometer (AAS) or inductively coupled plasma spectrometer (ICP) (20). Many studies have been so far conducted to investigate the risks of the accumulation of heavy metals in soil and plants (21). Farrag et al showed that in Egypt, the concentration of heavy metals varied among different species, and except for chromium and nickel, the concentration of most heavy metals was within the allowable range (22). Mahmood et al showed that concentrations of metals in soil and vegetables irrigated by wastewater were significantly higher compared to well water, and leafy vegetables also accumulated higher levels of heavy metals (23). According to the study by Akbudak and Bicen, the concentration of Ni and Pb in vegetables irrigated with effluent is higher than that irrigated with urban water, the contents of Cd and Co in the studied plants were similar in both types of irrigation water, and for a long-time treated wastewater can be used (24). A study by Sultana et al showed that receiving heavy metals Pb and As through the consumption of vegetables has a significant non-cancerous risk. However, intake of other heavy metals through consumption of vegetables in the study area was safe (25).

In the study by Ogunwale et al, the target hazard quotient (THQ) for the consumption of vegetables contaminated with Cd, Pb, Zn, and Cu was less than one (THQ > 1) and the presence of these metals had no direct effect on health. However, THQ levels for As and Fe were very high (26). The study by Tajik et al showed that the THQ of heavy metals Pb and Cd through the consumption of fruits and vegetables in Arak was less than one (THQ > 1) (27). Considering the significant impact of heavy metals on both the environment and living organisms, as well as the rising usage of urban and industrial wastewater for agricultural irrigation, and the increasing consumption of vegetables in people's diets, there is a noticeable absence of research on the levels of heavy metals in vegetables irrigated with specific concentrations of treated wastewater under controlled conditions. This study was conducted to compare the concentration of heavy metals (Cd, Pb, and As) in vegetables irrigated with synthetic wastewater to the permissible concentration of metals for irrigation and well water under greenhouse conditions in Kashan.

Materials and Methods

Sampling and analysis of water and soil samples

According to a survey conducted in Kashan city, water from 10 public wells was used for agriculture. Water samples were collected from all these wells and digested according to method 200.7, edition 4.4 provided by the EPA (28). Five soil samples were transferred from different farms in polyethylene bags to the laboratory and digested according to the EPA Method 3050B (29). The concentration of heavy metals in water and soil samples was measured by inductively coupled plasma-optical emission spectrometry (ICP-OES) induction coupled plasma. The ICP device measures concentration by plotting the intensity curve of spectral lines based on the desired elements' concentration (calibration curve). First, five different concentrations of each element (Cd, Pb, and As) from the German Merck standard solution were diluted and analyzed using the ICP device. Subsequently, the heavy metal concentrations were determined by creating a calibration curve in the device's memory. Water and soil samples with the lowest concentrations of heavy metals were used for the cultivation of vegetables.

Preparation of synthetic effluent of Pb, Cd, and As

Wastewater samples were prepared by synthesizing them with various concentrations of Pb (1, 3, and 5) from Merck's 99% lead nitrate salt, Cd (0.01, 0.03, and 0.05) from Merck's cadmium nitrate tetrahydrate, and As (0.1, 0.2, and 0.4) from Sigma Aldrich's 98% sodium arsenate. These concentrations were selected based on the limits of the WHO standard and the Iranian environmental protection standard for the reuse of treated wastewater in irrigation.

Cultivation and preparation of vegetables

Seeds of cress, coriander, and radish of Pakan Seed Company of Isfahan were planted in pots with a diameter of 40 cm and were irrigated in greenhouse conditions with synthetic wastewater samples (Figure 1). Finally, 144 samples of the edible parts of cress, coriander, radish leaves, and roots were collected, and then, they were washed with distilled water in two stages. The samples were dried at 105°C for 48 hours. Then, one gram of each sample was digested according to methods 3030 F and 3030 J of the standard methods for the examination of water and wastewater book (30). The concentrations of heavy metals in vegetables were determined using ICP-OES.

Health risk assessment

In the present study, synthetic effluents with heavy metal

Figure 1. (a) root of radish, (b) leaf of radish, (c) coriander, and (d) cress

concentrations were prepared with the allowable limits of the WHO and IRNDOE effluents for irrigation in agriculture. The potential health risks of heavy metals through the consumption of cress, coriander, radish leaves, and roots were assessed:

Daily intake of metals (DIM)

$$DIM = \frac{Cmetal \times Cfactor \times Cfood\ intak}{Average\, body\ weight\,(BW)} \tag{1}$$

Where *DIM* is heavy metal intake per day (by adults), *Cmetal* is the concentration of heavy metals in vegetables (mg/kg), *Cfactor* is the vegetable conversion ratio (0.085) from fresh to dry weight of vegetables. *Cfood intak* is the estimated daily intake of vegetables, and *BW* is *the* average human body weight.

DIM is used to calculate the content of heavy metals consumed by adults per day. $C_{food\ intake}$ based on the studies of vegetable consumption in Kashan is equal to 90 g/day (31,32), in the present study, BW with interviews with 300 people aged 35-65 years was determined at 62.8 kg.

Health risk index (HRI)

The HRI was calculated to quantify the risk of each contaminant to consumer health.

$$HRI = \frac{DIM}{RfD} \tag{2}$$

where *RfD* is reference oral doses *(*mg/kg/day*)*.

RfD for Pb, Cd, and As are 0.004, 0.001, and 0.003 mg/kg/day, respectively (28). HRI > 1 means that the population exposed to the metal is not safe from its risks (32,33).

Target hazard quotient

The THQ was calculated to determine the duration of exposure and the non-carcinogenic risk of heavy metals.

$$THQ = \frac{\mathrm{EFr} \times \mathrm{ED} \times \mathrm{FIR} \times \mathrm{M}}{\mathrm{RfD} \times \mathrm{BW} \times \mathrm{ATn}} \times 10^{-3} \tag{3}$$

Where *EFr* is the frequency of exposure (350 days per year), *ED* is duration of exposure (30 years), *FIR* is the amount of food consumed (90 g/day), *M* is the concentration of metals in vegetables (mg/kg), *RfD* is reference oral doses (mg/kg/day), *BW* is the average human body weight, and *ATn* is the average time of exposure to carcinogens (10500).

If the THQ value is greater than 1 (THQ > 1), exposure to the metal is likely to cause obvious side effects (31,34).

Hazard Index (HI)

$$HI = \Sigma THQ \tag{4}$$

This parameter considers the cumulative effect of ingesting potentially toxic metals through the consumption of agricultural products, in other words, HI determines the potential risk of exposure to several chemical contaminants to assess, so that when HI > 1, there is a serious potential health risk (35-37).

Target cancer risk (TR)

Target cancer risk was used to indicate the carcinogenic risk of vegetables.

$$TR = \frac{\mathrm{M} \times \mathrm{FIR} \times \mathrm{CPSo} \times \mathrm{EF} \times \mathrm{ED}}{\mathrm{BW} \times \mathrm{ATn}} \times 10^{-3} \quad (5)$$

Where *CPSo* is the slope of oral carcinogenicity (mg/kg/day).

The parameters M, FIR, EF, ED, BW, and ATn were described in formula 3. According to the USEPA guidelines, CPSo values for Pb, Cd, and As are 0.0085, 0.6, and 1.5, respectively. The range of TR is described as follows: $TR \leq 10^{-6}$ = low, 10^{-4}-10^{-3} = medium; 10^{-3}-10^{-1} = high, $TR \geq 10^{-1}$ = very high.

Statistical analysis

Data were statistically analyzed using SPSS version 22, and the results were expressed as mean-standard deviation. T-test and Mann-Whitney test were used to evaluate the significant difference between the concentration of heavy metals in vegetables grown in synthetic effluents contaminated with the heavy metals Pb, Cd, As, and well water.

Results

Heavy metals Pb, Cd, and As in soil and well water

The concentrations of heavy metals (Pb, Cd, and As) in the selected soils were 11.2, 22.3, and zero mg/kg and for well water, they were 0.019, 0.043, and zero mg/kg.

Heavy metals Pb, Cd, and As in vegetables

As can be seen in Figure 2, the average intake of Pb in the studied vegetables is radish leaf > coriander > cress > radish root, respectively, and in all samples, it is higher than the WHO/FAO guideline. According to the results of the analysis of variance, Pb concentration in radish leaves is significantly different from other vegetable groups ($P < 0.001$). The vegetables under study had the following average intake of Cd metal: radish leaf, followed by cress, radish root, and coriander. Nevertheless, the statistical test findings showed that there was no significant difference in the mean Cd concentration across any of the groups under investigation ($P = 0.669$). As was found to have only accumulated in cress when it came to the absorption of As in the tested vegetable groups; its concentration was zero in coriander, radish leaves, and leaves. According to the results of the analysis of variance, the concentration of As in cress is significantly different from other vegetable groups. According to Table 1, the maximum concentration of Pb was observed in the leaves and roots of radish at a Pb concentration of 5 mg/L, in coriander at a Pb concentration of 3 mg/L, and in cress at a Pb concentration of 1 mg/L, according to the results of statistical test, Pb concentration of 5 mg/L in radish leaves was significantly different from other groups of vegetables ($P = 0.002$), the maximum concentration of Cd was observed in coriander vegetables at the concentration of 0.05 mg/L and in cress, radish

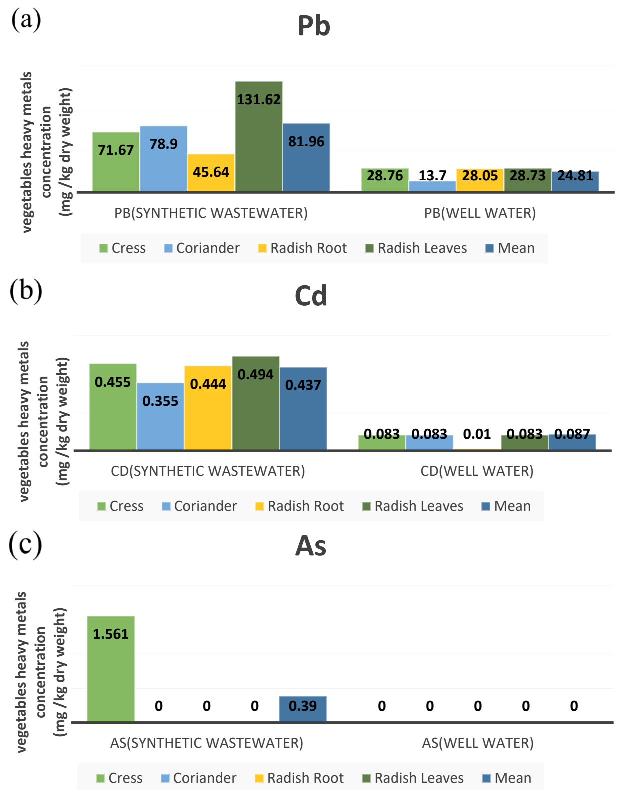

Figure 2. Comparative evaluation of mean concentrations of heavy metals in irrigated vegetables with synthetic effluent compared to well water: (a) Pb, (b) Cd, and (c) As

leaves and roots at the concentration of 0.03 mg/L. The maximum concentration of As in cress was 0.02 mg/L, which according to the results of analysis of variance was significantly different from other vegetable groups ($P = 0.043$). In addition, the samples were irrigated with well water. The highest concentration of Pb was observed in cress and radish leaves (Figure 1). However, according to the results of the statistical test, the difference between the mean concentration of Pb in vegetables irrigated with well water was not significant ($P = 0.210$). In the study of Cd and As concentrations of vegetables irrigated with well water, no significant difference was observed in vegetable groups ($P = 0.910$). The findings showed that the average concentrations of Pb, Cd, and As in vegetables irrigated with synthetic effluent with the maximum allowable concentration of effluent for agriculture are significantly different from well water ($P < 0.05$), According to the findings, the concentration of Pb and Cd in all samples of vegetables irrigated with well water and synthetic effluent is much higher than the WHO/FAO standard in vegetables.

Vegetable risk assessment

Daily intake of metals

One of the most important factors in assessing the health risk of any pollutant is estimating daily intake. The results of daily intake of heavy metals (DIM) in vegetable groups irrigated with well water and synthetic effluent are shown

Table 1. Mean concentrations of heavy metals of Pb, Cd, and As at different concentrations of synthetic effluent in various vegetables

Heavy metals	Vegetables	Concentration	Mean/standard deviation (mg/kg dry weight)	*P* value
Pb	Cress	1*	11.06±82.48	0.042
		3	7.53±74.50	
		5	8.24±58.03	
		Total	13.35±71.67	
	Coriander	1	27.32±59.25	0.072
		3	5.24±109.55	
		5	27.75±67.90	
		Total	30.47±78.90	
	Radish root	1	29.90±44.35	0.698
		3	12.26±39.26	
		5	12.14±53.31	
		Total	18.33±45.64	
	Radish leaves	1	6.63±83.18	0.002
		3	26.46±107.48	
		5*	31.82±204.20	
		Total	59.27±131.62	
Cd	Cress	0.01	0.175±0.233	0.092
		0.03	0.256±0.616	
		0.05	0.028±0.516	
		Total	0.232±0.455	
	Coriander	0.01	0.288±0.166	0.127
		0.03	0.208±0.316	
		0.05	0.301±0.583	
		Total	0.260±0.355	
	Radish root	0.01	0.189±0.216	0.113
		0.03	0.351±0.733	
		0.05	0.189±0.383	
		Total	0.317±0.444	
	Radish leaves	0.01	0.050±0.400	0.245
		0.03	0.057±0.566	
		0.05	0.175±0.516	
		Total	0.121±0.494	
As	Cress	0.1	0.476±1.80	0.043
		0.2	0.553±2.33	
		0.4	0.909±0.550	
		Total	0.984±1.56	
	Coriander, radish root, and radish leaves	0.1	0	N.D
		0.2	0	
		0.4	0	
		Total	0	

*Significant difference.

in Table 2. According to the findings, the daily intake of Pb, Cd, and As in vegetable vegetables, coriander, radish leaves, and roots irrigated with various effluents is more than well water. As can be seen, the highest daily intake of Pb in radish leaves irrigated with effluent was 5 mg/L.

Health risk index

According to the findings of Table 3, HRI values for vegetables irrigated with Pb, Cd, and As effluents were higher than those irrigated with well water. The HRI of Pb in all samples of vegetables irrigated with effluent and well water is much more than 1.

Target hazard quotient

Potential risks to human health from consuming vegetables irrigated with synthetic effluent and well water are shown in Table 4. As observed, the THQ value of Pb at concentrations of 3, 1, and 5 mg/L are variable in vegetables and the highest level was observed in radish leaves and the lowest one in radish root. THQ results show that the Pb intake through the consumption of vegetables has a significant non-carcinogenic risk for consumers. In all vegetable samples irrigated with Cd effluent, As effluent, and well water, THQ < 1 had no direct effect on health. However, THQ values for As in cress may be hazardous to human health, and the risk factor for As in cress is a long-term concern.

Hazard Index

Given that in the present study the concentrations of synthetic effluents of Pb, Cd, and As are variable, HI was calculated for all possible conditions in cress, coriander, radish leaves, and roots. Figure 3 shows the mean HI calculated for all types of vegetables irrigated with synthetic effluent and well water. The findings show that HI for all vegetables irrigated with Pb, Cd, and As effluents is higher than well water. HI was higher than 1 (HI > 1) in cress, coriander, and radish leaves irrigated with synthetic effluents.

Target cancer risk

The results of Table 5 show that the carcinogenic risk index in radish leaves irrigated with Pb effluent of 5 mg/L and cress irrigated with As effluent of 0.1 and 0.2 mg/L was TR $\leq 10^{-4}$, indicating a moderate carcinogenic risk. In other groups of vegetables irrigated with various effluents and well water, it was TR $\leq 10^{-5}$, indicating a low carcinogenic risk.

Table 2. DIM values at different concentrations of synthetic effluent and well water in different vegetables

Heavy metals	Concentration	Cress	Coriander	Radish root	Radish leaves
Pb	1	0.46	0.33	0.25	0.47
	3	0.42	0.61	0.22	0.6
	5	0.32	0.38	0.30	1.14
	Well water	0.16	0.08	0.16	0.16
Cd	0.01	0.001	0.001	0.001	0.002
	0.03	0.003	0.002	0.004	0.003
	0.05	0.003	0.003	0.002	0.003
	Well water	0.0004	0.0004	0.0005	0.0004
As	0.1	0.01	-	-	-
	0.2	0.01	-	-	-
	0.4	0.003	-	-	-
	Well water	0	-	-	-

Table 3. HRI values at different concentrations of synthetic effluent and well water in different vegetables

Heavy metals	Concentration	Cress	Coriander	Radish root	Radish leaves
Pb	1	115.6	83.07	62.18	116.6
	3	104.4	153.6	55.05	150.7
	5	725.4	847.7	666.4	2552.5
	Well water	40.33	19.21	39.33	40.29
Cd	0.01	1.308	0.935	1.215	2.243
	0.03	3.458	1.776	4.113	3.178
	0.05	2.898	3.272	2.150	2.898
	Well water	0.467	0.467	0.561	0.467
As	0.1	300	-	-	-
	0.2	43.62	-	-	-
	0.4	10.28	-	-	-
	Well water	0	-	-	-

Table 4. The value of THQ at different concentrations of synthetic effluent and well water in different vegetables

Heavy metals	Concentration	Cress	Coriander	Radish root	Radish leaves
Pb	1	1.361	0.98	0.731	1.372
	3	1.229	1.807	0.648	1.773
	5	0.957	1.120	0.879	3.368
	Well water	0.474	0.226	0.463	0.474
Cd	0.01	0.015	0.011	0.014	0.026
	0.03	0.042	0.022	0.050	0.039
	0.05	0.035	0.040	0.026	0.035
	Well water	0.006	0.006	0.007	0.006
As	0.1	0.413	-	-	-
	0.2	0.535	-	-	-
	0.4	0.126	-	-	-
	Well water	0	-	-	-

Table 5. TR value at different concentrations of synthetic effluent and well water in different vegetables

Heavy metals	Concentration leaves	Cress	Coriander	Radish root	Radish leaves
Pb	1	$^{5-}10\times4.6$	$^{5-}10\times3.3$	$^{5-}10\times2.5$	$^{5-}10\times4.6$
	3	$^{5-}10\times4.2$	$^{5-}10\times6.1$	$^{5-}10\times2.2$	$^{5-}10\times6$
	5	$^{5-}10\times3.3$	$^{5-}10\times3.8$	$^{5-}10\times3$	$^{5-}10\times1.1$
	Well water	$^{5-}10\times1.6$	$^{6-}10\times8$	$^{5-}10\times1.6$	$^{5-}10\times1.6$
Cd	0.01	$^{6-}10\times9$	$^{6-}10\times7$	$^{6-}10\times9$	$^{5-}10\times1.6$
	0.03	$^{5-}10\times2.4$	$^{5-}10\times1.3$	$^{5-}10\times2.9$	$^{5-}10\times2.2$
	0.05	$^{5-}10\times2$	$^{5-}10\times2.3$	$^{5-}10\times1.5$	$^{5-}10\times2$
	Well water	$^{6-}10\times3$	$^{6-}10\times3$	$^{6-}10\times4$	$^{6-}10\times3$
As	0.1	$^{4-}10\times1.8$	-	-	-
	0.2	$^{4-}10\times2.3$	-	-	-
	0.4	$^{5-}10\times5.4$	-	-	-
	Well water	0	-	-	-

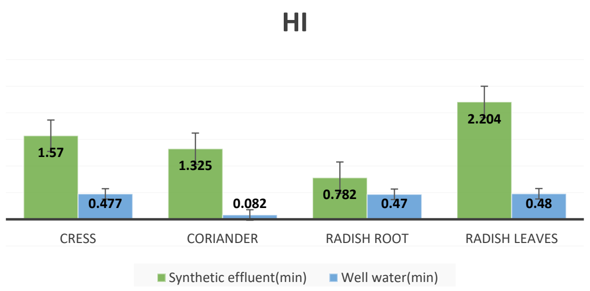

Figure 3. HI value at different concentrations of synthetic effluent and well water in different vegetables

Discussion

Heavy metals of Pb, Cd, and As in vegetables

As observed, the mean concentration of heavy metals in different vegetables is different. The accumulation of heavy metals in vegetables is a complex process influenced by several factors. The factors include the physiochemical properties of the soil and irrigation water, the chemical properties of the heavy metals, the interaction of metals in the soil and plants, plant-specific properties such as age and species, as well as the climatic conditions of the region and the duration of irrigation (38-40). The absorption of heavy metals in plant roots and their movement within the plant are influenced by various synergistic and antagonistic effects. These effects can lead to changes in the amount of metal absorbed by the plant or specific organs (41). In addition, studies have shown that the concentration of heavy metals in the surface layers of the soil is higher than in the deep layers. The difference in root types and root penetration depths can be another significant factor (42).

The findings show that the average concentration of all the metals studied in vegetables irrigated with synthetic wastewater exceeded that of those irrigated with well water. Moreover, it has been verified that higher levels of heavy metals in the environment lead to increased accumulation in plants (24,43). Additionally, the concentration of metals in irrigation water can significantly impact the transfer and accumulation of metals in crops (44,45). The continuous use of treated sewage or wastewater leads to changes in soil properties. These changes include an increase in organic carbon, a decrease in pH, an increase in cation exchange capacity, and soil conductivity, which result in greater mobility of heavy metals from soil to plants (46,47).

Research findings indicate that heavy metals tend to accumulate more in the leaves of radish than in its roots. The transportation of heavy metals from roots to shoots and leaves depends on phytochelatins and the concentration of organic acids (48,49). Factors such as high growth rate, high transpiration, leaf morphology, and physiology (including large surface area and waxy texture) play a key role in the absorption of heavy metals in leaves (50,51). Additionally, pollutants can be absorbed through atmospheric absorption on the aerial parts of the leaf surface (25,52).

The study results show a high accumulation of Pb in all types of vegetables studied. In general, Pb is an element with significant accumulation properties that are not easily destroyed and can enter the body through water, air, and food products. The concentration of Pb in plants increases with higher cation exchange capacity, lower pH, and increased soil organic matter (53).

The concentration of As in cress was found to be higher than in other vegetables. On the contrary, a study by Nazemi and Khosravi on vegetables offered in the markets of Shahrood revealed that the concentration of As in the leaves and roots of radishes is higher than that of cress (54). This discrepancy might result from the controlled greenhouse settings of the present study, which eliminated the influence of outside variables and made use of As-free soil. The distinct features of watercress, including its quick growth, high water needs, leaf structure, and superficial roots, could potentially boost the plant's absorption of As.

In addition, the concentrations of Pb and Cd in all samples of vegetables irrigated with well water are higher than the WHO/FAO standard for vegetables. This could be potentially dangerous to the health of consumers with continuous and long-term consumption (32,55).

Vegetable risk assessment

According to the DIM results, the daily intake of metals from vegetables irrigated with synthetic wastewater is higher compared to those irrigated with well water. The order of DIM values for metals in vegetables irrigated with synthetic wastewater is Pb > As > Cd, while for vegetables irrigated with well water, it is Pb > Cd > As. These findings are consistent with the findings of previous studies (37,43,56).

The present research findings indicate that the HRI values for all samples were greater than one. This suggests a potential risk to consumer health. Similar studies have presented varied results, with some emphasizing the potential health risks associated with the use of sewage and effluents (32,37,43), while others have reported that it is not dangerous. This discrepancy in the results could be caused by variations in the organic matter content, plant species, DIM, soil quality, and kind of water or wastewater used (57,58).

It has been found that the intake of Pb through the consumption of leafy vegetables can pose a potential non-carcinogenic risk to consumers, as indicated by THQ values. Similarly, studies have confirmed that vegetables irrigated with treated wastewater containing Pb and Cd can also pose a potential non-carcinogenic risk (25,59,60).

The HI values indicate that regularly consuming leafy vegetables irrigated with wastewater contaminated with heavy metals within the permissible limits of irrigation could pose significant health risks. These findings are supported by numerous studies demonstrating that HI levels in leafy vegetables pose the highest potential health risk and could be fatal (37).

Pb is one of the most dangerous metals in TR. Even low levels of Pb can cause severe harm. As a result, if the edible part of vegetables contains high amounts of Pb, it may pose a potential risk of causing cancer (61). The findings from the risk assessment indicate that consuming products contaminated with heavy metals can be dangerous. This is because these metals can build up in the tissues of plants and animals, eventually leading to various diseases in humans.

Conclusion

Wastewater reuse mainly affects the concentration of heavy metals in soils and crops. Given that the use of vegetables in societies is increasing today, it is necessary to control the food consumed by humans. The results of the present study showed that despite irrigation of vegetables with synthetic effluent with permissible concentrations of Pb and As in the WHO and IRNDOE agricultural water, the accumulation of heavy metals in the studied vegetables is higher than the FAO/WHO allowable amount in vegetables. Risk assessment in this study shows that contamination and accumulation of heavy metals in vegetables irrigated with effluents contaminated with Pb, Cd, and As can be of great concern to consumers. Continuous irrigation with treated wastewater can pose a serious risk to human health, however, well water may also have high levels of metals in the long run. Although this study focused on a limited number of vegetables consumed raw and unprocessed vegetables, only three types of heavy metals were studied. Besides several existing studies, the results of this study show that to maintain food safety, in determining the allowable concentration of heavy metals in effluents for agriculture, the conditions of the region, vegetable morphology, and chemical properties of heavy metals, etc. should be considered.

Acknowledgments

The authors would like to thank the Vice-Chancellor for Research and Technology of Kashan University of Medical Sciences for supporting this project (Grant No. 97108).

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Competing interests

The authors declare that there is no conflict of interest.

Ethical issues

The Research Ethics Committee of Kashan University of Medical Sciences approved this study (Ethical code: IR.KAUMS.NUHEPM.REC.1397.38)

Funding

The Vice-Chancellor for Research and Technology of Kashan University of Medical Sciences funded this research (Grant No. 97108).

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