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Heavy Metals in Some Vegetables, Soil and Water in Industrial and Non-Industrial Zones of Central Region of Iran

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Abstract

The presence of heavy metals in water, soil, and agricultural products is considered a significant threat to human health. This study aimed to evaluate different heavy metals such as Mercury (Hg), Lead (Pb), Arsenic (As), Cadmium (Cd), Zinc (Zn) and Cobalt (Co), in some vegetable varieties like cucumber, tomato and eggplant and also in the soil and water resources, in greenhouses around the mega industrial zones vicinity (1-10 Km) and comparing it with a greenhouse located in suburb of Isfahan, Iran. Measurement of heavy metals was carried out using ICP-OES in replicate. Concentrations of heavy metals in soil varied by region and generally following the descending pattern: Co > Pb > As > Hg > Zn > Cd. Heavy metals transfer factor were in the order of Cd > Hg > Zn > Pb > Co > As. According to the results, the mega industrial zones of Isfahan province showed a hazardous situation, and notably, heavy metal levels in the suburban region of Isfahan exceeded the health risk index (HRI). Based on the findings, it is recommended that producers adopt regular monitoring of irrigation and soil quality, apply phytoremediation and organic soil amendments to reduce heavy metal uptake, and select low-accumulating crop varieties in order to minimize health risks and ensure sustainable greenhouse production near industrial zones.

Keywords: Heavy metals pollution, ICP-OES, Health risk assessment, Industrial zones, Vegetable

Introduction

Heavy metals (HMs) contamination in soil and consequently in vegetable is considered a major health hazard. Several factors influence heavy metal uptake in plants, such as climatic conditions, environmental pollution, soil characteristics, and plant maturity at harvest (Voutsa, Grimanis, & Samara, 1996). Vegetables are an essential component of a healthy diet and provide vital nutrients such as potassium, fiber, folate, and vitamins A and E. In Iran, vegetable consumption is relatively high, with an average daily intake of 278 g, which exceeding many other countries (Gharib, Fatoorechian, & Ahmadiniar, 2003). Therefore, assessing the accumulation of heavy metals (HMs) in food products is crucial for evaluating related health risks. Heavy metals, defined as elements with a specific density greater than 5 g/cm³, are harmful to the environment and living organisms (Järup, 2003). They are persistent in nature due to their long biological half-lives and persistence to degradation, resulting in their accumulation within human tissues over time (Singh, Sharma, Agrawal, & Marshall, 2010; Nabulo, Black, & Young,

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2011; Briffa, Sinagra, & Blundell, 2020; Radkhah, Eagderi, & Sadeghinejad Masouleh, 2022; Radkhah, Eagderi, & Atash Afrazah, 2025). Studies have confirmed that soil acidification can enhance Cd accumulation in vegetable tissues (Yang *et al*., 2014). Greenhouse production, which is expanding globally, has also been associated with increased level of metals such as Cd and Zn in soil, particularly due to manure application in organic systems (Yang *et al*., 2014; Cai *et al*., 2015). HMs can adversely affect multiple organs, including the nervous, skeletal, circulatory, enzymatic, endocrine, and immune systems, while some are carcinogenic and impair nutrient absorption, leading to disorders and organ damage (Khan *et al*., 2013). Sources of heavy metals in agricultural systems include industrial wastewater discharge, pesticide application, and other anthropogenic activities (Al-Hossainy, Mohamed, Hassan, & Abd Allah, 2017).

In Iran, several studies have investigated heavy metal accumulation in plants, water and environmental samples inorder to determine significant levels of HMs in vegetables from contaminated farmlands, highlighting the potential risk to human health (Rezaei Malidareh, Shokrzadeh, Khasi, Rouhi, & Zaboli, 2016; Sadegh, Rezaei, & Sayadi Anari, 2019; Ranjbar, Najafpoor, & Dehghan, 2020; Kakouei Dinaki, Cheraghi, Lorestani, Sobhan Ardakani, & Chamani, 2021; Sabourmoghaddam, 2024). Similar concerns have been raised in other countries: for instance, Rehman *et al.* (2018) measured Zn, Cr, Hg, Cu, and Ni in soil of Pakistan and found levels below critical limits, while Bi, Zhou, Chen, Jia, & Bao, (2018) reported differential transfer factors for Cd, Zn, Cu, As, Hg, and Pb in vegetables grown in China.

Isfahan, the third populated city in Iran, faces increasing industrial activity, which may contribute to environmental heavy metal pollution. Therefore, the present study aimed to determine the concentrations of heavy metals such as arsenic (As), cadmium (Cd), lead (Pb), zinc (Zn), cobalt (Co), and mercury (Hg) in cucumber, tomato, and eggplant, as well as in soil and water resources, from greenhouses located near mega-industrial zones of Isfahan province and a suburban reference site.

Materials and Methods

Study area

According to Fig. 1, the study area encompasses 4 greenhouses, with tomato (*Solanum lycopersicum*), cucumber (*Cucumis sativus*), and eggplant (*Solanum melongena*) cultivation. The first one was located at a distance of 3 km from the western gate of Mobarakeh Steel Company, the second one 8 km from Isfahan Steel company, the third one 1 km from Isfahan Cement Factory, the forth one 1 km from Sepahan Cement Factory and the fifth one 15 km from Isfahan in Dorcheh zone (control).

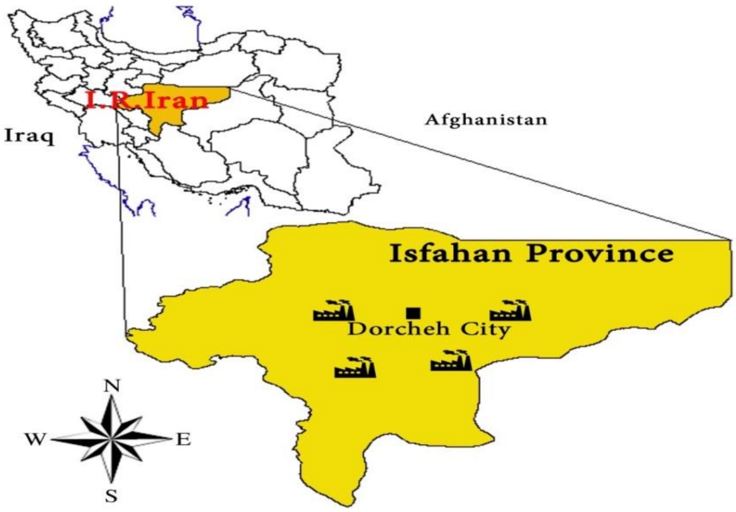

Fig. 1. Location of obtained samples near Mega-Factories and Dorcheh City

Sample Collection

Soil sampling: Soil samples (~500 g) composed of 10–15 sub-samples (each ~30–50 g), excluding the top 2–3 cm, were collected using an X-pattern sampling strategy and stored in clean, sealed plastic bags (Ferri *et al*., 2015).

Water sampling: Samples from well water used for irrigation practices were collected in pre-cleaned 500 ml high-density polyethylene bottles with two replications from each site (Gebrekidan, Weldegebriel, Hadera, & Van der Bruggen, 2013).

Plant sampling: Four samples per vegetable variety (tomato, cucumber, and eggplant) were collected from each greenhouse, washed with distilled water, then dried, and stored in sealed polyethylene bags at (-20)°C for future analysis.

Pretreatment and Digestion Procedures

Soil Pretreatment and Digestion Procedures

All composite soil samples were thoroughly homogenized, oven-dried at 65°C for one day, and then sieved to obtain a particle size of 150µm. A 0.25g soil sample was weighed and 6 ml of concentrated nitric acid and 3 ml of concentrated hydrochloric acid were then added. The mixture was heated up to 210°C on a hot-plate until near drying. After cooling off, the sample was diluted to a specific volume (100 mL). Then 6 ml concentrated hydrochloric acid added and the mixture was placed on a hot-plate until it became honey colored indicating dissolution of the elements. Finally, the resulting solution was diluted to the final volume of 250 mL (Ferri *et al.*, 2015; Beccaloni, Vanni, Beccaloni, & Carere, 2013).

Water Digestion Method for Injection

Water was filtered through syringe filters (pore size = 0.45µm) prior to analysis. This filtration step effectively removes particulate matter, ensuring that the water samples are suitable for ICP-OES analysis without additional digestion, pH adjustment was performed (by addition of 5 ml concentrated nitric acid or 2 ml of concentrated hydrochloric acid) before injection to ICP-OES instrument (Noli & Tsamos, 2016).

Plant Pretreatment and Digestion Procedures

After removal of inedible parts (except the skin), vegetables were rinsed with distilled water, excessive water was then removed and the vegetables were cut into smaller pieces and homogenized. For digestion, 2 g (wet basis) of each sample was placed in a polytetrafluoroethylene vessel with 5 mL of concentrated nitric acid in addition to 2 mL of hydrogen peroxide (Khillare, Jyethi, & Sarkar, 2012). This solution was then diluted to a final volume of 50 mL.

Transfer Factor

Transfer factor represents how readily a metal is absorbed by a specific plant from the surrounding soil environment. The transfer factor (TF) values from soil to plants were calculated using the following equation:

Eq (1): $MTF = C_{plant}/C_{soil}$

C_{plant} and C_{soil} indicate the levels of a given element in plant tissues and corresponding soil samples, respectively (Khan *et al.*, 2013).

Sample Analysis

Inductively coupled plasma optical emission spectrometry (ICP-OES) was employed to determine heavy metal concentrations in all collected samples (vista pro, Varian, Australia). The instrument was calibrated with a standard solution containing individual heavy metals.

Statistical Analysis

All statistical evaluations were initially tested for normal distribution and variance homogeneity using the Kolmogorov–Smirnov test. Where applicable, data were subjected to one-way analysis of variance (ANOVA). Further analysis was conducted using a General Linear Model (GLM) under a nested design framework, implemented via SAS software (version 9, Windows platform). Mean comparisons were performed using the Least Significant Difference (LSD) test at a significance level of $p < 0.05$. Additionally, Pearson correlation coefficients were computed to assess relationships between metal concentrations in soil, water, and plant samples.

Results and Discussion

Heavy metal concentrations varied significantly in soil samples and were determined in the following order: Co>Pb>As>Hg>Zn>Cd. Similar trend was found in water and plant as follow: Co>Pb>Hg>As>Zn>Cd. In water, Co and Cd showed the highest and the lowest range, respectively. Our findings indicated that metal concentrations in plants are more influenced by levels in irrigation water compared to those in soil; possibly due to higher solubility and bioavailability of metals in water which was in agreement with other reports (Khan, Cao, Zheng, Huang, & Zhu, 2008).

Table 1 provides a summary of heavy metal concentrations measured in soil samples taken from the five greenhouse sites under investigation. The results show that the mean concentration of arsenic in soil samples collected from the five locations of the studied areas varied from 59.585mg/kg to 82.372mg/kg; the lowest belonging to the soil of Dorcheh, and the highest to Sepahan Cement Company. Sepahan Cement Factory and Dorcheh had the lowest mercury (26.96 and 33.499 mg/kg) and Isfahan Steel Company and Mobarakeh Steel company showed the highest (50.363 and 44.107 mg/kg) mercury concentration, respectively. Hg concentrations were found to be highest in the soils of Isfahan Steel and Mobarakeh Steel companies ($p<0.05$). The Zn concentrations also varied in different sampling locations. Isfahan Cement Company had the lowest zinc concentration (4.114 mg/kg). The mean concentration of Co varied from 669.823 mg/kg to 674.405 mg/kg. The lowest as shown in Table 1 was from the soil of Isfahan Steel Company and the highest was from Dorcheh area but the differences were not significant ($p>0.05$). Similarly, the highest amount of Cd was from Isfahan Cement Factory (1.065 mg/kg) (Table 1).

Data presented in Table 1 clearly showed that concentrations of heavy metals in the soil samples collected from the five different locations were not all the same. Heavy metal build-up in soil is caused by applications of agrochemicals, treated wastewater, and agricultural waste.

Table 1- Heavy metal concentrations (mg/kg) in the soil sampled from the study area

Study area	Pb	As	Hg	Zn	Co	Cd
ISC*	107.163±2.39^{a}	74.625±12.182^{b}	50.363±11.43^{a}	5.117±0.446^{ab}	669.823±3.542^{b}	0.279±0.215^{c}
MSC	108.235±0.758^{a}	71.831±7.374^{b}	44.107±20.806^{ab}	5.7±0.288^{a}	671.628±3.525^{ab}	0.394±0.234^{bc}
SCF	107.722±2.295^{a}	69.02±9.31^{b}	26.96±14.938^{c}	5.657±0.496^{a}	673.125±1.783^{ab}	0.819±0.618^{ab}
ICF	108.497±1.724^{a}	82.372±8.027^{a}	42.31±34.289^{b}	4.114±1.442^{b}	673.146±4.739^{ab}	1.065±0.568^{a}
D	108.656±2.471^{a}	59.585±4.125^{c}	33.499±15.156^{c}	4.739±0.203^{ab}	674.405±3.265^{a}	0.28±0.258^{c}

*ISC: Isfahan Steel Company ; MSC: Mobarakeh Steel company :SCF: Sepahan Cement Factory; ICf: Isfahan Cement Factory ; D: Dorcheh

Results are mean ± SD. In each column means followed by the same letter are not significantly different at P<0.05 using LSD test.

Analysis of the variances (ANOVA) showed significantly different amounts of As, Hg and Zn in water from different areas. Concentration of the heavy metals found in the water used for irrigation in the studied areas are presented in Table 2. Analysis of Dorcheh water showed the presence of a higher amount of arsenic than other areas (0.076 mg/l). Isfahan Steel and Mobarakeh Steel companies had the lowest amount of As (0.054 mg/l and 0.057 mg/l, respectively). Water used in the greenhouse in the Isfahan Cement Factory zone carried the highest amount of Hg (0.095 mg/l), and the water used in the greenhouse near Mobarakeh Steel Company had the highest amount of Zn (0.066 mg/l). There were no significant variations for Zn in other areas.

Table 2- Heavy metal concentration (mg/L) in water for irrigation sampled from the study area

Study area	Pb	As	Hg	Zn	Co	Cd
WISC*	0.11±0.003^{a}	0.054±0.007^{c}	0.072±0.003^{c}	0.008±0.001^{b}	0.675±0.006^{ab}	0.002±0.001^{a}
WMSC	0.112±0.002^{a}	0.057±0.01^{bc}	0.074±0.009^{bc}	0.066±0.007^{a}	0.68±0.006^{ab}	0.003±0^{a}
WSCF	0.111±0.004^{a}	0.06±0.011^{b}	0.078±0.005^{b}	0.029±0.003^{b}	0.679±0.005^{ab}	0.002±0.001^{a}
WICF	0.11±0.003^{a}	0.06±0.008^{b}	0.095±0.075^{a}	0.029±0.003^{b}	0.682±0.008^{a}	0.001±0001^{a}
WD	0.11±0.004^{a}	0.076±0.021^{a}	0.075±0.006^{bc}	0.028±0.003^{b}	0.672±0.006^{b}	0.003±0.002^{a}

*WISC: Water used for irrigation in Isfahan Steel Company; WMSC: water used for irrigation in Mobarakeh Steel Company: WSCF: water used for irrigation in Sepahan cement Factory; WICF: water used for irrigation in Isfahan cement Factory; WD: water used for irrigation in Dorcheh

Results are mean ± SD. In each column means followed by the same letter are not significantly different at p<0.05 using LSD test.

The level of the heavy metals in tomato, cucumber and eggplant collected from the study areas were analyzed. The results as shown in Table 3 indicate that the highest concentration of Pb was observed in eggplant (8.101 mg/kg) and the lowest in cucumber (1.922 mg/kg). The highest Arsenic was measured in eggplant (1.440 mg/kg). Cucumber and tomato carried comparatively lower levels of As. Hg and Co in cucumber had the lowest amount (1.891 mg/kg) and (17.585 mg/kg), respectively. There was no significant difference in Hg and Co levels of tomato and eggplant. The mean concentration of Zn was the highest in tomato (0.544 mg/kg). The mean concentration of Cd was the highest in tomato (0.157 mg/kg) and the lowest in cucumber (0.044 mg/kg).

Table 3- Heavy metal concentration (mg/kg) in plant sampled from the study area

Vegetables	Pb	As	Hg	Zn	Co	Cd
Tomato	3.95±0.312^{b}	1.048±0.316^{b}	1.891±0.113^{a}	0.544±0.042^{a}	17.585±0.464^{a}	0.157±0.071^{a}
Cucumber	1.922±0.824^{c}	0.882±0.352^{b}	1.116±0.453^{b}	0.089±0.038^{b}	11.139±4.381^{b}	0.044±0.031^{c}
Eggplant	8.101±4.162^{a}	1.44±0.343^{a}	2.165±0.139^{a}	0.102±0.037^{b}	17.373±0.225^{a}	0.105±0.028^{b}

Results are mean ± SD. In each column means followed by the same letter are not significantly different at p<0.05 using LSD test.

The transfer factors from soil to plants for the examined vegetables were calculated; the results as presented in Table 4 show different transfer factors for different vegetables and locations. Cd had the higher transfer factor in all vegetable varieties and ranged from 0.683 in tomato cultivated near the Isfahan Steel Company to 0.005 in cucumber, which was cultivated near the Sepahan Cement Factory. Pb had the highest transfer factor in eggplants cultivated near Isfahan Cement Factory (0.122). Tomato had the higher Zn transfer factor than eggplant and cucumber. Tomato cultivated in a green- house near Isfahan Steel Company had the highest Zn transfer factors (0.366).

Table 4- Transfer factors from soil to vegetables in study area

Study area	Plant	Pb	As	Hg	Zn	Co	Cd
ISC	Tomato	0.04 ± 0.001^{d}	0.019 ± 0.002^{b}	0.035 ± 0.007^{d}	0.015 ± 0.006^{c}	0.026 ± 0^{a}	0.683 ± 0.297^{a}
ISC	Cucumber	0.012 ± 0^{h}	0.012 ± 0.002^{cde}	0.02 ± 0.003^{d}	0.012 ± 0^{c}	0.013 ± 0.001^{b}	0.402 ± 0.078^{abc}
ISC	Eggplant	0.055 ± 0^{c}	0.019 ± 0.004^{b}	0.04 ± 0.11^{d}	0.02 ± 0.003^{c}	0.026 ± 0^{a}	0.333 ± 0.109^{abc}
MSC	Tomato	0.035 ± 0^{de}	0.011 ± 0.001^{cde}	0.066 ± 0.011^{cd}	0.017 ± 0.004^{c}	0.026 ± 0.001^{a}	0.448 ± 0.026^{abc}
MSC	Cucumber	0.012 ± 0^{h}	0.011 ± 0.001^{cde}	0.015 ± 0.004^{d}	0.012 ± 0.002^{c}	0.012 ± 0^{b}	0.263 ± 0.095^{abc}
SCF	Tomato	0.036 ± 0^{de}	0.016 ± 0.001^{bcd}	0.042 ± 0.003^{cd}	0.366 ± 0.034^{a}	0.027 ± 0.0001^{a}	0.614 ± 0.363^{ab}
SCF	Cucumber	0.019 ± 0.009^{gh}	0.016 ± 0.008^{bcd}	0.065 ± 0.034^{cd}	0.021 ± 0.013^{c}	0.019 ± 0.009^{ab}	0.005 ± 0.002^{c}
SCF	Eggplant	0.097 ± 0.002^{b}	0.017 ± 0.002^{bc}	0.162 ± 0.08^{ab}	0.028 ± 0.006^{c}	0.026 ± 0^{b}	0.28 ± 0.232^{abc}
ICF	Tomato	0.033 ± 0.002^{def}	0.008 ± 0^{e}	0.195 ± 0.008^{a}	0.028 ± 0.027^{c}	0.027 ± 0.001^{a}	0.116 ± 0.065^{abc}
ICF	Cucumber	0.025 ± 0.11^{fg}	0.009 ± 0.00^{de3}	0.046 ± 0.017^{d}	0.021 ± 0.005^{c}	0.02 ± 0.001^{a}	0.098 ± 0.06^{bc}
ICF	Eggplant	0.122 ± 0.001^{a}	0.022 ± 0.001^{ab}	0.026 ± 0.003^{d}	0.02 ± 0.003^{c}	0.02 ± 0.003^{c}	0.202 ± 0.08^{abc}
D	Tomato	0.04 ± 0.002^{d}	$0.015 \pm 0^{bcd-}$	0.129 ± 0.013^{bc}	0.079 ± 0^{b}	0.026 ± 0^{ab}	0.341 ± 0.106^{abc}
D	Cucumber	0.019 ± 0.009^{gh}	0.019 ± 0.009^{b}	0.028 ± 0.013^{d}	0.023 ± 0.009^{c}	0.018 ± 0.009^{a}	0.4 ± 0.168^{abc}
D	Eggplant	0.028 ± 0.002^{efg}	0.028 ± 0.003^{feg}	0.048 ± 0.002^{d}	0.012 ± 0.004^{c}	0.026 ± 0^{a}	0.238 ± 0.124^{abc}

ISC: Isfahan Steel Company; MSC: Mobarakeh Steel Company; SCF: Sepahan Cement Factory; ICF: Isfahan Cement Factory; D: Dorcheh

Results are mean ± SD. In each column means followed by the same letter are not significantly different at $p<0.05$ using LSD test

In a study carried out by Khan *et al.* (2013), the concentration of different heavy metals namely Cd, Ni, Zn, Mn and Cr were measured in agricultural soil and crops in Pakistan (Khan *et al.*, 2013). Contradictory to our results none of measured HMs were higher than Codex and Iran standard except for Cd (0.05 mg/kg). Maximum limit for Pb and Cd is 0.05 mg/kg of food samples like the plants of this study (Codex No. 193; National Standard No. 12968; EC No. 1881). Since Arsenic is used in pesticides formula and Pb is the major pollutant of steel companies, hence there levels are remarkably higher in Isfahan Province in comparison with Swat province of Pakistan (with no steel factory up to 100Km). Also, in comparison with the current study, *Rehman et al.* (2018) measured Zn, Cu, Ni, Mn and Cr concentrations in agricultural soils of Pakistan. Although climate characteristics of Isfahan and Khyber province are approximately similar, results were totally different. All measured HMs by Rehman *et al.* (2018) were lower than the legal limit, however the current study proved that As, Hg and Cd were higher than legal limits in most of the zones. Table 5 summarizes the amount of different heavy metals in vegetables cultivated in studied zones. Tomatoes cultivated in greenhouse near Sepahan Cement Factory had the highest value for Zn and Co. Eggplants picked up from the green house near Isfahan Cement Factory contained very high value of Pb. According to the results, food-crop cultivated on contaminated agricultural soils can easily absorb high amounts of heavy metals, which will cause entrance of HMs to human food chain.

Since different regions showed relatively different amounts of HMs, therefore, as a result absorbed amount of HMs were different for each site.

Table 5- Evaluation of the interaction effects of Region and plant on heavy metals (mg/kg)

Region	Plant	Cd	Co	Zn	Hg	As	Pb
ISC	Tomato	0.13±0.04^{bcd}	17.33±0.02^{a}	0.07±0.02^{c}	1.9±0.04^{ab}	1.54±0.11^{ab}	4.18±0.07^{de}
ISC	Cucumber	0.06±0^{fgh}	8.71±0.51^{b}	0.06±0^{c}	0.77±0.12^{d}	0.68±0.03^{d}	1.37±0.04^{h}
ISC	Eggplant	0.07±0.01^{fgh}	17.29±0.08^{a}	0.1±0^{c}	2.15±0.13^{a}	1.53±0.27^{ab}	5.79±0.02^{c}
MSC	Tomato	0.26±0^{a}	17.26±0.23^{a}	0.1±0.03^{c}	1.81±0.05^{abc}	0.78±0.02^{cd}	3.82±0.03^{def}
MSC	Cucumber	0.04±0.01^{gh}	8.36±0.01^{b}	0.07±0.01^{c}	0.86±0.08^{d}	0.74±0.02^{cd}	1.34±0.02^{h}
SCF	Tomato	0.14±0.06^{bc}	18.05±0.66^{a}	2.12±0.18^{a}	1.94±0.14^{ab}	1.2±0.09^{bc}	3.78±0.13^{def}
SCF	Cucumber	0.01±0.003^{h}	12.53±3.89^{ab}	0.12±0.07^{c}	1.32±0.69^{bcd}	1.16±0.56^{bcd}	2.08±0.97 ^{gh}
SCF	Eggplant	0.11±0.002^{cde}	17.4±0.14^{a}	0.15±0.03^{c}	2.19±0.33^{a}	0.95±0.07^{cd}	10.53±0.02^{b}
ICF	Tomato	0.17±0.04^{b}	17.75±0.75^{a}	0.05±0.01^{c}	1.99±0.08^{ab}	0.74±0.02^{cd}	3.6±0.16^{def}
ICF	Cucumber	0.08±0.02^{defg}	13.63±4.5^{ab}	0.09±0.03^{c}	1.49±0.57^{abcd}	0.71±0.26^{d}	2.74±1.23^{fg}
ICF	Eggplant	0.14±0.04^{bc}	17.52±0.49^{a}	0.1±0.02^{c}	2.16±0.04^{a}	1.72±0.1^{a}	13.01±0.05^{a}
D	Tomato	0.07±0.01^{efg}	17.54±0.24^{a}	0.37±0.08^{b}	1.81±0.19^{abc}	0.97±0.08^{cd}	4.37±0.17^{d}
D	Cucumber	0.04±0.02^{gh}	12.47±3.87^{ab}	0.11±0.04^{c}	1.15±0.54^{cd}	1.12±0.54^{bcd}	2.08±0.97^{gh}
D	Eggplant	0.1±0.02^{cdef}	17.28±0.08^{a}	0.06±0.01^{c}	2.16±0.08^{a}	1.55±0.25^{ab}	3.08±0.07^{efg}

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Results are mean ± SD. In each column means followed by the same letter are not significantly different at $p<0.05$ using LSD test

Data presented in Table 6 show the Pearson correlation coefficients of heavy metals in soil and the plants studied in this research. Soil mercury and plant arsenic showed a positive and significant correlation of 0.521. Lead content in the plant had a positive and significant correlation with arsenic (0.466), mercury (0.639), and cobalt (0.520) in the plant. Plant arsenic also had a positive and significant correlation with mercury (0.521) in soil and cobalt (0.464) in plant. The highest correlation between the elements measured in the plant was observed between mercury and cobalt (0.937). Mercury also showed a positive and significant correlation with cadmium (0.506).

Table 6- Pearson correlation coefficients of elements measured in soil and plants (tomato, eggplant and cucumber)

	Pb (soil)	As (soil)	Hg (soil)	Zn (soil)	Co (soil)	Cd (soil)	Pb (plants)	As (plants)	Hg (plants)	Zn (plants)	Co (plants)	Cd (plants)
Pb (soil)	1											
As (soil)	−0/310	1										
Hg (soil)	−0/036*	0/156	1									
Zn (soil)	0/010	−0/246	0/161	1								
Co (soil)	0/284	−0/407*	0/074	0/089	1							
Cd (soil)	0/109	0/421*	−0/389*	−0/112	−0/218	1						
Pb (plants)	−0/216	0/106	0/273	0/044	0/186	0/072	1					
As (plants)	−0/536**	0/113	0/521**	0/105	−0/158	−0/050	0/464*	1				
Hg (plants)	−0/335*	0/280	0/001	−0/114	−0/300	0/181	0/639**	0/618**	1			
Zn (plants)	−0/292	0/103	0/034	0/237	−0/061	−0/176	−0/026	0/078	0/165	1		
Co (plants)	−0/297	0/312	−0/084	−0/067	−0/263	0/171	0/520**	0/563**	0/937**	0/246	1	
Cd (plants)	−0/167	0/384*	−0/048	−0/088	−0/297	0/124	0/306	0/017	0/506**	0/147	0/569	1

* and ** are significant at 5 percent and 1 percent probability levels, respectively

Conclusion

In this study, different heavy metals namely Pb, As, Cd, Co, and Hg in cucumber (*Cucumis sativus*), eggplant (*Solanum melongena*), tomato (*Solanum lycopersicum*), water, and soil of greenhouses near (1–10 km) mega-industrial zones were determined and compared with a greenhouse located in the suburb of Isfahan. The Pb values of the three vegetables examined in this experiment were above the standard limits. Eggplant showed the highest Pb content, which was 10 times higher than the standard level. Pb and Hg transfer factors in eggplant were higher compared to the other both studied vegetables. Eggplant and tomato absorbed the highest amounts of Pb and Co, indicating higher transfer factors in these plants. Tomato absorbed the highest levels of Zn and Cd, indicating higher Zn and Cd transfer factors. Among the three studied vegetables, cucumber was less susceptible to heavy metal absorption. Based on these findings, it is recommended to monitor soil and irrigation water quality regularly, apply soil amendments and phytoremediation techniques to reduce heavy metal uptake, and select plant varieties with lower metal accumulation to minimize health risks. For future research, studies should focus on long-term monitoring of heavy metals in different crop varieties, air, water and soil, assessment of seasonal variations, and evaluation of mitigation strategies to improve food safety and environmental sustainability. These efforts will contribute to more informed management practices in greenhouse production near industrial zones.

Author Contributions

Ashkan Nasresfahani: Study conception and design, data collection, draft manuscript preparation. **Nafiseh Zamindar:** Study conception and design, data collection, analysis and interpretation of results, Investigation, Validation, Supervision, draft manuscript preparation, Project administration, Conceptualization. **Saeed Paidari:** Writing – review & editing, Data curation. **Haniyeh Rezaee Barzani:** Interpretation of results, draft manuscript preparation, review & editing.

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فلزات سنگین در برخی سبزیجات، خاک و آب در مناطق صنعتی و غیرصنعتی منطقه مرکزی ایران

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چکیده

وجود فلزات سنگین در آب، خاک و محصولات کشاورزی تهدید قابل توجهی برای سلامت انسان به شمار می‌آید. هدف از این مطالعه، ارزیابی فلزات سنگینی همچون جیوه (Hg)، سرب (Pb)، آرسنیک (As)، کادمیم (Cd)، روی (Zn) و کبالت (Co) در برخی سبزیجات مانند خیار، گوجه‌فرنگی و بادمجان و همچنین در منابع خاک و آب گلخانه‌ها واقع در فاصله نزدیک (۱–۱۰ کیلومتر) از مناطق صنعتی بزرگ و مقایسه آن با یک گلخانه واقع در حومه استان اصفهان بود. اندازه‌گیری فلزات سنگین با استفاده از روش ICP-OES و با تکرار انجام شد. غلظت فلزات سنگین در خاک بر اساس منطقه متفاوت بود و به‌طور کلی الگوی نزولی Cd > Zn > Hg > As > Pb > Co را نشان داد. فاکتور انتقال فلزات سنگین نیز به‌ترتیب Cd > Hg > Zn > Pb > Co > As بود. نتایج نشان داد که مناطق صنعتی بزرگ استان اصفهان وضعیت مخاطره‌آمیزی دارند و قابل توجه است که سطح فلزات سنگین در منطقه حومه اصفهان نیز از شاخص ریسک سلامت (HRI) فراتر رفته است. بر اساس یافته‌ها، پیشنهاد می‌شود که تولیدکنندگان نظارت منظم بر کیفیت آب آبیاری و خاک را انجام دهند، از روش‌های گیاه پالایی و بهبود دهنده‌های آلی خاک برای کاهش جذب فلزات سنگین استفاده کنند و گونه‌های گیاهی کم‌جذب را انتخاب نمایند تا خطرات سلامت کاهش یابد و تولید پایدار در گلخانه‌های نزدیک مناطق صنعتی تضمین شود.

واژه‌های کلیدی: آلودگی فلزات سنگین، سبزیجات، شاخص ریسک سلامت، مناطق صنعتی، ICP-OES

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