Research Article

Evaluation of the ecological risk index (Er) of heavy metals (HMs) pollution in urban field soils

Hojjat Miranzadeh Mahabadi[1] · Mahmoud Ramroudi[1] · Mohammad Reza Asgharipour[1] · Hamid Reza Rahmani[2,3] · Majid Afyuni[4]

Abstract

This study presents the importance of urban field soils for producing vegetable crops. This study was conducted in the three local areas of Isfahan (first region), Falavarjan (second region), and Natanz, Feridan, and Golpayegan (third region) to evaluate transfer factor (TF), contamination factor, ecological risk (Er) and potential ecological risk index (RI) which were employed to investigate the Pb, Cu, Co, Cd, and Cr pollution of the urban field soils affecting vegetable to reveal the potential hazards of HMs pollution for the first time in Isfahan city in Iran. To measure the pollution of such heavy metals (HMs) as Pb, Cu, Co, Cd, and Cr, the related soil samples were collected and their pollution and ecological risk indices were assessed. The results showed the highest pollution of Pb and Cr in the field soils of the first (127.37 and 112.65 mg kg^{-1}) and second (6.94 and 4.61 mg kg^{-1}) regions, respectively, which were greater than the amounts recommended by Iran's Environmental Protection Agency. The high TF of Cr (0.56 mg kg^{-1}), Cd (0.23 mg kg^{-1}), and Co (0.30 mg kg^{-1}) from the soils to the tubers were found to mostly involve leafy and fruity vegetables. The highest contamination factor (PF) of Cr (12.46 mg kg^{-1}) in the first region was in the class of very high pollution. The highest Er of Cd in first and second regions was 264.0 and 214.9 mg kg^{-1}, respectively, which were considered in the high-risk class. These indices revealed possible increases in potential ecological RI in the mentioned regions (up to 330.8 and 272.4 mg kg^{-1}, respectively), which were classified in the classes of high and moderate pollution risk. Principal component analysis indicated that the pollution of the HMs in Isfahan and Falavarjan was overlapped. Cr in PC1 and Cd and Co in PC2 had the highest distributions and impacts representing enhancing transfer factor from the soils to onions, potatoes, and basil.

Keywords Soil urban pollution · Ecological risk index · Transfer factor · Vegetable fields · Heavy metals

1 Introduction

Rapid industrialization and urbanization have led to soil pollution in urban areas. Heavy metals (HMs) in soil have originated from such pollution sources as industrial wastes, air sedimentation, city emissions, and other activities [4–6]. HMs in urban soils can exert their toxicities through ingestion pathways, inhalation, and dermal routes, thus influencing on human health, in addition to leaving their serious consequences [7, 8, 21, 28].

In recent decades, HMs as the most important environmental pollutants interfering with agroecosystem health have become as the main concern [23]. Although there are low concentrations of HMs in soils, plants, and natural water, industrial activities can expose some ecosystems to serious pollution [19].

✉ Mohammad Reza Asgharipour, m_asgharipour@uoz.ac.ir | [1]Department of Agronomy, University of Zabol, Zabol, Iran. [2]Department of Soil and Water, Isfahan Agricultural and Natural Resources Research Center, Isfahan, Iran. [3]Soil and Water Department, Agricultural and Natural Resources Research Center, Agricultural Research Education and Extension Organization (AREEO), Isfahan, Iran. [4]Department of Soil Sciences, Isfahan University of Technology, Isfahan, Iran.

The study conducted by Ghadimi [14] on the amounts of pollution in Arak Region demonstrated that the levels of HMs in the soils collected from the industrialization sites were higher than those of the distal areas. The main source of the soil pollution was the hazardous wastes produced by industrial activities in the study area and spread all over the region through rainfalls or winds. Wu et al. [31] discovered the pollution of traffic-related metals and agricultural wastes. Geochemical approaches combined with multivariate analysis of the concentrations of HMs in the coastal areas of Montenegro demonstrated much higher Cd and Pb contents in the soil samples compared to those of the background area [24]. Wang et al. [30] reported their mine site to have contained high levels of Hg and Pb pollutants although the overall pollution was moderate.

In another research [25] carried out on the contamination of Donghu Lake in China, the potential ecological risks index (RI) of HMs was ranked as $Cd > As > Cr > Cu > Pb > Zn$. Cd had an intermediate potential ecological risk index (RI) in the environment and was the main contributor to the possible HMs-toxicity responses in the lake. The main pollutants in the area were Cd and Pb, representing moderate levels of ecological hazards. Through the correlation analysis of HMs, the main external sources of pollution were found by Shahid et al. [29] to be excessive pesticide applications, as well as residual gas productions of diesel and gasoline engines. As shown by Qiu [26] and Al-Anbari et al. [3], the main origin of pollution was the high background quantities of their studied newly covered soil. In the cold region of Harbin, China, the contents of Cd, Pb, Cu, and Cr were found to be 0.2 ± 0.2, 26.5 ± 8.4, 29.1 ± 8.6, and 56.5 ± 6.3, respectively [20]. It was reported that the integrated RI of the HMs was 216.8, which categorized the region under an intermediate ER [26]. The PER of HMs found in Heidaigou opencast coal mine varied from 113.04 to 235.19 with an average value of 146.68, representing a slight ER [22, 30]. Mugoša et al. [24] observed that soil pollution with Cd, Pb, Zn, and Cu was shared by anthropogenic activities according to their principal component analysis (PCA). Calculations of the various factors of ecological pollution demonstrated that Cd was the main contributor to enhanced RI. Ravankhah et al. [27] found the average pollution of Pb, Cu, and Cd in the soil of Arano-Bidgol to be 11.41, 14.82, and 0.72 mg kg^{-1}, respectively, all of which were greater than their reference quantities. Considering the RI values and reference quantities, this area showed a comparably great level of pollution. Afshari et al. [1] determined the RI means in the agriculture land, rangeland, and urban land uses to be 114.09, 122.08, and 339.62, respectively; thus, the urban land use had the highest RI for the inhabitants.

The multivariate statistical approach combined with a broad range of indices provides a modern method for evaluating HMs pollution in urban field soils in a way that it can be applied to other analogous soil pollution systems as well. In this research, transfer factor (TF), contamination factor (CF), ecological risk (Er) and potential ecological risk index (RI) were employed to investigate the Pb, Cu, Co, Cd, and Cr pollution of the urban field soils affecting vegetable to reveal the potential hazards of HMs pollution for the first time in Isfahan city in Iran.

2 Materials and methods

2.1 Study area

This research was conducted in summer, 2017, in Isfahan City (51.64481° Long. and 32.68339°). The study area included the three different local areas, Isfahan (first region), Falavarjan (second region), and Feridan, Golpayegan, and Natanz (third region) (Fig. 1). The pollution in the studied regions was related to the presence of industries producing industrial pollutants and urban waste applications for growing vegetables in varied distal areas [18].

2.2 Measurements

In the first step, a total of 37 field soil samples were randomly taken from the depths of 0–30 cm with three replications for each sample in all of three regions. Then, they were transferred to the Water and Soil Laboratory of the Research Center of Agriculture and Natural Resources in Isfahan. Next, they were air-dried, crushed, passed through a 2-mm-mesh sieve, and placed in an oven at 75 °C for 48 h. Finally, they were stored in paper bags at ambient temperature until the extraction time. A wet digestion technique (3–1) with 65% nitric acid and 37% hydrochloric acid was applied for extraction [11]. In the second step, 1 gm of each sample was added to a flask containing concentrated HCl (10 mL) and HNO^3 (30 mL) and the flask was covered with a watch glass for at least 12 h. Then, the mixture was progressively heated to the boiling point for 2 h. After cooling and rinsing with deionized water, the rinse water was recovered in the digestion flask. Passing the intakes through a prewash filter, the filtrates were employed to make a volume of up to 50 mL. The prepared samples were refrigerated in polyethylene bottles washed with acid at 4 °C before the final analysis. The concentrations of the HMs (Pb, Cu, Co, Cd, and Cr) of the digested soil samples were measured with a flame atomic absorption spectrometer (Konik Won M300, Barcelona, Spain) [12, 17]. The detection limits of flame atomic absorption spectrometer for Pb, Cu, Co, Cd and Cr were 0.498, 0.450, 0.380, 0.00797 and 0.00107 ppm, respectively.
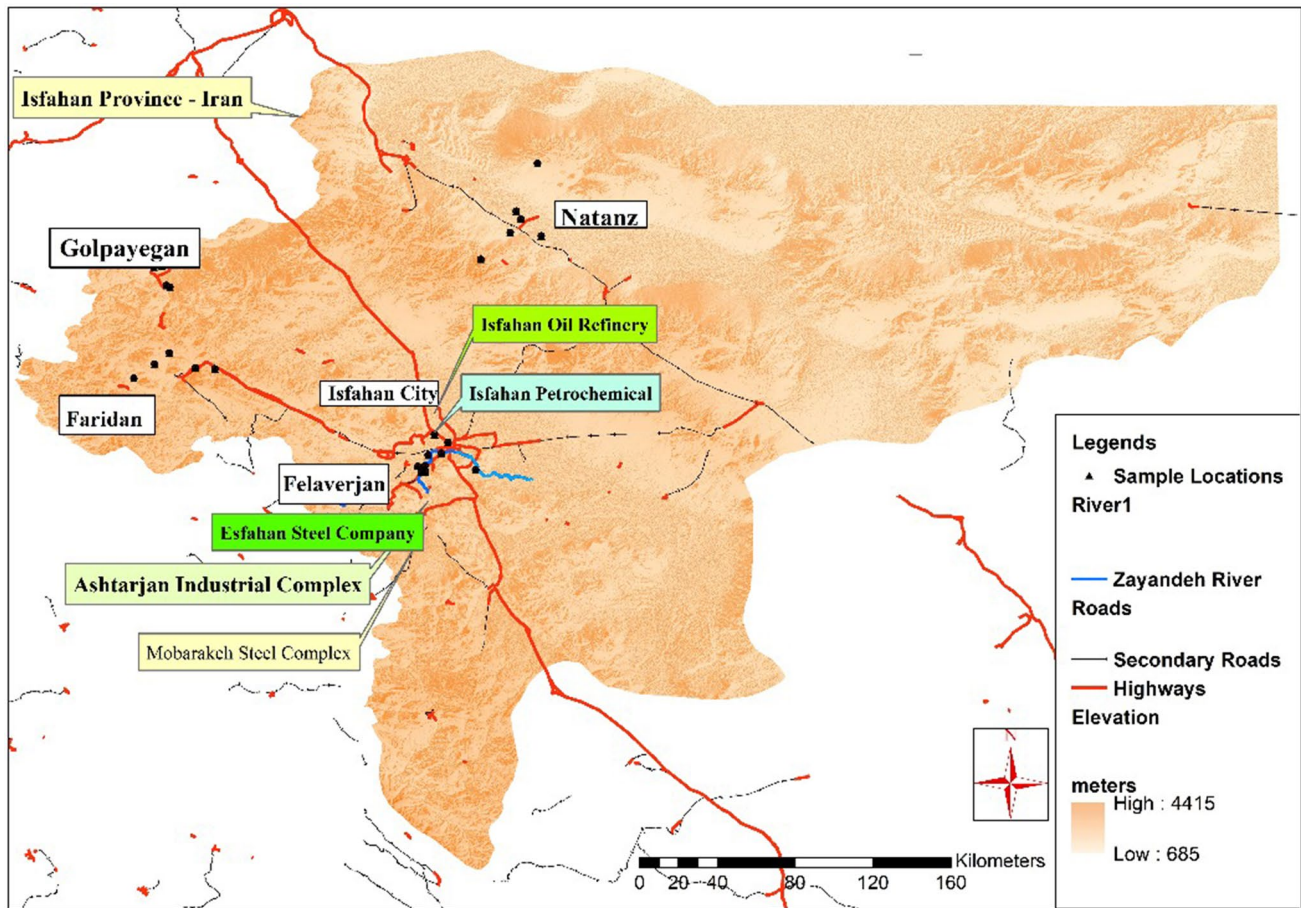
Fig. 1 Map of the study areas in the Isfahan city, Iran

2.3 Evaluation of soil pollution risks

Evaluations of the soil pollution were done by calculating the following indices: transfer factor (TF), contamination factor (CF), ecological risk index (Er), and potential ecological risk index (RI).

The TF values of the HMs from the soils to the vegetables were calculated according to Eq. 1 [12]:

$$TF = \frac{MCP}{MCS} \qquad (1)$$

where MCP and MCS are metal contents, respectively, in plant tissues (per dry weight) and the soil, in which vegetables are grown.

CF indicates metal contamination degree in soil (Eq. 2):

$$CF = \frac{C^i}{C_{ref}} \qquad (2)$$

where C^i denotes total metal contents in the analyzed soil samples; and C_{ref} stands for the reference value that can be applied to some of the suggested values as it is not a

uniform value and relates to the background level, average crust level, and national criteria. In this research, the reference values for Pb, Cu, Co, Cd, and Cr were 18, 13.2, 7, 0.25, and 0.28, respectively. CF was classified into 4 pollution groups [15] (Table 3).

The Er for each metal was quantitatively calculated to express the RI (Eqs. 3 and 4) as suggested by Hakanson [15]. CF was measured via Eq. 2.

$$Er = Tr \times CF \qquad (3)$$

$$RI = \sum_{i=1}^{n} Er \qquad (4)$$

where Tr represents the toxic response factor for a given substance. The Tr values of the HMs were as follows: Pb, Cu, and Co = 5; Cd = 30; and Cr = 2 [15].

RI is commonly used as a diagnostic tool for controlling water pollution, but it can be also successfully utilized for evaluating the HMs pollution of soils in the environment. RI is defined as the sum of Er. Hakanson [15] and Yang et al. [32] showed that RI could express HMs toxicities in urban

Table 1 Quantification of the contamination factor (CF), ecological risk index (Er), and potential ecological risk index (RI)

Contamination factor (CF)		Ecological risk index (Er)		Potential ecological risk index (RI)	
CF < 1	Low	Er ≤ 40	Low	RI ≤ 150	Low
1 ≤ CF > 3	Moderate	40 ≤ Er ≤ 80	Moderate	150 ≤ RI ≤ 300	Moderate
3 ≤ CF > 6	Considerable	80 ≤ Er ≤ 160	Considerable	300 ≤ RI ≤ 600	High
CF > 6	Very high	160 ≤ Er ≤ 320	High	RI ≥ 150	Very high
–	–	Er ≥ 40	Very high	–	–

Table 2 Average, maximum, and minimum concentrations of the HMs (Pb, Cu, Co, Cd, and Cr) in the urban field soils in the first (Isfahan), second (Falavarjan), and third (Natanz, Golpayegan, and Feridan) regions (mg kg^{-1})

Region	Index	Concentrations of the HMs in the urban field soils (mg kg^{-1})				
		Pb	Cu	Co	Cd	Cr
First region	Average	81.53	44.80	3.21	2.20	3.48
	Max.	127.37	94.18	7.23	4.01	6.94
	Min.	37.55	12.56	1.01	1.02	1.68
Second region	Average	72.30	38.03	2.08	1.79	2.93
	Max.	112.65	93.17	6.42	2.43	4.61
	Min.	27.52	12.38	1.12	0.97	1.63
Third region	Average	14.57	14.75	1.48	0.63	1.27
	Max.	54.23	38.23	2.92	0.79	1.92
	Min.	3.08	4.42	0.07	0.43	0.79
Recommended amount	Average	75	200	50	5	2

field soils and their environmental responses. Several studies have shown that HMs can cause various types of health hazards [26, 30]. To describe the ER and RI values, the terminology depicted in Table 1 was employed. The required multivariate analysis was also performed through PCA by using the PAST (PAleontological STatistics) software [13, 16].

3 Results and discussion

3.1 HMs concentrations in the soil samples

The descriptive statistics for the average, maximum and minimum amounts of HMs concentrated and polluted the urban field soils in three regions of study presented in Table 2. The results revealed the highest average concentrations of Pb (81.53 mg kg^{-1}) and Cr (3.48 mg kg^{-1}) in the first region and Cr (2.93 mg kg^{-1}) in the second region. The highest concentrations of Pb and Cr, respectively, in the first (127.37 and 6.94 mg kg^{-1}) and second (112.65 and 4.61 mg kg^{-1}) regions were higher than their amounts (75 and 2 mg kg^{-1}, respectively) recommended by Iran's Environmental Protection Agency (IEPA) [2]. The highest concentrations of the metals in the soils of the studied regions were ranked in the following decreasing order: Pb > Cu > Co > Cr > Cd (Table 4). Pb concentrations
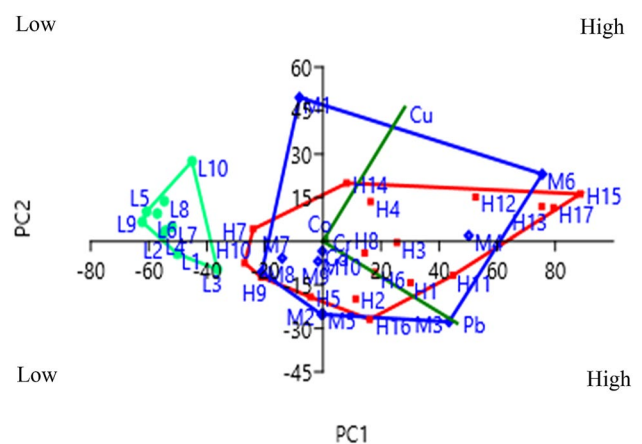

Fig. 2 Biplot of PC1 (87%) and PC2 (12.8%) representing the data of the urban field soils samples using PCA model Pb, Cu, Co, Cd, and Cr are the variables used in the PCA model symbolizing the total contents of the HMs in the soil samples

were higher in the urban soil samples compared to those of more distant soils, while decreasing by distance from the centers of distribution. In other words, the pollution levels of the HMs in the soil samples collected from the urban farms were high, while reducing to medium and low levels at farther distances (Fig. 2). The urban field soils and vegetables polluted by the HMs could be

influenced by different sources, as well as by their own structures and agroecosystem functions [19, 23].

The analytical data of the HMs in the soil samples were logarithmically standardized and processed through the PAST software based on the matrix of variance–covariance and the eigenvalue analyses of coefficients (Fig. 2). The PCA biplots of PC1 and PC2 (distributions through longitudinal and transverse diameters, respectively) clearly segregated the regions (H and M) of anthropogenic soil pollution from the low-pollution region (L). The model, built on the HMs-polluted vegetables, was able to compare the pollution dispositions in the biplot areas, but could not make a clear distinction between the two H and M regions. The pollution of the HMs in the first and second regions was overlapped (Fig. 2). The probability of HMs pollution in the urban soils of the mentioned closely related regions supported the idea that pollution does not clearly remain in a one region [4, 31]. The HMs pollution in the different soil samples revealed some variations and suggested the natural variability and varied origins of the mentioned metals. Different rates of HMs tend to accumulate in the soils of urban areas. The related pollution directly influences on economic development and human health by damaging soil quality, function, and structure. Soil HMs in the environment are comparatively stable, making them to be difficultly eliminated from soil processes. Therefore, assessment and monitoring of environmental soil quality play a vital role in restoring damaged ecosystems and developing a scientific basis for urban farming health.

3.2 Transfer factor (TF) evaluation

TF represented the HMs transfers from the urban soil farmlands to the vegetables. The descriptive statistics of the TF results, such as average, maximum and minimum values of total data of HMs transferred, means of the groups of vegetables, and means of the regions in terms of the measured HMs in the urban field soils and the vegetables grown in them are presented in Table 3. The results showed that the TF values of Pb from the soils to the vegetables in the three studied regions were lower than the recommended amounts. The TF values of Cr (0.56 mg kg^{-1}), Cd (0.23 mg kg^{-1}), and Co (0.30 mg kg^{-1}) from the soils to the tubers showed to be higher than those to the leafy and fruity vegetables, while the highest TF (0.07 mg kg^{-1}) to the leafy vegetables was related to Cu. In this study, the highest TF to the edible parts of the vegetables belonged to Cd (0.30 mg kg^{-1}) and Co (0.30 mg kg^{-1}) in the first and Cr (0.42 mg kg^{-1}) in the third regions. Therefore, there was an increasing possibility of unwanted and unknown hazards and diseases triggered by the consumptions of the HMs-polluted vegetables by the consumers of the society. For this reason, monitoring programs for HMs pollution

Table 3 Average, maximum, and minimum amounts of the vegetable groups (fruity, leafy, and tuber vegetables) and TF means of the HMs (Pb, Cu, Co, Cd, and Cr) in the urban field soils in the first (Isfahan), second (Falavarjan), and third (Natanz, Golpayegan, and Feridan) regions (mg kg^{-1})

Index	Transfer factor (TF) of heavy metals (mg kg^{-1})				
	Pb	Cu	Co	Cd	Cr
Average	0.010	0.04	0.24	0.18	0.38
Max.	0.018	0.08	0.44	0.43	0.70
Min.	0.002	0.01	0.06	0.04	0.11
Fruity vegetable	0.01	0.07	0.24	0.18	0.25
Leafy vegetable	0.01	0.03	0.19	0.14	0.33
Tuber vegetable	0.01	0.04	0.30	0.23	0.56
First region	0.01	0.05	0.30	0.30	0.38
Second region	0.01	0.05	0.22	0.18	0.35
Third region	0.001	0.04	0.20	0.09	0.42

in the mentioned regions would be quite incumbent. The average TF values of the HMs were in the following order: Cr > Co > C d > Cu > Pb (Table 4). The higher TF values of the HMs in the urban vegetables could be attributed to some characteristics of the used resources as the absorptions and translocations of metals in plants depend on the agrochemical traits of water, soil, and air [29]. This could be more clearly explained by the homeostasis of the studied vegetables, each of which would limit excessive accumulations of HMs in its tissue via the specific–specific mechanism in response to its growth conditions.

Each variable (HMs) with its particular load shows how well it is taken into account by the components of the TF model, which reflects how much each HMs contributes to the significant variation (or correlation) of the data, thus interpreting the relationship of the HMs. Each sample would bear a score along with the components of the TF model representing variance of the different samples (Table 5). This variance is applied to detect sample patterns, groupings, similarities, and differences. Here, the effects of the HMs variables were studied after indicating the variances and loading the principle components, including PC1 and PC2 (61.6 and 27.7% of variances, respectively). The analysis process of the principle components and eigenvalue percentages are shown in the scree plot. These figures further depict that Cr in PC1 and Cd and Co in PC2 are the most effective variables in increasing TF values with no correlations [13].

A better grouping of Cr, Cd, and Co in the positive quarters of PC1 and PC2 in the biplot (Fig. 3) resulted in higher TF risk of onion (H5, M5 and L5), potato (H6, M6 and L6), and basil (H3, M3 and L3) consumptions in all the studied regions. Tomato (H2, M2 and L2) in the center of the biplot, cucumber (H1, M1 and L1) in the negative quarter of PC1

Table 4 CF assessments of the HMs (Pb, Cu, Co, Cd, and Cr) in the urban field soils in the first (Isfahan), second (Falavarjan), and third (Natanz, Golpayegan, and Feridan) regions

Region	City	Contamination Factor (CF)				
		Pb	Cu	Co	Cd	Cr
First region	Isfahan	4.53	3.39	0.46	8.80	12.46
Second region	Falavarjan	4.02	2.88	0.40	7.16	10.48
	Natanz	0.43	1.33	0.25	2.73	5.52
Third region	Golpayegan	0.78	0.75	0.22	2.46	4.56
	Feridan	1.59	1.27	0.15	2.38	3.26

Table 5 Er and RI assessments of the HMs (Pb, Cu, Co, Cd, and Cr) in the urban field soils in the first (Isfahan), second (Falavarjan), and third (Natanz, Golpayegan, and Feridan) regions

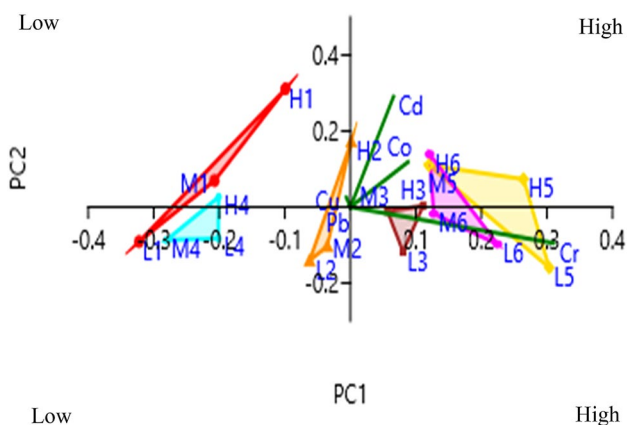| Region	City	Ecological risk index (Er)					Potential ecological risk index (RI)
		Pb	Cu	Co	Cd	Cr	
First region	Isfahan	22.65	16.97	2.29	264.04	24.92	330.88
Second region	Falavarjan	20.08	14.41	2.01	214.94	20.95	272.40
	Natanz	2.13	6.66	1.26	81.93	11.05	103.03
Third region	Golpayegan	3.89	3.77	1.08	73.86	9.13	91.72
	Feridan	7.95	6.34	0.76	71.28	6.52	92.86

Fig. 3 Biplot of PC1 (61.6%) and PC2 (27.7%) for the soil and vegetable data using PCA model Pb, Cu, Co, Cd, and Cr are the variables used in the PCA model symbolizing the TF of the HMs in the first (H), second (M), and third (L) regions

and PC2, and lettuce (H4, M4 and L4) in the positive quarter of PC2 had lower TF risk of the HMs (Fig. 3). This meant that some vegetables from the study regions had the highest TF risk induced by the pollution. Those vegetables were well separated from the other species. Some vegetables grown in the polluted H and M regions were associated with greater TF hazards, particularly due to such toxic metals as Cr, Cd, and Co, thus indicating their consumptions could impose significant risks on human health [9, 10].

3.3 CF, Er, and RI assessments in the urban field soils

According to groups of Hakanson Index in Table 1, the highest amounts of CF of Cr in the first (12.46) and second (10.11) regions were at very high pollution levels. Cd pollution in the first (8.80) and second (7.16) regions was also at a very high level of pollution (Table 5). In all the three regions, CF values of Co were at low-pollution levels ranging between 0.15 and 0.46. Calculations of the CF values further demonstrated that Pb and Cu were at high levels of soil pollution. In the third studied regions, CF ranged between low and high levels. The Er of the HMs in the first region were ranked as Cr > Cd > Pb > Cu > Co (Table 5). The results revealed the highest CF values of the urban field soils, which might be due to the urbanization activities, such as traffic and transports, as well as the existence of industrial activities near the Isfahan City [24].

RI is based on the comprehensive considerations of ecological and environmental effects and toxicities of HMs in soils, which also provide a quantitative approach to directly isolating the extents of potential hazards when associated with Hakanson Index. However, one drawback of this method is that it implies a great degree of subjectivity and overlooks the combined antagonism of different HMs and their weighing roles. The assessment results of the ecological hazards are displayed in Table 5. The highest Er of Cd in the first (264.0) and second (214.9) regions could be categorized in the high-risk class, indicating a possible increase in the total Er. The lowest Er of all of the five HMs was observed in the third region (Table 5). The Er of the HMs in the first region were ranked as Cd > Cr > Pb > Cu > Co. Since Co has a

comparatively less toxic response factor and plays a vital role in plant nutrition, it represents the least ecological hazard [28].

Er demonstrates the risks of various pollutants and pervasive impacts of some of them appearing in the ecosystem. As the comprehensive of RI measures of all the five HMs and their pollution degrees, the RI of the HMs in the soil samples of the first region was 330.8 indicating a high-risk level. In the second region, RI displayed a moderate risk (272.4). The RI of Cd in most of the soil samples appeared in the high-risk class, showing the two regions to be prone to enhance Er (Table 5). The RI of the field soils in Natanz (103.0), Golpayegan (91.7), and Feridan (92.8) was determined to be in the low-risk class. Among the five HMs, Cd pollution with an index of 300–600 based on Hakanson index could cause a serious ecological risk concern (Tables 3 and 5). The means of the RI for the agricultural land, rangeland, and urban land uses were 114.09, 122.08, and 339.62, respectively. Among all, the urban land use showed the highest RI for its inhabitants [1, 27].

The results revealed the highest pollution of Pb and Cr in the field soils of the first (127.37 and 6.94 mg kg^{-1}) and second (112.65 and 4.61 mg kg^{-1}) regions, respectively. Both metals depicted higher amounts than those recommended by IEPA (Table 3). The RI indicated different assessment results as Pb and Cr in the soil samples showed to have few ecological hazards despite bearing the highest pollution compared with Cd risk. The RI was able to highlight the role of the harm Cd could have in the soils and ecosystems as demonstrated by its toxic response factor (Cd = 30). Cd has been shown to have the highest RI and be the most hazardous metal in soils and vegetables. In its lengthy history of accumulation, Cd may demonstrate great Er for crops and soil ecosystems, as well as for human health [20, 30].

Er evaluation would be a starting point for prospecting the future of soil contaminations and production fields. It would be more efficient for managers and planners to take benefits of more appropriate decision-making tools and options in such regions by prioritizing RI values representing pollution classes for districts and by determining their distribution degrees in cities. In this investigation, it seemed that the HMs originating from the anthropogenic and industrial activities and city sources and introducing their pollution to the soils in the urban vegetable fields of Isfahan could elevate the Er. This would be an alarming sign for the pollution trends relevant to industrial developments, thus urging managers for serious attempts in favor of environmental health conservation [14, 24]. Further research should be conducted to consider any possible ways of monitoring similar sites and reducing the pertinent hazards.

4 Conclusion

The highest concentrations of Pb and Cr in the first (127.37 and 6.94 mg kg^{-1}) and second (112.65 and 4.61 mg kg^{-1}) regions, respectively, were higher than the amounts recommended by IEPA. The TFs of Cr (0.56 mg kg^{-1}), Cd (0.23 mg kg^{-1}), and Co (0.30 mg kg^{-1}) from the soils to the tubers were higher than those to the leafy and fruity vegetables. Also, the highest TF of Cu (0.07 mg kg^{-1}) to the leafy vegetables was observed. The RI of the HMs in the soil samples of the first region was 330.8, which could be classified in the high-risk class. In the second region, the RI of the soil pollution was 272.4 (moderate-risk class), while that of Cd in most of the soil samples would put them in the high-risk class, indicating the two regions to be prone to enhance their RI. The assessment results obtained from the indices revealed similar levels of the HMs pollution in the urban farms. Moreover, the urban regions were polluted with the HMs to varying degrees compared to the non-urban soil fields. Now, we would inevitably face the phenomenon of the boiled frog principle or the gradual and destructive effects of pollutants in the human body and the environment.

To the best of our knowledge, no similar studies on the RI assessments of soils in agricultural and urban areas have been carried out anywhere in the world so far and thus, this research could be a reference for future investigations in other similar areas. Further research should be conducted to solve the above-mentioned problems and find any possible ways for monitoring similar sites and reducing the associated risks.

Compliance with ethical standards

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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