



Pollution, human health risk assessment and spatial distribution of toxic metals in urban soil of Yazd City, Iran

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Abstract Heavy metal pollution significantly reduces the quality of the environment and threatens human health, especially in industrial cities. This study investigated toxic metals concentrations, pollution levels and human health risks assessment of urban soils in Yazd City, as an industrial city in center of Iran. Soil surface samples (0–10 cm) were collected from 30 points in the area for geochemical analysis. The concentrations of heavy metals were determined using an inductively coupled plasma mass spectrometry (ICP-MS). The values of the mean concentrations of toxic metals (mg kg^{-1}) in the urban soils decrease in the order of Zn (83.9) > Pb (34.5) > Cr (32.6) > Cu (23.5) > Ni (23.4) > As (5.86) > Co (4.86) > Cd (0.27). The mean concentration of Zn, Pb, As and Cd elements was higher than the background and the crust values. A pollution assessment by Geo-accumulation Index (I_{geo}), Pollution Index (PI), Contamination Degree (C_D), the Integrated Pollution Index (IPI), the Pollution Load Index (PLI) and Integrated Nemerow Pollution Index (INPI) showed that As, Cd and Pb were moderately enriched and the study area polluted considerably by these toxic metals. Based on

PI results, 88.9% of the urban soil samples highly polluted by As. Overall, the quality of the urban soil in Yazd City is clearly affected by toxic metals. Due to the prevailing wind direction, the route of the north–south highway of Iran and the population density and traffic of the northwestern and southern areas of the study area were found the highest level of pollution indicators (IPI > 1.8; LPI > 1.3; C_D > 15 and INPI > 4.3). The results of Pearson correlation analysis indicated that all pollution evaluation indicators were influenced by As and Cu, and showed high significant correlation with these two elements, while neither of them had a significant relationship with Pb and was found also a weak link statistically with Cd. Health risk assessment of toxic metals has been performed in both carcinogenic and non-carcinogenic sectors. The results indicate that oral intake is the main pathway that toxic metals can harm human health for both the child and adults. The carcinogenic risks (RI) of adults and child by toxic metals were as follows: Ni > Pb > Cr > As > Cd. Hazard quotients (HQ) and hazard index (HI) values for child also were higher than these for adults. Generally, the results demonstrated that the potential carcinogenic health risks for adults of toxic metals were in an acceptable range in study area, whereas for Cr, Ni and Pb with $RI > 10^{-4}$, the risk of cancer in child probably increases.

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Introduction

One of the most important problems threatening the health and food security of a society is environmental pollution and heavy metals production resources (Cai et al. 2012). The presence of heavy elements in soils depends on the natural evolution of the parent material or is due to human-source contamination. Soil contamination with heavy metals such as Cd, Cu, Cr, Pb, Ni and Zn in aridity ecosystems is known as a serious environmental health crisis. Soil is a source of nutrition for the biotic community and a buffer zone for environmental pollutants, and long-term entry of heavy metals into the soil can directly reduce soil buffering capacity, which adversely affects soil ecological performance due to inhibition of soil microbial activity (Tepanosyan et al. 2016; Pan et al. 2016; Wang et al. 2017). Due to their non-biodegradability and long detention time, these heavy metals tend to enter food chains and eventually accumulate in plant, animal and human tissues (Namuhani and Cyrus 2015). It can accumulate in agricultural soils, leading to a gradual decrease in soil fertility, degradation of soil biology and reduced crop productivity (Zhao et al. 2014; Xu et al. 2017). Excessive consumption of heavy metals also causes acute and chronic poisoning such as damage to systems central nervous system, blood, lungs, kidneys, liver and even death (Wei et al. 2015). Over the past few decades, exposure to soil which enriched with heavy metals has been widely examined in terms of pollution and their health problems. These investigations have been done either on urban soils (Imperato et al. 2003; Cai et al. 2012; Guo et al. 2012; Luo et al. 2015; Pan et al. 2018; Yang et al. 2020; Li et al. 2020), lake sediments (Bai et al. 2011; Liu et al. 2018; Bahloul et al. 2018; Xu et al. 2020), road dust (Charlesworth et al. 2003; Soltani et al. 2015; Dehghani et al. 2017; Xiao et al. 2019; Cui et al. 2020), stormwater runoff (Brown and Peake 2006), agricultural soils (Agarwal et al. 2009; Baltas et al. 2020; Doabi et al. 2018) or in soils under different land use (Ma et al. 2020). Due to the fact that urban soils are mainly affected by the rapid expansion

of urbanization, human activities, high city traffic and increase of industrial and agricultural activities near cities, this study focuses on pollution, health risk assessment and pollution indicators from Yazd urban soil in the center of Iran.

Investigating the ratio of heavy metals from human activities to the concentration of metals derived from natural sources, in the form of enrichment indicators and pollution factors, is one of the most common solutions for soil contaminants investigation (Franco et al., 2009). Higher than average background indicates human input sources in the region. Because of its possible damage to human health and the quality of the environment in urban areas, indicators such as potential Ecological Risk Index (RI), Contamination factor (C_f), potential Ecological Risk factor (Er), Pollution Load Index (PLI), Enrichment factor (EF), Geoaccumulation Index (I_{geo}), Contamination Degree (C_d), Integrated pollution index (IPI), Integrated Nemerow Pollution Index (INPI), Pollution Index (PI), hazard index (HI), carcinogenic risk (RI) and hazard quotient (HQ) for health risk assessment, etc., have been calculated by some researchers broadly to assess soil contamination with heavy metals in recent decades. For example, Bartas et al. (2020) to investigate the pollution status and spatial distribution of heavy metals such as Cr, Fe, Ni, Cu, Zn, As and Pb in soil around Sinop Province, Turkey, metal pollution parameters such as EF, I_{geo} , CF, PLI and the human health risks model introduced by USEPA were applied. Their results suggested that child are slightly more sensitive to the non-carcinogenic and carcinogenic effects of metals than adults and the non-carcinogenic risk for child has not an acceptable risk to human health, but it was for adults. Yang et al. (2020) were used contamination factor C_f , PLI, RI and potential ecological risk factor to assess the pollution degree of heavy metals in 0–10 and 10–20 cm soil depth from Linfen in China and showed the pollution from heavy metal is considerable; almost 50% of the study area were polluted and conclude that there was not observed significant differences between topsoil and subsoil samples and the concentration of toxic elements was higher than background values. Xiao et al. (2019) to determine comprehensively the contamination level and human health risk by trace elements in road dust of city Anshan, Northeast China, calculated RI, PI, I_{geo} , RI and HI. The I_{geo} and PI values of heavy metals were reduced in the following

order: Cd > Sb > Zn > Fe > Pb > Cu > Cr > Sn > Mn > Ni. Also, the HI showed a probability of non-carcinogenic risk for child in urban areas compared to adults.

Due to the greater sensitivity of children compared to adults to possible damage caused by heavy metals, in urban industrial areas such as Yazd, which has the main industries of tiles, ceramics and steel, it is necessary to determine the concentration and level of contamination of toxic metals and also to identify the hot spots of heavy metals in the study area. For this purpose, in the present study, the pollution assessment indexes such as I_{geo} , PI, LPI, IPI, C_D , INPI and hazard index (HI), carcinogenic risk (RI) and hazard quotient (HQ) for health risk assessment indicators have been calculated to evaluate the degree of contamination and health risk assessment in both groups of child and adults in the urban soil of Yazd in central Iran. Also, Geographical Information System (GIS), inverse distance weighting method (IDW) was applied to zone the concentration of heavy metals or indexes in study area. The results of this study will quite suitable for planning, risk assessment, decision making by environmental managers and the policy makers of the municipality in this area.

Materials and methods

Study area

Yazd Province with an area of 131,600 Km² located between 52° and 55' to 56° and 37' east longitude and 29° and 52' to 33° and 27' north latitude in the center of Iran. Yazd Province is one of the driest and industrial regions in Iran, where the tile, ceramic, steel, textile industries and mining operations are developed significantly in recent years. Due to the natural location and geomorphological characteristics of the province, the precipitation varies from less than 50 mm in desert areas to more than 450 mm. The main part of the province is a dry and semi-arid climate, which is characterized by low and irregular rainfall and humidity, extreme temperature fluctuations, high evaporation and hot and long periods (Sharifi et al. 2020). The Yazd City is the capital of the province with a population of 656,474. Due to the industrialization of the city in the past twenty years, many immigrants from around Iran have migrated to this

city, which has led to rapid urbanization growth. Yazd Industrial Town and Iran Alloy Steel Company are located in the west of the city with a distance of about 10 and 30 km from the city center and in the direction of prevailing winds. On the other hand, this city is located on the main north–south highway of Iran, which has high road traffic every year (Fig. 1). Considering the mentioned points, the concentration of toxic metals in the area is significantly predicted, and it seems necessary to study the concentration of these elements in the soil of urban areas and to examine the degree of their pollution.

Soil sampling

In winter 2019, 30 samples of topsoil (weighing approximately 500 g) were collected from different places with suitable dispersion in Yazd City from a depth of 0–10 cm. Soil samples were collected close to airport, terminal, highways, as well as busy vehicle areas in the city center (Soltani et al. 2015). Each sample was collected by gentle sweeping of an area of about 400 cm² using a hand-held plastic broom and transferred to a clean, self-packed polyethylene bag. In the laboratory, the samples are first dried at room temperature and then mechanically passed through a 2-mm sieve to separate waste particles and large sizes and plant leaves. The four-acid method has been used to digest soil samples in the study area. In this method, 0.25 g of soil samples passed through a mesh of 200, dried and prepared with D4698-92 standard (Pietilä et al. 2015; Amr et al. 2016) was heated in a mixture of acids HF-HNO₃-HClO₄ and then the residual material is dissolved in HCL. The concentrations of heavy metals of the solution digested in 4 acids (As, Cd, Co, Cr, Cu, Ni, Pb and Zn) were determined using an inductively coupled plasma mass spectrometry (ICP-MS, method, Perkin-Elmer, USA). Each soil sample was analyzed with three times, and the mean values were obtained.

Statistical analysis

Statistically significant differences between the mean of the toxic elements concentrations in the urban soil are tested using a one-way analysis of variance (ANOVA) followed by a post hoc Duncan's test in SPSS package version 16.0 for Windows. Pearson's correlation analysis using a 2-tailed test of significance

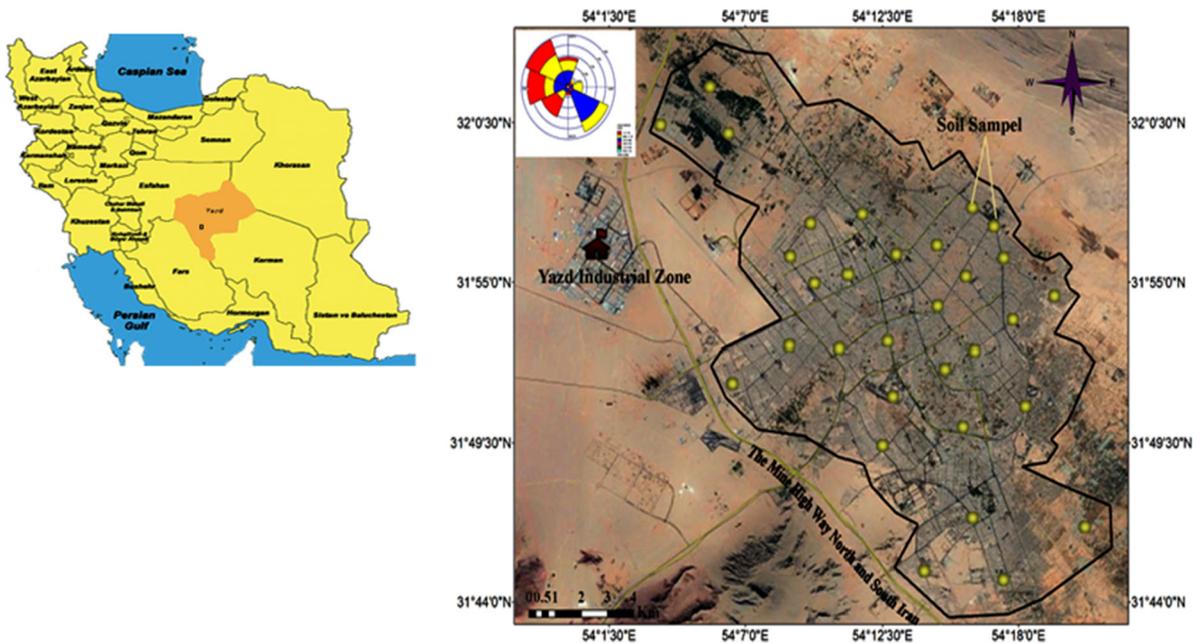


Fig. 1 Location of sampling points and Yazd City in Iran

was performed to determine relationships among the considered variables and whether toxic metals may be from the similar source. The grouping of toxic metals in urban soil was implemented by hierarchical cluster analysis (HCA), Ward's method with Euclidean distances. Also, Geographical Information System (GIS), inverse distance weighting method (IDW) was used to distribute spatially the concentration of heavy metals or indexes in study area.

Health risk assessment

Health risk assessment of toxic metals is a multi-step process that has been performed in both carcinogenic and non-carcinogenic sectors based on the method of health risk assessment provided by the United States Environmental Protection Agency (USEPA). In the study of both carcinogenic and non-carcinogenic risks, human exposure to metals from all three pathways of ingestion, inhalation and dermal contact was considered and the daily intake dose (ADD) in each of the pathways was calculated by using Eqs. (1–3):

$$ADD_{\text{ing}} = C \times \frac{\text{IngR} \times \text{EF} \times \text{ED}}{\text{BW} \times \text{AT}} \times 10^{-6} \quad (1)$$

$$ADD_{\text{inh}} = C \times \frac{\text{InhR} \times \text{EF} \times \text{ED}}{\text{PEF} \times \text{BW} \times \text{AT}} \quad (2)$$

$$ADD_{\text{dermal}} = C \times \frac{\text{SL} \times \text{SA} \times \text{ABS} \times \text{EF} \times \text{ED}}{\text{BW} \times \text{AT}} \times 10^{-6} \quad (3)$$

These three ways of exposure are often applied to evaluate the risk of metal exposure to human in urban areas (Pan et al. 2018). For the evaluation of the human health risk of urban soils polluted by toxic metals, the carcinogenic risk (RI), hazard index (HI) and hazard quotient (HQ) methods were used (Wei et al. 2015). The HQ was calculated by dividing the ADD for each exposure pathway by the reference dose (a metal's maximum daily dose from a special exposure route by attention to sensitive individuals during a life through both child and adults) using Eqs. (4). The HI is the sum of the HQ values, which was calculated by using Eqs. (5). If HQ and HI are less than 1, it will not be found adverse health effects, while HQ and HI > 1 indicate undesirable effects on human health (USEPA, 2001). The carcinogenic risk to health can be ignored if $RI < 10^{-6}$, whereas for $RI > 10^{-4}$ the risk of cancer in humans probably increases and values between 10^{-4} and 10^{-6} will lead to acceptable risk to human health (Hu et al. 2011; Xiao et al. 2019).

$$HQ_i = \frac{ADD_i}{RfD_i} \tag{4}$$

$$HI = \sum_1^i HQ_i = HQ_{ing} + HQ_{inh} + HQ_{dermal} \tag{5}$$

$$Risk(RI) = \sum ADD_i \times SF_i \tag{6}$$

where C is the concentration of toxic metals urban soil in Eq. (1)–(3). InhR is the inhalation rate. EF is the exposure frequency. ED is the exposure duration. SA is the exposed skin area. SL is the skin adherence factor. BW is the human body weight. ABS is the dermal absorption factor (unitless). PEF is the particle emission factor. AT is the average exposure time. RfD is the daily intake reference dose (Liu et al. 2018). SF is the development probability of cancer per unit exposure level of mg kg⁻¹ day. The values of those parameters are summarized in Table 1.

Pollution indexes

Heavy element pollution indexes are divided into two main groups. The first category of individual indicators is for assessing an element pollution. Some of them include the Geo-accumulation Index (I_{geo}) and the Pollution Index (PI). The second category

examines the pollution of more than one element and is integrated indicators. These include the Contamination Degree (C_D), the Integrated Pollution Index (IPI), the Pollution Load Index (PLI) and Integrated Nemerow Pollution Index (INPI). In the present study, these indicators have been calculated and examined to evaluate the level of contamination of toxic metals in urban soils from Yazd City.

Geo-accumulation Index (I_{geo})

The I_{geo} is calculated using Eq. (7) (Muller 1969):

$$I_{geo} = \log_2 \left[\frac{C_n}{1.5B_n} \right] \tag{7}$$

where C_n is the measured concentration of the element in the soil sample and B_n is the background concentration (soil or earth crust) of the same element (Wei et al. 2009; Chen et al. 2005). The Geo-accumulation Index (I_{geo}) is assessed by dividing it into 7 categories as follows: class 1, unpolluted (I_{geo} ≤ 0); class 2, unpolluted to moderately polluted (0 < I_{geo} < 1); class 3, moderately polluted (1 < I_{geo} < 2); class 4, moderately to highly polluted (2 < I_{geo} < 3); class 5, highly polluted (3 < I_{geo} < 4); class 6, highly to very highly polluted (4 < I_{geo} < 5); and class 7, very highly polluted (I_{geo} ≥ 5) (Gueguen et al. 2012).

Table 1 Parameters of health risk assessment

Exposure parameters	Unit	Child	Adults	Reference			
IngR (ingestion rate)	mg·day ⁻¹	200	100	USEPA (2001)			
InhR (inhalation rate)	m ³ ·day ⁻¹	7.63	12.8	Xiao et al. (2019)			
EF (exposure frequency)	day·year ⁻¹	350	350	Xiao et al. (2019)			
ED (exposure duration)	years	6	24	USEPA (2001)			
BW (body weight)	Kg	15	55.9	Xiao et al. (2019)			
AF (skin adherence factor)	mg·cm ⁻² ·day ⁻¹	0.2	0.07	USEPA (2001)			
SA (exposed skin area)	cm ²	1600	4350	Xiao et al. (2019)			
PEF (particle emission factor)	m ³ ·kg ⁻¹	1.36E + 09	1.36E + 09	USEPA (2001)			
ABF (dermal absorption factor)	Unitless	0.001	0.001	USEPA (2001)			
AT (the average exposure time)	days	356*ED	356* ED	USEPA (1989)			
Metals	As	Cd	Cr	Cu	Ni	Pb	Zn
R _i D _{ing} (mg kg ⁻¹ day ⁻¹)	3.00E-04	1.00E-03	3.00E-03	4.00E-02	2.00E-02	3.50E-03	3.00E-01
R _i D _{inh} (mg kg ⁻¹ day ⁻¹)	3.10E-04	1.00E-03	2.80E-05	4.02E-02	2.06E-02	3.52E-03	3.00E-01
R _i D _{derm} (mg kg ⁻¹ day ⁻¹)	1.23E-04	1.00E-05	6.00E-05	1.20E-02	5.40E-03	5.25E-04	6.00E-02
SF (mg kg ⁻¹ day ⁻¹)	1.51E-01	6.30E-01	4.20E-01	–	8.40E-01	4.20E-02	–

Pollution index (PI)

The PI was calculated (Chen et al. 2005; Xiao et al. 2015):

$$PI = \frac{C_n}{B_n} \quad (8)$$

According to the value of PI, pollution index was calculated and divided into three classes as either low ($PI \leq 1$), middle ($1 < PI < 3$), or high ($PI \geq 3$).

Pollution Load Index (PLI)

To investigate a sample's total contamination status was calculated the Pollution Load Index (PLI) by Eq. (9) (Chen et al. 2015):

$$PLI = (PI_1 \times PI_2 \times PI_3 \times \dots \times PI_n)^{\frac{1}{n}} \quad (9)$$

where n is the number of toxic elements analyzed. According to Chakravarty and Patgiri (2009) scale, if $PLI > 1$, the study area is contaminated by metals, and if $PLI < 1$, there is no contamination by metals in the area.

Integrated pollution index (IPI)

The IPI is defined as the average amount of heavy metal PI (Chen et al. 2005) and then was categorized as low ($IPI \leq 1$), middle ($1 < IPI < 2$), or high ($IPI \geq 2$).

$$IPI = \frac{\sum_{i=1}^n PI}{n} \quad (10)$$

Contamination Degree (C_D)

The Contamination Degree (C_D) includes the total PI for each element (Nazzal et al. 2013) and is calculated from the following equation, and four classes of pollution are defined based on Contamination Degree (C_D) as follows: class 1, low polluted ($C_D < 5$); class 2, moderately polluted ($5 \leq C_D < 10$); class 3, considerably polluted ($10 \leq C_D < 20$); and class 4, highly polluted ($C_D \geq 20$).

$$C_D = \sum_{i=1}^n PI_i \quad (11)$$

Integrated Nemerow Pollution Index (INPI)

Considering all the toxic elements in the soil, the Integrated Nemerow Pollution Index (INPI) can be calculated based on Eq. (12) for each sampling station (Niu et al. 2020).

$$INPI = \sqrt{(PI_{ave})^2 + \frac{(PI_{max})^2}{2}} \quad (12)$$

where PI_{ave} and PI_{max} are the mean value of the PI for all the toxic elements and the maximum value of PI among these 8 toxic elements. The level of pollution based on Integrated Nemerow Pollution Index (INPI) classified into the 5 pollution classes as follows: class 1, unpolluted ($INPI < 0.7$); class 2, moderately unpolluted ($0.7 \leq INPI < 1$); class 3, low polluted ($1 \leq INPI < 2$), class 4, moderately polluted ($2 \leq INPI < 3$), and class 4, highly polluted ($INPI \geq 3$).

Results and discussion

Toxic elements concentration

To compare the heavy metals contents in urban soil of Yazd City with reported values for other countries and cities also for background and crust values in previous studies, Table 2 is presented. The values of the mean concentrations of heavy metals ($mg\ kg^{-1}$) in the urban soils decrease in the order of $Zn (83.9) > Pb (34.5) > Cr (32.6) > Cu (23.5) > Ni (23.4) > As (5.86) > Co (4.86) > Cd (0.27)$. The mean concentration of Zn, Pb, As and Cd elements was higher than the background and crust values, while those of Ni and Cu elements were found more than the background values but less than the crust value. The elements of Cr and Co were also obtained less than both background and crust concentrations. Overall, the mean concentration of all toxic elements in Yazd is lower compared to its value in other cities except Kerman in Iran (Sistani et al. (2017), except for Pb in Damascus, Syria (Moller et al. (2005), nickel in Guangzhou, China (Cai et al. (2012), Cu in Linfen, China, (Yang et al. (2020), Cr in Naples, Italy (Imperatoa et al. (2003), and Cd in Guangzhou (Cai et al. (2012) and Varamin (Babaakbari et al. (2019) in Iran and As in Tehran (Dehghani et al. (2017), capital of Iran. Zhou et al. (2014) reported that in Huanghuai Plain, China, the amount of

Table 2 Mean concentration of toxic elements (mg kg⁻¹) in urban soil in various sites of countries and cities

City	As	Cd	Cr	Co	Cu	Ni	Pb	Zn	References
Tehran (Iran)	3.9	0.5	41.1	NA	74.0	39.4	64.5	277	Dehghani et al. (2017)
Kerman (Iran)	NA	0.038	3.54	NA	NA	9.98	20.86	54.38	Sistani et al. (2017)
Varamin (Iran)	NA	0.092	73.1	4.9	42.06	25.02	52.3	146	Babaakbari et al. (2019)
Linfen (China)	15.20	NA	40.46	NA	14.99	36.24	28.12	91.41	Yang et al. (2020)
Guangzhou (China)	NA	0.23	22.4	NA	41.6	11.1	65.4	277	Cai et al. (2012)
Naples (Italy)	NA	NA	11	NA	74	NA	262	251	Imperatoa et al. (2003)
Yibin (China)	10.55	NA	NA	NA	56.35	NA	61.23	138.88	Guo et al. (2012)
Damascus (Syria)	NA	NA	57	13	34	39	17	103	Moller et al. (2005)
Beijing (China)	NA	0.59	NA	NA	83	NA	62	280	Hou et al. (2019)
Datong (China)	NA	9.46	NA	NA	74.67	NA	68.16	401.2	Hou et al., (2019)
Nanjing (China)	NA	4.37	NA	NA	120.8	NA	82.65	302.7	Hou et al. (2019)
Yazd (Iran)	5.86	0.27	32.61	4.86	23.5	23.4	34.5	83.9	This study
Background values	4.7	1.1	42	6.9	14	18	25	62	Alloway (2010)
Crust value	1.5	0.098	83	17	25	44	17	71	McLennan (2001)

heavy metals is similar to or slightly higher than the background values in this area, with the exception of Cd, which averages almost twice the background value. Wang et al. (2017) stated that the mean concentrations of heavy metals in a typical industrial area in Sichuan were lower than the national threshold values, but were slightly higher than their corresponding background values. The spatial distribution of the concentration of 8 toxic elements in the urban soil of Yazd City is illustrated in Fig. 2. As the results shows, the spatial variability pattern of Co, Cr, and Ni metals is similar, and the highest values of these toxic elements are found in the northern, northwestern, and eastern parts of the study area. This could be a reason for the possible similarity source of these elements in surface soil (Norouzi et al. 2017). Since the amount of these elements is less than the values of background and crust, they probably have a natural and geogenic source (Qing et al., 2015; Yang et al. 2020). The elements of Cu, Zn, and Pb follow a similar pattern and are most prevalent in the southern parts of the city, where the population density and traffic are high. De Miguel et al. (1997) suggested that heavy metals in the urban area could be classified as “urban” elements (e.g., Cd, Cu, Pb, Zn) and elements of a mixed source or which are affected by geochemical changes from their original sources (e.g., Cr, Ni). Moreover, many

authors suggested enrichment of Cu, Zn, and Pb in the urban soils deriving from main anthropogenic source (Lee et al. 2006; Yang et al. 2020).

Contamination levels of toxic elements

Geo-accumulation Index (I_{geo})

Calculated Geo-accumulation Index (I_{geo}) values in the urban soils of Yazd City are summarized in Table 3. Also, the spatial distribution maps of Geo-accumulation Index (I_{geo}) values of toxic metals are presented in Fig. 3. I_{geo} values were illuminated with the background concentration of earth crust defined by McLennan (2001). The average I_{geo} values of the toxic metals were found in the order of As (1.36) > Cd (0.89) > Pb (0.42) > Zn (-0.36) > Cu (-0.7) > Ni (-1.54) > Cr (-1.97) > Co (-2.43). For other toxic metals, except As, Cd and Pb, the average I_{geo} index was found to be smaller than 0. According to the Müller scale, the index of I_{geo} indexes in the study area is not polluted with Zn, Ni, Cu, Cr and Co, unpolluted to moderately polluted with Cd and Pb and moderately polluted with As. The results of researchers in other parts of the world are different, for example the mean I_{geo} trend for heavy elements in soils of industrial estate, Pakistan, was Cr > Pb > Cu > Zn > Fe >

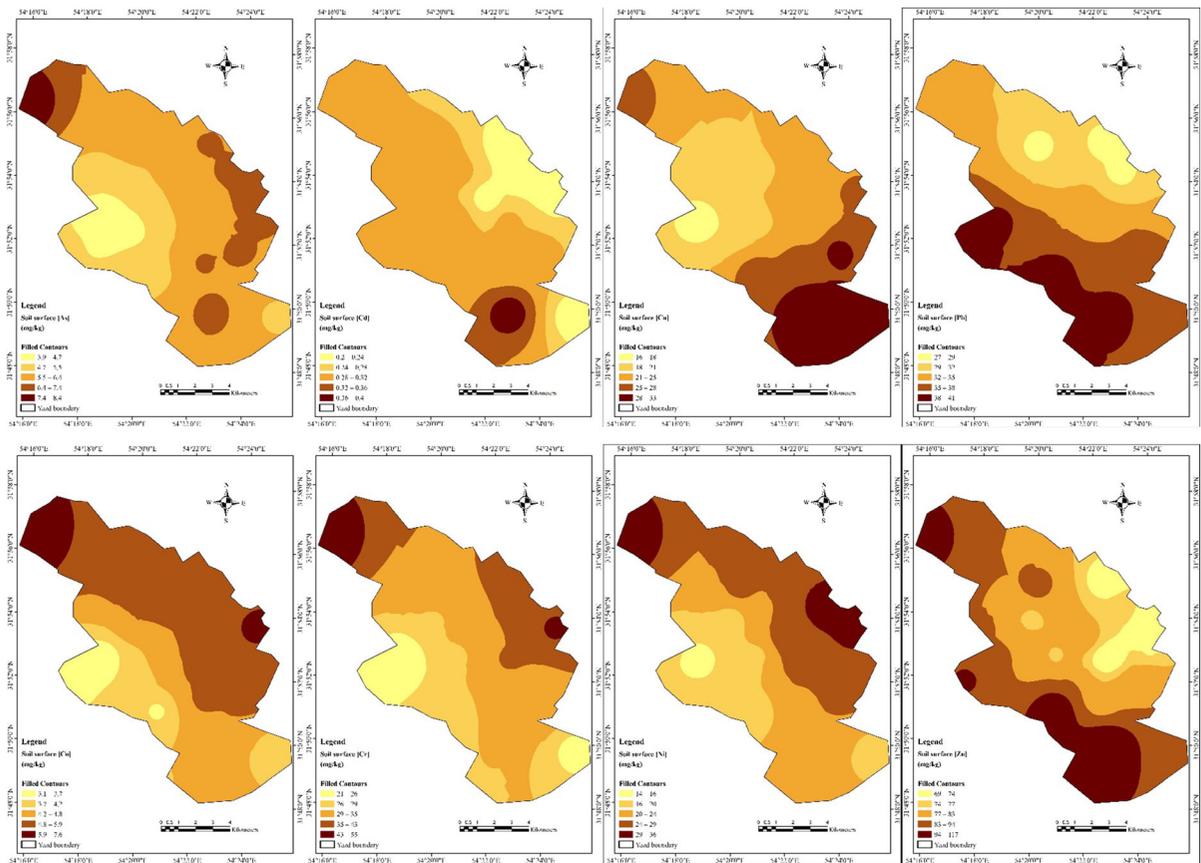


Fig. 2 Spatial distribution of the concentration of toxic elements in the urban soil of Yazd City

Table 3 Health risk from toxic metals in the urban soil of Yazd City

Metals	HQ ing		HQ inh		HQ derm		Adults		Child	
	Adults	Child	Adults	Child	Adults	Child	HI	RI	HI	RI
As	3.36E-02	2.50E-01	3.06E-06	6.79E-06	2.49E-04	9.78E-04	3.61E-02	1.53E-06	2.51E-01	1.14E-05
Cd	1.59E-04	1.19E-03	1.49E-08	3.32E-08	1.45E-04	5.69E-04	1.61E-03	3.02E-07	1.76E-03	2.24E-06
Cr	1.87E-02	1.39E-01	1.84E-04	4.09E-04	2.84E-03	1.11E-02	4.73E-02	2.36E-05	1.51E-01	1.76E-04
Cu	1.01E-03	7.52E-03	9.44E-08	2.10E-07	1.02E-05	4.01E-05	1.11E-03	–	7.56E-03	–
Ni	2.02E-03	1.50E-02	1.84E-07	4.08E-07	2.27E-05	8.90E-05	2.25E-03	3.40E-05	1.51E-02	2.52E-04
Pb	1.70E-02	1.26E-01	1.58E-06	3.52E-06	3.43E-04	1.35E-03	2.04E-02	2.50E-05	1.27E-01	1.86E-04
Zn	4.81E-04	3.58E-03	4.52E-08	1.00E-07	7.30E-06	2.87E-05	5.54E-04	–	3.61E-03	–
Sum							1.56E-02	8.44E-05	7.96E-02	6.28E-04

Mn > Co > Ni > Cd (Hussain et al., 2015). Wang et al. (2017) point out the I_{geo} values of heavy metals in Sichuan showed the order of Cu > Zn > Cr > Hg >

Cd > As. The average I_{geo} values of the heavy metals were found in the order of As > Cr > Pb > Zn > Ni > Cu > Fe in Turkey (Baltas et al. 2020). The

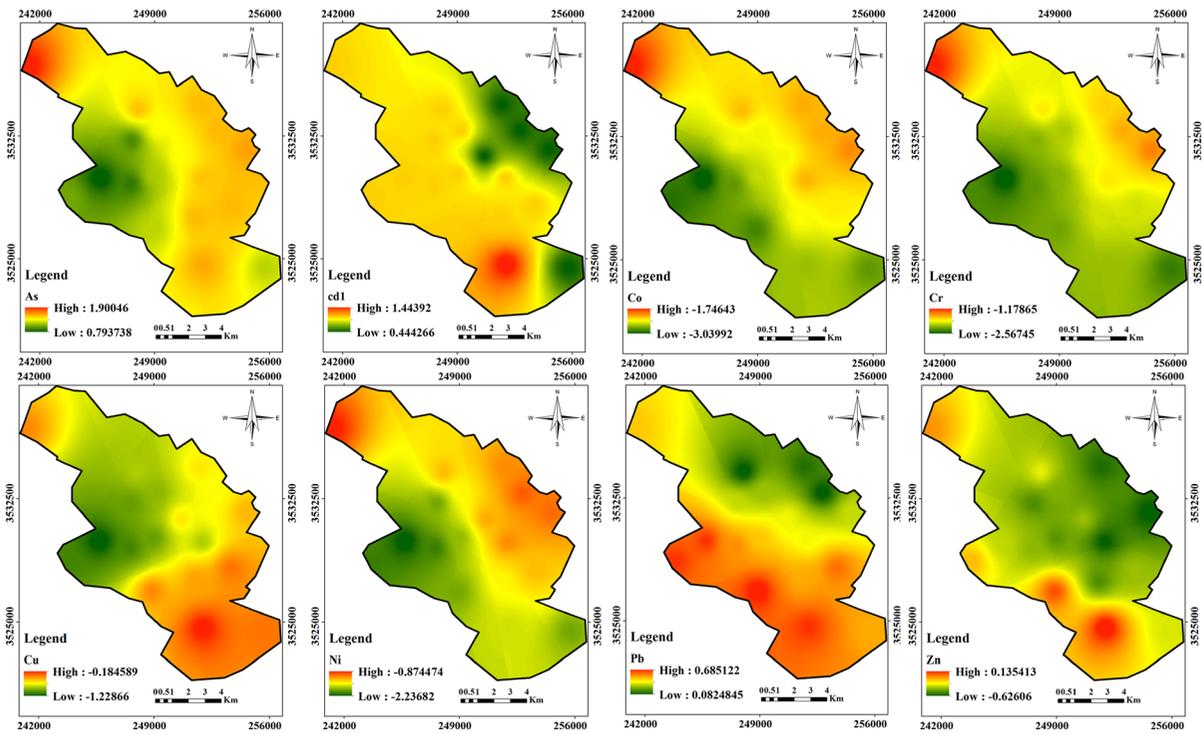


Fig. 3 Geo-accumulation Index (I_{geo}) values of toxic metals in the urban soils of Yazd City

results are variable in terms of type and amount of pollution, land use or the presence of various pollution sources due to different conditions of the studied areas.

Pollution index (PI)

Boxplots and the characteristics of PI for toxic metals in the urban soil samples of Yazd are indicated in Figs. 4 and 5. According to the results of this index, the elements of Cu (from 0.64 to 1.32 with a mean of 0.94), Ni (from 0.32 to 0.82 with a mean of 0.53), Cr

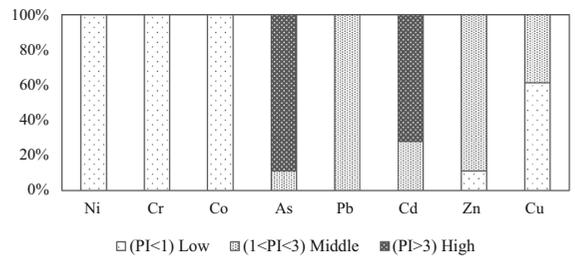


Fig. 5 The pollution index (PI) characteristics of toxic metals in the urban soils of Yazd

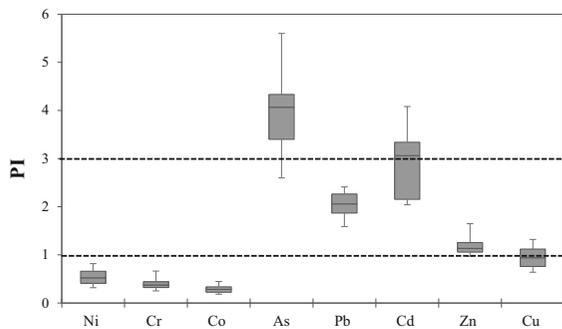


Fig. 4 Boxplots of PI for toxic metals in the urban soil samples of Yazd

(from 0.25 to 0.66 with a mean of 0.39) and Co (from 0.18 to 0.44 with a mean of 0.28) indicated low PIs in the urban soils, showing that the concentrations of Cu, Ni, Cr and Co in the urban soil samples were comparable with the earth crust values of toxic metals in soils, and there was no clear pollution of Cu, Ni, Cr and Co; however, 61.1% and 38.9% of soil samples were classified as low PIs and moderately polluted for Cu, respectively, as well 100% of them were categorized as low PIs for Ni, Cr and Co. Middle PIs found for Cd (from 2.04 to 4.08 with a mean of 2.83) with 72.2% and 27.8% of soil samples were determined as moderately and high polluted, respectively, Pb (from

1.58 to 2.41 with a mean of 2.03) with 100% of samples, and Zn (from 0.97 to 1.65 with a mean of 1.18) with 88.9% of the urban soils, whereas the PIs of As were considerably higher, varying from 2.6 to 5.6 with a mean of 3.91; were classified with 88.9% of samples as highly polluted. In the soils of Yibin City, China Guo et al. (2014) reported the PI value of As ranged from 0.24 to 1.93, with a mean value of 0.86. The PI value of Pb ranged from 0.66 to 7.24. The PI value of Zn varied from 0.42 to 4.19 with a mean value of 1.61. The PI of Cu was in the range of 0.62–5.25, with a mean value of 1.78 (Fig. 4 here).

IPI, PLI, INPI and C_D

The IPIs of eight toxic elements in urban soil samples varied from 1.32 to 1.90 with a mean of 1.51 (Fig. 6) and were classified as moderate pollution. It was clear that the high IPI in most of soil samples was mainly considered by As, Pb and Cd values. IPI values of these metals varied from 0.82 to 3.54, with a mean of 1.6 in urban soils from southwest China (Guo et al., 2014). The minimum, maximum, and mean values of PLI were 0.96, 158.2, and 21.8, respectively, in Pakistan (Hussain et al. 2015). As well as, PLI was found to change from 0.82 to 1.38 with a mean of 1.04 and about of 33% of soil samples exhibited no contamination (Fig. 7). A previous study in Turkey by Baltas et al. (2020) showed that the average PLI value was found to be 1.18. The Contamination Degree (C_D) or the total PI for each element in urban soils ranged from minimum 10.59 to maximum 15.19 with a mean of 12.11; as a result, the study area was found as considerably polluted. The mean of the INPI

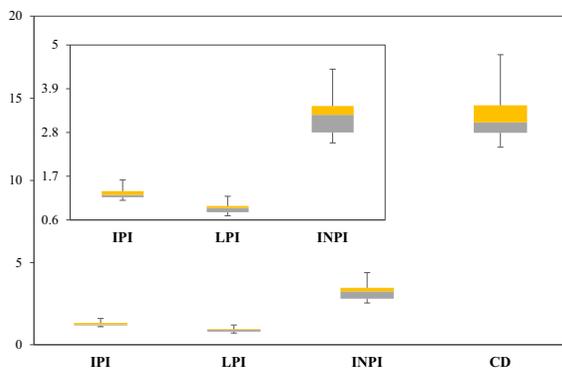


Fig. 6 Boxplots of IPI, LPI, INPI and Cd indexes for toxic metals in the urban soil samples of Yazd

index calculated in 30 stations ranged from 2.57 to 4.39 with a mean of 3.18 and the standard deviation was equal to 0.48, values which 39% of stations fall within the medium pollution class (Category 4) and 61% of them showed high pollution (Category 5). The high NPI value ranged from 0.90 to 3.55 with a mean value of 1.65, indicating moderate pollution by the heavy metals in Sichuan (Wang et al. 2017). Overall, the quality of the urban soil in Yazd City is clearly affected by toxic metals. The highest values of pollution indicators (IPI > 1.8; LPI > 1.3; C_D > 15 and INPI > 4.3) were found in the northwestern areas (the area closest to the main highway) and the south of the study area (the area with high population density and high traffic).

Human health risk assessment of toxic elements

Carcinogenic and non-carcinogenic risk assessment

Human health risk evaluation methods have been used to assess the risk to child and adults. Table 4 shows the health risk assessment results due to exposure to toxic metals in the urban soils in Yazd City. The mean HQ_{ing} values As, Cd, Cr, Cu, Ni, Pb and Zn were 2.50E-01, 1.19E-03, 1.39E-01, 7.52E-03, 1.50E-02, 1.26E-01 and 3.58E-03 for child and were 3.36E-02, 1.59E-04, 1.87E-02, 1.01E-03, 2.02E-03, 1.70E-02 and 4.81E-04 for adults, respectively. The mean HQ values by inhalation for child found 6.79E-06, 3.32E-08, 4.09E-04, 2.10E-07, 4.08E-07, 3.52E-06 and 1.00E-07, while for adults were obtained 3.06E-06, 1.49E-08, 1.84E-04, 9.44E-08, 1.84E-07, 1.58E-06 and 4.52E-08, respectively. Also, the mean HQ_{derm} values As, Cd, Cr, Cu, Ni, Pb and Zn were calculated 9.78E-04, 5.69E-04, 1.11E-02, 4.01E-05, 8.90E-05, 1.35E-03 and 2.87E-05 for child, while were 2.49E-04, 1.45E-04, 2.84E-03, 1.02E-05, 2.27E-05, 3.43E-04 and 7.30E-06 for adults, respectively. As the results suggested, three-pathway exposure to metals for both child and adults has decreased in the form of HQ_{ing} > HQ_{inh} > HQ_{derm}. The results indicate that oral intake is the main pathway that toxic metals can harm human health for both the child and adults. Also, the ranking of HQ_{ing}, HQ_{inh} and HQ_{derm} levels of child and adults by toxic metals was, respectively, as follows: As > Cr > Pb > Ni > Cu > Zn > Cd; Cr > As > Pb > Ni > Cu > Zn > Cd and Cr > Pb > As > Cd > Ni > Cu > Zn, respectively. Of

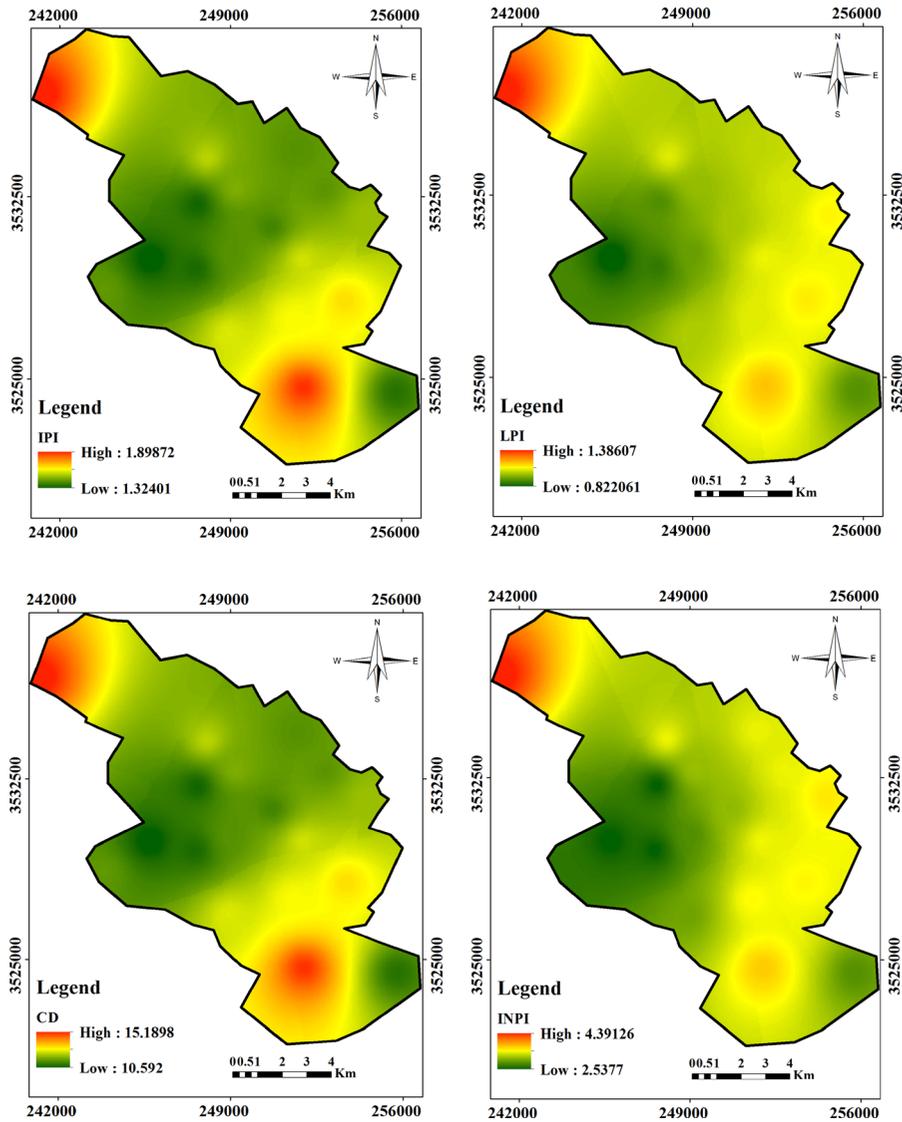


Fig. 7 Spatial distribution of the pollution indexes IPI, LPI, INPI and CD in the urban soil of Yazd City

Table 4 Descriptive statistics of calculated Igeo due to toxic metal concentration

Toxic metals	Range	Minimum	Maximum	Mean	Std. Deviation	Variance	Skewness
As	1.11	0.79	1.90	1.36	0.28	0.07	−0.36
Cd	1.00	0.44	1.44	0.89	0.30	0.09	−0.58
Co	1.29	−3.04	−1.75	−2.43	0.34	0.11	−0.02
Cr	1.39	−2.57	−1.18	−1.97	0.34	0.12	0.56
Cu	1.04	−1.23	−0.18	−0.70	0.29	0.09	−0.04
Ni	1.36	−2.24	−0.87	−1.54	0.39	0.16	−0.07
Pb	0.60	0.08	0.69	0.42	0.19	0.04	−0.47
Zn	0.76	−0.63	0.14	−0.36	0.22	0.05	0.96

course, it should be noted that HQs and HI values for child also were higher than these for adults. HI of toxic metals' values for child decreased as: As > Cr > Pb > Ni > Cd > Cu > Zn > Cd while with a slight change ranked for adults as: Cr > As > Pb > Ni > Cd > Cu > Zn > Cd. All HI values of toxic metals were less than 1. This suggests that there is no non-carcinogenic risk for child and adults in study area. Wei et al. (2015) and Xiao et al. (2019) also reported that compared with the non-carcinogenic health risk for child, such risk for adults was lower. Furthermore, the carcinogenic risks (RI) and the total carcinogenic risks (TRI) for As, Cd, Cr, Ni and Pb were evaluated and are presented in Table 4. According to results, the carcinogenic risk (RI) values were relatively higher for child than that for adults. Similar results were obtained by Zheng et al. (2010), Dehghani et al. (2017), Baltas et al. (2020) and Ma et al. (2020). Their research showed that the non-carcinogenic risk for children was above the threshold level, but low for adults. This suggests that child may be at greater risk for toxic metals in urban soil because child is most likely to have oral intake by hand and mouth (Kusin et al. 2018). As shown in Table 4, RI values were 1.53E-06 (As), 3.02E-07 (Cd), 2.36E-05 (Cr), 3.40E-05 (Ni) and 2.50E-05 (Pb) for adults and were found 1.14E-05 (As), 2.24E-06 (Cd), 1.76E-04 (Cr), 2.52E-04 (Ni) and 1.86E-04 (Pb) for child. The RI ranged between 2.24E-06 and 2.52E-04 for child and between 2.36E-05 and 3.02E-07 for adults. RI of adults and child by toxic metals was as follows: Ni > Pb > Cr > As > Cd. The total carcinogenic risks (TRI) of the toxic metals for adults and child were 8.44E-05 and 6.28E-04, respectively. Generally, the results demonstrated that the potential carcinogenic health risks for adults of toxic metals were in an acceptable range (10^{-6} – 10^{-4}) in the urban soils in study area, whereas for Cr, Ni and Pb with $RI > 10^{-4}$, the risk of cancer in child probably increases. However, Soltani et al. (2015) reported that Isfahan residents in the neighborhood of the study area are potentially exposed to high cancer risk via both dust ingestion and dermal contact.

Multivariate statistical analysis

Pearson correlation analysis and hierarchical cluster analysis (HCA) as effective tools were applied to determine the common relationship of soil elements

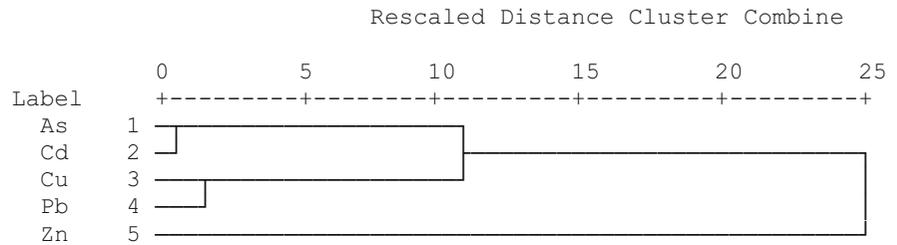
that may indicate a similarity in source (Yang et al. 2018, 2020; Tholkappian et al. 2018). Pearson correlation coefficient between soil toxic metals and pollution indexes from urban soils is presented in Table 5. As can be seen, significant positive correlations were found at the 0.01 level between As and Co (0.854), As and Cr (0.869), As and Cu (0.641), As and Ni (0.889); Co and Cr (0.961), Co and Ni (0.943); Cr and Ni (0.947); and Pb with Zn (0.597), but at the 0.05 level, Cd and Pb (0.527), Cd and Zn (0.558). While significant association negatively was observed between Pb and Co (-0.630), Pb and Ni (-0.604) and Pb with Cr (-0.514). Like many previous studies that have shown a strong positive correlation between toxic metals as a reason for their common source (Jaffar et al. 2017; Yang et al. 2020), the results of this study suggest a common and anthropogenic source for some toxic metals. Cr, Co and Ni, as mentioned earlier, had a negative I_{geo} , and based on the results of correlation analysis, they also have the strongest correlation (> 0.94) and probably have a common natural and geological source. In the next rank, Pb and Zn showed the most positive link, and according to the results of the Geo-accumulation Index, they probably have a similar anthropogenic source such as coal burning, iron and steel production, vehicle transport emissions and industrial activities (Lu et al. 2010; Schleicher et al. 2011). All pollution evaluation indicators were influenced by As and Cu and showed high significant correlation with these two elements, while neither of them had a significant relationship with Pb. There was found also a weak correlation statistically with Cd and Zn. Further, to explore the potential contamination source, was conducted hierarchical cluster analysis (HCA), Ward's method with Euclidean distances. Dendrogram of hierarchical cluster analysis for toxic metals from Yazd City with the influential variables on soil pollution (As, Cd, Cu, Pb and Zn) is shown in Fig. 8. Three elements (Co, Cr, Ni) with I_{geo} lower than 0 (probably the same natural and geogenic origin) were removed from cluster analysis to decrease the number of variables to the effective parameters. According to the results, three clusters in urban soils were distinguished. The first category was determined for the toxic metals As and Cd. Toxic metals Cu and Pb were clustered at similar Euclidian distances, suggesting a probably same origin. Zn did not cluster with any of the other toxic metals, and probably Zn came from different sources.

Table 5 Pearson correlation coefficient between soil toxic metals and pollution indexes from urban soils

	As	Cd	Co	Cr	Cu	Ni	Pb	Zn	IPI	LPI	C _D
Cd	-0.072										
Co	0.854**	-0.260									
Cr	0.869**	-0.290	0.961**								
Cu	0.641**	0.022	0.264	0.319							
Ni	0.889**	-0.374	0.943**	0.947**	0.363						
Pb	-0.343	0.527*	-0.630**	-0.514*	0.187	-0.604**					
Zn	0.098	0.558*	-0.268	-0.124	0.454	-0.230	0.597**				
IPI	0.780**	0.503*	0.471*	0.520*	0.699**	0.469*	0.211	0.579*			
LPI	0.958**	0.123	0.795**	0.830**	0.673**	0.801**	-0.157	0.283	0.893**		
C _D	0.780**	0.503*	0.471*	0.520*	0.699**	0.469*	0.211	0.579*	1.000**	0.893**	
INPI	0.986**	0.035	0.819**	0.848**	0.645**	0.847**	-0.242	0.181	0.843**	0.974**	0.843**

** and * Correlation is significant at the 0.01 and 0.05 level (2-tailed), respectively

Fig. 8 Dendrogram of hierarchical cluster analysis for toxic metals from Yazd City



Conclusion

The concentrations, contamination levels and health risks assessment of toxic metals (As, Cd, Cr, Co, Zn, Cu, Pb and Ni) in urban soils from Yazd City were studied. Results showed that for other toxic metals, except As, Cd and Pb, the average of the geo-accumulation index (I_{geo}) was found to be smaller than 0. According to the Müller scale, the index of I_{geo} indexes in the study area is not polluted with Zn, Ni, Cu, Cr and Co, unpolluted to moderately polluted with Cd and Pb and moderately polluted with As. Based on Pollution Index (PI), the concentrations of Cu, Ni, Cr and Co in the urban soil samples were comparable with the earth crust values of toxic metals in soils and there was no clear pollution of Cu, Ni, Cr and Co. Middle PIs were found for Cd, Pb and Zn, whereas the PIs of As were considerably higher and were classified with 88.9% of samples as highly polluted. LPI was found to change from 0.82 to 1.38 with a mean of 1.04 and about of 33% of urban soil samples exhibited no

contamination, while the Contamination Degree (C_D) in urban soils resulted as considerably polluted. Further, according to the results of Integrated Nemerow Pollution Index (INPI), 61% of stations showed high pollution. The results of health risk analysis suggest that three-pathway exposure to metals for both child and adults has decreased in the form of $HQ_{ing} > HQ_{inh} > HQ_{derm}$. HQs and HI values for child also were higher than these for adults. Also, the potential carcinogenic health risks for adults of toxic metals were in an acceptable range, whereas for Cr, Ni and Pb, the risk of cancer in child probably increases in study area. According to the level of pollution in the study area and the risk of carcinogenic risk for children, it is necessary to provide and implement appropriate management strategies to reduce toxic metals pollution in the area.

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Compliance with ethical standards

Conflict of interests The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Ethical approval The manuscript has not been sent to more than one journal for simultaneous consideration. The submitted work is original and has not been published elsewhere in any form or language, unless the new work concerns an expansion of previous work. The study has not been splitted up into several parts to increase the quantity of submissions and has not submitted to various journals or to one journal over time. Results have been presented clearly, honestly, and without fabrication, falsification or inappropriate data manipulation (including image-based manipulation). Authors have adhered to discipline-specific rules for acquiring, selecting and processing data. No data, text, or theories by others are not presented as if they were the author's own ('plagiarism').

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