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RESEARCH PAPER

Human Health Risks Associated with Potentially Harmful Elements from Urban Soils of Hamedan City, Iran

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ABSTRACT

Previous studies have shown that certain urban elements and arsenic are significantly concentrated in the surface soils of Hamedan, the largest city in western Iran. This study was carried out to assess the non-cancer and cancer risks from exposure to these potentially harmful elements (As, Cd, Cr, Cu, Ni, Pb, and Zn) for Hamedan residence. In so doing, thirty-one urban and three background soil samples were analyzed by ICP-MS and the Risk Assessment Model established by the USEPA was applied to assess the health risk. It was found that the hazard index values for all the concerned elements are below 1, which indicates negligible to low non-carcinogenic risk for the exposed population. Nevertheless, some close to threshold values were recognized for As, Cr, and Pb implying that these elements have the potential to cause non-cancer risk for Hamedan citizens in case of long-term overexposure. The contribution of HQ-ingestion to total HI was the highest while the health effect associated with the inhalation exposure was trivial. Children were found to be more susceptible to potentially harmful elements than adults. The cancer risk calculation revealed that both children and adults are at increasing risk of developing cancer over a lifetime through ingestion, inhalation, and skin contact. All of the verified elements exceeded the tolerable level (1×10^{-6}) of cancer risk however arsenic and chromium were found to be the most carcinogenic elements followed by Pb, Ni, and Cd. The carcinogenic risks were moderate for adults and high for children. This study indicates the necessity of designing effective strategies to reduce elemental pollution and to mitigate adverse human health effects of PHEs in Hamedan.

KEYWORDS: Anthropogenic pollutants; Carcinogenic Risk; Non-Carcinogenic Risk; Toxic elements.

INTRODUCTION

During the last few decades, the Earth’s environment has undergone significant geochemical changes caused by intensive human activities. The world's population is growing fast and is becoming increasingly urban (Cohen, 2004; Montgomery, 2008; Hamzeh & Hasanzadeh, 2009). Cities are the most densely populated human habitats with more than half of the world’s population; a proportion that is estimated to be reached up to 68% or two-thirds of the world’s population by 2050 (United Nations, 2018). Urbanization and associated industrialization, despite being the forefront of economic development of many societies, entail distinct geochemical and environmental features among which the accumulation of potentially harmful elements (PHEs) is a major matter of concern (Pan et al., 2017; Cicchella

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et al., 2020). Diverse anthropogenic activities in cities (e.g. vehicular sources, industrial effluents, commercial and domestic activities, waste production and disposal, agricultural operations, weathering of buildings and pavement surface, construction, demolition, etc.) increase the concentration of PHEs including toxic metals and metalloids in urban soils (Wong et al., 2006; Biasioli et al., 2007; Wei & Yang, 2010; Albanese & Breward, 2011; Cheng et al., 2015; Rodríguez-Seijo et al., 2017; Adimalla, 2020). Nevertheless, the contribution of underlying parent materials to the soil chemistry even in highly urbanized areas should not be overlooked (Norra, 2009; Argyraki & Kelepertzis, 2014).

PHEs are well-known environmental pollutants due to their biological toxicity (Charlesworth et al., 2011; Rate, 2018; Antoniadis et al., 2019). They are persistent and non-biodegradable and often tend to remain in the environment for decades after the termination of source emission (Alloway, 2013). PHEs via surface soil can incorporate into the human body through the three main pathways of hand-to-mouth ingestion, mouth and nose inhalation, and dermal absorption (Abrahams, 2002). Long-term or overexposure to PHEs can threaten human health and may lead to various chronic diseases such as skin lesions, cardiovascular issues, neurological problems, diabetes mellitus, impaired psycho-social behaviors as well as carcinogenic effects (Raj & Maiti, 2020). Hence, the chemical composition of urban soils serves as an indicator of environmental quality and dwellers' well-being and has been verified in many cities susceptible to anthropogenic impacts from all over the world (Cappelletti et al., 2018; Flem et al., 2018; Hołtra & Zamorska-Wojdyła, 2018; Kowalska et al., 2018; Woszczyk et al., 2018; Hiller et al., 2020; Morera-Gómez et al., 2020; Sappa et al., 2020).

Iranian cities as well have not been an exception so that several recent investigations have been conducted on urban soils of various cities in the country to estimate the PHEs' contamination, possible sources, distribution, and their potential human health risks (Khosravi et al., 2014; Mohammadi et al., 2018; Eghbal et al., 2019; Fazeli et al., 2019; Jahandari, 2020). Concerns regarding the possible health risks of PHEs in urban soils of Hamedan city, in the west of Iran, arose after our previous work disclosed a significant enrichment of certain urban elements and arsenic in surface soils of this city (Modabberi et al., 2018). A recent study conducted by Hosseini et al. (2020) also confirmed the relation between the traffic volume and high amounts of Cd, Cu, Pb, Ni and Zn in roadside soils of Hamedan. Even though, health implications due to the PHEs concentration in Hamedan atmospheric dust have already been studied (Sobhanardakani, 2018a), possible risks from surface soils to the city's population have not yet been addressed in previous researches. This gap ignited the spark of interest in assessing the extent of cancerous and non-cancerous effects associated with PHEs in urban soils of Hamedan. With this regard, the modified USEPA's assessment model of health risk was applied in this study.

MATERIALS AND METHODS

The current study has been conducted in Hamedan City, the capital of Hamedan province in the west of Iran with an area of about 60 km^2 located between latitudes of 34° 45′ 46″ and 34° 51′ N and longitudes of 48° 28′ 07″ and 48° 34′ 25″ E (Fig.1). The population in the municipality of Hamedan has been estimated to be approximately 600,000 in 2016. Hamedan as the first capital of the Persian Empire is an ancient city with more than 3000 years of civilization. This city is nowadays a center for manufacturing, economy and transportation while containing a combination of roads, residential areas, commercial and industrial centers as well as green spaces and agricultural lands.

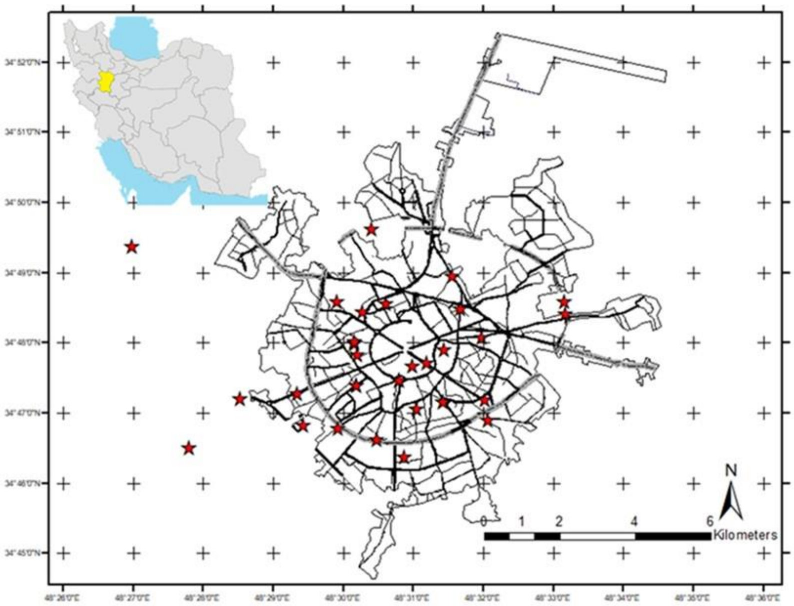

Fig.1. Location and geographical positions of the soil sampling sites in Hamedan city

In total, 31 topsoil samples were randomly collected at different districts with different land uses including residential (8 samples), green spaces (11 samples), agricultural lands (6 samples), parks (4 samples), and playgrounds (2 samples) from across the Hamedan city. Samples were taken from the top 10 cm because the upper parts of soils are more susceptible to contain urban elements and can be affected by re-suspension. Moreover, three samples were taken from remote areas far from the urban influence to obtain natural background concentrations. At each sampling station, a composite sample consisting of five subsamples was collected at the corners and center of a 2 × 2 m^2 square using a stainless steel shovel and was thoroughly mixed to have a representative sample (2 kg). Soil samples were air-dried and after removing large rocks and organic debris, were manually disaggregated by agate mortar and pestle to pass through a 2 mm plastic sieve. Soils were stored in two layers polyethylene ziplock bags and a fraction of them was sent to ActLabs analytical laboratory, Canada.

Soil samples were analyzed for major and trace element concentrations using the aqua regia extraction method in ActLabs analytical laboratory, Canada. The amount of 0.25 g of each sample was weighed out in an acid-cleaned PTFE digestion vessel and was then digested at 90 °C in a microprocessor-controlled digestion block for 2 h. The digested solutions were made up to 125 ml HDPE bottles and were measured for “pseudototal” concentration of 63 elements by PerkinElmer Sciex ELAN ICP-MS. Of these, seven elements of As, Cd, Cr, Ni, Cu, Pb and Zn were selected for health risk assessment in this study. These are the most common hazardous elements almost ubiquitous in world cities (Wong et al., 2006; Yesilonis et al., 2008; Giusti, 2011; Morera-Gómez et al., 2021) and are shown to have contribution in the study area based on previous findings (Solgi et al., 2016; Modabberi et al., 2018; Sobhanardakani, 2018a).

Three samples were analysed in duplicate to verify the precision of analysis; the relative percentage difference between duplicate measurements was always less than 8% and never higher than 10%. ActLabs analytical laboratory used standard analytical batch including reagent blank to measure background and Certified Reference Material (CRM) to assure the accuracy of data prior to release.

This study uses the EPA's assessment model of health risk (USEPA, 2002) to evaluate the degree of non-carcinogenic and carcinogenic risks associated with PHEs in Hamedan urban soils. Nowadays, risk analysis is broadly applied to assess the probability of health damage, disease, or death of human due to exposure to risk factors including chemical elements (Rapant et al., 2011; Nasrabadi & Bidabadi, 2013; Nasrabadi et al., 2015). The EPA modified procedure has been developed after the first release in the 1980s. This method considers the three major soil-related exposure routes of ingestion, inhalation, and dermal to evaluate the level of risk from the PHEs attached to urban surface soils. The calculation was carried out on two susceptible groups of residents; adults (up to the age of 70 years) and children (up to the age of 15 years). The average daily intakes of elements via the pathways of ingestion ($\mathrm{ADI_{ing}}$), inhalation ($\mathrm{ADI_{inh}}$), and dermal contact ($\mathrm{ADI_{drm}}$) were calculated using the Eqs. (1-3):

$$ADI_{ing} = C_s \times \frac{IngR \times EF \times ED}{BW \times AT} \times 10^{-6} \tag{1}$$

$$ADI_{drm} = C_s \times \frac{ESA \times SAF \times DAF \times EF \times ED}{BW \times AT} \times 10^{-6} \tag{2}$$

$$ADI_{inh} = C_s \times \frac{InhR \times EF \times ED}{PEF \times BW \times AT} \tag{3}$$

where C_S is total concentration of metal in soil; *IngR* is ingestion rate (mg/d); *EF* is exposure frequency (d/yr); *ED* is exposure duration (yr); *BW* is body weight (kg); *AT* is averaging time (d), *ESA* is exposed surface area ($\mathrm{cm^2}$); *SAF* is skin adherence factor ($\mathrm{mg/cm^2}$), *DAF* is dermal absorption factor (unitless); *InhR* is inhalation rate ($\mathrm{m^3/d}$) and *PEF* is particle emission factor ($\mathrm{m^3/kg}$). The definition and the applied factors selected by reference standards are presented in Table 1.

Table 1. Various factors for calculating human health risk (from USEPA (2002), unless otherwise indicated)

Factor	**Definition**	**unit**	**value**	
			Adults	**Children**
Cs	Heavy metal concentration	(mg/ kg)	-	-
IngR	Ingestion Rate	(mg/d)	100	200
InhR	Inhalation Rate	(m/d)	20	7.6 (a)
PEF	Particle Emission Factor	(m/kg)	1.36×10^9	1.36×10^9
EF	Exposure Frequency	(d/yr)	350	350
ESA	Exposed Surface Area	($\mathrm{cm^2}$)	5700	2800
SAF	Skin Adherence Factor	($\mathrm{mg/cm^2}$)	0.07	0.2
DAF	Dermal Absorption Factor	(unitless)	As: 0.03; All else: 10^{-3}	
ED	Exposure Duration	(yr)	30	6
BW	Body Weight	(kg)	70	15
AT	Averaging Time	(d)	10950	2190

Ngole-Jeme & Fantke (2017); Yang et al. (2017)

The hazard quotient (HQ) accounting for non-carcinogenic risk was calculated for each element and exposure route by dividing the average daily intakes to a specific reference dose (Eq. 4) given for the corresponding element (Table 1). The accounted HQs for individual intake routes were summed to obtain the overall risk of Hazard index (HI) (Eq. 5).

$$HQ_e = \frac{ADI_e}{RfD} \tag{4}$$

$$HI = \sum HQ_e = \sum \frac{ADI_e}{RfD} \tag{5}$$

where R_fD is the reference dose (mg/kg/day) as an estimation of the maximum allowable rate and *e* represents the pathway. According to USEPA (2002), when HI value is < 1, adverse health effects are less likely to be experienced by city dwellers. Whereas HI> 1 indicates the potential of non-carcinogenic health effects.

The carcinogenic risk (CR) of each element was quantified with the use of human intake values and the slope factor (SF) corresponding to each element (Eq. 6). Because of the non-availability of slope factor values for PHEs via the dermal pathway, only cancerous risk by skin absorption of arsenic is generally calculated. Total cancer risk (TCR) of all carcinogenic PHEs was calculated by Eq. 7 to evaluate the incremental probability of developing cancer during a person's lifetime in Hamedan city.

$$CR_e = ADI_e \times SF \tag{6}$$

$$TCR = \sum CR_e \tag{7}$$

where *e* stands for the exposure pathway and *SF* represents the slope factor. The CR values surpassing 1.00×10^{-4} are considered to be unacceptable with an individual's lifetime cancer incidence risk from toxic elements, while the values below 1.00×10^{-6} are not viewed to cause significant health effects. The values between 1.00×10^{-6} and 1.00×10^{-4} indicate tolerable risk (USEPA, 2002; Fryer et al., 2006). The slope factor values used in this study are given in Table 2.

Table 2. Reference dose (mg/kg/day) and slope factor (mg/kg/day) for ingestion, inhalation and dermal pathways

	As	Cd	Cr	Ni	Cu	Pb	Zn
RfDing	3.0E-04	1.0E-03	3.0E-03	2.0E-02	4.0E-02	3.5E-03	3.00E-01
RfDinh	3.01E-04	1.0E-03	2.86E-05	2.06E-02	4.02E-02	3.52E-03	NA
RfDdrm	1.23E-04	1.0E-05	6.0E-05	5.4E-03	1.2E-02	5.25E-04	6.00E-02
Ing SF	1.5E+00	NA	5.0E-01	NA	NA	8.5E-03	NA
Inh SF	1.51E+01	6.3E+00	4.2E+01	8.4E-01	NA	4.2E-02	NA
Drm SF	3.66E+00	NA	NA	NA	NA	NA	NA

RESULTS AND DISCUSSION

The summary descriptive statistics of PHEs concentrations in urban soils of Hamedan are presented in Table 3 along with the mean concentrations by land-use type, inclusive of background values of the soils from the remote suburb of Hamedan. As it is noticeable from the listed values, there is not a significant variation in the accumulation of elements in different land-use types which has been statistically confirmed by the Kruskal–Wallis H test (Modabberi et al., 2018). The concentration of metals in the analysed soil samples ranged from 11.1 to 27 for As (median= 18.9), 0.01 to 0.4 for Cd (median= 0.1), 9.1 to 17.1 for Co (median= 13.1), 42 to 76 for Cr (median= 58), 23 to 79 for Cu (median=35.4), 0.01 to 1.34 for Hg (median= 0.09), 37 to 71 for Ni (median = 54), 18 to 289 for Pb (median= 38) and 67 to 322 for Zn (median= 101) mg/kg. The results showed that As in Hamedan soils has been concentrated up to 10 times higher than that in the world average soil. Arsenic is naturally accumulated in both urban and suburban Hamedan soils which can be attributed to the enrichment of this element in granitic, metamorphic, and hydrothermal alteration zones of Sanandaj–Sirjan belt in this region. It is admitted that dispersion and level of arsenic is to large extent a function of geological makeup at local and regional scales (Garcia-Sanchez & Alvarez-Ayuso, 2003). Arsenic is toxic following both acute and chronic intakes (Whitacre, 2008). Likewise, the content of Cr was found below that in suburban areas indicating that a geogenic source, in addition to other origin(s) from human activities has added chromium to the urban soils. This deduction is similar to that reported by other works in Hamedan (Khodakarami, 2010; Yeganeh et al., 2012). In contrast, the average contents of Cd, Cu, Hg, Mn, Pb and Zn in the studied urban soils exceed their corresponding background concentrations, suggesting the influence of anthropogenic sources. There is a substantial body of literature indicating these elements as typical contaminants in city environments. The detailed description of elemental concentrations and their source apportionment in Hamedan urban soils have already been documented (Modabberi et al., 2018).

Table 3. Descriptive statistics of PHEs concentration in Hamedan urban and background soils (mg/kg)

		As	**Cd**	**Co**	**Cr**	**Cu**	**Ni**	**Pb**	**Zn**
Total	Min	11.1	0.0	9.1	42.0	22.7	37	18	67
	Max	27.0	0.4	17.1	76.0	79.3	71	289	322
	Median	18.8	0.1	13.1	58.0	35.4	54	38	101
	SD	3.9	0.1	2.0	7.2	13.3	9.0	50	47
	Skew	-0.07	0.53	-0.02	0.19	1.65	0.06	3.7	3.0
	KS	-0.55	-0.82	-0.34	0.70	2.98	-0.88	16.8	12.0
Total	Mean	18.9	0.1	13.1	56.4	39.1	55	52	115
Residential		20.8	0.1	13.8	58.0	37.8	56	44	101
Greenspace		17.3	0.2	12.0	52.5	40.1	49	62	115
Urban Park		17.1	0.2	13.5	57.0	38.5	55	58	170
Playground		17.7	0.1	12.6	54.0	27.4	57	25	89
Agricultural		21.3	0.1	14.1	62.0	43.1	63	49	107
Background		21.9	0.07	18.2	72.5	36.5	62	14	91

The proximity of soils to city dwellers enhances the risk of exposure to PHEs. Health risks of As, Cd, Cr, Cu, Ni, Pb, and Zn in urban topsoils of Hamedan were assessed for adults and children based on the average daily intake of these elements through three exposure pathways of ingestion, inhalation, and dermal contact. Under the same circumstances, the degree of health risk may vary significantly among the exposed populations based on the difference in the average daily intake. The higher average daily dose of intake leads to higher risk.

The result of this study showed that the ADI values of all of the concerned elements are relatively higher in children than adults. Similar to what has been found for Hamedan atmospheric dust (Sobhanardakani, 2018a), PHEs in urban soils are also more exposed to children than adults. The highest ADI_{ing} value was found for Zn (4.12×10^{-3}), following by Pb (3.69×10^{-3}) and Cu ($1.01\times10^{\ 3}$) in children. Moreover, the route of exposure can affect the degree of potential health hazards (Huang et al., 2016). As it is reported in many publications, prolonged oral exposure to high doses of PHEs might trigger more adverse health effects than other pathways (Martin & Griswold, 2009; Luo et al., 2012; Karim & Qureshi, 2014; Yang et al., 2017). A similar result was obtained in the current study so that the HQ values, as non-cancer risk index, decreased in the following order: ingestion> dermal contact> inhalation (Table 4).

In other words, for both age groups, the contribution of the ingestion pathway to total non-carcinogenic health risk caused by PHEs in Hamedan urban soils is the highest while inhalation is the lowest harmful pathway. The highest HQ_{ing} values were obtained for As in children (1.15) and adults (1.23×10^{-1}) and the highest HQ_{inh} values were observed for Cr in both children (9.49×10^{-4}) and adults (5.35×10^{-4}). As can be seen in Table 4, the average HQ values for children through ingestion are one order of magnitude higher compared to adults. In general, the higher average values of HQ for all elements confirm that children are more vulnerable to PHEs in Hamedan urban soils.

Table 4. Hazard quotient (HQ) and hazard risk (HI) for PHEs in Hamedan urban soils through three exposure routes

		Adults				Children			
		HQing	**HQinh**	**HQdrm**	**HI**	**HQing**	**HQinh**	**HQdrm**	**HI**
As	Min	5.07E-02	7.43E-06	1.48E-02	6.55E-02	4.73E-01	1.32E-05	3.23E-03	4.76E-01
	Max	1.23E-01	1.81E-05	3.60E-02	1.59E-01	1.15E+00	3.20E-05	7.86E-03	1.16E+00
	Med	8.58E-02	1.26E-05	2.51E-02	1.11E-01	8.01E-01	2.23E-05	5.47E-03	8.07E-01
Cd	Min	1.37E-05	2.01E-09	5.47E-06	1.92E-05	1.28E-04	3.57E-09	3.58E-05	1.64E-04
	Max	4.79E-04	7.05E-08	1.91E-04	6.71E-04	4.47E-03	1.25E-07	1.25E-03	5.73E-03
	Med	1.51E-04	2.22E-08	6.01E-05	2.11E-04	1.41E-03	3.93E-08	3.94E-04	1.80E-03
Cr	Min	1.92E-02	2.96E-04	4.25E-05	1.95E-02	1.79E-01	5.25E-04	2.51E-02	2.05E-01
	Max	3.47E-02	5.35E-04	7.69E-05	3.53E-02	3.24E-01	9.49E-04	4.53E-02	3.70E-01
	Med	2.65E-02	4.09E-04	5.87E-05	2.70E-02	2.47E-01	7.24E-04	3.46E-02	2.83E-01
Cu	Min	7.77E-04	1.14E-07	2.07E-03	2.85E-03	7.26E-03	2.02E-07	6.77E-05	7.32E-03
	Max	2.72E-03	3.97E-07	7.22E-03	9.94E-03	2.53E-02	7.05E-07	2.37E-04	2.56E-02
	Med	1.21E-03	1.77E-07	3.22E-03	4.44E-03	1.13E-02	3.15E-07	1.06E-04	1.14E-02
Ni	Min	2.51E-03	3.59E-07	3.71E-05	2.55E-03	2.35E-02	6.36E-07	2.43E-04	2.37E-02
	Max	4.84E-03	6.90E-07	7.15E-05	4.91E-03	4.51E-02	1.22E-06	4.68E-04	4.56E-02
	Med	3.70E-03	5.28E-07	5.47E-05	3.75E-03	3.45E-02	9.36E-07	3.58E-04	3.49E-02
Pb	Min	6.93E-03	1.01E-06	1.84E-04	7.11E-03	6.47E-02	1.80E-06	1.21E-03	6.59E-02
	Max	1.13E-01	1.65E-05	3.01E-03	1.16E-01	1.06E+00	2.93E-05	1.97E-02	1.08E+00
	Med	1.48E-02	2.17E-06	3.95E-04	1.52E-02	1.38E-01	3.85E-06	2.58E-03	1.41E-01
Zn	Min	3.06E-04		6.10E-06	3.12E-04	2.86E-03		4.00E-05	2.90E-03
	Max	1.47E-03		2.93E-05	1.50E-03	1.37E-02		1.92E-04	1.39E-02
	Med	4.61E-04		9.20E-06	4.70E-04	4.30E-03		6.03E-05	4.36E-03

The overall accumulative non-carcinogenic risks of PHEs, the HI values, were found in the safe limit (≤ 1) indicating insignificant non-carcinogenic risk for both subpopulation groups. This finding suggests that the PHEs in the urban soil of Hamedan city have generally a low potential for causing non-carcinogenic risks to the residents. However, exceptions were found for As with few places exhibiting the hazard index slightly higher than the threshold for children. For the under 15 year's old group, the HI values of As range from 4.76×10^{-1} to 1.16 (median= 8.07×10^{-1}). For better visualization, graphical representations of HI are illustrated in Fig.2. Long-term exposure to arsenic can cause remarkable health problems such as neurological complications, diabetes, skin lesions, cerebrovascular disease, and cardiovascular issues (Duker et al., 2005).

The hazard index for Cr is relatively high but it is still in the acceptable range probably because of its higher oral reference dose (Robson, 2003). Even though HI for Pb does not exceed the safe allowable limit, Hamedan inhabitants might be at non-carcinogenic risk from this element in case of long-term exposure. This is particularly true for children as they absorb Pb more rapidly than adults (Yang & Massey, 2019), and the non-carcinogenic risk of Pb for this age group was found close to the threshold in Hamedan. Sobhanardakani (2018b) has shown that busy ring roads with the high volume of traffic are responsible for elevated concentrations of Pb in Hamedan. Chronic exposure to Pb, even at low levels, can result in neurotoxicity, behavioral disorders, cardiovascular and kidney diseases (Yang & Massey, 2019). The median of HI values decreased in the order of As> Cr> Pb> Cu> Ni> Zn> Cd for adults and As> Cr> Pb> Ni> Cu> Zn > Cd for children. The HI values for Pb range from 7.11×10^{-3} to 1.16×10^{-1} (median= 1.52×10^{-2}) for adults and 6.59×10^{-2} to 1.08 (median= 1.41×10^{-1}) for children; Cr ranges from 1.95×10^{-2} to 3.53×10^{-2} (median= 2.70×10^{-2}) for adults and 2.05×10^{-1} to 3.70×10^{-1} for children (median= 2.83×10^{-1}); Cu ranges from 2.85×10^{-3} to 9.94×10^{-3} (median= 4.44×10^{-3}) for adults and 7.32×10^{-3} to 2.56×10^{-2} for children (median= 1.14×10^{-2}); Ni ranges from 2.55×10^{-3} to 4.91×10^{-3} (median= 3.75×10^{-3}) for adults and

2.37×10^{-2} to 4.56×10^{-2} for children (median= 3.49×10^{-2}); Zn ranges from 3.12×10^{-4} to 1.50×10^{-3} (median= 4.70×10^{-4}) for adults and 2.90×10^{-3} to 1.39×10^{-2} for children (median= 4.36×10^{-3}); Cd ranges from 1.92×10^{-5} to 6.71×10^{-4} (median= 2.11×10^{-4}) for adults and 1.64×10^{-4} to 5.73×10^{-3} for children (median= 1.80×10^{-3}). All of the elements showed the trend of children>adults indicating that children are at higher risk to be affected by non-carcinogenic elements during their lifetime. A similar result has been reported for the non-carcinogenic risks associated with PHEs in urban soils of different cities. Health risk associated with land-use variation seems not to be meaningful because of no significant difference of PHEs in urban soils of Hamedan land uses.

Regarding the carcinogenic health risk (CR), again ingestion was found to be the primary exposure pathway threatening the health of Hamedan residents (Table 5).

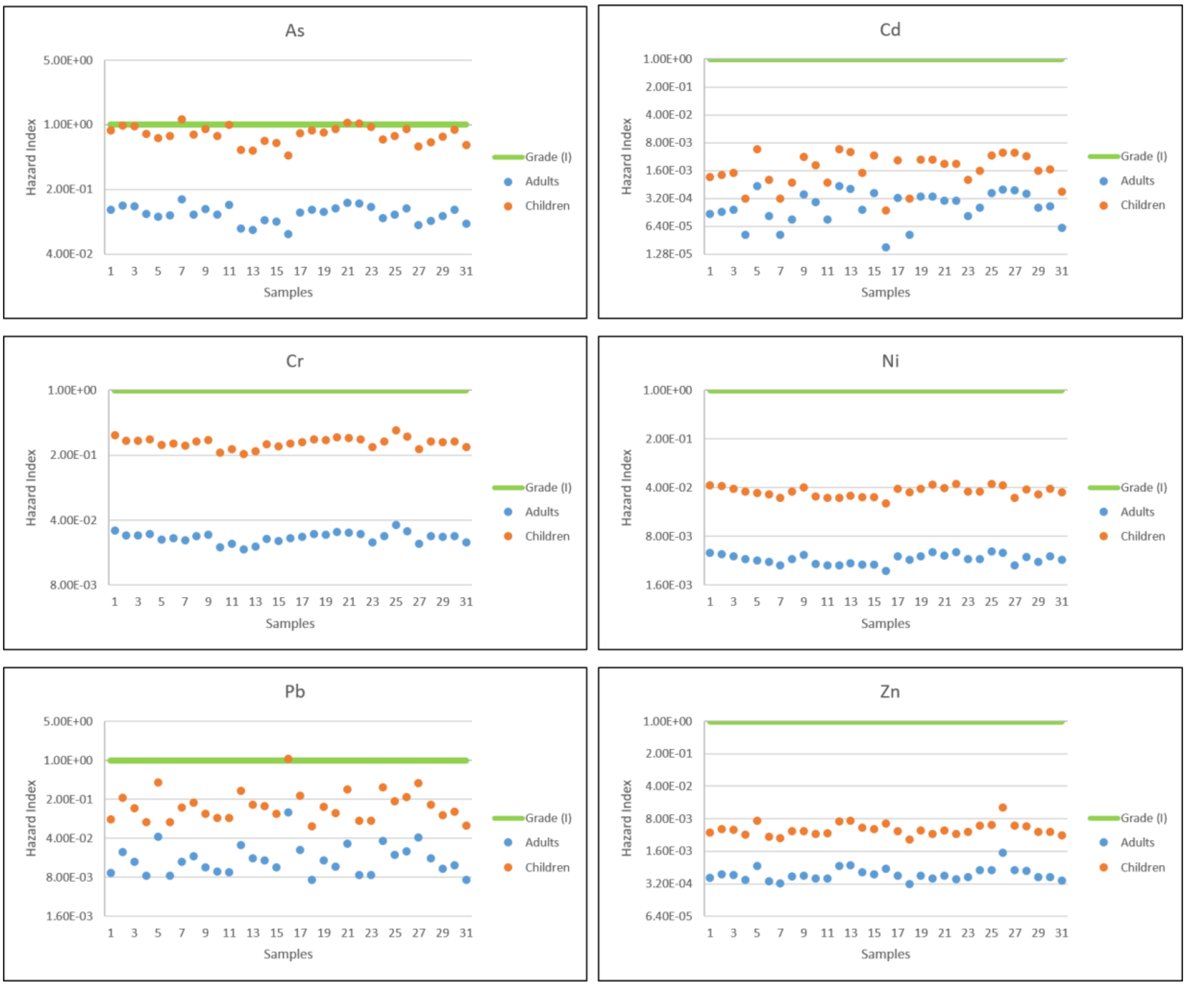

Fig. 2. Hazard index of PHEs in Hamedan urban soils for children and adults and the Grade (I) threshold (HI=1.00)

Table 5. Carcinogenic risk of PHEs in Hamedan urban soils through three exposure routes

		CR_{ing}			CR_{inh}					CR_{drm}
		As	**Cr**	**Pb**	**As**	**Cd**	**Cr**	**Ni**	**Pb**	**As**
Adult	Min	1.6E-05	2.88E-05	1.25E-07	2.36E-09	1.27E-11	3.55E-09	6.21E-09	9.05E-11	4.68E-06
	Max	5.55E-05	5.21E-05	3.37E-06	8.16E-09	4.44E-10	6.43E-09	1.2E-08	2.45E-09	1.62E-05
	Med	3.92E-05	3.97E-05	4.08E-07	5.77E-09	1.33E-10	4.91E-09	9.14E-09	2.96E-10	1.15E-05
child	Min	1.50E-04	2.68E-04	1.16E-06	4.18E-09	2.25E-11	6.30E-09	1.10E-08	1.61E-10	1.02E-06
	Max	5.18E-04	4.86E-04	3.14E-05	1.45E-08	7.88E-10	1.14E-08	2.12E-08	4.34E-09	3.54E-06
	Med	3.66E-04	3.71E-04	3.80E-06	1.02E-08	2.36E-10	8.70E-09	1.62E-08	5.25E-10	2.5E-06

The CR related to skin contact was considered only for As. The inhalation pathway showed a minor contribution to total cancer risk. These findings are consistent with many previous studies on urban soils of different cities throughout the world (Benhaddya et al., 2016; Adimalla, 2020; Othman and Latif, 2020; Zhang et al., 2020). The carcinogenic risks associated with the three main pathways were assessed as moderate in adults ($10^{-5} \leq CR < 10^{-4}$) and high in children ($10^{-4} \leq CR < 10^{-3}$). This indicates that children are at higher health risk when exposed to urban soils. The TCR values of As were 7.3 times higher for children than those for adults. Lead and Cr, well-known for their carcinogenicity, revealed 9.3 times more potential to cause carcinogenic risk in children compared to adults. This difference is less significant for Cd and Ni with the TCR values of about 2-fold higher in children. The results also revealed that all of the studied elements in Hamedan urban soils have a lifetime risk of developing cancer. The TCR values for As range from 2.07×10^{-5} to 7.17×10^{-5} (median= 5.07×10^{-5}) for adults and 1.51×10^{-4} to 5.21×10^{-4} (median= 3.69×10^{-4}) for children; Cd range from 1.27×10^{-11} to 4.44×10^{-10} (median= 1.33×10^{-10}) for adults and 2.25×10^{-11} to 7.88×10^{-10} (median= 2.36×10^{-10}) for children; Cr range from 2.88×10^{-5} to 5.21×10^{-5} (median= 3.97×10^{-5}) for adults and 2.68×10^{-4} to 4.86×10^{-4} (median= 3.71×10^{-4}) for children; Ni range from 6.21×10^{-9} to 1.20×10^{-8} (median= 9.14×10^{-9}) for adults and 1.10×10^{-8} to 2.12×10^{-8} (median= 1.62×10^{-8}) for children; Pb range from 1.25×10^{-7} to 3.37×10^{-6} (median= 4.08×10^{-7}) for adults and 1.16×10^{-6} to 3.14×10^{-5} (median= 3.80×10^{-6}) for children. The TCR values for the most carcinogenic elements decreased in the order of Cr> As> Pb for children and As> Cr> Pb> for adults. Regarding the carcinogenicity of chromium, however, it should be noted that oxidation state is the determining factor. Since here the total concentration of Cr is calculated and not the species, the TCR for this element might be misleading.

Spatial distribution maps of total carcinogenic risks (TCR) of PHEs in Hamedan urban soils are depicted in Fig.3. It is evident from the maps that carcinogenic health risk is a function of the concentration of elements in surface soil.

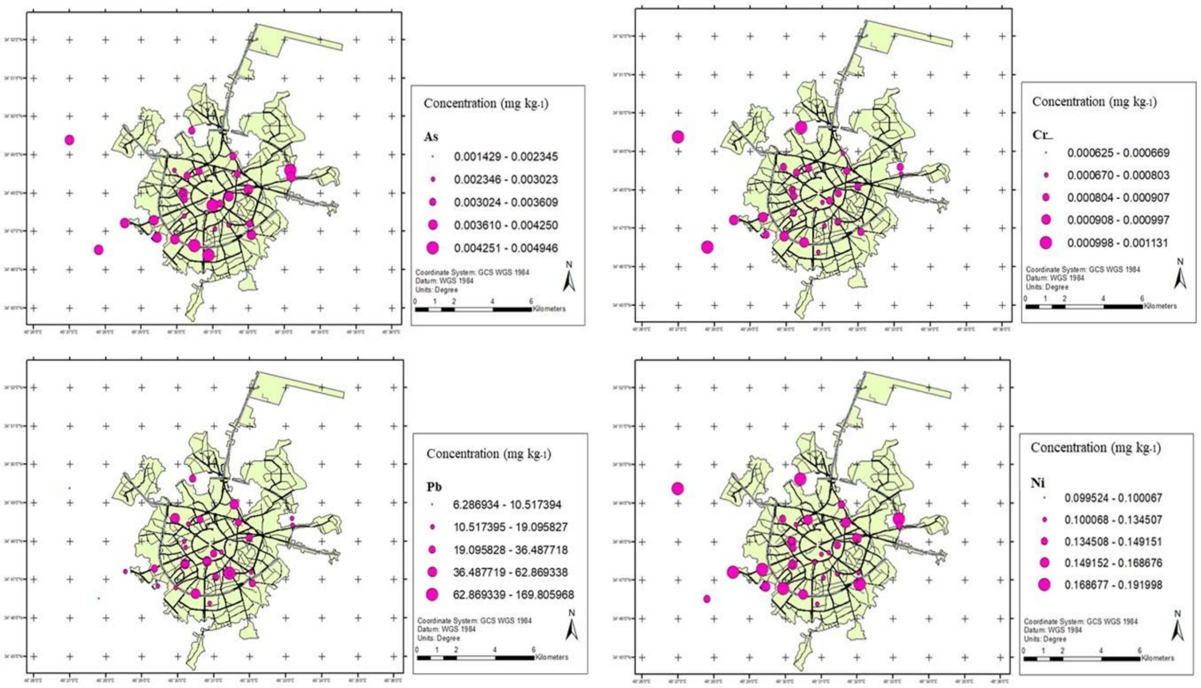

Fig.3. Distribution maps of total carcinogenic risk (TCR) for selected PHEs in Hamedan urban soils

CONCLUSION

This study was carried out to assess the non-cancer and cancer risks of potentially harmful elements in urban topsoils of Hamedan, Iran. Concentrations of target elements and consequently their average daily intakes were not found at levels that cause non-carcinogenic or chronic diseases for Hamedan residents. However, some alarming levels of risks from arsenic, chromium, and lead were recognized. The maximum levels of HI in children with 1.16 for As and 1.08 for Pb slightly exceeded the safe limit. These are the most enriched elements in the studied soils which have the potential to exert toxicity and induce health risk to the exposed population in the long term. The results also indicated that ingestion is the main pathway of PHEs' intake for both adults and children followed by dermal contact and respiratory exposures. Nevertheless, children appeared to be more vulnerable probably because of their low tolerance to toxic elements and they are at higher risk of exposure likely due to inadvertent ingestion of soils. This was also evident from the result of cancer risk where children showed high levels of TCRs compared to the moderate levels in adults. All of the investigated elements in urban soils of Hamedan exceeded the recommended limit of 1×10^{-6}, however, arsenic and chromium were found to be the most carcinogenic elements followed by Pb, Ni, and Cd. This study showed that more attention needs to be paid to PHEs' release and accumulation in urban soils of Hamedan to set efficient controlling strategies and mitigate the hazardous health impacts.

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CONFLICT OF INTEREST

The authors declare that there is not any conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy have been completely observed by the authors.

LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

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