

Health and Ecological Risk Assessment of Exposure to Toxic Heavy Metals Found in Settled Dust in the City of Kerman, Southeast of Iran

Azam Rajabi

Kerman University of Medical Sciences

Aliakbar Roudbari

Shahrood University of Medical Sciences

majid aghasi (✉ roodbari@shmu.ac.ir)

<https://orcid.org/0000-0002-9672-3646>

Research

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Abstract

Background: Heavy metals are toxic elements and can cause serious complications for human health. The aim of the study was to biological monitoring of heavy metals in blood of Kerman residents and its effective parameters.

Methods: This research is a cross-sectional descriptive study with the aim of bio monitoring of heavy metals found in blood of residents in Kerman. Sampling was conducted by random sampling at 8 sites on a total of 80 people (10 per site). The samples were examined by acid digestion using ICP-OES to measure the heavy metals.

Results: The results of the present study confirmed a concentration of toxic heavy metals in the blood of residents of Kerman. The maximum concentration of heavy metals were observed in the blood of the residents of Moshtagh and Azadi districts, which were the heavy-traffic areas of the city. A statistically significant relationship was seen between the concentration of some of the above elements and occupation, education and smoking. Statistical tests showed a significant relationship between lead concentration and age.

Conclusions: The results suggested that exposure to lead elements can cause some degrees of depression in humans. The presence of toxic heavy metals in the blood of residents can affect their health and also cause some complications.

1. Introduction

Aerodynamic particles with diameter smaller than 2.5 μm are considered as one of the most important air contaminants for human health [1, 2]. Dust is considered as a primary source of air contamination in urban environment. Dust particles contain a complex mixture of heavy metals, microorganisms, and numerous carcinogens. The source, composition and concentration of the components of these particles are different [3]. Toxic heavy metals include cadmium, lead, mercury, chromium and arsenic [4]. The chemical elements found in dust enter the blood circulation shortly after skin, digestive and respiratory contacts in human and reach most organs of the body [5].

Heavy metals enter urban dust because of human activities such as transport, social activities, and industrial productions. Dust contamination with heavy metals in urban environments threatens the health of residents [6]. In general, high concentration of heavy metals in the environment can cause health risks such as nervous system disorders, blood, cardiovascular system, kidney, and reproductive system. Its other effects are intelligence decline, attention deficit, and behavioral disorders [7]. In recent years, there is growing concern about the potential exposure to dust containing toxic metals in human. Some metals, such as copper and zinc are harmless in small contents, but some, such as lead, arsenic, mercury, and cadmium are toxic even at very low concentrations, and cause many diseases and cancers [8].

Cadmium and lead are naturally found in soil, and therefore, they can be transferred to air as dust by wind [9]. Dust found in the air, sits easily on the skin and causes heavy metals to enter the body through contact or digestion, or they enter the body directly through the respiratory tract, and finally all of them enter the blood circulation and can affect all organs of the body [10]. Traffic is a potential source of cadmium and lead as a result of combustion of fuel and braking, depreciation of tires, and other components in the air [11, 12].

The results of a study that was conducted to measure heavy metal contamination in the air of two major cities in an eastern province of Saudi Arabia by Sharkawy et al. showed that the concentration of metals in street dust was much higher than the environmental dust. This shows the great contribution of motor vehicles to environmental contamination with metals [13]. Allen et al. (2001) said that the distribution of metals in atmospheric aerosols in the UK has entered atmosphere through a combination of processes including human activities and transport [14]. The results of a study by Wahlin et al. in 2006 show that heavy metals are often associated with high traffic congestion [15].

The potential respiratory and neurological risks of exposure to metals found in the air in Kagiso, South Africa in 2015 was evaluated by Oosthuizen et al. [16]. A study that was carried out by Zheng et al. (2015) on the contamination characteristics and health risk assessment of heavy metals in the air collected from bus stations in Beijing showed that both carcinogenic and non-carcinogenic risk of the selected metals such as cadmium, chromium and lead are in safe range [17].

Measurement of heavy metal contamination level and estimate of health risk of their exposure for humans was conducted by Shabaj et al. in Jeddah, Saudi Arabia using the risk assessment model provided by the US Environmental Protection Agency (USEPA). The results showed that children and adults were at low non-carcinogenic risk. Moreover, the most considerable pathway of exposure has been reported to be the absorption through the skin [18]. The health risk of exposure to toxic heavy metals in dust found in the air of Hamadan city, Iran was evaluated by Sobhan Ardakani (2018). The results showed that the non-carcinogenic risk of chromium for both children and adults was in safe range, and the carcinogenic risk of chromium was below one and acceptable for residents [10]. The results of a study by Ghadimi et al. (2013) on 29 dust samples in city of Arak, Iran, confirmed the large amounts of heavy metals in urban dust [19].

The city of Kerman is located in the semi-arid regions and a decrease in annual rainfall has resulted in decreased vegetation. These factors have increased the amount of dust in the air. Thus, today, the incidence of dust and storms containing dust is increased and is one of the serious environmental issues of Kerman [20]. Consequently, the present research aimed to evaluate the health risk of exposure to heavy metals found in dust in the air of the studied area.

2. Methods And Materials

Study design

This research is a descriptive cross-sectional study and is conducted based on collecting dust samples from air of the city of Kerman in certain locations and measuring the concentration of their toxic heavy metals. The carcinogenic and non-carcinogenic risk of their exposure was also evaluated.

1. Study area

The city of Kerman is the capital of Kerman province in southeastern Iran and is located on a wide plain in a semi-arid area (Fig. 1). This city is located at latitude of 30.3 and longitude of 57.1. The elevation above sea level of this city is 1756 m. The area of the city of Kerman is 45401 km² and has a population of 634132 people based on Census of 2016 [21].

1. Sample Size Determination

Sample size was set at 24 based on the correlation calculated from the pilot study and using the sample size determination formula [22].

1. Sample locations

In Fig. 2, the borders of eight dust sampling sites in city of Kerman have been specified. At each location, the sampling was carried out at a radius of 5 km. The names of the sampling locations were Jihad Boulevard, beginning of Kuhpayeh Road, Havaniruz junction, Kowsar Square, Resalat Boulevard, Azadi Square, Moshtagh Square, and Khaju Square.

1. Sampling

Dust sampling was performed using Dust Fall Jar method. Dust settling container is an open container that is used for collecting particles of air. In this apparatus, the deposition method is used [23]. In eight locations noted in Map 2, the sampling was conducted 3 times and each time during 30 days. The sampling container was installed 2 m above the ground and was filled with water by half. The container was covered by net to prevent the birds and other objects from entering. The samples were transferred to the laboratory after collection. The sampling was performed during the first 6 months of 2019.

1. Sample preparation

Preparation of air settling particle samples was conducted based on the method used by Shao et al. with slightly modification [6]. The samples were digested with a mixture of HF-HNO₃-HClO₄. The preparation steps were as follows. The collected dust sample was dried by heating and 0.5 g of the dried dust sample was dissolved in 50 ml of polytetrafluoroethylene in crucible, and then 5 ml of HF, 5 ml of HNO₃, and 3 ml of HClO₄ were added. The solution-containing container was heated to reach an almost dry state. Then 3 ml of HF, 3 ml of HNO₃, and 1 ml of HClO₄ were added and heated to approximately reach the dried state. Afterwards, 5 ml of 1 mol/L of HNO₃ solution was used as solvent. Finally, the samples were kept in a 25 ml container until analysis.

1. Sample analysis

Analysis of elements was performed using Inductively Coupled Plasma Spectroscopy Method (ICP-OES) made in Australia with a detection limit of ppm to ppb. In this method, the wavelength calibration was performed using internal calibration by a mercury vapor lamp [24].

1. Data Analysis

Data analysis was performed using SPSS v. 26 and Excel 2019. The central tendency and dispersion indicators were used for data description and the correlation analysis was used for data analysis.

1. Data interpretation

In this research, various environmental indicators have been used to determine the level of heavy metal contamination. These indicators are as follows: Index of geoaccumulation (Igeo), Enrichment factor, Pollution load index (PLI), Potential ecological risk, and Health risk assessment.

1. Index of geoaccumulation (Igeo)

Igeo is used to assess the metal contamination in settle dust [25]. It is computed using Equation1:

$$I_{geo} = \log_2 \left(\frac{C_n}{1.5B_n} \right) + 1$$

Where C_n is the measured concentration of the examined metal in the settled dust and B_n is the geochemical background concentration of the metal. Factor 1.5 was used because of possible variations in background values for a given metal in the environment as well as very small anthropogenic influences. The geoaccumulation index (I_{geo}) was distinguished into seven classes. $I_{geo} \leq 0$, class 0, unpolluted; $0 < I_{geo} \leq 1$, class 1, from unpolluted to moderately polluted; $1 < I_{geo} \leq 2$, class 2, moderately polluted; $2 < I_{geo} \leq 3$, class 3, from moderately to strongly polluted; $3 < I_{geo} \leq 4$, class 4, strangle polluted; $4 < I_{geo} \leq 5$, class 5, from strongly to extremely polluted; and $I_{geo} > 5$, class 6, extremely polluted [26, 27].

1. Enrichment factor

The enrichment factor of the metals in settled dust was calculated based on Eq. 2 using iron as a reference element since it is the most naturally abundant element in soil [28].

$$EF = \frac{\left(\frac{M}{Fe}\right)_{sample}}{\left(\frac{M}{Fe}\right)_{shale}} - 2$$

Where EF is enrichment factor, $[M]_{sample}$ and $[Fe]_{sample}$ are the concentrations of each metal and iron at various location of the dumpsite, while $[M]_{shale}$ and $[Fe]_{shale}$ are average shale concentrations of each metal and iron. Enrichment factor is an indication of the level of accumulation of the element of interest to the natural background level. Thus, it measures the geochemical trend and can be used in making comparisons between an area and overtime. Five contamination categories are recognized on the basis of enrichment factor [29]. These categories are: Deficiency to minimal enrichment for values below 2, Moderate enrichment for values from 2 to 5, Significant enrichment for values from 5 to 20, Very high enrichment for values 20 to 40, Extremely high enrichment for values above 40.

1. Pollution load index (PLI)

The pollution load index (PLI) is another simple method to assess the level of pollution, was calculated using Eq. 3. In this study, PLI is determined the method proposed by Saleh et. al. [30].

$$PLI = \sqrt[n]{C_{F1} \times C_{F2} \times \dots \times C_{Fn}} - 3$$

Where n is the number of metals studied and CF is the contamination factor calculated based on Eq. 4.

The PLI gives an estimate of the metal contamination status and the necessary action that should be taken. $PLI < 1$ denotes perfection; $PLI = 1$ presents that only baseline levels of pollutants are present, and $PLI > 1$ would indicate deterioration of site quality.

1. Potential ecological risk

Potential ecological risk indicator has been used to evaluate the potential environmental risks of metals in dust. In the present study, equations 4 and 5 were used to calculate the ecological risk of heavy metals. In this study, Potential ecological risk is determined the method proposed by Zhang et. al. [31].

$$Er^i = T_r^i \times C_f^i C_b^i = \frac{C_i}{C_b} - 4$$

$$RI = \sum_{i=1}^m Er^i - 5$$

Where, C_f^i is Contamination factor of the element, C_i is Concentration of the element in the soil sample, C_b is Background concentration of the element reference soil (lead = 25, Arsenic = 4.52, cadmium = 0.25, chromium = 79)

Where T_r^i =toxic response factor of a given element (lead = 5, Arsenic = 10, cadmium = 30, chromium = 2). Er^i is the potential ecological risk index of a single element; RI is a comprehensive potential ecological risk index [32].

The following terminology were used for the potential ecological risk index: $Er^i > 40$, low potential ecological risk; $40 \geq Er^i > 80$, moderate potential ecological risk; $80 \geq Er^i > 160$, considerable potential ecological risk; $160 \geq Er^i > 320$, high potential ecological risk; and $Er^i \leq 320$, very high ecological risk and The following terminology are used for the potential ecological risk index: $RI > 150$, low ecological risk; $150 \geq RI > 300$, moderate ecological risk; $300 \geq RI > 600$, considerable ecological risk; and $RI \leq 600$, very high ecological risk [29].

1. Health risk assessment:

Health risk assessment was conducted based on the risk assessment of human exposure to risks introduced by U.S. EPA [33]. It was assumed in the present study that the residents receive heavy metals in the dust mainly through mouth, respiration and skin contact.

In this study, the contaminants / human body weight (mg/kg × day) was used to represent the exposure to contaminants. Formulas 6 to 8 show the average daily exposure to dust through the mouth, skin contact and inhalation, respectively. Formula 9 is the average daily exposure through inhalation of carcinogenic heavy metals. Similar to other studies, the respiratory exposure is considered in this study to evaluate the carcinogenic risk [6].

The daily average exposure dose through hand-mouth feeding (ADD_{ing}):

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

The daily average exposure dose through skin contact (ADD_{dermal}):

$$ADD_{dermal} = C \times \frac{SA \times SL \times ABS \times EF \times ED}{BW \times AT} \times 10^{-6} \quad 7$$

The daily average exposure dose through inhalation (ADD_{inh}):

$$ADD_{inh} = C \times \frac{InhR \times EF \times ED}{PEF \times BW \times AT} \quad 8$$

The daily average exposure for life through inhalation of carcinogenic heavy metal (LADD_{inh}):

$$LADD_{inh} = \frac{C \times EF}{PEF \times AD} \times \left(\frac{InhR_{adult} \times ED_{adult}}{BW_{adult}} + \frac{InhR_{child} \times ED_{child}}{BW_{child}} \right) \quad 9$$

Where the ADD_{ing}, ADD_{inh} and ADD_{dermal} are the average daily dose (mg kg⁻¹ day⁻¹) exposure to metals through ingestion, inhalation and dermal contact, respectively. LADD is the lifetime average daily dose exposure to metals (mg kg⁻¹ day⁻¹) for cancer risk, The detailed description of the values of exposure factors for children and adults applied to the above models (Equations 5– 8) are given in Tables 1 and 2 [6].

Table 1
Values of exposure factors for heavy metals doses for children and adults

Parameters/Unit	Description	adult	child
C/mg/kg	Concentration of metals in dusts		
EF/mg/day	Exposure frequency	180	180
ED/years	Exposure duration	25	6
BW/kg	Average body weight	70	15
AT/days	Average time	ED × 365 (non-carcinogen) 70 × 365 (carcinogen)	ED × 365 (non-carcinogen) 70 × 365 (carcinogen)
IngR/mg.d ⁻¹	Ingestion rate of dust	100	200
InhR/m ³ .d ⁻¹	Inhalation rate of dust	20	10
SA/cm ²	Surface area of skin exposed to dust	3300	2800
SL/mg.cm ⁻² .d ⁻¹	Skin adherence factor	0.07	0.2
PEF/m ³ .kg ⁻¹	Particular emission factor	1.36 × 10 ⁹	1.36 × 10 ⁹
ABS	Absorption factor (Dermal)	0.001	0.001

Table 2
RfD and SF values of heavy metals

Element	ing RfD	Dermal RfD	Inhal. RfD	SF Inhal.
Pb-non cancer	3.50E-03	5.25E-04	3.50E-02	
Pb- cancer				8.40E-01
Cd-non cancer	1.00E-03	1.00E-05	0.001	
Cd-cancer				6.30E + 00
Cr-non cancer	3.00E-03	6.00E-05	0.0001	
Cr-cancer				4.20E + 01
As-non cancer	3.00E_04	1.00E-05	1.00E-03	
As-cancer				1.51E + 01

In order to evaluate the human health risk of heavy metal exposure from dusts in Kerman, the HQ (Non-carcinogenic hazard quotient), HI (hazards index), and Risk (carcinogenic risk assessment) were applied. The potential risk of carcinogenic and non-carcinogenic hazards for individual metals were calculated using the following equations [12].

$$HQ = \frac{ADD}{RfD} 10$$

$$HI = \sum HQ_i 11$$

$$Risk = LADD \times SF 12$$

$$Risk_T = \sum Risk_i 13$$

Where RfD and SF are the values of reference dose ($\text{mg kg}^{-1} \text{day}^{-1}$) and slope factor. RfD is an estimation of maximum permissible risks to human population through daily exposure. It is recommended that the value of $Risk < 10^{-6}$ can be regarded as negligible, whereas $Risk > 10^{-4}$ is likely to be harmful to human beings. The acceptable or tolerable risk for regulatory purposes is in the range of $10^{-6} \sim 10^{-4}$. If the value of $HQ \leq 1$, there is no adverse health effect. The value $HQ > 1$, adverse health effects occur. HI value show the sum of the value of the HQ for different substance through different pathways and refers to total risk of non-carcinogenic for a single metal. The value of $HI \leq 1$ refers that there is no significant non-carcinogenic risk. On the other hand, there is a chance that non-carcinogenic effects may occur when $HI > 1$, and the probability increase with increasing the value of HI [6, 34].

3. Results

The descriptive results of the heavy metals measurement in the settled dust found in the air of the city of Kerman are shown in Table 3.

Table 3
Descriptive information of heavy metals in air dust in Kerman

Location	Sample	Heavy metal concentration (mg/kg)				
		Pb	Cd	AS	Cr	Fe
1	1	67.17	0.23	8.25	36.17	13671
	2	63.27	0.19	6.93	31.75	11396
	3	60.49	0.17	6.29	28.93	12528
	Mean ± SD	63.64 ± 3.35	0.19 ± .030	7.15 ± 0.99	32.28 ± 3.64	12531.66 ± 1137.50
2	1	84.23	0.44	10.61	34.12	13759
	2	81.31	0.41	9.7	31.72	11856
	3	73.62	0.32	7.67	27.73	13281
	Mean ± SD	79.73 ± 5.48	0.39 ± 0.062	9.32 ± 1.51	30.99 ± 3.22	12965.34 ± 989.99
3	1	82	0.29	9.43	40.75	14262
	2	79.17	0.23	9.15	36.18	13897
	3	71.29	0.19	8.75	31.57	14359
	Mean ± SD	78.48 ± 5.54	0.23 ± 0.05	9.11 ± 0.34	36.16 ± 4.59	14172.67 ± 243.61
4	1	89	0.37	12.5	46.91	12528
	2	86	0.31	11.2	41.32	14379
	3	81	0.27	9.3	37.16	13698
	Mean ± SD	85.33 ± 4.04	0.31 ± 0.05	11 ± 1.61	41.70 ± 4.89	13535 ± 936.20
5	1	72	0.30	10.91	41.51	13693
	2	69	0.27	9.32	37.33	12685
	3	57	0.21	7.53	31.57	14593
	Mean ± SD	66 ± 4.04	0.26 ± 0.05	9.25 ± 1.60	36.80 ± 4.89	13657 ± 954.50
6	1	93	0.45	14.6	52	17884
	2	89.12	0.39	12.8	47.6	15893
	3	81.23	0.36	11.2	41.8	16742
	Mean ± SD	87.78 ± 5.99	0.4 ± 0.04	12.86 ± 1.70	47.13 ± 5.11	16839.67 ± 999.08
7	1	47.23	0.5	12.8	42	18955
	2	51.01	0.7	13.6	43.7	16564
	3	83.37	0.43	13.53	49.13	14398
	Mean ± SD	60.53 ± 19.82	0.54 ± 0.14	13.31 ± 0.44	44.27 ± 3.72	16639 ± 2279.42
8	1	79	0.39	11.21	42.17	15682
	2	71.12	0.29	9.78	39.19	13994
	3	63.15	0.23	7.91	34.67	14195
	Mean ± SD	71.09 ± 7.92	0.3 ± 0.08	9.63 ± 1.65	37.66 ± 3.77	14623.67 ± 922.03
Total	24	73.94 ± 12.26	0.33 ± 0.12	10.20 ± 2.27	38.62 ± 6.51	14370.50 ± 1818.47
standard		19	0.35	7.2	54	26000
The results of the Igeo, EF and PLI formulas are presented in Table 4.						

Table 4
Index of geoaccumulation (Igeo) and Enrichment factor (EF) of heavy metals in the settled dust

Metal	Igeo	EF	PLI
Pb	0.98	4.32	1.234
Cd	3.11	1.92	
Cr	-1.62	0.71	
As	0.59	3.29	
Fe	-1.13	1	

The results obtained from formulas of potential ecological risk are presented in Table 5.

Table 5
The potential ecological risk index of heavy metals in the dust

Metal	Cf	E _r ⁱ
Pb	2.95	14.75
Cd	1.32	39.6
Cr	0.49	0.98
As	2.25	22.5
Fe	0.68	-
total		77.83

The non-carcinogenic risk (HQ) of all three pathways (ingestion, skin contact and inhalation) for each of the heavy metals for children and adults are presented in Tables 6 and 7.

Table 6
Non-carcinogenic risk of heavy metals in each route of Kerman air dust by adults and children

metal	ADD inh		ADDing		ADD derm		HQ inh		HQ ing		HQ derm	
	Non carcinogen		Non carcinogen		Non carcinogen		Non carcinogen		Non carcinogen		Non carcinogen	
	child	adult	child	adult	child	adult	child	adult	child	adult	child	adult
Pb	17.8E-09	7.06E-09	486.18E-06	52.91E-06	1.36E-06	0.12E-06	5/11E-07	2/02E-07	138908/8E-06	14883/08E-06	0/25E-02	0/02E-02
Cd	0.08E-09	0.03E-09	2.16E-06	0.23E-06	0.05E-07	0.05E-08	79E-09	33E-09	2.16E-06	230E-06	500E-06	50E-06
Cr	9.34E-09	4.002E-09	253.94E-06	27.21E-06	0.71E-06	0.06E-06	93360E-09	40011E-09	84646/56E-06	9069/26E-06	1185E-06	1046/66E-04
As	2.46E-09	1.05E-09	67.07E-06	7.18E-06	0.17E-06	0.01E-06	2/46E-06	1/05E-06	22/35E-02	2/39E-02	0/18E-01	0/01E-01
HI							96.41E-06	40.25E-06	223557.52E-06	24182.34E-06	1685E-06	1096.66E-06

Table 7
Risk of carcinogenicity of heavy metals in each route of Kerman air dust by adults and children

metal	LADD-carcinogen
Pb	4.26E-09
Cd	0.02E-09
Cr	0.59E-09
As	2.23E-09

4. Discussion

The descriptive results of the heavy metals measurement in the settled dust found in the air of the city of Kerman are shown in Table 3.

The results show that the highest concentration of lead is at Azadi Square (district 6) and the highest concentration of cadmium, arsenic and chromium is at Moshtagh Square (district 7). The lowest concentration is at Moshtagh Square (district 7) for cadmium and arsenic, at Khaju Square (district 1) of lead, and for chromium at beginning of Kuhpayeh Road (district 2). The standards of heavy metals found in dust presented by U.S. Environmental Protection Agency (U.S.EPA) are shown in Table 3 [35]. According to this table, the arsenic and lead levels are above the permissible limit and the levels of cadmium, chromium and iron are below the permissible limit.

Districts 6 and 7 are among the crowd areas of the city. District 6 was related to the Azadi Square area. Due to the heavy traffic, the dust in the air in this part of the city has the highest concentration of lead. District 7 was related to the Moshtagh Square area. The high concentrations of metals such as cadmium, arsenic and chromium in this area can be associated with small industrial workshops and heavy traffic of vehicles. To determine the relationship between vehicle traffic and heavy metals in dust, some studies are performed by Adedeji (2013) in Nigeria [36], Zhang (2012) in Tibet [37], and Wang (2016) in China [38]. The results of the above studies showed that with an increase in vehicle traffic, the heavy metals in the dust are increased.

1. Index of geoaccumulation (Igeo), Enrichment factor, Pollution load index (PLI)

The results of the Igeo, EF and PLI formulas are presented in Table 4. According to Table 4, it was found that average level of measured EF was reduced as $Cr < Fe < Cd < As < Pb$. In other words, it can be said that the highest dust enrichment with metals based on EF index is related to lead and the lowest is related to chromium. The average level of Igeo also had a downward trend: $Cr < Fe < Cd < As < Pb$, such that the Igeo index also showed that the highest and lowest levels of dust enrichment with metals are related to lead and chromium, respectively. The index values of Igeo were negative for cadmium, chromium and iron, which represent no environmental contamination with these three elements, whereas lead and arsenic elements have no contamination to average contamination. The PLI value was above 1, representing contamination with dust elements in the air of Kerman city.

According to the PLI index, the dust in the air of this city is contaminated. This is also in agreement with the results of the study by Mmolawa et al. [39]. In the present study, the highest amount of dust enrichment with metals is related to lead. This element is an unnecessary metal for the human body and its excessive absorption can cause damages to the nervous, circulatory, enzymatic, skeletal, endocrine, and immune systems [40–42]. The results of a similar study by Addo et al. to investigate the heavy metal contamination in Ghana showed that the highest amount of enrichment was related to lead with moderate contamination. In the mentioned study, the PLI index was also higher than 1 that represents contamination with dust elements in the air of that city [43]. The results of another study in Nigeria by Ihedioha et al. showed that the PLI index is smaller than 1 that indicates no contamination with metals found in dust in the air. Although this waste was highly enriched and is heavily contaminated with cadmium, the contamination had not reached to the point that requires an immediate intervention to alleviate contamination [27].

1. Potential ecological risk

The results obtained from formulas of potential ecological risk are presented in Table 5. The results show that the potential ecological risk is low for all the measured metals given the RI value (total ecological risk of elements) that was equal to 77.83, and therefore is low. In the present study, the total ecological risk of the elements was low. This is consistent with results of the study by Xiong et al. in China, year 2017 [44]. A similar study was conducted by Boban et al. to evaluate the ecological risk of heavy metal contamination in Montenegro. The results showed that the highest ecological risk was related to cadmium and the average ecological risk of all studied elements was low [45]. The results of another study in Ghana by Nkansah showed that the potential ecological risk of elements was high, and the difference in the results compared to the present study is due to the large amount of contamination with arsenic in that country [46].

1. Carcinogenic and non-carcinogenic risk assessment

The human health risk assessment is caused by the exposure to heavy metals found in dust samples in the air. The non-carcinogenic risk (HQ) of all three pathways (ingestion, skin contact and inhalation) for each of the heavy metals for children and adults are presented in Tables 6 and 7. According to the results shown in Table 6, the HI value was 0.45. Since it is below 1, the non-carcinogenic risk of the toxic heavy metals found in dust in the air is low or insignificant. Given that the $Risk_T$ value is calculated equal to 106.14×10^{-9} , it was found that the heavy metals in the air have no carcinogenic risk.

According to the carcinogenic and non-carcinogenic risk assessment of the present study, the highest HQ in both age groups for all heavy metals was higher through ingestion than skin absorption and respiration, and this is in agreement with the results of the study by Li et al., and We et al. It is said in the studies that the level of HQ in the ingestion and respiration pathways in children is higher than the adults, and it is reported to be more for adults than children in the skin absorption pathway [47, 48]. In other studies, such as Tianjie et al. in China, the non-carcinogenic risk of exposure to lead and cadmium in the air has been reported to be high for both adults and children [6].

5. Conclusion

Given that the city of Kerman is located in a semi-arid area, its residents are daily exposed to dust. Dust-containing storms sometimes exacerbate this matter. The results of the present study confirmed a concentration of toxic heavy metals such as lead, cadmium, arsenic and chromium in the dust found in the air of Kerman. Due to the accumulative nature of these elements in nature, the presence of these toxic elements in the dust found in the air and its respiration can cause health-related complications in the residents and increase the ecological risk. According to the calculated concentration of elements and a comparison with standards, it can be concluded that the levels of cadmium, chromium and iron are below the permissible limit and has no a serious risk for health, and the levels of arsenic and lead are above the permissible limit and can threaten the health of residents, especially children.

Abbreviations

USEPA
United States Environmental Protection Agency
ICP-OES
Inductively Coupled Plasma Spectroscopy Method
Igeo
Index of geoaccumulation,
PLI
Pollution load index
ADDing
Average daily dose ($\text{mg kg}^{-1} \text{ day}^{-1}$) exposure to metals through ingestion
ADDinh
Average daily dose ($\text{mg kg}^{-1} \text{ day}^{-1}$) exposure to metals through inhalation
ADDdermal
Average daily dose ($\text{mg kg}^{-1} \text{ day}^{-1}$) exposure to metals through dermal contact
HQ
Non-carcinogenic hazard quotient
HI
Hazards index

Declarations

Ethics approval and consent to participate: This research has been registered with code: IR.KMU.REC.1398.292 on 18 September 2019, in Ethics Committee of Kerman University of Medical Sciences.

Consent to publication: Not applicable.

Availability of data and material: All required data are included in manuscript.

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Authors' contributions: M. Aghasi designed the study and wrote the manuscript. A. Rajabi Analyzed the data, did the experiments and edited the draft. A.A. Roudbari edited the draft and wrote the discussion section and edited the draft.

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Competing interests

The authors declare that they have no conflict of interests.

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Figures

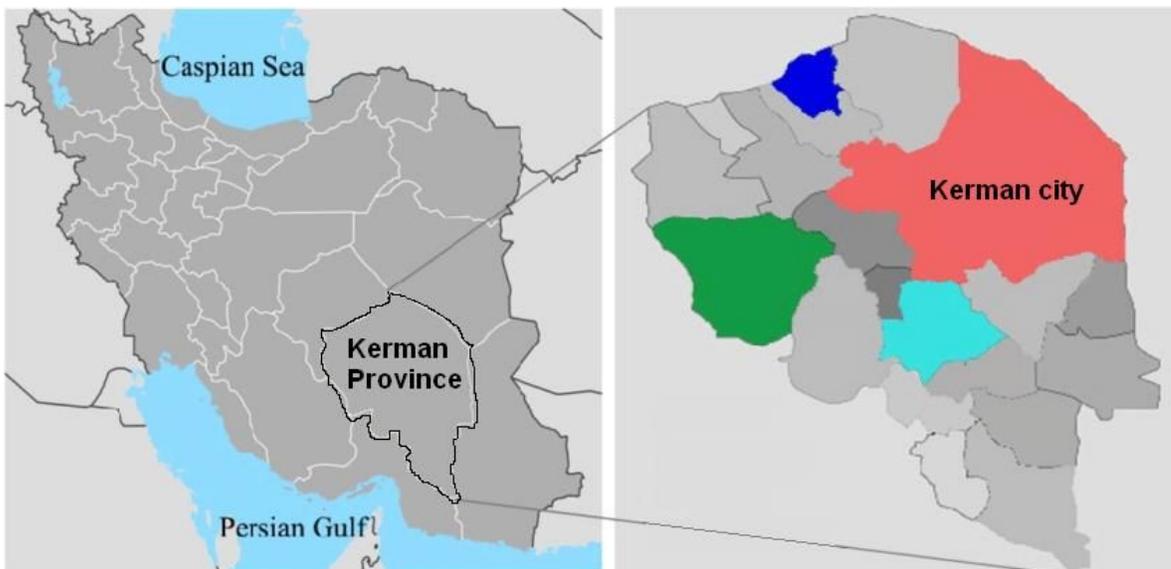


Figure 1

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Study Area (Kerman City)

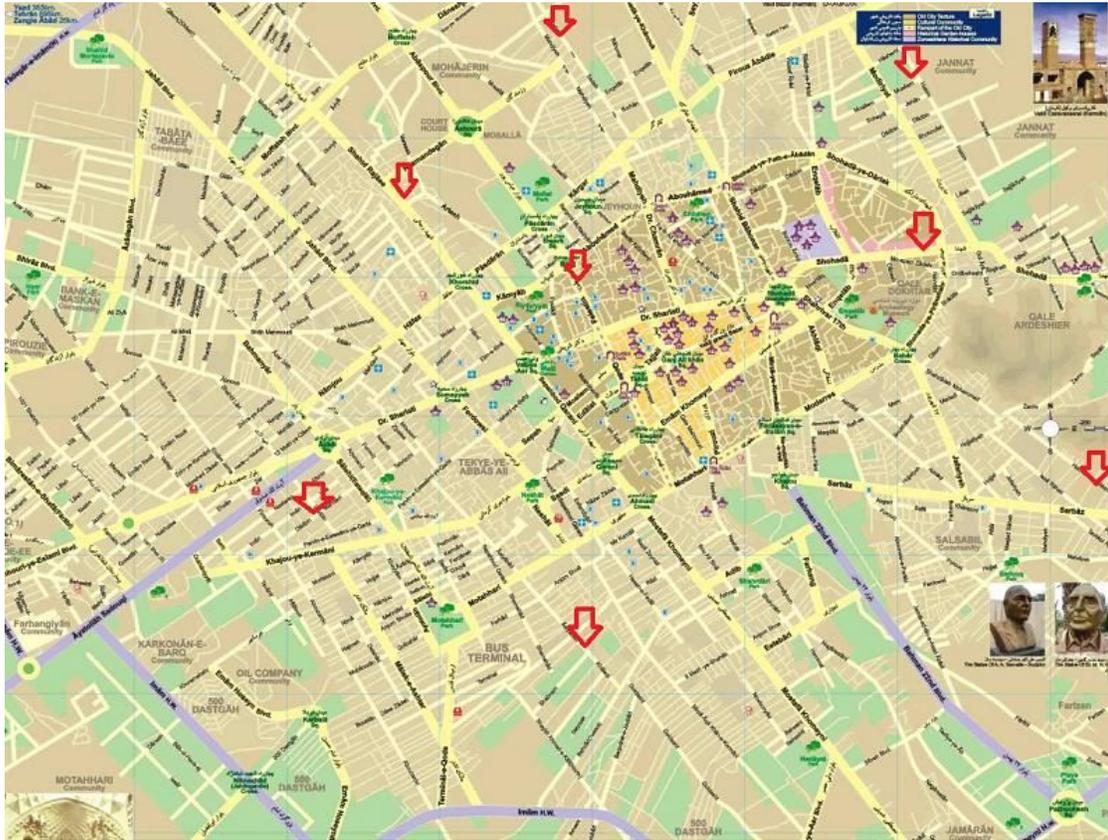


Figure 2

Dust sampling sites in Kerman