Hazard, ecological and human health risk assessment of heavy metals in street dust in Dezful, Iran

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Abstract

This study aimed to investigate the potentially toxic metal (Pb, Zn, Cu, Cr, Cd, Ni, V, As, and Co) hazard in street dust from Dezful, Iran. For this purpose, we collected 30 samples of street dust from the main pedestrian sidewalks of Dezful. Subsequent heavy metal concentration data for these samples was evaluated using human health risk and potential ecological risk index (RI) assessments. The average toxic metal concentrations for Pb, Zn, Cu, Cr, Cd, Ni, V, As, and Co were 54, 224, 51, 44, 0.4, 46, 38, 3, and 8 (mg/kg), respectively. Except for As, V, and Co, the mean concentration value of all heavy metals was several times higher than that of baseline concentrations. Calculations for potential ecological risk (PER) suggested a low street dust ecological risk from Pb, Zn, Cu, Cr, Ni, and V, while Cd presented a moderate ecological risk level. The highest hazard quotient (HQ) in children and adults was related to Pb by ingestion, while the lowest value was for Cd via inhalation. For all heavy metals, the hazard index (HI) was higher for children than adults, which confirmed the risk of exposure to these potentially harmful heavy metals is higher for children. The cancer risk (CR) value for Ni, As Cd and Pb for children and adults, were lower than the threshold, 10^{-6}, suggesting that the cancer risk for the majority of heavy metals measured was negligible, but more significant than the threshold for Cr, indicating that the presence of Cr in street dust requires urgent attention.

Keywords: Heavy metal pollution, Hazard index, Street dust, Spatial distribution, Dezful

Introduction

Dust is one of the main causes of human exposure to potentially harmful metals in the urban environment (Lu et al., 2014b; Rout et al., 2013; Ghanavati and Nazarpour, 2018). Natural factors contributing to more elevated concentrations of metals in dust include parent material and processes of soil formation, coupled with anthropogenic factors, including industrial activities, traffic, fuel combustion, waste disposal and constructions (Holnicki et al., 2017; Lu et al., 2014a). Potentially toxic metals can affect human health through exposure pathways including direct human contact, transfer to plants and animals, thus entering the human food chain, contamination of surface and groundwater drinking supplies and inhalation (Bourliva et al., 2017; Ander et al. 2016; Nazarpour et al., 2017). Metals accumulate in fat and muscle tissue, and bones, contributing to the prevalence of numerous diseases and conditions (Khan et al., 2008). Exposure to street dust containing potentially toxic metals has reported pathways and implications for human health via ingestion, dermal contact, and inhalation over varying periods of time (Nazarpour et al., 2018; Yufeng Jiang et al., 2017b). Accordingly, several studies have been conducted on the human health risks associated with toxic metal contamination in street dust and soil (Ebqa'ai and Ibrahim, 2017; Lin et al., 2015; Dehghani et al., 2017). Children are particularly susceptible to the ingestion of dust via hand to mouth contact (Wei et al., 2015). Therefore, health risk assessment calculations are considered as a tool to assess health outcomes (cancerous and non-cancerous outcomes) and pathways of exposure to risk factors (chemical contaminants, toxic metals, etc.) to inform a risk management strategy (Ahmadi et al., 2015; Ghanavat and Nazarpour, 2016). Behravesh et al. (2015) reported that street dust in Mashhad city (Iran) contained potentially toxic metals such as Pb, Cu, Zn and Ni at concentrations above background levels, in addition to a positive correlation between toxic metals like Zn and Cu, as well as Pb and Zn to potential sources. For example, fuel consumption as well as wear and tear from vehicle brake linings and tires. Similarly, Ghanavati (2018) reported that the HI for toxic metals in street dust of Abadan, Iran, was higher for children than adults, showing that children were at higher risk of exposure to toxic metals than adults. In both age groups, Cr had the highest cancer risk index, while Pb had the lowest value. Likewise, Ravankhah et al. (2015) showed that the average concentrations of Cd, Pb, Ni, Zn, and Cu in the regions of Aran and Bidgol were higher than the local baseline concentrations. Also, the highest hazard index (HI) in both children and adults was for Pb, while the lowest value was found for Zn. Besides, the HI of all metals for children older than 17 years and adults were found to be more than 2. Studies by Zhang et al. (2013) in the suburbs of Shanghai showed that the average amount of heavy metal concentrations in the samples gathered from small cities street dust was much higher than the amount of background concentrations found within the soil. Pollution from toxic metals was found to be relatively high, posing serious potential environmental hazards. Over the past few years, large amounts of atmospheric dust have entered Iran through the western borders with Iraq, Saudi Arabia, Syria, and Jordan, which are the main source of dust transfer to Western Iran, especially in Khuzestan province and Dezful city, as the second-largest city in terms of the size and population after Ahvaz in Khuzestan province. Zarasnavdi et al. (2011) reported that Dezful city with an average of 159 days from 1996-2009 has the highest number and duration of summer dusty days in Khuzestan.

Accordingly, this study aimed to undertake a hazard assessment of exposure to potentially toxic metals in street dust of Dezful city by 1) determining the toxic metal concentrations (Pb, Zn, Cu, Cd, Ni, Cr, As, V and Co) in street dust, 2) source apportionment of metal pollution (natural or anthropogenic), and 3) calculate the potential hazard for human and ecological health through exposure to metals from street dust.

Materials and methods

Study area

Dezful city is located at 32°50'40" N and 48°20'21"E with approximately 443,000 inhabitants in 2016 in south-west Iran-Iraq border; the deserts located in this region are the main sources of dust storms over Iran (Gilavand & Mohammadbidaghi, 2019). The combustion of fossil fuels like oil and gas, industrial pollution as well as traffic on the city streets have been reported as the main sources of the city pollutants. Thus, it is important to assess the potential ecological and human health risk factors of toxic metals in Dezful street dust in order to better manage the existing contaminants.

Sampling and analysis

To investigate the concentration of the toxic metal in Dezful, we collected 30 samples of street dust in the dry season in May 2016, from the city's hotspots, squares, main streets, shopping centers, residential areas, sidewalks, and other places where dust had accumulated. Figure 1 shows the distribution map of the sampling points. The street dust samples were selected from 30 points in such a way to cover the area thoroughly. The samples were combined in a mixture of 3 samples at intervals of 5 to 10 m and weighed approximately 100 g. Surface dust samples were separated with brushes and placed in amber glasses without the interference of any metal tools. They were then sealed with aluminum foil to prevent exposure to the direct light. Dust samples were air-dried, passed them through a 220mesh (63µm), and then stored in polyethylene bags; labeling carried out based on McKenzie et al. (2008).

Extraction and analysis of heavy metals

For each sample, we digested 0.35 g in 10 ml of Aqua regia (HCl, HNO_3) in a ratio of 3: 1 in PTFE Teflon containers at 160 ° C for 6 hours (Ruuskanen et al., 2014) and made up its volume to 50 ml with deionized water. Afterward, the metals Ni, Pb, Cu, Zn, Cd, Cr, Co, As, and V were measured by an Atomic Absorption Spectroscopy (AAS, Xplora, and GBC models).

To determine the existence of metal ions PerkinElmer Model 3110 atomic absorption spectrometer equipped with PerkinElmer single-element hollow cathode lamps and 10-cm air-acetylene burner was used. The Analytical parameters for PerkinElmer 3110 AAS were; 357.9 nm wavelength, 0.7 mm slit width and 12 mA lamp current for Pb element; 324.7 nm wavelengths, 0.7 mm slit width and 15 mA lamp current for Cu element; 213.9 nm wavelength, 0.7 mm slit width and 15 mA lamp current for Zn element; 193.7 nm wavelength, 0.7 mm slit width and 380 W lamp current for As element; 228.8 nm wavelength, 0.7 mm slit width and 5 W lamp current for Cd element; 357.9 nm wavelength, 0.7 mm slit width and 25 mA lamp current for Cr element; 232 nm wavelength, 0.2 mm slit width and 25 mA lamp current for Ni element (Kariper,2015; Lauenstein and Cantillo, 1998). Standard soil reference material, SRM2711 Montana II (NIST, Canada) was used to measure the accuracy and reproducibility of analyses. For assurance and control of quality, we used duplicates, method blanks, and standard reference materials. The amount of individual metals recovery in SRM 2711 materials was in the range of 88-109%. The comparative percentage difference was less than 10% among sample duplicates.

Pollution assessment

Potential Ecological Risk (PER)

The potential ecological risk of toxic metals was assessed using the method presented by Hakanson (Hakanson, 1980). Many researchers have evaluated the potential environmental hazards of toxic metals in soil and street dust samples using this method (Soltani et al., 2015; Sun et al., 2010). The calculation of potential ecological risk index was as follows:

$$\mathbf{C_f = {}^{C_S}/_{C_n}} \quad (1)$$

$$\mathbf{E_r = T_r \times C_f} \quad (2)$$

$$\mathbf{RI = \sum_{i}^{n} E_r} \quad (3)$$

In this equations, C_s represents the toxic metal concentration in the selected sample, C_n represents the corresponding toxic metals background value, T_r represents the toxicity response factor of each toxic metal, which are 30, 5, 5, 5, 2, 1 and 2 for Cd, Ni, Cu, Pb, Cr, Zn, and V, respectively (Hakanson, 1980), E_r represents the potential ecological risk of each studied metal. The risk index in equation 3 corresponds to the sum of potential ecological risk for multiple toxic metals. The values of potential ecological risk can be classified as follows: Low (Er<40), moderate (40≤Er<80), considerable (80≤Er<160), high (160≤Er<320) and very high potential ecological risk (Er≥320)(Zhao et al., 2014); the contamination levels were classified according to the risk index in four groups: low (RI<150), moderate (150≤RI< 300), significant (300≤RI< 600) and high ecological risk (RI≥600).

Health Risk assessment

Human health risk assessment of carcinogenic or non-carcinogenic toxic metals was conducted as a multi-stage process in two parts based on the US Environmental Protection Agency (USEPA) (Sinha et al., 2007). The average daily dose value (ADD) (mg/kg/day), the risk of exposure to a contaminant by ingestion, inhalation, and dermal contact were estimated using equations 4, 5 and 6 (Bennet et al., 2001):

$$\mathbf{ADD_{ing} = \frac{C \times IngR \times CF \times EF \times ED}{BW \times AT}} \quad (4)$$

$$\mathbf{ADD_{inh} = \frac{C \times InhR \times EF \times ED}{PEF \times BW \times AT}} \quad (5)$$

$$\mathbf{ADD_{dermal} = \frac{C \times SA \times CF \times AF \times ABF \times EF \times ED}{BW \times AT}} \quad (6)$$

In which ADD_{ing}, ADD_{inh}, ADD_{dermal} are respectively the average daily metal intake (mg/kg-day) by ingestion, inhalation, and dermal contact. C is the concentrations of metals in the dust (mg/kg), IngR and InhR are the ingestion rate and inhalation rate of dust (mg/day and m^3/day), respectively; EF is the exposure frequency to metals (day/year), ED is the exposure duration to metals (year), BW is the bodyweight of the person exposed to metals (Kg), AT is the averaging time (the period in which exposure is averaged-days) to any amount of metals on a daily basis, PEF is the particle emission factor for metals from dust to air (m^3/kg), SA is the skin area exposed to metals (cm^2), AF is adherence factor (mg/cm^2-day). ABF is the dermal absorption factor (unit less). The details of each parameter and its values in the risk assessment equations (Wei et al., 2015; Chabukdhara and Nema, 2013; Qing et al., 2015) are given in Table (1). After the calculation of average daily dose value of the metals (ADD) via the three routes of ingestion, inhalation, and dermal contact, hazard quotient (HQ) was calculated based on reference daily intake ($\mathbf{R_f D_i}$) using equation (7).

$$\mathbf{HQ_i} = \sum \frac{\mathbf{ADD_i}}{\mathbf{R_f D_i}} \qquad (7)$$

HQ_i is the hazard quotient in each intake path, ADDi is the average daily dose value of metal intake by each of the three mentioned routes (mg/kg/day) and $\mathbf{R_f D_i}$ is reference daily intake that estimates the maximum risk in the human population exposed daily to heavy metals considering sensitive groups (i.e., adults and children) (Man et al., 2010; Thompson et al., 1992). The values of $\mathbf{R_f D_i}$ were collected from the US Department of Energy's Risk Assessment Information System (RAIS) (Ferreira-Baptista and De Miguel, 2005). If the average acceptable daily intake (ADD_i) is less than the reference daily intake there will be no adverse effects on human health; otherwise, if ADDi is higher than the $\mathbf{R_f D_i}$, it is likely to have an adverse effect on human health (Kurtz et al., 2001). When the HQ value is ≤1, there will not be an adverse effect, but when HQ> 1, it is expected to have an adverse effect on human health (Man et al., 2010; Thompson et al., 1992). By summing up the hazard quotient in each intake path (HQi), the HI can be generated to estimate the risk of all contaminated metals according to equation (8):

$$\mathrm{HI} = \sum_{\mathbf{i=1}}^{\mathbf{3}} \mathbf{HQ}_{\mathrm{I}} \qquad (8)$$

The calculated HI for all elements indicates the severity of undesirable effects in all pathways of human exposure (Staff, 2001). For HI ≤ 1, there are no apparent adverse health effects of heavy metals, whereas, for HI>1, there will be hostile health effects for residential populations (Bennet et al., 2001). The health risk assessment for carcinogenic heavy metal exposures for both adults and children was calculated through each of the three routes of ingestion, inhalation, and dermal contact by Eq. (9).

$$\mathbf{Carcinogenic\ risk(CR)} = \sum \mathbf{ADD_i} \times \mathbf{SF_i} \qquad (9)$$

In the above equation, CR is the cancer risk, and SF is the carcinogenic slope factor (mg/kg/day). SF captures the assessed daily contaminant intake during a lifetime of exposure to the growing risk of an individual developing cancer (Hu et al., 2011). In general, according to the US Environmental Protection Agency, if the carcinogenic risk (CR) is less than 1×10^{6} (the probability of one's cancer in every one million people), this risk is negligible, while if the CR is more than 1×10^{4}, it is harmful and hazardous to human health. CR between the range of 1×10^{-6} and 1×10^{-4} represents an acceptable risk under the control and monitoring conditions (Wei et al., 2015).

Results and discussion

Heavy metals concentration

Heavy metal concentration data in Dezful street dust were compared to background/upper continental crust (UCC) values (Rudnick and Gao, 2003) in Table 2. The average concentration of Pb, Zn, Cu, Cr, Cd, Ni, V, As and Co were 54, 224, 51, 44, 0.4, 46, 38, 3, and 8 (mg/kg), respectively. Except for As, V, and Co, the mean concentration value for all heavy metals was several times higher than that of the background concentrations, indicating possible anthropogenic input of metals from vehicle wear and tear from brake linings and tires, road wear and the combustion of fossil fuels (Dehghani et al., 2017; Keshavarzi et al., 2015; Najmeddin et al., 2018). Data from this study are comparable to street dust reported by Ghanavati et al. (Ghanavati, 2018) in Abadan, Iran which showed that concentrations of samples of Pb, Zn, Cu, Cr, Cd, Ni, As and Co, except for V, were several times higher than the background concentrations. These findings imply that the high concentrations were related to anthropogenic issues such as industrial activities, traffic, (bad) burning of fossil fuels, as well as the construction activities. The study of Mehrasbi et al. (Farahmandkia et al., 2010) on heavy metals in particulate matter in the air of Zanjan showed that the pollution from industrial activities was the most important factor in increasing the concentration of heavy metals in wet and dry atmospheres. Men et al. (Men et al., 2018) reported concentrations of metals in Beijing street dust, eight times above the background levels, with the exception of As and Mn and Cd. This shows the strong impact of human activities on Beijing's street dust.

Table 3 compares heavy metal concentration in street dust from this study to other cities around the world. The mean concentration of Pb and Zn in this study was less than in street dust from Tehran, Isfahan, Nanjing, Hong Kong, Madrid, Newcastle, Oslo, and Amman; however, higher than Shiraz (Iran), Konya (Turkey) and Ottawa (Canada). The mean concentrations of Cu and Co in Dezful street dust were less than the mean concentration values of these metals in other cities except Konya. Besides, the mean concentration of Cr in Dezful street dust samples was less than the mean concentrations of these metals in cities like Shiraz, Isfahan, Nanjing, Hong Kong, and Madrid, while more than Tehran, Amman, Konya, and Ottawa. Additionally, the mean concentration of Cd in Dezful street dust was less than the mean concentrations of all cities except Ottawa. Also, the mean concentration of Ni was lower than its concentrations in Nanjing and Isfahan, while it was more than Shiraz, Tehran, Hong Kong, Newcastle, Oslo, Konya, Amman, Madrid, and Ottawa. The mean concentration of As in Dezful street dust was lower than that of Hong Kong, Nanjing, Newcastle, Isfahan, while higher than that of Ottawa. Moreover, the mean concentration of V in Dezful was found to be higher than the average concentration value of V in Hong Kong, while lower than that of Konya. Therefore, high levels of some pollutants in Dezful street dust require consideration of their source, such as vehicle emissions.

Heavy metal source identification

Statistical correlation between different elements can inform the assessment of the environmental impact and source identification more accurately. Spearman's correlation coefficients were thus used to determine the relationship and correlations between different elements (Table 4). Understanding these relationships can be useful in identifying the source of the element and how it is transmitted in the environment. The correlation coefficient between pollutants showed that the Pb element had a positive and significant correlation at ($p<0.01$) with Cu (0.75) and Zn (0.51). The strong positive correlation indicates that these toxic metals originate from common human activity sources. Cr, Ni, V, As and Co were found to have significant positive correlation with each other at $p<0.01$. These elements also had a significant positive correlation with Cd at $p<0.05$, which indicated another origin. Using principal component analysis (PCA) Bartlett's test of sphericity at $p<0.001$ was significant; the analysis of Kaiser–Meyer–Olkin Index was 0.772, which confirmed that the toxic metal concentrations were appropriate for PCA. The result of PCA with varimax rotation showed that two Principal Components (PC) accounted for 79% of the total variance, as illustrated in Figure 2. The first principal component (PC1) comprised 52% of the total variance and included Co, V, As, Cr, Cd, and Ni metals with the factor loadings >0.8. The origins of these heavy metals were likely from anthropogenic sources (for Cr, Cd, and Ni metals), such as traffic, wear and tear of vehicle rings and tires, and the use of gasoline as well as natural resources (for Co, V and As metals). The second principal component (PC2), which contained 27% of the total variance, included Pb, Cu, and Zn, with the factor loadings >0.7 indicating possible anthropogenic sources such as tire wear of vehicles, corrosion of metals, burning of waste and industrial gases (Kong et al., 2012).

Spatial distribution of heavy metals

The spatial distribution maps of heavy metal concentration values assist in identifying hotspots and pollution sources. In this study, the most concentrated values were related to very high population density and near urban centers, areas near the Andimeshk-Dezful highways, old urban area, city center, areas with high traffic density of Dezful. Areas with relatively low pollution were identified to be those areas developed in the last few decades (compared to the old parts of the city), which had low traffic and low population density. The spatial distribution patterns of heavy metals are accordingly shown in Figure 3.

Potential Ecological Risk

Table 5 and Table 6 show the potential ecological risk (Er) and risk index (RI) values. The trend of Er in dust samples shows Cd>Pb>Ni>Cu>Zn>As>Co>V>Cr. Based on the mean value of Er for heavy metals, Cr (0.9), V (1), Co (4), As (7), Zn (7), Cu (9), Ni (11) and Pb (18) were found to have low potential ecological risk (Er<40), while Cd (59) had moderate potential ecological risk (40≤ Er≤ 80). The results showed that RI of all samples varied from at least 102 to a maximum of 147 based on the average value of RI (118), the samples are low risk (RI<150). Also, the results showed that all samples (100%) posed low risks. Among the heavy metals studied, the potential ecological risk (Er) of Cd was higher than that of other metals. Accordingly, the environmental contamination caused by this metal, which exists in diesel fuel, oil lubricants, and rubber coatings, should be carefully considered (Foti et al., 2017). In effect, Cd can be released due to tire wear in hot climates as a result of the friction between roads and vehicle tires. Consequently, the high concentrations of Cd might be due to high traffic in Dezful. The spatial distribution pattern of potential ecological risk (Er) and risk index (RI) help identify hot areas and pollution sources. In this study, the highest pollution index was found for very high population density and near urban centers, areas near the Andimeshk-Dezful highways, old urban area, city center, areas with high traffic density of Dezful. Areas with low pollution were mostly those developed in the last few decades, which had low traffic and low population density (Fig3, 4).

Health risk assessment

The assessment of human health risks from the exposed street dust samples from the three main pathways of ingestion, inhalation, and dermal contact was investigated for children and adults. The hazard quotient (HQ) of heavy metals for all three pathways for children and adults is presented in Table 7. The results indicated that the dust exposure pathways of heavy metals for children decreased as ingestion>dermal contact>inhalation. The hazard quotient (HQ) in children's ingestion and inhalation pathways were found to be higher than that of adults, while it was higher for adults through dermal contact. Also, for both age groups, HQ was highest for Pb metal through ingestion. These findings are comparable to studies conducted by Cheng et al. (Cheng et al., 2018) and Jiang et al. (Yanxue Jiang et al., 2017a). Similarly, Urrutia-Goyes et al. (Urrutia-Goyes et al., 2018) showed that the highest absorption of heavy metals was due to ingestion. Thus, this pathway is of primary concern for the potential exposure and subsequent risk of heavy metals in street dust. The HQ of heavy metals on all three routes of ingestion, dermal contact, and inhalation were found to be less than 1, indicating no harmful effects for humans. Moreover, the lowest risk of HQ in children and adults was for Cd via inhalation. According to Table (7), the hazard index (HI) values of all three pathways for children were 7-2 times higher than those for adults. Also, the HI of all heavy metals in street dust samples for children and adults were 0.60 and 0.13, respectively, which indicates that children are more exposed to the risk of heavy metals than adults. The evaluation of HI for all three exposure pathways and for each of the metals, separated by children and adults, are presented in Chart (1); the order for children was Cr> Pb> As>Ni> Cu>Zn>Cd, and for adults were Cr> Pb>As> Ni> Cd> Cu> Zn. The HI values of heavy metals were less than 1, indicating that the HI is low for heavy metals. Accordingly, it revealed that the highest HI of all three pathways in both groups of children and adults was related to Cr, and the lowest was for Cd and Zn, respectively. Studies by Keshavarzi et al. (Keshavarzi et al., 2015) on-street dust samples in Shiraz similarly showed that HQ in children was higher than that of adults. In particular, HQ values for children through the ingestion pathway were 2.5 times higher than those in adults. The path of ingestion, followed by dermal contact, seems to be the main source of exposure to the street dust for children and adults, while the HQ was insignificant through breathing. The cancer risk (CR) assessment of heavy metals for children and adults are presented in Chart (2) and follow the order as Cr>Ni>As>Cd>Pb. Thus, in both age groups, Cr had the highest CR, while Pb had the lowest CR. In children, CR values were higher than those in adults. In addition, the CR value for Ni, As, Cd and Pb for children and adults were lower than the 1×10^{-6} threshold (the probability of one person's cancer in one million people), suggesting that we could neglect the cancer risk of toxic heavy metals in the street dust for this study. However, the cancer risk of Cr was greater than 1×10^{-6}, which indicates that the cancer risk of Cr requires urgent attention, particularly as children were more likely to be exposed to human health risks of heavy metals than adults.

Conclusions

In this study, we examined the concentration values, the ecological and human health risk of the potentially harmful heavy metals (Pb, Zn, Cu, Cr, Cd, Ni, V, As, and Co) in Dezful street dust. The results indicated that the mean concentration of all heavy metals, except for As, V, and Co, was several times higher than that of the background concentrations; which demonstrates that the pollution source may be related to anthropogenic sources. According to the results of PCA and Pearson's correlation coefficient the major sources of heavy metals in street dust could be grouped into two main sources: As, Co and V which mainly come from natural sources, whilst Pb, Zn, Cu, Cr, Cd and Ni originate from anthropogenic sources such as traffic, wear and tear of vehicles rings and tires, the use of gasoline and the combustion of fossil fuels. We found that the average potential ecological risk values, Er, in dust for Cr, V, Co, As, Zn, Cu, Ni, and Pb are low. Cadmium (59.30), in contrast, showed moderate PER mean values. The order of considered heavy metals exposure pathways for street dust samples is as follows: ingestion>dermal contact>inhalation. The hazard quotients (HQ) of potentially heavy metals in Dezful street dust samples were higher for children as compared to adults. For each metal, the HI value was less than 1, which excludes non-carcinogenic risks for the inhabitants. However, the carcinogenic risk (CR) for all the inhabitants is greater than 1×10^{-6}. This study may be helpful and valuable for local and national authorities to execute proper actions and initiatives in order to reduce the risks and protect the citizens of Dezful, particularly children and other regional studies inform regional cooperation to reduce transport and exposure of potentially harmful metals.

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Figure captions

Fig. 1. Location of street dust samples sites in the Dezful city.

Fig.2. Principal component analysis (PCA) of heavy metals in Dezful street dust Samples.

Fig. 3. Spatial distribution of heavy metals in Dezful street dust.

Fig. 4. Spatial distribution of the potential ecological risk (Er) in Dezful city.

Figure 5. Spatial distribution of risk index (RI) of heavy metals in Dezful city

Figure 6. Non-Cancer Cumulative Risk (HI) of heavy metals in adults and children.

Figure. **7.** Cancer risk (CR) of heavy metals in dust street in Dezful

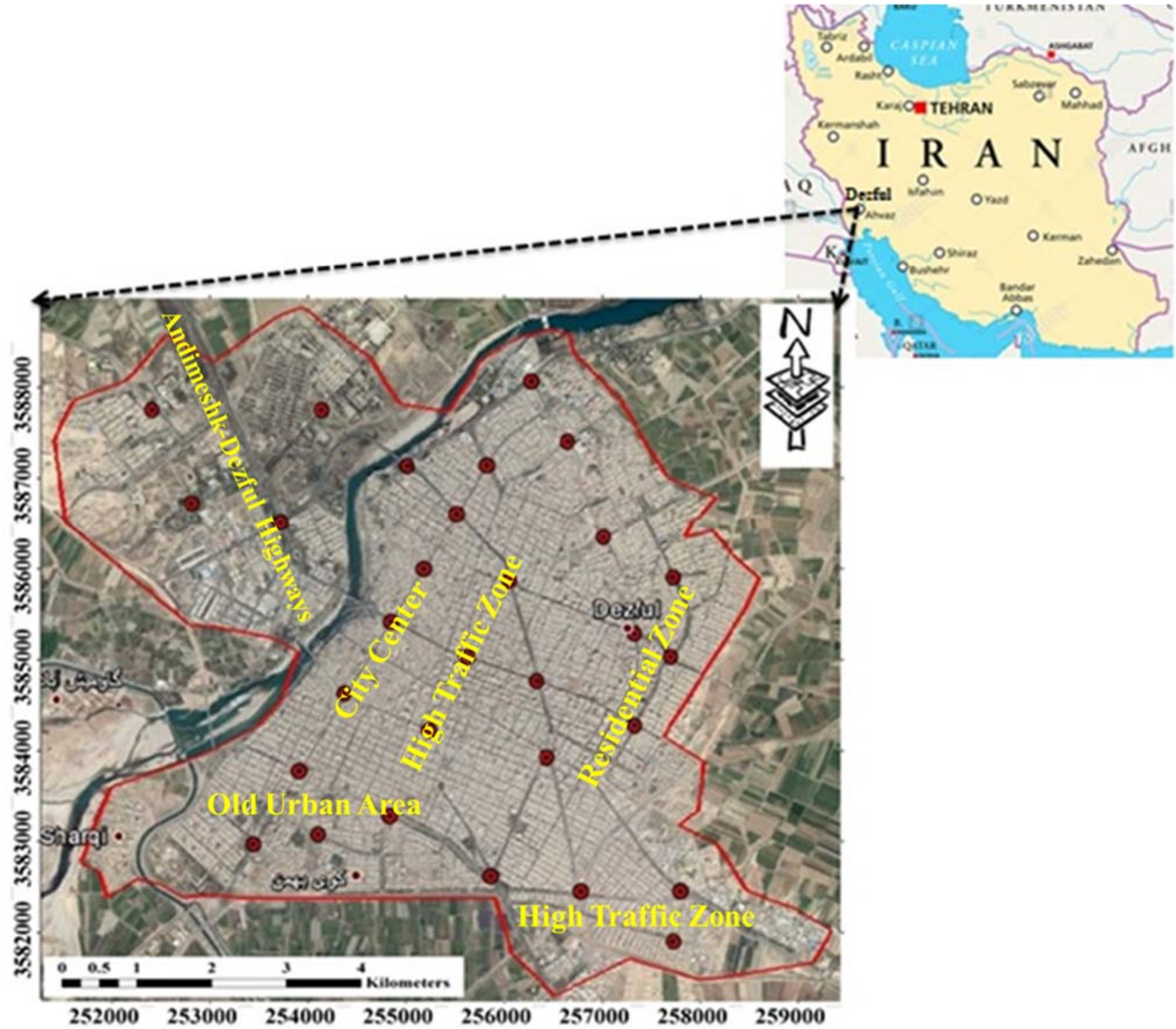
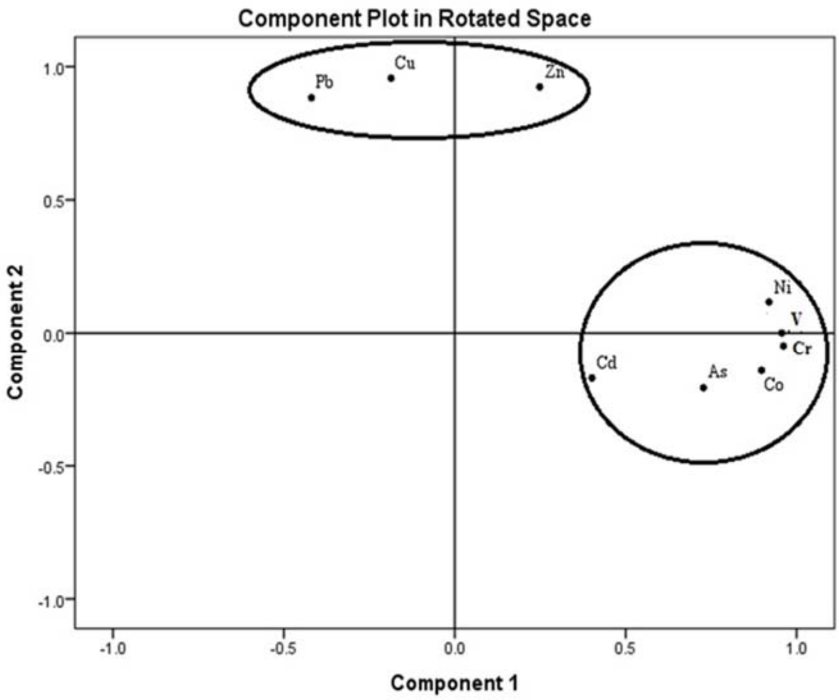
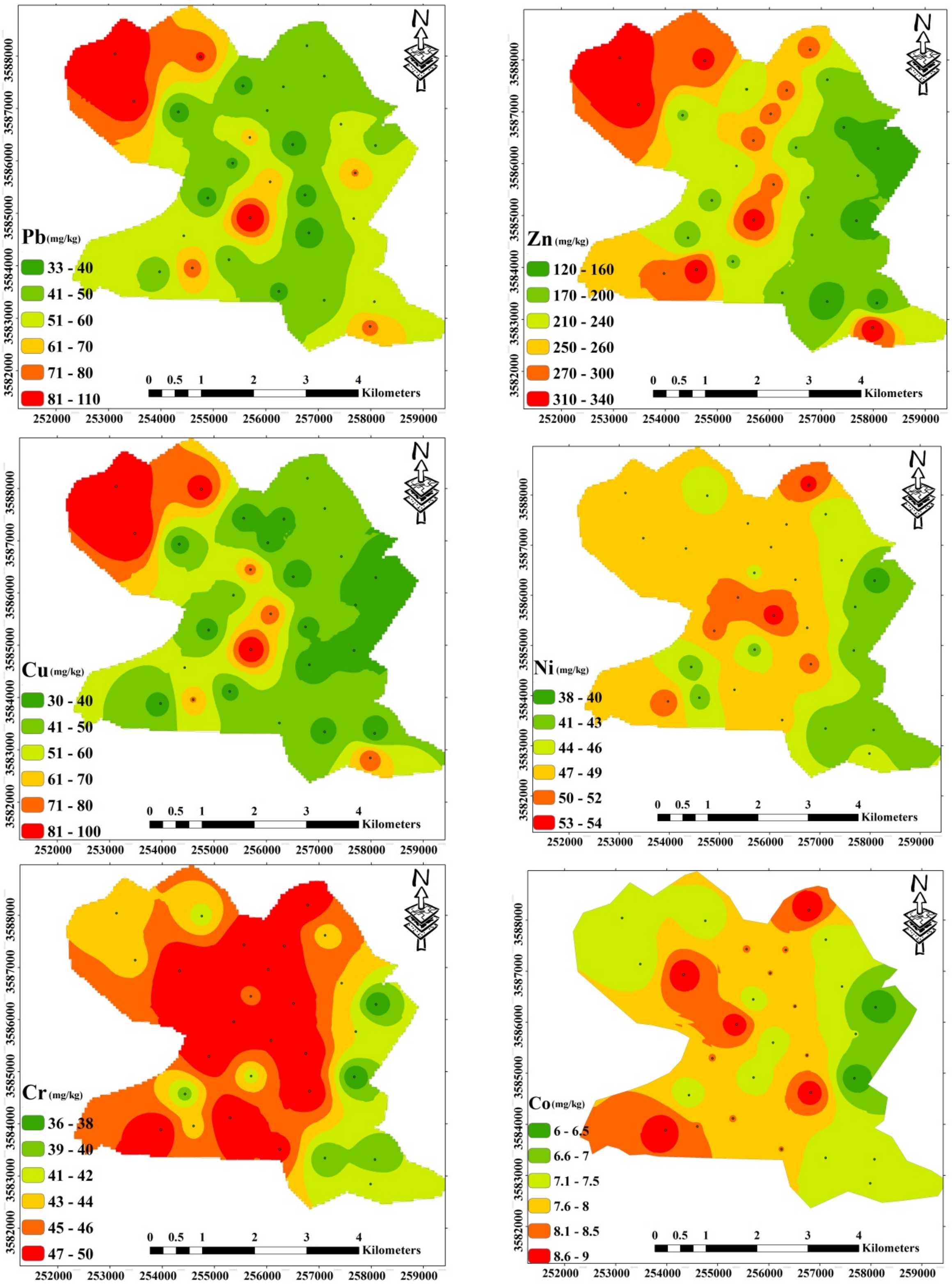

IRAN
TEHRAN
CASPIAN SEA
Dezful
Andimeshk-Dezful Highways
City Center
High Traffic Zone
Residential Zone
Old Urban Area
High Traffic Zone
Dezful
Sharqi
Kilometers
N

Figure1.



Component Plot in Rotated Space
Pb
Cu
Zn
Ni
V
Cr
Cd
As
Co
1.0
0.5
0.0
-0.5
-1.0
-1.0
-0.5
0.0
0.5
1.0
Component 2
Component 1

Figure 2.


Pb (mg/kg)
33 - 40
41 - 50
51 - 60
61 - 70
71 - 80
81 - 110
Zn (mg/kg)
120 - 160
170 - 200
210 - 240
250 - 260
270 - 300
310 - 340
Cu (mg/kg)
30 - 40
41 - 50
51 - 60
61 - 70
71 - 80
81 - 100
Ni (mg/kg)
38 - 40
41 - 43
44 - 46
47 - 49
50 - 52
53 - 54
Cr (mg/kg)
36 - 38
39 - 40
41 - 42
43 - 44
45 - 46
47 - 50
Co (mg/kg)
6 - 6.5
6.6 - 7
7.1 - 7.5
7.6 - 8
8.1 - 8.5
8.6 - 9
0 0.5 1 2 3 4 Kilometers
N
252000 253000 254000 255000 256000 257000 258000 259000
3582000 3583000 3584000 3585000 3586000 3587000 3588000

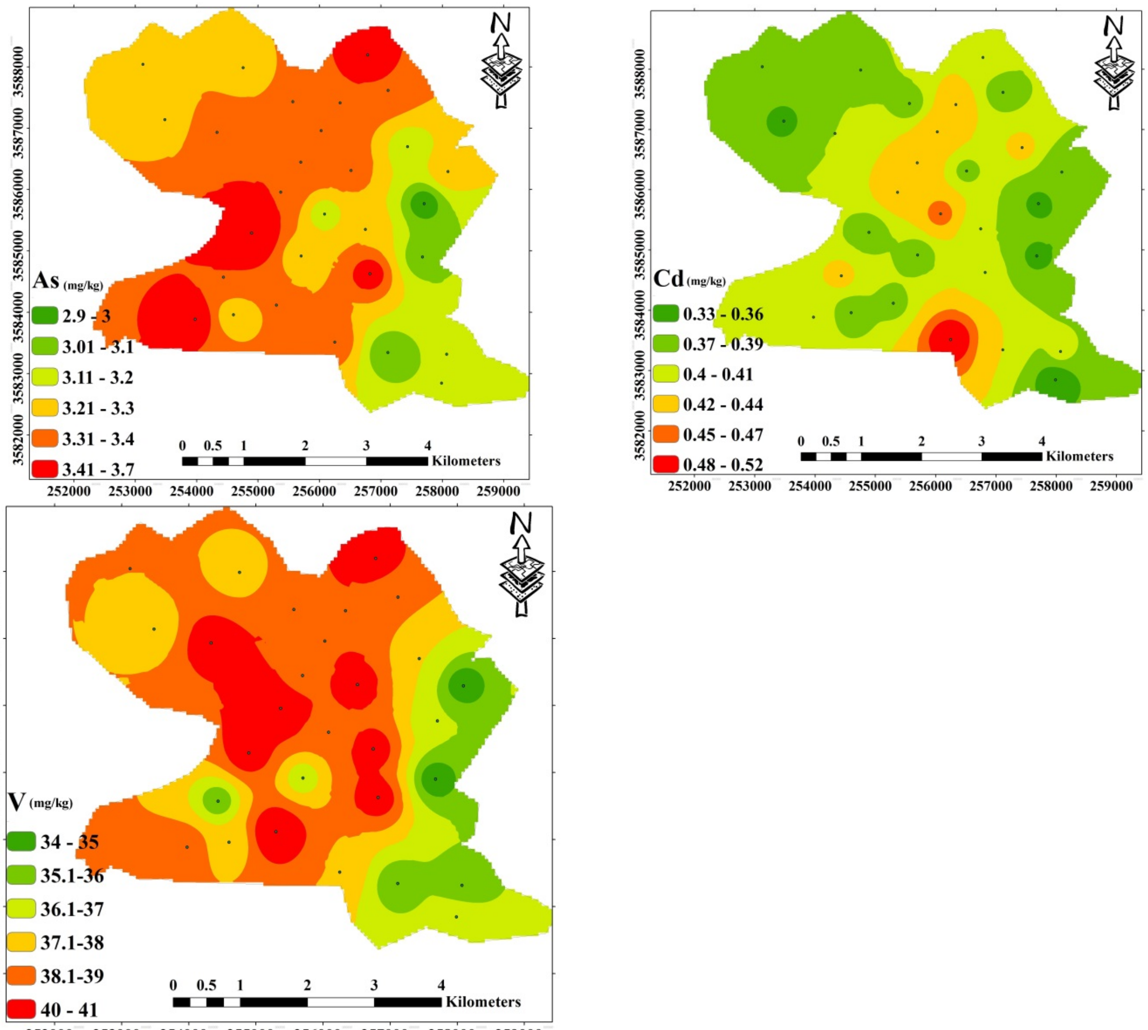
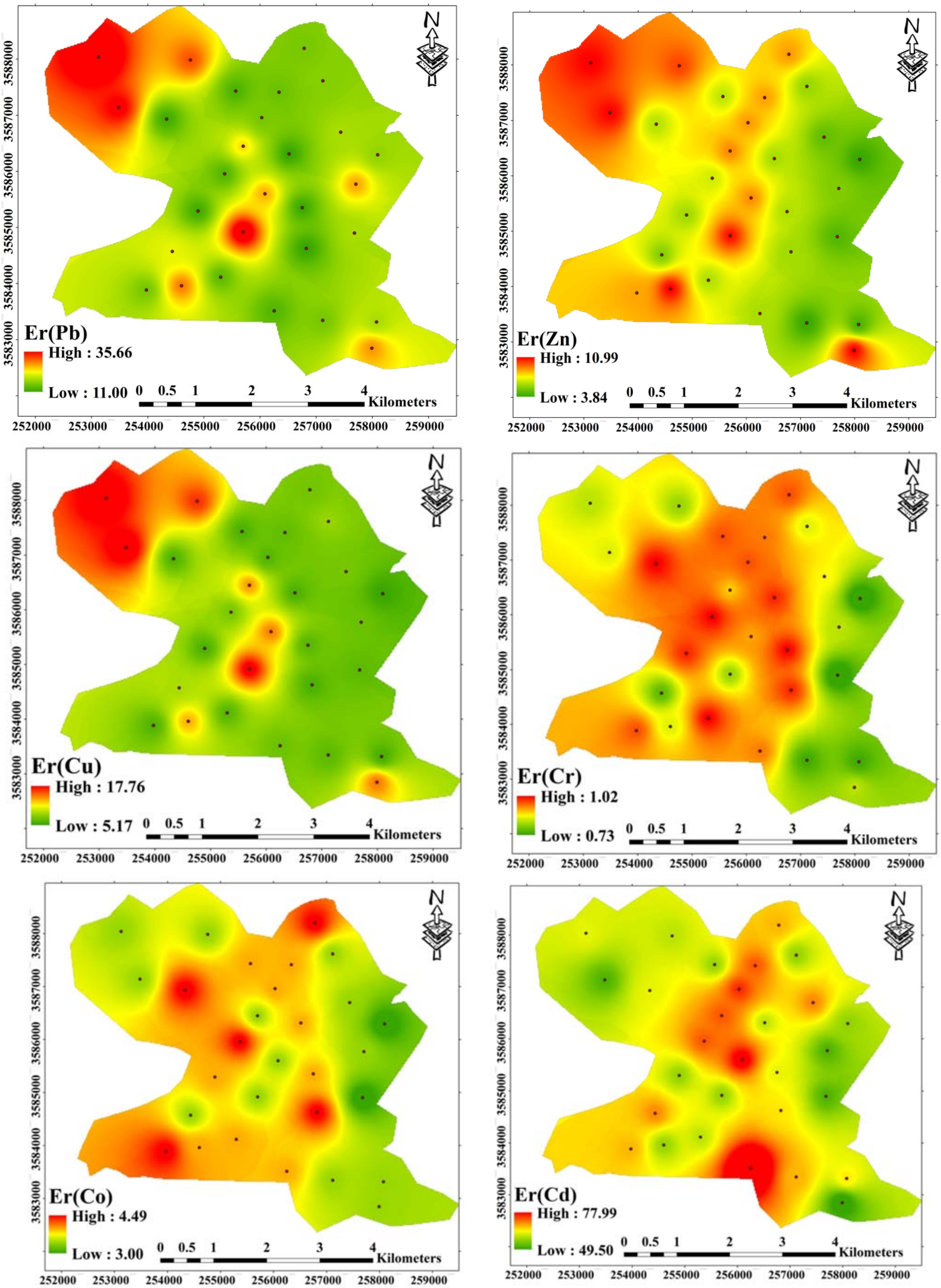

As (mg/kg)
2.9 - 3
3.01 - 3.1
3.11 - 3.2
3.21 - 3.3
3.31 - 3.4
3.41 - 3.7
Cd (mg/kg)
0.33 - 0.36
0.37 - 0.39
0.4 - 0.41
0.42 - 0.44
0.45 - 0.47
0.48 - 0.52
V (mg/kg)
34 - 35
35.1-36
36.1-37
37.1-38
38.1-39
40 - 41
0 0.5 1 2 3 4
Kilometers
N
252000 253000 254000 255000 256000 257000 258000 259000
3582000 3583000 3584000 3585000 3586000 3587000 3588000

Figure 3.



Er(Pb)
High : 35.66
Low : 11.00
Er(Zn)
High : 10.99
Low : 3.84
Er(Cu)
High : 17.76
Low : 5.17
Er(Cr)
High : 1.02
Low : 0.73
Er(Co)
High : 4.49
Low : 3.00
Er(Cd)
High : 77.99
Low : 49.50
0 0.5 1 2 3 4 Kilometers
N
252000 253000 254000 255000 256000 257000 258000 259000
3583000 3584000 3585000 3586000 3587000 3588000

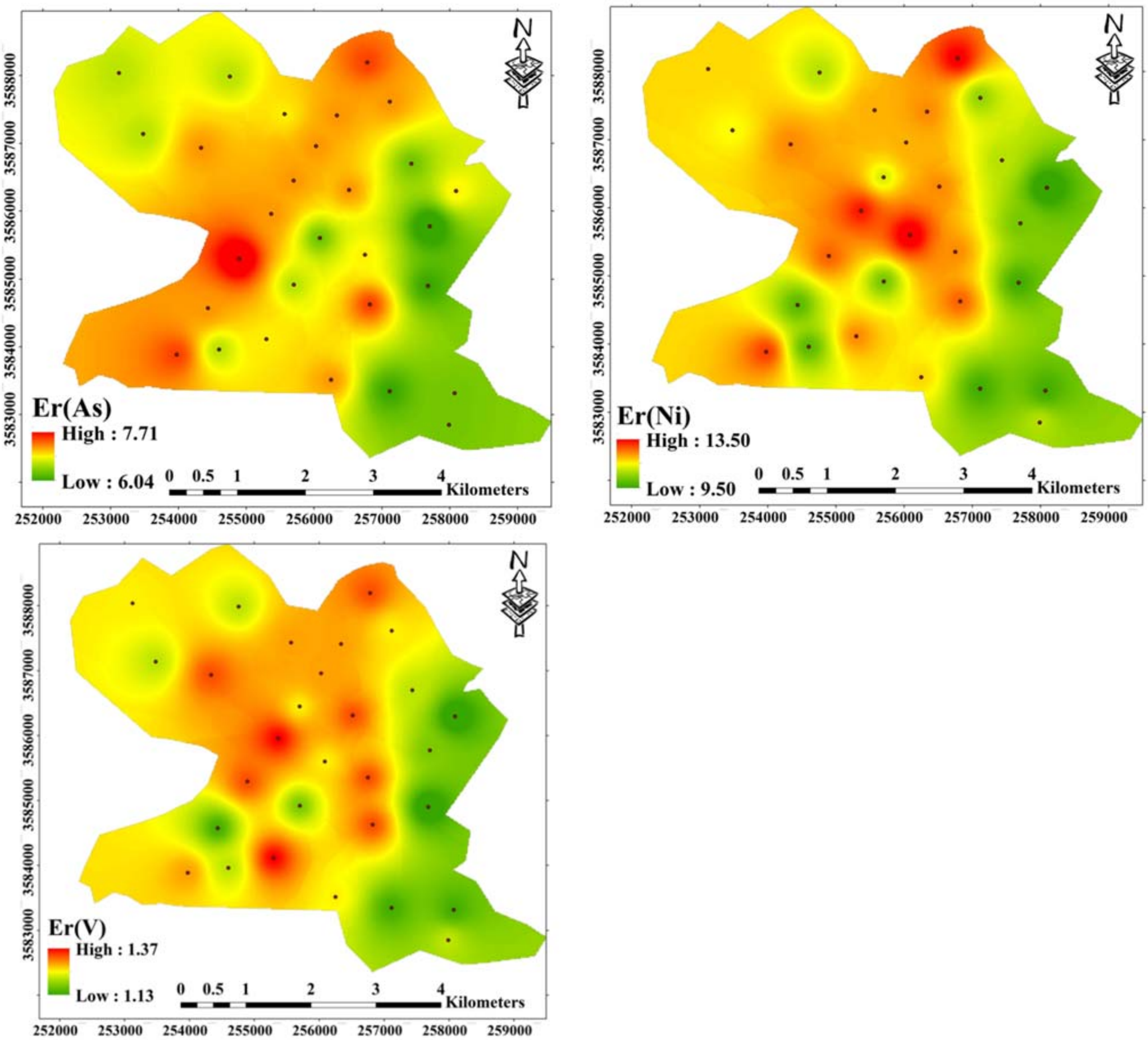

Er(As)
High : 7.71
Low : 6.04
Er(Ni)
High : 13.50
Low : 9.50
Er(V)
High : 1.37
Low : 1.13
N
0 0.5 1 2 3 4 Kilometers
252000 253000 254000 255000 256000 257000 258000 259000
3583000 3584000 3585000 3586000 3587000 3588000

Figure 4.

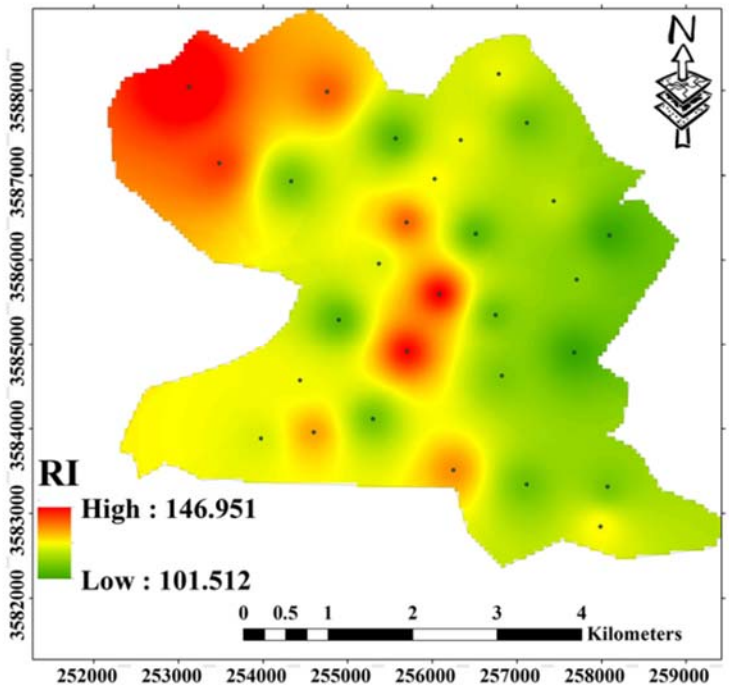

N
RI
High : 146.951
Low : 101.512
0
0.5
1
2
3
4
Kilometers
3588000
3587000
3586000
3585000
3584000
3583000
3582000
252000
253000
254000
255000
256000
257000
258000
259000

Figure 5.

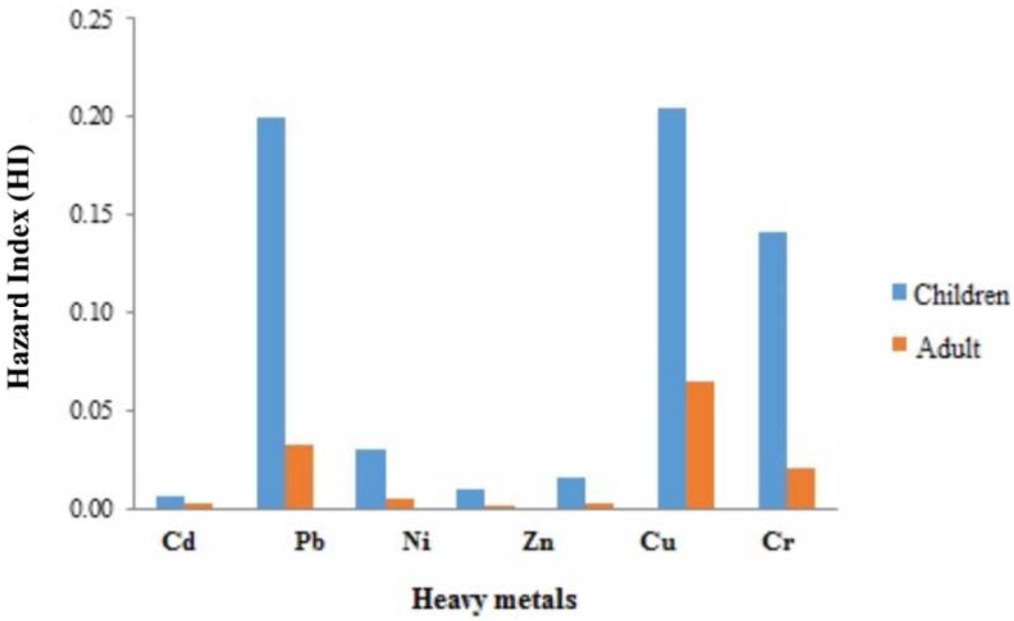

0.25
0.20
0.15
0.10
0.05
0.00
Hazard Index (HI)
Cd
Pb
Ni
Zn
Cu
Cr
Heavy metals
Children
Adult

Figure 6.

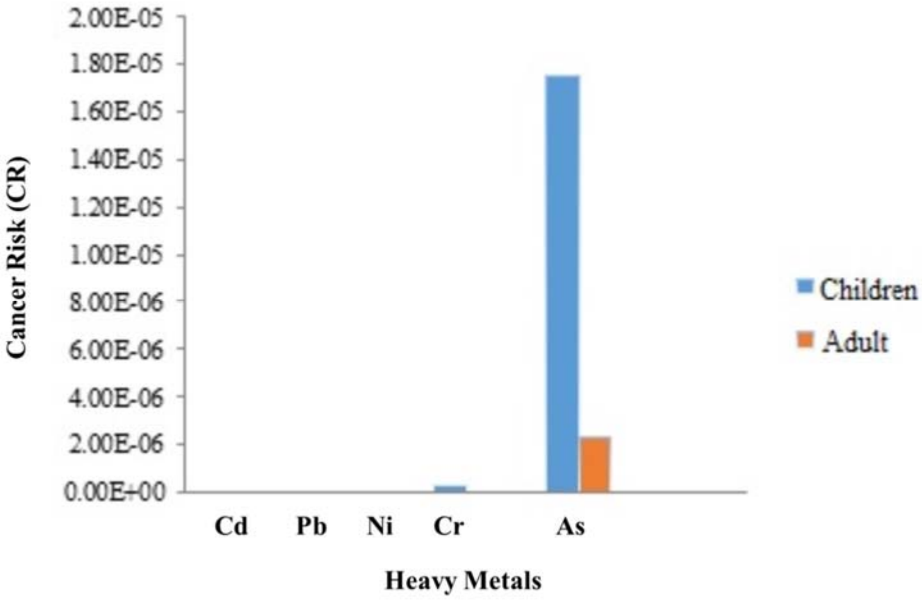

2.00E-05
1.80E-05
1.60E-05
1.40E-05
1.20E-05
1.00E-05
8.00E-06
6.00E-06
4.00E-06
2.00E-06
0.00E+00
Cancer Risk (CR)
Cd
Pb
Ni
Cr
As
Heavy Metals
Children
Adult

Figure 7.

Table captions

Table 1. Exposure factor for metals doses.

Table 2. Summary metal concentrations in street dusts a from Dezful (mg/kg)

Table 3. Mean concentrations of heavy metals in Dezful street dust samples and other selected cities (mg/kg).

Table 4. Correlation matrix for heavy metal concentrations in street dusts from Dezful.

Table 5. Statistical analysis of potential ecological risk factor (Er) of studied potentially heavy metals.

Table 6. Potential ecological risk indices for street dust.

Table 7. Health risk factors from heavy metal in street dusts of Dezful.

Table 1.

Factor	Unit	Adult	Children
IngR	mg/day	100	200
InhR	m^3/day	12.8	7.63
EF	day/year	350	350
ED	year	24	6
BW	Kg	55.9	15
AT	days	ED×365	ED×365
EF	m^3/kg	1.36E+09	1.36E+09
SA	cm^2	4350	1600
AF	mg/cm^2-day	0.7	0.2
ABF	-	0.001	0.100

Table 2.

Element	Unit	Min-Max	Mean ± SD	Skewness	Upper crust content[a]
Pb	(mg/kg)	33-107	54 ± 21	1	15
Zn	(mg/kg)	119-341	224 ± 71	0.4	31
Cu	(mg/kg)	30-103	51 ± 23	1	29
Cr	(mg/kg)	36-50	44 ± 4	-0.4	35
Cd	(mg/kg)	0.3-0.5	0.4 ± 0.1	1	0.1
Ni	(mg/kg)	38-54	46 ± 4	-0.04	20
V	(mg/kg)	34-41	38 ± 2	-0.3	60
As	(mg/kg)	3-4	3 ± 0.2	-0.1	4.8
Co	(mg/kg)	6-9	8 ± 0.8	0.3	10

a(Rudnick and Gao, 2003)

Table 3.

Location	Pb	Zn	Cu	Cr	Cd	Ni	As	Co	V	Reference
Tehran (Iran)	257	873	225	34	11	35	-	-	-	(Saeedi et al., 2012)
Isfahan (Iran)	393	707	182	82	2	70	22	14	-	(Soltani et al., 2015)
Shiraz (Iran)	11	34	225	873	257	35	-	-	-	(Keshavarzi et al., 2015)
(China) Nanjing	103	394	123	126	1	56	13	11	-	(Hu et al., 2011)
Hong Kong (China)	120	3840	110	124	-	29	67	10	37	(Yeung et al., 2003)
(Canada) Ottawa	39	113	66	43	0.4	15	1	8	-	(Rasmussen et al., 2001)
Amman (Jordan)	976	410	250	18	1	16	-	-	-	(Jiries, 2003)
Konya (Turkey)	19	68	16	22	-	10	-	7	68	(Kariper et al., 2019)
Madrid (Spain)	1927	476	188	61	-	44	-	-	-	(de Miguel et al., 1997)
Newcastel (UK)	992	421	132	-	1	26	6	-	-	(Okorie et al., 2012)
Oslo (Norway)	180	412	123	-	1	41	-	-	-	(de Miguel et al., 1997)
Dezful (this study)	54	224	51	44	0.4	46	3	8	38	-

Table 4.

	Pb	Zn	Cu	Cr	Cd	Ni	V	As	Co
Pb	1								
Zn	0.507**	1							
Cu	0.751**	0.638**	1						
Cr	0.378	0.246	0.248	1					
Cd	0.238	0.033	0.003	0.420*	1				
Ni	0.271	0.388	0.065	0.869**	0.426*	1			
V	0.248	0.304	0.205	0.967**	0.410*	0.892**	1		
As	0.103	0.071	0.331	0.621**	0.559*	0.576**	0.664**	1	
Co	0.266	0.228	0.321	0.863**	0.518*	0.766**	0.851**	0.696**	1

*Correlation is significant at the 0.05 level (2-tailed)

**Correlation is significant at the 0.01 level (2-tailed)

Table 5.

Element	Min	Max	Mean	Standard Deviation	Skewness
Pb	11	36	18	6.8	1.2
Zn	4	11	7	2.3	0.4
Cu	5	18	9	3.9	1.3
Cr	0.7	1	0.9	0.1	-0.4
Cd	50	78	59	5.7	1.2
Ni	10	14	12	1.1	-0.1
V	1	1	1	0.1	-0.3
As	6	8	7	0.4	-0.1
Co	3	5	4	0.4	0.3

Table 6.

RI			Number of samples			
Min	Max	Mean	Low Risk	Moderate risk	Considerable risk	High risk
102	147	118	30(%100)	0	0	0

Table 7.

(mg/kg)	Pb	Zn	Cu	Cr	Cd	Ni	As
C(95% UCL)	54	224	51	44	0.4	46	3
RfD_{ing} (mg/kg day)	3.00E - 03	3.00E - 01	4.00E - 02	3.00E - 03	1.00E - 03	2.00E-02	3.00E - 04
RfD_{inh} (mg/kg day)	3.52E - 03	3.00E - 01	4.02E - 02	2.86E - 05	1.00E - 03	2.02E-02	3.10E - 04
RfD_{derm} (mg/kg day)	5.25E - 04	6.00E - 02	1.20E - 02	6.00E - 05	1.00E - 05	5.40E-03	1.23E - 04
SF_{inh} (mg/kg day)$^{-1}$	-	-	-	4.20E + 01	6.30E + 00	8.40E-01	1.51E +01
Children							
HQ_{ing}	1.98E-01	9.52E-02	1.61E-02	1.89E-01	5.11E-03	2.92E-02	1.40E-01
HQ_{inh}	5.52E-06	2.67E-07	4.50E-07	5.56E-04	1.43E-07	7.97E-07	3.80E-06
HQ_{derm}	2.11E-03	7.62E-05	8.60E-05	1.51E-02	8.18E-04	1.73E-04	5.47E-04
$HI=\sum HQ_i$	1.99E-01	9.60E-03	1.62E-02	2.05E-01	5.93E-03	2.95E-02	1.40E-01
CR	2.14E-08	-	-	1.75E-05	2.37E-08	3.62E-07	4.64E-08
Adults							
HQ_{ing}	2.65E-02	1.27E-03	2.16E-03	2.53E-02	6.68E-04	3.92E-03	1.88E-02
HQ_{inh}	2.48E-06	1.23E-07	2.03E-07	2.50E-03	6.45E-08	3.58E-07	1.71E-06
HQ_{derm}	5.38E-03	1.94E-04	2.19E-04	3.86E-02	2.08E-03	4.43E-04	1.39E-03
$HI=\sum HQ_i$	3.19E-02	1.47E-03	2.38E-03	6.42E-02	2.77E-03	4.37E-03	2.02E-02
CR	2.87E-09	-	-	2.35E-06	3.18E-09	4.85E-08	6.22E-09