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Assessment of Heavy Metals in Road Dust of Behbahan City, Iran: Distribution, Sources and Health Risks

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ABSTRACT

Introduction: Road dust is a group of solid particles that are presented in the urban areas and are originated from both natural and human-induced sources. This study aims to determine concentrations of heavy metals in urban dusts in Behbahan to identify their natural or anthropogenic sources.

Materials and Methods: In this study, a total of 20 samples were collected from main roads with different land uses, including residential, industrial, and commercial areas in Behbahan city, Khuzestan province.

Results: The results of mineralogy identification showed that calcite, dolomite, quartz, albite, and gypsum were the most identified minerals in dust samples. In addition, heavy metals of As, Co, Cr, Cu, Mn, Fe, Ni, Zn, Pb, Sb, U, Cd, Hg, and Mo were investigated in the collected settled road dust. The results indicated that the level of heavy metals, such as Co and Sb in the places with high traffic load were much higher than other areas. The highest I_{geo} value for Pb, Cu, and Sb were 1.39, 2.19, 2.46, respectively, suggesting that Pb, Cu, and Sb in the road dust were originated from the anthropogenic sources. Moreover, the results demonstrated that road dust may pose serious health threats to humans (both adults and children).

Conclusion: In this study, the concentration of heavy metals in road dust of Behbahan was investigated. The concentration of heavy metals, such as Cu, Zn, Ni, As, Cr, Pb, U, and Fe in the road dust of the commercial section were much higher than other sections.

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Introduction

The road dust is a group of solid particles that accumulate in urban areas from both natural and human-induced sources. It should be noted that human resources have a greater share in creating road dust. Road dust particles can be considered as a main source of heavy metals [1-4]. Natural and human-induced airborne particles have a great effect on human health and environment. These particles (dust) are very common phenomena in sizes ranging from 1 to 10,000 µm. Dust generates from a variety of sources, such as mining, is settled due to their high resistance, toxicity, and accumulation in organisms [5].

The origin of heavy metals in dust particles of the urban areas are mostly traffics and possible industrial activity in the vicinity of city. In addition, heavy metals in the dust particles are chemically composed of silicates, carbonates, and organic matter. The accumulated pollutants in the road dust have a short shelf life; so their amounts in the settled road dust reflect the recent contamination. Therefore, road dust should be considered as an important indicator for measuring recently accumulated pollutants (i.e. PTEs) [6-9].

The main exposure pathways for dust and their associated chemicals, such as heavy metals are inhalation, ingestion, and skin contact. The interned metals may accumulate in the body's adipose tissue, build on the central nervous system, accumulate in different organs of the human body, and disrupt the function of these organs. Therefore, detection and estimation of exposure to heavy metals through road dust is very important [4, 10]. The smaller dust particles are greater risk. Particles smaller than 100µm are easily suspended and enter the breathing system, and particles smaller than 10µm can enter the lungs. Inhalable dust smaller than 2.5µm can enter the blood stream. Particles with a diameter of 1 to 10µm, especially particles with a diameter of less than 2.5µm, have the most harmful effects on human health. It should be noted that too small particles do not have enough time to suck in the lungs and exhale after exiting the lung. The vehicles emissions in the urban areas involve very small particles that can be deposited on road surfaces or on impermeable surfaces. On the other hand, dust that enters the surrounding environment in urban area is also a factor in the transmission of pollutants. When precipitation occurs, these particles are washed with various pollutants, and finally they are transferred to water in contact with them, such as urban runoffs [11-13], which in all of these cases, creates health problems. This study aims to determine mean concentrations of heavy metals in urban dusts in Behbahan city to identify their natural or anthropogenic sources.

Materials and Methods

Study area

This study was conducted in the urban area of Behbahan city in south western of Khuzestan province in Iran with total area of 3195 km^2 (Figure 1). The population of Behbahan was 186293 in 2019. Its coordinates are 30.5959°N – 50.2417°W. Behbahan climate is semi-desert or foothills. Behbahan city due to its location in the proximity to Zagros Mountains and southern ports of Iran, as well as having rugged rivers of Maroon, Kheirabad, and Zohreh has special status and special areas. Pazanan, Mansourabad, and Peranj oilfields are located 2 km from Behbahan city. Also Bidband Gas refinery is located in 2 kilometers west of Behbahan city. Nowadays, due to different oil and gas industries around the city and other small and large industries in the city center, compliance with environmental laws and standards by industry owners is inevitable, in which regard the role of city environmental monitoring .It is very important and effective in reducing the amount of environmental pollution.

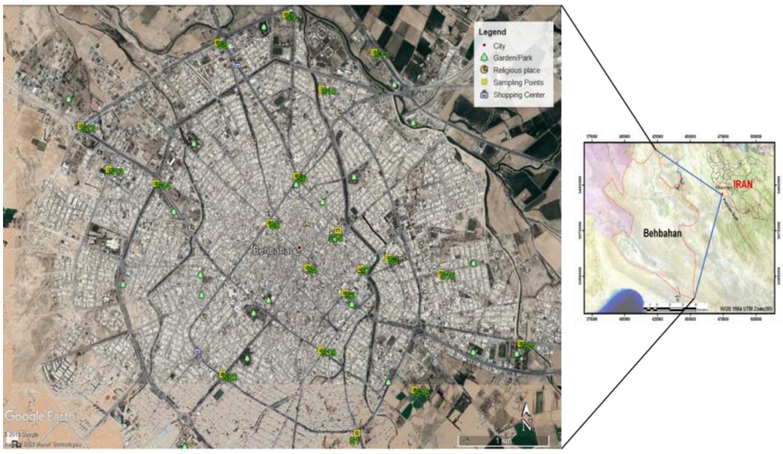

Figure 1: Location of sampling in Iran and sampling points of road dust in Behbahan city

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The study area was divided into various land uses, including residential, industrial, commercial, and heavy traffic, and samples were taken from each user. The samples (n = 20) (Figure 1) were collected from main roads and main fields (due to road length and traffic volume), residential, industrial and commercial areas. In order to obtain more accurate data for risk assessment, the samples were collected from crowded places, such as hospitals, schools, parks, shopping centers.

Since road dust sampling was not feasible during the day, it was done after midnight. The samples were taken off the road, the road and the fields using a plastic sander, and plastic brush (between 300 and 500 grams of samples). For sampling with less error, the samples were taken as composite, so that each sample represented about 10 sub-samples. After each sampling, the brush was completely cleaned and washed with distilled water and acetone. The samples were then transferred to zipper thick bags and stored in a cool and dry environment after encoding. First, for separation of wooden and metal parts, leaves, cigarette filters, glass, and other unwanted materials from the samples, samples were taken from a 2 mm sieve, and then passed through a 63-micron beaker. The samples were then transferred to small, colorless, thick bags, encoded, and sent to laboratory for further analysis.

Sample preparation

The samples were mixed, dried, and passed through a 0.125mm sieve. The samples were digested with HNO_3, HF, and $HClO_4$ and concentrations of metals were analyzed with ICP/MSS, which its limit of quantification (LOQ) was in the range of o.1-1000 ppm. The composition of road dust was determined with X-ray diffraction (Philips-expert-pro).

Statistical analysis

The EPA PMF 5.0.14, XLSTAT software (2016), and Microsoft Excel 2016 were applied. Shapiro-Wilk test showed that the data were not normal. Spearman correlation analysis was applied to evaluate the association between heavy metals. Biplot principal component analysis (PCA) was used to clarify the relationship and sources of heavy metals. The significance level of all analyses was considered < 0.05.

Heavy metal evaluate in road dust

Contamination factor (CF), degree of contamination (DC), and pollution load index (PLI) were applied to evaluate heavy metal concentration in road dust, as well as to provide a criterion for determining the DC [14]. The CF, DC, and PLI parameters were calculated using Eqs.1, 2, and 3:

$$CF = \frac{Cmetal}{Cbackground} \quad (1)$$

$$DC = \sum CF \quad (2)$$

$$PLI = \sqrt[n]{(CF1 \times CF1 \times CF1 \times \ldots \times CFn)} \quad (3)$$

Where, C_{metal} is pollutant concentration in the dust, $C_{Backgroud}$ is amount of background metals, and n is the number of metals. The PLI is a comparison tool for evaluating the quality of site under investigation. The PLI index was presented by Tomilson et al. [15].

Pollution indices

The ecological risk index (ERI) [14] and geo-accumulation (I-geo) [16] are applied to assess the ecological risk of heavy metals in road dust. Geo-accumulation index (I_{geo}) was applied to specify the severity of heavy metal contamination of soil. This index was calculated using Eqs.4,5, and 6:

$$C_f = \frac{Cs}{Cn} \quad (4)$$

$$ERF = T_r \times C_f \ (5) RI = \sum_{i=1}^{m} ERF \quad (6)$$

Where, C_f is metal contamination index, C_n refers to metal concentration in the sample, C_s represents background metal concentration, ERF indicates potential ecological risk factor (ERF). T_r shows heavy metal response coefficient determined by Hackenson for different elements (Zn = 1 < Cr = 2 < Cu = Ni = Pb = 5 < As = 10 < Cd = 30 < Hg = 40), and ERI is ERI. I-geo was determined according to Eq.7:

$$I\text{-}geo = \log_2\left(\frac{CS}{1.5 \times Bn}\right) \quad (7)$$

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Where, Cs is metal concentration in soil samples and Bn is geochemical background. 1.5 shows a correction factor for lithospheric effects [16].

The risk of total non-carcinogenic metals (As, Co, Cr, Cu, Mn, Ni, Zn, Pb, Sb, and U) and total carcinogenic risk for As, Co, Cr, Ni, and Pb can be determined by adding the risks of calculated exposure. The exposure dose for all three exposure routes (swallowing, breathing, and skin contact of dust particles) is calculated using Eq.8, 9, and 10 [17]:

$$D_{ing}(mg\ kg^{-1}day^{-1}) = C(mg\ kg^{-1}) \times \frac{R_{ing} \times EF \times ED}{BW \times AT} \times 10^{-6} \quad (8)$$

$$D_{inh}(mg\ kg^{-1}day^{-1}) = C(mg\ kg^{-1}) \times \frac{R_{inh} \times EF \times ED}{PEF \times BW \times AT} \quad (9)$$

$$D_{dermal}(mg\ kg^{-1}day^{-1}) = C(mg\ kg^{-1}) \times \frac{SA \times SL \times ABS \times EF \times ED}{BW \times AT} \times 10^{-6} \quad (10)$$

The lifetime average daily dose (LADD) is used to assess cancer risk, which is found for respiratory elements (Cd, Co, Cr and Ni). It was calculated using Eq.11[17].

$$LADD(mg\ kg^{-1}day^{-1}) = \frac{C(mg\ kg^{-1}) \times EF}{AT \times PEF} \times \left(\frac{CR_{child} \times ED_{child}}{BW_{child}} \times \frac{CR_{adult} \times ED_{adult}}{BW_{adult}}\right) \quad (11)$$

Where, R_{ing} is ingestion rate [17]. The R_{inh} is the rate of respiration that accounts for 7.6 m^3day^{-1} for children and 20 m^3day^{-1} for adults. The EF is repeatedly exposed and is given 180 days of a year [6,18]. The ED is subject to year-round exposure, with values set by the US Environmental Protection Agency (EPA) being 6 years for children and 24 years for adults [17]. The SA is an area of exposed skin that is 2800 cm^3 for children and 5700 cm^3 for adults. The SL is a skin aeration factor that is 0.2 for children and 0.07 mg cm^{-3} for adults [17].

The CR is the rate of contact or absorption, CR for ingestion is Ing R, for respiration is Inh R, and for skin absorption is according to Eq.12:

CR = SL. ABS. SA (12)

The ABS is the skin absorption coefficient for all elements except 0.001. This factor for arsenic is 0.03. The VF is the evaporation coefficient [17]. The BW is the average body weight (Kg) that is 15 for children and 70 for adults [17]. The AT is the average time that is 25550 days for carcinogenic elements and ED × 365 for non-carcinogenic elements [6]. The C parameter is also the concentration of exposed elements.

Based on this parameter the hazard quotient (HQ) as well as the hazard index (HI) can be calculated [17]. The HQ is based on the semantic risk of non-carcinogenic elements, and is calculated by dividing the average daily absorption by reference dose (RfD) (Man et al., 2010). The RfD (mg $kg^{-1}day^{-1}$) is an evaluation of the maximum allowable daily intake in human life. The HI is the sum of HQs and is used to evaluate health risk for exposure from various routes (Eqs.12, 13, 14, and 15). If the HI value ≤ 1, it will not adversely affect human health and if the HI value > 1, it will be detrimental to human health [19].

$$HQ\ ing = \frac{D_{ing}}{\text{oral RfD}} \quad (12)$$

$$HQ\ inh = \frac{D_{inh}}{inhal\ RfD}$$

(RFD = Corresponding RfD0) (13)

$$HQ\ dermal = \frac{D\ dermal}{\text{dermal RfD}} \quad (14)$$

$$HI = \sum HQ \quad (15)$$

For carcinogens, carcinogenic risk (CR) is also estimated by multiplying the dose in the carcinogenic process [6].

Cancer Risk = LADD. SF (SF = Slope Factor) (16)

Ethical issue

The ethical issue of this research was IR.NIMAD.REC.1397.009.

Results

XRD analysis

The Minerals, such as calcite, dolomite, quartz, albite, lizardite, lithite, gypsum, rutile, arsenolite, cristobalite, and muscovite were identified in the road dust samples of the study area (Figure 2). Calcite, dolomite, and quartz minerals were the dominant minerals in the sampling point. All minerals were distributed equally in all sampling stations.

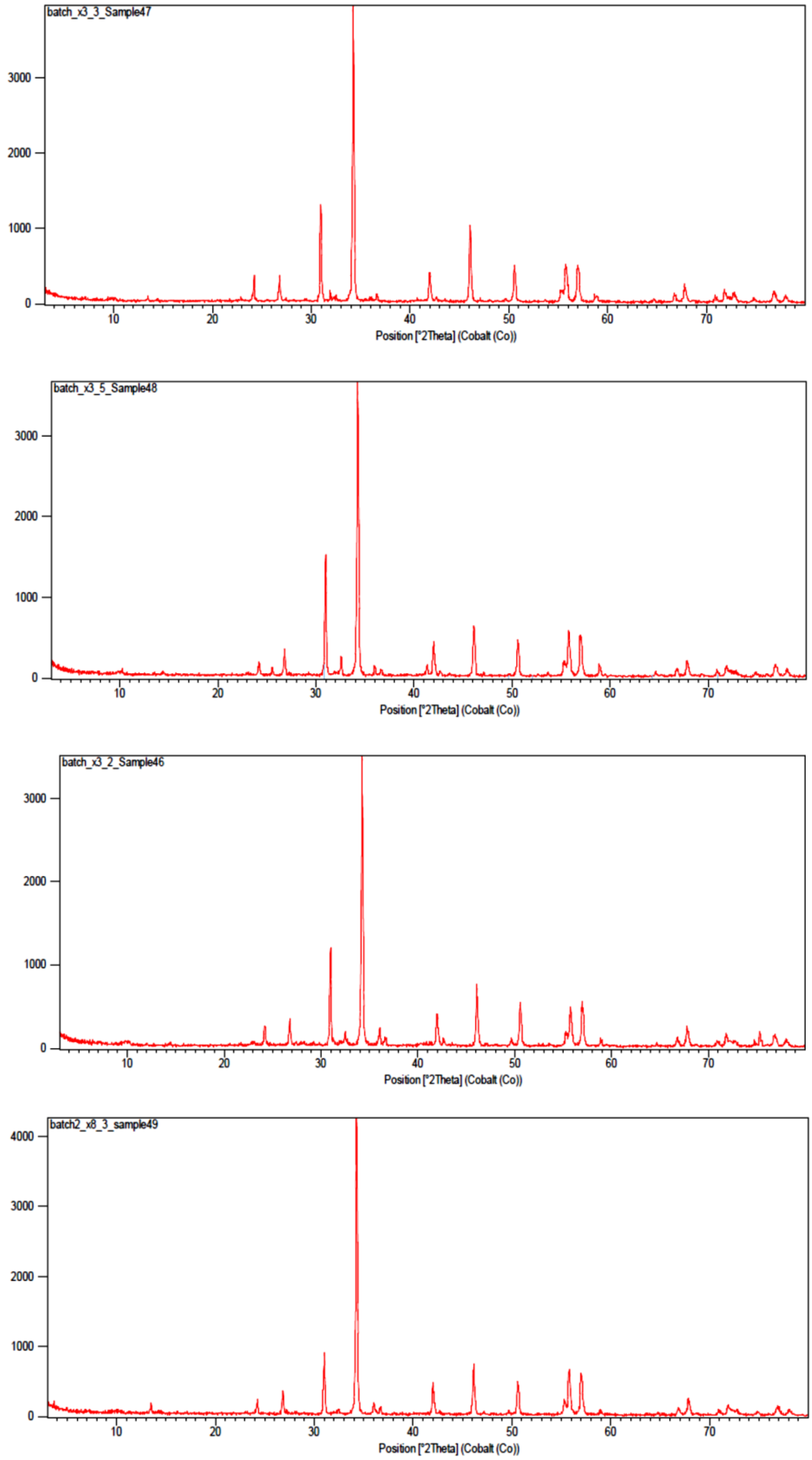

Figure 2: XRD analysis of road dust

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Heavy metal concentration in rod dust

Road dust samples for As, Co, Cr, Cu, Mn, Fe, Ni, Zn, Pb, Sb, U, Cd, Hg, and Mo were investigated to evaluate metal dust contamination from different sampling sites. Among these metals, Cd and Hg were excluded from the statistical analysis, since their concentrations in all samples were below the detection limit in the dust samples. The descriptive statistics of heavy metals concentrations in road dust of Behbahan city were showed in Table 1. The coefficient of variation of the concentration of elements for Cu and Pb is lower than 50%, indicating the low variation of the concentration of these elements in the soil of the region. The sampling points can be subdivided into 4 different zones, including residential, commercial, industrial, and heavy traffic. The heavy metals level in each section were as follows: residential zone Mn > Zn > Pb > Cu > Cr > Ni > As > Co > Mo > Sb > U > Fe, commercial zone Mn > Zn > Pb > Cu > Cr > Ni > As > Co > Mo > Sb > U > Fe, industrial zone Mn > Pb > Zn > Cr > Cu > Ni > As > Co > Sb > Mo > U > Fe, and heavy traffic Mn > Zn > Cu > Pb > Cr > Ni > As > Sb > Co > Mo > U > Fe.

The concentration of heavy metals, such as Cu, Zn, Ni, As, Cr, Pb, U, and Fe in the road dust of commercial zone were much higher than other zones due to the most heavy traffic in this zone. The concentration of heavy metal, such as Co and Sb in the heavy traffic zone were much higher than other zones. The Igeo value was presented in Figure 3, the main I_{geo} value was showed I_{geo} value lower than 0, indicating that road dust in Behbahan city was uncontaminated with Co, Cr, Fe, Zn, U, Mo, Ni, and Mn.

Table 1: Descriptive statistics of elements concentration (mg/kg) of road dusts in Behbahan city

Statistic	As	Co	Cr	Cu	Fe	Mn	Mo	Ni	Pb	Sb	U	Zn
No. of samples	20	20	20	20	20	20	20	20	20	20	20	20
Minimum	5.44	2.43	21.61	14.00	0.57	104.39	1.21	8.99	12.44	1.13	0.75	32.95
Maximum	13.97	4.54	58.23	95.69	1.2	169.35	3.71	18.39	98.38	5.11	2.07	126.19
1st quartile	6.89	3.18	26.26	20.50	0.7675	118.04	1.31	11.70	22.04	2.06	1.04	52.20
Median	7.36	3.50	27.89	26.74	0.82	129.56	1.55	13.00	36.89	2.36	1.26	66.32
3rd quartile	8.57	3.67	31.77	44.36	0.945	132.96	2.22	14.49	56.83	2.87	1.47	82.44
Mean	8.04	3.50	30.08	35.70	0.8525	129.63	1.79	13.12	4 2.16	2.50	1.25	68.94
Standard deviation	1.86	0.55	7.45	22.18	0.1575	18.36	0.63	2.25	25.62	0.78	0.36	24.15
CV(SD/median)	0.23	0.16	0.25	0.62	0.18	0.14	0.35	0.17	0.61	0.31	0.29	0.35
Skewness	1.57	0.12	2.59	1.32	0.36	0.81	1.47	0.30	0.81	1.59	0.17	0.60
Background value	4.7	6.9	42	14	3.5	412.4	1.8	18	25.02	0.62	3.7	62

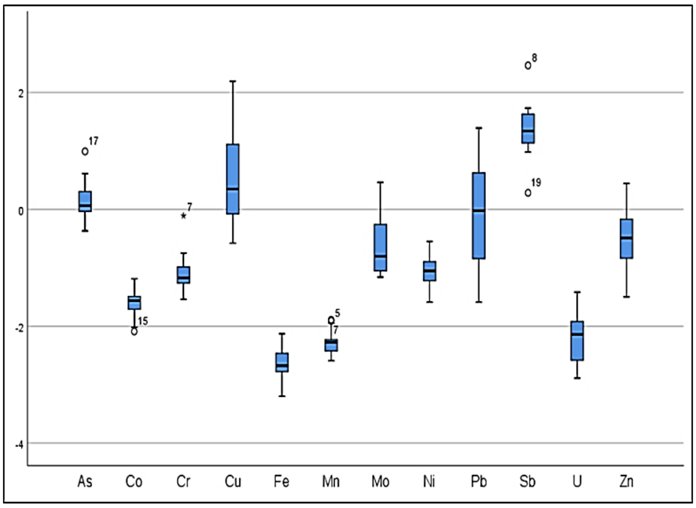

Figure 3: I_{geo} of road dusts in Behbahan city

Geo-accumulation index

The I_{geo} index value for Sb was 1.3, which showed that road dust in Behbahan city was moderately contaminated with Sb. The highest I_{geo} value for each metal also indicated that the road dust was partially contaminated and uncontaminated to moderately contaminated by the metals except for Pb, Cu, and Sb.

Contamination load index

The values of CF (Figure 4), DC, and PLI were calculated. The results showed that CF values of Co, Cr, Fe, Mn, Mo, and U were in the scope of low CF (CF < 1), while CF values of Ni, Cu, Pb, and Zn were in the scope of moderate contamination (1 < CF < 3). The CF value of Sb was in the scope of considerable contamination (3 < CF < 6).

In the evaluation of the CF index, Sb, Pb, and Cu had the most pollution in all stations, respectively. The DC value in all stations was in the scope of moderate contamination (8 ≤ DC ≤ 16) except stations 3, 7, 8, and 12. Based on the results, most stations were classified as uncontaminated sites (PLI < 1) and stations 7and 8 were classified as contaminated sites (PLI > 1). These two stations are located in heavy traffic areas of Behbahan city.

Ecological risk assessment

ERF for all metals was determined low with ERF values < 40 except Pb that ERF was determined moderate (Figure 5). ERI in all sectors was determined low with ERI values <150.

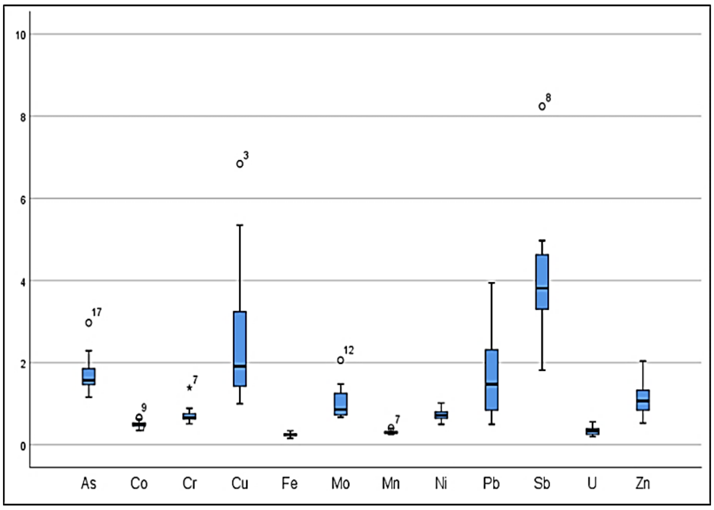

Figure 4: The CF of road dusts in Behbahan

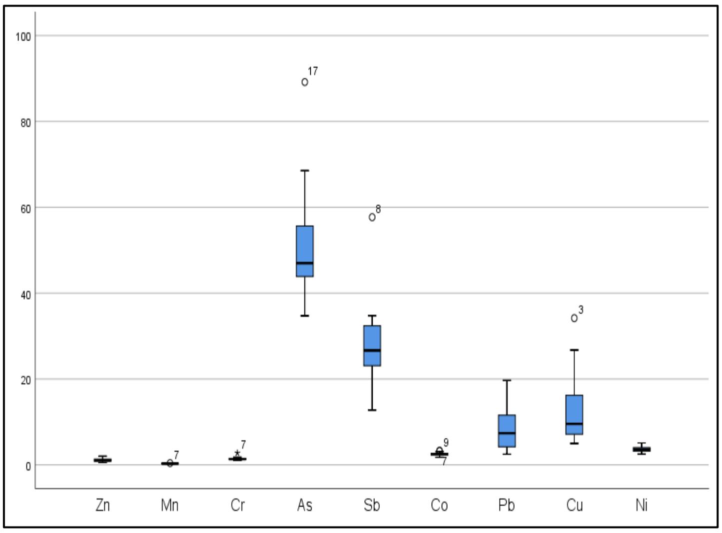

Figure 5: Determination of ERF in road dusts of Behbahan

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Source identification of road dust

The results of spearman correlation coefficients are presented in Table 2 for metals in road dust samples of Behbahan city. Specific positive correlations were considered for some metals: As-Sb, As-U, Co-Cr, Co-Cu, Co-Fe, Co-Mn, Co-Ni, Co- Zn, Cr-Cu, Cu-Fe, Cu-Mn, Cu-Ni, Cu-Zn, Fe-Mn, Fe-Zn, Mn-Ni, Mn-Zn, Mo-Sb, Ni-Zn, Pb-Sb.

The first two principal components (PCs) show 59.82% of the variance within the data. The first factor (PC1), representing 37.82% of total variance included Ni, Cu, Mn, Zn, Fe, Cr, and Co.

In addition, the PC Biplot demonstrates the spatial distribution of the sampling stations according to their symmetry. The stations in the first and fourth sectors (S_3, S_4, S_5, S_7, S_8, S_9, S_{12}, S_{16}, and S_{18}) demonstrated high concentrations of heavy metals (Figure 6). However, plotted stations in the second and third quadrants demonstrated somewhat low concentration of heavy metals. Industrial source (second factor) was prevailingly loaded on Pb (78.4%), As (37.5%), Sb (29.6%), U (36%), and Mo (39%).

Positive matrix factorization (PMF) model was performed to investigate the contribution of various sources of heavy metal in road dust of Behbahan city. Results were indicated that urban source (factor 1) was prevailing by Pb (35%), Cu (72.5%) and Zn (54.6%) (Figure 7).

Table 2: Spearman correlation analysis for metals concentrations of road dust in Behbahan

Elements	As	Co	Cr	Cu	Fe	Mn	Mo	Ni	Pb	Sb	U	Zn
As	1	-0.184	-0.089	-0.314	-0.259	-0.105	0.382	-0.325	0.086	0.496	0.734	-0.168
Co		1	0.557	0.675	0.497	0.520	-0.003	0.712	0.227	0.154	-0.138	0.677
Cr			1	0.480	0.282	0.089	-0.132	0.313	0.427	0.344	-0.201	0.335
Cu				1	0.722	0.537	0.068	0.564	-0.041	0.002	-0.180	0.881
Fe					1	0.561	0.347	0.422	0.099	0.340	-0.049	0.765
Mn						1	0.427	0.654	0.056	0.151	0.266	0.647
Mo							1	0.164	0.030	0.479	0.339	0.055
Ni								1	-0.012	0.003	-0.257	0.547
Pb									1	0.600	0.110	-0.063
Sb										1	0.356	0.068
U											1	-0.002
Zn												1

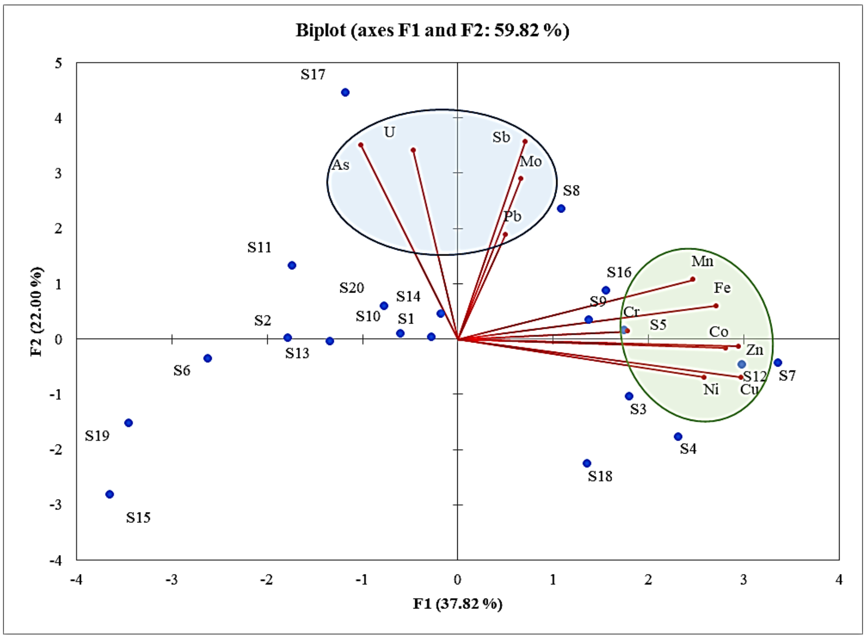

Figure 6: PC biplot of station and metals in road dust of Behbahan

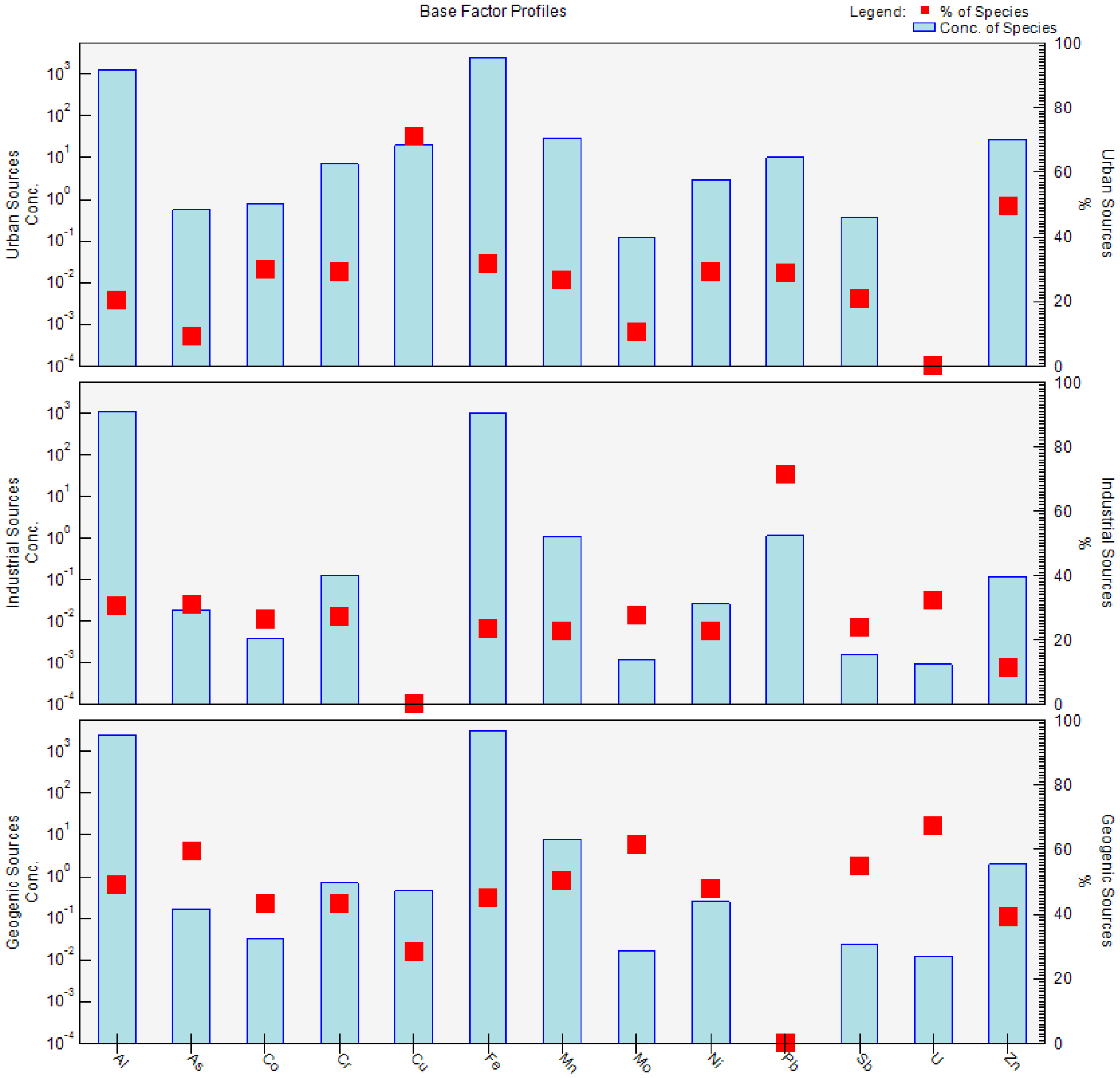

Figure 7: Source profile and factor fingerprint of the road dust samples from PMF model analysis

Health risk assessment

The health risks for humans caused due to heavy metals in road dust of Behbahan city, through various pathways (ingestion, inhalation, and dermal contact), were calculated (Table 3). The results indicated that chronic exposure of humans (both adults and children) to road dust in the study area may pose adverse health effects (HQ, HI, and THI > 1).

However, the sequence of non-carcinogenic risk of different exposure for children was dermal contact > inhalation > ingestion and for adults were dermal contact > ingestion > inhalation. Moreover, lower HQ values were obtained for adults in all metals and through all exposure pathways. Hence, children may have more potential non-carcinogenic risks than adults. In the case of carcinogenic risks, as shown in Table 3, the average carcinogenic risks of carcinogen metals (As, Co, Cr, Ni, and Pb) under different routes for adults and children were bellow 10^{-2}. Furthermore, TCR for adults and children were 6.89E-03 and 4.02E-02, respectively.

Table 3: Health risks due to environmental exposure to road dust's metals in Behbahan city

Element/index		Children Inhalation	Children Ingestion	Children Dermal	Adults Inhalation	Adults Ingestion	Adults Dermal
Non-carcinogenic risk							
HQ	As	-	4.3	3.46	-	8.56	7
	Co	-	2.8×10^{-1}	1.26×10^{-1}	6.6×10^{-2}	3.25×10^{-2}	1.8×10^{-2}
	Cr	1.78	1.3	1.66	4.6×10^{-2}	1.86	4.15
	Cu	-	1.425	1	-	1.65×10^{-1}	2.9×10^{-1}
	MO	-	5.72×10^{-1}	6.44×10^{-1}	-	6.6×10^{-2}	1.48×10^{-1}
	Ni	-	1.05	9.4×10^{-1}	-	1.22×10^{-1}	2.16×10^{-1}
	Pb	-	2.23	30	-	2.6	7
	Sb	-	10.05	11.12	-	1.16	25.87
	U	-	6.7×10^{-1}	-	-	3.3×10^{-2}	1.47
	Zn	-	3.6×10^{-1}	4×10^{-1}	-	4×10^{-2}	9.5×10^{-2}
HI		1.78	20.35	47.24	1.12×10^{-1}	14.18	45.49
THI			69.375			59.67	
Carcinogenic risk							
CR	As	1.5×10^{-4}	1.9×10^{-2}	1.2×10^{-3}	2.3×10^{-8}	9.75×10^{-4}	1.061×10^{-3}
	Co	-	-	1.1×10^{-2}	-	-	2.84×10^{-3}
	Cr	-	-	4.2×10^{-3}	-	-	1.045×10^{-3}
	Ni	-	-	3.94×10^{-3}	-	-	9.07×10^{-4}
	Pb	2.1×10^{-4}	5.69×10^{-4}	-	7.77×10^{-8}	6.63×10^{-5}	-
TCR			4.02×10^{-2}			6.89×10^{-3}	

Discussion

The composition of road dust can vary depending on the factors, such as geographic place, land use, traffic specification, and drought periods [3, 20].

The differences in the amount of minerals at different stations can be due to their different environmental conditions. The percentage of calcite mineralization in downtown stations increased. This could be due to increased construction activities (using plaster, etc.) which are more in downtown than other areas. In areas of the city where there are more sources of pollution, various minerals (such as car exhaust) are released which can reduce the quartz percentage [21]. The iron oxides observed in road dust samples can be affected by anthropogenic sources in addition to terrestrial sources. Magnetite minerals, for example, are probably produced by the burning of fossil fuels, vehicle exhaust emissions, solid waste dispersal, and dust from smelting activities and other industries [22].

The sampling points can be subdivided into 4 different sections, including residential, commercial, industrial, and heavy traffic. The heavy metals level in each section were as follows: residential section Mn > Zn > Pb > Cu > Cr > Ni > As > Co > Mo > Sb > U > Fe, commercial section Mn > Zn > Pb > Cu > Cr > Ni > As > Co > Mo > Sb > U > Fe, industrial section Mn > Pb > Zn > Cr > Cu > Ni > As > Co > Sb > Mo > U > Fe, and heavy traffic Mn > Zn > Cu > Pb > Cr > Ni > As > Sb > Co > Mo > U > Fe. Similar trend was reported in previous studies [23]. The mean concentrations of heavy metals, such as As, Cu, Zn, Pb, and Sb were higher than background heavy metal concentrations. The results were observed in road dust of Isfahan city [24].

A previous study reported that the mean concentrations of heavy metals were higher than background concentrations, indicating that the metals originate from human resources in the region [25]. On the other hand, another study reported that it is not possible to conclude about soil pollution and the role of human activities on the concentration of metals only with respect to the background concentration. It is due the fact that the relationship between heavy metals in the soil is complex and ambiguous[25, 26]. Many factors, such as the concentrations of heavy metals in rocks and parent materials, various soil formation processes, and human factors determine the

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relative abundance of metal concentrations in soils [27].

The concentration of Mn and Mo in the residential section was much higher than other sections, suggesting the two metals in road dust mainly related to natural sources [18, 28, 29].

These metals vary extensively between different zones and between samples, due to heterogeneity of sample and different variables that cannot be controlled. This can be described by a high grade of metal variation regardless of distinctive characteristic of economic activity in each section [23, 30]. Depending on coefficient of variation (CV), the studied metals can be divided into two categories, including metals with CV higher than 0.4, such as Cu and Pb and metals with CV less than 0.4, such as As, Co, Cr, Ni, Fe, Mn, Mo, Sb, and Zn. It is expected that metals with low CV are influenced by natural resources. However, metals with high CV are influenced by anthropogenic resources. This trend is similar to studies conducted in other cities of Iran, including Isfahan and Tehran [24, 31]. The range of changes in the concentration of heavy metal and the CV of heavy metal concentrations indicate the human factors affecting the concentration of metals in the road dust of study area. The highest CV were related to Cu (0.62) and Pb (0.61), indicating the effect of human activities on increasing the concentration of these metals in the road dust of the region. The concentration of Mn, Cu, and Pb in all sections were significant. These metals are associated to road pavement materials, tire and brake wear, lubricants, and fuel combustion [23, 28]. The Pb levels in areas with low traffic around industries section are significantly lower than other areas. It was shown that industry cannot play a specific role in the level of Pb in road dust and vehicle have a major role [32].

The Zn level mainly originates from cars due to lubricating oils and tires [32]. Due to the high temperature, tire wear can be increased and Zn was also used as a welding agent in tires [33]. The existence of Cu in road dust can be obtained from car engine wear. Also Brake pads are rich in metals, especially Cu [34]. Fe is a widely used metal in industrial practices and especially in smelting industries [35]. Cr originates from the erosion of Cr coatings and alloys in automobiles. The main reasons for presence of Ni are the use of fossil fuels by industries in this region. The Ni and Mn mainly have industrial origin [36]. The mean concentrations of heavy metals in Behbahan road dust were lower than other cities of Iran, such as Esfahan [24] and Tehran [31].

The I_{geo} was applied to investigate the severity of heavy metal contamination of soil. The I_{geo} was introduced by Muller[16] to assess soil contamination by heavy metals. This index is applied to assign the level of contamination and impact of human factors on natural factors in the soil and sediment environment. The I_{geo} index value was in the range of 0 to 1, indicating that road dust in Behbahan city was uncontaminated to moderately contaminated with As and Cu. As and its compounds are used as pesticides. Metal arsenic is also used in the production of alloys of Pb, Cu ,and steel and in the electronics industry [37].

The I_{geo} value for Sb was 1.3, revealing that road dust in Behbahan city was moderately contaminated with Sb. This is due to its small amount of this metal in the earth's crust[38]. The highest I_{geo} value for Pb, Cu, and Sb were 1.39, 2.19, and 2.46, which may suggest that Pb, Cu, and Sb in the road dust were most affected by anthropogenic sources. These results have been observed in other studies[39, 40]. The Cu compounds are used as anti-corrosives in ores. These compounds create a protective layer on the surface of the engine that reduces friction and prevents damage from wear between different parts of the engine [37].

The high level of Pb in the road dust was usually associated with point sources of pollution and transportation of vehicle emissions. It was observed that increase in Pb concentration in road dust was caused by contamination of exhaust emission components and wear of car components [29].

The values of CF (Figure 4), DC, and PLI were calculated. In the evaluation of the CF index, Sb, Pb, and Cu had the most pollution in all stations, respectively. The DC value in all stations was in the scope of moderate contamination (8 ≤ DC ≤ 16) except stations 3, 7, 8, and 12. This phenomenon is due to this fact that these areas are overcrowded and the pollution caused by vehicles in these areas is very high.

The lowest ecological risk was determined in residential zone. Heavy traffic zone shows the maximum ERI value and ecological risk of the road dust samples. This phenomenon is the main local source of road dust contamination due the vehicular traffic. The findings of present study are in line with studies conducted in cities, such as Tehran. In studies carried out in Tehran, the ERI was very high in all sections [31].

Shapiro-Wilk and Kolmogorov-Smirnov tests indicated that distribution of metals concentrations was not normal. Thus, spearman correlation analysis was applied for determination of the association between heavy metals and their origin. The results showed the highest correlation coefficients ($r > 0.6$) for metals, including Cu, Fe, Ni, Sb, Zn, and U, indicating that they originate from the same anthropogenic source.

PCA establishes further data about the possible correlation between heavy metals and their sources [41]. The classification of Ni, Cr, Fe, and Mn suggests geogenic sources. The second PC (PC2) representing 22.00% of the total variance shows high level of As, Sb, U, Pb, and Mo (metals highly related to anthropogenic sources).

Positive matrix factorization (PMF) model was performed to investigate the contribution of various sources of heavy metals in road dust of Behbahan city. Previous studies reported that Cu, Zn, and Pb in road dust might be due to traffic emission. The important sources of Cu, Pb, and Zn in road dusts were petrol combustion by vehicles. Additionally, high level of Pb and Zn in road dust might be related to fossil combustion and industrial practice [42]. All of these metals (Pb, Cu, and Zn) are related to road pavement materials, tire and brake wear, lubricants, and fuel combustion. Previous studies indicated that Pb, Cr, As, Mo, and Sb originated from industrial area [43]. Another study investigated that source of Cd and Cr was from industrialization and human activities [44]. Anthropogenic source (third factor) was prevailed by Fe (52%), Al (49%), Ni (56.2 %), Mn (58.9 %), Co (44.3 %), and Cr (43.9%). Al and Fe indicated that common geochemical commitment of significant stone framing components is in industrial region soils.

Because of children's physiological and behavioral characteristics, such as high respiration rates, hand to mouth activities, and high gastrointestinal absorption, they have a higher sensitivity of exposure to pollutants than adults [45]. The average carcinogenic risks of carcinogen metals (As, Co, Cr, Ni, and Pb) under different routes for adults and children were bellow 10^{-2}. Furthermore, TCR for adults and children were 6.89 E-03 and 4.02 E-02, respectively, demonstrating that human exposure to road dust in the study area may not pose significant health effects to adults, but may pose carcinogenic effects to children.

Conclusion

In this study, the concentration of heavy metals in road dust of Behbahan city was investigated. The concentration of heavy metals, such as Cu, Zn, Ni, As, Cr, Pb, U, and Fe in the road dust of the commercial zone were much higher than other zones. The concentrations of heavy metals, such as Co and Sb in the heavy traffic section were much higher than other sections. These metals vary widely between different sections and between samples, due to heterogeneity of samples and various variables that cannot be controlled. The highest I_{geo} values for Pb, Cu, and Sb were 1.39, 2.19, and 2.46, which may suggest that Pb, Cu, and Sb in the road dust were most affected by anthropogenic sources. The lowest ecological risk was determined in residential zone. Heavy traffic zone shows the maximum RI value and ecological risk of the road dust samples. The results indicated that chronic exposure of humans (both adults and children) to road dust in the study area may pose adverse health effects. Furthermore, TCR for adults and children were 6.89 E-03 and 4.02 E-02, respectively, indicating that human exposure to road dust in the study area may not pose significant health effects to adults, but may pose carcinogenic effects to children. The results reported the highest correlation coefficients (r > 0.6) for metals, such as Cu, Fe, Ni, Sb, Zn, and U that represent they originated from the same anthropogenic source.

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Conflict of interests

The authors declare no conflict of interest.

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