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Heavy metal induced ecological risk in the city of Urumqi, NW China

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Abstract A total of 169 samples of road dust collected in the city of Urumqi, capital of the Xinjiang Uygur Autonomous Region in northwest China, were analyzed by method of inductively coupled plasma-mass spectrometry for 10 elements (i.e., Cd, Cr, Cu, Ni, Pb, Mn, Be, Co, Zn, and U). The possible sources of metals are identified with multivariate analysis such as correlation analysis, principal component analysis, and cluster analysis. Besides, enrichment factors are used to quantitatively evaluate the influences of human activities on heavy metal concentrations. Moreover, the potential ecological risk index is applied to evaluating the ecological risk of heavy metal pollutants. The results indicate that: (1) the concentrations of the heavy metals involved were much higher in urban areas than the background values, except those of Co and U. Mn, U, and Co are mainly of natural origin; Cu, Pb, Zn, and Cr are mainly of traffic sources and are partly of industrial sources; Ni and Be are mainly the results of industrial activities, such as machine shops, firepower plants, tire and rubber factories, cement factories, and textile mills and are partly of the traffic sources; (2) with high "toxic-response" factor and high concentration, Cd has more serious influences on the environment than other heavy metals. Therefore, commercial and industrial areas are usually characterized by higher potential ecological risk when compared with residential areas and new developing urban areas. The results of this study could be helpful for the management of environment in industrial areas.

Keywords Road dust · Heavy metal · Multivariate analysis · Ecological risk · Urumqi

Introduction

Dusts deposited on the roads are usually called "road dusts," "road-deposited sediments," or "street dusts" (Tokalioğlu and Kartal 2006). Heavy metals in road dusts are the major pollutants in the urban environment which are mainly from traffic instruments, heating systems, building materials, corrosion of galvanized metal structures, mining activities, and industrial activities (Akhter and Madany 1993; Al-Khashman 2004; Ferreira-Baptista and De Miguel 2005). Fossil fuel

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combustion (coal or oil materials) usually produces large amounts of heavy metals such as Be, Co, Hg, Mo, Sb, Se, Sn, Ni, and V and some other pollutants like As, Cr, Cu, Mn, and Zn. Industrial metallurgical processes also produce such by-products as As, Cd, Cu, Ni, and Zn. Heavy metals of Pb, Cu, Zn, Ni, and Cd are the main results of exhausted gasoline emissions. In addition, tire abrasion can also give rise to Zn (Lv et al. 2006). In recent decades, heavy metals in urban road dusts have been receiving increasing concerns from the public due to their negative influences on the ecosystem and human health (e.g., Ahmed and Ishiga 2006). Numerous studies are available addressing the concentration and associated distribution of heavy metals in different cities, e.g., Madrid and Oslo (De Miguel et al. 1997), Hong Kong (Li et al. 2001), Birmingham and Coventry (Charlesworth et al. 2003), Naples (Imperator et al. 2003), Istanbul (Sezgin et al. 2003), Brisbane (Herngren et al. 2006), and Gela (Manno et al. 2006). Some studies have shown that the sources of heavy metals in urban roads are mainly traffic instruments, industrial activities, as well as weathering of building facades (Li et al. 2001; Charlesworth et al. 2003; Han et al. 2006; Tokalioğlu and Kartal 2006; Meza-Figueroa et al. 2007; Xue and Wang 2007).

Albeit numerous studies of heavy metal concentrations have been carried out in developed countries (e.g., Meza-Figueroa et al. 2007), almost no thorough studies are available addressing the concentrations of heavy metals in developing countries, China in particular. Furthermore, most of these studies mainly focus on Pb, Cu, and Zn (Charlesworth et al. 2003), and few studies involve Ni, Mn, Cr, Be, Co, and U which have significant impacts on environment. With these in mind, the objectives of this study include: (1) to determine concentrations of 10 types of heavy metal pollutants (Cd, Cr, Cu, Ni, Pb, Mn, Be, Co, Zn, and U) in urban road dusts in Urumqi, with comparison with similar studies in other cities of the world (e.g., De Miguel et al. 1997; Li et al. 2001; Charlesworth et al. 2003; Ferreira-Baptista and De Miguel 2005; Han et al. 2006; Al-Khashman 2007; Xue and Wang 2007); (2) to identify the possible sources of these pollutants based on principal component analysis, cluster analysis, and correlation analysis; (3) to figure out the degree to which human activities influence the heavy metal contaminations; and (4) to assess the potential ecological risk of these heavy metal pollutants.

Study region, materials, and methods

Study region

The Urumqi city (86°37′33″ – 88°58′24″ E, 42°45′32″ – 44°08′00″ N), capital of Xinjiang Uygur Autonomous Region of China, is located in northwest China, with a continental and arid climate. Situated on the northern piedmont plains (about 800 m above sea level) of the Tianshan Mountains (Fig. 1), it has a population of over 1.94 million in 2005 and more than 0.23 million motor vehicles in 2006. A total of 11.4 million tons of coal was consumed in 2006, about 4 million tons more than that in 2000. In recent years, the increasing population, vehicles, and manufactures, as a result of rapidly developing economy, have resulted in deteriorating environment. The main factories, including machine, tire, rubber, and cement factories, are located in the northern Urumqi; paper mills, firepower plants, textile mills, automobile factories, chemical plants, and other manufactories concentrate in the east of the city.

Urumqi is an economically quickly developing city in northwestern arid China. However, in 1998, the city was evaluated by the Word Health Organization as one of the top 10 (ranked as the fourth) heavily polluted cities over the world (Li et al. 2008). Li et al. (2008) found that the concentration of total suspended particle matter and $PM_{2.5}$ in winter in Urumqi is more than 12 times the US standard value and more than three times the China standard value. Unfortunately, the detailed information of the heavy metal contaminations in road dusts in Urumqi was not available. The present study could not only facilitate better understanding of the mechanism of environmental pollution and possible causes but also lay solid basis for environment management in the study region.

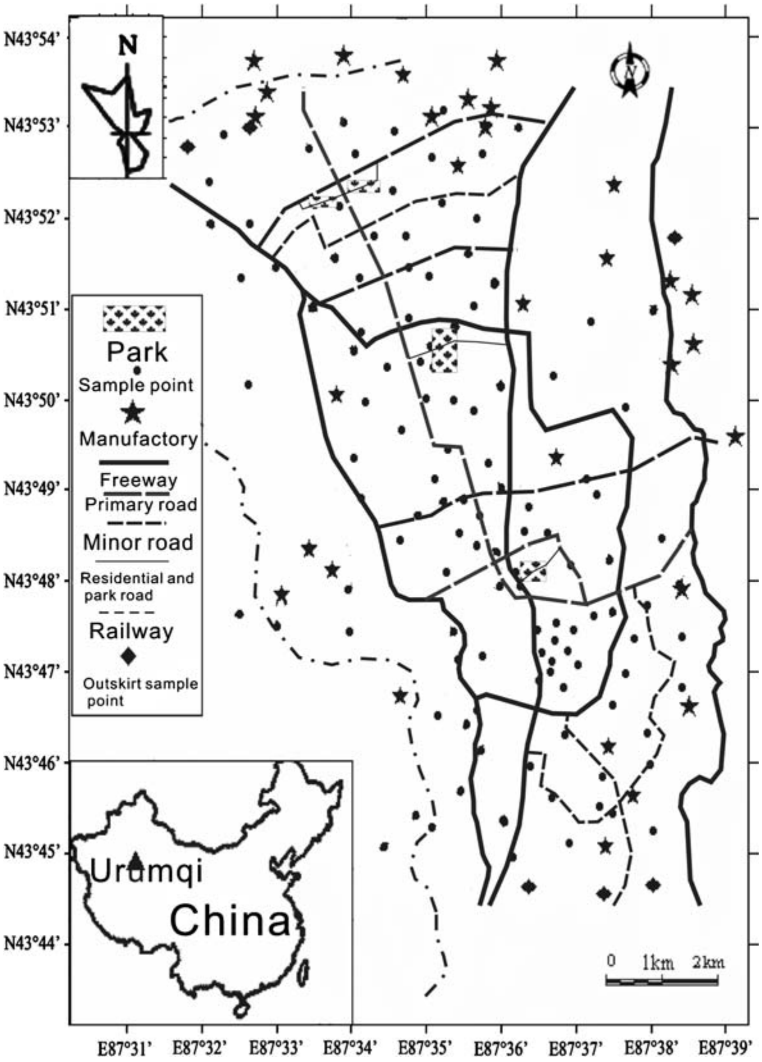


Fig. 1 Sketch map showing the study area and sampling sites (*top left corner*: wind rose)

Sampling

A total of 169 road dust samples were collected in August 2007 from different roads, i.e., 24 from highway, 64 from primary roads, 65 from minor roads, 10 from residential roads, and six from park roads in the Urumqi city. Six of them were collected in the outskirts of the city where the influences of traffic and industrial activities on the samples can be ignored. In a sampling point, approximately 200 g of the dust particles was collected on impervious surfaces (road, pavement, gutter) at the roadsides (the sampling resolution is 1 × 1 m square) with a clean plastic dustpan and a brush and were transferred to self-sealing polyethylene bags for transport to laboratory for further analysis. The sampling points were located with Global Positioning System instrument, as shown in Fig. 1.

Sample processing

All the samples were air-dried in the laboratory with standard method (Ferreira-Baptista and De Miguel 2005; Tokalioğlu and Kartal 2006), and then, these dried samples were sieved via a nylon sieve with a diameter of $\leq$0.149 mm. Then, 0.1 g of the sieved dust samples was digested with 5:2:1 $HNO_3/H_2SO_4/HF$ mixture. The well-prepared solution was heated at 120°C for 30 min, at 150°C for 30 min, at 200°C for 30 min, and at 260–270°C for

Table 1 The detection limits and recovery of standard samples for each element

Metal	Detection limits (μg/kg)	Recovery of standard samples %	Standard value (mg/kg)	Standard value ± 1s (mg/kg)	Determination value (mg/kg)
Cd	0.06	94.32	0.088	0.066–0.11	0.086
Cr	0.57	95.58	194	179–209	186
Cu	0.66	105.50	21.8	19.8–23.8	23
Ni	0.60	103.95	76	65–87	79
Pb	0.144	95.08	24.4	19.7–29.1	23.2
Mn	0.54	106.52	920	860–980	980
Be	0.40	93.33	3	2.5–3.5	2.8
Co	0.57	105.39	20.4	17.1–23.7	21.5
Zn	0.11	96.20	79	69–89	76
U	0.19	102.27	4.4	3.9–4.9	4.5

60 min in turn (Charlesworth et al. 2003; Lv et al. 2006). Finally, the molten samples were diluted in a 50-ml flask with deionized water. Ten types of heavy metals (i.e., Cd, Cr, Cu, Ni, Pb, Mn, Be, Co, Zn, and U) were analyzed with inductively coupled plasma-mass spectrometry (ELANDRC II, PerkinElmer). Quality controls were realized with: (1) analysis of 12 random samples and four national standard samples; and (2) random selection of samples to ensure that the mean deviation be less than 3%. The detection limits and recovery of standard samples for each element are represented in Table 1.

Data analysis

Multivariate analysis techniques, e.g., principal component analysis and cluster analysis, have been widely used to identify the sources of pollutants in soil (Micó et al. 2006; Zhang 2006; Saeedi et al. 2008), particulate matter (Viana et al. 2006), sediments (Qu and Kelderman 2001; Simeonov et al. 2007), and urban road dusts or street dusts (Banerjee 2003; Han et al. 2006; Tokalioğlu and Kartal 2006; Al-Khashman 2007; Meza-Figueroa et al. 2007). In our study, multivariate analysis was performed by using SPSS 13.0 for Windows. Pearson correlation coefficients were also calculated for evaluating the relations of variables.

Principal component analysis (PCA) was used to reduce the dimensions of dataset. Varimax normalized rotation was adopted to maximize the variances of the factor loadings. Factor loadings >0.71 are typically regarded as being acceptable (Han et al. 2006).

Cluster analysis (CA) was performed to differentiate the components of various sources and to classify them into several categories. Hierarchical cluster analysis was carried out in this study with the Ward's Method, and the distance method was square Euclidean (Micó et al. 2006; Tokalioğlu and Kartal 2006). Results were shown in a dendrogram (Fig. 3).

Enrichment factor (EF) was calculated to differentiate between the metals originating from human activities and those from natural provenance or the mixed source of the metals and assess the degree of anthropogenic influence. The enrichment factor of an element x (EF_x) is calculated as:

$$\mathrm{EF}_x = \left(\frac{C_x}{R}\right)_{\text{sample}} \Big/ \left(\frac{C_x}{R}\right)_{\text{reference}} \tag{1}$$

where C_x is heavy metal concentration; R is the reference element concentration; *sample* means the metal-reference ratio for the road dust; and *reference* denotes the metal-reference ratio for the uncontaminated soil. In this evaluation, the reference values of metals are the background values of the study area, and U denotes the reference element.

Assessment of potential ecological risk

The potential ecological risk of the heavy metals is quantitatively evaluated by the potential ecological risk index (Hakanson 1980; Zhu et al. 2008), which takes into account both concentrations of heavy metals and ecological factors, and the "toxic-response" factor. The potential risk index can be acquired as follows:

$$E_r^i = T_r^i \times C_f^i \qquad (2)$$

$$\mathrm{RI} = \sum_{i=1}^{n} E_r^i \qquad (3)$$

$$C_f^i = C_s^i \times C_n^i \qquad (4)$$

where E_r^i denotes the potential ecological risk factor of individual metal; *RI* denotes the potential ecological risk factor of multiple metals; T_r^i denotes the "toxic-response" factor for heavy metals. Hakanson (1980) suggested that T_r^i of Cd, Cr, Cu, Pb, and Zn is 30, 2, 5, 5, and 1, respectively; C_f^i denotes the contamination of heavy metals; C_s^i is the measured metal content in the sampling sites (i); and C_n^i denotes the background value of heavy metals in the uncontaminated soil.

In this study, the minimum, mean, and maximum E_r^i and RI of Cd, Cr, Cu, Pb, and Zn were calculated for each metal pollutant; RI of Cd, Cr, Cu, Pb, and Zn were calculated for all sample sites.

Results and discussions

Heavy metal concentrations

The mean concentration of Cd, Cr, Cu, Ni, Pb, Mn, Be, Co, Zn, and U of all samples, as well as associated background values, are displayed in Table 2. Except for Co and U, the mean concentrations of eight metal pollutants are larger than their background values in the study region. These eight metal pollutants are also characterized by higher mean concentrations than the six samples from outskirts of Urumqi (the mean concentration of Cd, Cr, Cu, Ni, Pb, Mn, Be, and Zn was 0.31, 41.09, 88.52, 37.83, 41.12, 841.16, 2.57, and 148.83 mg/kg, respectively), showing that road dust samples may be contaminated by traffic-induced heavy metal pollutants. The mean concentrations of 10 heavy metals from the outskirts are different from the background values, i.e., the concentrations of the heavy metals in uncontaminated soil. These results demonstrate that the samples from the city roads are more seriously contaminated by traffic and industry activities than those from the outskirts.

Table 2 Mean concentration of metals (mg/kg) in street dust in Urumqi and several other cities

City	Cd	Cr	Cu	Ni	Pb	Mn	Be	Co	Zn	U
Urumqi	1.17	54.28	94.54	43.28	53.53	926.6	2.75	10.97	294.47	2.13
Std Dev	2.00	19.73	42.39	11.91	18.20	139.1	0.84	2.15	129.11	0.35
Background- values[a]	0.12	49.3	26.7	26.6	19.4	688	1.65	15.9	68.8	2.8
Birmingham[b]	1.62	–	466.9	41.1	48.0	–	–	–	534.0	–
Coventry[b]	0.9	–	226.4	129.7	47.1	–	–	–	385.7	–
Luanda[c]	1.1	26	42	10	351	258	–	2.9	317	0.97
Hongkong[d]	3.77	–	173	–	181	–	–	–	1450	–
Kayseri[e]	10.1	–	66.7	57	165.5	274	–	26.1	–	–
Oslo[f]	1.4	–	123	41	180	833	5.9	19	412	2.4
Madrid[f]	–	61	188	44	1927	362	–	3	476	–
Xi'an[g]	–	167.28	94.98	–	230.52	687	–	–	421.46	–
Xuzhou[h]	0.54	78.4	38.2	34.3	43.3	543.1	1.97	11.7	144.1	–

Std Dev standard deviation for each element in road dust in Urumqi

[a] CEPA and CGSEM (1990)

[b] Charlesworth et al. (2003)

[c] Ferreira-Baptista and De Miguel (2005)

[d] Li et al. (2001)

[e] Al-Khashman (2007)

[f] De Miguel et al. (1997)

[g] Han et al. (2006)

[h] Xue and Wang (2007)

Table 3 Pearson's correlation matrix for the metal concentrations, $N = 169$

Element	Cd	Cr	Cu	Ni	Pb	Mn	Be	Co	Zn	U
Cd										
Cr	0.031									
Cu	0.111	0.480**								
Ni	0.104	0.577**	0.438**							
Pb	0.071	0.303**	0.352**	0.298**						
Mn	0.118	0.577**	0.453**	0.633**	0.365**					
Be	−0.009	0.163*	0.092	0.397**	0.090	0.437**				
Co	0.101	0.440**	0.297**	0.653**	0.228**	0.565**	0.453**			
Zn	0.164*	0.330**	0.510**	0.189*	0.378**	0.162*	−0.009	0.153*		
U	−0.053	−0.037	−0.167*	0.072	−0.251**	−0.071	0.071	0.213**	−0.231**	

*$p = 0.05$ correlation is significant (two-tailed)

**$p = 0.01$ correlation is significant (two-tailed)

In China, the concentrations of Cr, Cu, Ni, Pb, and Zn in urban road dusts are commonly elevated (Han et al. 2006; Xue and Wang 2007), while it can be observed from Table 2 that the concentrations of the metals in road dusts from China are lower than that in cities of developed countries. The concentration level of Cd in the study region was generally higher than that in other cities of the developed countries or regions with exceptions of Hong Kong and Kayseri. The mean concentrations of Zn, Pb, and Cu in the study region are lower than those in the developed countries but are higher than that in Xuzhou, a new economically developing city of China, indicating that the concentrations of these heavy metals may be closely related to economic development. Higher concentrations of Cd, Pb, Cu, and Zn can be observed in the road dusts from the urban areas, implying that these heavy metals may be from motor vehicle emissions (Charlesworth et al. 2003; De Miguel et al. 1997). The mean concentration of Ni (43.28 mg/kg) in the study region is higher than that in other cities of the developed countries or regions with exceptions of Madrid and Coventry. In general, elevated Ni concentration in urban road dusts can be attributed to vehicle instruments because of the engines using nickel gasoline as fuel (Al-Khashman 2007).

Manganese is a kind of common metal pollutant in road dusts. The mean concentration of Mn in the study region was higher than in several other cities of the world (Table 2) and is also much higher than its background value. Therefore, Mn may also be attributed to other sources such as traffic emissions and industrial activities besides natural sources. The concentrations of Co, Be, and U do not vary much over the study region.

Table 4 The results of principal component analysis ($n = 169$)

Component	Initial eigenvalues			Extraction sums of squared loadings			Rotation sums of squared loadings		
	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %
1	3.654	36.543	36.543	3.654	36.543	36.543	2.726	27.258	27.258
2	1.677	16.772	53.315	1.677	16.772	53.315	2.250	22.505	49.763
3	0.992	9.918	63.233	0.992	9.918	63.233	1.233	12.232	61.995
4	0.899	8.988	72.221	0.899	8.988	72.221	1.023	10.225	72.221
5	0.680	6.799	79.020						
6	0.647	6.474	85.494						
7	0.454	4.539	90.032						
8	0.408	4.084	94.116						
9	0.321	3.212	97.328						
10	0.267	2.672	100.000						

Table 5 The component matrix and rotated component matrix of the 10 heavy metals in the Urumqi city

Metal	Component				Rotated component			
	1	2	3	4	1	2	3	4
Cd	0.176	−0.182	0.929	−0.224	0.057	0.078	−0.021	0.984
Cr	0.750	−0.045	−0.121	0.293	0.453	0.665	0.073	−0.115
Cu	0.681	−0.375	−0.015	0.257	0.222	0.778	−0.115	0.041
Ni	0.818	0.256	0.018	0.049	0.746	0.409	0.110	0.031
Pb	0.537	−0.414	−0.166	−0.195	0.249	0.462	−0.499	−0.001
Mn	0.818	0.156	−0.058	−0.182	0.771	0.339	−0.142	0.030
Be	0.465	0.498	−0.094	−0.500	0.802	−0.245	−0.141	−0.014
Co	0.728	0.423	0.104	0.037	0.771	0.254	0.237	0.082
Zn	0.467	−0.608	0.095	0.230	−0.067	0.752	−0.222	0.173
U	−0.077	0.666	0.232	0.565	0.114	−0.105	0.893	−0.026

Correlations among the heavy metal pollutants

Table 3 shows that Cu, Cr, Mn, Pb, and Zn are all significantly correlated at <0.05 significance level, indicating that these metal pollutants share common sources such as traffic emission. Moreover, Co, Cu, Ni, Mn, Cr, and Be are significantly correlated. These metal pollutants may mainly be attributed to industrial activities. A good relationship between U and Co may indicate a common source of the metals.

Principal component analysis

In this study, PCA was applied to identify possible sources of the 10 kinds of heavy metal pollutants in Urumqi. The factor loadings after Varimax rotation as well as eigenvalues are listed in Table 4. Principal factors extracted from the variables with eigenvalues >0.8 are selected. The component matrix and rotated component matrix of all the 10 kinds of heavy metal pollutants are shown in Table 5. PCA loadings (including PCA1, PCA2, and PCA3) are also illustrated in Fig. 2, and the relationships among the 10 metal pollutants are readily seen. Just as expected, four factors are obtained, accounting for 73% of the total variance. Factor 1 is dominated by Cr, Cu, Ni, Pb, Mn, Be, Co, and Zn, accounting for 36.5% of the total variance. In this study, Cu, Pb, Be, and Zn loadings (0.681, 0.537, 0.465, and 0.467, respectively) are not as high as the loadings of other metal pollutants of the group, implying that the four metal pollutants may be from different sources. Therefore, factor 1 can be classified as "heavy metals of strong anthropogenic sources." The anthropogenic sources include traffic emission, industrial activities, mining activities, and so forth. Factor 2 explained about 17% of the total variance. It is dominated by Be, Co, and U. Factor 3 is dominated by Cd, accounting for 10% of the total variance. And factor 4 explains 9% of the total variance. It is dominated by U, which is mainly of natural sources.

Cluster analysis

CA was applied to standardize the bulk concentration of heavy metal pollutants using Ward's

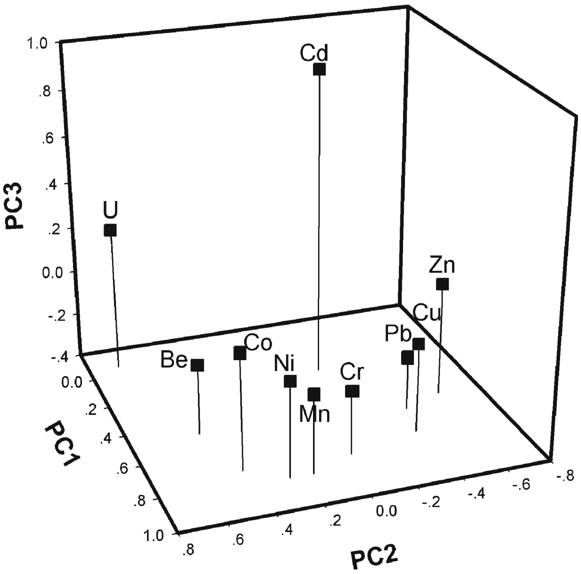


Fig. 2 PCA loading 3-D plot (PC1 vs. PC2 vs. PC3) for 10 heavy metals

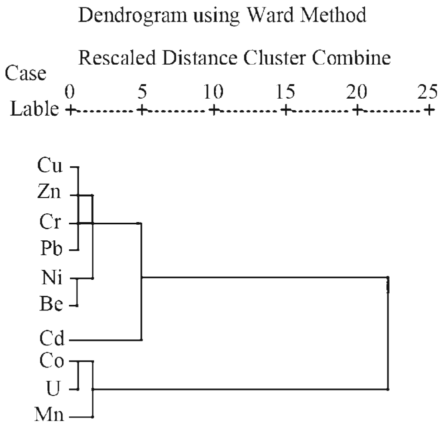


Fig. 3 Hierarchical dendogram for 10 elements obtained by Ward's hierarchical clustering method (the distances reflect the degree of correlation between different elements)

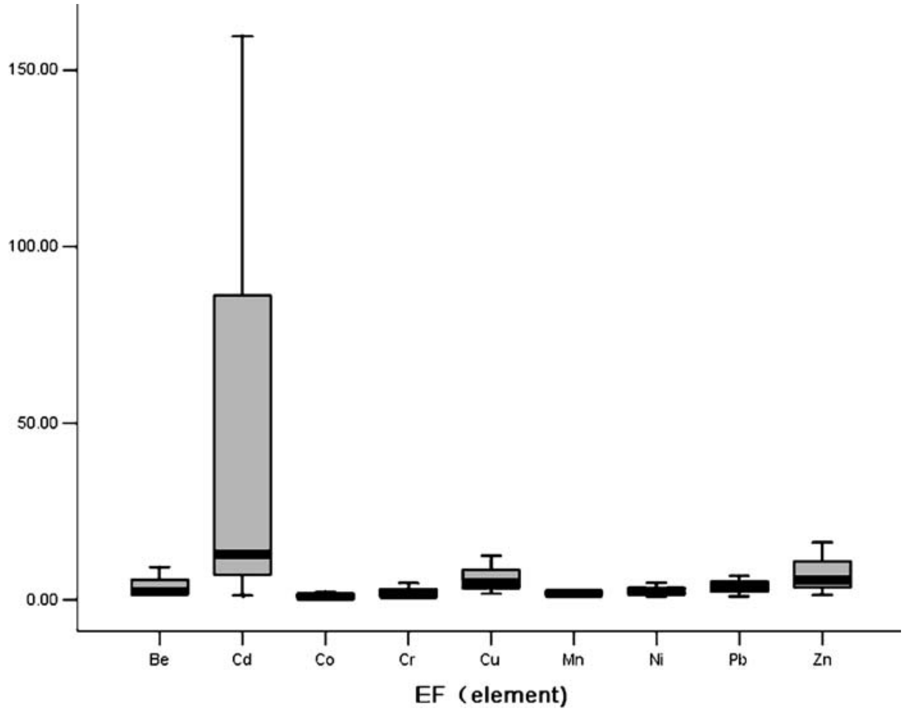
method by square Euclidian distances. The results of CA are shown in Fig. 3. Four subgroups are identified: (1) Cu, Zn, Cr, and Pb; (2) Ni and Be; 3) Cd only; and 4) Co, U, and Mn.

Enrichment factor analysis

PCA and CA analysis results indicate that U is a kind of inert element in the environment. The EF value of each metal is calculated with U as the reference element. Figure 4 demonstrates the maximum, mean, and minimum EF values of elements. The mean EF values of Cd (1.21–159.61), Cu (1.66–12.42), Pb (0.94–6.74), and Zn (1.32–16.17) are greater than 3; that of Cr (0.54–4.65), Ni (0.96–4.72), Mn (1.02–2.79), and Be (1.23–9.21) vary between 1 and 3; and that of Co (0.55–2.10) vary between 0 and 1. The elements, with the maximum EFs much higher than 10, are considered to be mainly of anthropogenic sources. Hence, EF can also be assumed to be an indicator of natural and anthropogenic sources (Han et al. 2006). The highest EF value of Cd is up to 150, and the mean and the maximum EF values of Cd are 1.17 and 14.57 mg/kg, respectively. However, the background value of Cd in soil is very low, only about 0.12 mg/kg. Thus, Cd is largely of anthropogenic source.

Figure 4 shows that the mean EFs of metal pollutants decrease in the following order: Cd > Zn > Cu > Pb > Be > Ni > Mn > Cr > Co. The lowest mean EF values are found for Co, implying a significant contribution of natural sources. The mean EFs of Cr, Ni, Mn, and Be range between 1 and 3, while those of Cd, Cu, Pb,

Fig. 4 Boxplot of enrichment factors for metals in the urban road dusts of Urumqi city (*X-axis* EF element, *Y-axis* EF ranges for each element)



and Zn are higher than 3. Therefore, the ranges of EFs suggest anthropogenic origins for these heavy metals. In terms of these heavy metal pollutants in atmosphere, fossil fuel combustion, traffic emissions, and industrial processes are considered as the major pollution sources (Meza-Figueroa et al. 2007).

Source identification

The results of PCA and CA are in good agreement with the interpretations mentioned above. CA results indicate that Co, U, and Mn are remarkably different from other groups of heavy metal pollutants, showing that Co, U, and Mn have different sources with other metal pollutants. Moreover, Cr, Cu, Zn, and Pb are significantly correlated, suggesting a common source. Significant correlation amongst Ni, Be, Mn, and Co by PCA may indicate another common source. PCA results indicate a close correlation between Co, Mn, and Ni, Be, Cr, but CA shows obvious difference from other metal pollutants, except for U, suggesting mixed sources (natural and anthropogenic) for Mn and Co. Moreover, PCA indicates that U is mainly of natural origin.

Based on PCA and CA, four main sources corresponding to groups of heavy metal pollutants can be identified: (1) Cu, Zn, Cr, and Pb; (2) Ni and Be; (3) Cd only; and (4) Co, U, and Mn. The results are discussed in more details as follows:

Group 1: Cu, Pb, Cr, and Zn. These metal pollutants have the highest mean concentrations compared with those of the reference ones. Previous studies, e.g., De Miguel et al. (1997), Sezgin et al. (2003), Al-Khashman (2004, 2007), and Ahmed and Ishiga (2006) indicated that the most important sources of human-induced Pb in road dust are gasoline additives. According to Jiries (2001) and Al-Khashman (2004), Cr, Cu, and Zn may be from abrasion of vehicles because these heavy metals are parts of the materials for brass alloy. These metal pollutants may also be from industrial activities, confirming the previous research results (e.g., De Miguel et al. 1997; Charlesworth et al. 2003; Ahmed and Ishiga 2006). In Urumqi, industries with potential to produce this group of metals are mainly located on periphery of the city. Therefore, traffic emissions may be the major pollution sources for Pb, Cu, Zn, and Cr, while Cr may originate mainly from mixed sources of traffic instruments and industrial activities.

Group 2: Ni and Be. Lv et al. (2006) suggested that coal combustion can produce Be, while Ni is mainly from oil combustion. Ahmed and Ishiga (2006) indicated that Ni and Be are mainly of industrial sources. In Urumqi, the main sources of Ni and Be may include traffic, industrial, and coal combustion emission. With the mean EFs between 1 and 3, Ni and Be may be of mixed sources, namely traffic, industrial, and natural sources.

Group 3: Cd. Its mean EF is over 10, with the maximum of 159, indicating that elevated Cd concentration may be due to human activities. PCA indicates no significant correlation between Cd and other heavy metal pollutants, while clusters 1, 2, and 3 join together at a relatively higher level by CA, indicating that Cd has a common source with groups 1 and 2. Charlesworth et al. (2003) suggested that Cd and Zn are associated with tire wear; Lv et al. (2006) demonstrated that Cd is from the by-products of industrial metallurgical processes and exhaust gasoline emissions. These studies and our results show that traffic and industrial sources may contribute much to the concentration of Cd in the urban road dusts. Moreover, Cd is widely used to shelter the alloy surface and building materials and also used in galvanization, batteries, plastic, and appliance machines. Therefore, corrosion of alloy and building materials, galvanization, batteries, and plastic may produce large amounts of Cd.

Table 6 Indices and grades of potential ecological risk assessment

	Potential ecological risk grades				
	Low	Moderate	Considerable	High	Significantly high
E_r^i	< 30	30–60	60–120	120–240	> 240
RI	< 110	110–220		220–440	> 440

Group 4: Co, Mn, and U. CA results indicate that these pollutants are obviously different from the others, which may suggest that they are mainly from natural sources. Their enrichment factors suggest a lithologic source, which is in agreement with the CA results. However, Co and Mn are correlated with Cr, Pb, Zn, Ni, and Be (Table 3), which may indicate that industrial and traffic sources maybe also contributed to elevated concentrations of Co and Mn in road dust from Urumqi. Besides, Mn is differentiated from Co and U, based on the results of CA. Therefore, this group can be divided into two subclusters.

Potential ecological risk

This paper assesses potential ecological risk of heavy metals mentioned above using Hakanson method. A total of five parameters, i.e. Cd, Cr, Cu, Pb, and Zn, are considered in this study. The terms used to describe the risk factor are shown in Table 6 (Cao et al. 2007).

The distribution of potential ecological risk factors E_r^i and RI (minimum, mean, and maximum) of heavy metal pollutants are displayed in Table 7. The results indicate that the mean and maximum concentrations of Cd have high and significantly high potential ecological risk, respectively; while Cr, Cu, Pb, and Zn have low potential ecological risk, and Cu has moderate ecological risk. Because, on the one hand, “toxic-response” factor of Cd is relative high, indicating high potential ecological risk, while the “toxic-response” factors of Cr, Cu, Pb, and Zn are much lower than Cd; on the other hand, road dusts in Urumqi have elevated concentration of Cd (the mean and maximum concentrations of Cd are more than 10 and 100 times its background values, respectively). Based on the potential ecological risk factors for multi-metal (RI), it can be seen that the minimum, mean, and maximum potential ecological risk grades of five metals are moderate, high, and significantly high, respectively.

The distribution of RI of the 169 sample sites is presented in Fig. 5. The results suggest that the northern parts of Urumqi are characterized by low and moderate potential ecological risk while the southern by high and significantly high potential ecological risk. This pattern may be due to the fact that the south part is the old city with long-history accumulation of heavy metal pollutants, while the north has just developed in recent couple of decades. Furthermore, the local prevailing wind is from north, blowing road dusts to the south. High buildings also cause more dusts to deposit on the road surfaces. Two obvious high RI sites are identified in the urban areas (Fig. 5). One is at the center of the old commercial area in the south

Table 7 Distribution of potential ecological risk factor E_r^i and RI of heavy metal in Urumqi

Element	Toxicity coefficient	Concentrations of metals			E_r^i			Reference
		min	mean	max	min	mean	max	Value[a] (mg/kg)
Cd	30	0.11	1.17	14.57	27.5	392.5	3642.5	0.12
Cr	2	20.23	54.28	174.57	0.8	2.2	7.1	49.3
Cu	5	33.63	94.54	252.17	6.3	17.7	47.2	26.7
Pb	5	13.87	53.53	99.45	3.6	13.8	25.6	19.4
Zn	1	69.26	294.47	846.15	1	4.3	12.3	68.8
RI					43	430.5	3734.7	

[a] CEPA and CGSEM (1990)

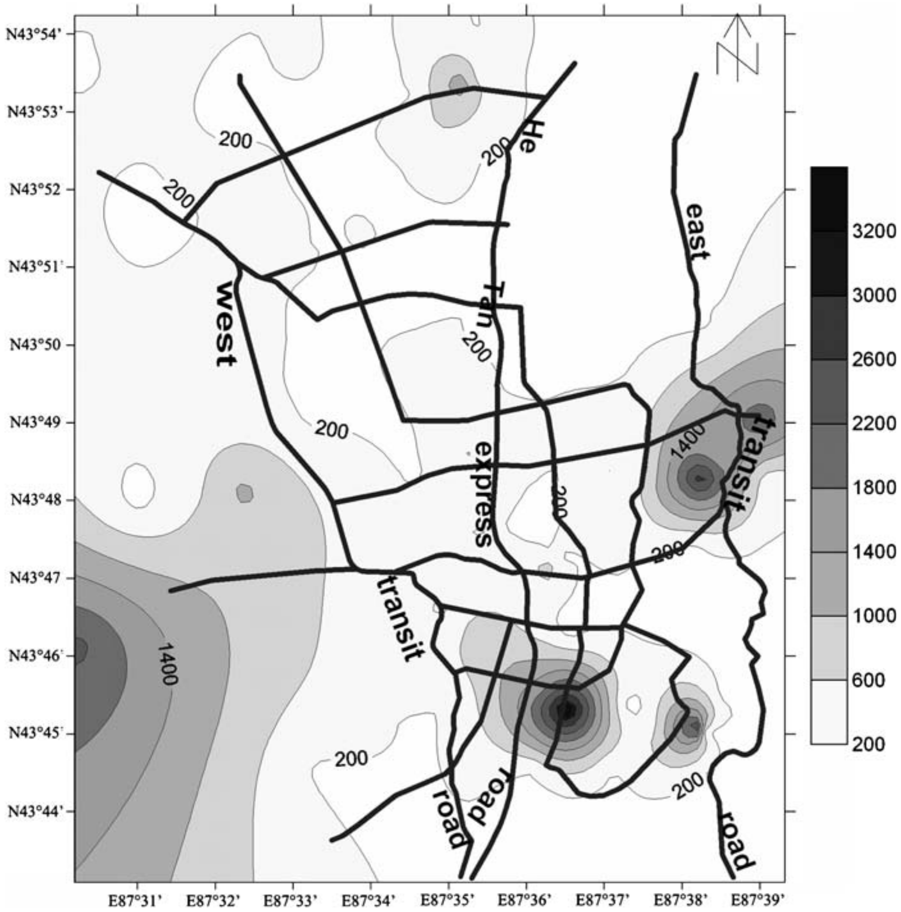


Fig. 5 Distribution of RI in the study area

with long-history accumulation of heavy metal pollutants and high traffic flows. Another high RI site is at the east, which can be attributed to many point-pollution sources, e.g., paper mill, firepower plant, textile mill, automobile factory, chemical plant, machine shops, and other manufactories. However, RI apparently increases in the west, beyond the study urban area but with a newly developing industrial estate nearby. The sites with high RI are usually close to the residential areas and playgrounds, which may imply high potential ecological risk.

Conclusions

This paper analyzes heavy metal pollutants in road dusts samples from Urumqi. Multivariate analysis, enrichment factor, and correlation analysis are used to identify possible sources of heavy metal pollutants. Some interesting conclusions can be drawn as follows:

1) Results by PCA, CA, and correlation analysis show that Mn, U, and Co are mainly of natural sources; Cu, Pb, Zn, and Cr originate mainly from traffic source and partly from industrial source; Ni and Be can be attributed to industrial activities and traffic source.
2) The sources of Cd are obviously different from those of other metal pollutants considered in this study. Corrosion of alloy and building materials, galvanization, batteries, and plastic may be the major sources of Cd. Traffic and industrial activities can also produce Cd.
3) The sources of Mn and Co are not only of natural source but also of traffic and industrial sources.

4) The above-mentioned results indicate that the dusts in Urumqi are significantly contaminated by Pb, Cu, Cd, and Zn and moderately contaminated by Cr, Ni, Be, and Mn, with almost no Co and U.
5) The potential ecological risk of Cd is high or significantly high in the study region. Most parts of Urumqi are at high potential ecological risk based on multi-metal (RI). They are associated with high traffic flows and industrial activities.

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