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Concentration and Source of Trace Metals in Street Dust from an Industrial City in Semi-arid Area of China

ABSTRACT

The concentrations of trace metals in street dust of Baotou, an industrial city in semi-arid area of northwest China, were determined by X-ray fluorescence spectrometry. Sources of trace metals analyzed in the dust were identified based on their concentrations, enrichment factor and multivariate statistical analysis. The results indicate that the street dust of Baotou has elevated concentrations of Ba, Co, Cr, La, Pb and Sr, which are 1.2–4.7, 4.0–10.7, 1.7–5.8, 1.0–5.1, 1.2–8.7 and 1.5–2.6 times the background values of local soil, respectively. Cr, Pb, Ba, La and Sr in the dust were moderately enriched, while Co was significantly enriched. Cu and Zn had low concentrations to moderately enriched. Other determined trace metals were of low concentrations to minimally enriched. Hf, Zr, Ti, Y, Th, U and Ni mainly originated from natural sources. Ga, Sr and Co are primarily derived from industry and construction sources. La, Mn, V, Cr, Ba, Pb, Cu and Zn have mixed natural, industrial and traffic sources.

Key words: *Metal; Dust; Source; Multivariate statistical analysis; Industrial city*

Xiufeng Han[1,2]
Dongqi Shi[1]
Xinwei Lu[1*]

[1] Department of Environmental Science, School of Geography and Tourism, Shaanxi Normal University, Xi'an 710119, P.R. China
[2] College of Resources and Environment, Baotou Normal College, Baotou 014030, P.R. China

*Corresponding author: luxinwei@snnu.edu.cn

INTRODUCTION

Street dust, one special type of environmental medium, has been reported in many countries containing elevated toxic organic (*Langer et al. 2010*) and inorganic pollutants (*Duong and Lee 2011*), especially trace metals (*De Miguel et al. 1997; Rasmussen et al. 2001; Yeung et al. 2003*). Trace metals in dust are of major concern because of their toxicity and non-degradability as well as threat to the environment and public health *(Maas et al. 2010; Moaref et al. 2014; Sulejmanović et al. 2014)*. Trace metals adhering to or absorbed by dust particles can enter the human body through inhalation, ingestion, or directly through the skin (*Ahmed and Ishiga 2006*), and can easily accumulate in fatty tissues or deposit in the circulatory system (*Ferreira-Baptista and De Miguel 2005; Zheng et al. 2010*), thus interfering with the normal functions of the internal organs or acting as auxiliary factors of other diseases (*Ferreira-Baptista and De Miguel 2005; Christoforidis and Stamatis 2009*). According to numerous studies, the sources of trace metals in street dust are mainly derived from anthropogenic sources, e.g. traffic emission (vehicle exhaust particles, tire wear particles, weathered street surface particles, brake lining wear particles), industrial emission (power plants, coal combustion, metallurgical industry, auto repair shop, chemical plant, etc.), domestic emission, weathering of building materials, atmospheric deposition, and many others (*Wei and Yang 2010*).

Nowadays, due to rapid urbanization and industrialization, as well as the serious harm of trace metals, numerous studies on trace metal contamination in street dust have been conducted internationally (*Rasmussen et al. 2001; Yeung et al. 2003; Ferreira-Baptista and De Miguel 2005; Al-Khashman 2007; Duong and Lee 2011; Khairy et al. 2011; Nazzal et al. 2013; Tang et al. 2013*), mostly in large or industrial cities in western countries. Limited information is available on metal contamination in rapid industrializing and urbanizing areas in other countries including China, especially the medium and small cities in western China (*Zhang et al. 2015*). Furthermore, most of these studies mainly focused on heavy metals like Pb, Cu, Zn, Ni, Cr, Mn and Co (*Charlesworth et al. 2003*), little attention was paid to other trace metals, such as, V, Ga, Y, Ba, La, etc. (*Sutherland and Tolosa 2000; Zhang et al. 2015*).

Baotou is a medium-sized industrial city in semi-arid area of northwest China. Like other metropolises of China, Baotou city faced many environmental problems caused by its hostile environment, poor urban planning, and rapid development, especially since the implementation of the Chinese Great Western Development policy in

1990s. The principal objectives of this work were: to determine the concentrations of trace metals in street dust of Baotou; to evaluate the degree of enrichment of trace metals in the dust; and to identify possible sources of trace metals in street dust of Baotou. The results could offer the basic information for regulators and engineers in environmental monitoring, protection and risk management.

MATERIALS AND METHODS

Study area

Baotou (109°15'-110°26'E, 40°15'-42°43'N), the biggest industrial city in Inner Mongolia autonomous region and the important basic industrial base of China, is located in the Tumochuan and Hetao Plain (**Figure 1**), with Yellow River to the south and Mongolia to the north. Baotou city has a typical semi-arid temperate continental monsoon climate. The local soil type is mainly chestnut soil. The total area and urban area of Baotou is 27,768 and 1,051 km^2, respectively, and its resident population was 2,692,900 in 2013. The number of motor vehicles was 458,000 in 2013. Baotou urban area covers the four districts of Kundulun, Qingshan, Jiuyuan and Donghe. It is an important industrial base and rare earth industrial center of China (*Wang and Liang 2014*). The main industries are rare earth industry, iron and steel manufacturing, coal-fired power generating, aluminum smelter, dairy, ceramic, heavy duty vehicle, metallurgy, machinery manufacturing.

Sampling and analytical procedures

A total of 121 street dust sampling sites were selected in four districts (Kundulun, Qingshan, Jiuyuan and Donghe) of Baotou urban area (**Figure 1**). At every sampling site, a dust composite sample of ~500 g composed of 5-8 dust subsamples was collected by sweeping using a clean plastic brush and dustpan during the cold and dry season in October 2012. Sweeping is a widely used sampling method in pollution research of road dust (*Ferreira-Baptista and De Miguel 2005; Ahmed and Ishiga 2006; Al-Khashman 2007; Lu et al. 2009, 2010; Khairy et al. 2011; Wang et al. 2016; Shi and Lu 2018*). 121 dust composite samples were collected in this manner. All dust samples were stored in re-sealable polyethylene bags, labeled, and transported to the laboratory. In the laboratory, all sample bags were opened and covered by papers to avoid the effect of atmospheric particles. After air-drying at room temperature for two weeks, all samples were sieved through a 1.0 mm nylon mesh to remove large particles such as leaves, refuse and small stones. About 50 g of each sample was taken and ground with agate mortar and pestle, then carefully homogenized and sieved through a 75 µm nylon mesh (*Lu et al. 2010*). All procedures of handling were carried out without contact with metals, to avoid potential cross-contamination of the samples.

To measure element concentration, 4.0 g of milled dust samples and 2.0 g of boric acid were weighed out, placed in the mold, and pressed into a 32 mm diameter

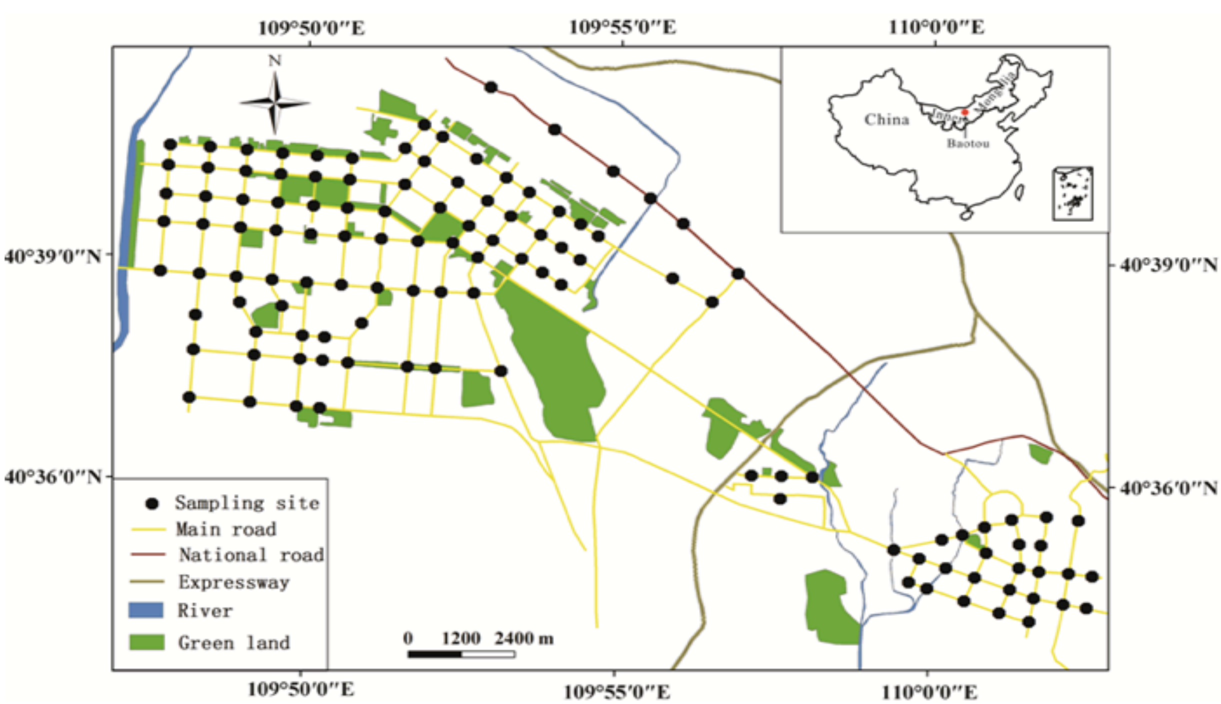

Figure 1. Study area and sampling sites in Baotou, China.

pellet under 30 t pressure (*Lu et al. 2010*). The concentrations of trace metals (Ba, Co, Cr, Cu, Ga, Hf, La, Mn, Ni, Pb, Sr, Th, Ti, U, V, Y, Zn and Zr) in the dust samples were measured by X-ray fluorescence spectrometry (XRF, PANalytical PW-2403 apparatus) (*Lu et al. 2010*). The measurement conditions of the apparatus and the quality assurance and quality control (QA/QC) methods can be found in the literatures (*Li and Huang 2007; Lu et al. 2010*). Standard samples (GSD12, GSS10) and 15% repeat samples were used for quality control in the experiment. The precision, calculated as the relative standard deviation of duplicate samples, was routinely 3-5%. The analyzed accuracy, calculated from the relative standard error of reference materials, was less than 5%.

Enrichment degree of trace metals in street dust

The enrichment factor was used to assess the degree of enrichment of trace metals in the dust from Baotou city. The enrichment factor (EF) of an element, an important parameter for evaluating the degree of impact human activities on its enrichment, is calculated by the following formula (*Buat-Menard and Chesselet 1979; Wang et al. 2016; Shi and Lu 2018*):

$$EF = (C_i/C_{ref})_{\text{sample}}/(C_i/C_{ref})_{\text{background}} \quad (1)$$

where C_i is the concentration of element *i* and C_{ref} is the concentration of reference element for normalization.

In EF calculation, the element with low occurrence variability, such as Al, Fe, Ti, Si, Sr and K (*Turner and Simmonds 2006*), is often used as reference elements. EF analysis can assist in differentiating anthropogenic sources from natural source. A value of EF close to 1 indicates natural origin, whereas values >10 are considered to originate mainly from anthropogenic sources (*Turner and Simmonds 2006*). EF can also assist in determining the degree of metal enrichment and contamination. EF ≤ 2 means deficient to minimal enrichment, 2 < EF ≤ 5 means moderate enrichment, 5 < EF ≤ 20 indicates significant enrichment, 20 < EF ≤ 40 signifies very high enrichment, and 40 < EF means extremely high enrichment (*Buat-Menard and Chesselet 1979; Lu et al. 2009; Wang et al. 2016; Shi and Lu 2018*).

Multivariate statistical analysis

To identify the relationship among trace metals in street dust and their possible sources, the principal component analysis (PCA) and cluster analysis (CA) were conducted using the commercial statistics software package SPSS version 19.0 for Windows (SPSS Inc. USA). PCA and CA have a wide application in environmental studies, which can define natural or anthropogenic sources of contaminants, identify possible non-point sources of contaminants and group them into some significant groups (*Lu et al. 2010*). PCA is a useful statistical tool to reduce data and to extract a smaller number of independent factors (principal components) for analyzing relationships among observed variables (*Shi et al. 2008*). CA classifies a set of observed variables into two or more mutually exclusive unknown clusters (*Lu et al. 2010*). A dendrogram is the most commonly used method of summarizing hierarchical clustering.

RESULTS AND DISCUSSION

Concentration of trace metal in street dust

Descriptive statistics, including Min (minimum), 25% (25th percentile), median, mean (arithmetic mean), GM (geometric mean), 75% (75th percentile), Max (maximum), SD (standard deviation), CV (coefficient of variation), kurtosis and skewness, of trace metals concentrations in street dust of Baotou, are presented along with the background values of local soil (*Wang et al. 2007*) (**Table 1**). Geometric means (GM) for Ba, Cr, Cu, La, Mn, Pb and Zn are less than their arithmetic means, while the geometric means for Co, Ga, Hf, Ni, Sr, Th, Ti, U, V, Y and Zr are close to their arithmetic means, which indicate the concentration variation of Ba, Cr, Cu, La, Mn, Pb and Zn in the dust samples are larger than Co, Ga, Hf, Ni, Sr, Th, Ti, U, V, Y and Zr (**Table 1**). The concentrations of all analyzed trace metals except for Hf, Ni, Ti, Th, U and Zr in most dust samples are higher than their corresponding background values of local soil, especially for Ba, Co, Cr, La, Pb and Sr, which are 1.2–4.7, 4.0–10.7, 1.7–5.8, 1.0–5.1, 1.2–8.7 and 1.5–2.6 times the background values of local soil, respectively. These indicate that the trace metals determined in the street dust of Baotou have different concentration characteristics.

The coefficients of variation (CVs) of Ba, Co, Cr, Cu, La, Pb and Zn in the dust are comparatively larger (> 20%) than other analyzed trace metals, particularly Cu, La and Pb, which CVs values are > 35%, demonstrating the wide variation of these metals concentrations in the dust. The skewness values of Ba, Cu, Ni and Pb are greater than unity, showing that these metals positively skew towards lower concentrations (*Lu et al. 2010*). Kurtosis values of all metals are evidently larger than zero except for Hf, Zn and Zr, demonstrating that the distributions of these heavy metals concentrations in the

Table 1. Descriptive statistics of trace metals in street dust of Baotou and the reference value (mg kg^{-1})

Metal	Min	25%	Median	Mean	GM	75%	Max	SD	CV(%)	Kurtosis	Skewness	Reference value[a]
Ba	641.5	902.9	1110.5	1186.1	962.2	1408.6	2454.1	349.2	29.4	1.4	1.1	527.7
Co	39.2	51.2	58.0	60.2	59.0	67.2	105.8	12.9	21.3	1.1	0.9	9.9
Cr	94.7	143.9	164.8	182.1	175.0	210.6	327.7	53.0	29.1	0.1	0.9	56.4
Cu	13.9	22.7	27.3	29.1	27.7	32.2	82.3	10.8	37.0	8.7	2.6	19.2
Ga	15.2	16.4	16.7	16.7	16.7	17.0	18.2	0.6	3.6	0.1	0.2	13.4
Hf	4.5	6.5	7.3	7.6	7.5	8.5	11.5	1.3	17.1	-0.4	0.5	7.1[b]
La	28.9	40.3	52.5	58.8	55.0	70.3	143.1	22.5	38.3	0.8	1.0	28.3
Mn	408.9	482.5	527.8	548.2	467.4	602.3	894.3	87.8	16.0	1.2	1.0	508.6
Ni	15.6	19.5	21.1	21.2	21.0	22.3	43.5	3.0	14.3	24.2	3.5	24.5
Pb	22.2	38.7	51.8	58.2	53.0	69.9	162.7	26.9	46.2	2.2	1.4	18.8
Sr	369.1	431.0	463.0	466.3	463.7	500.2	639.1	50.1	10.7	0.6	0.5	245.3
Th	6.5	9.5	10.4	10.3	10.2	11.0	14.4	1.4	13.7	1.2	0.0	9.6
Ti	2366.0	2795.0	2953.0	2967.5	2956.3	3126.0	3840.0	260.2	8.8	0.3	0.3	3080
U	0.7	2.0	2.2	2.1	2.1	2.4	3.8	0.3	14.3	3.3	-0.4	2.1
V	58.6	68.9	74.0	75.1	74.7	79.9	103.2	7.9	10.5	1.4	0.9	65.5
Y	17.2	20.3	21.5	21.4	21.4	22.5	25.7	1.6	7.6	0.4	0.1	19.9
Zn	43.3	70.0	85.5	85.9	83.5	101.4	136.4	19.8	23.1	-0.7	0.1	55.7
Zr	173.9	232.6	260.9	269.6	265.2	298.3	396.7	46.6	17.2	-0.4	0.5	216.9

[a]*Wang et al.* (*2007*); [b]*CNEMC* (*1990*).

dust are steeper than normal. The concentration variation of all trace metals determined in street dust of Baotou may be associated with their sources, which will be discussed in the following section.

It is a common practice to compare mean concentrations of trace metals in street dust of different city, although there are no universally accepted sampling and analytical procedures (*De Miguel et al. 1997; Charlesworth et al. 2003*). The trace metals concentrations in Baotou street dust are compared with data reported for other cities *(De Miguel et al. 1997; Rasmussen et al. 2001; Yeung et al. 2003; Ferreira-Baptista and De Miguel 2005; Al-Awadhi and AlShuaibi 2013; Zhang et al. 2015*) in the world (**Table 2**). The mean concentrations of Ba, Co, Cr, La and Sr in Baotou street dust are respectively 2.0–¬9.1, 1.8–20.8, 1.4–7.0, 1.2–8.5 and 1.1–3.9 times the corresponding metals mean contents of other compared cities, while the mean concentrations of Cu and Zn in street dust from Baotou are lower than other cities (**Table 2**). Other trace metals concentrations in Baotou street dust are in similar range with those measured from the compared cities. Dusts from different cities have various concentration levels of metals, which may be attributed to the differences in the levels of metals in their natural environment, economic development, degree of urbanization, industrial activities, traffic, environmental protection and pollution control technologies, etc. (*Zhang et al. 2015*).

Assessment of trace metal enrichment in street dust

Enrichment factors (EFs) of all analyzed trace metals were calculated for each dust sample relative to the background value of local soil, with Al chosen as the reference element owing to its smallest variance (CV=2.1%) in the investigated dust samples. The EF values of Ga, Hf, Mn, Ni, Th, Ti, V and Y in all dust samples, U in 99%, and Zr in 98% dust samples are < 2, showing that these metals in street dust of Baotou are deficient to minimal enrichment (**Figure 2**). The mean EF value and 94% EF of Co are in a range of 5 to 20, indicating significant enrichment. The mean values of EF for Cr, Pb, Ba, La and Sr, 86% EF of Cr, 69% EF of Pb, 68% EF of Ba and 50% EF of La are in a range of 2 to 5, showing moderate enrichment. The mean EF values of Cu and Zn, 83% EF of Cu and 74% EF of Zn are < 2, indicating deficient to minimal enrichment, while 17% EF of Cu and 27% EF of Zn are in a range of 2 to 5, showing moderate enrichment.

Multivariate statistical analysis results

Principal component analysis (PCA) was applied to identify the potential sources of trace metals in street dust collected from Baotou by applying varimax rotation with Kaiser Normalization. The KMO (Kaiser–Meyer–Olkin) test value (0.742) and Bartlett's test value of sphericity (1970.859) showed that the trace metals in street dust of Baotou are suitable for principal component analysis.

Table 2. A comparison of the trace metal concentrations (mg kg^{-1}) in street dust of Baotou and other selected cities.

City	Tongchuan	Luanda	Kuwait	Hong Kong	Ottawa	Oslo	Baotou
Ba	602.4	131.0	149.9	253.0	576.0	526.0	1186.1
Co	34.0	2.9	24.0	9.5	8.3	19.0	60.2
Cr	106.5	26.0	131.0	124.0	43.3		182.1
Cu	32.4	42.0	97.0	110.0	65.8	123.0	29.1
Ga	18.3	1.4				17.0	16.7
Hf	5.8						7.6
La	23.1	6.9				48.0	58.8
Mn	369.7	258.0	315.0	594.0	431.5	833.0	548.2
Ni	25.3	10.0	193.6	28.6	15.2	41.0	21.2
Pb	75.2	351.0	32.1	120.0	39.1	180.0	58.2
Sr	336.3	172.0	232.0	121.0	459.0	344.0	466.3
Th	9.6	1.7				7.6	10.3
Ti	23.97.4	107.0	524.2	2370.0		7452.0	2967.5
U	2.6	0.97	1.1		0.8	2.4	2.1
V	55.8	20.0	56.3	36.6	34.0		75.1
Y	20.6			43.4		24.0	21.4
Zn	141.8	317.0	213.0	3840.0	112.5	412.0	85.9
Zr	178.0		14.5	378.0			269.6
Reference	*Zhang et al. 2015*	*Ferreira-Baptista and De Miguel 2005*	*Al-Awadhi and AlShuaibi 2013*	*Yeung et al. 2003*	*Rasmussen et al. 2001*	*De Miguel et al. 1997*	This work

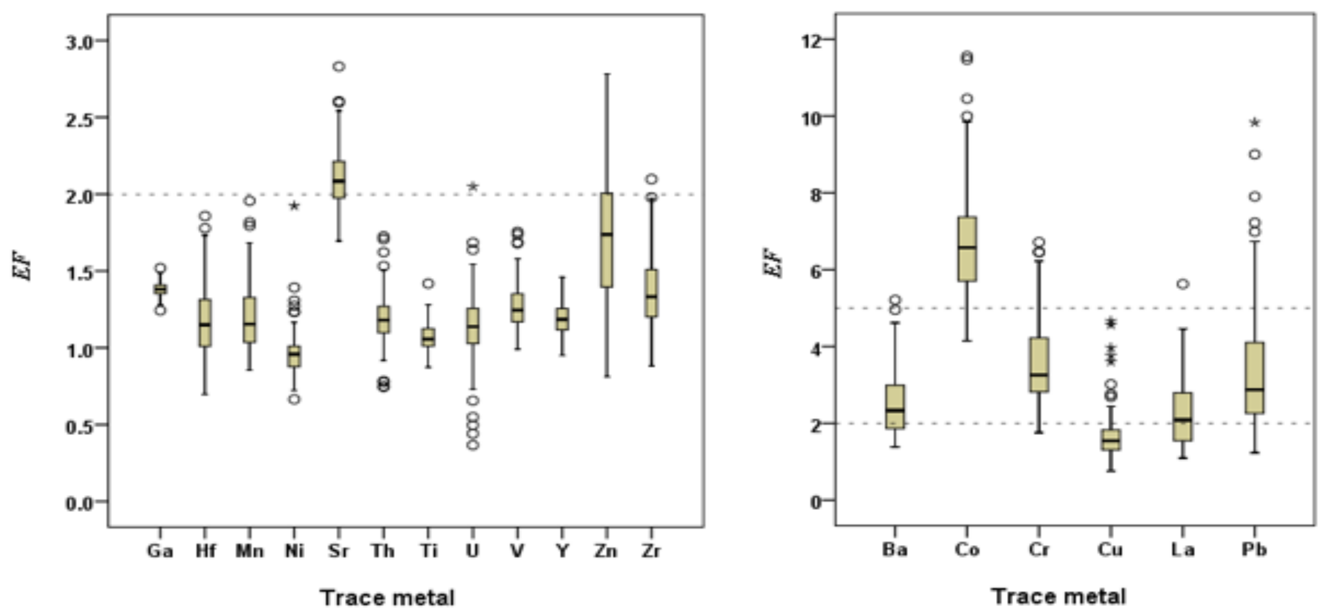

Figure 2. Box-plot of EF for trace metal in street dust of Baotou.

By extracting the eigenvalues and eigenvectors from the correlation matrix, the number of significant factors and variance explained by each of them were calculated. The factor loadings with a varimax rotation wer presented, as well as the eignvalues and communalities (**Table 3**).

There are six eigenvalues higher than one and that these six factors explain 81.37% of the total variance. Factor 1 is loaded primarily by Hf, Ti, Y and Zr, and also moderately by Th and V, accounting for 21.88% of the total variance. The Th and V loadings are not as high as the Hf, Ti, Y and Zr loadings, which may imply quasi-independent behavior within the group (*Lu et al. 2010*). Factor 2 explains 16.52% of the total variance and loads heavily on Cr, La, Mn and V, and moderately on Ni. Factor 3 is loaded primarily by Ba, Cu, Pb and Zn, explaining 14.75% of the total variance. Factor 4 is dominated by Ni, Th and U, accounting for 10.95% of the total variance. Factor 5 is correlated strongly with Ga and Sr which has a high loading value (0.871 and 0.873, respectively) and explains 10.65% of the total variance. Factor 6, dominated by Co, explains 6.62% of the total variance.

Table 3. Rotated component matrix for data of Baotou street dust (PCA loadings >0.4 are shown in bold).

Element	Component						Communalities
	1	2	3	4	5	6	
Ba	-0.262	0.079	0.840	-0.184	0.186	-0.025	0.850
Co	-0.032	-0.068	0.001	0.056	-0.039	0.953	0.919
Cr	0.005	0.828	-0.013	0.174	0.014	0.060	0.721
Cu	0.185	0.367	0.488	0.180	0.180	0.121	0.487
Ga	0.034	-0.082	0.017	0.198	0.871	-0.116	0.820
Hf	0.897	0.081	-0.206	0.267	-0.077	-0.082	0.937
La	0.011	0.728	0.307	0.024	-0.428	-0.205	0.850
Mn	0.153	0.808	0.341	0.049	-0.253	-0.123	0.874
Ni	0.233	0.418	0.173	0.454	-0.010	-0.065	0.470
Pb	-0.218	0.107	0.885	0.036	-0.082	0.134	0.868
Sr	-0.148	-0.169	0.140	-0.138	0.873	0.064	0.856
Th	0.462	0.331	-0.009	0.706	0.021	0.063	0.826
Ti	0.916	0.112	-0.070	0.058	0.122	-0.020	0.876
U	0.245	-0.027	-0.034	0.911	0.069	0.046	0.898
V	0.559	0.707	0.157	-0.047	-0.067	-0.056	0.847
Y	0.777	0.180	0.162	0.354	-0.187	0.002	0.822
Zn	0.115	0.275	0.728	0.123	-0.105	-0.389	0.785
Zr	0.916	0.046	-0.194	0.237	-0.077	0.011	0.941
Eigenvalue	3.94	2.98	2.66	1.97	1.92	1.19	
% of variance explained	21.88	16.52	14.75	10.95	10.65	6.62	
% of cumulative	21.88	38.40	53.15	64.10	74.75	81.37	

Cluster analysis (CA) was used to help identify the anthropogenic or natural source of metals *(Lee et al. 2006*), and to check the results of principal component analysis (PCA) for metals (*Yuan et al. 2014*). The CA for the determined trace metals are shown as a dendrogram (**Figure 3**). The metal concentration data (the variables) were standardized by means of z-scores prior to CA and Euclidean distances for similarities in the variables were calculated. Hierarchical clustering by applying Ward's method was performed on the standardized data set. Five distinct clusters were observed between 10 and 15 distance from the dendrogram for the trace metals in street dust of Baotou: (1) Hf–Zr–Ti–Y–Th–U–Ni (corresponding to Factor 1 and Factor 4 of PCA); (2) Ga–Sr (corresponding to Factor 5 of PCA); (3) Co (corresponding to Factor 6 of PCA); (4) La–Mn–V–Cr (corresponding to Factor 2); (5) Ba–Pb–Cu–Zn (corresponding to Factor 3 of PCA), which is in total agreement with the PCA results. It is observed, however, that cluster 2 and 3, as well as cluster 4 and 5 are joined together at a relatively higher level, implying that they possibly have common a source.

Source identification of trace metal in street dust

Compared with the background values of local soil, the concentrations of Hf, Ni, Th, Ti, U, Y and Zr in most dust samples from Baotou are having values close to or slightly higher than their corresponding background values, indicating that they mainly originated from local soil. While other trace metals have relatively elevated concentrations in Baotou street dust suggesting anthropogenic sources of these elements. Three main sources can be identified according to the principal component analysis (PCA) and cluster analysis (CA) results, as well as the concentration levels and enrichment characteristics of trace metals, i.e. (1) Hf, Zr, Ti, Th, Y, U and Ni mainly originated from natural source (local soil); (2) Ga, Sr and Co represented industry and construction sources; (3) La, Mn, V, Cr, Ba, Pb, Cu and Zn have mixed natural, industrial and traffic sources.

One group of elements consisting of Hf, Zr, Ti, Th, Y, U and Ni is strongly correlated in PCA (**Table 3**) and classified together in CA (**Figure 3**). The concentrations of these metals in most dust samples collected from Baotou are having values close to or slightly higher than their corresponding background values in local soil. In addition, they are obviously separated from the other elements in CA, and the long distance between them and other elements may suggest a mainly non-anthropogenic source (*Zhang et al. 2015*). Therefore, Hf, Zr, Ti, Th, Y, U and Ni in street dust of Baotou mainly originated from local soil.

A second group of elements consists of Ga, Sr, and Co, which are strongly positively correlated in PCA and

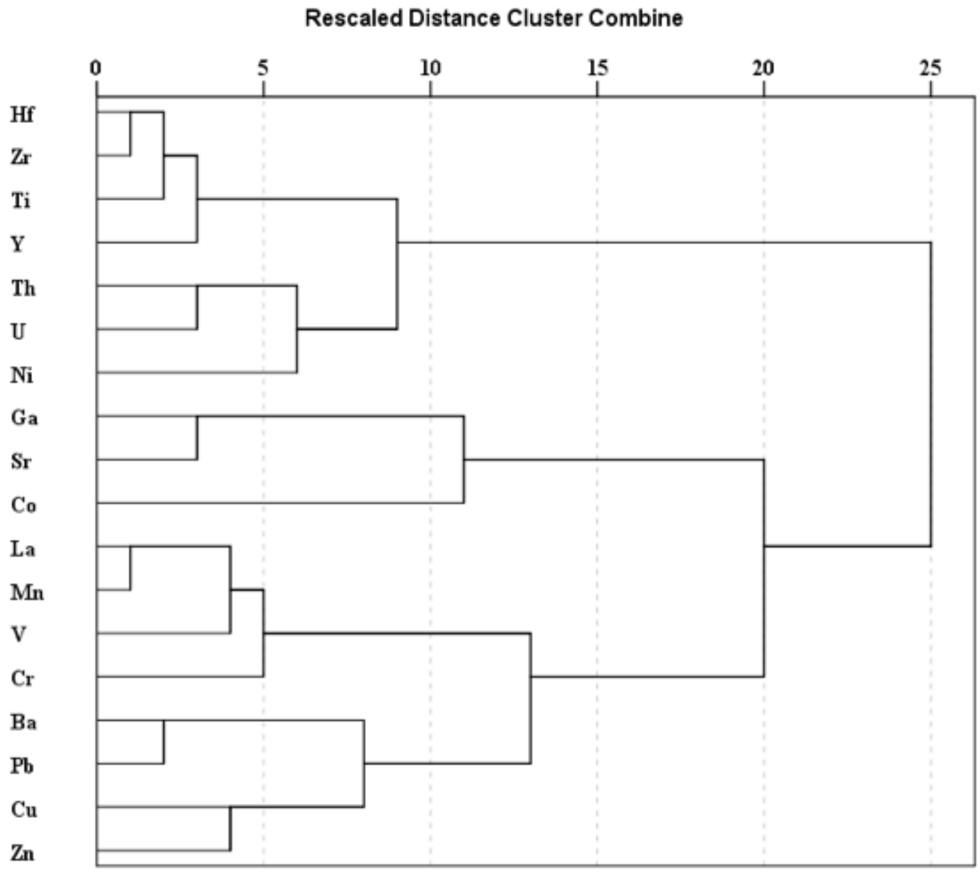

Figure 3. Dendrogram results from Ward method of hierarchical cluster analysis for 18 trace metals.

are separated from other elements in CA. The concentrations of Ga, Sr and Co in all dust samples are higher than their background values, particularly Sr and Co, which are significantly (**Table 1**), suggesting that their concentrations in the dust were affected by local human activities. The high-value spots and high-value areas of Sr and Ga concentrations are found in the vicinities of metallurgical plants, machine manufactures and weapons factories. Sr is widely used in alloys, chemical industries, electronics, military industries and pyrotechnics (*Zhang et al. 2015*). Ga is mostly used in alloys, semiconductors and photodiodes. Therefore, Sr and Ga in street dust of Baotou mainly originated from the local industrial sources. Co is extensively used in alloys, coating materials, paints and pigments. These Co-containing materials are widely used in modern buildings due to their gloss, faultless color and visual impact (C*hen et al. 2014*). This is true to the reconstruction of the middle-south commercial area and the construction of north residential area in Baotou city where are exactly the high-value areas of Co concentration in the dust. This suggests that Co in street dust of Baotou predominantly originated from building construction or renovation and weathering and corrosion of building materials.

A third group of elements consisted of Ba, Pb, Cu, Zn, Cr, La, Mn and V, which are separated from the other elements obviously in CA. From the results of PCA and CA, it can be seen that this group can be further subdivided into two clusters. Ba, Pb, Cu and Zn belong to Factor 3 in PCA and are classified together in CA (Cluster 5). La, Mn, V and Cr belong to Factor 2 in PCA and Cluster 4 in CA. Elements in the Ba, Pb, Cu and Zn cluster, and elements in the La, Mn, V and Cr cluster are joined together at a relatively higher level in CA, implying a similar source. Concentrations of Ba, Cr, La and Pb in all dust samples, 25th percentile values of Cu, V and Zn, as well the median of Mn are higher than their corresponding background values of local soil, indicating that these group of elements primarily originated from anthropogenic sources and Mn, Cu, V and Zn are partly derived from natural source (**Table 1**). Ba is widely used as detergents/dispersants and oxidation or corrosion inhibitors in lubricating oils for diesel and other combustion engines (*De Miguel et al. 1997; Yeung et al. 2003*). Enrichment of Pb, Zn and Cu in urban street dust is commonly found to be anthropogenic as these are from traffic-related sources (*Shi et al. 2008*). High Pb concentrations in street dusts have been recognized for mainly being linked to traffic activities (*Lu et al. 2010*). Cu is also present in brass automotive radiators due to its high corrosive resistance and high thermal conductivity (*Yang et al. 2011*) and is often used in car lubricants (*Lu et al. 2010*). Zn alloy and galvanized board are widely used in motor vehicles. Zn compounds have also been employed extensively as antioxidants and as detergent/dispersant improvers for lubricating oils (*De Miguel et al. 1997*). The wear and tear of vulcanized vehicle tires and corrosion of galvanized automobile parts are the main sources of Zn in the urban environment (*Lu et al. 2010*). Deterioration of the mechanical parts in vehicles over time results in Cu and Zn being emitted to the surrounding environment (*Li et al. 2004*). Cu and Zn can be released to the urban environment as a result of wear of automobile oil pumps or corrosion of metal parts which come into contact with the oil (*Lu et al. 2010*). The high concentrations of Ba, Pb, Zn and Cu found in the dust samples collected from the heavy traffic sites suggests that these four metals in Baotou street dust mainly originated from vehicle and traffic sources.

V is normally regarded as a marker for fuel oil or petroleum burning (*Yeung et al. 2003*). Mn is widely used in alloy and steel. Cr is widely used to produce stainless steel, automobile parts, aluminum alloy and titanium alloy. Corrosion of cars and chrome plating of some motor vehicle parts were confirmed to be the source of Cr in urban environment (*Chen et al. 2012*). The distributions of the higher-value sites of Cr, La, Mn and V concentrations in street dust of Baotou are similar, i.e. the neighborhoods of steel plant, aluminum plant, coal-fired power plant and machinery plant. In addition, the dust samples collected the heavy traffic sites also have higher Cr and V concentrations. So, these information suggest that Cr, La, Mn and V in street dust of Baotou mainly originated from industrial and traffic sources and partly from local soil. Finally, Ba, Pb, Cu, Zn, Cr, La, Mn and V in Baotou street dusts have mixed sources of natural, industry and traffic.

CONCLUSIONS

The concentration, enrichment and source of trace metals Ba, Co, Cr, Cu, Ga, Hf, La, Mn, Ni, Pb, Sr, Th, Ti, U, V, Y, Zn and Zr in street dust collected from Baotou, China have been studied in this work. The concentrations of Ba, Co, Cr, Cu, Ga, La, Mn, Pb, Sr, V, Y and Zn in the dusts are higher than their corresponding background values of local soil, while the level of other trace metals in the dusts are close to or slightly higher than their background values. The results of enrichment factor assessment confirm that Ga, Mn, Ni, Th, Ti, V, Y, Hf, U and ZR in street dust of Baotou are deficient to minimally enriched. Cu and Zn are deficient to moderately enriched. Co is significantly enriched. Cr, Pb, Ba, La and Sr in the dust are moderately enriched. Three main sources of trace metals in street dusts of Baotou were identified using PCA and CA analyses. Hf, Zr, Ti, Y, Th, U and Ni mainly originated from natural sources. Ga, Sr and Co are primarily derived from industry and construction sources. La, Mn, V, Cr, Ba, Pb, Cu and Zn have mixed natural, industry and traffic sources.

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