

# Grain-size distribution and contamination characteristics of heavy metal in street dust of Baotou, China

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**Abstract** The concentration, contamination level and grain-size distribution of Ba, Co, Cr, Cu, Mn, Ni, Pb, V and Zn in street dust samples from Baotou, an industrial city in the semi-arid area of northwest China, were determined in the present work. Contamination levels of heavy metals were assessed based on the pollution load index (PLI) and geo-accumulation index ( $I_{geo}$ ). The results for the measured concentrations indicated that street dust in Baotou had elevated heavy metal concentrations, particularly Ba, Co, Cr and Pb. The concentrations for these metals (Ba, Co, Cr and Pb) lay in the ranges of 1.2–4.7, 4.0–10.7, 1.7–5.8 and 1.2–8.7 times the background values of local soil, respectively. Except for the Ba and Co, all of the analyzed heavy metals in the dusts were largely accumulated in the <50  $\mu\text{m}$  particles. Results for the  $I_{geo}$  assessment indicated that Co, Cr, Pb, Ba and Zn showed different degrees of contamination of the street dust. Mn, Ni and V in the dust samples fell in the category of ‘uncontaminated’. The PLI results showed that most dust samples were ‘uncontaminated to moderately contaminated’ by heavy metals.

**Keywords** Heavy metal · Grain-size distribution · Contamination assessment · Dust · Industrial city

## Introduction

Street dust, which mainly consists of the solid particles that accumulate on outdoor hard pavements or cement roads in urban areas (Ferreira-Baptista and De Miguel 2005; Shi et al. 2011; Lu et al. 2014a), is one of the most pervasive and important factors affecting human health (Han et al. 2006; Al-Khashman 2007; Zheng et al. 2010). Acting simultaneously as a source as well as a sink for the atmospheric particulates (Ferreira-Baptista and De Miguel 2005; Ma and Singhirunnusorn 2012; Zhao and Li 2013), street dust often contains elevated amounts of the toxic heavy metals and organic contaminants such as anthropogenic polycyclic aromatic hydrocarbons (Han et al. 2008; Lu et al. 2010; Yuen et al. 2012; Chen et al. 2014). Human activities, e.g. industrial production, traffic emission, coal-fired power generation, combustion of the fossil fuels and municipal waste disposal cause an increase in the concentration of heavy metals in the street dust (Wei and Yang 2010; Apeagyei et al. 2011; Duong and Lee 2011; Yuen et al. 2012; Rout et al. 2013; Zhu et al. 2013; Nazzal et al. 2014). Heavy metals in street dust are highly concerning because of their toxicity and non-degradability, as well as threat to the environment and the public health (Banerjee 2003; Wei and Yang 2010). These particles can easily enter human body through inhalation, ingestion or dermal contact (Ahmed and Ishiga 2006; Wei and Yang 2010; Shi et al. 2011). In human body, these can either be accumulated in fatty tissues or can get deposited in the circulatory system (Han et al. 2006; Zheng et al. 2010; Ma and Singhirunnusorn 2012), thus either interfering with the normal functions of the internal organs or acting as auxiliary factors for other diseases (Ferreira-Baptista and De Miguel 2005; Christoforidis and Stamatis 2009). Some investigations show that contamination by the heavy metals

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in the street dust strongly depends on the mineral composition and the particle size of the dust (Manno et al. 2006; Han et al. 2008; Acosta et al. 2011; Fujiwara et al. 2011; Zhang et al. 2012; Krishna and Mohan 2013; Yao et al. 2013). Therefore, the concentrations of heavy metals in different size particles of the street dust are critical to estimate their potential contributions towards the deterioration of the environment and the human health (Han et al. 2008).

In recent decades, a number of studies have been conducted on the source, concentration, distribution, degree of contamination and the risk level of heavy metals (Li et al. 2001; Charlesworth et al. 2003; Sezgin et al. 2003; Ferreira-Baptista and De Miguel 2005; Manno et al. 2006; Wei and Yang 2010; Acosta et al. 2011; Atiemo et al. 2011; Lu et al. 2014a, b). Most of these studies are based upon bulk dust samples and have been conducted in developed countries or megacities of developing countries (Banerjee 2003; Ahmed and Ishiga 2006; Han et al. 2006; Shi et al. 2008; Lee et al. 2013; Tang et al. 2013; Nazzal et al. 2014). Limited information is available on heavy metal contamination of street dust in rapidly industrializing and urbanizing cities of small to medium size (Lu et al. 2014a). Very few studies have focused on analyzing differently sized particles of dust for heavy metal contamination in these small- to medium-sized cities (Han et al. 2008). The environmental protection technologies and the environmental management measures of these small- to medium-sized cities are generally poor and therefore, the environmental issues prevailing in these cities are serious.

Baotou is a medium-sized industrial city in the semi-arid area of northwestern China and is currently the largest rare-earth industrial base of China (Wang and Liang 2014). Like other metropolises of China, Baotou city faces many environmental problems which are caused by its hostile environment, poor urban planning, and rapid development, especially since the Chinese Great Western Development policy implementation in 1990s. The work on accumulation and fractionation of rare-earth elements in atmospheric particulates around the tailing of a mine in Baotou indicates that the enrichment of the rare-earth elements in atmospheric particulates was caused by anthropogenic sources and was influenced by the strong winds in the spring season (Wang and Liang 2014). Zn, Mn, Pb, and Cr were the major metallic pollutants in both the inhalable particulate matter and the fine particles collected from Baotou, China (Li et al. 2015). In our previous work, we have determined the concentrations of Co, Cr, Cu, Mn, Ni, Pb, Zn and V in 83 bulk dust samples collected from Qingshan and Kundulun districts of Baotou city and found that street dust in Baotou had increased amounts of heavy metals (Han et al. 2014). Another study has reported the ecological and health risk assessments for heavy metals in

re-suspended particles (grain size  $<100\ \mu\text{m}$ ) of street dust in Baotou, China (Xu et al. 2015). To the best of our knowledge, literature about heavy metal concentration and contamination assessment in different-sized particles of street dust from Baotou is still non-existent. Differently sized particles of the street dust have different modes of transport and diverse environmental and health effects (Han et al. 2008). In the present study, the grain-size distribution and the contamination level of heavy metals in the street dust of Baotou have been analyzed. The objectives of the present study were: (1) to determine the concentrations of Ba, Co, Cr, Cu, Mn, Ni, Pb, V and Zn in the street dusts of Baotou; (2) to assess the contamination levels of metals in the street dust; and (3) to study the heavy metal distribution in different particle-size fractions of the dust. The results from the present study are useful for regulators and engineers with regard to the environmental management and its protection.

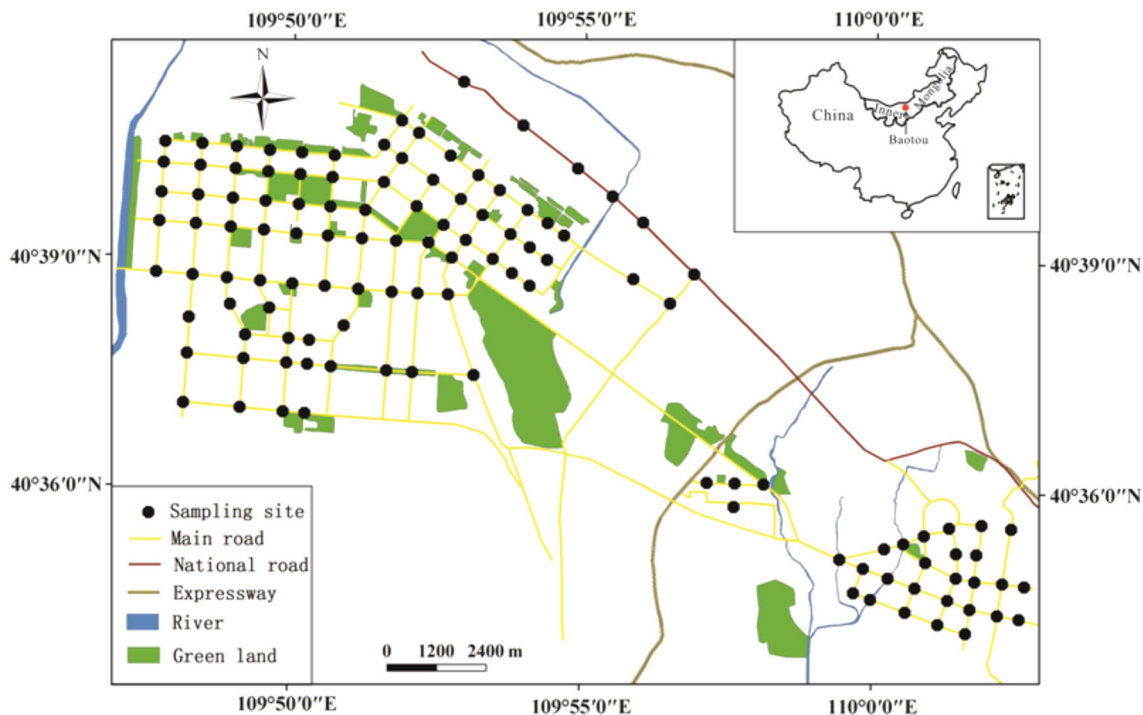
## Materials and methods

### Background of study area

Baotou ( $109^{\circ}15'–110^{\circ}26'E$ ,  $40^{\circ}15'–42^{\circ}43'N$ ), the biggest industrial city in Inner Mongolia autonomous region, is located in the Tumochuan and Hetao Plain, with Yellow River to the south and Mongolia to the north of the city (Fig. 1). It has a typical semi-arid temperate continental monsoon climate, with an annual average temperature of  $6.5\ ^{\circ}\text{C}$ , annual average precipitation of 240–400 mm and annual evaporation capacity of 1940–2340 mm. The local soil type is mainly chestnut soil. The prevailing wind direction is northwest. The total area and urban area of Baotou is 27,768 and 1051  $\text{km}^2$ , respectively. In 2013, Baotou's resident population was 2,692,900 individuals. Baotou is the railway and highway transportation hub, linking the north and northwest of China. The number of motor vehicles driven in Baotou in 2013 was 458,000 vehicles. Baotou has abundant iron, rare-earth, niobium, titanium, manganese, gold, copper and other mineral resources. It is an important industrial base and rare-earth industrial center of China. Rare-earth industry, iron and steel manufacturing, coal-fired power production, aluminum smelting, dairy products, manufacturing of heavy duty vehicle, metallurgy and machinery manufacturing constitute the major industries of Baotou.

### Dust sampling and analytical procedures

A total of 121 street dust sampling sites were selected in Baotou urban area (Fig. 1). At every sampling site, a dust composite sample of  $\sim 500\ \text{g}$  composed of 5–8 sub-dust



**Fig. 1** Study area and sampling sites in Baotou, China

samples was collected by sweeping. To collect the samples, a clean plastic brush and a dustpan were used during both the cold and the dry season in October 2012. Hence, 121 dust composite samples were collected in this manner. The collected dust samples were labeled and stored in the self-sealed polyethylene bags. These samples were then transported to the laboratory. All samples were air-dried naturally at room temperature in the laboratory and then sieved through a 1.0-mm nylon mesh to remove refuse and small stones. About 50 g of each sample was separated by halving and then was ground with agate mortar and pestle. It was then carefully homogenized and sieved through a 75- $\mu\text{m}$  nylon mesh (Lu et al. 2010). Further, a portion (300 g) of each sample was sieved into five grain-sized fractions of <50, 50–100, 100–300, 300–500 and 500–1000  $\mu\text{m}$ . The different-sized fractions were weighted and the fractions of dust with sizes >50  $\mu\text{m}$  were ground with agate mortar and pestle and sieved through a 75- $\mu\text{m}$  nylon mesh. In order to avoid any potential cross-contamination of the samples, all procedures of handling were carried out without contact with metals. The remaining portion of each sample was used to analyze the physico-chemical properties of the dust.

To measure metal concentration, 4.0 g of milled dust sample and 2.0 g of boric acid were weighed out, placed in the mold, and then pressed into a 32-mm diameter pellet under a pressure of 30 t (Lu et al. 2010). The concentrations of Ba, Co, Cr, Cu, Mn, Ni, Pb, V and Zn in the sample

were measured by wavelength dispersive X-ray fluorescence spectrometry (XRF, PANalytical PW-2403 apparatus) (Lu et al. 2010). Standard samples (GSD12, GSS10) and 15 % repeat samples were used for quality control in the experiment. The reproducibility, measured by calculating the relative standard deviations of duplicate samples, was found to be in the range of 3–5 %. The analyzed accuracy, calculated from the relative error of standard reference materials, was less than 5 %.

The pH and the electrical conductivity (EC) was measured in a 1:2.5 (sample:distilled water) mixture (Banerjee 2003; Al-Khashman 2007). The organic matter (OM) content was measured by the loss-on-ignition method. Samples were oven-dried at 105  $^{\circ}\text{C}$ , weighed and then ignited in a muffle furnace at 400  $^{\circ}\text{C}$  for 4 h before being reweighed to determine the organic material loss (Lu et al. 2009a). Magnetic susceptibility parameters (low-frequency magnetic susceptibility  $\chi_{\text{LF}}$ , high-frequency magnetic susceptibility  $\chi_{\text{HF}}$  and frequency-dependent magnetic susceptibility  $\chi_{\text{FD}}$ ) of the dust samples were measured using a Bartington MS2 Magnetic Susceptibility Meter (Lu et al. 2009a).

**Contamination assessment and grain-size distribution of heavy metals in the street dust**

A number of calculation methods have been applied to quantify the degree of heavy metals’ pollution or

enrichment of heavy metals in the street dust (Shi and Wang 2013). Some of these methods included single pollution index and integrated pollution index (Lu et al. 2009b; Wang et al. 2015), enrichment factor (Han et al. 2006; Lu et al. 2009a, b; Shi and Wang 2013), geo-accumulation index (Lu et al. 2009a, b; Shi and Wang 2013), Nemerow pollution index (Shi and Wang 2013), and pollution load index (Suresh et al. 2011; Lu et al. 2014b; Zhao et al. 2014). Each method has its own advantages and disadvantages. In case of single pollution index and integrated pollution index methods, the calculations are simpler and easier to undertake. However, the integrated pollution index method underestimates the weights of polluted heavy metals while, the single pollution index method does not consider the variation of background values. Besides revealing the contamination levels of the heavy metals, the enrichment factor can also differentiate if the metals originate from anthropogenic activities or from natural processes. Therefore, the enrichment factor can also assess the degree of anthropogenic influence (Han et al. 2006). However, in order to successfully apply the enrichment factor method, the choice of a reference element needs to be specified and the concentration of reference element in all investigated samples needs to be measured. Nemerow pollution index can overcome the shortcomings of integrated pollution index method, but the method lacks accuracy while determining the influences of certain parameters. The geo-accumulation index can partly overcome the shortcomings of both the single pollution index and the enrichment factor methods; whereas, the pollution load index can partially overcome the shortcomings of the integrated pollution index and Nemerow pollution index methods. Due to these characteristics, the geo-accumulation index and the pollution load index methods were used in the study to assess the level of contamination caused by heavy metals in the street dust of Baotou city. The geo-accumulation index ( $I_{geo}$ ) was calculated using the Eq. (1) (Lu et al. 2009a, b).

$$I_{geo} = \log_2 \frac{C_i}{1.5B_i}, \quad (1)$$

where  $C_i$  is the measured concentration of heavy metal  $i$  and  $B_i$  is the geochemical background value of heavy metal  $i$ . In this study,  $B_i$  is the background value of local soil (Wang et al. 2007). The constant 1.5 is introduced to minimize the effect of possible variations in the background values. The  $I_{geo}$  for each metal is calculated and classified as: uncontaminated ( $I_{geo} \leq 0$ ); uncontaminated to moderately contaminated ( $0 < I_{geo} \leq 1$ ); moderately contaminated ( $1 < I_{geo} \leq 2$ ); moderately to heavily contaminated ( $2 < I_{geo} \leq 3$ ); heavily contaminated ( $3 < I_{geo} \leq 4$ ); heavily to extremely contaminated ( $4 < I_{geo} \leq 5$ ); extremely contaminated ( $I_{geo} > 5$ ) (Lu et al. 2009b).

The pollution load index (PLI) reflects the comprehensive pollution level of heavy metals in a sample and is calculated using Eq. (2) (Suresh et al. 2011; Lu et al. 2014b; Zhao et al. 2014)

$$PLI = \sqrt[n]{\prod_{i=1}^n C_i/B_i}, \quad (2)$$

where  $C_i$  is the concentration of heavy metal  $i$ , and  $B_i$  is the background value of heavy metal  $i$ . The results from PLI values are categorized as follows: background concentration ( $PLI = 0$ ); uncontaminated ( $0 < PLI \leq 1$ ); uncontaminated to moderately contaminated ( $1 < PLI \leq 2$ ); moderately contaminated ( $2 < PLI \leq 3$ ); moderately to highly contaminated ( $3 < PLI \leq 4$ ); highly contaminated ( $4 < PLI \leq 5$ ); extremely highly contaminated ( $PLI > 5$ ) (Suresh et al. 2011; Lu et al. 2014b).

To determine how particles of different grain sizes contributed to the overall contamination of street dust, the pollution load percentage was computed for individual samples by combining the concentration data for the grain-size fractions and their mass size percentages. The equation used for computing the heavy metal loadings on a grain-size fraction ( $GSF_{loading}$ ) was (Sutherland 2003; Acosta et al. 2011)

$$GSF_{loading} = \frac{C_i \times GS_i}{\sum_{i=1}^m (C_i \times GS_i)}, \quad (3)$$

where  $C_i$  is the concentration of heavy metal  $i$  in an individual grain-size fraction in  $mg\ kg^{-1}$ ,  $GS_i$  is the mass percentage of that size fraction while  $m$  represents the total number of grain-size fractions.

## Results and discussion

### Physicochemical properties of the street dust

The physicochemical properties of the street dust from Baotou are shown in Table 1. The pH values ranged from 7.35 to 10.92 with an average of 9.20. These values are higher than the values of dusts from Baoji (Lu et al. 2009a) and Murcia (Acosta et al. 2011). The organic matter content in the studied dust samples ranged from 1.5 to 8.7 % with an average of 2.9 %. These values for the organic matter content are higher than Murcia (Acosta et al. 2011), but are lower than those found for Baoji (Lu et al. 2009a) and Huludao (Xu et al. 2013). The electrical conductivity (EC) varied from 224 to 1923  $\mu s\ cm^{-1}$  with an average of 952  $\mu s\ cm^{-1}$ . Higher EC values were observed in the vicinities of garages and commercial areas. Low-frequency magnetic susceptibility ( $\chi_{LF}$ ) which represents the total contribution of ferromagnetic minerals (Shilton et al. 2005;

**Table 1** Physicochemical properties of the street dust from Baotou, China

Parameters	pH	EC ( $\mu\text{s cm}^{-1}$ )	OM (%)	$\chi_{\text{LF}}$ ( $10^{-8} \text{ m}^3 \text{ kg}^{-1}$ )	$\chi_{\text{HF}}$ ( $10^{-8} \text{ m}^3 \text{ kg}^{-1}$ )	$\chi_{\text{FD}}$ (%)
Min	7.35	224	1.5	291.3	283.7	0.02
Mean	9.20	952	2.9	674.7	666.0	1.21
Median	9.20	988	2.7	618.0	608.7	0.87
Max	10.92	1923	8.7	3357.3	3249.1	4.38
SD	0.72	374	1.1	316.1	307.5	1.00
CV (%)	7.79	36.7	36.8	46.9	46.2	82.35

**Table 2** Pearson correlation coefficients between physicochemical properties and heavy metals in the street dust

Heavy metal	Ba	Co	Cr	Cu	Mn	Ni	Pb	V	Zn
pH	0.08	-0.20	0.29**	0.12	0.56**	0.06	0.04	0.41**	0.14
EC	-0.02	-0.18	0.23*	0.17	0.36**	0.09	-0.09	0.40**	0.19*
OM	-0.02	-0.09	0.43**	0.18*	0.24**	0.41**	-0.07	0.26**	0.16
$\chi_{\text{LF}}$	-0.01	-0.14	0.81**	0.31**	0.64**	0.80**	0.01	0.55**	0.14
$\chi_{\text{HF}}$	-0.01	-0.13	0.81**	0.31**	0.65**	0.79**	0.01	0.56**	0.14
$\chi_{\text{FD}}$	-0.01	-0.08	0.11	0.13	0.00	0.20*	-0.04	0.04	0.11

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

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

Lu et al. 2009a) varied from  $291.3 \times 10^{-8}$  to  $3357.3 \times 10^{-8} \text{ m}^3 \text{ kg}^{-1}$  with an average of  $674.7 \times 10^{-8} \text{ m}^3 \text{ kg}^{-1}$ . The average value of the low-frequency magnetic susceptibility is lower than the corresponding value observed for Baoji street dust (Lu et al. 2009a). The frequency-dependence magnetic susceptibility ( $\chi_{\text{FD}}$ ) varied from 0.02 to 4.38 %, with an average of 1.21 %, which is close to that of street dust from Baoji (Lu et al. 2009a). The maximum low-frequency magnetic susceptibility was observed in the neighborhoods of the steel plant, coal-fired power plant and the machinery plant. This highlights the effect of human activities on the magnetic characteristics of street dust. Table 2 presents the relationships between the physicochemical properties and the analyzed heavy metals of street dust from Baotou. It can be observed that the pH shows a significantly positive correlation with respect to the Cr, Mn and V, while the EC presents a significantly positive correlation with respect to the Mn and V at  $P < 0.01$ . OM,  $\chi_{\text{LF}}$  and  $\chi_{\text{HF}}$  are all positively correlated with Cr, Cu, Mn, Ni and V. These results demonstrate that the physicochemical characteristics of the street dusts can indirectly indicate the concentration level or the existing state of heavy metals in the dust.

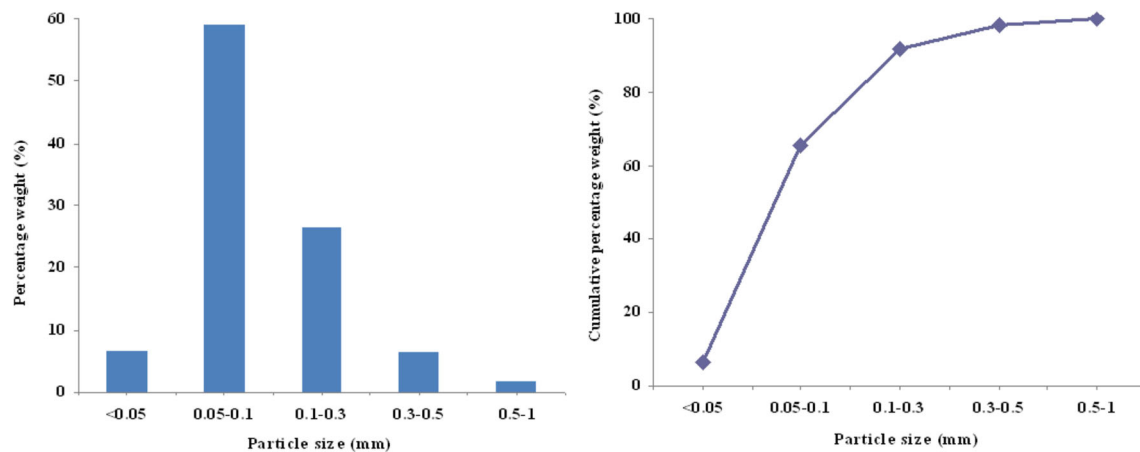
Figure 2 indicates that the particle-size fraction of 50–100  $\mu\text{m}$  is the most abundant (59.0 %) in street dust of Baotou, followed by the fractions of 100–300  $\mu\text{m}$  (26.4 %), <50  $\mu\text{m}$  (6.6 %) and 300–500  $\mu\text{m}$  (6.4 %). The coarse fraction of 500–1000  $\mu\text{m}$  only accounts for 1.6 % of street dust.

The particles with diameters below 100  $\mu\text{m}$ , accounting for 65.6 % of street dust in Baotou, are suspended in the air

and move around in the wind stream. Such particles possess greater environmental impacts and health risks than coarse particles (Xu et al. 2015).

### Heavy metal concentration in the street dust

Data obtained from Descriptive Statistics representing the heavy metals concentrations in the street dust of Baotou and the values for the background of the local soil (Wang et al. 2007) are listed in Table 3. Table 3 shows that the values of the arithmetic mean for the concentrations of Ba, Co, Cr, Cu, Mn, Ni, Pb, V and Zn are 1186.1, 60.2, 182.1, 29.1, 548.2, 21.2, 58.2, 75.1 and 85.9  $\text{mg kg}^{-1}$ , respectively. The arithmetic means and medians of all analyzed heavy metals (except for Ni) in the street dust of Baotou were clearly higher than their corresponding background values of the local soil. This indicates that these heavy metals were accumulated in the dust due to the intensive anthropogenic activities taking place in the region. This was especially true for Ba, Co, Cr and Pb, which were 1.2–4.7, 4.0–10.7, 1.7–5.8 and 1.2–8.7 times the background values of the local soil, respectively. The ratio of the arithmetic means of the heavy metals in the dust to their corresponding background values of the local soil follows the order of:  $\text{Co} > \text{Cr} > \text{Pb} > \text{Ba} > \text{Zn} > \text{Cu} > \text{V} > \text{Mn} > \text{Ni}$ . The coefficients of variation (CVs) of Ba, Co, Cr, Cu, Pb and Zn in the dust are relatively larger (>20 %), demonstrating that the effects of the anthropogenic activities on the concentrations of these heavy metals are obvious and striking. The skewness values of Ba, Cu, Ni and Pb are greater than unity, showing that these metals



**Fig. 2** Size distribution of street dust collected from Baotou

**Table 3** Descriptive statistics of heavy metal concentration in the street dust of Baotou and the reference value ( $\text{mg kg}^{-1}$ )

Heavy metal	Ba	Co	Cr	Cu	Mn	Ni	Pb	V	Zn
Min	641.5	39.2	94.7	13.9	408.9	15.6	22.2	58.6	43.3
5 %	741.4	41.4	116.4	18.7	437.2	17.4	28.9	64.8	55.7
25 %	902.9	51.2	143.9	22.7	482.5	19.5	38.7	68.9	70.0
Median	1110.5	58.0	164.8	27.3	527.8	21.1	51.8	74.0	85.5
Mean	1186.1	60.2	182.1	29.1	548.2	21.2	58.2	75.1	85.9
GM	962.2	59.0	175.0	27.7	467.4	21.0	53.0	74.7	83.5
75 %	1408.6	67.2	210.6	32.2	602.3	22.3	69.9	79.9	101.4
95 %	1848.2	82.8	288.7	47.4	706.5	24.7	110.9	87.5	120.0
Max	2454.1	105.8	327.7	82.3	894.3	43.5	162.7	103.2	136.4
SD	349.2	12.9	53.0	10.8	87.8	3.0	26.9	7.9	19.8
CV (%)	29.4	21.3	29.1	37.0	16.0	14.3	46.2	10.5	23.1
Skewness	1.1	0.9	0.9	2.6	1.0	3.5	1.4	0.9	0.1
Kurtosis	1.4	1.1	0.1	8.7	1.2	24.2	2.2	1.4	-0.7
Reference value <sup>a</sup>	527.7	9.9	56.4	19.2	508.6	24.5	18.8	65.5	55.7

GM geometric mean, SD standard deviation, CV coefficient of variation

<sup>a</sup> Wang et al. (2007)

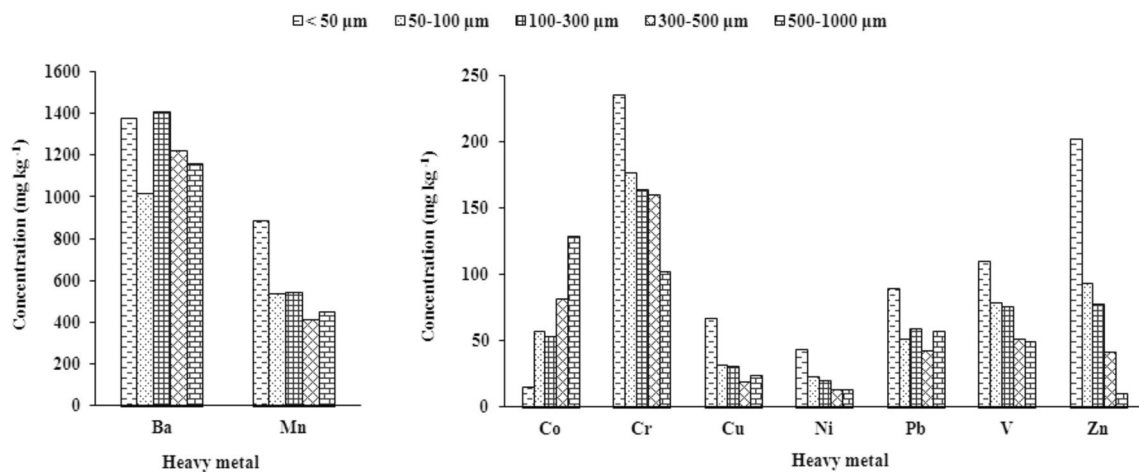
positively skew towards the lower concentrations (Lu et al. 2010). Kurtosis values of all metals are evidently larger than zero except that for the Zn, demonstrating that the distributions of the concentrations of these heavy metals in the dust are steeper than normal.

### Concentrations and mass percentages of heavy metals in particle-size fractions of the street dust

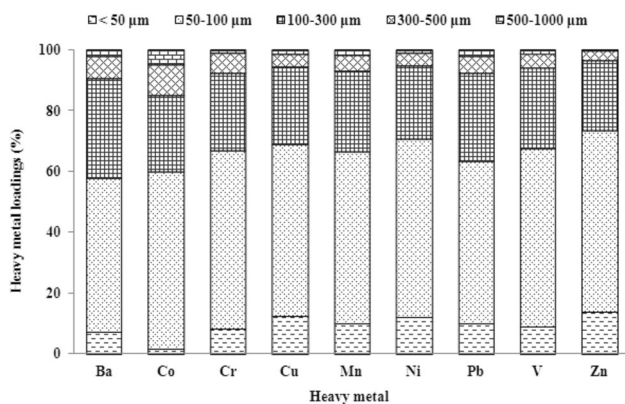
Heavy metals concentrations in differently sized street dust particles of Baotou are shown in Fig. 3. It can be seen that the variation patterns of Cr, Cu, Mn, Ni, Pb, V and Zn concentration in the dust are similar, and their highest concentrations appear in the smallest grain-size fraction ( $<50 \mu\text{m}$ ). Values for the highest concentrations for Cr, Cu, Mn, Ni, Pb, V and Zn are 235.5, 66.5, 882.7, 43.5,

89.0, 109.9 and 201.2  $\text{mg kg}^{-1}$ , respectively. The concentrations of these metals decrease with an increase in the particle size in the different grain size particles. This result is in agreement with some studies which suggested that high concentrations of metals were usually associated with smaller grain size particles (Duong and Lee 2011). This happens due to their larger specific area and higher adsorption rate compared to larger particles. However, authors of a few other studies have been found to be in disagreement with such findings (Han et al. 2008).

The concentration variations of Ba and Co in different size fractions are not in agreement with other heavy metals. The highest content of Co in the dust from Baotou was observed in the particle size of 500–1000  $\mu\text{m}$ , which was 128.3  $\text{mg kg}^{-1}$ , followed by the particle size of 300–500  $\mu\text{m}$ , which was 81.6  $\text{mg kg}^{-1}$ . The dusts with the



**Fig. 3** Concentrations of heavy metals in particle-size fractions of street dust from Baotou



**Fig. 4** The loadings of heavy metals in different particle-size fractions of the street dust

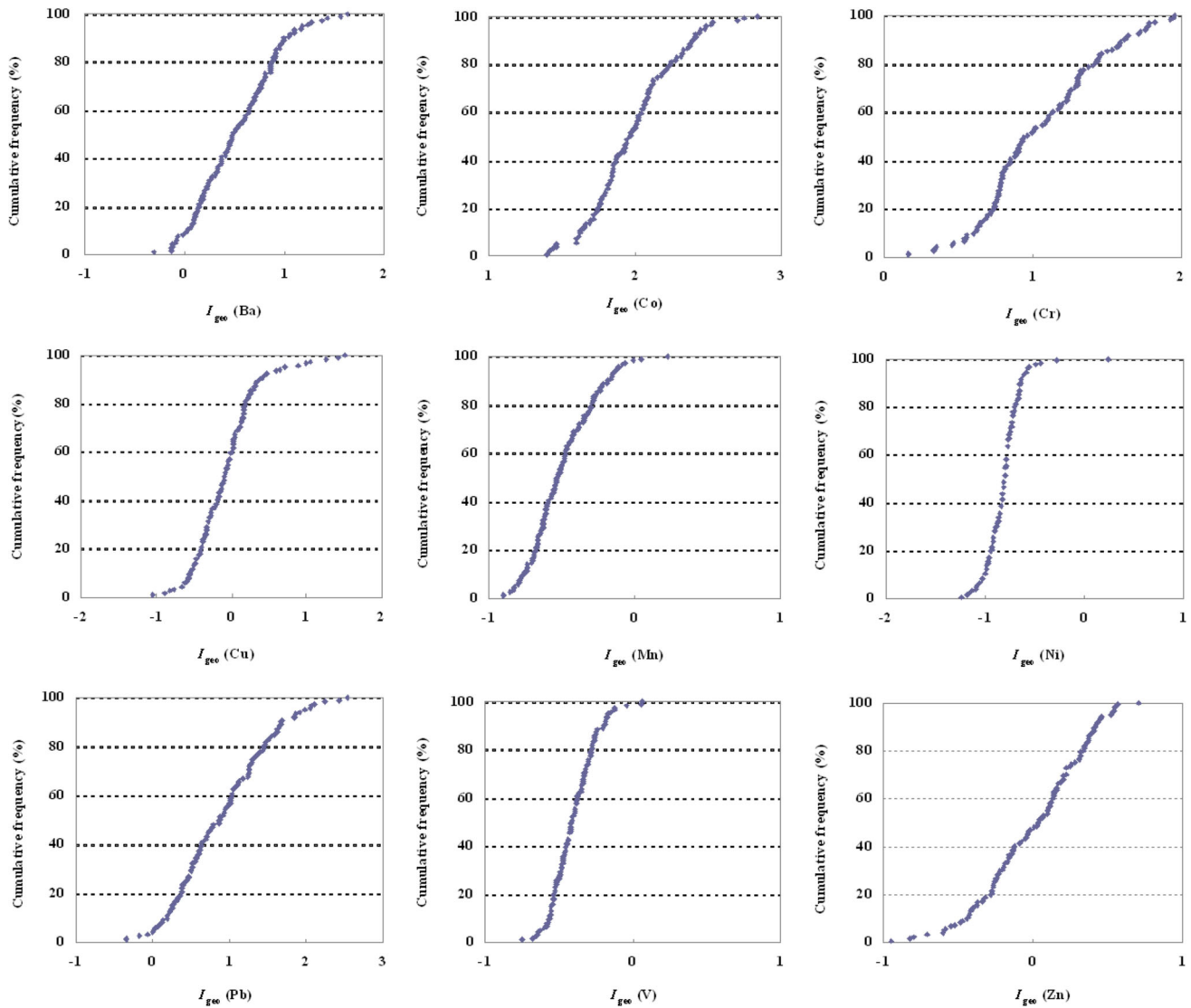
particle size of 50–100  $\mu\text{m}$  and 100–300  $\mu\text{m}$  had comparable contents of Co, which were 56.9 and 52.8  $\text{mg kg}^{-1}$ , respectively. The street dust with the smallest grain-size fraction (<50  $\mu\text{m}$ ) had the lowest concentration of Co, which was 14.9  $\text{mg kg}^{-1}$ . The content of Ba was relatively higher compared to other analyzed heavy metals and ranged from 1013.8 to 1406.0  $\text{mg kg}^{-1}$ . The highest content of Ba was observed in the particle size of 100–300  $\mu\text{m}$ . However, the concentrations of Ba varied in different size fractions.

To assess the amount of heavy metals from each size fraction with respect to the total concentration in the bulk dust, the mass loadings for metals from each particle grain-size group were calculated. The proportions of metal loadings in different size fractions of Ba, Co, Cr, Cu, Mn, Ni, Pb, V and Zn in the road dusts are presented in Fig. 4. In general, finer particles in the dust showed higher heavy metal enrichment. For nine kinds of heavy metals, more than 50 % of the concentrations of all studied heavy metals resided in the particle grain-size fraction of 50–100  $\mu\text{m}$ ,

and the lowest contribution to the total metal concentration in the dust came from coarse fraction.

**Contamination level of heavy metal in the street dust**

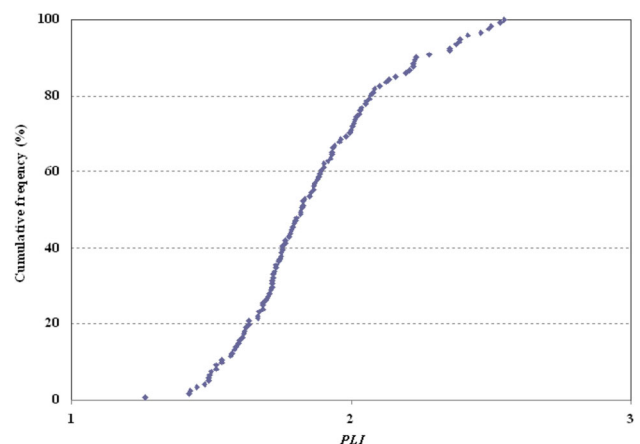
The cumulative frequency distributions of the geo-accumulation index ( $I_{\text{geo}}$ ) values of all analyzed heavy metals in the street dust of Baotou are shown in Fig. 5. Figure 5 shows that the  $I_{\text{geo}}$  values of Ba, Co, Cr, Cu, Mn, Ni, Pb, V and Zn lie in the ranges of  $-0.30$  to  $1.63$ ,  $1.40$ – $2.83$ ,  $0.16$ – $1.95$ ,  $-1.05$  to  $1.51$ ,  $-0.90$  to  $0.23$ ,  $-1.24$  to  $0.24$ ,  $-0.35$  to  $2.53$ ,  $-0.75$  to  $0.07$  and  $-0.95$  to  $0.71$  with average values of 0.58, 2.02, 1.11, 0.01,  $-0.48$ ,  $-0.79$ , 1.05,  $-0.39$  and 0.04, respectively. The mean  $I_{\text{geo}}$  and 82 %  $I_{\text{geo}}$  of Ba are between 0 and 1, showing ‘uncontaminated to moderately contaminated’ level of contamination. The 10 %  $I_{\text{geo}}$  of Ba lies in the range of 1–2, demonstrating ‘moderately contaminated’ level of contamination. The  $I_{\text{geo}}$  values of Co are higher than other heavy metals. The  $I_{\text{geo}}$  values of Co in 47 % samples and the corresponding mean value are in the range of 2–3, indicating ‘moderately to heavily contaminated’ level of contamination. In 53 % samples, the  $I_{\text{geo}}$  values are in the range of 1–2, showing ‘moderately contaminated’ level of contamination. The mean  $I_{\text{geo}}$  and 50 %  $I_{\text{geo}}$  of Cr are in the range of 1–2, indicating ‘moderately contaminated’ level of contamination, while 50 %  $I_{\text{geo}}$  of Cr is between 0 and 1, showing ‘uncontaminated to moderately contaminated’ level of contamination. The mean  $I_{\text{geo}}$  values of Cu and Zn, 45 %  $I_{\text{geo}}$  of Cu and 55 %  $I_{\text{geo}}$  of Zn are between 0 and 1, demonstrating ‘uncontaminated to moderately contaminated’ level of contamination, while 52 %  $I_{\text{geo}}$  of Cu and 45 %  $I_{\text{geo}}$  of Zn are <0, indicating ‘uncontaminated’ level of contamination. The mean  $I_{\text{geo}}$  and 98 %  $I_{\text{geo}}$  of Mn, Ni and V are <0, indicating that the street dust of Baotou was



**Fig. 5** Cumulative frequency distribution of  $I_{geo}$  of heavy metals in the street dust

‘uncontaminated’ by these metals. The mean  $I_{geo}$  and 40 %  $I_{geo}$  of Pb are between 1 and 2, demonstrating ‘moderated contaminated’ street dust, while 52 %  $I_{geo}$  of Pb is in the range of 0–1, showing ‘uncontaminated to moderately contaminated’ dust.

The PLI-calculated results of heavy metals in the street dust samples collected from Baotou city are presented in Fig. 6. The PLI values of heavy metals in all dust samples range from 1.26 to 2.55 with an average of 1.87, indicating that the dust samples from Baotou were contaminated by heavy metals to different degrees. The PLI values of heavy metals in 84 dust samples (69 %) are between 1 and 2, showing ‘uncontaminated to moderately contaminated’ dust samples. In 37 dust samples (31 %), the PLI values are in the range of 2–3, indicating ‘moderately contaminated’ dust samples.



**Fig. 6** Cumulative frequency distribution of PLI of heavy metals in the street dust



## Conclusions

The concentration, contamination level and grain-size distribution of Ba, Co, Cr, Cu, Mn, Ni, Pb, V and Zn in street dust samples from a medium-sized industrial city (Baotou) of China have been studied in this work. Compared to the local soil, the studied dust samples have elevated concentrations of heavy metals. The mean concentrations of Ba, Co, Cr, Cu, Mn, Ni, Pb, V and Zn in the dust are 1186.1, 60.2, 182.1, 29.1, 548.2, 21.2, 58.2, 75.1, and 85.9 mg kg<sup>-1</sup>, respectively. The analysis of the grain-size distribution of heavy metals in the dust shows that Cr, Cu, Mn, Ni, Pb, V and Zn were mainly accumulated in the <50 μm particles, while Co was primarily accumulated in 300–1000 μm dust particles, whereas Ba was mostly present in 100–300 μm particles. The mean geo-accumulation index values of the analyzed heavy metals in the dusts decreases in the order of Co > Cr > Pb > Ba > Zn > Cu > V > Mn > Ni. Dust samples were ‘uncontaminated’ with regard to the V, Mn and Ni, while Pb, Ba and Zn indicated uncontaminated to moderately contaminated degree in the dust. Co and Cr fell in the moderately contaminated category. Assessment results of pollution load index indicated that the dust samples were uncontaminated to moderately contaminated by the heavy metals as a whole. The environmental impacts and health risks of heavy metals in street dust are not only related to their concentrations and grain-size distribution, but are also dependent on their speciation in the dust. Therefore, the speciation of heavy metals in the dust will be carried out in the future.

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