CrossMark

ORIGINAL PAPER

Contamination levels and human health risk assessment of toxic heavy metals in street dust in an industrial city in Northwest China

Yufeng Jiang · Leiping Shi · A-long Guang · Zhongfeng Mu · Huiying Zhan · Yingqin Wu

Abstract This study investigated the content, distribution, and contamination levels of toxic metals (Cd, Cr, Cu, Pb, and Zn) in street dust in Lanzhou, an industrial city in Northwest China. Meanwhile, the risk these metals posed to the urban ecosystem and human health was also evaluated using the potential ecological risk index and human exposure model. Results showed that concentrations of these metals in the dust are higher than the background value of local soil, with Cu having the highest levels. The districts of Anning and Xigu had the most extreme levels of contamination, while Chengguan and Qilihe districts were lightly contaminated, which can be partly attributed to human activities and traffic densities. In comparison with the concentrations of selected metals in other cities, the concentrations of heavy metals in Lanzhou were generally at moderate or low levels. Heavy metal concentration increased with decreasing dust particle size. The pollution indices of Cr, Cd, Cu, Pb, and Zn were in the range of 0.289–2.09, 0.332–2.15, 1.38–6.21, 0.358–2.59, and 0.560–1.83 with a mean of 1.37, 1.49, 3.18, 1.48, and 0.897, respectively. The geo-accumulation index (I_{geo}) suggested that Zn in street dust was of geologic origin, while Cd, Cr, Pb, and Cu were significantly impacted by anthropogenic sources. The comprehensive pollution index showed that urban dust poses a high potential ecological risk in Lanzhou. Non-carcinogenic and carcinogenic effects due to exposure to urban street dust were assessed for both children and adults. For non-carcinogenic effects, ingestion appeared to be the main route of exposure to dust particles and thus posed a higher health risk to both children and adults for all metals, followed by dermal contact. Hazard index values for all studied metals were lower than the safe level of 1, and Cr exhibited the highest risk value (0.249) for children, suggesting that the overall risk from exposure to multiple metals in dust is low. The carcinogenic risk for Cd and Cr was all below the acceptable level ($< 10^{-6}$).

Y. Jiang (✉) · L. Shi · A.-l. Guang · Z. Mu
School of Environmental and Municipal Engineering, Lanzhou Jiaotong University, Lanzhou 730070, People's Republic of China
e-mail: Jiangyf7712@126.com

H. Zhan
Chemical Engineering College, Lanzhou University of Arts and Science, Lanzhou 730000, People's Republic of China

Y. Wu
Key Laboratory of Petroleum Resources Research, Institute of Geology and Geophysics, Chinese Academy of Sciences, Lanzhou 730000, People's Republic of China

Introduction

Heavy metals, including Cu, Cd, Zn, Pb, and Cr, are common trace constituents in the earth's crust, but their concentration in many local environments has increased dramatically since the industrial revolution (Davydova 2005; Ahmed and Ishiga 2006). Heavy metals found in the urban environment may come from rock weathering, vehicle emissions, and industrial discharges, among other activities (Al-Khashman 2007). Traffic and industrial activities are also regarded as two of the most important sources of anthropogenic heavy metals (Faiz et al. 2009; Kong et al. 2011). Heavy metals are usually non-degradable; they can accumulate in human fatty tissues, can be toxic to the human central nervous system (US EPA 2000; Denier et al. 2009), and some of them, such as Cr and Cd, may also enter the human circulatory system and disrupt its normal functioning (US EPA 2000).

Heavy metals can accumulate in street dust through atmospheric deposition by sedimentation interception (Christoforidis and Stamatis 2009). In street dust, anthropogenic sources of heavy metals include traffic emissions (vehicle exhaust, tire and brake lining wear, and weathered street surfaces), industrial emissions (power plants, coal combustion, metallurgical industry, auto repair shops, chemical plants, etc.), domestic emissions, weathering of building and pavement surfaces, atmospheric depositions and so on (US EPA 2000). Street dust in urban areas, which contributes significantly to urban environmental pollution, is therefore an indicator of the extent of heavy metal contamination from atmospheric deposition (Ahmed and Ishiga 2006). People living close to urban streets are exposed to street dust through direct inhalation, ingestion, and absorption following dermal contact (Ferreira-Baptista and Miguel 2005; Ahmed and Ishiga 2006). Recent studies have focused on contamination levels of heavy metals in street dust and the health risk they pose, in mega cities (Kong et al. 2011; Mohmand et al. 2015; Ma et al. 2016; Dehghani et al. 2017; Gope et al. 2017); several studies suggest that heavy metals are present in dust found in China's urban environments (Kong et al. 2011; Shi et al. 2011; Li et al. 2013, 2016; Wei et al. 2015; Tang et al. 2017).

Lanzhou is an important, rapidly developing city in northwestern China and was chosen for this study because it is considered one of the most polluted cities in the country. It contains a variety of industries, such as petrochemical complexes, smelters, nonferrous metal industries, construction, chemical plants, and thermal power plants. It is also one of the most densely populated cites in northwestern China with heavy automobile traffic. The primary fuel is coal, which causes serious air pollution, and the city occupies a valley surrounded by mountains that trap dirty air. High levels of total suspended particulates (TSP) and photochemical smog (Xi et al. 2000; Jiang et al. 2001; Ta et al. 2004) resulted in high incidences of respiratory diseases, such as asthma and lung cancer (Tian and Zhou 1994). It is possible that urban street dust, transferred to humans via ingestion, inhalation, or dermal contact, might have a direct effect on public health. Our earlier study has shown that Lanzhou's streets and soil are heavily polluted by polycyclic aromatic hydrocarbons (Jiang et al. 2014, 2016). However, less data are available about heavy metal contamination in Lanzhou street dust. It is important to identify the contamination level and health risk of heavy metals in street dust and to estimate population heavy metal exposure from street dust. The objectives of the present study were: (1) to determine the levels of toxic heavy metal contamination in Lanzhou street dust; (2) to obtain detailed information on the spatial distribution of heavy metals in dust; and (3) to elucidate the potential ecological and human exposure risk from toxic heavy metals in Lanzhou street dust.

Materials and methods

Study area

Lanzhou, the capital of Gansu Province and the second largest city in northwest China, is located at the intersection of the Qinghai-Tibet Plateau, the Inner Mongolian Plateau, and the Loess Plateau (Fig. 1). It is 1631.6 km^2 in area, 114 km wide on its east–west axis and approximately 35 km on its north–south axis. The city is surrounded by mountains and hills that rise to 600 m above the valley floor. It has a North Temperate Zone continental climate, with an annual average temperature of 9.5 °C; relative humidity of 57%; and an annual precipitation of 327.7 mm, half of which falls from July to September. Due to the influence of its topography, the monthly average surface wind speed is approximately 0.8 m/s and the
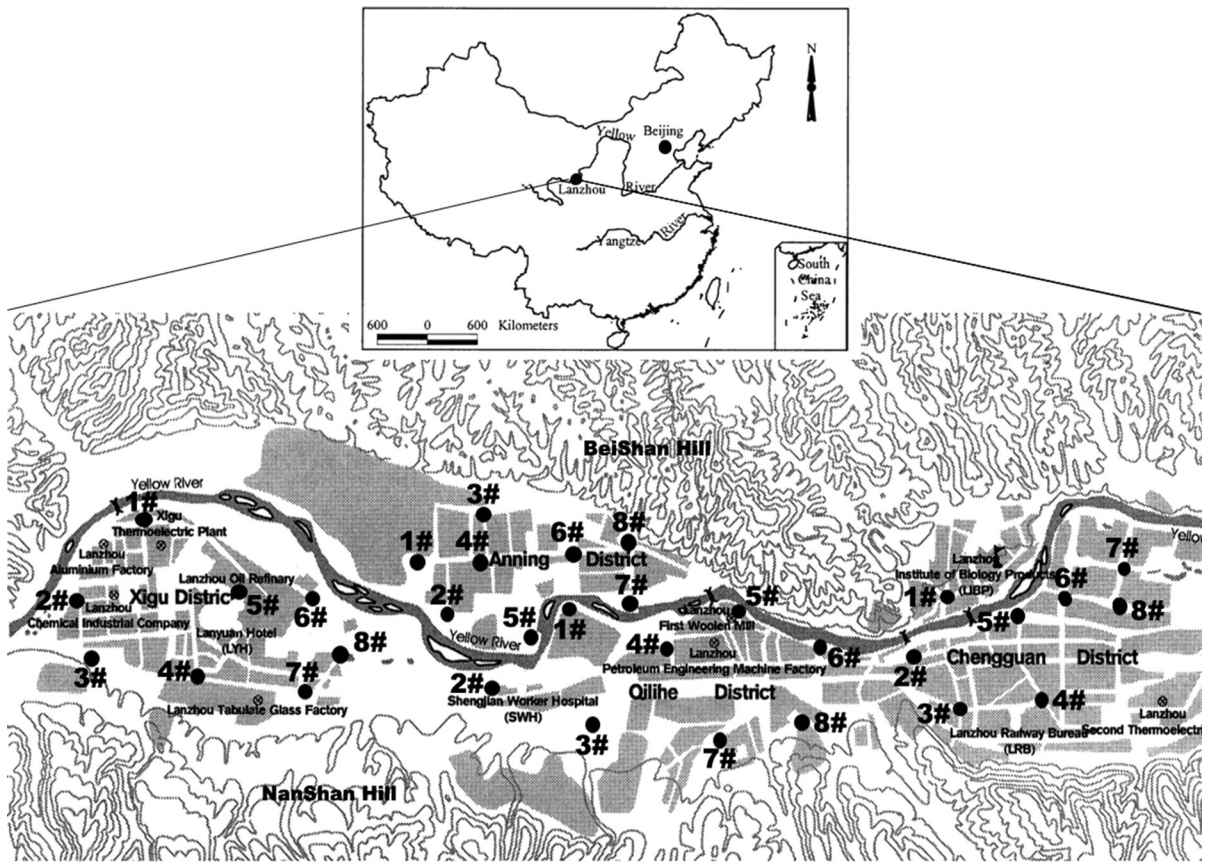
Fig. 1 Schematic map of sampling sites in urban area of Lanzhou

dominant wind direction varies from east at 10 m to west at 600–900 m (Ta et al. 2004). Approximately 2.5 million people live in four districts within the city: Chengguan (CG), Qilihe (QLH), Anning (AN), and Xigu (XG). Chengguan and Qilihe districts are older than the other two and have higher populations and heavier traffic. Chengguan is a commercial center, Anning developed in recent years as a suburban area, and Xigu has been an industrial estate for several decades (Tang et al. 1985).

Dust sampling

A total of 32 street dust samples were collected around the main streets of Lanzhou city in April 2011, in all four districts, including areas with heavy and low traffic density and commercial, industrial, and residential areas: A1–8, C1–8, Q1–8, and X1–8 (Fig. 1 and Supplementary Material Table S1). Street dust composite samples of approximately 500 g were collected using a polyethylene brush on impervious surfaces (roads, pavement, and crossroads) within a 2.5 m radius circle around each sampling site. All collected dust samples were stored in sealed polyethylene bags, labeled, and then transported to the laboratory. Dust samples collected at A2, A4, C1, C5, Q3, Q5, X1, and X8 were selected at random and were divided into four categories, based on dust particle size: < 75, 75–180, 180–850, and > 850 mm, using laboratory test sieves. Three soil samples were also collected from the central district of Lanzhou and used to determine background levels of heavy metals. The soil samples were taken every 10 cm depth, with the maximum depth of 30 cm. Each soil sample consisted of five subsamples from 5 m^2 area. Soil samples were air-dried at room temperature, grounded, and subsequently separated into 0.15 mm using a mesh.

Analytical procedures

About 500 mg of dust was digested in sequence with 8 ml of aqua regia, 5 ml of HClO$_4$(72%, v/v), and 2 ml of HF (40%, v/v) in a microwave digestion system for 30 min, and the digested solution was diluted to 25 ml with ultra-pure water (Zhan et al. 2014). Concentrations of Cr, Cu, Pb, and Zn were determined using an atomic absorption spectrophotometer (AAS 5100, Perkin-Elmer Inc.). An air/acetylene flame was used to excite the metal atoms. Specific hollow cathode lamps of characteristic wavelength and slit width were used to estimate concentrations of each element. Duplicates, method blanks, and standard reference materials were used for quality assurance and quality control. Recovery of individual metals in standard reference materials varied from 89 to 110%, and the relative percentage difference among sample duplicates was less than 10%.

Assessment model

Pollution index

Both a pollution index (PI) and an integrated pollution index (*IPI*) for the heavy metals were used to assess soil quality in reference to an environmental background value. The *PI* of each element was defined as the ratio of heavy metal concentration to the background value of the corresponding areas and calculated as follows (Cai et al. 2013):

$$PI = \frac{C_n}{B_n}, \tag{1}$$

where C_n is the concentration of a heavy metal and B_n is the background value of heavy metals in the study area. Integrated pollution index (*IPI*) is defined as the mean value of the pollution index (*PI*) of an element. *PI* and *IPI* for these metals may indicate the role of pollutants in the soil, especially the effect of high pollutant concentration on soil quality, which is also used to evaluate the contamination of heavy metals in dust (Faiz et al. 2009; Wei et al. 2009; Lu et al. 2010). Based on these indices, soil quality was divided into three environmental pollution grades: low (*IPI* $\leq$ 1), moderate (1 < *IPI* $\leq$ 2), and high (*IPI* > 3.0).

Geo-accumulation index

The geo-accumulation index (I_{geo}) has been widely used to assess trace metal contamination levels (Muller 1969) as well as distinguish between geologic and anthropogenic sources of heavy metals in urban soil and dust (Wei et al. 2009, 2015; Lu et al. 2010; Kong et al. 2011; Gope et al. 2017). I_{geo} is expressed as follows:

$$I_{geo} = \log_2\left(\frac{C_n}{1.5B_n}\right), \tag{2}$$

where C_n is the concentration of a metal and B_n is the background value. The constant 1.5 allows us to analyze natural fluctuations in the content of a given substance in the environment and to detect very small anthropogenic influences. Seven classes of I_{geo} were determined: uncontaminated ($I_{geo} < 0$); uncontaminated to moderately contaminated ($0 < I_{geo} < 1$); moderately contaminated ($1 < I_{geo} < 2$); moderately to heavily contaminated ($2 < I_{geo} < 3$); heavily contaminated ($3 < I_{geo} < 4$); heavily to extremely contaminated ($4 < I_{geo} < 5$); and extremely contaminated ($5 < I_{geo}$).

Potential ecological risk

The potential ecological risk index (*RI*) is affected by: (a) heavy metal content in the environment (the potential ecological risk index increases as heavy metal content increases), (b) the type of heavy metals found, (c) the toxicity of individual heavy metals, and (d) the environmental sensitivity on the heavy metals, i.e., a high sensitivity of soil on heavy metals with a relatively higher *RI* value. The *RI* and C_d values for heavy metals in dust from the study areas were calculated to elucidate potential ecological risk for inhabitants (Zheng et al. 2010). *RI* and C_d are expressed as follows:

$$E_r^i = T_r^i \times C_f^i \tag{3}$$

$$RI = \sum E_r^i \tag{4}$$

$$C_f^i = \frac{C_D^i}{C_n^i} \tag{5}$$

$$C_d = \sum C_f^i, \tag{6}$$

where E_r^i is a single metal's potential ecological risk parameters—a metal toxicity response factor (dimensionless); RI represents the comprehensive metal potential risk index; C_f^i is a single pollution parameter; C_D^i is heavy metal concentration; C_n^i is a heavy metal background value; and C_d is the polymetallic comprehensive pollution index. Toxic response factor T_r^i reflects the ecological risk heavy metals pose for humans and ecosystems; the toxic response factor for Cu, Cr, Pb, Cd, and Zn were taken from the literature (Hakanson 1980). Four categories of metal contamination risk were developed: low ($RI \leq 50$), moderate ($50 < RI \leq 100$), considerable ($100 < RI \leq 200$), and high ($RI > 200$).

Exposure dose

The model used in this study to calculate the exposure of children and adults to trace metals in street dust is based on those developed by the US Environmental Protection Agency (US EPA 1996), the Dutch National Institute of Public Health and Environmental Protection (Van den Berg 1995), and related publications that define guidelines for or screening levels of soil contaminants in urban exposure scenarios (Shi et al. 2011; Li et al. 2013).

The following assumptions underlie the model applied in this study before using the models developed by US Environmental Protection Agency: (a) Human beings are exposed to road dust through three main pathways: ingestion of dust particles, inhalation of dust particles, and dermal contact with dust particles. (b) Intake rates and particle emission can be approximated by those developed for soil. (c) Relevant exposure parameters of children and adults in the study areas are similar to those of reference populations. (d) The overall non-carcinogenic risk for each metal (Cd, Cr, Cu, Pb, and Zn) and the overall carcinogenic risk for Cd and Cr can be calculated by summing the individual risks from the three exposure pathways:

$$D_{ing} = C \times \frac{IngR \times EF \times ED}{BW \times AT} \times 10^{-6} \qquad (7)$$

$$D_{inh} = C \times \frac{InhR \times EF \times ED}{PEF \times BW \times AT} \qquad (8)$$

$$D_{dermal} = C \times \frac{SL \times SA \times ABS \times EF \times ED}{BW \times AT} \times 10^{-6}, \qquad (9)$$

where EF is exposure frequency—in this study, 180 days year^{-1} (Zheng et al. 2010); ED is exposure duration—in this study, 6 years for children and 24 years for adults (US EPA 2001); SA is exposed skin area—in this study, 2800 cm^2 for children and 5700 cm^2 for adults (US EPA 2001); SL is a skin adherence factor—in this study, 0.2 mg cm^{-2} d^{-1} for children and 0.07 mg cm^{-2} d^{-1} for adults (US EPA 2001); ABS is a dermal absorption factor (unitless)—in this study, 0.001 for all elements (Man et al. 2010); PEF is a particle emission factor—in this study, 1.36×10^9 m^3 kg^{-1} (US EPA 2001); BW is average body weight—in this study, 15 kg for children and 70 kg for adults (US EPA 2001); and AT is the averaging time—for non-carcinogens, $ED \times 365$ days; for carcinogens, $70 \times 365 = 25{,}550$ days (Zheng et al. 2010).

C is the exposure point concentration (mgkg^{-1}). C in Eqs. (7)–(9), combined with the values for the exposure factors shown above, is considered to yield an estimate of the "reasonable maximum exposure" (US EPA 1989), which is the upper limit of the 95% confidence interval for the mean. Since the concentration of most elements in the street dust samples has an approximate lognormal distribution, the 95% upper confidence limit (UCL) was calculated as shown in Eq. (10) (US EPA 1996). Calculation of the exposure point concentration term for log-transformed data:

$$C_{95\%UCL} = \exp\left\{ \bar{X} + 0.5 \times s^2 + \frac{s \times H}{\sqrt{n-1}} \right\} \qquad (10)$$

where $\bar{X}$ is the arithmetic mean of the log-transformed data, s the standard deviation of the log-transformed data, H the H-statistic (Gilbert 1987), and n the number of samples.

Risk characterization

The potential non-carcinogenic and carcinogenic risks for individual metals were calculated as follows (Li et al. 2013):

$$HQ = \frac{D}{R_f D_0} \qquad (11)$$

$$CR = D \times SF_0 \qquad (12)$$

The hazard quotient (HQ), which is based on non-cancer toxic risk, was calculated by dividing the average daily dose by a specific reference dose (R_fD_0) (Man et al. 2010). The reference dose (mg kg^{-1} day^{-1}) was an estimate of maximum permissible risk to a human population through daily exposure during a lifetime. The hazard index (HI) was equal to the sum of HQs and was used to estimate the health risk of different exposure pathways. HI values of ≤ 1 indicate no adverse health effects, and HI values > 1 indicate possible adverse health effects (Kong et al. 2011). For carcinogenic risk (CR), the dose was multiplied by the corresponding slope factor to produce an estimate of cancer risk (Zheng et al. 2010; Li et al. 2013). In this study, both HI and CR were used to assess population health risk from exposure to heavy metals in street dust in Lanzhou.

Results and discussion

Heavy metal concentration in street dust

Chromium: Cr is a naturally occurring element in rocks, animals, plants, soil, and volcanic dust and gases. Its most common anthropogenic sources include the industrial oxidation of mined chromium deposits and possibly combustion of fossil fuels, wood, paper, etc. (WHO 1988), as well as industrial processes, such as refining (ore), processing (chemical and refractory), production (cement and automobile brake linings and catalytic converters), and tanning (leather) (ATSDR 2011). Cr levels in Lanzhou dust ranged from 18.8 to 135 mg kg^{-1}, with the maximum concentration 7.18 times higher than the minimum value (Table 1); the geometric mean of 96.9 mg kg^{-1} is 62% higher than soil background values. The highest levels of Cr (101–135 mg kg^{-1}, mean 112 mg kg^{-1}) were found in Chengguan, with the maximum value of 135 mg kg^{-1} found in C4, a value two times greater than the soil background value. Cr concentrations in Chengguan did not fluctuate much between sampling sites (Table 1), suggesting that contamination comes mainly from nonpoint source pollution. As in many other northern Chinese cities, coal is heavily used for home heating in the winter, which lasts for nearly 5 months, as well as in industry,

and coal is the primary contributor of Cr contamination in the local environment in addition to ore refining, chemical and refractory processing, cement-producing plants, and a thermal power plant. The lowest concentration of Cr (18.8–101 mg kg^{-1}, average 82.7 mg kg^{-1}) was found in Qilihe. The lowest value of 18.8 mg kg^{-1} was at Q1, near a residential area, likely less influenced by industrial activities.

Cadmium: Cd, a relatively rare heavy metal, occurs naturally in combination with other metals. The primary sources of airborne Cd are the burning of fossil fuels and the incineration of municipal waste materials (US EPA 2000). Cd concentration in Lanzhou ranged from 0.102 to 3.21 mg kg^{-1}, with a geometric mean of 0.812 mg kg^{-1} (Table 1), a maximum value 31.5 times higher than the minimum, and a mean much higher than soil background values. The highest concentrations of Cd (0.487–3.21 mg kg^{-1}, mean 1.06 mg kg^{-1}) were observed in Chengguan. The highest concentration of 3.21 mg kg^{-1} at C5 is nearly 29.1 times greater than background value and was sampled in a crossroad in front of the construction materials market—an area with both a high population and traffic volume, near a thermal power and a metal processing plant. Cd contamination in dust samples is strongly affected by traffic emissions and industrial and incinerator emissions (Faiz et al. 2009): high concentrations of Cd have been found in dust samples from industrial areas in Korea (Duong and Lee 2011) and along an expressway in Pakistan (Faiz et al. 2009). Thus, it seems reasonable to infer that the high concentration found at this sampling site results from industrial and traffic emissions in this dense commercial and industrial mixed zone. The lowest concentrations (0.102–2.19 mg kg^{-1}, average of 0.457 mg kg^{-1}) were found in Anning, with the lowest levels at A4—a residential area. This district, located far from the city center, has relatively light traffic and with primarily cultural and educational activities probably receives less heavy metal contamination from industrial activity and traffic emissions.

Copper: Cu is an essential trace element, widely distributed in the environment. It occurs naturally in elemental form and as a component of many minerals. It is also commonly used as a chemical catalyst. It has been previously reported that the petroleum industrial may produce more heavy metals through industrial processes and traffic emission (Manno et al. 2006; Duong and Lee 2011). Concentrations of Cu in

Table 1 Heavy metal concentrations in street dust from different districts in Lanzhou (mg kg^{-1})

Element	Street dust ($n = 32$)			Soil background ($n = 3$)			Background[a]
	Min–Max	Mean ± SD	CV (%)	Min–Max	Mean ± SD	CV (%)	
Cr	18.8–135	96.9 ± 24.6	25	55.3–61.2	59.8 ± 5.22	16	64.9
Cd	0.102–3.21	0.812 ± 0.720	40	0.071–0.132	0.098 ± 0.009	8	0.11
Cu	33.6–151	77.4 ± 19.8	38	16.8–24.9	21.6 ± 3.28	11	24.3
Pb	8.42–61.0	34.7 ± 12.2	36	19.8–24.3	21.9 ± 2.17	7	23.5
Zn	41.5–109	56.6 ± 40.6	23	48.7–53.2	51.2 ± 3.11	9	54.3

SD standard deviation; *CV* coefficient of variation

[a]Data from Chinese National Environmental Monitoring Center (CNEMC 1990)

Lanzhou street dust ranged from 33.6 to 151 mg kg^{-1} with a geometric mean of 77.4 mg kg^{-1}; the maximum value was about 4.49 times greater than the minimum (Table 1). CV of Cu was moderate at 38%. The highest concentration (62.8–124 mg kg^{-1}, mean 92.6 mg kg^{-1}) was found in Chengguan. But at X4, an even higher concentration of 151 mg kg^{-1} was found, about 6.21 times greater than the background level, perhaps because this sampling site is a major crossroad, close to the Lanzhou oil refinery, and a building materials market, with high traffic volumes. The lowest concentrations of Cu (33.6–109 mg kg^{-1}, average 57.5 mg kg^{-1}) were in Anning, with concentrations at A4 only slightly higher than the soil background value.

Lead: Pb is a ubiquitous pollutant in industrialized areas. In Lanzhou, Pb concentrations in dust ranged from 8.42 to 61.0 mg kg^{-1} with a geometric mean of 34.7 mg kg^{-1} (Table 1) and a maximum value 7.24 times higher than the minimum. Mean Pb concentrations in Lanzhou are 57.8% higher than background levels. *CV* of Pb at 36% was moderate. Highest concentrations (23.7–61.0 mg kg^{-1}, mean 48.2 mg kg^{-1}) were observed in Qilihe, except for a highway overpass in Xiaoxihu, near the highway transport hub and a commercial center, where levels reached 61.0 mg kg^{-1}, nearly 2.60 times higher than background value (Fig. 2). This is not surprising as Faiz et al. (2009) have reported that high Pb concentration in road dust samples is associated with traffic burden, brick kilns, and use of leaded gasoline. Lowest concentrations (8.42–43.3 mg kg^{-1}, average 25.0 mg kg^{-1}) were detected in Anning, with the lowest concentration (8.42 mg kg^{-1}) at the west railway station of Lanzhou, although this was 61.7% greater than the background value, suggesting that Pb is a ubiquitous pollutant in Lanzhou.

Zinc: Zn is an essential trace element widely distributed in the environment; contamination in dust samples is strongly effected by traffic emissions, including engine emissions, mechanical abrasion of vehicles, and tire and brake wearing (Duong and Lee 2011). Concentrations of Zn in street dust ranged from 41.5 to 109 mg kg^{-1} with a geometric mean of 56.6 mg kg^{-1} (Table 1) and a maximum value 2.63 times higher than the minimum. These concentrations are comparable with background values of Lanzhou city (Table 1), which suggest that Zn comes from geologic origin. The highest concentrations of Zn, 2.01 times higher than soil background levels, were found at sampling location C3, located at across road near the highway transport hub with high traffic volumes. The lowest levels, comparable to soil background levels, were found at sampling Q4, near the southern hills, which is less influenced by human activities, and so the dust sample probably includes particles carried thereby wind.

A comparison of heavy metals concentrations in street dusts of Lanzhou with those of the different worldwide regions

Worldwide concentration values of these elements in road dust have been compiled from literature and are given in Supplementary Material Table S2. The global Cd concentrations ranged from nd to 691 mg kg^{-1} (Supplementary Material, Table S2). Among the 26 places reported, the concentration of Cd in this study is less than that of the data cited for 13 cities as given in Supplementary Material Table S2. There are seven places where the concentration is less than that of our study. Cd concentration of six places is comparable to that of this study. The concentration of Cr varies from

Fig. 2 Concentrations of heavy metals in road dusts in each of the four size fractions
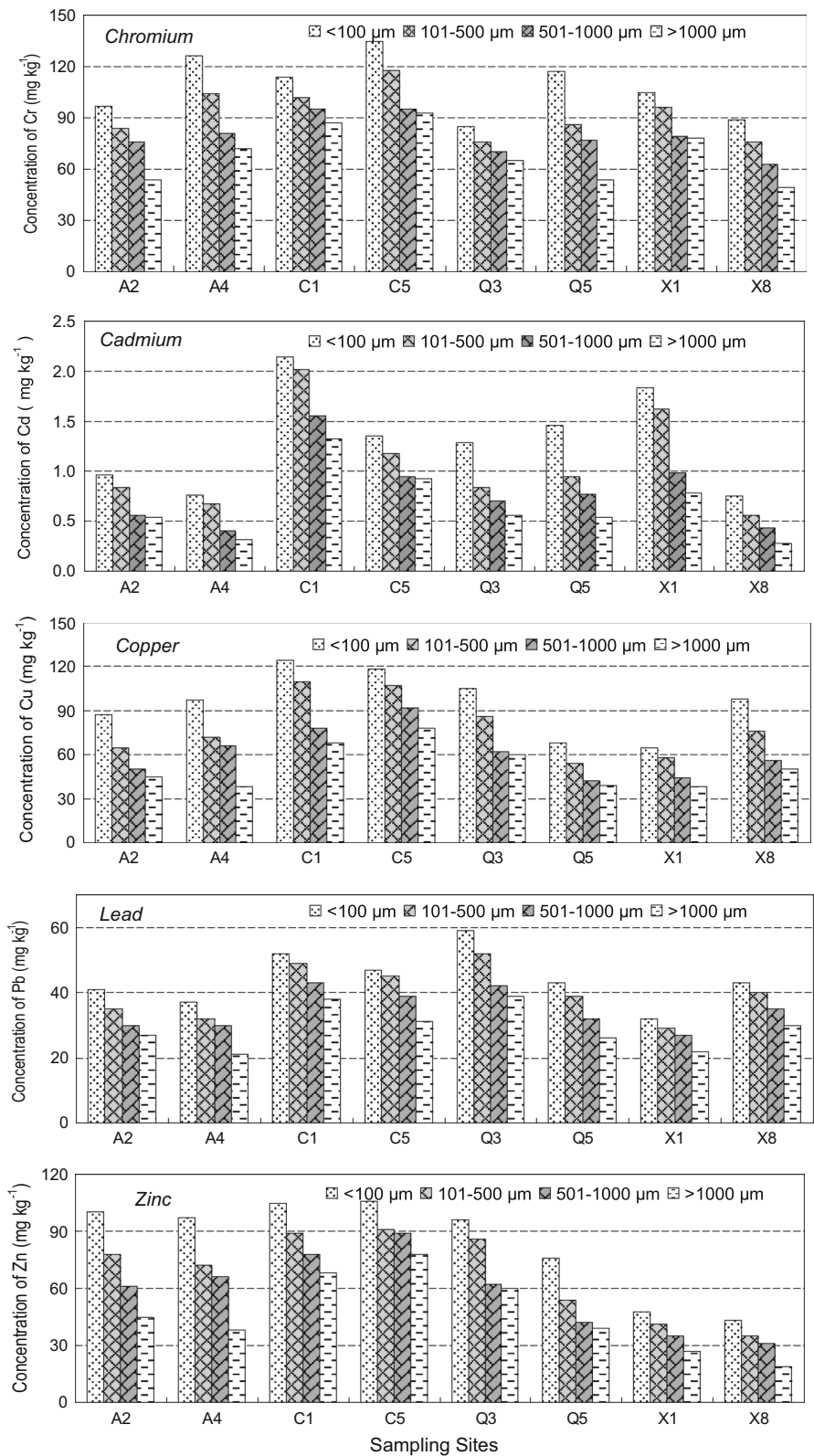
2.29 to 10268 mg kg^{-1} (Supplementary Material, Table S2). Among the 23 places reported, there are 13 places in the world where the concentration of Cr is greater, five places where it is lower than that in Lanzhou; and five places where the concentration of Cr is equal to that in Lanzhou. The global concentration of Cu as reported varies from 5.46 to 6688 mg kg^{-1} (Supplementary Material, Table S2). Among the 28 places reported, 17 places have higher and ten places have lower concentration of Cu than that determined in Lanzhou dust samples. The concentration of Cu in Luanda (Angola) is comparable to that in the dust of Lanzhou. From the compiled data given in Supplementary Material Table S2, it is evident that there is a great variation in Pb concentration, varying from not detected (nd) to 17578 mg kg^{-1}. There are 23 places in the world where Pb concentration is greater, only one place where concentration is lower than that in the dust of Lanzhou. The level of Cu in Huainan and Urumqi (China) is comparable to that in the dust of Lanzhou. The global concentration of Zn is in the range 47.6–35400 mg kg^{-1}, as given in Supplementary Material Table S2. The amount of Zn in road dust from Lanzhou is lower than all of the data cited in literature. In comparison with the concentrations of selected metals in other cities, the concentrations of heavy metals in Lanzhou were generally at moderate or low levels.

Size distribution of heavy metals in street dust

The grain size distributions of street dust were similar for eight dust samples, characterized by significant distribution with most particles in the range of 76–1000 μm, especially 200–400 μm. The average concentration of heavy metals in the 12 street dust samples collected from the four districts in the four size fractions (< 75, 76–250, 251–1000, and > 1000 μm) is shown in Fig. 2. Concentrations of all heavy metals increased with decreasing particle size, and distribution patterns of heavy metal concentrations as a function of size fraction were similar at all of the study areas. There are several possible explanations for higher concentrations of heavy metals in dust samples with smaller particles: they can be direct by-products of vehicular and industrial activities (Duong and Lee 2011); their relatively larger available surface area per unit mass for deposition of or coating

by heavy metals released into the atmosphere or deposited near street surfaces means a higher adsorption rate for heavy metals compared to larger particles (Deletic and Orr 2005); they might have lower densities and contain a greater proportion of organics and clay minerals that facilitate the adsorption of metals.

Risk assessment

Pollution index

PI and *IPI* values of each metal element were calculated according to the background values of heavy metals in soil (CNEMC 1990) and varied across the different metals (Table 2). The *IPI* of Pb was 1.48, and its *PI* ranged from 0.358 to 2.59. For Cr, *IPI* was 1.37 and all of the samples had higher *PI* values (0.289–2.09). Cd also exhibited higher *PI* values, ranging from 0.332 to 2.15 with an *IPI* of 1.49, also with few samples classified as low *PI*. As given in Table 2, 96.8, 78.1, and 84.4% of dust samples for Cr, Cd, and Pb were in middle level of pollution, respectively, suggesting that Cr, Cd, and Pb are ubiquitous pollutants in Lanzhou urban dust. The highest *PI* values for Cu ranged between 1.38 and 6.21, indicating a high level of Cu pollution. Zn exhibited lower *PI* values, ranging from 0.560 to 1.83 with an *IPI* of 0.897, indicating a level of Zn comparable to the soil background value and no obvious contamination of Zn. The highest *PI* values were found at sampling sites A5, X5, C1, C2, Q2, and Q8; in these areas, pollutants may affect human health, something to which more attention should be paid.

Geo-accumulation index

The background values of each heavy metal were derived from background data in soil from the study areas (CNEMC 1990). I_{geo} values are shown in Table 3, along with Muller's geo-accumulation index. The I_{geo} value for Cd was greater than 0 for all dust samples and ranged from 0.108 to 2.02, suggesting a moderate contamination of street dust by Cd, significantly impacted by anthropogenic activities. This is also the case for Cu (I_{geo} 0.034 to 1.85). Cr I_{geo} values ranged from − 2.26 to 0.593, with 71.8% of samples having an $I_{geo} > 0$, so dust was classified as also uncontaminated to moderately contaminated by Cr,

Table 2 A pollution index (*PI*) and an integrated pollution index (*IPI*) of individual heavy metal in street dust of Lanzhou

Element	Pollution index (*PI*)			*NOE*[a]	*ROE*[b] (%)	Pollution classification
	Min	Max	Mean (*IPI*)			
Cr	0.289	2.09	1.37	25	78.1	Middle level of pollution
Cd	0.332	2.15	1.49	31	96.8	Middle level of pollution
Cu	1.38	6.21	3.18	32	100	High level of pollution
Pb	0.358	2.59	1.48	27	84.4	Middle level of pollution
Zn	0.560	1.83	0.897	12	37.5	Low level of pollution

[a]NOE numbers of dust samples with individual metal exceeding the classification values

[b]ROE the ratio of exceeding the classification values

Table 3 I_{geo} values of individual heavy metal in street dust of Lanzhou

Element	I_{geo}			*NOE*[a]	*ROE*[b] (%)	Origin of individual metal
	Min	Max	Mean			
Cr	− 2.26	0.593	0.653	23	71.8	Anthropogenic origin
Cd	0.108	2.02	1.10	32	100	Anthropogenic origin
Cu	0.034	1.85	1.12	32	100	Anthropogenic origin
Pb	− 1.98	0.875	− 0.01	20	62.5	Anthropogenic origin
Zn	− 5.57	0.112	− 1.31	4	12.5	Geologic origin

[a]NOE numbers of dust samples with individual metal I_{geo} exceeding the classification values

[b]ROE the ratio of exceeding the classification values

significantly impacted by anthropogenic activities. The I_{geo} of Pb ranged from − 1.98 to 0.875 with 62.5% dust samples having an I_{geo} between 0 and 1, leading to the conclusion that street dust is uncontaminated to moderately contaminated by Pb. Zn had an I_{geo} of − 5.57–0.112 with 12.5% dust samples having an I_{geo} greater than 0, so it is likely of geologic origin and street dust samples were classified as uncontaminated with Zn.

Potential ecological risk

RI and C_d for each sampling site and individual element are given in Fig. 3. The results show that *RI* of Anning, Xigu, Chengguan, and Qilihe was 23.2, 28.5, 34.1, and 31.4, respectively. *RI* levels varied among districts—with levels in Chengguan > Qilihe > Xigu > Anning—though all of the ecological risk indices are less than 50, meaning the potential ecological risk from urban dust in Lanzhou is low. However, the comprehensive pollution index (C_d) of individual heavy metals displayed the difference in
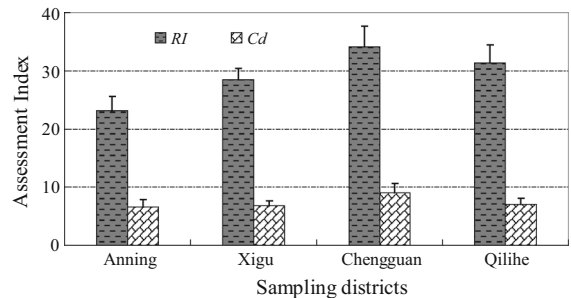
Fig. 3 *RI and C_d* values of heavy metals in dust of Lanzhou

dust of Lanzhou. C_d was 9.02, 7.04, 6.84, and 6.63—Chengguan > Qilihe > Xigu > Anning—indicating high potential ecological risk in Qilihe, Xigu, and Anning and extremely high risk in Chengguan.

Exposure to heavy metals in dust

Pb, Cu, Zn, and Cr all had total exposure levels in same order of magnitude (10^{-5} mg kg^{-1} d^{-1} for adults and

Table 4 Exposure risks of cancer and non-cancer of toxic metals from Lanzhou urban street dust

Metals	$Cr_{noncarc.}$	$Cr_{canc.}$	$Cd_{noncarc}$	$Cd_{canc.}$	Cu	Pb	Zn
Oral $R_fD_0^a$	3.00 E–03		1.00 E–03		4.00 E–02	3.50 E–03	3.00 E–01
Dermal $R_fD_0^a$	6.00 E–05		1.00 E–05		1.20 E–02	5.25 E–04	6.00 E–02
Inhal. SF^a		42		6.3			
Child							
HQ_{ing}	2.48 E–01		2.37 E–02		1.53 E–02	7.94 E–02	1.77 E–03
HQ_{inh}	6.40 E–06		3.56 E–07		3.99 E–07	2.07 E–06	4.63 E–08
HQ_{Dermal}	1.34 E–04		3.25 E–02		1.38 E–03	2.35 E–05	3.57 E–03
HI^b	2.49 E–01		5.62 E–02		1.67 E–02	7.94 E–02	5.34 E–03
Carcinogenic risk		4.61 E–10		5.66 E–11			
Adult							
HQ_{ing}	2.30 E–02		1.18 E–03		1.37 E–03	7.09 E–03	1.47 E–04
HQ_{inh}	3.63 E–06		1.98 E–07		2.55 E–07	1.17 E–06	2.61 E–08
HQ_{Dermal}	2.04 E–04		4.95 E–02		2.11 E–03	3.53 E–05	5.44 E–03
HI^b	2.32 E–02		5.07 E–02		3.48 E–03	7.13 E–03	5.59 E–03
Carcinogenic risk		8.93 E–10		1.09 E–10			

Values of HQ, HI, and CR were calculated based on the values of D_{ing}, D_{inh}, and D_{Dermal} at the 95% confidence intervals

[a] Data based on previous published paper (Li et al. 2013)

[b] $HI = HQ_{ing} + HQ_{inh} + HQ_{Dermal}$

10^{-4} mg kg^{-1} d^{-1} for child), with exposure levels of Cd for both children and adults 1–2 orders of magnitude lower (Supplementary Material, Table S3). Exposure was highest for Cr (at about 35.5%), followed by Cu (28.3%), Zn (22.7%), and Pb (12.9%). The maximum Cr exposure doses were 8.93×10^{-4} mg kg^{-1} d^{-1} for children and 9.93×10^{-5} mg kg^{-1} d^{-1} for adults.

Exposure levels via dermal contact and ingestion ranged from 10^{-6} to 10^{-4} in all the dust samples, while the mean exposure doses via inhalation were 10^{-11} to 10^{-8}, about 10^2 to 10^7 times lower than through ingestion and dermal contact (Supplementary Material, Table S3). Ingestion contributed 99.6 and 91.5% to the total exposure doses of non-carcinogenic and carcinogenic elements, respectively, in children, 96.0 and 73.4% in adults. Dermal contact ranked second, accounting for 0.398% (non-carcinogens) and 9.49% (carcinogens) of doses for children, 3.99 and 26.5% for adults. Inhalation of dust particles contributed least to health risk and could be ignored compared with the risk from ingestion and dermal contact, as was found in earlier studies (Shi et al. 2011; Li et al. 2013).

Exposure doses via ingestion were within the same order of magnitude (10^{-8} to 10^{-4}) as via dermal contact, indicating that ingestion and dermal contact are significant sources of risk for both children and adults (Supplementary Material, Table S3). However, exposure via direct ingestion was significantly higher ($P < 0.01$) for children—young children are probably the most at-risk subpopulation due their tendency to put their hands in their mouths, allowing for ingestion of contaminated dust (Meza-Figueroa et al. 2007). In addition, their lower body weight leads to a higher relative intake of toxic metals and a concomitant higher health risk for children exposed to urban dust than for adults.

Human exposure risk

As described above, the values of available HQ, HI, and CR were calculated based on the values of D_{ing}, D_{inh}, and D_{dermal} at the 95% confidence interval and the results are summarized in Table 4. For non-carcinogenic effects, ingestion appeared to be the main route of exposure to dust particles and thus posed a higher health risk to both children and adults for all metals, followed by dermal contact.

For children, *HI* values were highest for Cr (0.249), decreasing in the order Cr > Pb > Cd > Cu > Zn (5.34×10^{-3}). As *HI* values were all lower than the safe level of 1, there is little health risk from dust

exposure in Lanzhou urban areas. But, even though the *HI* for Cr (0.249) is lower than the safe level (1.0), Cr is cumulative, and inhaled Cr is a human carcinogen, increasing the risk of lung cancer (US EPA 2000). So Cr exposure via street dust cannot be overlooked. Furthermore, given the increased risk of ingestion in young children, exposure to Cr in street dust may be a greater health risk for them. The non-carcinogenic health risk from exposure to heavy metals in street dust was lower for adults than children by one order of magnitude. *HI* values were highest for Cd (5.07×10^{-2}), followed by Cr (2.32×10^{-2}), Pb (7.13×10^{-3}), Zn (5.59×10^{-3}), and Cu (3.48×10^{-3}) (Table 4), though all were far below the safe level, indicating no non-carcinogenic risks for adults.

Carcinogenic risk due to urban street dust exposure to Cd and Cr was assessed for ingestion and was found to be low, with higher values for Cr (8.93×10^{-10}) than Cd (1.09×10^{-10}), but still much lower than the internationally accepted precautionary criterion(10^{-6}) (US EPA 2001), and therefore acceptable.

Conclusion

Nearly all concentrations of the studied metals in Lanzhou street dust are higher than their background values. In comparison with the concentrations of selected metals in global areas, the concentrations of heavy metals in Lanzhou were generally at moderate or low levels. But the *PI* values indicated moderate pollution by Cr, Cd, and Pb, high pollution by Cu, and light pollution by Zn. I_{geo} values showed that Zn in street dust is geologic in origin, while Cr, Cd, Pb, and Cu levels are significantly impacted by anthropogenic sources. The *RI* of the heavy metals was less than 50, indicating low potential ecological risk. However, C_{d} indicated a high potential ecological risk in Anning, Xigu, and Qilihe, and extremely high risk in Chengguan. This inconsistency between the potential ecological risk index *RI* and comprehensive pollution index C_d suggests that more than one method must be used to assess ecological risk. Both HQ and *HI* indicated a low level of potential health risk from urban dust in Lanzhou, which may be higher for children than that for adults.

References

Agency for Toxic Substances and Disease Registry (ATSDR) (2011). Case Studies in Environmental Medicine (CSEM): Chromium Toxicity. http://www.atsdr.cdc.gov/csem/chromium/docs/chromium.pdf.

Ahmed, F., & Ishiga, H. (2006). Trace metal concentrations in street dusts of Dhaka city Bangladesh. *Atmospheric Environment, 40,* 3835–3844.

Al-Khashman, O. A. (2007). The investigation of metal concentrations in street dust samples in Aqaba city Jordan. *Environmental Geochemistry and Health, 29,* 197–207.

Cai, Q. Y., Mo, C. H., Li, H. Q., Lü, H., Zeng, Q. Y., Li, Y. W., et al. (2013). Heavy metal contamination of urban soils and dusts in Guangzhou, South China. *Environmental Monitoring and Assessment, 185,* 1095–1106.

Charlesworth, S., Everett, M., McCarthy, R., Ordóñez, A., & deMiguel, E. (2003). A comparative study of heavy metal concentration and distribution in deposited street dusts in a large and a small urban area: Birmingham and Coventry, West Midlands. *UK. Environ. Int., 29,* 563–573.

Christoforidis, A., & Stamatis, N. (2009). Heavy metal contamination in street dust and roadside soil along the major national road in Kavala's region, Greece. *Geoderma, 151,* 257–263.

CNEMC (China National Environmental Monitoring Centre). (1990). *The background values of chinese soils.* Beijing: Environmental Science Press of China.

Davydova, S. (2005). Heavy metals as toxicants in big cities. *Microchemical Journal, 79,* 133–136.

De Miguel, E., Llamas, J. F., Chacón, E., Berg, T., Larssen, S., Røyset, O., et al. (1997). Origin and patterns of distribution of trace elements in street dust: Unleaded petrol and urban lead. *Atmospheric Environment, 31,* 2733–2740.

Dehghani, S., Moore, F., Keshavarzi, B., & Hale, B. A. (2017). Health risk implications of potentially toxic metals in street dust and surface soil of Tehran Iran. *Ecotoxicology and environmental safety, 136,* 92–103.

Deletic, A., & Orr, D. W. (2005). Pollution buildup on road surfaces. *Journal of Environmental Engineering, 131,* 49–59.

Denier, X., Hill, E., Rotchell, J., & Minier, C. (2009). Estrogenic activity of cadmium, copper and zinc in the yeast estrogen screen. *Toxicology in Vitro, 23,* 569–573.

Duong, T. T. T., & Lee, B. K. (2011). Determining contamination level of heavy metals in road dust from busy traffic areas with different characteristics. *Journal of Environmental Management, 92,* 554–562.

Faiz, Y., Tufail, M., Tayye Javed, M., Chaudhry, M. M., & Naila-Siddique., (2009). Road dust pollution of Cd, Cu, Ni, Pb and Zn along Islamabad Expressway, Pakistan. *Microchemical Journal, 92,* 186–192.

Ferreira-Baptista, L., & De Miguel, E. (2005). Geochemistry and risk assessment of street dust in Luanda, Angola: a tropical urban environment. *Atmospheric Environment, 39,* 4501–4512.

Gilbert, R. O. (1987). *Statistical methods for environmental pollution monitoring* (pp. 177–185). New York: Van Nostrand Reinhold.

Gope, M., Masto, R. E., George, J., Hoque, R. R., & Balachandran, S. (2017). Bioavailability and health risk of some potentially toxic elements (Cd, Cu, Pb and Zn) in street dust of Asansol, India. *Ecotoxicology and Environmental Safety, 138*(2017), 231–241.

Hakanson, L. (1980). An ecological risk index for aquatic pollution control: a sedimentological approach. *Water Research, 14,* 975–1001.

Han, Y. M., Du, P. X., Cao, J. J., & Posmentier, E. S. (2006). Multivariate analysis of heavy metal contamination in urban dusts of Xi'an, Central China. *Science of the Total Environment, 355,* 176–186.

Hjortenkrans, D., Bergbäck, B., & Häggerud, A. (2006). New metal emission patterns in road traffic environments. *Environmental Monitoring and Assessment, 117,* 85–98.

Jiang, Y., Hu, X., Yves, U. J., Zhan, H., & Wu, Y. (2014). Status, source and health risk assessment of polycyclic aromatic hydrocarbons in street dust of an industrial city, NW China. *Ecotoxicology and Environmental Safety, 106,* 11–18.

Jiang, D., Wang, S., Lang, X., Shang, K., & Yang, D. (2001). The characteristics of stratification of lower-layer atmospheric temperature and their relations with air pollution in Lanzhou proper. *Journal-Lanzhou University Natural Sciences, 37,* 134–139. **(In Chinese)**.

Jiang, Y., Yves, U. J., Sun, H., Hu, X., Zhan, H., & Wu, Y. (2016). Distribution, compositional pattern and sources of polycyclic aromatic hydrocarbons in urban soils of an industrial city, Lanzhou China. *Ecotoxicology and Environmental Safety, 126,* 154–162.

Keshavarzi, B., Tazarvi, Z., Rajabzadeh, M. A., & Najmeddin, A. (2015). Chemical speciation, human health risk assessment and pollution level of selected heavy metals in urban street dust of Shiraz, Iran. *Atmospheric Environment, 119,* 1–10.

Kong, S. F., Lu, B., Ji, Y. Q., Zhao, X. Y., Chen, L., & Li, Z. Y. (2011). Levels, risk assessment and sources of PM10 fraction heavy metals in four types dust from a coal-based city. *Microchemical Journal, 98,* 280–290.

Li, H., Qian, X., Hu, W., Wang, Y., & Gao, H. (2013). Chemical speciation and human health risk of trace metals in urban street dusts from a metropolitan city, Nanjing, SE China. *Science of the Total Environment, 456–457,* 212–221.

Li, F., Zhang, J., Huang, J., Huang, D., Yang, J., Song, Y., et al. (2016). Heavy metals in road dust from Xiandao District, Changsha City, China: characteristics, health risk assessment, and integrated source identification. *Environmental Science and Pollution Research, 23,* 13100–13113.

Lu, X., Wang, L., Lei, K., Huang, J., & Zhai, Y. (2010). Contamination assessment of copper, lead, zinc, manganese and nickel in street dust of Baoji, NW China. *Journal of Hazardous Materials, 173,* 744–749.

Ma, Z., Chen, K., Li, Z., Bi, J., & Huang, L. (2016). Heavy metals in soils and road dusts in the mining areas of Western Suzhou, China: a preliminary identification of contaminated sites. *Journal of Soils and Sediments, 16,* 204–214.

Man, Y. B., Sun, X. L., Zhao, Y. G., Lopez, B. N., Chung, S. S., & Wu, S. C. (2010). Health risk assessment of abandoned agricultural soils based on heavy metal contents in Hong Kong, the world's most populated city. *Environment International, 36,* 570–576.

Manno, E., Varrica, D., & Dongarrà, G. (2006). Metal distribution in road dust samples collected in an urban area close to a petrochemical plant at Gela, Sicily. *Atmospheric Environment, 40,* 5929–5941.

Meza-Figueroa, D., De la O-Villanueva, M., & De la Parra, M. L. (2007). Heavy metal distribution in dust from elementary schools in Hermosillo, Sonora, Mexico. *Atmospheric Environment, 41,* 276–288.

Mohmand, J., Eqani, S. A. M. A. S., Fasola, M., Alamdar, A., Mustafa, I., Ali, N., et al. (2015). Human exposure to toxic metals via contaminated dust: bio-accumulation trends and their potential risk estimation. *Chemosphere, 132,* 142–151.

Muller, G. (1969). Index of geo-accumulation in sediments of the Rhine River. *GeoJournal, 2,* 108–118.

Pagotto, C., Rémy, N., Legret, M., & LeCloirec, P. (2001). Heavy metal pollution of road dust and roadside soil near a major rural highway. *Environmental Technology, 22,* 307–319.

Pathak, A. K., Yadav, S., Kumar, P., & Kumar, R. (2013). Source apportionment and spatial temporal variations in the metal content of surface dust collected from an industrial area adjoining Delhi. *India. Sci. Total Environ., 443,* 662–672.

Rasmussen, P. E., Subramanian, K. S., & Jessiman, B. J. (2001). Amulti-element profile of house dust in relation to exterior dust and soils in the city of Ottawa, Canada. *Science of the Total Environment, 267,* 125–140.

Sezgin, N., Ozcan, H. K., Demi, R. G., Nemlioglu, S., & Bayat, C. (2004). Determination of heavy metal concentrations in street dusts in Istanbul E-5 highway. *Environment International, 29,* 979–985.

Shi, G. T., Chen, Z. L., Bi, C. J., Wang, L., Teng, J. Y., Li, Y. S., et al. (2011). A comparative study of health risk of potentially toxic metals in urban and suburban road dust in the most populated city of China. *Atmospheric Environment, 45,* 764–771.

Shi, G., Chen, Z., Xu, S., Zhang, J., Wang, L., Bi, C., et al. (2008). Potentially toxic metal contamination of urban soils and roadside dust in Shanghai, China. *Environmental Pollution, 156,* 251–260.

Sutherland, R. A., & Tolosa, C. A. (2000). Multi-element analysis of road-deposited sediment in an urban drainage basin, Honolulu, Hawaii. *Environmental Pollution, 110,* 483–495.

Ta, W., Wang, T., Xiao, H., Zhu, X., & Xiao, Z. (2004). Gaseous and particulate air pollution in the Lanzhou Valley, China. *Science of the Total Environment, 320,* 163–176.

Tang, Z., Chai, M., Cheng, J., Jin, J., Yang, Y., Nie, Z., et al. (2017). Contamination and health risks of heavy metals in street dust from a coalmining city in eastern China. *Ecotoxicology and Environmental Safety, 138,* 83–91.

Tang, X. Y., Tian, B. S., Chen, C. H., & Reng, Z. H. (1985). A study of photochemical smog pollution and its control at

the Xigu district in Lanzhou city. *Chinese Journal of Environmental Science, 5,* 1–11. **(In Chinese)**.

Tian, Q. X., & Zhou, L. Z. (1994). Study on the effect of air pollution on resident's health in Lanzhou city. *China Environmental Science, 14,* 200–205. **(In Chinese)**.

United States Environmental Protection Agency (US EPA) (1989). Risk Assessment Guidance for Superfund, vol. I: Human Health Evaluation Manual. EPA/540/1-89/002. Office of Soild Waste and Emergency Response, http://www.epa.gov/oswer/riskassessment/ragsa/pdf/preface.pdf.

United States Environmental Protection Agency (US EPA) (1996). Soil Screening Guidance: Technical Background Document. EPA/540/R-95/128. Office of Soild Waste and Emergency Response, http://www.epa.gov/reg3hscd/risk/human/rb-concentration_table/chemicals/SSG_nonrad_technical.pdf.

United States Environmental Protection Agency (US EPA) (2000). Cadmium Compounds (A): Hazard Summary, http://www.epa.gov/ttnatw01/hlthef/cadmium.html.

United States Environmental Protection Agency (US EPA), (2001). Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites. OSWER 9355. 4-24. Office of Soild Waste and Emergency Response,http://www.epa.gov/reg3hwmd/risk/human/rb-concentration_table/chemicals/SSG_nonrad_supplemental.pdf.

Van den Berg R. (1995). Human exposure to soil contamination: a qualitative and quantitative analysis towards proposals for human toxicological intervention values. RIVM Report no. 725201011. Bilthoven, The Netherlands: National Institute of Public Health and Environmental Protection (RIVM).

Wei, X., Gao, B., Wang, P., Zhou, H., & Lu, J. (2015). Pollution characteristics and health risk assessment of heavy metals in street dusts from different functional areas in Beijing, China. *Ecotoxicology and Environmental Safety, 112,* 186–192.

Wei, B., Jiang, F., Li, X., & Mu, S. (2009). Spatial distribution and contamination assessment of heavy metals in urban road dusts from Urumqi, NW China. *Microchemical Journal, 93,* 147–152.

WHO (1988). International programmer on chemical safety, environmental health and criteria, Geneva. http://www.inchem.org/documents/ehc/ehc/ehc61.htm#SubSectionNumber:1.1.2.

Xi, X. X., Quan, J. N., Bai, Y. L., He, Z. M., Wang, S. H., & Liu, Y. H. (2000). An analysis of TSP and aerosol pollution in spring in Lanzhou city and their characteristics. *Journal-Lanzhou University Natural Sciences, 36,* 118–121. **(In Chinese)**.

Yu, B., Wang, Y., & Zhou, Q. (2014). Human health risk assessment based on toxicity characteristic leaching procedure and simple bio-accessibility extraction test of toxic metals in urban street dust of Tianjin, China. *PLoS One, 9,* e92459. doi:10.1371/journal.pone.0092459.

Zhan, H. Y., Jiang, Y. F., Yuan, J. M., Hu, X. F., Nartey, D. O., & Wang, B. L. (2014). Trace metal pollution in soil and wild plants from lead-zinc smelting areas in Huixian County, Northwest China. *Journal of Geochemical Exploration, 147,* 182–188.

Zheng, N., Liu, J. S., Wang, Q. C., & Liang, Z. Z. (2010). Health risk assessment of heavy metal exposure to street dust in the zinc smelting area, Northeast of China. *Science of the Total Environment, 408,* 726–733.