



# Contamination characteristics of heavy metals in particle size fractions from street dust from an industrial city, Central China

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## Abstract

In order to investigate the heavy metal pollution level and distribution characteristics in different particle sizes, and to evaluate the health risk, 42 street dust samples were collected in January 2015 from Huangshi, as an industrial city in Central China. The results analyzed by flame atomic absorption spectrometry (FAAS) showed that the average content of Cu, Pb, Zn, Cd, Mn, and Fe in the fine particle diameter ( $< 25 \mu\text{m}$ ) was 1041.12, 361.64, 890.00, 14.43, 3178.52, and 61841.79  $\text{mg kg}^{-1}$ , respectively. Meanwhile, the average content of Cu, Pb, Zn, Cd, Mn, and Fe in the coarse particle diameter ( $25 < D < 75 \mu\text{m}$ ) was 1628.54, 401.52, 593.16, 9.54, 5316.07, and 76765.37  $\text{mg kg}^{-1}$ , respectively. Compared with other cities, the heavy metal pollution of street dust in Huangshi was more serious. The results indicated that heavy metals were more easily enriched in fine grains street dust, except for Cu, Mn, and Fe. The heavy metal elements showed obvious spatial heterogeneity in different regions, and the interference from human sources was greater. Heavy metals in Huangshi street dust are generally at moderate or higher pollution levels (except Fe), of which Cu and Cd are the most seriously polluted. Multivariate statistical analysis shows that the heavy metals in fine-grained street dust mainly come from traffic/industrial mixed sources (74.5%) and industrial sources (25.5%); the heavy-grained street dust heavy metals mainly come from mixed traffic/industrial sources (55.1%) and soil source (44.9%). For non-carcinogenic heavy metals, mainly through the hand-mouth contact pathway into the human body, there are also no non-carcinogenic health risks in both hand-mouth ingestion and dermal contact. For carcinogenic heavy metals, Cd in street dust did not have carcinogenic risk.

**Keywords** Huangshi · Different particle size · Heavy metal · Pollution · Distribution characteristics

## Introduction

Street dust is composed of soil, deposited air-suspended particulates, building materials, and industrial and vehicle emissions and is one of the most important host media for environmental pollutants. To some extent, street dust is a more targeted indicator than urban environmental quality, rather than a single compartment for air, water, and soil monitoring, as it reflects the multimedia pollutants (Tan et al. 2018). Urban street dust distribution is extremely extensive, in the role of the driving force (such as wind, traffic, and cleaning), can again enter the atmosphere environment (Abrahams 2002). After hand-mouth ingestion, breathing inhalation, skin contact pathways accumulate in the human body, resulting in human biological performance disorders, and even irreversible damage. Through the dry and wet deposition process and the flushing of precipitation, so that the toxic and harmful substances into the water, soil environment, under the appropriate conditions to re-release, further aggravate the water body, soil pollution,

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and eventually through the food chain into the organism, seriously affecting the surrounding environment and human normal life activities (Getachew et al. 2019, Shi et al. 2016). Thus, the street dust not only brings together the regional atmospheric subsidence, human life production activities caused by particulate pollutants, but also to a certain extent caused by air pollution and water contamination. Because of the increasing level of urbanization in China in recent years, the influence of urban street dust on environment and human health is more and more obvious, and the analysis of urban pollution problems such as urban dust pollution has become one of the hot spots in domestic and foreign scholars (García-Rico et al. 2015).

Heavy metal pollution is highly toxic and difficult to degrade and easy to accumulate, which can cause irreversible effects on environment and health through the transfer of different environmental media. Heavy metals are widely distributed in urban street dust, and automobile exhaust emissions, mining, coal, and a variety of processing and manufacturing activities will cause street dust in a variety of trace elements of heavy metal content increase (Gope et al. 2017; Tchounwou et al. 2012). Metals can accumulate in adipose tissue, affecting organ function and destroying the nervous system or endocrine system. What is more, some metals can also cause biological mutations, teratogenicity, and carcinogenesis (Jaishankar et al. 2014; Lee et al. 2013).

A large number of studies have shown that heavy metals are mainly enriched at less than 75- $\mu\text{m}$  particle size levels (Ewen et al. 2009). What is more, 75  $\mu\text{m}$  is the United States EPA minimum particle size level standard (US EPA and Standards 2006). The current scholar mainly uses the sieving method to the dust. The soil sample carries on the granularity classification; the smallest particle diameter generally achieves less than 63  $\mu\text{m}$  or less than 75  $\mu\text{m}$ . This research will collect the sample sieve to divide into less than 75  $\mu\text{m}$  and less than 25  $\mu\text{m}$  two kinds of granularity level. The distribution regularity of heavy metals in the minimum particle size level of street dust is further discussed. Huangshi is a typical resource-based mining city; there are a large number of mining plants, nonferrous smelting plants, processing factories, etc., making the heavy metal pollution in its street dust is more serious. At present, there are relatively many studies on the dust around rivers, soils, and smelters in Huangshi City, and less on the overall pollution level of dust and heavy metals in different particle sizes of Huangshi City. With this background, the straightforward objectives of the present study were to (i) investigate the pollution status of heavy metals Cu, Pb, Zn, Cd, Mn, and Fe in street dust with a particle size of < 75  $\mu\text{m}$ ; (ii) analyze two particle size distribution of heavy metals and explore their possible sources; (iii) assess the health risks associated with heavy metal pollution, and the results are beneficial to local stakeholders and authorities to take effective measures related to heavy metal risks.

## Material and methods

### Study area

The current survey is conducted in a typical mining city—Huangshi City (114° 31′–115° 30′ E, 29° 30′–30° 15′ N), located in the southeastern of Hubei province, Central China, in the middle and lower reaches of the Yangtze River. As a result of long-term reliance on mining rich mineral resources to seek economic development, has entered the ranks of resource-exhausted industrial cities, while in the constant exploitation of mineral resources, making heavy metal pollution is extremely serious in Huangshi. Huangshi is one of the national irons and copper production bases; there are a large number of mining and nonferrous metal smelters. Huangshigang District is located in the center of Huangshi; traffic developed mainly in business-oriented, densely populated Xisaishan District in the east of Huangshi, mainly an industrial region. Pb, Zn, coal, and other mineral resources are quite abundant; there are a large number of machineries, relatively dense; there are many metallurgical machinery building material industries in the region. Tieshan District iron ore resources are located in the mineral collection area, with a large number of iron ore mining and industrial parks. Daye City is rich in minerals; there are a large number of mining and smelting enterprises, one of China's important raw material industrial bases. Located in the hinterland of downtown Huangshi, Xialu District is the transportation hub of Huangshi.

### Sample collection

In January 2015, a total of 42 street dust samples were collected in the Huangshi Daye area (D1–D10), Huangshigang District (H1–H9), Xisaishan District (XS1–XS9), Xialu District (XL1–XL9), and Tieshan District (T1–T5), using uniform distribution points and combined with the actual situation. Collect street dust samples at least seven consecutive days without rain, and every street dust samples were to avoid obvious sources of pollution, such as smelters, mining plants, gas stations, such as a small plastic brush cleaning the street surface part of the larger particles of dust, sampling points near the 5 m<sup>2</sup> in a number of sample points mixed, loaded into the plastic sealed bag, had been well-established, seal, and brought back to the laboratory for analysis. Each sampling point was positioned with a GPS locator, recording its detailed latitude, longitude, the time of sampling, and the characteristics of the surrounding marked properties for subsequent analysis. The sample points are shown in Fig. 1.

### Sample processing and heavy metal analysis

The collected samples were naturally air-dried, and impurities were initially removed such as stones, cigarettes, leaves, and

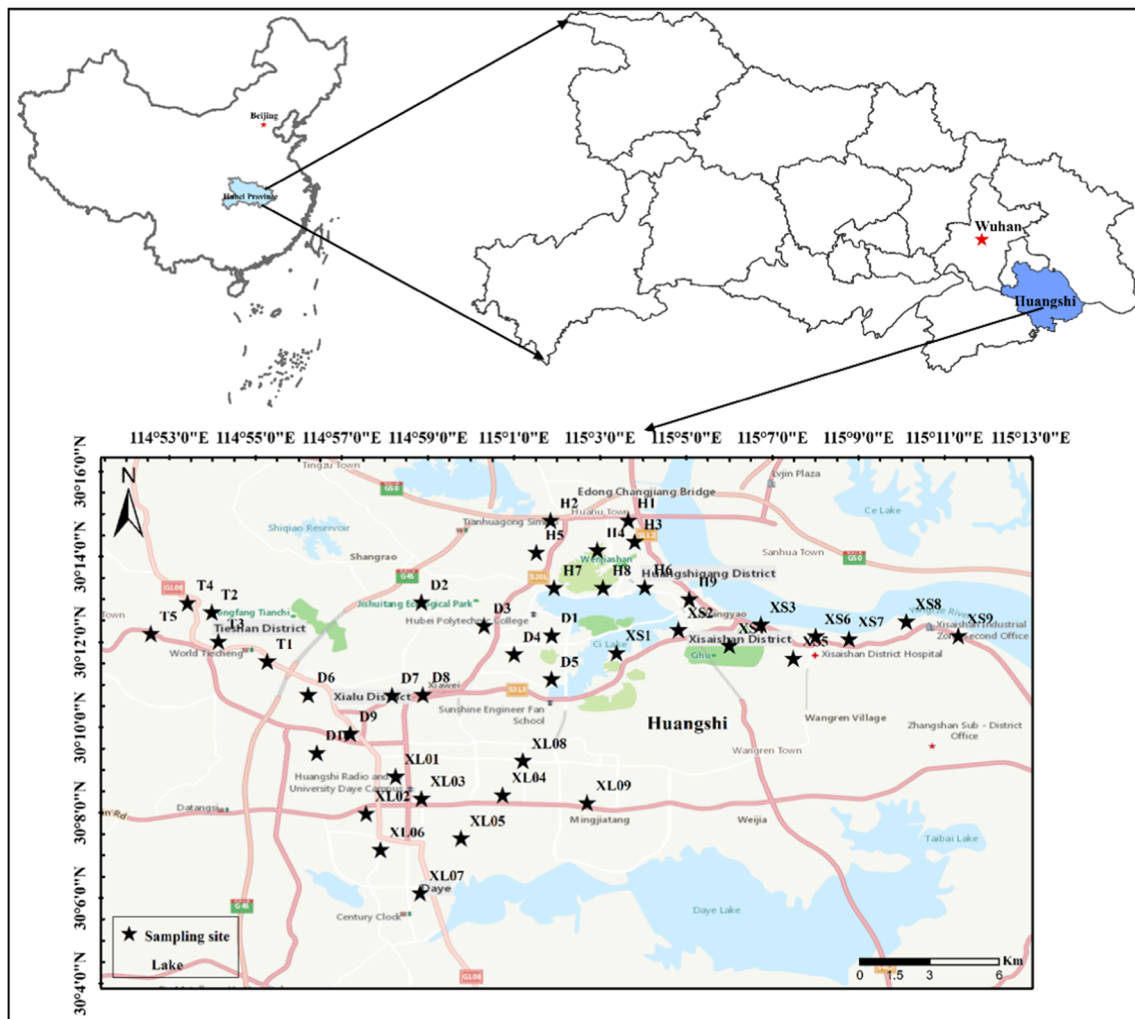


Fig. 1 Sampling sites

hair, and respectively, 200 mesh ( $< 75 \mu\text{m}$ ), 500 mesh ( $< 25 \mu\text{m}$ ), nylon mesh sieves were successively passed. Jayarathne et al. (2018) reported that particle size less than  $25 \mu\text{m}$  is defined as fine particle, and less than  $75 \mu\text{m}$  but more than  $25 \mu\text{m}$  is defined as coarse particle. The samples were digested by acid dissolving method ( $\text{HCl-HNO}_3\text{-HF-HClO}_4$ ), similar to the report of Xu et al (2018), and the total amount of Cu, Pb, Zn, Cd, Mn, and Fe of each sample was measured by Flame atomic absorption spectrometer (USA Varian AA240) after digestion.

In order to avoid contamination of the sample, the experimental process was the use of excellent grade pure drugs and non-metallic materials of the vessel, where in each vessel used before using 1 mol dilute nitric acid soaked for 24 h, and then washed with tap water, the final respectively with distilled, ultra-pure water each run three times. Use the same processing method for blank and repeated measurements to ensure QA/QC. In addition, the accuracy of analysis was evaluated by processing soil standard reference materials (GSS-3, National Research Center

for Certified Reference Materials, Beijing, China). The recovery rate of regularly recovered samples was between 86.5 and 115.2%, indicating the measured value in excellent consistency. The relative percentage difference was  $< 7\%$  for duplicate samples. Analytical accuracy is expressed as relative standard deviation (RSD) between repeated samples within 10% for all analyzed elements.

### Statistical analysis

Use SPSS 22 to analyze the correlation between each heavy metal, and screen for several principal components that can represent the majority of the change in the heavy metal content in the sample, and identify the type of source through the main factor load, linear regression, to get the contribution rate of pollution sources. Related statistical charts were finished by Origin 2017. The spatial distribution of Cu, Pb, Zn, Cd, Mn, and Fe contents in street dust were mapped by the software package ArcGIS version 10.2 for Window.

## Data processing

### Geo-accumulation index ( $I_{geo}$ )

In the study, contamination levels of all analyzed heavy metals in the dusts were characterized by geo-accumulation index ( $I_{geo}$ ); this method was proposed by German scientist Müller in 1979 (Muller 1979). It is a widely used method for evaluating the pollution of heavy metals in soil, dust, and water environment sediments at home and abroad (Adewumi and Laniyan 2020; Li et al. 2017). The calculation formula is as follows:

$$I_{geo} = \text{Log}_2(C_n/1.5B_n) \tag{1}$$

In the formula,  $I_{geo}$  is the geological accumulation index of the  $n$ th heavy metal in the soil;  $C_n$  is the measured concentration of the  $n$ th heavy metal in the environment ( $\text{mg kg}^{-1}$ );  $B_n$  is the geochemical background value, usually referring to the global shale element concentration ( $\text{mg kg}^{-1}$ ). In this study, the background concentration of soil heavy metals in Hubei Province was used as the background value for calculating the  $I_{geo}$  value. 1.5 is a constant set considering that the rock-forming movement may cause background value fluctuations. The calculated  $I_{geo}$  classification standards for each heavy metal are unpolluted ( $I_{geo} \leq 0$ ), unpolluted to moderately polluted ( $0 < I_{geo} \leq 1$ ), moderate pollution ( $1 < I_{geo} \leq 2$ ), moderately to strongly polluted ( $2 < I_{geo} \leq 3$ ), strongly polluted ( $3 < I_{geo} \leq 4$ ), strongly to extremely polluted ( $4 < I_{geo} \leq 5$ ), and extremely polluted ( $I_{geo} \geq 5$ ) (Wang et al. 2013; Yakun et al. 2016).

### Health risk assessment

The risk assessment method of human exposure was used in the health risk assessment. Street dust can be inhaled through

the hand-mouth ingestion ( $\text{ADD}_{\text{ing}}$ ), inhalation ( $\text{ADD}_{\text{inh}}$ ), and dermal contact ( $\text{ADD}_{\text{dem}}$ ) ways into the body, thereby causing harm to the human body. Among them, respiratory inhalation is the most harmful to human body, but usually through-mouth ingestion has the greatest impact on children (Al-Shidi et al. 2020; Li et al. 2017). The exposure dose is calculated as follows:

$$\text{ADD}_{\text{ing}} = C \times \frac{\text{IngR} \times \text{EF} \times \text{ED}}{\text{BW} \times \text{AT}} \times 10^{-6} \tag{2}$$

$$\text{ADD}_{\text{inh}} = C \times \frac{\text{InhR} \times \text{EF} \times \text{ED}}{\text{PEF} \times \text{BW} \times \text{AT}} \tag{3}$$

$$\text{ADD}_{\text{dem}} = C \times \frac{\text{SA} \times \text{SL} \times \text{ABS} \times \text{EF} \times \text{ED}}{\text{BW} \times \text{AT}} \times 10^{-6} \tag{4}$$

$$\text{LADD} = \frac{C \times \text{EF}}{\text{PEF} \times \text{AT}} \times \left( \frac{\text{InhR}_{\text{child}}}{\text{BW}_{\text{child}}} + \frac{\text{InhR}_{\text{adult}} \times \text{ED}_{\text{adult}}}{\text{BW}_{\text{adult}}} \right) \tag{5}$$

In this study, the amount of exposure was calculated with the confidence limit of 95% heavy metal content, and the calculation parameters are shown in Table 1.

The heavy metals of street dust have the carcinogenic and non-carcinogenic risk to human health, in which the respiratory inhalation is the only way to carcinogenic exposure of heavy metals. In this study, the metal elements Cu, Pb, Zn, Mn, and Fe only have non-carcinogenic risk; Cd have both carcinogenic and non-carcinogenic risks. Because the relevant parameters of Fe are not clear, this paper only studies the non-carcinogenic risk and carcinogenic risk of five kinds of metals (Cu, Pb, Zn, Cd, Mn). Risk quotient (HQ) and risk index (HI) indicate non-carcinogenic risk, risk (TCR) indicates carcinogenic risk, and the formula is as follows:

**Table 1** Parameter values in average daily dose of heavy metal

Parameter	Unit	Meanings	Values		Reference
			Child	Adult	
C	$\text{mg kg}^{-1}$	Heavy metals concentrations	95%UCL		This study
ED	a	Exposure duration	6	24	US EPA (2002)
BW	kg	Average body weight	15	70	(Doabi et al. 2018)
EF	$\text{da}^{-1}$	Exposure frequency	180	180	(Ferreira-Baptista and De Miguel 2005)
AT (non-carcinogens)	d	Average time	$365 \times \text{ED}$		(Wu et al. 2017)
AT (carcinogens)	d	Average time	$365 \times 70$		(Wu et al. 2017)
IngR	$\text{mg d}^{-1}$	Ingestion rate	200	100	US EPA (2011)
InhR	$\text{m}^3 \text{d}^{-1}$	Inhalation rate	7.6	20	US EPA (2002)
PEF	$\text{m}^3 \text{kg}^{-1}$	Particle emission factor	$1.36 \times 10^9$		US EPA (2002)
SL	$\text{mg cm}^{-2} \text{d}^{-1}$	Conversion factor	0.2	0.07	(Dehghani et al. 2017)
SA	$\text{cm}^2 \text{d}^{-1}$	Exposed skin area	2800	5700	US EPA (2002)
ABS	Unitless	Sermal absorption factor	0.001		US EPA (2011)

$$HQ_{mn} = \frac{ADD_{mn}}{RFD_n} \quad (6)$$

$$HI = \sum_{n=1}^5 \sum_{m=1}^3 HQ_{mn} \quad (7)$$

$$TCR = LADD_{inh} \times SF_{inh} \quad (8)$$

The SF value of the studied heavy metals and the relevant parameter meanings can be provided according to the data in the previous literature report (Keshavarzi et al. 2015). For non-carcinogenic risk, if HI (HQ) < 1, it indicates that heavy metal does not exist or its risk is not high; if HI (HQ) > 1, there is a probability of risk, and probability risk increases with the increase of HI values (Jiang et al. 2018; Qing et al. 2015). The risk of cancer, if TCR < 10<sup>-6</sup>, indicates that there is no risk, if 10<sup>-6</sup> < TCR < 10<sup>-4</sup>, indicating that the human body can withstand the risk, if the TCR > 10<sup>-4</sup>, indicating that the human body can not bear the risk (Lin et al. 2017).

## Results and discussion

### Morphological analysis

When analyzing the topographical features of some particles in street dust of different particle sizes, a total of 222 SEI images were used. Here, eight magnifications of 500 and 2000 were selected, and eight scales of 10 μm and 1 μm were introduced, as shown in Fig. 2. Scanning electron micrographs (a) and (b) show that street dust of different particle sizes in the study area is mainly irregular particles and nearly spherical particles. The irregularly occurring particles are mainly mineral particles, which may be derived from construction dust and ground dust; the particles present in the near sphere are mainly fly ash particles, which may be derived from industrial soot, such as coal-fired fly ash. The comparison of street dust scanning electron micrographs in different regions shows that the grain edges and corners of Tieshan District and Daye District are more obvious, while the particles in Huangshigang District are more round, which is consistent with the characteristics of this area. Scanning electron micrographs (c) and (d) of different particle size street dusts show that the fine particle size distribution is more uniform than the coarse particle size, and the fine particle size pores are more, indicating that the fine particle size may be more likely to adsorb pollutants in the environment.

### Heavy metal concentrations in street dust

The statistics about the heavy metal concentrations and background values of the metals in soils of Hubei Province (CNEMC 1990) are shown in Table 2. The concentrations of 6 metals varied widely and followed the order of Fe > Mn

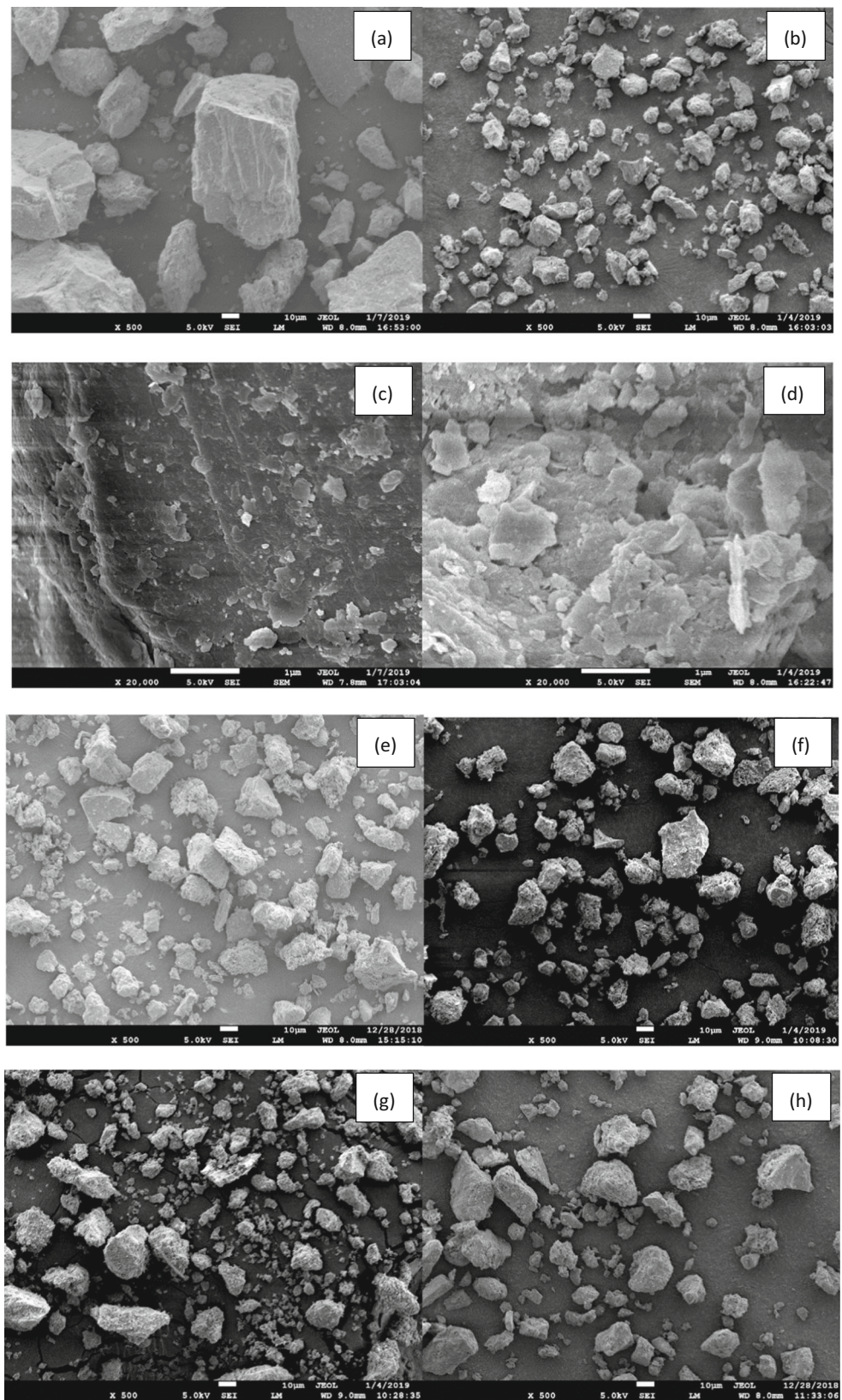
> Cu > Zn > Pb > Cd in the street dust of different particle sizes in Huangshi. The average heavy metal content of street dust in different particle sizes exceeded the background value of Hubei Province; the mean concentrations of Cu, Pb, Zn, Cd, Mn, and Fe were respectively 33.91, 13.54, 83.11, 10.39, 4.46, and 1.58 (fine particle) and 53.05, 15.04, 55.48, 7.10, 7.47, and 1.96 (course particle) times of the background value, indicating that the street dusts were polluted by these metals, especially Cu and Cd. The coefficients of variation (CVs) of Zn of fine particle and Zn and Fe of course particle in the street dust were relatively larger than 20%. Particularly, the CVs for Cu, Pb, Cd, and Mn of fine particle and Cu, Pb, Cd, and Mn of course particle in the street dust were relatively larger than 40%, which demonstrates that the effects of anthropogenic activities on the concentrations of these metals were striking, especially for Cu, Pb, Cd, and Mn in the street dust of different grain sizes in Huangshi.

At present, when studying heavy metals in dustfall at home and abroad, most of the pretreatments are over 200 mesh sieves, that is, samples with a particle size of 75 μm. Therefore, this study selects coarse-grain street dust heavy metal data to compare with other studies, as shown in Table 3. Generally speaking, the concentrations of heavy metal in both particles were higher than that of other cities in other countries. The average concentration of Cu, Cd, Mn, and Fe was much higher than Beijing, Shanghai, Shenyang, Changchun, Baoji, Guangzhou, Chengdu, Xian, Nanjing, Hong Kong, Massachusetts, Thessaloniki, Egypt, Toronto and Shiraz which have measured the corresponding heavy metal concentration. The average concentration of Pb was only lower than Baoji. The average concentration of Zn was only lower than Shanghai, Hong Kong, and Egypt. The average concentration of Cd was only lower than Shanghai.

### Spatial distribution and particle size effect of heavy metals

Figure 3 showed the spatial distribution of heavy metals in different sizes of street dust in Huangshi City. It can be seen that the content of heavy metal elements in different particle sizes showed significant changes. Among the fine particle sizes, the elements Cu, Cd, and Pb show very similar distribution characteristics, and their high concentrations are preferentially distributed in the vicinity of Tonglushan iron ore, industrial park, and main traffic trunks. The elemental Zn is highly enriched in downtown Huangshi. Significant enrichment was observed near Tonglushan Iron Mine, Daye Iron Mine, and traffic trunk road. The elemental Mn was highly enriched near Xinye Steel, followed by industrial park. The elemental Fe was near Daye Iron Mine. It is highly enriched and distributed evenly in other areas. Combined with the previous statistics, it can be seen that Fe in Huangshi City far exceeds the city with the background value and the

**Fig. 2** Scanning electron micrograph. **a, c** Coarse-grained particles in Daye District. **b, d** Fine-grained particles in Daye District. **e–h** Fine-grained particles in Tieshan District, Huangshigang District, Xisaishan District, and Xialu District



comparison of this study, which may be related to the long-term mining in Huangshi City.

In the coarse grain size, the elements Cu, Pb, and Cd exhibit a very similar spatial pattern, and the high concentration

**Table 2** Descriptive statistics and background values of heavy metal concentrations of street dust

Size	Elements	Cu	Pb	Cd	Zn	Mn	Fe
Fine particle	Mean	1041.12	361.64	14.30	869.00	3178.52	61841.79
	Median	740.19	330.16	8.16	852.21	2761.86	53797.06
	Minimum	148.69	166.12	3.23	495.77	344.09	29881.74
	Maximum	2875.82	761.46	112.93	1501.03	15014.13	141568.76
	Standard deviation	800.50	144.37	17.79	243.42	2655.66	28435.86
	95% UCL <sup>a</sup>	1290.57	406.63	19.84	944.86	4006.08	70703.03
	CV/% <sup>b</sup>	0.77	0.40	1.24	0.28	0.84	0.46
Course particle	Mean	1628.54	401.52	9.54	593.16	5316.07	76765.37
	Median	969.46	330.16	7.72	576.18	5150.97	74018.57
	Minimum	116.80	104.88	61.93	930.33	10627.71	126994.06
	Maximum	10145.64	1933.83	0.48	180.56	1793.12	25152.74
	Standard deviation	2080.36	326.56	10.12	165.61	2133.08	25578.34
	95% UCL	2276.82	503.28	12.70	644.77	5980.78	84736.14
	CV/% <sup>b</sup>	1.28	0.81	1.06	0.28	0.40	0.33
The background value <sup>c</sup>	30.70	26.70	0.17	83.60	712.00	39100.00	

<sup>a</sup> Upper limit of the 95% confidence interval for the mean

<sup>b</sup> CV is Coefficient of Variation,  $CV = (\text{Standard deviation}/\text{Mean}) \times 100\%$

<sup>c</sup> Background values for soils in Hubei Province from the China National Environmental Monitoring Center (CNEMC 1990).

is preferentially distributed in the vicinity of the Tonglushan Iron Mine, the industrial park, and the railway. The elemental Zn is preferentially enriched in the downtown area of Huangshi (Huangshigang), followed by the traffic trunk, indicating that Zn may be mainly for commercial activities and traffic activities. The elemental Mn is more obvious in the

vicinity of Xinye Steel, Tonglu Mountain, and Jinshan Industrial Park, and it is more evenly distributed in most areas, indicating that elemental manganese may be mainly derived from industrial activities. The elemental Fe is highly concentrated in most areas, especially Daye Iron Mine, Tonglushan Iron Mine, and Golden Mountain Industrial Park. These

**Table 3** The average concentrations of heavy metals in dust from different cities ( $\text{mg kg}^{-1}$ )

City	Cu	Pb	Zn	Cd	Mn	Fe	Reference
Huangshi	1628.54	401.52	593.16	9.54	5316.07	76765.4	This study
Beijing, China	83.12	60.88	280.63	0.59	553.73	2974.62	(Men et al. 2018)
Shanghai, China	186.41	212.94	687.25	0.97	—	—	(Shi et al. 2008)
Changchun, China	53.73	94.99	169.79	21.43	375.64	13300	(Li et al. 2018)
Hangzhou, China	116.04	202.16	321.4	1.59	509.56	—	(Zhang and Wang 2009)
Baoji, China	123.2	433.2	715.3	—	804.2	—	(Lu et al. 2010)
Guangzhou, China	24	58	162.6	0.28	—	—	(Li et al. 2009)
Chengdu, China	100	82.3	296	1.66	—	—	(Li et al. 2017)
Xi'an, China	94.98	230.52	421.46	—	687	—	(Yongming et al. 2006)
Nanjing, China	71.96	65.43	228.6	0.945	—	—	(Li et al. 2013)
Hong Kong, China	173	181	1450	3.77	—	—	(Li et al. 2001)
Massachusetts, American	105	73	240	—	456	—	(Apeagyei et al. 2011)
Thessaloniki, Greece	526.2	191	671	—	529.1	—	(Bourliva et al. 2016)
Egypt	102	307	1839	2.98	503	32050	(Khairy et al. 2011)
Toronto, Canada	162	182.8	232.8	0.51	1407.2	4823.4	(Nazzal et al. 2013)
Shiraz, Iran	136.34	115.71	403.46	0.5	438.5	20254.6	(Keshavarzi et al. 2015)





degree of heavy metal enrichment also has a certain relationship with the particle size of street dust. Generally, it will accumulate to fine particles. Generally speaking, the smaller the particle size, the larger the surface area, and the more pollutants that can be adsorbed, but there are differences in the particle size effects of different heavy metals. For example, scholars have found that the heavy metals Pb and Cd from Beijing Olympic Park have a higher enrichment ratio of particle size less than 38.5  $\mu$  and particle size between 38.5 and 76, while Cu and Zn are opposite (Li et al. 2015). The heavy metals Cu and Pb in the road sediments of Hamilton (New Zealand) are more concentrated at a particle size of less than 32  $\mu$  and a particle size between 32 and 63, while Zn is the opposite (Zanders 2005).

### Assessment of heavy metal pollution in street dust

Figure 4 presents the results of  $I_{geo}$  values for heavy metals analyzed in street dust of both particle sizes from Huangshi City. The average  $I_{geo}$  value of heavy metals in the street dust of both particle sizes follows  $Cd > Cu > Pb > Zn > Mn > Fe$ , and its corresponding range was 4.23–9.36, 2.28–6.55, 2.64–4.83, 2.57–4.17, –1.05–4.40, –0.39–1.86 (fine particle) and 1.48–8.49, 1.93–8.37, 1.97–6.18, 1.11–3.48, 1.33–3.90, –0.64–1.70 (coarse particle), respectively. These results of these orders of magnitude are basically opposite to the aforementioned range of metal concentrations in street dust.

For fine particle, the mean  $I_{geo}$  and 43%  $I_{geo}$  of Cu falling into class 6 reveal strongly to extremely polluted; 33%  $I_{geo}$  of Cu falling into class 7 indicates extremely polluted; about 24%  $I_{geo}$  values of Cu were between 4 and 5 showing strong to extremely polluted. The mean  $I_{geo}$ , 67%  $I_{geo}$  of Pb, and 71%  $I_{geo}$  of Zn falling into class 5 indicate strongly polluted; 24%  $I_{geo}$  of Pb and 9%  $I_{geo}$  of Zn falling into class 4 show moderately to strongly polluted; 24%  $I_{geo}$  of Pb and 5%  $I_{geo}$  of Zn falling into class 6 show strongly to extremely polluted. The mean  $I_{geo}$  and 79%  $I_{geo}$  of Cd falling into class 7 indicate extremely polluted; 21%  $I_{geo}$  falling into class 6 shows strongly to extremely polluted. For Mn, percentage  $I_{geo}$  averagely

falling into class 1–5 indicates unpolluted to unpolluted to strongly polluted. The mean  $I_{geo}$  and 40%  $I_{geo}$  of Mn falling into class 4 indicate moderately to strongly polluted. For Fe, percentage  $I_{geo}$  averagely falling into class 1–3 indicates unpolluted to moderate pollution. The mean  $I_{geo}$  and 67%  $I_{geo}$  of Fe falling into class 2 indicate moderately to unpolluted to moderately polluted.

For coarse particle, the mean  $I_{geo}$  and 29%  $I_{geo}$  of Cu falling into class 6 reveal strongly to extremely polluted; 50%  $I_{geo}$  of Cu falling into class 7 indicates extremely polluted, about 21%  $I_{geo}$  values of Cu were between 3 and 5 showing moderate to extremely polluted. For Pb and Cd, percentage  $I_{geo}$  averagely falling into class 3–7 indicates moderate to strongly to extremely polluted. The mean  $I_{geo}$  and 48%  $I_{geo}$  of Pb falling into class 5 indicate moderately to strongly polluted. The mean  $I_{geo}$  and 62%  $I_{geo}$  of Cd falling into class 7 indicate extremely polluted. For Zn and Mn, percentage  $I_{geo}$  averagely falling into class 3–5 indicates moderate to strongly polluted. The mean  $I_{geo}$ , 67%  $I_{geo}$  of Pb, and 45%  $I_{geo}$  of Mn falling into class 4 indicate moderately to strongly polluted. For Fe, percentage  $I_{geo}$  averagely falling into class 1–3 indicates unpolluted to moderate pollution. The mean  $I_{geo}$  and 52%  $I_{geo}$  of Fe falling into class 2 indicate moderately to unpolluted to moderately polluted.

### Sources identification of heavy metal

The correlation between heavy metal elements can effectively reflect the similarity of the sources and speculate on their source. At the same time, in order to make up for the single correlation analysis which is not enough to clarify the shortcomings of heavy metal pollution sources, this study also uses principal component analysis for further analysis. Before the principal component analysis of heavy metals in street dust, the measured data were tested by Kaiser-Meyer-Olkin (KMO) measure and Barlett's test of sphericity, and the correlation between heavy metal pollutants was found to be strong, and the correlation of Bartlett sphericity test was accompanied. Both are 0.00, less than the significance probability of 0.01,

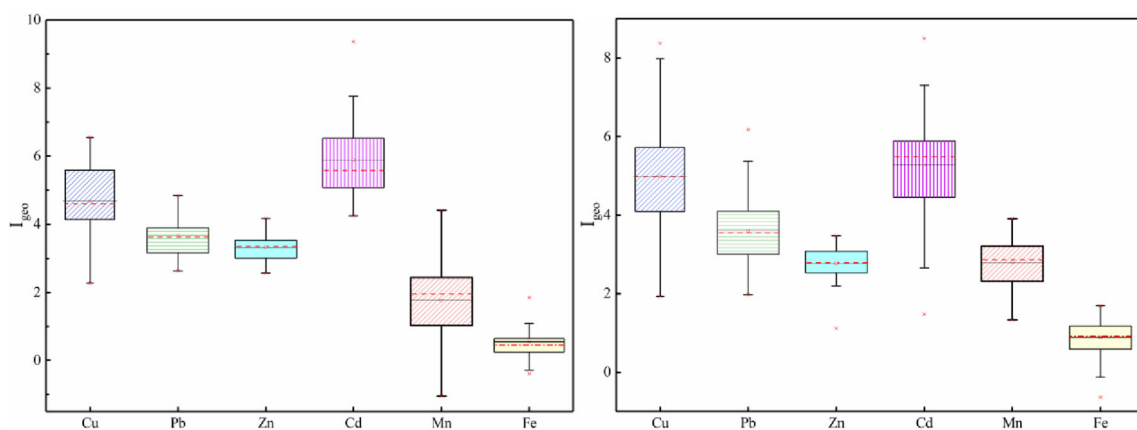


Fig. 4 Heavy metal  $I_{geo}$  of fine and coarse particle size in street dust

and the KMO measure coefficients of heavy metals in the coarse and fine particle sizes are 0.546 and 0.592, respectively, both of which are greater than 0.5, indicating that the measured data can be subjected to principal component analysis. In this study, based on the limit value of eigenvalue greater than 1, the principal component matrix was rotated by the standardized maximum variance method for dust heavy metals of different particle sizes in Huangshi City. Table 4 shows the results of correlation analysis and principal component analysis. Significant correlations were found in this study between Cu and Pb, Cu and Cd, Cu and Zn, Pb and Cd, Pb and Zn, Cd and Zn in fine-grain street dust heavy metals, indicating that Cu, Pb, Cd, Zn have homology. Significant correlations were found between Pb and Zn, Fe and Zn, Cd and Zn, Fe and Mn in coarse-grain street dust heavy metals, indicating Zn, Pb, Cd have homology, Fe and Mn have homology.

It can be seen from Table 4 that the principal component analysis obtained a total of two principal components, and the fine particle size street dust can explain the variability of 64.120% of the data. The main component F1 represents 42.165% of the total variation, which mainly dominates the sources of Cu, Pb, Cd, and Zn. The study found that Cu pollution originated from traffic sources, including motor exhaust and tires, engines and other mechanical wear, on the one hand released in industrial activities, including metal processing, smelting, building materials, and mineral mining. Pb is mainly from automobile exhaust emissions, smelting, coal burning, and other industrial boiler emissions. Zn on the one hand is affected by industrial production activities, on the other hand from the combustion of vehicle gasoline and the dust generated when the car tire wears. Cd is a characteristic element of

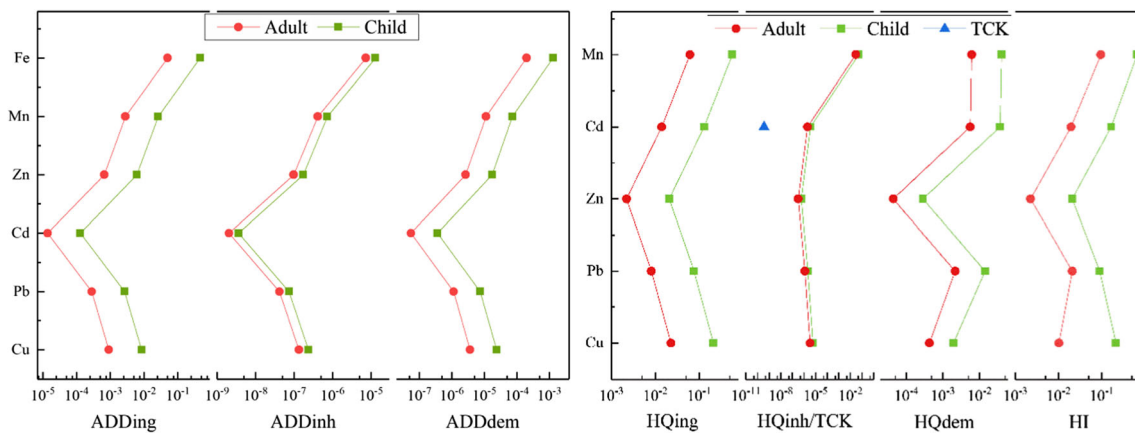
road dust, and widely exists on the surface of protective alloys and building materials, and is also used in electroplating, batteries, plastics, and fertilizers. The contents of heavy metal elements Cu, Pb, Cd, and Zn are higher than those of other cities, and the degree of enrichment is high. Combined with the characteristics of Huangshi City as a typical working city, it shows that Cu, Pb, Cd, and Zn are seriously polluted in this area. The elements Cu, Pb, Zn, and Cd have excellent correlation, and their concentration far exceeds the soil background value of Hubei Province, so the first principal component is classified into traffic/industrial mixed sources. The main component F2 represents 21.955% of the total variation, which mainly dominates the source of Mn. The previous statistical analysis shows that manganese far exceeds the soil background value, and the coefficient of variation is large, mainly from human activities. Combined with the spatial distribution characteristics, manganese is mainly distributed in industrial areas, so the second principal component is classified as industrial source. In the coarse-grained street dust, the variability of 58.397% of the data can be explained. The main component F1 represents 35.667% of the total variation, which mainly dominates the sources of Pb and Zn. The same reason can be analyzed. Pb and Zn mainly come from traffic sources and industrial sources. The principal component F2 represents 22.730% of the total variation, mainly Mn and Fe. Mn and Fe are crustal elements, and Fe is at a light pollution level, so F2 is classified as a soil source.

In order to further quantitatively analyze the main pollution sources and their relative contribution to the total heavy metal concentration, multiple standardized linear regression analysis was performed with the standardized main factor score as the

**Table 4** Matrix of correlation and principal component analysis for metal concentrations

Size	Elements	PC1	PC2	Cu	Pb	Cd	Zn	Mn	Fe
Fine particle	Cu	<b>0.792</b>	- 0.351	1	0.503**	0.430**	0.554**	- 0.136	0.190
	Pb	<b>0.861</b>	0.295		1	0.512**	0.655**	0.383*	0.029
	Cd	<b>0.861</b>	0.195			1	0.324*	- 0.098	- 0.054
	Zn	<b>0.683</b>	- 0.169				1	0.206	- 0.035
	Mn	0.149	<b>0.858</b>					1	- 0.135
	Fe	0.094	- 0.558						1.000
	Cumulative percent (%)	42.165	21.955						
Course particle	Cu	0.400	0.340	1	0.086	0.245	0.301	0.149	0.164
	Pb	0.774	- 0.283		1	0.167	0.492**	- 0.161	0.009
	Cd	0.801	0.398			1	0.370*	0.038	0.072
	Zn	0.591	0.078				1	0.207	0.495**
	Mn	- 0.141	0.835					1	0.367*
	Fe	0.275	0.775						1
	Cumulative percent (%)	35.667	22.730						

For this study, by bold are marked values indicated that the factor loadings of PCn above 0.50 were considered for explanation \*\*Correlation is significant at P< 0.01 (two-tailed) \*Correlation is significant at P< 0.05 (two-tailed)



**Fig. 5** Exposure doses, carcinogenic and non-carcinogenic risk of heavy metal

independent variable and the standardized total water-soluble ion concentration as the dependent variable to obtain fine particle size and coarse particle size, respectively. The regression equation of the street dust is:  $y = -443.56 + 0.870PC1 + 0.298PC2$  ( $R^2 = 0.971$ ),  $y = -12750.58 + 0.472PC1 + 0.384PC2$  ( $R^2 = 0.665$ ), indicating that heavy metals in fine-grained street dust in Huangshi City. The main sources of pollution are traffic/industrial mixed sources (74.5%) and industrial sources (25.5%), and the main sources of heavy metal pollution in coarse-grained and medium-sized street dust are traffic/industrial mixed sources (55.1%) and soil sources (44.9%).

### Human health risk assessment

Fine particle size of dust more easily under the external force again raised through the respiratory system, skin, and other ways into the body; the health of the human body caused greater potential harm (Fang et al. 2010). Therefore, it was more convincing and credible to evaluate the human health risk of heavy metal exposure on the 500 mesh (25  $\mu\text{m}$ ) dust particle size level. It is shown in Fig. 5 the 6 kinds of heavy metals exposure, carcinogenic risk, and non-carcinogenic risk in Huangshi street dust. The study showed that the rank for exposure risk among the three different pathways was for all element ingestion > dermal > inhalation, while the exposure risk for inhalation of dust can be considered as negligible. Accordingly, hand-mouth ingestion was the main route of exposure to metals in street dust and can pose the highest level of risk to human health. This result is also consistent with other earlier studies (Li et al. 2016; Safiur Rahman et al. 2019; Tang et al. 2017). So, frequent hand washing may be a simple but effective way to reduce the health risk of heavy metal for human in this area. Among the metals analyzed, Fe has the highest exposure risk to children and adults, followed by Mn, Cu, Zn, Pb, and Cd; Mn has the highest non-cancer health risks for children and adults, followed by Cu, Cd, Pb, and Zn, which may be related to the fact that Fe and Mn are important materials for the formation of parent materials and

the exploitation of local copper and iron resources. In different exposure pathways, children have a much higher risk of non-carcinogenic exposure than adults, which may be due to their low tolerance and unconscious exposure to the streets while eating food or playing near roads (Acosta et al. 2009).

For non-carcinogenic risks, the non-carcinogenic risk quotient (HQ) and risk index (HI) of all heavy metal elements in this study were less than 1, indicating that these elements have no non-cancer risk for children and adults. However, it is worth noting that the total non-carcinogenic HQ of the five heavy metals entering the child through hand-mouth intake, inhalation, and skin contact are 1.01,  $5.12 \times 10^{-2}$ , and  $9.32 \times 10^{-2}$ , respectively. The carcinogenic HQ is  $1.08 \times 10^{-1}$ ,  $2.90 \times 10^{-2}$ , and  $1.44 \times 10^{-2}$ , and the total non-carcinogenic HI for children and adults is 1.16 and  $1.52 \times 10^{-1}$ , which means that the comprehensive non-carcinogenic risk of various metals is obviously higher than single metal; and in this study, the combined non-carcinogenic risk of single elements Mn, Cu, Cd, and five heavy metals is close to this risk level, indicating that the government needs to pay attention to and control the non-carcinogenic risk of heavy metal elements in this area. In view of the health risks of heavy metals in this study, of considerable concern, should be Mn and somewhat Cu and Cd. The results of this study reflect that exposure to toxic metals on the streets does not have a serious health impact on Huangshi. In fact, the calculated risk of exposure to street dust by non-carcinogenic and carcinogenic heavy metals is highly uncertain (Wei et al. 2015). So far, no model has been developed for health risk assessment for China's actual situation.

### Conclusions

This study provides basic information concerning the concentrations of heavy metal in street dust from a typical industrial city in Central China, and providing an information record of the regional anthropogenic impacts.

Heavy metal concentrations in the dust from Huangshi City showed high variability, which indicated that the emissions source was heterogeneity. The spatial distribution of heavy metals was clearly influenced by local industrial and transportation activities. Multivariate statistics and spatial distribution analysis indicated that heavy metal elements in different particle sizes were mainly derived from industrial and transportation sources. The metal elements in street dust of different particle sizes showed obvious accumulation and distribution characteristics. Cu, Mn and Fe were the higher in enrichment in the larger particle size, while the opposite of Pb, Zn and Cd. In addition, health risks indicate that non-carcinogenic heavy metals enter the human body mainly through hand-to-mouth contact, and there is no non-carcinogenic health risk in hand intake and skin contact. Cd in street dust of different particle sizes has no carcinogenic risk. In general, the heavy metal concentration in the streets of Huangshi City was higher than the soil background value of Hubei Province and some large cities. With the exception of Fe, all other metals are above moderate pollution levels, and the potential health risks in the future cannot be ignored.

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