Ecological and health risk assessment of metal in resuspended particles of urban street dust from an industrial city in China

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Concentrations and ecological and health risks of metals in the resuspended particles of urban street dust collected from an industrial city, Baotou, China were studied. The results show that the average concentrations of Ba, Co, Cr, Cu, Mn, Ni, Pb, V and Zn in the studied samples are 990.1, 56.2, 247.8, 31.5, 566.3, 26.1, 59.9, 82.2 and 77.5 mg kg^{-1} respectively, which are higher than the background values of Inner Mongolia soil, especially Co, Cr and Pb. The results of potential ecological risk analysis demonstrate that Ba, Mn, V, Zn and Ni in the samples are in low ecological risk levels whereas Cr, Cu and Pb are in low to moderate ecological risk levels. Co reveals moderate to considerable ecological risk. The aggregate ecological risk of metals in the resuspended particles of street dust from Baotou is in the moderate level. Human health risk assessment shows that ingestion is the main exposure pathway of metals in dust to the local habitants. The upper limit of the 95% confidence interval of hazard indices for non-cancer risks of all analysed metals in the resuspended particles of street dust is within the safe level, while the maximum hazard index of Cr for children exceeds the safe level. Thus, the health risk of Cr for children due to dust exposure is a matter of concern. The cancer risk of Co, Cr and Ni to local habitants, considering only inhalation, is within the currently acceptable range.

Keywords: Environmental health, metal contamination, risk assessment, street dust.

STREET dust, an important environmental medium in urban areas, is referred to as solid particles that accumulate on urban street[1,2]. It often contains elevated metal concentrations due to the effects of human activities, such as traffic (vehicle exhaust, tire wear, brake lining wear), industrial activities (coal combustion, metallurgy, auto repair shops, chemical engineering, etc.), and road construction (asphalt, concrete and road paint)[3–6]. Metals in dust can enter the human body through inhalation, ingestion and dermal contact[1,7–10], and accumulate in adipose tissue or deposit in the circulatory system, causing respiratory and cardiovascular diseases and even mortality[11–13], affecting the normal function of organs and undermining the nervous system or the endocrine system[14,15]. Therefore, numerous studies on metals in street dust have been conducted on concentration, distribution, contamination assessment, source identification and health risk for humans during the past decades[2,4,8,9,15–25]. However, most of these mainly focused on metals in street dust bulk sample. Information about metal contamination and risk level in smaller than 100 μm street dust particles is limited, especially in developing countries, including China.

The amount of dust particles inhaled, ingested and through dermal contact by humans is usually dependent on the grain size of the particles[26]. The particles with diameters below 100 μm in street dust are inclined to be suspended in the air and move in the wind stream[27]; these are also called resuspended particles. The available studies on different grain sizes of street dust illustrated that there is an enrichment of metals in the resuspended particles[28,29] due to their smaller size and greater surface area[30]. The resuspended particles in street dust possess greater environmental impacts and health risks than coarse particles[31]. Hence, contamination and environmental risk of metals in resuspended particles of street dust should be studied in greater detail.

The urban environments of developing countries like China are experiencing unprecedented challenges due to population explosion, urbanization and industrialization. Baotou is the biggest industrial city of Inner Mongolia autonomous region in the northwest of China. Rapid growth of urban population and industrial activities in Baotou have put pressure on the urban environment. To our knowledge, literature about metal contamination in resuspended particles of street dust from Baotou is unavailable. The main objectives of this study are to determine the concentrations of metals in resuspended particles of street dust from Baotou and assess their potential ecological risk and health risk.

Materials and methods

Background of the study area

Baotou, the biggest city in Inner Mongolia autonomous region with an urban area of 1051 km^2 and a population

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of 1,722,800 is located in the Tumochuan and Hetao Plain, with Yellow River to the south and Mongolia to the north. Three districts, Qingshan, Kundulun and Donghe, are included in the study area. Baotou has a semi-arid, temperate, continental monsoon climate with an annual average temperature of 6.5°C, annual average precipitation of 240–400 mm and evaporation of 1940–2340 mm. The soil type is mainly chestnut soil. The prevailing wind direction is northwest. Dust storms frequently occur in this area from March to May every year due to the frequent exchange of warm and cold air. The average wind speed is 3 m s^{-1} and the average number of days per year with strong wind, floating dust and the dust storm is about 46, 25.9 and 43.3 respectively[32]. Baotou has abundant iron, rare earth, niobium, titanium, manganese, gold, copper and other mineral resources. It is an important industrial base and rare earth industrial centre of China. The main industries include rare earth industry, iron and steel manufacturing, metallurgy and machinery manufacturing.

Sampling and analytical methods

A total of 116 street dust samples were collected from Qingshan ($n = 45$), Kundulun ($n = 45$) and Donghe ($n = 26$) districts of Baotou city (Figure 1). At each sampling site, dust sample was collected from five to eight points of the road or pavement edges by sweeping with a plastic brush and a clean tray, and then mixed thoroughly to obtain a dust composite sample of ~500 g. The actual latitude and longitude coordinates of each sampling site were recorded by global positioning system (GPS). All dust samples were collected in this manner during the dry season in October 2012 and sealed in polyethylene bags. The dust samples were air-dried naturally under the conditions of ventilation, dark and room temperature in the laboratory for at least two weeks. Then ~100 g of each dried dust sample was separated using the quartering method and sieved through a 100 μm nylon mesh. The fractions below 100 μm particles (resuspended particles) in street dust were collected. For measuring metal concentration, these fractions were ground with a vibration mill and sieved through a 75 μm nylon mesh. All handling was carried out without contact with metals, to prevent cross-contamination.

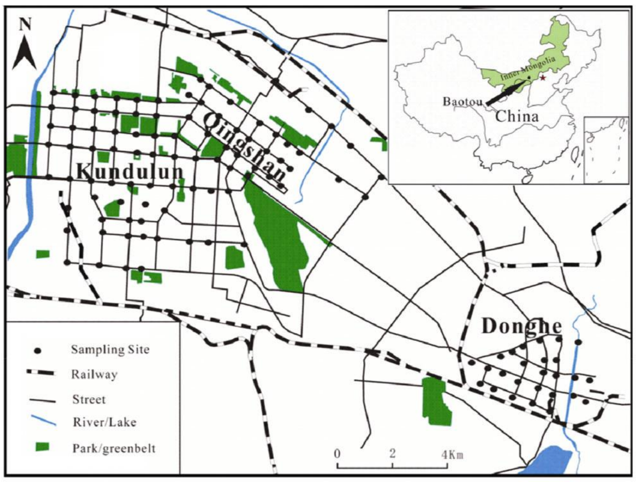

Figure 1. The study area and sampling sites.

To measure metal concentration, 4.0 g of milled dust samples and 2.0 g of boric acid were weighed, placed in the mould, and pressed into a 32 mm diameter pellet under 30 t pressure[22]. The concentrations of Ba, Co, Cr, Cu, Mn, Ni, Pb, V and Zn in the resuspended particles of street dust were measured by wavelength dispersive X-ray fluorescence spectrometry (XRF, PANalytical PW2403)[22]. Standard samples (GSD12, GSS10) and 15% repeat samples were used for quality control in the experiment. The precision, calculated from the relative standard deviation of duplicate samples, was routinely 3–5%. The analysed accuracy, calculated from the relative error of standard reference materials, was less than 5%.

Potential ecological risk assessment

Potential ecological risk index (RI), proposed by Håkanson[33], was introduced to assess the potential ecological risk levels of metals in the resuspended particles of street dust from Baotou. RI is defined as

$$\mathrm{RI} = \sum_{i=1}^{\mathrm{n}} E_i = \sum_{i=1}^{n} T_i C_{\mathrm{f}}^i = \sum_{i=1}^{n} T_i \frac{C_{\mathrm{s}}^i}{C_{\mathrm{b}}^i}, \tag{1}$$

where E_i is the potential ecological risk factor of metal i; T_i the toxic response factor of metal i, i.e. Co = Cu = Ni = Pb = 5, V = Cr = 2 and Zn = Ba = Mn = 1 (refs 33–35); C_{f}^i the pollution factor of metal i; C_{s}^i the concentration of metal i in the analysed sample and C_{b}^i the background value of metal i. In the present study, C_{b}^i is the background value of Inner Mongolia soil[36]. RI represents the sensitivity of the biological community to the toxic metals and illustrates the potential ecological risk caused by the overall contamination. Since the number of pollutants considered in this study is different from that of Håkanson[33], adjustment of the factor standards was made as shown in Table 1 (refs 37–39).

Health risk assessment model

The model used in this study to calculate the exposure of humans to metals in street dust is based on those developed by the Environmental Protection Agency of the United States (USEPA)[40]. The following assumptions underlie the model applied in Baotou: (1) Human beings are exposed to street dust via three primary pathways:

ingestion of dust particles (D_{ing}), inhalation of resuspended particles from dust through the mouth and nose (D_{inh}) and dermal absorption of metals in particles adhered to exposed skin (D_{dermal}). (2) Intake rates and particle emission factors can be approximated by those developed for the soil. (3) Relevant exposure parameters of children and adults in the observed areas are similar to those of reference populations. (4) The total non-carcinogenic risk for each metal (Cu, Pb, Zn, Co, Cr, Mn, Ni, V and Ba) and the overall carcinogenic risk for Co, Cr and Ni can be calculated by summing the individual risks obtained from the three exposure pathways[1,41].

Exposure is expressed in terms of daily dose and calculated separately for each metal and for each exposure pathway. The exposure dose contacted through each of the three paths is calculated as follows[40,42].

Dose contacted through ingestion of street dust particles (mg kg^{-1} day^{-1})

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

Dose contacted through inhalation of street dust particles (mg kg^{-1} day^{-1})

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

Dose absorbed through dermal contact with street dust particles (mg kg^{-1} day^{-1})

$$D_{\text{dermal}} = C \times \frac{\text{SA} \times \text{SL} \times \text{ABS} \times \text{EF} \times \text{ED}}{\text{BW} \times \text{AT}} \times 10^{-6}. \tag{4}$$

The lifetime average daily dose (LADD; mg kg^{-1} day^{-1}) for Co, Cr, and Ni inhalation exposure route is used for cancer risk assessment as

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

where C is the exposure-point concentration (mg kg^{-1}) of the metal. In the present study, the minimum, maximum and the upper limit of the 95% confidence interval for the mean (95% UCL)[1,8,9] were used. In this study IngR, ingestion rate, is 200 mg day^{-1} for children and 100 mg day^{-1} for adults[43]. InhR, inhalation rate, is 7.6 m^3 day^{-1} for children and 20 m^3 day^{-1} for adults[44]. EF, exposure frequency, is 180 days year^{-1} (refs 1, 8). ED, exposure duration, is 6 years for children and 24 years for adults[43]. SA, exposed skin area, is 2800 cm^2 for children and 5700 cm^2 for adults[43]. SL, skin adherence factor, is 0.2 mg cm^{-2} day^{-1} for children and 0.07 mg cm^{-2} day^{-1} for adults[8,43]. ABS, dermal absorption factor (unitless), is 0.001 for all metals[1,45]. PEF, particle emission factor[43] is 1.36×10^9 m^3 kg^{-1} (ref. 43). BW, average body weight (kg) is 16.2 kg for children and 61.8 kg for adults[46]. AT, averaging time, ED × 365 days for non-carcinogens and 72 × 365 = 26,280 days for carcinogens[46].

Hazard indexes (HIs) for both carcinogenic and non-carcinogenic effects were applied to each exposure pathway in the analysis. The doses calculated for each metal and exposure pathway were subsequently divided by the corresponding reference dose (RfD; mg kg^{-1} day^{-1}) to yield a hazard quotient (HQ) (or non-cancer risk), whereas for carcinogens the dose was multiplied by the corresponding slope factor (SF; $(\text{mg kg}^{-1}\ \text{day}^{-1})^{-1}$) to produce a level of cancer risk. The hazard index (HI) is then the sum of HQ[1,8,9,47]. If HI < 1, there is no significant risk of non-carcinogenic effects. If HI > 1, there is a chance that non-carcinogenic effects may occur, with a probability which tends to increase as HI increases[43]. Carcinogenic risk is the probability of an individual developing any type of cancer from lifetime exposure to carcinogenic hazards. The acceptable or tolerable risk for regulatory purposes is in the range 10^{-6}–10^{-4} (ref. 1). These values indicate that one additional case in a population of 1,000,000 to one in 10,000 people is acceptable[47]. In this study, hazard index and cancer risk methods were used to assess health risks of metal exposure to resuspended particles in street dust of Baotou. The RfD and SF values[1] of all metals analysed in this study are presented in Table 2.

Results and discussion

Heavy metal concentration

The concentrations of Ba, Co, Cr, Cu, Mn, Ni, Pb, V and Zn in the resuspended particles of street dust collected from Baotou, China are shown as a box-plot in Figure 2. These range from 501.7 to 2480.8, 28.4 to 208.4, 120.6 to 1192.4, 17.6 to 86.3, 381.7 to 938.7, 17.0 to 279.4, 26.2 to 150.1, 62.9 to 106.5, and 21.7 to 106.5 mg kg^{-1}, with an average of 990.1, 56.2, 247.8, 31.5, 566.3, 26.1, 59.9, 82.2 and 77.5 mg kg^{-1} respectively. The mean concentrations of Ba, Co, Cr, Cu, Mn, Ni, Pb, V and Zn in the studied

Table 1. Grade of ecological risk

E_i	Ecological risk grade	RI	Ecological risk grade
$E_i < 15$	Low	RI < 50	Low
$15 \le E_i < 30$	Moderate	50 ≤ RI < 100	Moderate
$30 \le E_i < 60$	Considerable	100 ≤ RI < 200	Considerable
$60 \le E_i < 120$	High	RI ≥ 200	High
$E_i \ge 120$	Very high		

E_i, The ecological risk factor of metal i; RI, the ecological risk index.

Table 2. Reference dose and slope factor of metals in the present study

Element	Ba	Co	Cr	Cu	Mn	Ni	Pb	V	Zn
RfD_{ing}	7.00E-02	2.00E-02	3.00E-03	4.00E-02	4.60E-02	2.00E-02	3.50E-03	7.00E-03	3.00E-01
RfD_{inh}	1.43E-04	5.71E-06	2.86E-05	4.02E-02	1.43E-05	2.06E-02	3.52E-03	7.00E-03	3.00E-01
RfD_{dermal}	4.90E-03	1.60E-02	6.00E-05	1.20E-02	1.84E-03	5.40E-03	5.25E-04	7.00E-05	6.00E-02
SF		9.80E+00	4.20E+01			8.40E-01			

RfD, Reference dose; SF, Slope factor.

Table 3. Comparison of metal concentration in resuspended particles of street dusts from Baotou and other cities ($mg\ kg^{-1}$)

City	Ba	Co	Cr	Cu	Mn	Ni	Pb	V	Zn	Reference
Luanda	131.3	2.9	25.65	41.78	258	10	351.3	20	316.6	1
Madrid		3	61	188	362	44	1927	17	476	48
Olso	526	19		123	833	41	180		412	48
Huludao				264.4			533.2		5271	8
Xi'an			52.61	36.29			76.92		159.52	29
Baotou	990.1	56.2	247.8	31.5	566.3	26.1	59.9	82.2	77.5	Present study

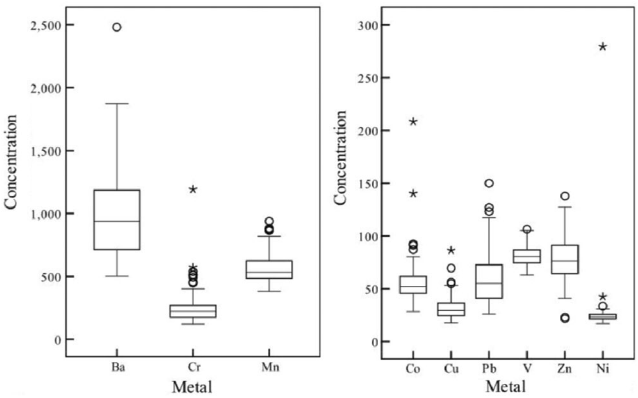

Figure 2. Concentration of metals in resuspended particles of street dust from Baotou.

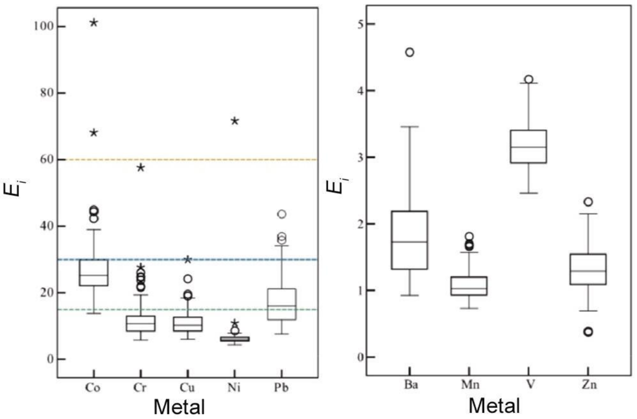

Figure 3. E_i values of metals in resuspended particles of street dust from Baotou.

samples are 1.8, 5.5, 6.0, 2.2, 1.1, 1.3, 3.5, 1.6 and 1.3 times the background values of Inner Mongolia soil respectively[36]. Larger coefficients of variation (CV = SD/mean × 100) are found for Ba, Co, Cr, Cu, Ni, Pb and Zn than for V and Mn in the samples, indicating that the variation of Ba, Co, Cr, Cu, Ni, Pb and Zn concentrations in the resuspended particles of street dust samples is relatively large.

Table 3 shows a comparison of metal concentration in the resuspended particles of street dusts from Baotou with some other cities reported in the literature[1,8,29,48]. The mean concentrations of Ba, Co, Cr and V in the resuspended particles of street dust from Baotou are higher than those for other cities, while the mean concentrations of Pb and Zn in the studied samples are lower compared to other cities. The mean concentrations of Cu, Mn and Ni in the studied samples of Baotou are in between those for other cities. The metal concentration level in the resuspended particles of street dust was affected by the local natural environment and human activities, such as topography, climate, industrial production, vehicle exhaust, waste disposal, fossil-fuel combustion, as well as population size and developing stage of the city[14,49]. Consequently, the diversity in the concentration of metals in the resuspended particles of street dust may be related to their sources and the intensity and way of human activities.

Potential ecological risk assessment results

Figure 3 shows that the potential ecological risk factor (E_i) of Ba, Co, Cr, Cu, Mn, Ni, Pb, V and Zn in the resuspended particles of street dust from Baotou ranges from 0.9 to 4.6, 13.8 to 101.2, 5.8 to 57.6, 6.1 to 29.9, 0.7 to 1.8, 4.4 to 71.6, 7.6 to 43.6, 2.5 to 4.2 and 0.4 to 2.3, with an average of 1.8, 27.3, 12.0, 10.9, 1.1, 6.7, 17.4, 3.2 and 1.3 respectively. The E_i values of Ba, Mn, V and Zn in all samples, and Ni in 99% samples are less than 15,

Table 4. Daily exposure dose (D) of metals in resuspended particles of street dust to children and adults through three routes (mg kg^{-1} day^{-1})

Metal		Ba	Co	Cr	Cu	Mn	Ni	Pb	V	Zn
Children										
D_{ing}	Minimum	3.05E-03	1.73E-04	7.34E-04	1.07E-04	2.32E-03	1.04E-04	1.60E-04	3.83E-04	1.32E-04
	Maximum	1.51E-02	1.27E-03	7.26E-03	5.25E-04	5.72E-03	1.70E-03	9.14E-04	6.48E-04	8.39E-04
	95%UCL	6.40E-03	3.65E-04	1.65E-03	2.04E-04	3.58E-03	1.86E-04	3.92E-04	5.11E-04	4.94E-04
D_{inh}	Minimum	8.53E-08	4.83E-09	2.05E-08	2.99E-09	6.49E-08	2.89E-09	4.46E-09	1.07E-08	3.69E-09
	Maximum	4.22E-07	3.55E-08	2.03E-07	1.47E-08	1.60E-07	4.75E-08	2.55E-08	1.81E-08	2.34E-08
	95%UCL	1.79E-07	1.02E-08	4.61E-08	5.69E-09	1.00E-07	5.19E-09	1.10E-08	1.43E-08	1.38E-08
D_{dermal}	Minimum	8.55E-06	4.84E-07	2.06E-06	3.00E-07	6.51E-06	2.90E-07	4.47E-07	1.07E-06	3.70E-07
	Maximum	4.23E-05	3.55E-06	2.03E-05	1.47E-06	1.60E-05	4.76E-06	2.56E-06	1.82E-06	2.35E-06
	95%UCL	1.79E-05	1.02E-06	4.62E-06	5.71E-07	1.00E-05	5.20E-07	1.10E-06	1.43E-06	1.38E-06
Total	Minimum	3.06E-03	1.73E-04	7.36E-04	1.07E-04	2.33E-03	1.04E-04	1.60E-04	3.84E-04	1.32E-04
	Maximum	1.51E-02	1.27E-03	7.28E-03	5.27E-04	5.73E-03	1.71E-03	9.16E-04	6.50E-04	8.41E-04
	95%UCL	6.42E-03	3.66E-04	1.66E-03	2.04E-04	3.59E-03	1.86E-04	3.93E-04	5.12E-04	4.96E-04
Adults										
D_{ing}	Minimum	4.00E-04	2.27E-05	9.62E-05	1.40E-05	3.05E-04	1.36E-05	2.09E-05	5.02E-05	1.73E-05
	Maximum	1.98E-03	1.66E-04	9.52E-04	6.89E-05	7.49E-04	2.23E-04	1.20E-04	8.50E-05	1.10E-04
	95%UCL	8.39E-04	4.79E-05	2.16E-04	2.67E-05	4.69E-04	2.43E-05	5.14E-05	6.70E-05	6.48E-05
D_{inh}	Minimum	5.89E-08	3.33E-09	1.42E-08	2.07E-09	4.48E-08	1.99E-09	3.07E-09	7.38E-09	2.55E-09
	Maximum	2.91E-07	2.45E-08	1.40E-07	1.01E-08	1.10E-07	3.28E-08	1.76E-08	1.25E-08	1.62E-08
	95%UCL	1.23E-07	7.04E-09	3.18E-08	3.93E-09	6.90E-08	3.58E-09	7.55E-09	9.85E-09	9.52E-09
D_{dermal}	Minimum	1.60E-06	9.04E-08	3.84E-07	5.60E-08	1.22E-06	5.41E-08	8.34E-08	2.00E-07	6.91E-08
	Maximum	7.90E-06	6.64E-07	3.80E-06	2.75E-07	2.99E-06	8.90E-07	4.78E-07	3.39E-07	4.39E-07
	95%UCL	3.35E-06	1.91E-07	8.63E-07	1.07E-07	1.87E-06	9.71E-08	2.05E-07	2.67E-07	2.58E-07
Total	Minimum	4.02E-04	2.28E-05	9.66E-05	1.41E-05	3.06E-04	1.36E-05	2.10E-05	5.04E-05	1.74E-05
	Maximum	1.99E-03	1.67E-04	9.55E-04	6.92E-05	7.52E-04	2.24E-04	1.20E-04	8.53E-05	1.10E-04
	95%UCL	8.42E-04	4.81E-05	2.17E-04	2.68E-05	4.71E-05	2.44E-05	5.16E-05	6.72E-05	6.50E-05
LADD	Minimum		1.51E-09	6.43E-09			9.06E-10			
	Maximum		1.11E-08	6.35E-08			1.49E-08			
	95%UCL		3.20E-09	1.44E-08			1.63E-09			

D_{ing}, Dose contacted through ingestion; D_{inh}, Dose contacted though inhalation; D_{dermal}, Dose absorbed through dermal contact; 95%UCL is the upper limit of the 95% confidence interval for the mean.

presenting low ecological risk. The mean E_i and 75% E_i of Co between 15 and 30 reveals moderate ecological risk, while 23% E_i between 30 and 60 reveals considerable ecological risk. The mean E_i values of Cr and Cu, 83% E_i of Cr and 90% E_i of Cu less than 15 indicate that Cr and Cu in the resuspended particles of street dust are at low ecological risk, while 16% E_i of Cr and 10% E_i of Cu between 15 and 30 indicate moderate ecological risk. The mean E_i and 50% Ei of Pb are between 15 and 30 indicating moderate ecological risk, while 44% E_i and 6% E_i in the <15 and 30–60 range indicate low ecological risk and considerable ecological risk respectively.

The potential ecological risk index (RI) values of metals studied in the samples range from 55.6 to 207.2 with an average of 87.7. The mean RI and RI values for most sampling sites (90% samples) in the range 50–100 reveal moderate ecological risk. The mean relative contributors of Co and Pb to RI are higher than those of Cu and Ni, though these four metals have the same toxic response factor. The reason for this is that the pollution factors of Co (C_f^i = 5.5) and Pb (C_f^i = 3.5) are significantly higher than those of Cu (C_f^i = 2.2) and Ni (C_f^i = 1.3). The toxic response factor of Cr (T_i = 2) is less than Cu (T_i = 5)[33–35]. The relative contributor of Cr to RI is similar to Cu because the pollution factor of Cr (C_f^i = 6.0) in the studied samples is the highest.

Health risk assessment results

Exposure doses of metals: Exposure doses of metals in the resuspended particles of street dust from Baotou for both children and adults are listed in Table 4. The maximum exposure doses for children and adults are 1.52E-02 and 1.99E-03 mg kg^{-1} day^{-1}, both for Ba. In the case of children, the daily doses of all metals by ingestion are 2–5 orders of magnitude higher than by the other two routes and the 95% UCL values of the total exposure doses of Ba, Cr and Mn are one order of magnitude higher than Co, Cu, Ni, Pb, V and Zn. While in the case of adults, the daily doses of all metals by ingestion are 2–4 orders of magnitude higher than by inhalation and dermal contact. In terms of total exposure amounts, Co, Cu, Mn, Ni, Pb, V and Zn are in the same order of magnitude

Table 5. Hazard quotient (HQ) and cancer risk of metals in resuspended particles of street dust from Baotou

Metal		Ba	Co	Cr	Cu	Mn	Ni	Pb	V	Zn
Children										
HQ_{ing}	Minimum	4.36-02	8.65E-03	2.45E-01	2.68E-03	5.05E-02	5.18E-03	4.56E-02	5.47E-02	4.40E-04
	Maximum	2.16E-01	6.34E-02	2.42E+00	1.31E-02	1.24E-01	8.51E-02	2.61E-01	9.26E-02	2.80E-03
	95%UCL	9.14E-02	1.83E-02	5.50E-01	5.09E-03	7.78E-02	9.29E-03	1.12E-01	7.30E-02	1.65E-03
HQ_{inh}	Minimum	5.97E-04	8.46E-04	7.17E-04	7.45E-08	4.54E-03	1.40E-07	1.27E-06	1.53E-06	1.23E-08
	Maximum	2.95E-03	6.21E-03	7.09E-03	3.65E-07	1.12E-02	2.31E-06	7.25E-06	2.59E-06	7.81E-08
	95%UCL	1.25E-03	1.79E-03	1.61E-03	1.42E-07	6.99E-03	2.52E-07	3.11E-06	2.04E-06	4.60E-08
HQ_{dermal}	Minimum	1.75E-03	3.03E-05	3.43E-02	2.50E-05	3.54E-03	5.37E-05	8.51E-04	1.53E-02	6.17E-06
	Maximum	8.63E-03	2.22E-04	3.39E-01	1.23E-04	8.70E-03	8.82E-04	4.87E-03	2.59E-02	3.92E-05
	95%UCL	3.66E-03	6.39E-05	7.70E-02	4.75E-05	5.45E-03	9.63E-05	2.09E-03	2.04E-02	2.31E-05
HI	Minimum	4.60E-02	9.52E-03	2.80E-01	2.70E-03	5.86E-02	5.23E-03	4.64E-02	7.00E-02	4.47E-04
	Maximum	2.27E-01	6.99E-02	2.77E+00	1.33E-02	1.44E-01	8.59E-02	2.66E-01	1.19E-01	2.84E-03
	95%UCL	9.63E-02	2.01E-02	6.29E-01	5.14E-03	9.03E-02	9.38E-03	1.14E-01	9.34E-02	1.67E-03
Adults										
HQ_{ing}	Minimum	5.72E-03	1.13E-03	3.21E-02	3.51E-04	6.62E-03	6.78E-04	5.97E-03	7.17E-03	5.77E-05
	Maximum	2.83E-02	8.31E-03	3.17E-01	1.72E-03	1.63E-02	1.11E-02	3.42E-02	1.21E-02	3.67E-04
	95%UCL	1.20E-02	2.39E-03	7.21E-02	6.68E-04	1.02E-02	1.22E-03	1.47E-02	9.56E-03	2.16E-04
HQ_{inh}	Minimum	4.12E-04	5.84E-04	4.95E-04	5.14E-08	3.13E-03	9.68E-08	8.73E-07	1.05E-06	8.49E-09
	Maximum	2.04E-03	4.28E-03	4.89E-03	2.52E-07	7.70E-03	1.59E-06	5.00E-06	1.79E-06	5.39E-08
	95%UCL	8.63E-04	1.23E-03	1.11E-03	9.77E-08	4.82E-03	1.74E-07	2.15E-06	1.41E-06	3.17E-08
HQ_{dermal}	Minimum	3.26E-04	5.65E-06	6.40E-03	4.67E-06	6.60E-04	1.00E-05	1.59E-04	2.86E-03	1.15E-06
	Maximum	1.61E-03	4.15E-05	6.33E-02	2.29E-05	1.62E-03	1.65E-04	9.10E-04	4.84E-03	7.31E-06
	95%UCL	6.83E-04	1.19E-05	1.44E-02	8.88E-06	1.02E-03	1.80E-05	3.90E-04	3.82E-03	4.31E-06
HI	Minimum	6.46E-03	1.72E-03	3.90E-02	3.56E-04	1.04E-02	6.88E-04	6.13E-03	1.00E-02	5.89E-05
	Maximum	3.19E-02	1.26E-02	3.85E-01	1.74E-03	2.56E-02	1.13E-02	3.51E-02	1.70E-02	3.74E-04
	95%UCL	1.35E-02	364E-03	8.76E-02	6.77E-04	1.60E-02	1.24E-03	1.51E-02	1.34E-02	2.20E-04
Cancer risk	Minimum		1.48E-08	2.70E-07			7.61E-10			
	Maximum		1.09E-07	2.67E-06			1.25E-08			
	95%UCL		3.13E-08	6.07E-07			1.37E-09			

HQ, Hazard quotient; HI, Hazard index.

(E-05 mg kg^{-1} day^{-1}), which is lower than Ba and Cr (E-04 mg kg^{-1} day^{-1}). On the whole, children are exposed to more metals in dust than adults by each of the three pathways. For carcinogenic metals, the maximum values of dose LADD for Co, Cr and Ni are in the same order of magnitude (E-08 mg kg^{-1} day^{-1}).

Health risk level: The results of the hazard quotient (HQ) values of different exposure pathways, hazard index (HI) and cancer risk of the analysed metals in the resuspended particles of street dust from Baotou are presented in Table 5. For non-cancer effect, ingestion of dust particles is the main route of exposure to metals in dust that leads to a higher risk, followed by dermal adsorption except for Co and Mn (Table 5), similar to other studies[1,8–10]. HQs of Cu, Ni, Pb, V and Zn for ingestion of dust particles are 3–5 orders of magnitude higher than for inhalation of dust particles. Therefore, inhalation of resuspended particles for these metals is almost negligible compared with the other exposure routes. There are some differences between the 95% UCL values of HIs for all the analysed metals in the resuspended particles of street dust from Baotou to both children and adults, i.e. for children the 95% UCL values of HIs decrease in the order Cr (6.29E-01) > Pb (1.14E-01) > Ba (9.63E-02) > V (9.34E-02) > Mn (9.03E-02) > Co (2.01E-02) > Ni (9.38E-03) > Cu (5.14E-03) > Zn (1.67E-03), while for adults they decrease in the order Cr (8.76E-02) > Mn (1.60E-02) > Pb (1.51E-02) > Ba (1.35E-02) ≈ V (1.34E-02) > Co (3.64E-03) > Ni (1.24E-03) > Zn (2.20E-04); they are all within the safe level (1) suggested by USEAP[42] indicating that there is little non-cancer health risk to local inhabitants due to metals in the resuspended particles of street dust. Whereas the maximum HI of Cr for children exceeds the safe level (1), indicating that Cr in the resuspended particles of street dust samples could constitute potential non-cancer risk to children. Cr is a neurological, renal and developmental toxicant at certain concentrations[50]. Hence, the health risk of Cr in the resuspended particles of street dust from Baotou cannot be overlooked. The HQ values of different exposure pathways and HI values of all analysed metals for children are higher than for adults, indicating that children may have more potential non-cancer risk than adults.

Table 5 shows that the cancer risks of Co, Cr and Ni due to street dust exposure in Baotou decrease in the order Cr > Co > Ni. The cancer risk levels of Cr, Co and Ni are lower than the acceptable range (10^{-6}–10^{-4}), indicating that these metals in the resuspended particles of street dust from Baotou cannot cause carcinogenesis to local habitants.

Conclusion

Concentrations of Ba, Co, Cr, Cu, Mn, Ni, Pb, V and Zn in the resuspended particles of street dust collected from Baotou were measured using XRD. The results indicate that these samples have elevated concentrations of metals – Ba, Co, Cr, Cu and Pb, which are 0.9–4.6, 2.8–20.2, 2.9–28.8, 1.2–6.0 and 1.5–8.7 times the background values of Inner Mongolia soil respectively. Ba, Mn, V, Zn and Ni in the resuspended particles of studied street dust present low ecological risk. Co reveals moderate to considerable ecological risk. Cr and Cu in most samples present low ecological risk and in some samples moderate ecological risk. Moreover, Pb presents low to moderate ecological risk. The general ecological risk of metals in the samples is in the moderate level. Health risk analysis shows that ingestion of dust particles is the main exposure route of metals in dust to children and adults. Children exhibited more non-cancer risk than adults. On the whole, the non-cancer risks of metals in the case of both children and adults due to dust exposure are limited. Nevertheless, maximum HI of Cr for children is higher than the safe level. Thus, the health risk of Cr in the resuspended particles of street dust from Baotou for children is a matter of concern. The cancer risks of Cr, Co and Ni are lower than the acceptable range.

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