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RESEARCH ARTICLE

Assessment of source and health risk of metal(loid)s in indoor/outdoor dust of university dormitory in Lanzhou City, China

Lili Bao [1,2] · Shengli Wang [1,2] · Huiling Sun [1,2] · Wen Huang [1,2] · Guanxin Wang [2] · Zhongren Nan [1,2]

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Abstract

The pollution of metal(loid)s from indoor and outdoor dust is of great concern because of its impact on human health. The concentrations of nine metal(loid)s (Mn, Cu, Zn, Cd, Cr, Ni, Pb, Hg, and As) were investigated in indoor and outdoor dust samples of university dormitories in winter and summer seasons in Lanzhou City, China. This study revealed the variations of metal(loid) concentrations in dust samples with the seasonal scale and floor heights. The results showed that the concentrations of some metal(loid)s (Cu, Cd, Ni, Pb, and As) in dust samples collected in winter were higher than those of the dust samples collected in summer. The Hg in indoor dust was mainly derived from building materials and indoor human activities. Additionally, the concentrations of some metal(loid)s (Hg, Mn, As, Cu, Cd) in dust samples varied with the height of the floors from ground level. The concentrations of Hg in dust samples collected on upper floors (9–16th floors) were higher than those collected on down floors (1–8th floors), while Mn and As were the opposite of that. Cu and Cd concentrations increased as the floor height increased. Our results demonstrated that the adults and the children (particularly the children) endured potential health risks due to exposure to metal(loid)s from both indoor and outdoor dust in the studied area.

Keywords Atmospheric deposition · Dust · Metal(loid)s · Pollution characteristics · Source identification · Health risk

Introduction

Urban dust is a source for various pollutants including metal(loid)s in atmosphere. It presents a potential threat to the ecosystem and inhabitant. The dust is exacerbated by resuspension and transport of the settled particles under wind forces (Lü et al. 2018; Moreno et al. 2013). Urban rainfall with low pH dissolves metal(loid)s in urban dust, which leads to the contamination of storm runoff and thus affects the environmental quality of receiving waters (Davis and Birch 2010; Liu et al. 2014; Munksgaard and Lottermoser 2010). The exposure to metal(loid)s through urban dust presents both the non-carcinogenic risks and the carcinogenic risks for humans (Cheng et al. 2018). The quality of indoor environment has been a great concern in recent years due to people spending large amounts of time in the indoor environment (US EPA 1997). Previous studies have shown that urban dust can pass from outdoors to indoors through two major routes: dust stuck to footwear and clothing tracked into the room and resuspension of urban dust floating into the indoor space through windows and doors (Kurt-Karakus 2012; Yadav et al. 2019).

Metal(loid)s in dust may originate from various sources in the city, including natural sources (e.g., soil particulate matters) and anthropogenic sources (e.g., fossil fuel combustion, industrial activities and traffic activities) (Charlesworth et al. 2011; Othman et al. 2018). The contribution of indoor dust from buildings (e.g., characteristics of buildings constituent materials) and indoor human activities (e.g., decoration activities, maquillage used, electronic products used, cleaning and cocking) cannot be ignored (Patino and Siegel 2018).

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✉ Shengli Wang
wangshengl@lzu.edu.cn

[1] Gansu Key Laboratory for Environmental Pollution Prediction and Control, College of Earth and Environmental Sciences, Lanzhou University, Lanzhou 730000, China

[2] Key Laboratory of Western China's Environmental Systems (Ministry of Education), College of Earth and Environmental Sciences, Lanzhou University, Lanzhou 730000, China

Human exposure to metal(loid)s can be through various routes such as ingestion (i.e., entering the gastrointestinal digestive), inhalation (i.e., entering the respiratory system), and dermal contact (Chary et al. 2008; Liu et al. 2013; Rasmussen et al. 2018). Generally, oral ingestion is the most critical exposure route to dust particulate matters for humans (Cheng et al. 2018). The dust particles can be swallowed directly or eventually reach the gastrointestinal tract after a short residence time in the bronchial region by breathing (Butte and Heinzow 2002). Metal(loid)s are non-biodegradable. The accumulation in human body can result in serious diseases such as liver and renal failure, nervous system damage, and arthralgia (Lü et al. 2018; Staessen et al. 1994; Staessen et al. 1999; Verougstraete et al. 2003). Therefore, it is necessary to study the effects of metal(loid)s in indoor and outdoor dust on human health, and special attention should be paid towards more vulnerable groups such as children.

Lanzhou City is located at the confluence of the upper reaches of the Yellow River in China, and it is the intersection of the Loess Plateau, Qinghai-Tibet Plateau, and Mongolian Plateau (Zhang et al. 2016). Lanzhou City is an important center for raw materials, characterized by petrochemical industry, non-ferrous metal smelting, heavy equipment manufacturing, and building material manufacturing. Anthropogenic pollutants are hard to spread around due to its unique basin topography, which may accumulate the pollutants to unsafe levels within the city (Zhang et al. 2013). In addition, sandstorms often occur in this region. Different authors reported the pollution levels of some elements in dust, not Hg and As, and lack of depth analysis of elements pollution characteristics (Li et al. 2014; Wang et al. 2008; Wang et al. 2012). Therefore, to our knowledge, this is the first study on the seasonal variation and the effect of sampling altitude of metal(loid)s (Mn, Cu, Zn, Cd, Cr, Ni, Pb, Hg, and As) in indoor and outdoor dust in Lanzhou City. The knowledge on atmospheric deposition of metal(loid)s in Lanzhou City can provide suggestions for local emission-reduction tasks and the establishment of the indoor environmental air quality standards.

The aims of the present work are as follows: (1) to determine the concentrations of metal(loid)s in indoor and outdoor dust; (2) to investigate the seasonal variation and the effect of sampling altitude of metal(loid) concentrations in indoor and outdoor dust; (3) to identify possible sources of metal(loid)s in dust; (4) to estimate the health risks of these metal(loid)s in the study area.

Materials and methods

Study area and sampling location

Lanzhou City (36° 01′–36° 09′ N, 103° 30′–104° 36′ E) is the capital city of Gansu Province in northwest China. Its area and population are 13,085.6 km^2 and 3.70 million, respectively. The average annual temperature and precipitations are 10.3 °C and 327 mm, respectively (Xue et al. 2016).

The Anning District is one of the four core urban districts of Lanzhou. It has a high population density and is a new high-tech economic and cultural area which integrates education, technology, and economic development. Giving the convenience of sampling and ensuring a fairly representative sampling of floor heights, we collected the dust samples from two dormitory buildings (high building with 16 and 18 floors) in Gansu Agricultural University in the Anning District (Fig. S1).

Sampling

Two dormitory buildings of Gansu Agricultural University close to the road were selected as sampling points for indoor and outdoor dust sample collections; the 136 dust samples were collected from the two dormitory buildings in winter (from January to February) and summer (from June to July) in 2017. The sampling frequency within sampling periods (January to February and June to July) was three times, respectively. The students were asked to answer some questions about sampling points (Table S1). The indoor dust samples were collected on the ground, table, top of wardrobe, and other places from the interiors of the student dormitories on different floors. The outdoor dust samples were collected on the windowsill outside of all student dormitories on different floors. The dust on the outdoor windowsill was cleaned before the first sampling in order to avoid the long term sinks of historical materials. Indoor/outdoor dust samples were collected by brushes (in order to avoid cross-contamination of the samples, the disposable brushes were used); dust samples were loaded into polyethylene sealed bags and brought back to the laboratory for cryopreservation at 4 °C. Samples were freeze-dried and passed through a 0.15-mm sieve (100-mesh sieve).

Chemical analysis

The dust samples were digested using Anton Paar model microwave digestion system (Anton Paar, Multiwave PRO 3000). The total concentrations of Mn, Cu, Zn, Cd, Cr, Ni, and Pb in soils were extracted by 6 mL of 65% HNO_3, 2 mL of 36% HCl, 2 mL of 40% HF, and 2 mL of 30% H_2O_2. Dust sample (0.2 g) was digested with 10 mL aqua regia (HCl:HNO_3 ratio of 3:1, v/v) for Hg and As (Zang et al. 2017). The temperature for microwave digestion system was raised gradually from room temperature to 180 °C within 20 min and kept at 180 °C for 40 min. Then, metal concentrations in dust samples were analyzed using an atomic absorption spectrophotometer (Analytik Jena, ZEEnit 700P) (Mn, Cu, Zn, Cd, Cr, Ni, and Pb) and an atomic fluorescence spectrometer (AFS-2880) (Hg and As).

Quality assurance and quality control

The quality control of the analysis was checked by analyzing the reference materials GBW07408 (GSS-8). Blank samples were analyzed simultaneously with the samples. To control the analytical precision of the analysis, each sample was analyzed in triplicate. The RSD % (relative standard deviation) was < 5% for all elements. The detection limits were 0.0090 mg L^{-1} for Mn, 0.0038 mg L^{-1} for Cu, 0.0077 mg L^{-1} for Zn, 0.0075 mg L^{-1} for Cd, 0.0474 mg L^{-1} for Cr, 0.0202 mg L^{-1} for Ni, 0.0806 mg L^{-1} for Pb, 0.002 μg L^{-1} for Hg, and 0.020 μg L^{-1} for As. The recoveries of metal(loid)s were as follows: Mn (97.1 ± 2.3%), Cu (100.4 ± 1.1%), Zn (95.4 ± 2.3%), Cd (93.8 ± 0.6%), Cr (102.3 ± 0.7%), Ni (96.4 ± 1.4%), Pb (103.6 ± 2.1%), Hg (104.4 ± 1.1%), and As (95.9 ± 0.3%).

Statistical analysis

The principal component analysis (PCA) was applied to identify sources of metal(loid)s. PCA is widely used to extract a small number of independent factors (principal components) in available data and to analyze the relationship among variables, making it easier to explain a given multidimensional system by showing the correlation among the original variables (Han et al. 2006). The correlation analysis was used to investigate whether the same elements between indoor and outdoor dust were correlated. The analysis of variance (ANOVA) was used to infer whether there were significant differences among the concentrations of elements (Yadav et al. 2019).

Pollution assessment methods

Enrichment factors

Enrichment factors (EFs) were used to indicate the degree of enrichment of elements in atmospheric particulate matter (Khademi et al. 2019; Wei et al. 2010). The EFs were calculated with the following formula:

$$\mathrm{EF} = \frac{(C_i/C_n)_{\mathrm{sample}}}{(C_i/C_n)_{\mathrm{background}}} \quad (1)$$

Here C_i/C_n was the ratio of concentrations between metal(loid) and the reference metal in samples and background area (the soil background values of Gansu Province). In present study, Mn was chosen as a reference element, due to its ubiquity in the Earth's crust, low sources of anthropogenic pollution, and good chemical stability. And the CV % (coefficient of variation) of elements was calculated in indoor and outdoor dust in winter and summer. Mn has the smallest mean CV % among all elements (CV_{Mn} (7%) < CV_{Fe} (9%) < CV_{Zn} (12%) < CV_{Ni} (13%) < CV_{Cu} (14%) < CV_{Cr} (18%) < CV_{Pb} (19%) < CV_{Cd} (28%) < CV_{As} (35%) < CV_{Hg} (81%)). Due to the lack of corresponding environmental standards, the pollution assessment of metals in atmospheric dust is mainly based on the evaluation method of soil metal pollution. Therefore, in this study, the soil background values of Gansu Province were selected as the concentration of metals in the background area.

Health risk assessment

There are three main pathways of exposure to metal(loid)s in dust and their average intakes are given by the following: (1) average daily intake of metal(loid)s in dust through ingestion (DI_{ing}); (2) average daily intake of metal(loid)s in dust through inhalation (DI_{inh}); (3) average daily intake of metal(loid)s in dust through dermal contact (DI_d). Metal(loid) daily intake through three pathways of exposure was calculated with Eqs. (2)–(4). Hg exposure is measured as intake of mercury vapor (DI_{vapour}) and is calculated according to Eq. (5). DI is the average daily intake of metal(loid)s in dust; LDI is the lifetime daily intake for metal(loid)s with carcinogenic effect (US EPA 1989; Zheng et al. 2010).

$$\mathrm{DI_{ing}}\left(\mathrm{LDI_{ing}}\right) = \mathrm{C} \times \frac{\mathrm{EF} \times \mathrm{ED} \times \mathrm{OSIR}}{\mathrm{AT} \times \mathrm{BW}} \times 10^{-6} \quad (2)$$

$$\mathrm{DI_{inh}}\left(\mathrm{LDI_{inh}}\right) = \mathrm{C} \times \frac{\mathrm{EF} \times \mathrm{ED} \times \mathrm{DAIR}}{\mathrm{AT} \times \mathrm{BW} \times \mathrm{PEF}} \quad (3)$$

$$\mathrm{DI_d}\left(\mathrm{LDI_d}\right) = \mathrm{C} \times \frac{\mathrm{EF} \times \mathrm{ED} \times \mathrm{SL} \times \mathrm{SA} \times \mathrm{ABS}}{\mathrm{AT} \times \mathrm{BW}} \times 10^{-6} \quad (4)$$

$$\mathrm{DI_{vapor}} = \mathrm{C} \times \frac{\mathrm{EF} \times \mathrm{ED} \times \mathrm{OSIR}}{\mathrm{VF} \times \mathrm{AT} \times \mathrm{BW}} \times 10^{-6} \quad (5)$$

where metal(loid) concentrations (C) are calculated as follows (Hu et al. 2011; Zheng et al. 2010):

$$C_{95\%\mathrm{UCL}} = x + t_{1-\alpha,\ n-1}\frac{s}{\sqrt{n}} \quad (6)$$

where $C_{95\%\mathrm{UCL}}$ represents the upper confidence limit for the mean metal(loid) concentration at $p = 95\%$; $\bar{x}$ is the mean concentration of metal(loid); s is the standard deviation; $1-\alpha$ is the confidence level; $n-1$ is the degrees of freedom; n is the number of samples.

The values of each parameter in the formula are shown in Table S2.

The DI for hazard quotient (HQ) and hazard index (HI) and the LDI for carcinogenic risk (CR) were calculated using the Eqs. (7)–(9) (US EPA 2007).

$$\mathrm{HQ}_{ij} = \frac{\mathrm{DI}_{ij}}{\mathrm{RfD}_{ij}} \quad (7)$$

$$HI_n = \sum_{j=1}^{m} HI_{nj} \quad (8)$$

$$CR_n = \sum_{j=1}^{m} LDI_{nj} \times SF_{nj} \quad (9)$$

where HQ_{ij} is the hazard quotient for a single exposure route of a single contaminant, RfD_{ij} is the reference doses for this route, HI_n is the hazard index for various exposure routes of a single contaminant, CR_n is the carcinogenic risk for various exposure routes of a single contaminant, and SF_{nj} is the carcinogenic slope factor for a single exposure rout of a single contaminant.

The reference doses (RfD) and carcinogenic slope factor (SF) of each metal(loid) element come from Regional Screening Levels (US EPA 2010) (Table S3). There is no RfD for Pb given by US EPA; therefore, our study refers to the FAO/WHO recommendation for the weekly Pb intake limit, 25 μg kg^{-1} (Hu et al. 2011; JECFA 1993; Ostapczuk et al. 1987).

Results and discussion

Concentrations of metal(loid)s in dust samples

The concentrations of metal(loid)s in dust samples (indoor and outdoor) collected in winter and summer are shown in Fig. 1. The order of the mean concentrations of the elements in winter outdoor dust samples was Mn (399 mg kg^{-1}) > Zn (228 mg kg^{-1}) > Pb (103 mg kg^{-1}) > Cu (75.3 mg kg^{-1}) > Cr (67.8 mg kg^{-1}) > Ni (43.2 mg kg^{-1}) > As (5.04 mg kg^{-1}) > Cd (4.88 mg kg^{-1}) > Hg (0.356 mg kg^{-1}) (winter indoor dust, summer indoor dust and summer outdoor dust, seeing Fig. 1 and Table S6). The order of concentrations Cd, As, Cu, and Cr was different in winter and summer: Cd < As in winter and Cd >As in summer, Cr < Cu in winter and Cr > Cu in summer outdoor, but these differences were not significant (Table S4). The concentrations of As and Cd in winter showed higher variations than those in summer. The mean concentrations of metal(loid)s (except Hg) in outdoor dust were significantly higher than those of indoor dust, Hg was indoor > outdoor, $p < 0.05$ (Table S5). In addition, the mean concentrations of metal(loid)s (except Hg, Cr, Zn, and Mn) in winter were significantly higher than those of concentrations in summer, $p < 0.05$ (Table S5). The mean concentrations of Cd, Hg, Pb, Zn, Cu, and Ni were greater than the soil background values of Gansu Province, by 42.1 times, 18.0 times, 5.48 times, 3.33 times, 3.12 times, and 1.23 times, respectively (China National Environmental Monitoring Center 1990). Although the concentration of Mn was the highest among the nine elements, it did not exceed the soil background value. On the contrary, the concentrations of Cd and Hg exceeded the soil background values. It showed that Mn was relatively deficient, while Cd and Hg demonstrated extremely high enrichment. It means that the Mn is probably derived from natural sources, and Cd and Hg are affected by additional anthropogenic factors/sources.

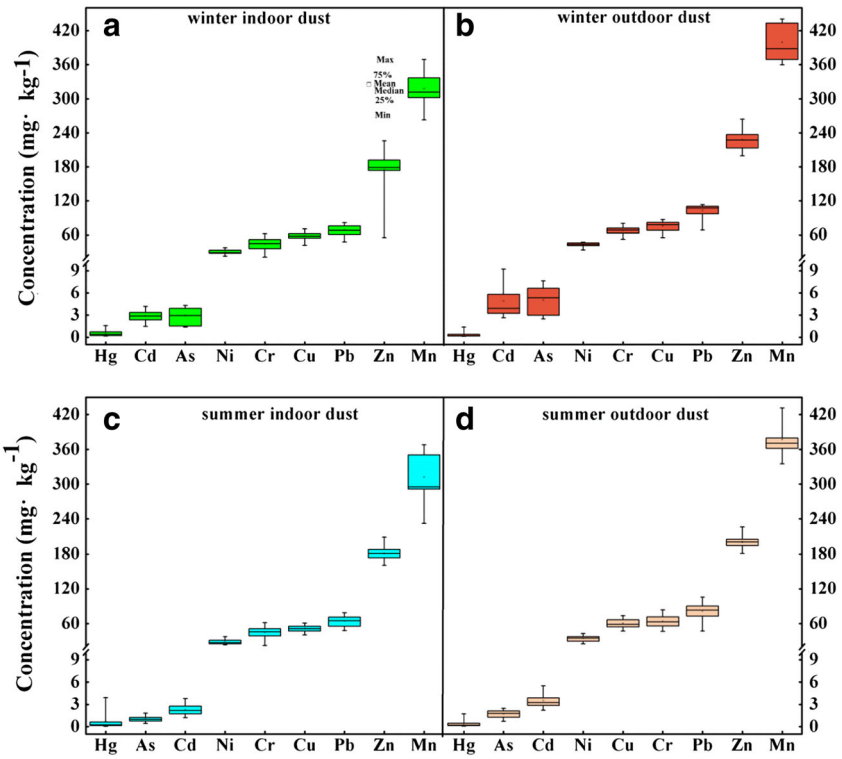

Fig. 1 Concentrations of elements in indoor and outdoor dust samples (mg kg^{-1}). Note: Each box represents interquartile range (25th and 75th percentile) of contents. **a** Winter indoor dust. **b** Winter outdoor dust. **c** Summer indoor dust. **d** Summer outdoor dust

The comparison of elements in Lanzhou dust samples with similar studies in China and other countries

The metal(loid) concentrations of Lanzhou dust samples were compared with similar studies conducted in other big cities in China and in other countries. Table S6 shows the concentrations of metal(loid)s in indoor and outdoor dust from Lanzhou and other cities. The concentration of Mn in the dust from Chengdu and Tianjin (natural source: soil particulate matters) was about two times higher than those of Lanzhou, but the concentration of Mn in Lanzhou was higher than those of Lahore and Sydney. The concentration of Cu in the dust of Warsaw was higher than those of Lanzhou. Meanwhile, the concentration of Cu in Lanzhou dust was equivalent to those of Al-Qunfudah. The concentrations of Zn in dust of Christchurch (anthropogenic source: galvanized iron), Tianjin, and Chengdu (anthropogenic source: painting) were higher than those of Lanzhou. However, Zn concentration in Lanzhou dust was two times higher than those of Lahore. The concentrations of Cd in Lanzhou dust were comparable to those of Chengdu, Tianjin, and Lahore. The concentrations of Cr in Lanzhou dust were equivalent to those of Almadinah Almunawarah, Ottawa, and Sydney. The concentrations of Pb in dust of Christchurch and Guangzhou (anthropogenic source: lead-based painting) were evidently higher than those of Lanzhou. In addition, the concentrations of Hg in indoor dust in Warsaw and Ottawa (anthropogenic source: house itself) were higher than those of Lanzhou. The concentrations of As in dust of Chengdu, Tianjin, and Guangzhou (anthropogenic source: household pollution source) were higher than those of Lanzhou. On a global level, the contamination of these nine metal(loid)s in dust from Lanzhou was at a moderate level.

The ratio of elements concentration in outdoor vs. indoor dust (outdoor/indoor) seemed to be more indicative that may explain the differences between area, seeing Fig. 2. Only Cd and As showed outdoor/indoor elements ratios higher than 1.5, indicating that outdoor (Cd and As) > indoor (Cd and As) in winter and summer in Lanzhou, China (this study). In summer, the values "outdoor/indoor" of the Pb and Hg elements were less than 0.6 in Guangzhou, China. The ratios of Hg concentrations in outdoor vs. indoor dust in Lanzhou and Guangzhou were less than 0.6, indicating that Hg concentration was as follows: indoor dust > outdoor dust. The values outdoor/indoor of the Zn element were less than 0.6 in Al-Qunfudah, KSA. The values outdoor/indoor of the Mn, Cu, Zn, Ni, and Pb elements were approximately equal to 1 in Lahore, Pakistan, which indicated that the element concentrations of indoor and outdoor dust were similar.

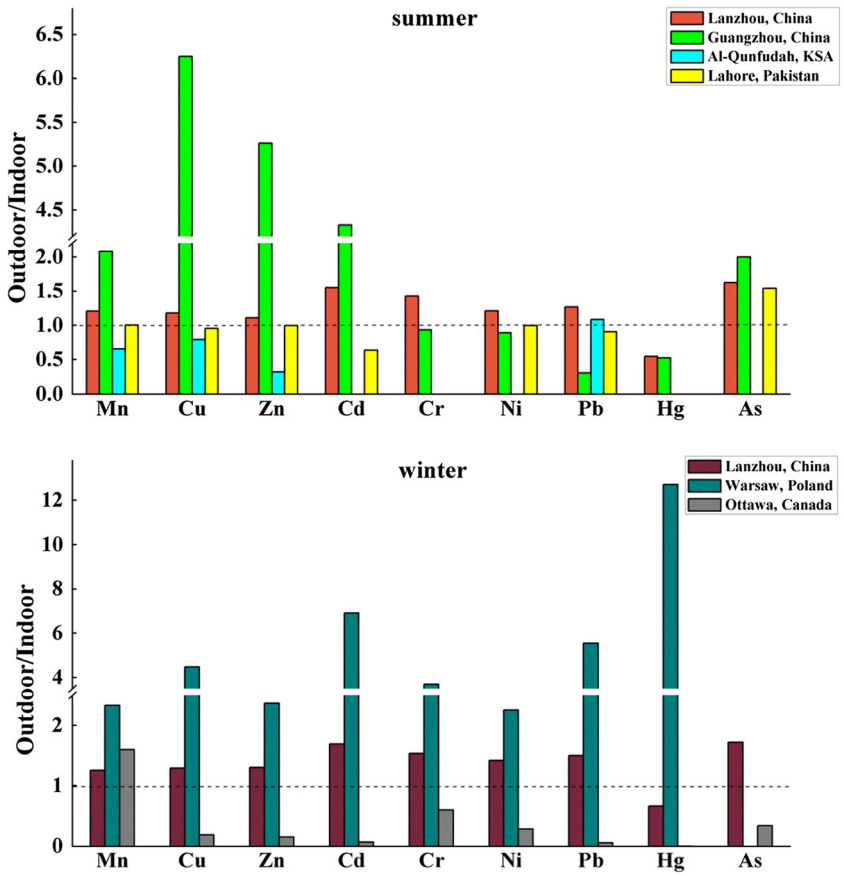

Fig. 2 The ratios of element concentrations in outdoor vs. indoor dust

In winter, the values outdoor/indoor of the Mn, Cu, Zn, Cd, Cr, Ni, Pb, and Hg elements were greater than 1.5 in Warsaw, Poland; Hg was different from Lanzhou, China. The concentrations of outdoor dust elements (except Mn) were lower than those of indoor dust elements in Ottawa, indicating that the distributions of dust element concentrations were different from those of Lanzhou.

The effects of floors level and seasonal variation of elements

Comparison of concentrations of metal(loid)s in indoor and outdoor dust

The concentrations of nine metal(loid)s in indoor and outdoor dust of different floors are shown in Fig. 3. The concentrations of metal(loid)s (Mn, Cu, Zn, Cd, Cr, Ni, Pb, and As) in outdoor dust were significantly higher than those of indoor dust; Hg concentration in indoor dust was significantly higher than that of outdoor dust, $p < 0.05$ (Table S5). The concentrations of Hg in indoor dust were higher than those of outdoor dust collected above the 8th floor. Because cosmetics, paint, thermometers, and fluorescent lamps all contribute to Hg concentrations, Hg was more affected by buildings and indoor activities. Besides, correlation analysis (Table S7) showed significant correlations ($p < 0.05$) between the same elements in indoor and outdoor dust samples collected at the same season. Significant correlations ($r^2 > 0.4$, $p < 0.05$) were found between outdoor and indoor elements (except Zn in winter and Cr and Hg in summer), indicating that there is a correlations between the concentrations of elements in indoor dust and outdoor dust. Strong and significant correlations ($r^2 > 0.6$, $p < 0.05$) were found between outdoor and indoor dust of As, Cd, and Ni in winter and summer and those of Cu, Mn, and Zn in winter. Moderate and significant correlations ($0.4 < r^2 < 0.6$, $p < 0.05$) were found between outdoor and indoor dust of Mn, Pb, and Cu in summer.

Variations of metal(loid) concentrations with floor heights level

Figure 3 shows that the concentrations of Cu and Cd were generally increased as the floor height level increased. This is probably linked with the dimensions of the dust particles, dust particles get finer with the increasing height (Ali et al. 2019). Finer particles also have higher specific surface areas, allowing for more absorption of metals (Cheng et al. 2018). This upward trend was not continuous but fluctuated up and down. However, the concentrations of Mn and As were higher on low floors and lower on high floors. It may be ascribed to the resuspension of soil dust particles (Charlesworth et al. 2011). The reasons for the differences between Cu, Cd and Mn, As were that Mn and As element concentrations did not exceed the soil background values, the main source may be the soil particulate matters on the ground; therefore, the Mn and As concentrations were higher on low floors. While the Cu and Cd concentrations exceeded the soil background value (3.12 times and 42.1 times), and anthropogenic pollution played a leading role. Local petrochemical, machinery, and metallurgical industry had a great contribution to Cu and Cd, and the exhaust gas from industrial production was discharged into the upper air through chimneys (see "Sources of metals in dust samples"). The fine particles in the upper air would combine more Cu and Cd elements, so the Cu and Cd concentrations increased as the floor heights level increased. Moreover, the concentration of Cu, Cd, Zn, Cr, Ni, and Pb was more stable. The concentration of Hg was higher on high floors (9–16th floors) than on low floors (1–8th floors), maybe it was because Hg was volatile and accumulated aloft. The greater the height is, the higher the concentration of gaseous elemental mercury in the urban atmosphere (Cairns et al. 2011).

Seasonal variation of metal(loid)s in dust samples

A comparison of metal(loid) concentrations in dust in winter and summer is represented in Fig. 3. The concentrations of metal(loid)s such as Cu, Cd, Ni, Pb, and As in winter dust were higher than those of summer, revealing that the contamination of these metal(loid)s was more serious in winter. For one thing, a large amount of coal was consumed for heating in winter. Previous studies have demonstrated that a large amount of fly ash and flue gas containing elements such as As, Cu, Cd, Ni, and Pb can be produced during the combustion of coal (Men et al. 2018). Furthermore, the high concentrations of these elements during winter may be attributed to the frequent temperature inversion of the ground and lower average wind speed in winter, which leads to the accumulation of atmospheric dust (Gansu Provincial Meteorological Bureau 2016). Relevant departments should pay more attention to these metal(loid)s (Cu, Cd, Ni, Pb, and As) when setting emission reduction targets.

Sources identification of metal(loid)s in dust samples

Principal component analysis

Principal component analysis (PCA) was carried out to assess the most probable sources of the elements in dust samples by using the statistical software SPSS. The emission sources of the metal(loid)s in dust samples were assessed by extracting the concentration data after orthogonal rotation of Kaiser Standardization. Table S8 shows principal factor loadings, the eigenvalue, contribution rates, and communalities of variables after Kaiser Standardized orthogonal rotation. The PCA loading diagram of nine metal(loid)s is shown in Fig. 4.

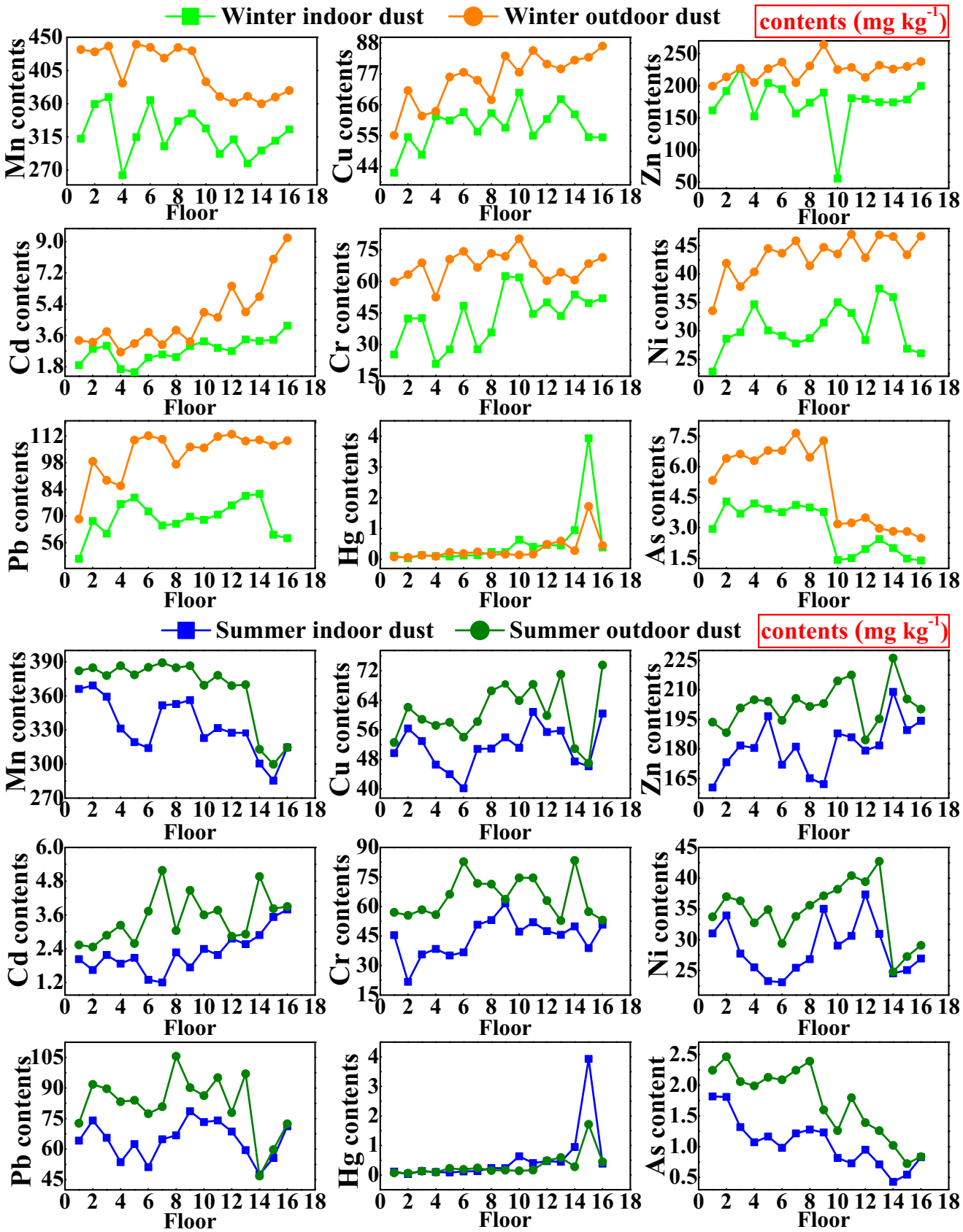

Fig. 3 Variations of concentrations (contents) of elements in dust samples with the floor heights level in winter and summer

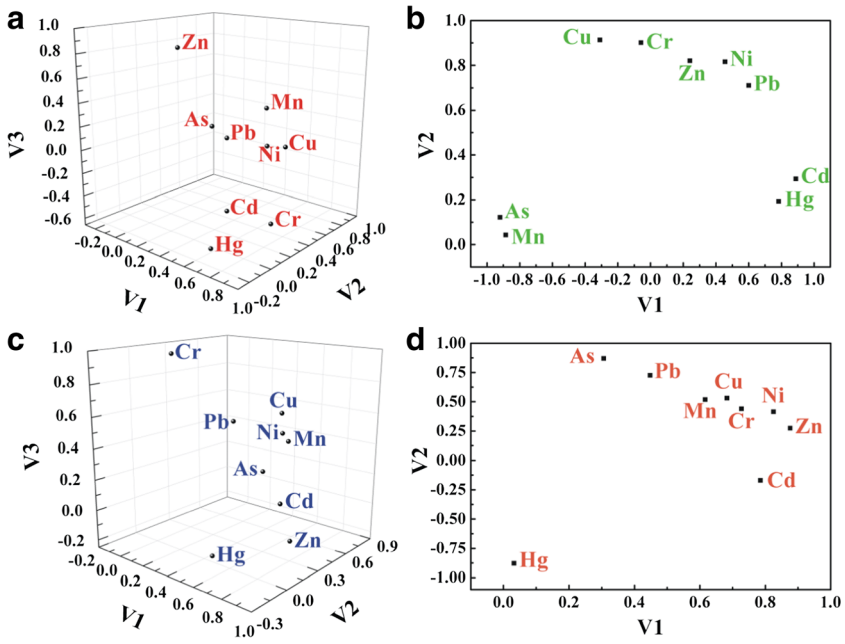

Fig. 4 PCA loading diagram for principal components of elements from dust samples. **a** Winter indoor dust. **b** Winter outdoor dust. **c** Summer indoor dust. **d** Summer outdoor dust

Table S8 reveals that the three principal components of winter indoor dust samples and the two principal components of winter outdoor dust samples accounted 84.8% and 82.1% of the total variance, respectively. In winter indoor dust samples, the first principal component (PC1-a) explained 46.3% of the total variance and mainly consisted of Cu, Cd, Cr, Ni, Pb, and Hg (Table S8; Fig. 4a). The second principal component (PC2-a) explained 20.6% of the total variance and was dominated by Mn and As. The third principal component (PC3-a) explained 18.0% of the total variance and was dominated by the positive loading of Zn and the negative loadings of Cr and Hg. Thereby, PC1-a for the metal(loid)s in winter indoor dust samples might be predominated by anthropogenic sources (i.e., cosmetics and paints). PC2-a might be natural sources (i.e., soil particulate matters). PC3-a might be anthropogenic sources (i.e., electrical equipments, electronic products and paints). In winter outdoor dust samples, the first principal component (PC1-b) explained 41.7% of the total variance and was based on the positive loadings of Cd, Ni, Pb, and Hg and the negative loadings of Mn and As (Table S8; Fig. 4b). The second principal component (PC2-b) explained 40.3% of the total variance and was dominated by Cu, Zn, Cr, Ni, and Pb. Therefore, PC1-b for the metal(loid)s in winter outdoor dust samples might be anthropogenic sources (i.e., mechanical productions and fossil fuel combustion). PC2-b might be anthropogenic sources (i.e., traffic and petrochemical industry).

According to the data in Table S8, the three principal components of summer indoor dust samples and the two principal components of summer outdoor dust samples accounted 82.5% and 75.7% of the total variance, respectively. In summer indoor dust samples, the first principal component (PC1-c) contributed 35.4% to the total variance and was dominated by Mn, Cu, Zn, Cd, Ni, and Hg (Table S8; Fig. 4c). The second principal component (PC2-c) explained 24.0% of the total variance and dominated by Cu, Zn, Pb, and As. The third principal component (PC3-c) explained 23.1% of the total variance and dominated by Mn, Cu, Cr, and Ni. PC1-c for the metal(loid)s in summer indoor dust samples might be the combination effects of anthropogenic and natural sources (i.e., cosmetics, paints and soil particulate matters). Both PC2-c and PC3-c might be predominated by anthropogenic sources (i.e., paints, cosmetics, and household appliances). In summer outdoor dust samples, the first principal component (PC1-d) explained 41.5% of the total variance and dominated by Mn, Cu, Zn, Cd, Cr, Ni, and Pb (Table S8; Fig. 4d). The second principal component (PC2-d) explained 34.2% of the total variance and dominated by the positive loadings of Mn, Cu, Cr, Ni Pb, and As and the negative loading of Hg. Consequently, PC1-d for the metal(loid)s in summer outdoor dust samples might be anthropogenic sources (i.e., traffic and fossil fuel combustion). PC2-d might be the combination of anthropogenic and natural sources (i.e., petrochemical and metallurgical industry and soil particulate matters).

Sources of metals in dust samples

Analytical method (PCA) was used to determine the possible source of elements. It only qualitatively discussed here because the studied elements in this study are not exclusive characteristic element(s) for a special source. Because Lanzhou City carries out oil smelting and petrochemical processes, and has a large number of motor vehicles, these human activities are undoubtedly the sources of metal(loid)s.

According to the results of PCA analysis, the possible main sources of metal(loid)s in indoor dust samples were identified. The Cu, Cd, Cr, Ni, Pb, Hg, and Mn elements in the PC1-a, PC3-a, PC1-c, PC2-c, and PC3-c groups mainly originated from interior decorations and paints. Cu, Zn, Pb, and As metal(loid)s came from the use of paints (Patino and Siegel 2018). The Hg, Cd, Pb, and As elements in the PC1-a, PC1-c, and PC2-c groups were mainly derived from cosmetics (Li et al. 2013). The Zn, Cr, and Hg elements in the PC3-a group mainly came from household appliances and eletronic products (Turner and Lewis 2018). The Mn and As elements in the PC2-a and PC1-c groups also came from the soil particulate matters.

The main sources of metal(loid)s in outdoor dust samples were analyzed accroding to the PCA and specific sitution of Lanzhou City. The Cu, Zn, Cr, Ni, and Pb elements in the PC2-b and PC1-d groups were mainly derived from traffic. Cr, Cu, Ni, and Zn might be from abrasion of vehicles because these metals are parts of the materials for brass alloy (Doabi et al. 2017). Pb might be from the combustion of gasoline and exhaust emmission (Al-Rajhi et al. 1996; Harrison et al. 2003). The Mn, Cd, and As elements in the PC1-b and PC1-d groups mainly came from fossil fuel combustion (Viana et al. 2006). The Cu, Cd, Cr, Ni, Pb, and Hg elements in the PC1-b and PC2-d groups mainly originated from petrochemical, machinery, and metallurgical industry (Cairns et al. 2011). The Mn elements in the PC2-d group also came from the soil particulate matters (Bonil et al. 1988).

Enrichment factor analysis and pollution level assessment

The results and enrichment intensity of enrichment factors (EFs) are shown in Fig. 5. The mean EFs of metal(loid)s in indoor dust samples are ordered as Cd (48.7) > Hg (46.4) > Pb (7.58) > Zn (5.23) > Cu (4.91) > Ni (1.79) > Cr (1.25) > As (0.48). The mean EFs of metal(loid)s in outdoor dust samples are ordered as Cd (66.4) > Hg (23.6) > Pb (8.66) > Zn (5.35) > Cu (4.99) > Ni (1.90) > > As (1.81) > Cr (1.55). The EF values of metal(loid)s (except Hg) in outdoor dust samples were higher than those of indoor dust, indicating that the contamination of metal(loid)s (except Hg) in outdoor dust samples was more serious than those of indoor dust. According to the classification standard of enrichment intensity (Han et al. 2006), the mean EF values of As, Cr, and Ni elements in indoor and outdoor dust samples ($EF < 2$) were classified as deficiency to minimal enrichment. The Cu in indoor and outdoor dust samples ($2 \le EF < 5$) was classified as moderate enrichment. The Zn and Pb in indoor and outdoor dust samples ($5 \le EF < 20$) were classified as significant enrichment. The Hg and Cd in indoor dust samples ($EF \ge 40$) were classified as extremely high enrichment, but in outdoor door dust samples, the Hg ($20 \le EF < 40$) was very high enrichment and the Cd ($EF \ge 40$) was classified as extremely high enrichment. The EFs of Zn, Pb, Cd, and Hg were significantly higher than other metal(loid)s, suggesting that the pollution of Zn, Pb, Cd, and Hg elements were more serious. Moreover, the EF values of Hg and Cd elements in dust samples increased as the floor heights increased, suggesting that the enrichment level of these two elements was higher on upper floors.

Health risk assessment

The results of the daily intake (DI and LDI) calculation of metal(loid)s of dust samples are shown in Tables S9 and S10. The effect of the mercury vapor exposure (DI_{vapor}) on mercury intake was very small and could be neglected. Dust ingestion was the most important exposure pathway leading to the carcinogenic and non-carcinogenic risks for metal(loid)s, with dermal contact and inhalation serving as second and third exposure pathway. It was similar to the results of Kurt-Karakus (Kurt-Karakus 2012).

For non-carcinogenic risk, the HI for metal(loid)s in indoor and outdoor dust is shown in Fig. 6. Pb was observed as the most high-risk non-carcinogenic element for humans. A value of HI exceeding 1 indicated that non-carcinogenic effects might occur

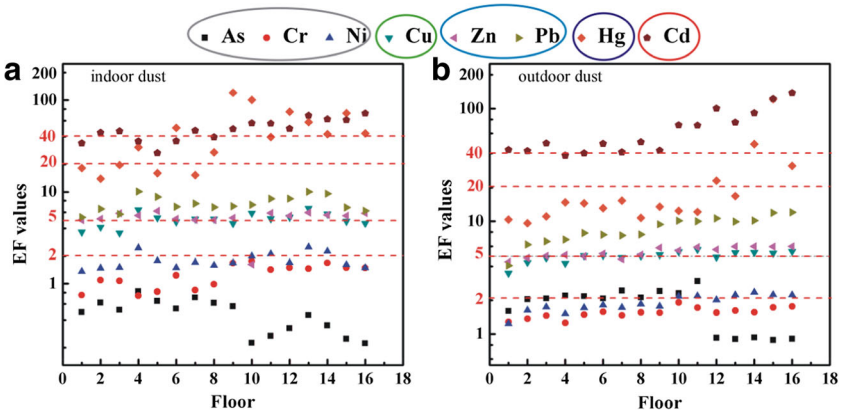

Fig. 5 The EF of elements in indoor and outdoor dust samples. **a** EF values in indoor dust. **b** EF values in outdoor dust

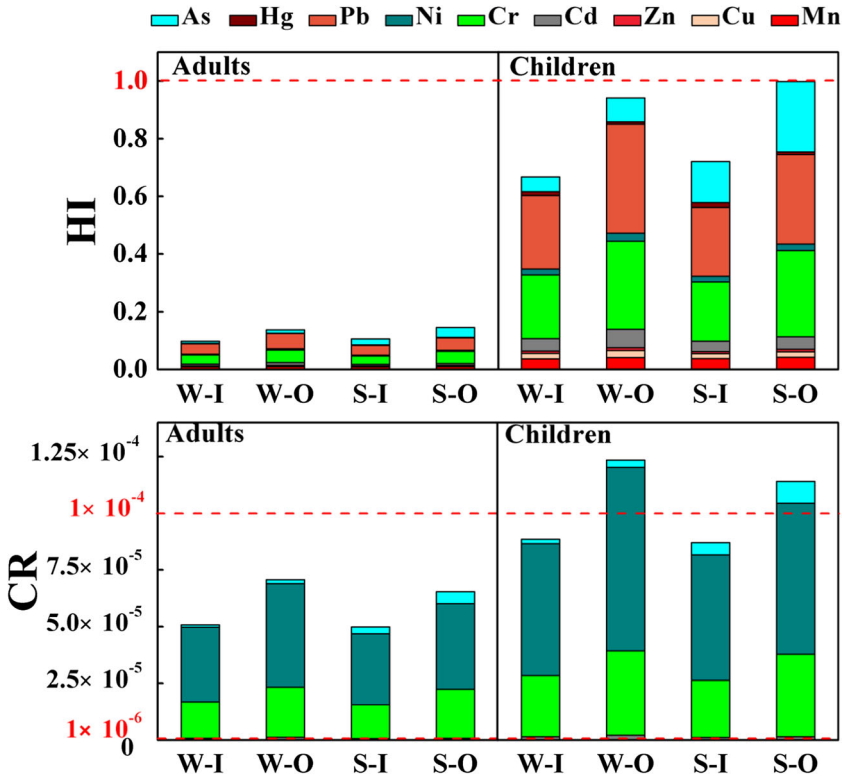

Fig. 6 Stacking column diagram of HI and CR of elements in dust samples. W-I winter indoor dust, W-O winter outdoor dust, S-I summer indoor dust, S-O summer outdoor dust

in humans, while the HI values less than 1 indicated no significant non-carcinogenic risk (US EPA 2001). In this study, although the HI values of individual metal(loid)s were all less than 1, for children, the sums of all metal(loid)s the HI values in winter and summer outdoor dust were 0.940 and 0.998, respectively. This indicated the non-carcinogenicic risk of metal(loid)s to children exposed to outdoor dust cannot be ignored.

The carcinogenic risk values of Cd, Cr, Ni, and As are shown in Fig. 6. The estimated value of CR indicated that the probability of a person developing cancer as a result of lifetime exposure to carcinogens and tolerable or acceptable risk ranges from 1×10^{-6} to 1×10^{-4} (US EPA 2001). In this study, for adults, not only individual the CR values of Cd, Cr, Ni and As but also the total CR values were within acceptable risk ranges, indicating that carcinogenic effects of Cd, Cr, Ni, and As were acceptable for adults. However, for children, the CR values of Cd, Cr, Ni, and As were less than 1×10^{-4}, carcinogenic risk of individual elements was acceptable, but the total CR values were greater than 1×10^{-4} in outdoor dust samples. Therefore, the carcinogenic risk of four metal(loid)s in children exposed to outdoor dust in winter and summer cannot be ignored.

It should be noted that both carcinogenic and non-carcinogenic risk exposures to outdoor dust were higher than those in indoors. Children as the vulnerable group had a higher potential risk than adults. Therefore, when the quality of indoor environment is assessed, the local government should consider the maximum allowable exposure of children and adults separately.

Conclusions

Metal(loid) concentrations of dust in Lanzhou City were in moderate level of the major cities around the world. Our results showed that the contamination of metal(loid)s (except Hg) in outdoor dust samples was more serious than those of indoor. But Hg contamination was of high severity indoors, indicating that building materials significantly contribute to the contimination of Hg loading in air. It was found that the pollution of Cu, Cd, Ni, Pb, and As was more severe during the winter months. Higher concentrations of Cu, Cd, and Hg were observed on higher floors of the dormitory; students living on upper floors were at higher risk of hazards associated with metal pollution in dust. We found that the levels of health risk were in the order as outdoor > indoor, children > adults. Furthermore, the results of this study had a reference value for other cities in arid regions. However, one of the shortcoming of this paper was that the data set was relatively small, which could only reflect the general situation of the fall of atmospheric dust in Lanzhou, the other was that the total amount of metal(loid)s used to calculate daily intake often overestimated the health risk of exposure to metal(loid)s. In conclusion, intake of metal(loid)s in dust through ingestion/dermal contact/inhalation route may pose potential health risk to adults and children in Lanzhou.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no competing interests.

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