

# Pollution distribution and health risk assessment of heavy metals in indoor dust in Anhui rural, China

Yuesheng Lin · Fengman Fang · Fei Wang ·  
Minglu Xu

Received: 6 February 2015 / Accepted: 20 July 2015 / Published online: 12 August 2015  
© Springer International Publishing Switzerland 2015

**Abstract** Zn, Pb, Cu, Cr, V, Ni, Co, and As concentrations of indoor dust in Anhui rural were determined by inductively coupled plasma–optical emission spectroscopy (ICP-OES). The degrees of metal pollution in indoor dust ranked as follows: Zn > Pb > Cr > Cu > V > Ni > Co > As, on average. The arithmetic means of Zn, Pb, Cu, Cr, V, Ni, Co, and As were 427.17, 348.73, 107.05, 113.68, 52.64, 38.93, 10.29, and 4.46 mg/kg, respectively. These were higher than background values of Anhui soil for Zn, Pb, Cu, Cr, and Ni, especially for Pb with the mean value of 13.21 times the background value. Heavy metal concentrations of indoor dust were different from different rural areas. House type (bungalows or storied house), sweeping frequency, and external environment around the house (such as the road grade) affected heavy metal concentrations in indoor dust. The results of factor analysis and correlation analysis indicated that Cu, Cr, Ni, Zn, and Co concentrations were mainly due to interior paint, metal objects, and building materials. Pb and As concentrations were due to vehicle emissions. V concentration was mainly of natural source. Average daily doses for the exposure pathway of the studied heavy

metals decreased in children in the following order: hand-to-mouth ingestion > dermal contact > inhalation. The non-carcinogenic risks of heavy metals ranked as Pb > V > Cr > Cu > Zn > As > Co > Ni, and the carcinogenic risks of metals decreased in the order of Cr > Co > As > Ni. The non-carcinogenic hazard indexes and carcinogenic risks of metals in indoor dust were both lower than the safe values.

**Keywords** Indoor dust · Heavy metal · Health risks · Pollution distribution · Anhui rural areas

## Introduction

The heavy metal contamination of outdoor and indoor dust is a major environmental issue because of potential toxic effects on ecological environment and human health (Marek et al. 2000; Fang et al. 2011; Cai et al. 2013; Chen et al. 2014; Wei et al. 2015). Indoor dust is major media of interest for heavy metal exposure to children (Lanphear et al. 1998; Rasmussen et al. 2001; Jun et al. 2014), which is derived from indoor activity such as paint chips and outdoor sources such as traffic and industrial activities and soil (Liggans and Nriagu 1998; Turner and Ip 2007). It has been shown that heavy metal concentration levels in indoor dust were higher than those of outdoor dust (Fergusson et al. 1986; Rasmussen et al. 2001). People spend a considerable amount of time

---

Y. Lin · F. Fang  
College of Live Sciences, Anhui Normal University,  
Wuhu 241000, China

F. Fang (✉) · F. Wang · M. Xu  
College of Territorial Resources and Tourism, Anhui Normal  
University, Wuhu 241003, China  
e-mail: ffm1974@mail.ahnu.edu.cn

indoors, which led to the exposure levels of pollutants to residents being higher than those outdoors (Hwang et al. 2008). Dust could easily enter human bodies through hand-to-mouth activity, respiratory inhalation, and dermal contact, which can result into heavy metal poisoning.

Some studies have reported on Pb concentration in indoor dust and its health risk to children (Jaroslav et al. 1974; James et al. 1974; Fergusson and Schroeder 1985). Others have reported on Cr, Zn, As, and Cd in indoor dust (Tong and Lam 1998; Chattopadhyay et al. 2003; Rasmussen et al. 2013). Some authors have studied the contributions of different sources, chemical form, influencing factors, and health risk of heavy metal in indoor dust (Kim and Fergusson 1993; Feng and Barratt 1994; Chattopadhyay et al. 2003; Petrosyan et al. 2006; Zheng et al. 2013; Yoshinaga et al. 2014; Lucas et al. 2014). Many studies showed that heavy metal concentrations of indoor dust in different cities, different regions, and different families have significant difference, and the influencing factors to distribution characteristics of heavy metal are different (Wang et al. 1997; Abdul-Wahaba and Yaghi 2004; Hassan 2012; Li and Xie 2013).

In this study, the concentrations of Zn, Pb, Cu, Cr, V, Co, Ni, and As in indoor dust of Anhui rural areas were analyzed. The objectives of this study are (1) to investigate the distribution characteristics of heavy metals in indoor dust in Anhui rural area, (2) to apply factor analysis and correlation analysis to get insight into the factors affecting heavy metal in indoor dust, and (3) to analyze the children exposure to heavy metal from indoor dust in Anhui rural areas.

## Materials and methods

### Sample collection

The study area is located in Anhui province (114° 54' to 119° 37' E, 29° 41' to 34° 38' N) in northwestern East China. One hundred twenty-five indoor dust samples were randomly collected from Anhui rural areas of Hefei, Huainan, Huaibei, Fuyang, Chuzhou, Bengbu, Bozhou, Suzhou, Anqing, Ma'anshan, Xuancheng, Lu'an, and Huangshan. Dust samples were collected from the residential floor using a brush and white plastic spatula. All collected dust samples were stored in transparent sealed polyethylene bags.

### Sample preparation and experimental analysis

The dust samples were sieved through a 0.149-mm mesh nylon sieve. About 0.2 g of the prepared dust sample was digested with a concentrated HNO<sub>3</sub> (3 ml)–HClO<sub>4</sub> (6 ml)–HF (14 ml) mixture and diluted with 2 % HNO<sub>3</sub> to 50 ml. The concentrations of Zn, Pb, Cr, Cu, Ni, As, V, and Co were determined by inductively coupled plasma–optical emission spectrometer (ICP-OES). For quality assurance and control, blanks samples (one blank sample for 20 dust samples), duplicate samples, and certified reference materials (GSS-1 and GSS-3) were simultaneously analyzed in the experiments to assess precision and bias.

### Health risk assessment model

Children exposure to heavy metals due to dust particles occurs via three main pathways: inhalation of dust through mouth and nose (ADD<sub>inh</sub>), ingestion of dust by hand-to-mouth activity (ADD<sub>ing</sub>), and dermal absorption of heavy metals to exposed skin (ADD<sub>derm</sub>). The dose received through each of the three pathways was calculated using Eqs. (1)–(3) (USEPA 1989, 1996, 2001). For carcinogenic, the lifetime average daily dose (LADD; inhalation exposure route for As, Co, Cr, and Ni) was used in the assessment of carcinogenic risk with Eq. (4) (USEPA 1996, 2001; Fang et al. 2011). The physical meaning and values of each parameter are listed in Table 1:

$$ADD_{ing} = \frac{CS \cdot IngR \cdot EF \cdot ED \cdot CF}{BW \cdot AT} \quad (1)$$

$$ADD_{inh} = \frac{CS \cdot InhR \cdot EF \cdot ED}{PEF \cdot BW \cdot AT} \quad (2)$$

$$ADD_{derm} = \frac{CS \cdot SA \cdot SL \cdot ABS \cdot EF \cdot ED \cdot CF}{BW \cdot AT} \quad (3)$$

$$LADD = \frac{CS \cdot EF}{PEF \cdot AT} \times \left( \frac{InhR_{child} \cdot ED_{child}}{BW_{child}} + \frac{InhR_{adult} \cdot ED_{adult}}{BW_{adult}} \right) \quad (4)$$

The CS (exposure-point concentration) in Eqs. (1)–(4), combined with the values for the exposure factors shown above, is considered to yield an estimate

**Table 1** Parameter values in average daily dose calculation models of heavy metals for children

Parameter	Physical meaning and units	Value	Data source
CS	Exposure-point concentration	95%UCL	This study
IngR	Ingestion rate, mg day <sup>-1</sup>	200	US EPA
InhR	Inhalation rate, m <sup>3</sup> day <sup>-1</sup>	7.63	US EPA
CF	transformation factor	10 <sup>-6</sup>	US EPA
EF	Exposure frequency, day a <sup>-1</sup>	180	US EPA
ED	Exposure duration, a	6	US EPA
SA	Exposed skin area, cm	1150	US EPA
SL	Skin adherence factor, mg cm <sup>-2</sup> day <sup>-1</sup>	0.2	US EPA
ABS	Dermal absorption factor, unitless	0.001	USEPA
PEF	Particle emission factor, m <sup>3</sup> kg	1.36×10 <sup>9</sup>	US EPA
BW	Average body weight, kg	15	US EPA
AT	Averaging exposure time, day	ED×365(for non-carcinogens) 70×365(for carcinogens)	US EPA

of the “reasonable maximum exposure” (USEPA 1989), which is the upper limit of the 95 % confidence interval for the mean (Fang et al. 2011). Since the concentration of most elements in indoor dust samples has an approximate log-normal distribution, the 95 % upper confidence limit (UCL) was calculated as shown in Eq. (5) (USEPA 1996). Calculation of the exposure point concentration term for log-transformed data is as follows:

$$CS_{95\%UCL} = \exp\left\{X + 0.5 \times s^2 + \frac{s \times H}{\sqrt{n-1}}\right\} \quad (5)$$

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

According to EPA’s guideline on health risk assessment, carcinogenic and non-carcinogenic effects are separate discussions. The doses calculated for each element and exposure pathway are subsequently divided by the corresponding reference dose (RfD, Table 2) to

yield a hazard quotient (HQ) calculated with Eq. (6) (Zheng et al. 2010), whereas for carcinogens, the dose is multiplied by the corresponding slope factor (SF) to produce a level of carcinogenic risk. The data of reference dose (RfD) and slope factor (SF) are from USEPA (1989, 1996, 2001). Hazard index (HI) is equal to the sum of HQ and means the total risk of non-carcinogenic for single element (USEPA 1989). If the value of HI is ≤1, it is believed that there is no significant risk of non-carcinogenic effects. If the value of HI is >1, it means that there is a great chance of non-carcinogenic effects, with a probability increasing with the increasing value of HI (USEPA 2001; Zheng et al. 2010). The acceptable or tolerable risk for regulatory purposes is in the range of threshold values (10<sup>-6</sup>–10<sup>-4</sup>) (Lu et al. 2014). In this study, hazard index methods and cancer risk methods were used to assess the human exposure to heavy metals in indoor dust from Anhui rural areas.

$$HQ = D/RfD \quad (6)$$

**Table 2** Reference doses and gradient factors of heavy metals for different exposure routes

	Zn	Pb	Cu	Ni	As	Co	V	Cr
RfD <sub>ing</sub>	0.30	3.50×10 <sup>-3</sup>	4.0×10 <sup>-2</sup>	2.00×10 <sup>-2</sup>	3.00×10 <sup>-4</sup>	3.00×10 <sup>-3</sup>	7.00×10 <sup>-3</sup>	3.00×10 <sup>-3</sup>
RfD <sub>inh</sub>	0.30	3.52×10 <sup>-2</sup>	4.02×10 <sup>-2</sup>	2.06×10 <sup>-2</sup>	3.00×10 <sup>-4</sup>	2.80×10 <sup>-5</sup>	7.00×10 <sup>-3</sup>	2.86×10 <sup>-5</sup>
RfD <sub>dem</sub>	6.00×10 <sup>-2</sup>	5.25×10 <sup>-4</sup>	1.20×10 <sup>-2</sup>	5.40×10 <sup>-3</sup>	1.23×10 <sup>-4</sup>	6.00×10 <sup>-5</sup>	7.00×10 <sup>-5</sup>	6.00×10 <sup>-5</sup>
SF				0.84	15.10	9.80		42.00

RfD reference dose, SF slope factor

**Table 3** Concentrations of heavy metals in indoor dusts in Anhui rural area (mg/kg)

	Zn	Pb	Cu	Ni	As	Co	V	Cr
Min	8.01	10.60	10.95	7.01	1.52	0.40	2.09	32.08
Max	6383.98	7628.91	1469.45	638.89	17.53	53.56	117.44	643.38
Mean	427.17	348.73	107.05	38.93	4.46	10.29	52.64	113.68
SD	367.42	302.38	77.94	24.22	1.25	5.13	12.61	52.12
CV	0.86	0.87	0.73	0.62	0.28	0.50	0.24	0.46
Background <sup>a</sup>	74.42	26.40	20.66	21.98	8.84	10.58	82.64	56.40

SD standard deviation, CV coefficient of variation

<sup>a</sup> Background values in soil of Anhui (Anhui Environmental Monitoring Center of China 1992)

$$HI = \sum HQ \quad (7)$$

$$R = LADD \cdot SF \quad (8)$$

Cu, Zn, Cr, and Ni were higher than their corresponding background values of Anhui soil, with the mean values of 13.21, 5.89, 5.69, 4.04, and 2.40 times the background values, respectively. The concentrations of As, Co, and V in most dust samples and mean values are lower than their background values. Spatial variations for Zn, Pb, Cu, Ni, Co, and Cr concentrations were different in different rural areas. The coefficients of variation (CVs) of Zn, Pb, Ni, and Cr were above 80 %.

## Results and discussions

### Heavy metal concentrations in indoor dust

Heavy metal concentrations in indoor dust samples of Anhui rural areas, as well as the arithmetic means and the standard deviations (SD), are shown in Table 3. Generally, variability of the heavy metal concentrations decreased in the order of indoor dust > street dust > soil (Fergusson et al. 1986). The mean concentrations of Pb,

Pb concentration in indoor dust of Anhui rural areas was higher than that of other provinces in China (Han et al. 2012). Compared with the indoor dust of other cities in China (Li and Xie 2013). Cr concentration in indoor dust of Anhui rural areas was higher than that in the urban areas of Guiyang, Chongqing, and Nanning, while other element concentrations are lower than those in the three cities (Li and Xie 2013). Traffic emission, construction waste, and industrial production are more

**Table 4** Mean concentrations of heavy metal in indoor dust in different rural areas of Anhui (mg/kg)

City	Zn	Pb	Cu	Ni	As	Co	V	Cr
Fuyang	623.70	230.48	92.29	37.43	3.82	11.96	53.37	122.76
Bozhou	366.61	185.86	65.29	28.51	4.64	8.32	47.14	117.15
Suzhou	166.69	112.80	160.64	29.16	7.14	10.00	69.28	91.23
Bengbu	451.66	947.43	94.57	32.75	6.14	8.66	54.21	107.28
Huaibei	347.42	199.20	71.94	36.04	3.74	10.29	46.31	84.80
Chuzhou	250.23	148.97	71.64	33.89	3.59	17.98	53.29	115.70
Huainan	308.10	410.23	218.47	53.65	4.52	10.73	56.91	167.10
Lu'an	455.42	396.55	99.95	40.91	3.82	10.28	46.91	93.14
Hefei	387.53	349.16	63.72	17.06	2.63	5.55	29.76	67.44
Ma'anshan	354.41	235.98	231.42	127.25	4.28	11.23	71.87	114.42
Anqing	545.71	469.91	74.78	29.21	3.96	12.58	56.28	100.08
Xuancheng	531.14	481.38	158.03	36.09	3.13	16.72	54.92	147.99
Huangshan	231.16	164.03	177.36	18.13	3.89	2.16	42.15	60.10

**Table 5** Correlation (Pearson) coefficient matrices for heavy metal concentrations in indoor dust ( $n=125$ )

	Zn	Pb	Cu	Ni	As	Co	V	Cr
Zn	1							
Pb	0.154	1						
Cu	0.183*	0.153	1					
Ni	0.098	0.077	0.592**	1				
As	0.164	0.164	0.032	-0.029	1			
Co	0.383**	0.024	0.085	0.138	0.149	1		
V	-0.183*	-0.004	0.038	-0.030	0.173	0.237**	1	
Cr	0.091	0.178	0.230**	0.337**	0.110	0.281**	0.081	1

\*Correlation is significant at the 0.05 level (two -tailed); \*\*correlation is significant at the 0.01 level (two-tailed)

in urban areas than in the rural areas, so the concentrations of Zn, Pb, Cu, and Ni in rural indoor dust are lower than those in the city (Li and Xie 2013).

Heavy metal concentrations in study areas

The mean heavy metal concentrations in indoor dust of study areas are summarized in Table 4. The mean concentrations of Ni and Cu were highest in Ma'anshan rural area possibly due to iron ore resource development and steel industrial activity in the area. The mean concentration of Pb in Bengbu rural area was significantly higher than that in other rural areas. Because Bengbu is an important transport hub in Anhui province, the traffic flow is heavier than that in other cities. Cr mean concentration in Huainan rural indoor dust was higher than that in other cities, mainly because of sampling point near the power plant, and closeness of house in rural area was poorer, leading to lots of dust settling into

indoor with the atmosphere. The highest mean concentration of As was 7.14 mg/kg in Suzhou rural area, mainly because the background value of Suzhou soil is high (Yuan et al. 2011). The highest mean concentration of Zn in Fuyang rural indoor dust was 623.70 mg/kg. The Co background value (18 mg/kg) of Chuzhou soil was high (Tao et al. 2013), which resulted a high Co mean concentration in indoor dust of Chuzhou rural area.

Correlation analysis and factor analysis

Pearson's correlation coefficient was used to measure the degree of correlation between the heavy metal. Zn-V pair showed negative relation at 95 % level; Zn-Cu, Ni-Cu, Cu-Cr, Zn-Co, V-Co, Cr-Co, and Cr-Ni pairs showed significant positive correlation at 95 % or higher confidence level (Table 5). As a composite source, the sources of heavy metal in indoor dust include street dust,

**Table 6** Matrix of factor analysis of heavy metals in indoor dust of Anhui rural

Item/component	Factor 1	Factor 2	Factor 3	Factor 4
Eigenvalue	2.103	1.369	1.18	1.032
Explained variances (%)	26.284	16.912	14.729	12.924
Zn	0.081	0.794	-0.396	0.198
Pb	0.185	-0.072	-0.142	0.829
Cu	0.825	0.029	-0.066	0.075
Ni	0.879	0.038	-0.043	-0.075
As	-0.100	0.240	0.298	0.651
Co	0.137	0.823	0.331	-0.046
V	0.022	0.006	0.893	0.051
Cr	0.542	0.221	0.251	0.188

soil, paint, carpet, smoking, and cosmetics (Fergusson and Schroeder 1985; Philippe et al. 2012; Barbieri et al. 2014; Lucas et al. 2014). Results indicated that most metals in indoor dust may have common sources, such as paint, road dust, soil, and automobile emission.

Four factors were identified with initial eigenvalues  $>1$ , by which 71.049 % of total variance was explained (Table 6). On the first factor, factor loadings of Cu, Cr, and Ni were high, and thus, it indicated a source of mixed origin such as paint, metal objects, and soil. On the second factor (16.912 %), loading of Zn (0.794) and Co (0.823) was very high, possibly due to alloy and building materials of Zn and Co. On the third factor (14.729 %), V showed high loading (0.893) and As, Cr, and Co also had a certain contribution, which is characteristically identified with natural source. On the fourth factor (12.924 %), loading of Pb (0.829) and As (0.651) was high, indicating that this factor could be a source of mixed origin such as vehicle emission and outdoor dust. Cu, Cr, Ni, Zn, and Co concentrations were mainly due to interior paint, metal objects, and building materials. Pb and As concentrations were mainly from vehicle emissions. V concentration was mainly from natural source.

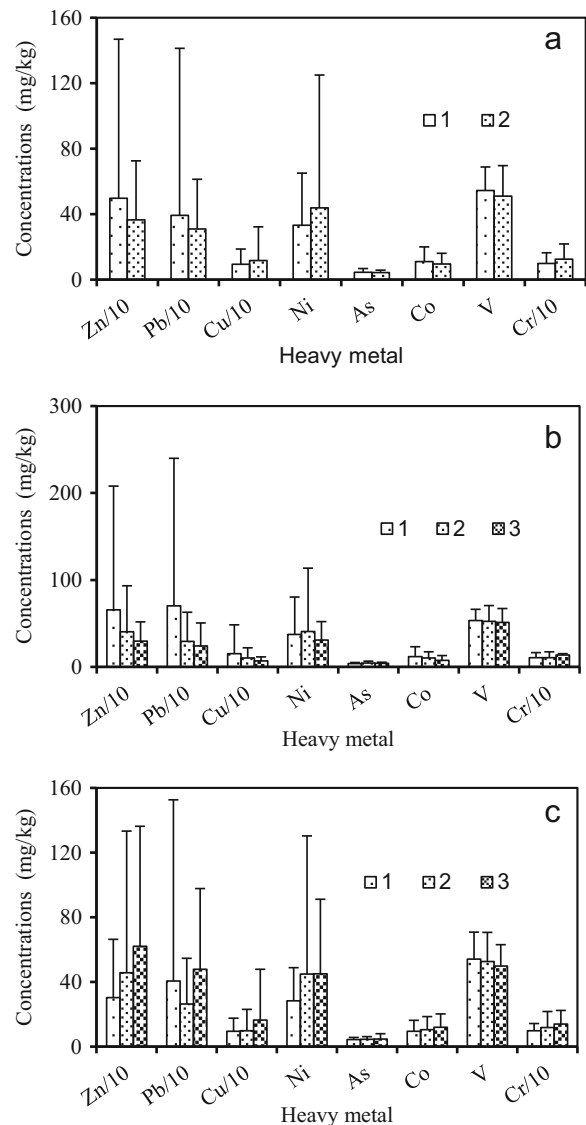
#### Analysis of influencing factors

Heavy metal concentrations in indoor dust were affected by the factors such as traffic activities, particle size of indoor dust, sweeping frequency, cooking activities, people's living habits, house type and structure, and renovation activities (Culbard et al. 1988; Tong and Lam 1998; Adgate et al. 1998; Meyer et al. 1999; Marek et al. 2000; Latif et al. 2011; Rasmussen et al. 2013; Taner et al. 2013). Mean concentrations of heavy metals in indoor dust of bungalows were significantly higher than those in the storied house except for Cr (Fig. 1a). As shown in Fig. 1b, concentrations of heavy metals in the clean house were significantly lower than those in indoor environment of dirty house; it shows that concentration of heavy metals in indoor dust are affected by the sweeping frequency and indoor environment quality. Cleaning of indoor environment can significantly reduce heavy metal in indoor dust. The road grade around a house is an important factor which affected heavy metal concentrations in indoor dust, especially Zn, Pb, and Cu. Figure 1c shows that the distribution rule of metal concentrations in indoor dust under different road grades around a house decreased in the order of

county road  $>$  township road  $>$  rural road, except for V. V concentration reduced with the improvement of road grade around a house.

#### Health risk assessment of heavy metal exposure to indoor dust

According to the concentrations of heavy metal in indoor dust and the exposure parameters, the children's



**Fig. 1** The concentrations of heavy metals under different conditions in indoor dust of Anhui rural areas. **a** 1 = bungalow, 2 = storied house; **b** 1 = dirty house, 2 = cleaner house, 3 = clean house; **c** 1 = house nearby the rural road, 2 = house nearby the township road, 3 = house nearby the county road

health risk assessment results of the analyzed metals in indoor dust of Anhui rural areas are shown in Table 7. Average daily exposure levels of all elements were characterized by hand-to-mouth ingestion > dermal contact > inhalation. Hand-to-mouth ingestion is the main pathway to indoor dust for children because of their hand-to-mouth activity. For non-carcinogenic elements, the exposure levels decreased in the order of Zn > Pb > Cu > V. The exposure levels of cancer elements decreased in the order of Cr > Ni > Co > As.

The results showed that the children’s non-carcinogenic risk coefficients of heavy metals with the pathway of hand-to-mouth ingestion, respiratory inhalation, and dermal contact were less than 1; there is no non-carcinogenic risk within the safety threshold. The non-carcinogenic risk coefficients of heavy metals of three exposure ways decreased in the order of hand-to-mouth ingestion > dermal contact > inhalation. For hand-to-mouth ingestion, the non-carcinogenic risk of Pb was the largest, reaching 0.66. The non-carcinogenic risks of all elements to indoor dust exposure decreased in the order of Pb > V > Cr > Cu > Zn > As > Co > Ni. For dermal contact, the non-carcinogenic risk of heavy metals decreases in the order of V > Pb > Cr > Co > Zn > Cu > Ni > As; the non-carcinogenic risk coefficient of V was  $5.69 \times 10^{-2}$ . The non-carcinogenic risk of heavy metals through respiratory inhalation decreased in the order of Co > Pb > Cr > Cu > Zn > V > As > Ni. Total non-carcinogenic risk (HI) of Pb in indoor dust was the highest, close to 0.7, which required urgent attention. The total non-carcinogenic risk (HI) of eight elements to indoor dust decreased in the order of Pb > V > Cr > Cu > Zn > As > Co > Ni. The results showed that the cancer risk of Co, Ni, As, and Cr to indoor

dust in Anhui rural areas decreased in the order of Cr > Co > As > Ni. The cancer risk coefficients were less than  $10^{-6}$ , significantly lower than the values of safety threshold, indicating that heavy metals Co, Cr, Ni, and As in indoor dust of Anhui rural areas have no obvious cancer risk.

**Conclusion**

The concentration levels, distribution characteristics, and health risk of As, Co, Cr, Cu, Ni, Pb, V, and Zn in indoor dust of Anhui rural areas, China, have been studied. The mean concentrations of heavy metals were higher than the background values of Anhui soil except for As, Co, and V. The spatial distribution is significantly different in different rural areas. The factor analysis and correlation analysis and distribution characteristics of metals indicated that As, Co, Cr, Cu, Ni, Pb, and Zn in indoor dust of Anhui rural areas were mainly due to anthropogenic activities such as paint, metal objects, alloy materials, and vehicle emissions, while V in the studied dusts was mainly emanating from natural source. The mean concentrations of heavy metals in bungalow dust were significantly higher than those in the storied house except for Cr, Ni, and Cu. Cleanliness of indoor environment affected heavy metal content in the indoor dust except for Ni, Cr, and As. Health risk analysis showed that the average daily exposure level of all elements were characterized by hand-to-mouth ingestion > dermal contact > inhalation; the hand-to-mouth ingestion is the main exposure pathway for metals in indoor dust to children. The levels of heavy metals to indoor dust exposure by the three pathways in

**Table 7** Exposure dose, hazard quotient for each element, and exposure pathway

	Zn	Pb	Cu	V	Ni	As	Co	Cr
ADD <sub>ing</sub>	$2.81 \times 10^{-3}$	$2.29 \times 10^{-3}$	$7.04 \times 10^{-4}$	$3.46 \times 10^{-4}$	$2.19 \times 10^{-5}$	$2.51 \times 10^{-6}$	$5.80 \times 10^{-6}$	$6.41 \times 10^{-5}$
ADD <sub>inh</sub>	$7.88 \times 10^{-8}$	$6.43 \times 10^{-8}$	$1.97 \times 10^{-8}$	$9.71 \times 10^{-9}$	$6.16 \times 10^{-10}$	$7.05 \times 10^{-11}$	$1.63 \times 10^{-10}$	$1.80 \times 10^{-9}$
ADD <sub>derm</sub>	$3.23 \times 10^{-6}$	$2.64 \times 10^{-6}$	$8.09 \times 10^{-7}$	$4.02 \times 10^{-7}$	$3.99 \times 10^{-7}$	$3.45 \times 10^{-8}$	$8.52 \times 10^{-8}$	$1.48 \times 10^{-7}$
LADD					$2.23 \times 10^{-9}$	$2.55 \times 10^{-10}$	$5.89 \times 10^{-10}$	$6.51 \times 10^{-9}$
HQ <sub>ing</sub>	$9.36 \times 10^{-3}$	0.66	$1.76 \times 10^{-2}$	$4.94 \times 10^{-2}$	$1.10 \times 10^{-3}$	$8.38 \times 10^{-3}$	$1.93 \times 10^{-3}$	$2.14 \times 10^{-2}$
HQ <sub>inh</sub>	$2.63 \times 10^{-6}$	$1.83 \times 10^{-5}$	$4.91 \times 10^{-6}$	$1.40 \times 10^{-6}$	$2.99 \times 10^{-8}$	$2.35 \times 10^{-7}$	$7.42 \times 10^{-5}$	$1.47 \times 10^{-5}$
HQ <sub>derm</sub>	$5.38 \times 10^{-5}$	$6.46 \times 10^{-3}$	$6.75 \times 10^{-6}$	$5.69 \times 10^{-2}$	$4.67 \times 10^{-6}$	$2.35 \times 10^{-6}$	$1.11 \times 10^{-4}$	$1.23 \times 10^{-3}$
HI	$9.42 \times 10^{-3}$	0.66	$1.76 \times 10^{-2}$	0.11	$1.10 \times 10^{-3}$	$8.38 \times 10^{-3}$	$2.12 \times 10^{-3}$	$2.26 \times 10^{-2}$
R					$1.87 \times 10^{-9}$	$3.85 \times 10^{-9}$	$5.77 \times 10^{-9}$	$2.73 \times 10^{-7}$

ADD average daily dose, LADD lifetime average daily dose, HQ hazard quotient, HI hazard index

Anhui rural areas decreased in the order of Pb > Zn > Cr > Cu > Ni > V > Co > As. The non-carcinogenic risks of all elements to indoor dust exposure were lower than the currently acceptable values. The total non-carcinogenic risk of Pb in indoor dust was the highest, close to 0.7, which required urgent attention. The cancer risk coefficients of Co, Ni, As, and Cr were within the safe range, which indicated that Co, Cr, Ni, and As in indoor dust of Anhui rural areas have no obvious cancer risk.

**Acknowledgments** The authors acknowledge the financial support of the National Natural Science Foundation of China (No. 41371480) and Anhui Key Laboratory of Natural Disaster Process and Protection Research.

## References

- Abdul-Wahaba, S., & Yaghi, B. (2004). Total suspended dust and heavy metal levels emitted from a workplace compared with nearby residential houses. *Atmospheric Environment*, *38*, 745–750.
- Adgate, J., Rhoads, G., & Liroy, P. (1998). The use of isotope ratios to apportion sources of lead in Jersey City, NJ, house dust wipe samples. *Science of the Total Environment*, *221*, 171–180.
- AEMC. (1992). *Soil environmental background value study report of Anhui province*. Anhui Environmental Monitoring Center.
- Barbieri, E., Fontúrbel, F. E., Herbas, C., Barbieri, F. L., & Gardon, J. (2014). Indoor metallic pollution and children exposure in a mining city. *Science of the Total Environment*, *487*, 13–19.
- Cai, Q., Mo, C., Li, H., Lv, H., Zeng, Q., Li, Y., et al. (2013). Heavy metal contamination of urban soils and dusts in Guangzhou, South China. *Environmental Monitoring and Assessment*, *185*, 1095–1106.
- Chattopadhyay, G., Lin, K., & Feitz, A. (2003). Household dust metal levels in the Sydney metropolitan area. *Environmental Research*, *93*, 301–307.
- Chen, H., Lu, X., & Li, L. (2014). Spatial distribution and risk assessment of metals in dust based on samples from nursery and primary schools of Xi'an, China. *Atmospheric Environment*, *88*, 172–182.
- Culbard, E., Thornton, I., Watt, J., Wheat, M., Moorcroft, Y., & Thompso, M. (1988). Metal contamination in British urban dusts and soils. *Journal of Environmental Quality*, *17*, 226–234.
- Fang, F., Wang, H., & Lin, Y. (2011). Spatial distribution, bio-availability, and health riskassessment of soil Hg in Wuhu urban area, China. *Environmental Monitoring and Assessment*, *179*(1–4), 255–265.
- Feng, Y., & Barratt, R. (1994). Lead and cadmium composition in indoor dust. *Science of the Total Environment*, *152*, 261–267.
- Fergusson, J., & Schroeder, O. (1985). Lead in house dust of Christchurch, New Zealand: sampling, levels and sources. *Science of the Total Environment*, *46*, 61–72.
- Fergusson, J., Forbes, E., Schroeder, R., & Ryan, D. (1986). The elemental composition and sources of house dust and street dust. *Science of the Total Environment*, *50*, 217–221.
- Gilbert, R. O. (1987). *Statistical methods for environmental pollution monitoring* (pp. 177–185). New York: VanNostrand Reinhold.
- Han, Z., Bi, X., Li, Z., Yang, W., Wang, L., Yang, H., et al. (2012). Occurrence, speciation and bioaccessibility of lead in Chinese rural household dust and the associated health risk to children. *Atmospheric Environment*, *46*, 65–70.
- Hassan, S. (2012). Metal concentrations and distribution in the household, stairs and entryway dust of some Egyptian homes. *Atmospheric Environment*, *54*, 207–215.
- Hwang, H., Park, E., Young, T., & Hammock, B. (2008). Occurrence of endocrine-disrupting chemicals in indoor dust. *Science of the Total Environment*, *404*, 26–35.
- James, W., Evan, C., Jaroslav, V., & Barry, P. (1974). House and hand dust as a potential source of childhood lead exposure. *Original Articles*, *127*, 167–170.
- Jaroslav, V., Ellen, T., James, W., & Evan, C. (1974). Lead analysis of house dust: a method for the detection of another source of lead exposure in inner city children. *Environmental Health Perspectives*, *7*, 91–97.
- Jun, Y., Kumiko, Y., Ayumi, Y., Yuri, I., Takaya, K., Kodai, M., et al. (2014). Lead and other elements in house dust of Japanese residents—source of lead and health risks due to metal exposure. *Environmental Pollution*, *189*, 223–228.
- Kim, N., & Fergusson, J. (1993). Concentrations and sources of cadmium, copper, lead and zinc in house dust in Christchurch, New Zealand. *Science of the Total Environment*, *138*, 1–21.
- Lanphear, B., Matte, T., Rogers, J., Clickner, R. P., Dietz, B., Bornschein, R. L., et al. (1998). The contribution of lead-contaminated house dust and residential soil to children's blood lead levels: a pooled analysis of 12 epidemiologic studies. *Environmental Research*, *79*, 51–68.
- Latif, M., Baharudin, N., Velayutham, P., Awang, N., Hamdan, H., Mohamad, R., et al. (2011). Composition of heavy metals and airborne fibersin the indoor environment of a building during renovation. *Environmental Monitoring and Assessment*, *181*, 479–489.
- Li, X., & Xie, X. (2013). A study on heavy metals in household dusts in 3 cities in Southwestern China. *China Environmental Science*, *33*, 365–371. In Chinese.
- Liggans, G., & Nriagu, J. (1998). Lead poisoning of children in Africa, IV: exposure to dust lead in primary schools in south-central Durban, South Africa. *Science of the Total Environment*, *221*, 117–126.
- Lu, X., Wu, X., Wang, Y., Chen, H., Cao, P., & Fu, L. (2014). Risk assessment of toxic metals in street dust from a medium-sized industrial city of China. *Ecotoxicology and Environmental Safety*, *106*, 154–163.
- Lucas, J., Bellanger, L., Strat, Y., Tertre, A., Gloennec, P., Bot, B., et al. (2014). Source contributions of lead in residential floor dust and within-home variability of dust lead loading. *Science of the Total Environment*, *471*, 768–779.
- Marek, L., Robert, H., & Jerzy, G. (2000). Granulometry and the content of toxic and potentially toxic elements in vacuum-cleaner collected, indoor dusts of the city of Warsaw. *Science of the Total Environment*, *263*(1/3), 69–78.



- Meyer, I., Heinrich, J., & Lippold, U. (1999). Factors affecting lead and cadmium levels in house dust in industrial areas of eastern Germany. *Science of the Total Environment*, 234, 25–36.
- Petrosyan, V., Braun, M., Spalinger, S., & Lindern, I. (2006). Seasonal variations of lead concentration and loading rates in residential house dust in northern Idaho. *Journal of Hazardous Materials*, 132, 68–79.
- Philippe, G., Lucas, J., Mandin, C., & Bot, B. (2012). French children's exposure to metals via ingestion of indoor dust, outdoor playground dust and soil: Contamination data. *Environment International*, 45, 129–134.
- Rasmussen, P., Subramanian, K., & Jessiman, B. (2001). A multi-element profile of house dust in relation to exterior dust and soils in the city of Ottawa, Canada. *Science of the Total Environment*, 267, 125–140.
- Rasmussen, P., Levesque, C., Chénier, M., Gardner, H. D., Jones-Otazo, H., & Petrovic, S. (2013). Canadian house dust study: population-based concentrations, loads and loading rates of arsenic, cadmium, chromium, copper, nickel, lead, and zinc inside urban homes. *Science of the Total Environment*, 443, 520–529.
- Taner, S., Pekey, B., & Pekey, H. (2013). Fine particulate matter in the indoor air of barbecue restaurants: elemental compositions, sources and health risks. *Science of the Total Environment*, 454, 79–87.
- Tao, C., Jia, S., Cheng, Y., Cheng, F., & Xin, R. (2013). A study on geochemical baseline value and environmental background value of soils in the Chuzhou area. *Geology of Anhui*, 23(4), 286–291. In Chinese.
- Tong, S., & Lam, K. (1998). Are nursery schools and kindergartens safe for our kids? The Hong Kong study. *Science of the Total Environment*, 216, 217–225.
- Turner, A., & Ip, K. (2007). Bioaccessibility of metals in dust from the indoor environment: application of a physiologically based extraction test. *Environmental Science & Technology*, 41, 7851–7856.
- US EPA. (1989). *Risk assessment guidance for superfund (volume I) human health evaluation manual* (pp. 1–89). Washington: Office of Solid Waste and Emergency Response, US Environmental Protection Agency.
- US EPA. (1996). *Soil screening guidance: Technical background document*. EPA/540/R-95/128. Office of Solid Waste and Emergency Response.
- US EPA. (2001). *Supplemental guidance for developing soil screening levels for superfund sites*. OSWER 9355.4-24. Office of Solid Waste and Emergency Response.
- Wang, Y., Thornton, I., & Farago, M. (1997). Changes in lead concentrations in the home environment in Birmingham, England over the period 1984–1996. *Science of the Total Environment*, 207, 149–156.
- Wei, X., Gao, B., Wang, P., Zhou, H., & Lu, J. (2015). Pollution characteristics and health risk assessment of heavy metals in street dusts from different functional areas in Beijing, China. *Ecotoxicology and Environmental Safety*, 112, 186–192.
- Yoshinaga, J., Yamasaki, K., Yonemura, A., Ishibashi, Y., Kaido, T., Mizuno, K., et al. (2014). Lead and other elements in house dust of Japanese residences—source of lead and health risks due to metal exposure. *Environmental Pollution*, 189, 223–228.
- Yuan, X., Zhang, C., Sun, Q., & Wu, C. (2011). Characteristics of heavy metal concentrations in soil around coal mining area in Suzhou city. *Environmental Chemistry*, 30(8), 1451–1455. In Chinese.
- Zheng, N., Liu, J., Wang, Q., & Liang, Z. (2010). Health risk assessment of heavy metal exposure to street dust in the zinc smelting district, Northeast of China. *Science of the Total Environment*, 408, 726–733.
- Zheng, J., Chen, K., Yan, X., Chen, S., Hu, G., Peng, X., et al. (2013). Heavy metals in food, house dust, and water from an e-waste recycling area in South China and the potential risk to human health. *Ecotoxicology and Environmental Safety*, 96, 205–212.