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Spatial Distribution and Health Risk Assessment of Heavy Metals in Urban Road Dust of Guiyang, China

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ABSTRACT

Due to rapid urbanization and industrialization, most of the cities are increasingly getting diversely polluted. Pollution from heavy metals is continuously emitted in to urban environment and poses potential adverse health effects on humans. A detailed investigation is conducted to determine concentrations of six heavy metals (Pb, Cu, Zn, Cd, Cr, Ni) in urban road dust of Guiyang. The selected metals spatial distribution analysis based on geostatistical analysis, and assessed potential health risk of these heavy metals for children and adults were carried out using the US EPA model. The results show that the mean concentrations of Cd, Pb, Cr, Cu, Ni and Zn in urban road dust are 0.61, 63.12, 129.04, 129.33, 60.43 and 176.05 mg/kg, respectively, indicating that their concentrations are evidently higher than reference values. The predication map of metals distribution reveals that the relatively large concentrations of Pb, Zn, Cr, Cd and Cu are existed in the city center, while the hotspots of Ni are concentrated in the east of the city center. The health risk assessment results show that children and adults have the same trend that the mean values of D_{ing} exhibit the following order: Zn>Cu>Cr>Pb>Ni>Cd, and the mean values of HQ are in the order of Cr>Pb>Cu>Ni>Cd>Zn. However, the D_{ing} and HQ values of selected heavy metals for children are much higher than those for adults, indicating that children suffer greater potential health risk than adults due to the urban road dust of Guiyang.

INTRODUCTION

Road dust has become a common contaminant in urban environment with the process of urbanization and industrialization. Road dust is a complex mixture, which consisted of industrial dust emissions, atmospheric deposition particles, soil particles, traffic emissions, construction materials and other substances (Hopke et al. 1980, Oliva & Espinosa 2007, Manasreh 2010). Furthermore, road dust often cumulates high levels of organic pollutants and toxic heavy metal elements (Banerjee 2003, Langer et al. 2010). Due to staying in the urban environment for a long time, these hazardous substances can easily be re-suspend into the atmosphere by wind or traffic and also leached into groundwater with rain (Wang et al. 2016), which pose a wide range potential threat to human health. The previous studies have shown that road dust is an important medium of transportation and diffusion of heavy metal elements (Harrison et al. 2003, Inyang & Bae 2006, Lioy et al. 2002), and the public health impact of heavy metal elements has increasingly become one of the research hotspots around the world (Ma & Singhirunnusorn 2012, Wei et al. 2015).

Heavy metals in road dust can easily enter human bodies by dust ingestion, inhalation or dermal contact. When heavy metals are present in high concentrations in urban environment, it result in health hazards such as adversely affecting the nervous, blood forming, cardiovascular, renal and reproductive systems (Christoforidis & Stamatis 2009). In particular, children are more susceptible to the hazards of dust heavy metals by frequent hand-mouth pathway (Mielke et al. 1999, Rasmussen et al. 2001). Even though lot of scholars have assessed the health risk of dust heavy metals on the local urban environment (Gomez et al. 2002, Ferreira-Baptista & Miguelb 2005, Chen et al. 2014), there is still a growing concern for the potential health risk contribution of ingested dust to heavy metals in human. Since, similar studies have not been previously conducted in Guiyang, the present study investigated the heavy metals (Pb, Cu, Zn, Cd, Cr , Ni) in urban road dust of Guiyang. We utilized the GIS and geostatistical analysis to determine their spatial distribution characteristics, and attempted to assess health risk of heavy metals based on the health risk assessment system by US EPA. The paper results have the practical significance for both local residents in taking protective measures, and local government in alleviating heavy metal pollution in urban environment.

MATERIALS AND METHODS

Study area and sampling: Guiyang, the capital city of Guizhou Province, is an important central city in southwest

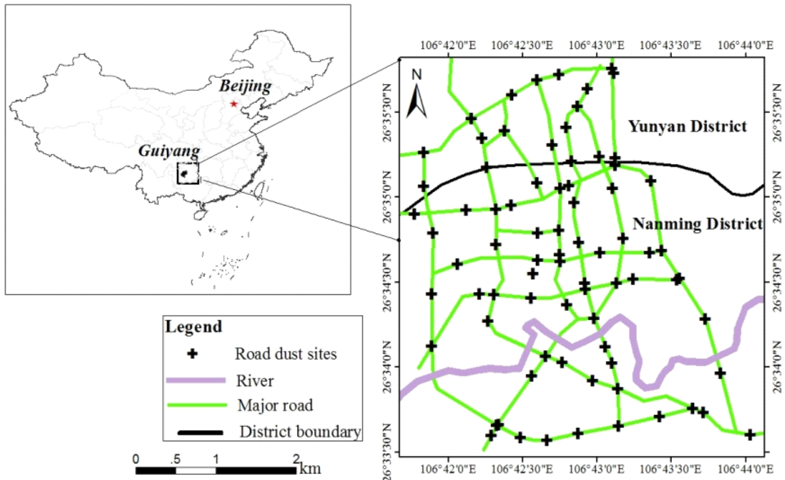

Fig. 1: Location of the study area and distribution of sampling points.

China. The area stretches from 106°07' to 107°17' E longitude and from 26°11' to 26°55' N latitudes. Guiyang has a typical subtropical monsoon humid climate with the annual average temperature and precipitation of 15.3°C and 1200 mm, respectively. According to the situations of urban transportation and road system, we selected the main urban districts (Yunyan and Nanming districts) as the study area. In total, 72 road dust samples were collected from 21 road surface edges in Guiyang (Fig. 1). Each dust sampling site was consisted of a mixture of four sub-samples and recorded using a global positioning system (GPS). In order to prevent cross-contamination, all the samples were respectively stored in polyethylene bags and transported to the laboratory. The samples were then air-dried naturally for at least two weeks.

Analytical methods: Stones, hair and other impurities in the samples were removed and then sieved through a 0.149 mm nylon sieve. Finally, each sample was thoroughly mixed and stored in polyethylene bags for analysis. Determination of the concentration of the heavy metals (Cd, Cr, Pb, Cu, Ni, Zn) was carried out by HNO_3-HCL-HF-$HClO_4$ digestion method using an inductively coupled plasma atomic emission spectrometer (ICP-OES Perkin Elmer, Optima 5300v). Certified geochemical soil reference materials GSS-1 and 20% of duplicated samples were also analysed to provide quality assurance and quality control (QA/QC) information in the experiment.

Spatial distribution analysis based on geostatistical analysis: Spatial interpolation and GIS mapping techniques were employed to produce spatial distribution maps for the six observed metals, taking the log-transformation of all non-normally distributed target variables (metal concentrations) by SPSS 22.0 (log-transformation) and Minitab 15.0 (Box-Cox transformation) software packages before using the ordinary Kriging to express the spatial variation. The statistical measures of distributions and trends of metal concentrations in Guiyang urban road dust are listed in Table 1. The skewness values indicate that most of the metal concentrations except for Cd, do not show a positively skewed pattern, therefore, the other metal concentrations were converted to a lognormal distribution. Trend analysis facilitates the concentrations and their characteristic trends, which is essential for removing a trend from the dataset before using the ordinary Kriging (Shi et al. 2008).

Health risk assessment model: Chronic daily intakes of metals: The model used in the study to calculate the exposure of human to selected metals is based on those by the Environmental Protection Agency of United States (US EPA) (Chang et al. 2009, Zheng et al. 2010a). Humans are exposed to contaminants via ingestion, dermal contact and inhalation. In comparison with hand-to-mouth ingestion, the other two exposure routes are considered negligible. The chronic daily ingestion (D_{ing}) via oral ingestion of dust particles is estimated as shown in eq. (1):

$$D_{ing} = C \times \frac{IngR \times EF \times ED}{BW \times AT} \times 10^{-6} \quad ...(1)$$

Where, C represents the heavy metal concentrations in dust (mg/kg), $IngR$ is the ingestion rate, assumed to be 200 mg/day for children and 100 mg/day for adults (US EPA 1996), EF is the exposure frequency, taken as 350 day/year, ED is exposure duration, assumed to be 6 years for children and 24 years for adults (US EPA 2001), BW denotes the average body weight, 15 kg for children and 70 kg for adults, AT is the average time, 365×ED days for both children and adults (US EPA 1996).

Table 1: Metals distribution patterns and trends in urban road dsut.

Metal	Skewness	Kurtosis	Distribution pattern	Kolmogorov-Smirnov	Trend pattern
Cd	-0.07	5.44	Normal	0.200	Fist-order
Pb	2.03	8.86	Lognormal	0.189	Fist-order
Cr	1.03	5.36	Lognormal	0.200	Second-order
Cu	1.45	6.13	Lognormal	0.200	Second-order
Ni	1.03	4.01	Lognormal	0.200	Second-order
Zn	0.86	3.34	Lognormal	0.200	Second-order

Health risk indexes of metals: To assess the chronic health risk only via ingestion, Hazard Quotient (HQ) is calculated according to eq. (2) :

$$HQ = \frac{D_{ing}}{RfD} \qquad ...(2)$$

Where, RfD is the reference dose, values of ingestion for Cd, Pb, Cr, Cu, Ni and Zn are 1.00E-03, 3.50E-03, 3.00E-03, 4.00E-03, 2.00E-02 and 3.00E-01, respectively mg/kg day^{-1} (Ma et al. 2016). If the D_{ing} value is lower than the RfD value, it is indicated that the adverse health effect is insignificant, otherwise, is significant. An HQ value greater than 1 is considered safe; otherwise, it denotes a possible adverse health risk for consumers.

RESULTS AND DISCUSSION

Descriptive statistics of heavy metal concentrations: The descriptive statistics of heavy metals from road dust in Guiyang are summarized in Table 2. The soil background value of Guizhou (Wang 1995) and China (CNEMC 1990) are used as the reference values. The range of the concentrations of Cd, Pb, Cr, Cu, Ni and Zn are 0.04~1.09, 24.65~177.70, 61.72~251.10, 45.60~331.10, 32.10~118.70 and 67.14~338.20 mg/kg, respectively, with the mean values of the mean concentrations of 0.61, 63.12, 129.04, 129.33, 60.43 and 176.05 mg/kg, respectively. The mean values of the six observed heavy metals greatly exceed the reference values, and especially for Cd, Pb, Cu and Zn the mean concentrations are more than 2 times greater than the soil background values of Guizhou. The coefficient of variation (CV) is used as the reference index that reflected differentiation of distribution and pollution levels of heavy metals in the study area. If CV>36% is high variation, 16% < CV≤36% is moderate variation, and CV≤16% is low variation. As can be seen from Table 2, the coefficients of variation of Pb and Cu (high variation) are relatively higher than other metals, which demonstrated that these two kinds of measured metal concentration variations in the investigated samples are large as well as show the strong influences of anthropogenic activities on their concentrations. Therefore, the researchers investigating metal pollution of road dust need to pay more attention to the elements like Pb and Cu in future research.

Spatial distribution of heavy metal concentrations: The predication map of metals distribution in urban road dust of Guiyang is illustrated in Fig. 2. The spatial distribution patterns of Pb, Zn, Cr, Cd and Cu (Fig. 2a-b, d-f) in urban road dust are generally similar, with relatively large concentrations existing in the city center (mainly distributed in Nanming district) for the five metals. Moreover, it is interesting to note that the five metals in road dust are significantly accumulated near the trunk road connecting inner-ring traffic. However, Ni concentration shows dissimilar distribution pattern from other metals concentration and the hotspots existing in the eastern part of the city (Fig. 2c), indicated that probably have different anthropogenic sources.

In general, the investigated metals display different distribution patterns in urban road dust of Guiyang, the reasons for this are the disturbance of anthropogenic activities in urban environment, e.g. traffic contamination, industrial dust emission, or urban construction. Additionally, it is observed that metal concentrations in urban road dust are higher on the Nanming district than those in the Yunyan district, which is probably associated with the near surface layer prevailing wind, under the control of the northeast wind, the atmospheric particulate pollutants are mostly deposited and distributed in Nanming district. Therefore, it follows that the prevailing wind may be another important factor affecting the metal concentration distribution in urban road dust of Guiyang.

Health risk assessment: The study is based on measuring data for heavy metals in combination with the health risk assessment model recommended by the US EPA. The chronic daily ingestion (D_{ing}) and Hazard Quotient (HQ) of heavy metals for both children and adults are listed in Table 3.

For children, the range of the D_{ing} of Cd, Pb, Cr, Cu, Ni and Zn are 5.11E-06~1.40E-04, 3.15E-03~2.27E-02, 7.89E-03~3.21E-02, 5.83E-03~4.23E-02, 4.10E-03~1.52E-02 and 8.58E-03~4.32E-02, respectively, with the mean values of of 7.76E-05, 8.07E-03, 1.65E-02, 1.66E-02, 7.73E-03 and

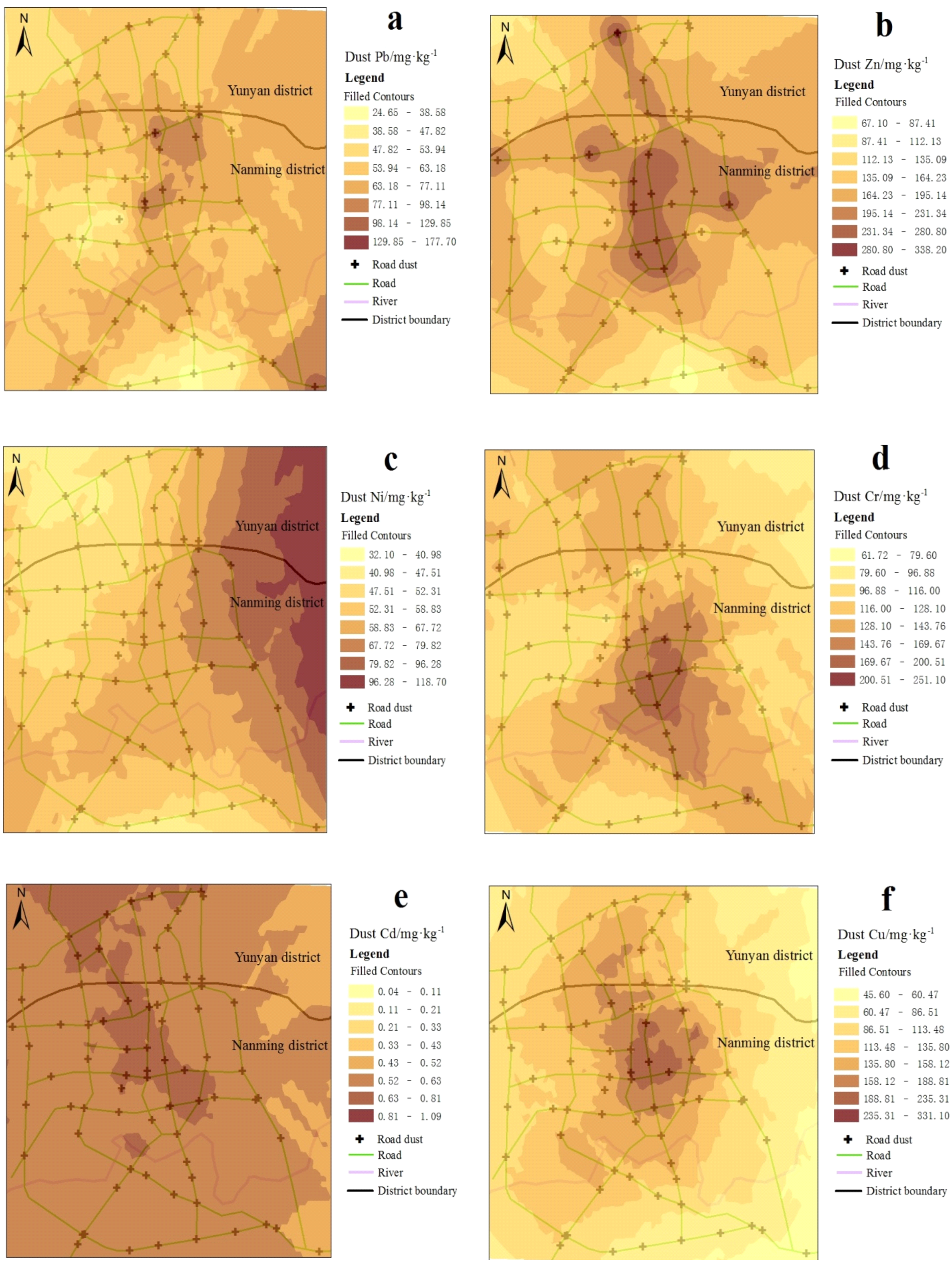

Fig. 2: Prediction maps of heavy metals distribution in urban road dust of Guiyang.

Table 2: Statistic values of heavy metal concentrations in road dust and reference values (mg/kg).

Parameter	Cd	Pb	Cr	Cu	Ni	Zn
Minimum	0.04	24.65	61.72	45.60	32.10	67.14
Maximum	1.09	177.70	251.10	331.10	118.70	338.20
Mean	0.61	63.12	129.04	129.33	60.43	176.05
SD (standard deviation)	0.15	25.90	33.54	52.84	17.74	53.36
CV (coefficient of variation), %	25.19	41.04	25.99	40.86	29.35	30.13
Background value of Guizhou	0.13	29.30	86.60	25.70	33.70	82.40
Background value of China	0.08	23.50	57.30	20.70	24.90	68.00

Table 3: Chronic daily ingestion and hazard quotient of selected metals.

		Cd		Pb		Cr		Cu		Ni		Zn	
		Children	Adults	Children	Adults	Children	Adults	Children	Adults	Children	Adults	Children	Adults
D_{ing}	Min	5.11E-06	5.48E-07	3.15E-03	3.38E-04	7.89E-03	8.45E-04	5.83E-03	6.25E-04	4.10E-03	4.40E-04	8.58E-03	9.20E-04
	Max	1.40E-04	1.50E-05	2.27E-02	2.43E-03	3.21E-02	3.44E-03	4.23E-02	4.54E-03	1.52E-02	1.63E-03	4.32E-02	4.63E-03
	Mean	7.76E-05	8.31E-06	8.07E-03	8.65E-04	1.65E-02	1.76E-03	1.66E-02	1.77E-03	7.73E-03	8.28E-04	2.25E-02	2.41E-03
HQ	Min	5.11E-03	5.48E-04	9.00E-01	9.65E-02	2.63E+00	2.82E-01	1.46E-01	1.56E-02	2.05E-01	2.20E-02	2.86E-02	3.07E-03
	Max	1.40E-01	1.50E-02	6.49E+00	6.95E-01	1.07E+01	1.15E+00	1.06E+00	1.13E-01	7.59E-01	8.13E-02	1.44E-01	1.54E-02
	Mean	7.76E-02	8.31E-03	2.31E+00	2.47E-01	5.50E+00	5.89E-01	4.13E-01	4.43E-02	3.86E-01	4.14E-02	7.50E-02	8.04E-03

2.25E-02, respectively. The mean values of D_{ing} of calculated heavy metals in urban road dust exhibit the following order: Zn>Cu>Cr>Pb>Ni>Cd. Several D_{ing} of Pb, Cu and Cr in dust samples exceeded the *RfD* value limit, respectively, suggesting that there likely existed some adverse health effect for children. The mean values of *HQ* of selected heavy metals are in the order of Cr>Pb>Cu>Ni> Cd>Zn, especially the mean values of Cr and Pb all are higher than 1 threshold, implying significant health risk for children. Contacted by children in large enough doses of lead contaminated dust can trigger neurological and developmental disorders (Zheng et al. 2010b). Meanwhile, chromium is one of the essential trace elements in human, but excessive intake can cause skin cancer, hepatitis, nephritis, conjunctivitis and other diseases. Therefore, the potential health risk from exposure to Pb and Cr are not negligible.

For adults, the range of the D_{ing} for Cd, Pb, Cr, Cu, Ni and Zn is 5.48E-07~1.50E-05, 3.38E-04~2.43E-03, 8.45E-04~3.44E-03, 6.25E-04~4.54E-03, 4.40E-04~1.63E-03 and 9.20E-04~4.63E-03, respectively, with the mean values of 8.31E-06, 8.65E-04, 1.76E-03, 1.77E-03, 8.28E-04 and 2.41E-03, respectively. The mean values of D_{ing} of calculated heavy metals in urban road dust exhibit the following order: Zn>Cu>Cr>Pb>Ni>Cd. Several D_{ing} of Cr in dust samples exceeded the *RfD* value limit. The mean values of *HQ* of selected heavy metals are lower than the threshold value, and the order of *HQ* for adults is Cr>Pb>Cu>Ni> Cd>Zn, indicating insignificant health adverse effect for adults. However, the highest value of Cr (*HQ*=1.15) is higher than 1, it is implied that there would be existed slight health risk.

The results obtained in the study show that the values of D_{ing} and *HQ* of heavy metals in ingestion exposure route for both children and adults have the same trend. However, the D_{ing} and *HQ* values of selected heavy metals for children are much higher than those for adults, indicating that children suffer greater potential health risk than adult in urban road dust of Guiyang. This conclusion is particularly significant when one considers the fact that implementing to minimize the contact with the hazardous particulates of road dust, would effectively reduce the potential health risk of heavy metals for children.

CONCLUSIONS

Urban road dust from Guiyang was collected, the concentration of the six heavy metals was measured, the spatial distribution of these metals was analysed, and their potential health risk was assessed. The following conclusions are based on the analytical findings: (1) The mean concentrations of Cd, Pb, Cr, Cu, Ni and Zn greatly exceed the reference values. However, the values of CV of Pb and Cu are relatively higher than other metals, which indicate that the two metal concentrations have been greatly affected by anthropogenic activities. (2) The predication map of metal distribution in urban road dust of Guiyang helped to identify several hotspots, most of which are located at the city center, the east of the city center or in regions near trunk road, which implies that the influence of traffic and industrial activities can promote accumulation process of metals in road dust. Additionally, the study also observed that the prevailing wind may be another important factor affecting metal concentration distributions in urban road. (3) The health risk assessment revealed that the D_{ing} and HQ values of the selected heavy metals for children are much higher than those for adults, beside, the mean values of HQ of Cr and Pb all are higher than 1 for children, indicating that children suffer greater potential health risk in urban road dust. Therefore, protection measures should be adopted to minimize the contact, which children have with the contaminated road dust in Guiyang.

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