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Assessment of Heavy Metals Contamination in Road Dust From Different Functional Areas in Guiyang, Southwest , China

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ABSTRACT

In recent years, the new environment pollution has become very serious in many cities, including atmospheric, particularly urban road dust through re-suspension into the atmosphere, which not only affects the environmental system but is also having a negative impact on human health. The article presents the results of a study of contaminants in road dust of different functional areas of Guiyang, the data indicated that the concentration of all analyzed heavy metals except for As were evidently higher than background values of Guizhou. In attempt to identifying the source of metals through correlation coefficient analysis and principal component analysis, the source analyses implied that As mainly derived from local soil and Ni existed the mixed sources of natural and anthropogenic, Hg, Cd, Cr, Cu and Zn were affected by industrial activities and vehicle emissions, while Pb largely originated from construction source and outside regional of Guiyang. Potential ecological risk index indicated that all of the study areas demonstrated “considerable category” risk index. Road dust increased along with city growth and it dynamics, the obtained results can serve as a theoretical source for urban environmental quality monitoring and management.

KEYWORDS
Contamination assessment; Heavy metals; Road dust; Functional areas; Guiyang

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Introduction

Road dust is one of the most common pollutants in the rapid urbanization and industrialization context in the world. Urban dust has been reported in many countries which contain toxic organic and inorganic pollutants, especially trace metals(Saeedi et al. 2012 ; Shi et al. 2008 ; Ahmed & Ishiga 2006). Trace

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metals in road dust may originate from various sources in urbanized areas, including industrial dust discharges, traffic emissions, atmospheric deposition and other anthropogenic activities, as well as natural geochemical processes(Hopke et al. 2002；Oliva & Espinosa 2007; Manasreh 2010). These toxic metals can remain in urban environments for a long time or be re-suspended into the atmosphere, they can be easily entered the human body likely occurs direct inhalation, ingestion and skin contact(Li et al. 2001；Cook et al. 2005；Aelion et al. 2008；Kong et al. 2011). There are substantial evidences that high metal contamination level on environment mainly cause growth retardation and effect behaviour and intelligence in children, as well as other chronic diseases in adults(Dietrich et al. 1990；Bellinger et al. 1990；Mcmichael et al. 1985). Therefore, road dust poses a potential threat to local environmental quality and public health(Oskarson et al. 1995).

During the recent decades, there have been a number of studies on toxic metals in road dust. Some researchers found that the concentration and spatial distribution of toxic metals in urban road dust were associated with the urban different land uses and human activities(Wang et al. 2016). The contaminants like Cu, Ni, Pb and Zn mainly concentrated in heavy traffic area and tourism area (Al-khashman O.A. 2013；Wei et al. 2015); the concentration of Cd and Cr were affected by industrial activities(Martinez & Poleto 2014). Generally, the higher anthropogenic heavy metals in dust mainly from heavy traffic sites and industrial sites(Herngren et al. 2006；Al-khashman O.A. 2007).

Guiyang lies on southwest China, developing rapidly, there are no extensive surveys on road dust and even fewer data available on heavy metals in road dust from different functional areas. The main objectives of the present work are to 1)determine metals concentration in road dust from different functional areas, 2)investigate the selected metals possible sources, and 3)calculate the potential ecological risk index to assess the pollution level of heavy metals on environment. The results of this research are intended to provide scientific information for the ecological city construction of Guiyang city.

Materials and methods

Study area

Guiyang , the capital city of Guizhou Province which is located in Yunnan-Guizhou Plateau slope zone in China, and it is situated beween 106°07′—107°17′E and 26°11′—26°55′N, it has a typical subtropical monsoon humid climate with the annual average temperature and precipitation of 15.3℃ and 1200mm, respectively, it covers an area of 8034km^2 with the population of 4.6218 million in 2015. Guiyang is the important center city of southwest region of China and the ecological leisure tourism city, as well as a gathering area of the leading big data technology innovation and application service demonstration in China. In order to adapt to the development of the city, there were gradually formed north-south and east-west traffic route network between the two old districts(Yunyan district and Nanming district). By the end of 2010, there were more than 610,800 cars registered in Guiyang, and the numbers are still increasing.

Sampling and analytical methods

A total of 79 road dust samples were collected from different functional areas in Guiyang city during the dry weather period, i.e. industrial area(IA)(N=2), business area(BA) (N=45) , traffic area(TA)(N=15), educational area(EA)(N=5), residential area(RA)(N=8) and public area(PA)(N=4), The study areas and all road dust sampling sites from different functional areas in Guiyang city(Fig.1). In this study, 1m×1m grids were applied on each traffic road surface edge, a mixture of multi-point samples were collected in polyethylene bags by sweeping with a clean plastic brush to be representative of each grid.

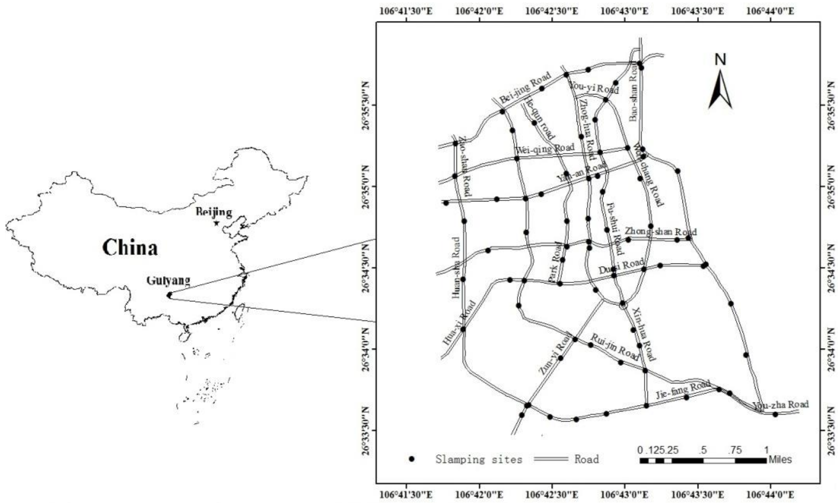

Figure 1. The sampling sites in Guiyang city

The dust samples were air-dried naturally in the laboratory for at least 2 weeks and then sieved through a 0.84mm nylon sieve to remove extraneous matter such as small paving stones, hair and other impurities. Then each dried dust sample was separated using the quartering method and sieved through a 0.149mm nylon sieve, and finally all the samples respectively stored in polyethylene bags, which aims to prevent cross-contamination. Determination the concentration of total heavy metals(Cd, Cr, Pb, Cu, Ni, Zn) was carried out according to the hydrochloric acid , nitric acid, hydrofluoric acid and perchloric acid digestion method, and they were measured using an inductively coupled plasma atomic emission spectrometer(ICP-OES Perkin Elmer, Optima 5300v). The concentration of Hg was digested using sulfuric acid, nitric acid, and potassium permanganate, and detected by cold atomic absorbent spectrophotometry(Perkin-Elmer, AA-800). The concentration of As was digested using sulfuric acid, nitric acid, and perchloric acid, and detected by atomic fluorescence spectroscopy(Perkin-Elmer, AF-640). Certified geochemical soil reference materials GSS-1 and GSS-2 and 20% of duplicated samples were also analyzed to provide quality assurance and quality control (QA/QC) information in the experiment.

Statistical methods of data and pollution indices

In this study, the description statistical of heavy metals in the samples from different functional areas, including mean concentration, maximum, minimum and coefficient of variation(CV) were calculated with Excel 2007. To identify the source and to determine the relationship among the heavy metals, the correlation coefficient analysis(CA) and principal component analysis(PCA) were performed with SPSS 17.0.

Hakanson's method (1980) has been used to reflect potential ecological risk of each metal and associates their contamination level and toxicity level in dust(Ogunkunle & Fatoba, 2013). The calculation method as follows:

$$C_r^i = C_i / C_n \quad (1)$$

$$C_d = \sum C_r^i \quad (2)$$

$$E_r^i = T_r \times C_r^i \quad (3)$$

$$RI = \sum E_r^i \quad (4)$$

where, C_i is the measured concentration of a road dust sample, C_n is the background value, C_r^i corresponds to the pollution factor for each metal and C_d corresponds to the pollution factor of multiple heavy metals, E_r^i shows the potential ecological risk of each metal, RI is the potential ecological risk index of multiple heavy metals, T_r is the toxic response coefficient that are Hg(40), Cd(30), As(10), Cu(5), Pb(5), Ni(5), Cr(2) , Zn(1), respectively. Classification of heavy metal contamination and potential ecological risk assessment are showed in Table 1.

Table 1. C_d, E_r^i, RI, the corresponding pollution degree and potential ecological risk degree

C_d		E_r^i		RI	
Value	Category	Value	Category	Value	Category
<8	Low	<40	Low	<150	Low
8～16	Moderate	40～80	Moderate	150～300	Moderate
16～32	Considerable	80～160	Considerable	300～600	Considerable
≥32	Very high	160～320	High	≥600	Very high
		≥320	Very high		

Results and discussions

Heavy metals concentration

The descriptive statistics of Hg, Cd, As, Pb, Cr, Cu, Ni and Zn concentration and summary statistics of road dust samples collected from different functional areas in Guiyang city , as well as background values are showed in Table 2. Compared to the soil background value of Guizhou, the elements of Hg, Cd, Pb, Cr, Cu, Ni and Zn had evidently elevated, which respectively are 25.29-0.98, 8.80-0.30, 12.15-0.84, 4.93-0.70, 13.0-1.77, 4.34-0.95, 7.75-0.81 times the corresponding background values. The coefficients of variation is used to indentify the heavy metals pollution sources from natural or anthropogenic activities(Li et al. 2006 ; Li et al. 2008). In the study, the elements of Hg, Pb, C u and Zn of the coefficients of variation are 91.38%, 62.38%, 44.38% and 42.09% , respectively, which suggested that their concentration have been affected by anthropogenic activities. IA has the higher concentration of road dust samples, particularly Hg, As, Pb, Cr and Ni. The Zn concentration in raod dust samples from EA is the highest. The concentration of Cd and Cu collected from PA are evidently higher than other functional areas. The diversities of heavy metals concentration from different functional areas may be affected by potential sources and anthropogenic activities.

Table 2. Mean concentration of heavy metals in road dusts from different functional areas in Guiyang and reference values and some domestic cities (mg kg^{-1})

Elements	Hg	Cd	As	Pb	Cr	Cu	Ni	Zn
IA	0.64	0.51	12.57	119.32	140	88.1	70.23	146.04
TA	0.38	0.61	11.16	57.82	138.1	136.1	58.91	180.45
BA	0.35	0.63	11.21	69.91	111.25	115.9	55.81	160.62
RA	0.34	0.53	12.22	122.41	140.14	140.5	68.34	175.98
EA	0.31	0.65	11.11	61.41	119.37	115.5	72.04	251.89
PA	0.53	0.72	12.19	89.16	131.26	164.2	68.62	239.06
Maximum	2.58	1.17	19.23	356.1	427.1	334.3	146.2	639
Minimum	0.10	0.04	7.15	24.65	60.59	45.6	32.1	67.14
Mean	0.379	0.618	11.281	67.805	131.225	129.803	61.073	185.976
CV(%)	91.13	27.94	19.99	62.38	36.51	44.38	33.19	42.09
Background value of Guizhou[a]	0.102	0.133	13.3	29.3	86.6	25.7	33.7	82.4
Beijing[b]	—	0.47	—	50.40	77.45	64.23	23.70	—
Shanghai[c]	—	1.23	—	294.9	159.3	196.8	83.98	733.8
Suzhou[d]	0.18	2.45	13.4	262.2	25.7	104.8	14.7	376.9
Baoji[e]	1.1	—	19.8	433.2	126.7	123.2	48.8	715.3
Urumqi[f]	—	1.17	—	53.53	54.28	94.54	43.28	294.47

— no data, CV coefficient of variation, [a] Wang et al. 1995, [b] Tang et al. 2013, [c] Shi et al. 2008,

[d]Ma et al. 2016, [e] Lu et al. 2010, [f] Wei et al. 2009

Comparison of heavy metal contents in road dust with some cities are given in Table 2. The mean concentration of Cr, Cu and Ni in road dust from Guiyang are lower than Shanghai, while higher than these for other comparison cities. The Zn and As concentration in road dusts from Guiyang are the lowest among the compared cities. The Cd and Pb concentration in samples from Guiyang are higher than Beijing, while lower than Shanghai and Suzhou. The mean concentration of Hg in samples from Guiyang is between that Suzhou and Baoji. The different concentration levels of heavy metals in road dust are related with natural and anthropogenic sources, as well as the physicochemical properties of the road dust. The source identification of heavy metals in road dust from different functional areas in Guiyang will be further analyzed in the following part.

Correlation coefficient analysis result

The Pearson's correlation coefficients of all measured heavy metals in road dust from different functional areas in Guiyang city are summarized in Table 3. A significantly positive correlation at $P<0.01$ was found between the elemental pairs Hg-Cu(0.391), Cd-Cr(0.388), Cd-Cu(0.501), Cd-Zn(0.371), Cr-Cu(0.572) and Cu-Zn(0.415), which demonstrated that elements of Hg, Cu, Cr, Cd and Zn in road dust samples from different functional areas have common sources, mutual dependences, and identical behaviors during the transport (Lu et al. 2010) . Ni and As had a positive correlation coefficient(0.274), this indicated that they may exist similar sources. However, Pb found at high concentration in different functional areas(Table 2), but shown not positive correlated with other heavy metals studied, implying that its anthropogenic sources might be differing from the other materials.

Table 3. Correlation coefficient of heavy metals in road dusts from different functional areas in Guiyang

	Hg	Cd	As	Pb	Cr	Cu	Ni	Zn
Hg	1							
Cd	0.238*	1						
As	-0.219	-0.204	1					
Pb	-0.147	0.037	0.218	1				
Cr	0.188	0.388**	0.081	0.102	1			
Cu	0.391**	0.501**	-0.630	0.056	0.572**	1		
Ni	-0.108	-0.097	0.274*	-0.099	0.252*	0.056	1	
Zn	0.011	0.371**	0.012	0.074	0.288*	0.415**	0.112	1

* Correlation is significant at $P<0.05$, ** Correlation is significant at $P<0.01$

Principal component analysis result

Principal component analysis can be used to distinguish the source of pollutions more accurately, which extracting the eigenvalues from the correlation matrix and calculating significant factors and the percent of variance(Möller et al. 2005). The results of statistical analysis are displayed in Table 4. There are three eigenvalues higher than one and that three factors explain 66.44% of the total variance. Factor 1 accounts for 34.42% of the total variance, which is dominated by Hg, Cd, Cr, Cu and Zn. Factor 2 explains about 18.22% of the total variance and presents hight loadings of As and Ni. Factor 3 is loaded primarily by Pb that has a high loading value(0.85) and accounts for 13.8 of the total variance, which may imply quasi-independent behavior within the group. The three-dimensional space in Fig.2 is more intuitively reflect the relations among the heavy metals of road dust.

Table 4. Principal component analysis data of heavy metals in road dusts from different functional areas in Guiyang city

Element	Factor 1	Factor 2	Factor 3
Hg	0.75	0.09	0.12
Cd	0.64	-0.47	0.04
As	0.02	0.82	0.16
Pb	0.19	0.29	0.85
Cr	0.82	0.18	-0.09
Cu	0.80	-0.13	-0.06
Ni	0.21	0.65	-0.56
Zn	0.62	-0.05	-0.07
Eigenvalue	2.75	1.46	1.10
Variance contribution rate(%)	34.42	18.22	13.80
Cumulative variance contribution rate(%)	34.42	52.64	66.44

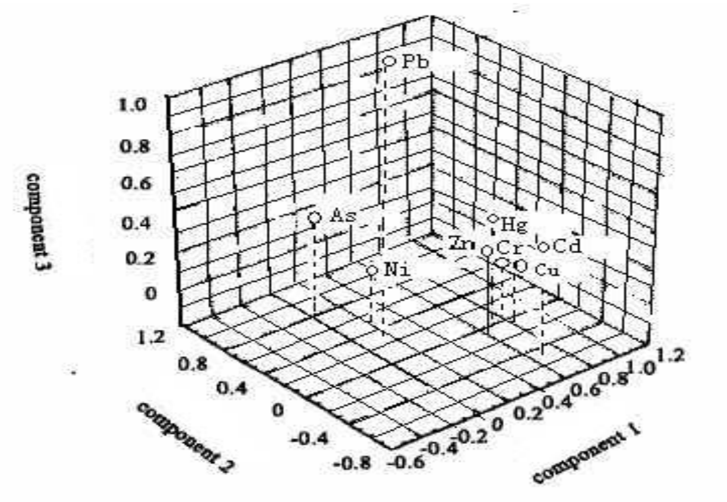

Figure 2. Loading plots of the heavy metals in road dusts in the space distribution by three-components

Source identification

The coefficients of variation and mean concentrations demonstrated that all analyzed heavy metals in road dust samples except for As were mainly affected by anthropogenic activities. The mean concentration of element As in road dust samples from different functional areas were less than the corresponding soil background value of Guizhou, which indicated that it mainly originated from local soil. As and Ni had a positive correlation coefficient (Table 3) and PCA(Table 4), implying Ni partly derived from local soil, while Ni and Cr are also positive correlation(0.252) and the coefficients of variation of Ni is relatively high(33.19%), which implied that Ni likely also arise from anthropogenic sources. In conclusion, Ni has the mixed sources of natural and anthropogenic.

The mean concentration, coefficients of variation of Hg, Cd, Cr, Cu and Zn in road dust from different functional areas in Guiyang city indicated that they were evidently affected by anthropogenic activities. The elemental pair Hg-Cd-Cr-Cu-Zn have significantly positive correlation(Table 3) and strongly correlation in PCA(Table 4), implying they have the common sources. Cr was extensively used to produce stainless steel, automobile parts, aluminum alloy, and titanium alloy(Chen et al. 2014). Al-Khashman(2004) found the Cu and Zn to be strongly associated with the mechanical abrasion of vehicles. Cd was associated with deterioration of tyres and engine parts(Ferguson and Kim 1991). The Guizhou Province has rich mercury resources which associated with industrial manufacturing activities, therefore, the concentration of Hg was affected by industrial wastewater , waste gas and dust discharges. The highest concentration of Hg(2.578 mg kg^{-1}), Cd(1.17 mg kg^{-1}), Cr(427.1 mg kg^{-1}) and Cu(334.3 mg kg^{-1}) were found in the road dust samples which collected from TA, the higher concentration of Zn was concentrated in EA and TA, as mentioned above, these five metals in road dust are concentrated in the heavy density traffic areas and dense buildings where more emissions of vehicles and industries over time result in heavy metals being emitted to the surrounding environment and impeded the dispersion. It can be concluded that Hg, Cd, Cr, Cu and Zn in road dust important pollutant sources from industrial activities and vehicle emissions represent for the studied area.

Pb is not correlated with other heavy metals and separated from other heavy metals in PCA(Fig.2), meaning quasi-independent behavior within the group. The coefficient of variation of Pb is relatively higher(62.38%) and the mean concentration in road dust samples form different functional areas are clearly higher than the background value of soil in Guizhou, which demonstrated that Pb in road dust form different functional areas in Guiyang city is mainly affected by human activities. According to Al-momani(2009), Pb derived from vehicular emission and previous usage and leak of leaded gasoline, and Faiz et al(2009) also found that Pb was strongly associated with emission from fossil fuels, brick kilns and industrial activities. Meanwhile, Pb was widely used in pigment, paint and coating material. It may explain why the concentration of Pb in road dust samples from RA and IA are higher than other studied areas. There are a lot of housing and building construction sites in RA and IA due to building materials and industrial raw materials, this indicated that Pb in road dust samples from RA and IA mainly originated from construction source. However, there were also high concentration in other studied areas, it is probable that Pb exists a source outside regional of Guiyang.

Potential ecological risk

To assess the intensity of all analyzed heavy metals contaminations and related risks, Table 5 presents the potential ecological risk in road dust from different functional areas in Guiyang city.

Combined these results with the criteria(Table 1), the results showed that all of the study areas demonstrated "considerable category" risk index(RI) and the pollution factor of multiple heavy metals(C_d). IA and PA showed the higher RI value and C_d value of the road dust samples, this also demonstrated that anthropogenic activities are the major source of road dust contamination in those two areas. The lowest RI value for road dust samples from RA, residential area are relatively far from major streets and traffic account for the lowest potential ecological risk index in these sampling locations. However, RA equally showed a high C_d value, indicating origins other than traffic or other localized contaminated particles from other regions wroth investigating.

The mean E_r^i values of all analyzed metals were in the following order: Hg > Cd > Cu > Pb > Ni > As > Cr > Zn. The mean E_r^i value of Hg was at high potential ecological risk and the mean E_r^i value of Cd was at considerable potential ecological risk in the sampling areas. The mean E_r^i values of As, Pb, Cr, Cu, Ni and Zn were in the range of 2.33 ~ 24.38, reflecting a low average potential ecological risk and these metals may not harm the ecosystem. The contribution ration of heavy metals to the potential ecological risk index from different functional areas in Guiyang city are shown in Fig.3, in road dust samples, the total contribution ration of Hg and Cd in high potential ecological risk group from IA, TA, BA, RA, EA and PA were 85.76%, 83.04%, 83.39%, 77.65%, 82.28% and 83.66%, respectively, which indicated that Hg and Cd pose a potentially high risk to the local ecosystem and some management modes of ecological concept and the sustainable development should be adopted in Guiyang city.

Table 5. Index of potential risk parameter of heavy metals in road dusts from different functional areas in Guiyang city

	E_r^i								RI	C_d
	Hg	Cd	As	Pb	Cr	Cu	Ni	Zn		
IA	250.8	114.9	9.4	20.35	3.22	15.6	10.4	1.77	426.44	23.69
TA	148.8	137.4	8.3	9.65	3.18	26.45	8.7	2.19	344.67	21.87
BA	137.2	141.9	8.4	11.9	2.56	22.55	8.25	1.94	334.7	20.76
RA	133.2	119.4	9.1	20.85	3.22	27.3	10.1	2.13	325.3	23.61
EA	121.2	146.4	8.3	10.45	2.74	22.45	10.65	3.05	325.24	21.87
PA	207.6	162.3	9.1	15.2	3.02	31.9	10.15	2.9	442.17	27.37
Mean	166.47	137.05	8.77	14.73	2.99	24.38	9.71	2.33	366.42	23.20

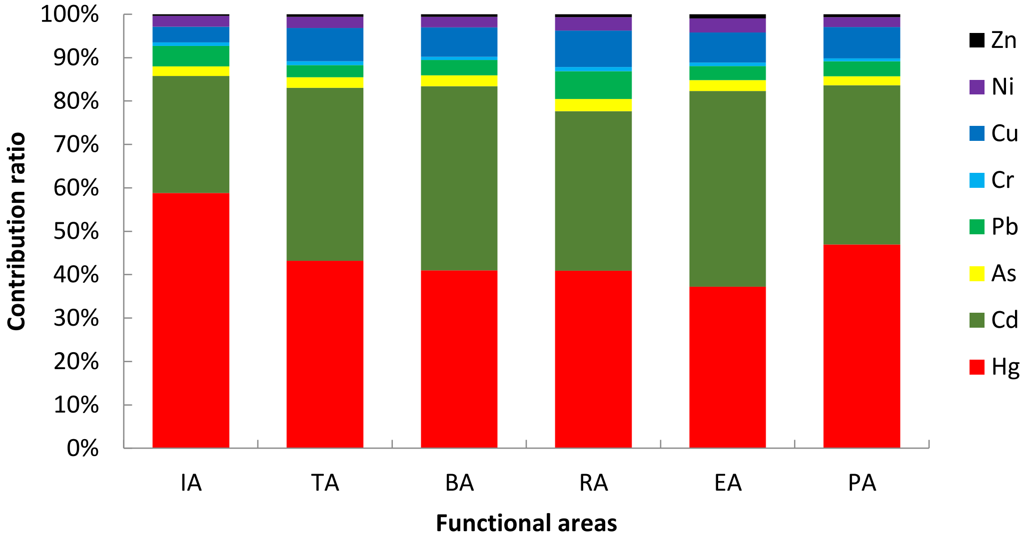

Figure 3. Contribution rates of heavy metals to the potential ecological risk indices(RI)

Conclusions

The road dust from different functional areas in Guiyang had evidently elevated Hg, Pb, Cr, Cu, Ni and Zn concentration. Heavy metals from six functional areas had different variation characteristics. Industrial area has the higher concentration of road dust samples, particularly Hg, As, Pb, Cr and Ni. The Zn concentration in road dust samples from educational area is the highest. The concentration of Cd and Cu collected from public area are closely higher than other functional areas. Correlation coefficient analysis and principal component analysis results demonstrated that the elements of Hg, Cu, Cr, Cd and Zn in road dust samples had similar sources which from industrial activities and vehicle emissions, and As and Ni also had a common source which is the local soil, in addition , Ni might also arised from anthropogenic sources, while Pb existed quasi-independent behavior within the group and derived from mixed sources of construction source and outside regional of Guiyang. The concentration, spatial distribution and main source in road dust from different functional areas are closely related to land utilization types and anthropogenic activities.

All of the study areas demonstrated "considerable category" risk index and the pollution factor of multiple heavy metals, particularly industrial area and public area. The elements of As, Pb, Cr, Cu, Ni and Zn in road dust from different functional areas reflected a low average potential ecological risk, while Hg and Cd posed a potentially high risk to all sampling locations in Guiyang, their toxicity, health risks and enrichment factors need further detailed studies.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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