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Occurrence, Distribution, and Assessment of Heavy Metals in Roadside Dusts in Universities in Beijing, China

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Abstract. A detailed study was conducted to determine the current statues of the heavy metals in roadside dusts collected from universities in Beijing, China. Twelve universities were selected and analyzed to determine the occurrence, distribution, and assessment of heavy metals in roadside dusts. The results showed that Cr, Cu, Zn, Cd and Pb exhibited higher metal concentrations than the local soil background values, indicating that the pollution may come from anthropogenic input. The assessment by Geoaccumulation Index (I_{geo}) indicates that Cr and Ni are at the unpolluted level, Cu and Zn at the slightly polluted level, Cd and Pb at the moderately contaminated. The pollution level was in the following order: Cd > Pb > Zn > Cu > Cr > Ni.

Introduction

Road dusts are a major contributor for metal pollutants in big cities [1]. The heavy metals in roadside dusts may come from vehicle exhaust particles, tire wear particles, weathered street surface particles, brake lining wear particles, and coal combustion, metallurgical industry, power plants, auto repair shop, chemical plant and make a significant contribution to the pollution in the urban environment[2-6]. Due to being non-bioavailability, non-biodegradability and long-standing existence, the heavy metals exceedingly accumulated in road dust may result not only in heavy metal contamination of the soils but also in increased human exposure to heavy metals due to their close proximity to human activities. The high concentration of heavy metals in urban road dust have been considered deleterious effect on human health, due to it can be easily transferred into human bodies with floated dust or by direct contact, breathing or dust ingestion under dynamic conditions such as wind, traffic, human activities, and so on[7].

Beijing, the capital of China, is the political, economic and cultural central of China. Beijing also is one of the oldest and most densely populated in the world. During the past decades, Beijing has acquired rapid development in urbanization and industrialization. However, the fast development has exerted a lot of pressure on its urban environment. Previous researches showed that the heavy metals pollution occurred in surface urban soils of Beijing during the past two decades. But spatial distribution of heavy metals in roadside dusts collected from universities in urban environment and the health risk assessment of heavy metals in road dusts of universities were still unknown. The objectives of the present study were to: (1) determine the current status of heavy metals concentrations and spatial patterns in roadside dusts collected from different universities in Beijing; (2) evaluate and assessment heavy meals pollution in roadside dust by the Geoaccumulation Index

Materials and Methods

Beijing, the capital of China, is situated at the northern tip of the roughly triangular North China Plain, with its center located at 39.9N and 116.4E. The city is surrounded by mountains in its west, north and northeast. As one of the four municipalities in China, it consists of 18 administrative districts (counties), among which eight districts constitute the urban area. The urban area of Beijing is situated in the south-central part of the municipality and occupies an expanding part of the municipality's area.

It spreads out of the concentric ring roads, of which the 6th Ring Road passes through several satellite towns. The city has a typical monsoon-influenced climate, characterized by hot, humid summers due to the East Asian monsoon, and generally cold, windy, dry winters due to the vast Siberian anticyclone. Its annual temperature is about 11.5 °C and the annual precipitation is about 600 mm. In the past three decades, Beijing has been undergoing a fast economic development and urban construction in China, during which the urban population has reached over 19 million.

Sixty roadside dust samples were collected from universities in Beijing. Twelve universities included Beijing normal university, China University of Mining and Technology, Tsinghua university, Beijing University of Posts and Telecommunications, Renmin University of China, Beijing Foreign Studies University, Graduate university of Chinese Academy of Sciences, Beijing Institute of Technology, Beijing Sport University, China University of Agriculture, National Defence University PLA China, North China Electric Power University and Beijing University of Agriculture. At each sampling site, about 200g of road dust sample was collected by sweeping using a polyethylene brush and tray from three to five points of road / pavement edges from February to May 2010. All the samples collected were stored in sealed polyethylene bags, labeled and then transported to the laboratory.

All chemical treatments were in the ultra clean laboratory, and all reagents were high purity grade. Total metal concentrations in the sediments were measured using established method. Briefly, a mass of 40 mg of dry sample was weighted and dissolved into 10 mL Teflon bombs. About 2 mL concentrated HNO_3+0.2 mL concentrated H_2O_2 were added to samples and was left on a hot plate for one day. This step was to remove organic materials from sediment samples. The samples were then taken to dryness at 120 °C. The residue was dissolved in 1 mL HNO_3+1 mL HF of sample. After 30 min ultrasonic procedure, the samples were taken into sealed bomb and were placed in an oven at 190 °C for 48 h. This procedure resulted in clear solutions for sediment sample. After evaporation at 120°C, samples were dissolved in 1% HNO_3. Inductively coupled plasma-mass spectrometry （ICP-MS, Perkin Elmer Elan DRC-e） was used to determine the total concentrations of Zn, Pb, Cr, Cd, Ni, and Cu. The quality controls for the strong acid digestion method included reagent blanks, duplicate samples, and standard reference materials. The QA/QC results show no sign of contamination in all the analysis. The accuracy of the analytical procedures employed for the analysis of the trace elements in sediments was checked using the certified reference material of stream sediment (GSD-12, GBW07312), obtaining good agreement with the certified values. The analytical precision (RSD) was within 10% for all measured metals and the recoveries were good (90-110%).

Heavy metal concentrations in roadside dusts

The statistic results of heavy metal concentrations in the investigated road dust samples from 12 universities campus of Beijing are given in Table 1, including the arithmetic means and the standard deviation. The concentrations of Cr, Ni, Cu, Zn, Cd and Pb varied between 32.02 and 227.48, 14.87 and 44.69, 5.46 and 213.09, 57.38 and 579.27, 0.13 and 2.04, 18.32 and 192.96 mg/kg, respectively. The mean concentrations of Cr, Ni, Cu, Zn, Cd and Pb were 79.46 ± 32.71, 26.32 ± 7.10, 49.19 ± 37.97, 213.76 ± 125.96, 0.69 ± 0.45 and 61.28 ± 34.66 $mg \cdot kg^{-1}$, respectively. Except for Ni, the mean concentrations of Cr, Cu, Zn, Cd and Pb in road dust greatly exceed the background values of Beijing soils[8] and those of roadside soils in Beijing[9]. In fact, the levels of Cu, Zn, Cd and Pb are even more than 2 times higher than the soil background values of Beijing, indicating that the pollution may come from anthropogenic sources. The sources of Cr, Cd and Pb in street dusts of Beijing may mainly originate from industrial activities and automotive emissions. The concentrations of Ni in dust samples were found to be in the range of 14.87–39.78 $mg \cdot kg^{-1}$ which contain the nickel background value of Chinese soils. This shows Ni in street dusts are mainly derived from natural source. The source of Cu and Zn in street dust was indicated by research as tyre abrasion, the corrosion of metallic parts of cars, lubricants and industrial and incinerator emissions[10].

Table 1. Heavy metal concentrations in road dust of some universities in Beijing (mg·kg^{-1}).

Location	Cr	Ni	Cu	Zn	Cd	Pb
Tsinghua University (N= 5)	48.39±4.27	16.05±0.65	16.25±2.18	67.88±12.08	0.14±0.05	36.35±8.84
China University of Mining and Technology (N= 5)	83.74±8.94	22.00±3.41	60.06±38.29	120.17±22.51	0.35±0.04	72.48±10.30
Beijing Foreign Studies University (N= 5)	72.12±21.48	20.33±5.40	38.05±19.22	123.89±8.83	0.31±0.02	34.75±7.07
Beijing Institute of Technology (N= 5)	121.15±92.09	24.51±0.80	155.23±58.23	229.53±26.39	0.51±0.07	64.83±28.19
Renmin University of China (N= 5)	102.55±15.00	19.72±2.77	46.22±14.79	170.78±16.53	0.80±0.48	148.46±44.86
Beijing University of Posts and Telecommunications (N= 5)	76.47±16.71	26.58±4.19	39.20±7.60	287.33±198.09	1.20±0.73	58.56±22.78
National Defence University PLA China (N= 5)	62.30±18.01	23.30±7.93	36.26±19.88	246.46±218.07	0.61±0.31	59.38±36.96
Chinese Academy of Sciences (N= 5)	116.66±37.90	26.42±7.47	41.19±3.37	172.41±7.99	0.62±0.07	35.56±5.91
Beijing Normal University (N= 5)	81.81±1.30	31.02±7.44	43.84±13.74	185.07±48.67	0.40±0.04	82.57±41.92
Beijing Sport University (N= 5)	85.94±22.42	31.49±9.33	39.71±17.70	263.48±90.60	1.02±0.50	52.95±11.13
North China Electric Power University (N= 5)	61.11±17.63	27.68±5.43	25.80±17.46	189.69±109.85	0.74±0.51	55.99±34.83
China Agricultural University (N= 5)	72.97±26.94	30.55±5.59	55.90±33.85	273.88±151.38	0.79±0.43	59.24±29.59
Minimum value	32.02	14.87	5.46	57.38	0.13	18.32
Maximum value	227.48	44.69	213.09	579.27	2.04	192.96
Mean ± S.D. (N= 60)	79.46±32.71	26.32±7.10	49.19±37.97	213.76±125.96	0.69±0.45	61.28±34.66
Roadside Soils of Beijing [9]	61.90±2.30	26.70±2.40	29.70±5.70	92.10±18.70	0.22±0.07	35.40±13.50
Background values of Beijing [8]	66.7	26.8	18.7	57.5	0.12	24.6

In Table 2, the heavy metals concentrations measured in street dusts of campus in Beijing are compared with data reported for other cities. For each city, it has its own characteristics component of elemental compositions, and the observed similarities as well as variations may not reflect actual natural and anthropogenic diversities among the different urban settings[10]. Meanwhile, the heavy metal concentrations in road dust of campus are also compared with the data from four major trunk roads of Beijing. It is found that the amount of Pb in campus is higher than all ring roads. The high amount of Pb may attribute to the dust accumlation from circumambient ring roads.

Table 2. A comparison of the heavy metal concentrations in road dusts in Beijing and other cities (mg kg^{-1}).

City	Cr	Ni	Cu	Zn	Cd	Pb	Reference
Campus in Beijing	79.46±32.71	26.32±7.10	49.19±37.97	213.76±125.96	0.69±0.45	61.28±34.66	This study
Second ring road	-	-	54.02±15.92	241.93±62.56	0.78±0.20	49.94±27.47	[11]
Third ring road	-	-	122.00±80.48	329.83±145.90	0.74±0.21	41.37±9.63	[11]
Fourth ring road	-	-	46.71±15.62	289.62±202.39	0.74±0.18	33.53±5.86	[11]
Fifth ring road	-	-	31.98±8.91	213.85±144.60	0.48±0.13	29.14±11.05	[11]
Shanghai	159.3	83.98	196.8	733.8	1.23	294.9	[12]
Hongkong	-	-	173	1450	3.77	181	[13]
Xi'an	167.28	-	94.98	421.46	-	230.52	[1]
Urumqi	54.28	43.28	94.54	294.47	1.17	53.53	[14]
Guangzhou	78.8	23	176	586	2.41	240	[10]
Baoji	-	48.83	123.17	715.1	-	408.41	[15]

Assessment of heavy metals contamination in roadside dusts

The contamination levels of heavy metals in road dusts have been evaluated by using geoaccumulation index (I_{geo}) introduced by Müller (1969). The method has been widely employed in European trace metal studies since the late 1960s. It is also introduced in pollution assessment of heavy metals in urban road dust[15, 16]. Geoaccumulation index is computed using the following equation[17, 18]:

$$I_{geo} = \ln \frac{C_n}{1.5B_n} \quad (1)$$

where C_n is the measured concentration of the element in environment, B_n is the geochemical background value in soil. In this study, the background geochemical compositions of the city soil types are chosen as the background values for calculating the I_{geo} values. The constant 1.5 allows us to analyze natural fluctuations in the content of a given substance in the environment and to find very small anthropogenic influences.

According to G. Muller (1969), the I_{geo} for each metal is calculated and typically classified as: uncontaminated ($I_{geo} \leqslant 0$); uncontaminated to moderately contaminated ($0< I_{geo} \leqslant 1$); moderately contaminated ($1 < I_{geo} \leqslant 2$); moderately to heavily contaminated ($2 < I_{geo} \leqslant 3$); heavily contaminated ($3 < I_{geo} \leqslant 4$); heavily to extremely contaminated ($4 < I_{geo} \leqslant 5$); extremely contaminated ($I_{geo} \geqslant 5$). The I_{geo} was computed for the metals under investigation, and the mean values of different regions, the minimum, maximum, and mean of the I_{geo} values of campus in Beijing. The results are given in Table 3.

Table 3. Geoaccumulation index (I_{geo}) of heavy metals in the roadside soil of campus in Beijing, China.

Location	Heavy metals					
	Cr	Ni	Cu	Zn	Cd	Pb
Tsinghua University	-0.73	-0.92	-0.55	-0.24	-0.23	-0.02
China University of Mining and Technology	-0.18	-0.60	0.76	0.33	0.65	0.68
Beijing Foreign Studies University	-0.33	-0.68	0.30	0.36	0.55	-0.06
Beijing Institute of Technology	0.19	-0.49	1.71	0.98	1.03	0.56
Renmin University of China	0.02	-0.71	0.50	0.68	1.49	1.39
Beijing University of Posts and Telecommunications	-0.27	-0.41	0.33	1.20	1.90	0.46
National Defence University PLA China	-0.47	-0.55	0.26	1.05	1.22	0.48
Chinese Academy of Sciences	0.15	-0.42	0.38	0.69	1.23	-0.04
Beijing Normal University	-0.20	-0.26	0.45	0.76	0.79	0.81
Beijing Sport University	-0.15	-0.24	0.35	1.12	1.74	0.36
North China Electric Power University	-0.49	-0.37	-0.08	0.79	1.42	0.42
China Agricultural University	-0.32	-0.27	0.69	1.16	1.48	0.47
Minimum value	-1.14	-0.99	-1.64	-0.41	-0.33	-0.70
Maximum value	0.82	0.11	2.03	1.90	2.43	1.65
Average	-0.23	-0.42	0.56	0.91	1.34	0.51

The I_{geo} ranges from -1.14 to 0.82 with a mean value of -0.23 for Cr, -0.99 to 0.11 with a mean value of -0.42 for Ni, -1.64 to 2.03 with a mean value of 0.56 for Cu, -0.41 to 1.91 with a mean value of 0.91 for Zn, -0.33 to 2.43 with a mean value of 1.34 for Cd and -0.70 to 1.65 with a mean value of 0.51 for Pb. The mean values of I_{geo} increase in the order of Ni < Cr < Cu < Pb < Zn < Cd.

Most of studied campuses for Ni (-0.99 – 0.11) and Cr (-1.14 – 0.82) had $I_{geo} \leq 0$, indicating that the environment was scarcely contaminated or moderately contaminated by Ni and Cr. The environmental pollution distribution of Cd (-0.33 – 2.43) was as follows: the most regions showed $I_{geo} \leq 2$, moderately contaminated; and excepted one was residential area which had some samples with values that were $2 < I_{geo} \leq 3$, moderately to heavily contaminated. For the content of Pb (-0.70 – 1.65) have heavily to moderately contaminated. However, the mean (0.51) of Pb was low. Basised of among all the I_{geo} values measured in this study, the environment around campus of Beijing was scarcely contaminated to moderately polluted from campus road dust.

Conclusions

The heavy metal pollution in roadside dusts collected from different universities of Beijing was investigated deeply in this present study. The concentrations of Cr, Ni, Cu, Zn, Cd and Pb in roadside dusts were higher than local soil background and roadside soil values, indicating that the this metal pollution may come from anthropogenic sources. The assessment by Geoaccumulation Index indicates that Cr and Ni were at the unpolluted level, Cu and Zn at the slightly polluted level, Cd and Pb at the moderately contaminated level in dusts. The pollution level of the heavy metals is: Cd > Pb > Zn > Cu > Cr > Ni.

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