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Pollution characteristics and health risk assessment of heavy metals in street dusts from different functional areas in Beijing, China ☆

Xin Wei [a,b], Bo Gao [a,*], Peng Wang [c], Huaidong Zhou [a], Jin Lu [a]

[a] State Key Laboratory of Simulation and Regulation of Water Cycle in River Basin, China Institute of Water Resources and Hydropower Research, Beijing 100038, China
[b] State Key Laboratory of Water Environment Simulation, School of Environment, Beijing Normal University, Beijing 100875, China
[c] College of Environment Science and Engineering, Kunming University of Science and Technology, Kunming, 650500, China

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ABSTRACT

Street dusts from Heavy Density Traffic Area, Residential Area, Educational Area and Tourism Area in Beijing, China, were collected to study the distribution, accumulation and health risk assessment of heavy metals. Cr, Cu, Zn, Cd and Pb concentrations were in higher concentrations in these four locations than in the local soil background. In comparison with the concentrations of selected metals in other cities, the concentrations of heavy metals in Beijing were generally at moderate or low levels. Ni, Cu, Zn and Pb concentrations in the Tourism Area were the highest among four different areas in Beijing. A pollution assessment by Geoaccumulation Index showed that the pollution level for the heavy metals is in the following order: Cd > Pb > Zn > Cu > Cr > Ni. The Cd levels can be considered "heavily contaminated" status. The health risk assessment model that was employed to calculate human exposure indicated that both non-carcinogenic and carcinogenic risks of selected metals in street dusts were generally in the low range, except for the carcinogenic risk from Cr for children.

1. Introduction

Street dusts receives various heavy metal inputs from a variety of mobile or stationary sources, such as vehicular traffic, industrial plants, power generation facilities, residential oil burning, waste incineration, city construction and demolition activities and the resuspension of surrounding contaminated soils (Bilos et al., 2001; Manno et al., 2006), and these dust make a significant contribution to metal pollution in the urban environment. The components and quantity of street dust are also potential pollution indicators for urban environment (Han et al., 2006). Because of a lack of bioavailability, biodegradability and persistence, heavy metals could accumulate and be enriched in urban environment. A previous study found that the contamination contents (e.g., heavy metals and other toxic trace elements) of road/street dusts are generally higher than those in other media (e.g. soils) (Shi et al., 2008). Moreover, heavy metals in street dusts could easily enter human bodies through dust ingestion, inhalation and dermal contact under dynamic conditions such as wind, traffic and other human activities.

Elevated levels of heavy metals are ubiquitous in urban settings as the result of a wide range of human activities, especially from industrial sources (Duzgoren-Aydin et al., 2006). As a consequence, adverse effects on human health may occur in urban environments, particularly in metropolitan cities where urbanization, industrialization and rapid population growth have been taking place on an unprecedented scale. Although numerous studies on heavy metal contamination of street dusts have been performed in developed countries (Chon et al., 1995; De Miguel et al. 1997; Charlesworth et al., 2003), only limited information is available for developing countries, especially for China. In addition, most previous literatures on road/street dusts have primarily focused on the heavy metals concentration, distribution, source identification and pollution assessments during the last decades (Banerjee, 2003; Ferreira-Baptista and De Miguel 2005; Chen et al., 2005; Ahmed and Ishiga, 2006; Tanner et al., 2008). In fact, the US EPA's health risk assessment method has been successfully employed to investigate heavy metal exposure from urban road dusts for children and adults (US EPA, 1997; US EPA, 2001a; US EPA, 2002; Hu et al., 2011). In fact, the result of the health risk assessment for heavy metals in street dusts is very useful for both types of residents in terms of taking protective measures and for

☆ **Capsule:** The Tourism Area may be a reservoir of heavy metals among the different functional areas and the carcinogenic risk for Cr in children deserves considerable attention in Beijing.

* Corresponding author.
E-mail address: gaosky34@hotmail.com (B. Gao).

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the government to alleviate heavy metals pollution of the street environment.

Over the last three decades, urbanization and industrialization have taken place at an unprecedented pace in China. Urban environmental pollution has become a very important issue for environmental researchers (Wei and Yang, 2010). Beijing, the capital of China, is the political, economic and cultural central of the nation. Beijing is also one of the oldest and most densely populated cities in the world. In the past few decades, Beijing has engaged in rapid development in terms urbanization and industrialization, which has exerted considerable of pressure on the urban environment. Previous studies showed that heavy metals pollution was found in the urban surface soils and street dusts of Beijing over the past two decades (Chen et al., 2005; Tanner et al., 2008; Chen et al., 2010a; Chen et al., 2010b; Xia et al., 2011). However, the spatial distribution of heavy metals in street dusts collected from different functional regions in the urban environment and the health risk assessment of heavy metals in street dusts from Beijing is still unknown. The objectives of the present study were as follows: (1) to determine the current status of heavy metals concentrations and spatial patterns in urban street dusts collected from different functional areas in Beijing; (2) to compare heavy metal concentrations in the street dusts of Beijing with those in other cities; (3) to evaluate and assess heavy meals pollution in street dusts using the Geoaccumulation Index; and (4) to assess the carcinogenic and non-carcinogenic health risks associated with heavy metals by US EPA health assessment methods.

2. Materials and methods

2.1. Study area

Beijing, the capital of China, is situated at the northern tip of the roughly triangular North China Plain, and its center is located at 39.9 N and 116.4E. Beijing is one of the four municipalities in China, and 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. This region spreads out of the concentric ring roads, from which the 6th Ring Road passes through several satellite towns. The city has a typical monsoon-influenced climate, and it is characterized by hot, humid summers from the East Asian monsoon and generally cold, windy, dry winters from the vast Siberian anticyclone. The city's annual temperature is approximately 11.5 °C and the annual precipitation is approximately 600 mm. Over the past three decades, Beijing has been undergoing some of the most rapid economic development and urban construction in China, during which the urban population has reached over 19 million.

2.2. Sample collection

One hundred fifty-four street dust samples were collected from urban areas consisting of different land use areas in Beijing, including four different functional sections as follows: (1) the Heavy Density Traffic Area (HDTA), this section covers Chang' an Avenue, the 2nd ring and the 3rd ring road in the central area of Beijing, and these sampling sites are the representative of the heaviest traffic areas. In the (2) Educational Area (EA), thirteen universities were selected including Beijing Normal University (BNU), China University of Mining and Technology (CUMT), Tsinghua University (THU), Beijing University of Posts and Telecommunications (BUPT), Renmin University of China (RUC), Beijing Foreign Studies University (BFSU), the Graduate University of Chinese Academy of Sciences(GUCA), Beijing Institute of Technology (BIT), Beijing Sport University (BSU), China University of Agriculture (CUA), National Defense University PLA China (NDU), North China Electric Power University (NCEPU) and Beijing University of Agriculture (BUA). For the (3) Tourism Area (TA), eight famous tourism sites were selected from inside the TA area, including the Summer Place (SP), Forbidden City (FC), Yuyuantan Park (YYP), Heaven Temple (HT), Jingshan Park (JSP) and Shichahai Park(SCP). For the (4) Residential Area (RA), Hui Longguan (HLG) was selected because it is one of the biggest residential districts in the urban part of Beijing city. For each sampling site, three～five subsamples (approximately 200 g each) from one street were collected with a small brush and a clean polymethyl methacrylate shovel from February to May 2010. All the samples were stored in sealed polyethylene bags, labeled and then transported to the laboratory. The sampling locations in Beijing are shown in Fig. 1.

2.3. Sample preparation and analysis.

The dust samples were dried at 100 °C for 5 h in an electric oven and sieved through a 0.125 mm stainless steel sieve. The total metal concentrations in the sediments were measured by an established method (Liu et al., 1996). In Brief, a 40 mg mass of dry sample was weighed and dissolved into 10 mL Teflon bombs. Approximately 2 mL of HNO_3 + 0.2 mL H_2O_2 was added to the samples and they were left on a hot plate for one day. This step was performed to remove organic materials from the dust samples. The samples were then taken evaporated to dryness at 120 °C. The residue was dissolved in 1 mL of HNO_3 + 1 mL HF sample. After 30 min of the ultrasonic procedure, the samples were placed in sealed bombs that were then placed in an oven at 190 °C for 48 h. This procedure yielded clear solutions for the dust samples. After evaporating at 120 °C, the 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 for all the analysis. The accuracy of the analytical procedures that were employed to analysis the trace elements in the dusts was checked by certified soil reference material (ESS-1, GSBZ 50011-88), and the results were consistent with the certified values (Supplementary informationTable S1).

3. Results and discussion

3.1. Heavy metal concentrations in the street dusts of Beijing

The heavy metal concentrations in the street dust samples are summarized in Table 1, including the arithmetic means and the standard deviation. The concentrations of Cr, Ni, Cu, Zn, Cd and Pb varied between 32.0 and 227, 14.9 and 60.0, 5.46 and 623, 57.4 and 908, 0.130 and 5.01, and 16.7 and 2.45×10^3 mg/kg, respectively. The mean concentrations of Cr, Ni, Cu, Zn, Cd and Pb were 84.7, 25.2, 69.9, 222, 0.723 and 105 mg/kg, respectively. With the exception of Ni, the mean concentrations of Cr, Cu, Zn, Cd and Pb in road dusts greatly exceeded the soil background values for Beijing (CNEMC, 1990) and the values in urban soils from Beijing (Fergusson, 1984). In fact, the Cu, Zn, Cd and Pb levels are even more than 3 times higher than the soil background values for Beijing, indicating that the pollution may come from anthropogenic sources (vehicular traffic, industrial plants, city construction and demolition activities).

Table 1 also shows the spatial variations for heavy metals concentrations in street dusts from different areas in Beijing city. In general, the Ni, Cu, Zn, and Pb concentrations in TA were the