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Particle size distribution and characteristics of heavy metals in road-deposited sediments from Beijing Olympic Park

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ABSTRACT

Due to rapid urbanization and industrialization, heavy metals in road-deposited sediments (RDSs) of parks are emitted into the terrestrial, atmospheric, and water environment, and have a severe impact on residents' and tourists' health. To identify the distribution and characteristic of heavy metals in RDS and to assess the road environmental quality in Chinese parks, samples were collected from Beijing Olympic Park in the present study. The results indicated that particles with small grain size (<150 μm) were the dominant fraction. The length of dry period was one of the main factors affecting the particle size distribution, as indicated by the variation of size fraction with the increase of dry days. The amount of heavy metal (*i.e.*, Cu, Zn, Pb and Cd) content was the largest in particles with small size (<150 μm) among all samples. Specifically, the percentage of Cu, Zn, Pb and Cd in these particles was 74.7%, 55.5%, 56.6% and 71.3%, respectively. Heavy metals adsorbed in sediments may mainly be contributed by road traffic emissions. The contamination levels of Pb and Cd were higher than Cu and Zn on the basis of the mean heavy metal contents. Specifically, the geoaccumulation index (I_{geo}) decreased in the order: Cd>Pb>Cu>Zn. This study analyzed the mobility of heavy metals in sediments using partial sequential extraction with the Tessier procedure. The results revealed that the apparent mobility and potential metal bioavailability of heavy metals in the sediments, based on the exchangeable and carbonate fractions, decreased in the order: Cd>Zn≈Pb>Cu.

Introduction

With the rapid growth of urbanization, the density of motor vehicles used to transport the increasing population and essential goods has increased dramatically. Aerosols and road-deposited sediments (RDS) are formed during the process, which has given rise to escalating levels of pollution along roadways in many parts of the world (Loganathan et al., 2013). RDS are the sinks and sources of inorganic and organic pollutants such as heavy metals, metalloids and polycyclic aromatic hydrocarbons (PAHs), which are derived from the emission of vehicles, vehicle tires, brakes and body frames, surfaces of asphalt roads, road railings/fences, deicing salt, paint markers, and pesticides and herbicides added to the pavement (Aryal et al., 2010; Murakami et al., 2008; Perry and Taylor, 2007).

Road-deposited sediments are widely recognized as a major non-point source of heavy metals that is difficult to categorize and manage, due to their dynamic characteristics. These emissions containing particulate matter are released to ambient

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air, or deposited on the road surfaces in the form of street emissions (Hur et al., 2007). During rain/storm/street-washing events, the street dust particles laden with contaminants are washed off and finally end up in receiving water bodies (Murakami et al., 2008; Yu et al., 2001; Jain, 2004; Stead-Dexter and Ward, 2004). Furthermore, the mobilization of heavy metals into the atmosphere by industrial activities has become an important process in the geochemical cycling of these metals. This is acutely evident in urban areas, where large quantities of heavy metals from various stationary and mobile sources are released into the atmosphere, plants and soil, exceeding the natural emission levels (Shi et al., 2008; Fujiwara et al., 2011; Škrbić et al., 2012). In fact, heavy metals are considered to be toxic pollutants, because they can accumulate in the sediments due to atmospheric deposition by sedimentation interception and may affect human health if their concentration reaches a certain level (Ferreira-Baptista and De Miguel, 2005).

In recent decades, a number of studies have focused on the concentration, distribution and source identification of heavy metals in street side dusts (Manno et al., 2006; Andersson et al., 2010; Cao et al., 2011). Most of the studies have shown that the concentration of heavy metals (Cu, Fe, Cd, Mn, Ni, Pb, Zn) decreases with the increase of particle size, and the highest concentration was measured in the finest fraction of the particles with size < 63–75 μm (Zhao et al., 2010, 2011; Singh, 2011; Lee et al., 2013). Metals in the fine fraction are generally considered to arise from exhaust emissions, whereas metals in the coarse particles are considered to be derived from the components of wear and tear of vehicles (Duong and Lee, 2011; Lim et al., 2006). Besides, study focusing on the heavy metal chemical compositions is important to assess their mobility and hence bioavailability, using sequential extraction. Cd was identified to be the most bioavailable element among heavy metals, as it shows the greatest affinity to operationally defined exchangeable sites and carbonates in sequential extraction (Banerjee, 2003). Zn and Pb are mainly associated with carbonates > Fe/Mn oxides > the exchangeable fraction (Li et al., 2001). Moreover, the vast proportion of Cu was bound to organic matter and a small proportion was an exchangeable matter, therefore Cu is the least likely to release to the environment under natural conditions (Peng et al., 2009). In general, to the best of our knowledge, the index of bioavailability reported in the limited number of studies conducted shows the order of Cd > Zn = Pb > Cu (Charlesworth et al., 2003).

A great number of studies on heavy metals in RDS have focused on developed countries (Kumar et al., 2010, 2013a; Lee et al., 2013; Kurt-Karakus, 2012; Lau and Stenstrom, 2005), but little information on heavy metals in RDS is available for developing countries, including China (Zhao and Li, 2013; Zhao et al., 2011), especially in public parks. The heavy metal pollution is determined by calculating the value of the integrated pollution index (IPI), concentration factor (CF), element enrichment factor (EF) and geoaccumulation index (I_{geo}) (Chen et al., 2005; Gong et al., 2008) while the health risk assessment of the metal is determined by calculating the hazard quotient (HQ) and health index (HI) in surface soils of urban parks in Beijing (Luo et al., 2012). The concentrations of Cu, Zn, Cd and Pb were much higher than their background values in Chinese soil and the health risk assessment of heavy metals in road dusts in Beijing urban parks indicated that ingestion, dermal contact and inhalation were the three main exposure pathways for people (Du et al., 2013). In addition, the results on the distribution of heavy metals in sediment from a public park lake suggested that potentially large contributions from point sources were related to human activities in highly urbanized regions (Yang et al., 2014). Although these studies of heavy metals in urban park soil and road sediment have been a central issue in China, there is little detailed data on the origin, distribution and concentration of heavy metals in the RDS in the Beijing parks. Among the different species of contaminants, heavy metals such as Cu, Cd, Pb and Zn are of particular concern due to their prevalence and persistence in the environment (Stead-Dexter and Ward, 2004). Therefore, the main objectives of this study are: (1) to determine the relationship between the particle size characteristics and the chemical compositions of several heavy metals (*i.e.*, Cu, Zn, Pb and Cd), using partial sequential extraction procedures, in sediment samples collected from Beijing Olympic Park (a famous tourist attraction in China), (2) to investigate the heavy metal contamination assessment in order to evaluate the road environmental quality of the dust in the urban parks and the potential risks to residents and tourists based on the geoaccumulation index (I_{geo}), and (3) to identify the potential heavy metal pollution contribution to the receiving park water bodies based on their availability due to the apparent mobility and potential metal bioavailability.

1. Materials and methods

1.1. Study area

Beijing, the capital of China, (39°54′N, 116°24′E) is located at the northern tip of the roughly triangular North China Plain, and spans 16,800 km^2. The Olympic Park is located at the northern end of the central axis of Beijing and is bounded by the Qing River and the North 5th Ring Road. The traffic load of the North 5th Ring Road is very heavy (300,000 vehicles per day). Furthermore, the park is bounded by the North 4th Ring Road (comparably busy) to the south, the Anli Road to the east, and the Lincui Road to the west. The national stadium, swimming center, and gymnasium are all sited near the Olympic Park (Qiao et al., 2011).

Particles were collected from eight different sampling sites (Table 1 and Fig. 1) within the Beijing Olympic Park, including industrial areas, areas with heavy and low traffic density, commercial areas and residential districts. The roads where the sampling was performed were major intersections. The samples were collected in the afternoon (15:00–17:00) of 14th, 28th Oct. and 12th, 25th, Nov. 2013 when the traffic loads were low. Before the samples of the last three times were collected, the length of the dry period was 7, 2, and 15 days, respectively.

1.2. Sample collection

The dust samples were collected from both sides of the road at the intersection on a dry day using a plastic dustpan and brush. An area generally ranging within 0.5 m of the curb of the road (Sartor and Boyd, 1972) and 30–50 m in length was swept in order to obtain a sufficient amount of sample for analysis and to