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Contamination and risk assessment of metals in road-deposited sediments in a medium-sized city of China

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A B S T R A C T

Road-deposited sediment (RDS) is a valuable environmental medium for characterizing contamination of metals in urban areas and the associated risks to human health. A total of 62 RDS samples were collected for metal test in four urban areas in a medium size city in eastern China. The areas that represented different land uses consisted of intense traffic area (ITA), commercial area (CA), residential area (RA), and riverside park area (RPA). The effects of particle size and different land uses on metal contamination and health risk were the major focus in this study. The test results showed that RDS in ITA appeared to have higher metal content, enrichment factor (EF), ecological risk index (RI), and the non-cancer and cancer risks than in the other areas. The metal contamination and health risk increased inversely with particle size. The particles less than 63 μm were found to be most critical in development of metal contamination and health risk. The EF was measured to be greater than 2.0 in the four areas, indicating a moderate enrichment. The measured RI ranged between 50 and 200, indicating considerable to moderate risks. The non-cancer risk for children was high in the four areas but was low for adults in all test areas except in ITA. The cancer risk of Cr for children was high in all test areas. Based on the test results, the contamination control and management for metals in RDS shall focus on the effects from such factors as particles (< 63 μm) and the land use for intense traffic (ITA).

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1. Introduction

Road-deposited sediment (RDS) is a potentially toxic medium as it contains such pollutants as metals and hydrocarbons, originated from a wide range of non-point sources including wet and dry deposition, vehicle exhausts, vehicle and road wear, de-icing operations, accidents, abrasion of construction materials and soil erosion (Kim and Sansalone, 2008; Yunker et al., 2002). RDS on impervious ground surface tends to accumulate more pollutants and thus the associated surface runoff carries a higher pollutant load (Jartun et al., 2008). RDS that is enriched with toxic metals has been blamed for the cause of a variety of health problems (Zheng et al., 2010). Therefore, a proper understanding of RDS contamination is crucial to urban environmental quality and human health.

Metals in RDS are of major concern because of their toxicity and non-degradability (Wei and Yang, 2010; Kong et al., 2011). The RDS quantity, particulate size, and particulate mobility are important factors for the assessment of metal pollution in public health. Fine RDS tends to contain a high percentage of metals. Sansalone and Buchberger (1997) indicated that the highest concentrations of Zn, Cu and Pb were associated with particles smaller than 250 μm. Murakami et al. (2005) concluded that RDS with particle size less than 100 μm were most significant in the pollution of surface runoff.

The contamination of metals in RDS can be assessed with different methods (Liu et al., 2008; Shi et al., 2010; Wei and Yang, 2010) which include (1) enrichment factor (EF), (2) Nemerow synthetic pollution index (PIN), and (3) potential ecological risk index (RI). Most of studies employing these methods focused on the pollutant distribution of RDS; however, the effects of particle size of RDS on contamination of metals and health risk were not considered (Yuen et al., 2012; Cao et al., 2014). RDS particle sizes have a direct impact on health risk. For example, the finer particles tend to be easier for transportation and more detrimental to human health; particles smaller than 66 μm can be easily blown

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away by a breeze (De Miguel et al., 1997). The fine particles (e.g. PM2.5) can penetrate deep into the respiratory system, after which they are retained and absorbed by the body. In addition, fine particles have the longer atmospheric residence time than coarse particles and the ability of long-range transport (Prabhakar et al., 2014; Gugamsetty et al., 2012; Sorooshian et al., 2012). The fine particles may enter the human body through dermal contact, inhalation, and ingestion exposures to environmental media. As such, it is also important to conduct health risk assessment to estimate the severity of the pollution and develop an effective risk mitigation program (Qu et al., 2012). One of the important parameters for health risk assessment is hazard quotient (HQ) which was developed by the US Environmental Protection Agency (USEPA) and has been widely used to characterize the non-cancer risk (Mari et al., 2009).

The RDS research is often conducted at the city scale. A city commonly consists of areas of different land uses which exhibit their own characteristics; and these characteristics affect the distribution and pollution level of the RDS directly or indirectly. Health risks of metals in soil and urban dust have been evaluated in many different cities, such as Luanda, Angola (Ferreira-Baptista and De Miguel, 2005), Shanghai, China (Shi et al., 2011) Nanjing, China (Liu et al., 2014), Beijing, China (Zhao and Li, 2013) and Xi'an, China (Lu et al., 2014). However, these studies did not evaluate the effects of particle sizes on the health risk, partly because of the lack of systematic multi-pathway health risk analyses (Cao et al., 2014). In general, the literature review indicates that it is significant to incorporate the RDS grain size distribution into the assessment of contamination of metals in RDS and the potential health risk (Zhao and Li, 2013; Zhu et al., 2008).

The objective of this paper was to assess contamination and health risk of metals in RDS in Zhejiang City, a medium size city in China. Within a city, the areas that are developed for different land uses may be subjected to different levels of RDS contamination. As such, RDS was collected from the four areas for different land uses including intense traffic area (ITA), commercial area (CA), residential area (RA), and riverside park area (RPA). The particle size distribution of RDS and metal concentrations were analyzed. Different methods were employed to assess the metal contamination and health risk. Eventually, the study in this paper intends to address the three questions: (1) effects of particle size distribution on the concentrations of metals in RDS, (2) effects of particle size distribution on contamination and health risk of metals in RDS, (3) effects of different land uses on contamination and health risk of metals in RDS.

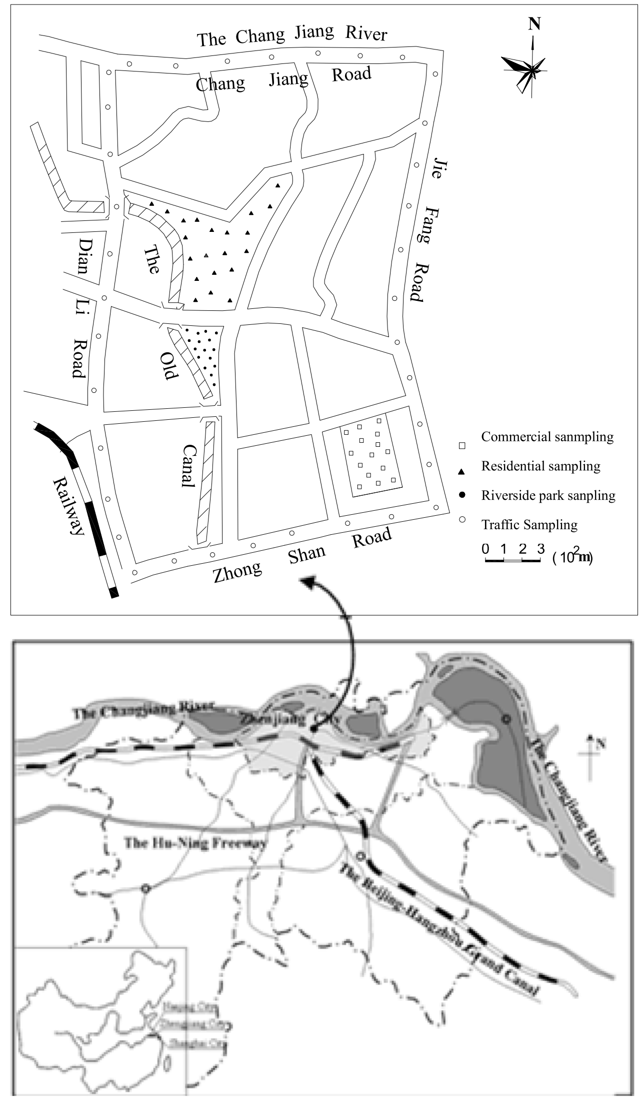

Fig. 1. Map of study areas and sampling locations.

2. Material and methods

2.1. Study area and RDS sampling

Zhenjiang City is located on the fertile Yangtze River delta in eastern China, where the Yangtze River and the man-made Beijing-Hangzhou Grand Canal meet. The city is approximately 260 km north of Shanghai. RDS samples were collected on the roads in the four urban areas in Zhenjiang: intense traffic area (ITA), commercial area (CA), residential area (RA), and riverside park area (RPA) as indicated in Fig. 1. The samples in the CA were collected near the major roads with the traffic of 2561 people per hour. In the RA that was a relatively old neighborhood, the roads were used as a temporary car parking area with the traffic volume of 651 peoples per hour, 121 cars per hour, and 306 motorcycles per hour. The RPA was located near one of the main roads in the city. The roads in the ITA had hourly traffic of 1438 vehicles, 18.6% of which were heavy duty trucks. The sampling areas represented four different land uses in a medium size city, featuring different population density, traffic density, energy consumption, street cleaning methods, distributions of industries, and ground surface conditions. A total of 62 samples were collected at locations using a random sampling strategy as to adequately cover the four areas as presented in Fig. 1. The sampling occurred after the roads were cleaned and was located on the road side within 1 m from the curb because metals such as Pb, Cd, and Zn tended to accumulate in RDS as a result of airborne redistribution by automobiles (Momani et al., 2002). Each sample, which weighed between 60 and 500 g, was collected from an area of 1 m^2 using a clean plastic dustpan and a brush. The samples were stored separately in self-sealing plastic bags and transported back to laboratory for subsequent analyses. In the meantime, to obtain the background levels of metals, soil samples were also collected in the relatively pristine areas adjacent to the sampling areas.

2.2. Sample analysis

The samples were dried for 48 h at a temperature of 105 °C and then cooled to room temperature in a dark place for further fractionation and chemical analysis. Metal concentrations are

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