Ecotoxicology and Environmental Safety 138 (2017) 83–91

Contents lists available at ScienceDirect

Ecotoxicology and Environmental Safety

journal homepage: www.elsevier.com/locate/ecoenv

Contamination and health risks of heavy metals in street dust from a coal-mining city in eastern China

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ARTICLE INFO

Keywords:
Heavy metal
Street dust
Pollution
Human health risk
Huainan

ABSTRACT

We collected street dust from Huainan, a typical coal-mining city in China, to investigate the contamination features and health risks of heavy metals. Concentrations of Co, Cr, Cu, Pb, As, and Sb were generally low to moderate, while pollution levels of Cd and Hg were moderate to high. Concentrations of Cd and Hg were associated with considerable health risks at 64.3% and 58.6% of sites, respectively. In particular, about a fifth of samples had associated high risks as a result of Hg contamination levels. Relative to other urban areas, the street dust from the mining area had no more severe metal pollution, which might be partly attributed to the deposition of coal dust onto street dusts. A source assessment indicated that metals in dust form Huainan were mainly derived from vehicular-related activities, industrial emissions, weathering of coal dust and natural soils, and coal combustion. Although the health risk levels from exposure to individual metals in dusts were low, the non-carcinogenic risks from multiple metals to local children exceeded the acceptable level (1.0), suggesting that the overall risk from exposure to multiple metals in dust is concerning.

1. Introduction

Intensive human activities result in environmental contamination, for example, through the release of various heavy metals including cadmium, lead, mercury and arsenic to urban environments (Li et al., 2013; Lu et al., 2014; Wei et al., 2015). Street dust is comprised of solid particles deposited on outdoor ground surfaces that act as a "reservoir" for accumulating short-term environmental materials from the surrounding areas (Tang et al., 2013a; Amato et al., 2016; Tang et al., 2016; Zhao et al., 2016). Humans can be exposed to dust containing multiple metals from a variety of sources through re-suspension-inhalation, hand-mouth ingestion, and dermal contact (Acosta et al., 2011; Mohmand et al., 2015). Dust that contains metals can enter aquatic systems via urban runoff, and soil environments via transport by wind (Birch and McCready, 2009; Al-Awadhi and AlShuaibi, 2013; Hwang et al., 2016). Concern over the problem of metal contamination of street dust has increased in recent decades and research efforts on the issue have correspondingly increased.

In addition to natural sources, such as soil weathering, metals in street dust mainly originate from a range of human activities, including vehicle emissions, disintegration of vehicle brakes and tires, road surface wear, coal combustion, residential heating, weathering of building materials and pavement, municipal activities, and atmospheric deposition (Li et al., 2013, 2016; Tang et al., 2013a; Liu et al., 2014; Lu et al., 2014a). Concentrations of metals in street dust have proven to be extremely variable. The spatial distribution of metals in the dust is controlled both by local population density and the emission source distribution (Wei et al., 2009, 2015; Liu et al., 2014; Acosta et al., 2015). Research on metal pollution and source identification of metals in street dust has provided information useful for the implementation of risk management strategies in cities. However, most previous studies have focused on metal contamination in developed

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http://dx.doi.org/10.1016/j.ecoenv.2016.11.003
Received 1 September 2016; Received in revised form 7 November 2016; Accepted 9 November 2016
Available online 22 December 2016
0147-6513/

countries or megacities. In China, heavy metal contaminations of street dusts and associated human health risks have been extensively studied in megacities, such as Shanghai (Shi et al., 2008, 2011), Beijing (Tang et al., 2013a; Wei et al., 2015), Tianjin (Guo et al., 2014; Hu et al., 2016), Guangzhou (Liu et al., 2012; Cai et al., 2013), and Nanjing (Liu et al., 2014). Similar information for small and medium-sized cities and in particular, mining industrial cities, is rare.

China has more than 120 mining cities, 55 of which are coal-mining cities (Lou and Gu, 2005). Elevated levels of heavy metals have been widely reported in the surrounding soils of coal-mining cities; such contamination is likely due to a lack of environmental protection and pollution control technology for mining activities (Liu et al., 2015, 2016; Pang et al., 2016). Coal-fired power plants, coal chemical plants, and industrial activities relying on coal are usually distributed densely in the Chinese coal-mining cities and likely discharge substantial quantities of various heavy metals (e.g. Hg, As, and Pb) at harmful levels into urban environments. For example, in soils downwind of a coal-fired power plant in Huainan, China, researchers observed elevated concentrations of some metals; concentrations associated with an unacceptably high level of potential health risks to children (Tang et al., 2013b). In these cities, poor management of coal transportation can also cause serious environmental pollution of urban roads due to coal being scattered from vehicles. It is reasonable to hypothesize that street dust in coal-mining cities is contaminated with metal pollution because there are a number of sources of toxic metals, which are different from those in metropolitan areas. Investigations of the contamination and health risks of heavy metals in street dust from coal-mining cities are therefore necessary.

We examined Huainan, a coal-mining city in eastern China, as a case study. Our primary aim is to investigate the concentrations and distribution of eight metals in street dust from different functional areas in Huainan. Subsequently, we assessed the potential health risks associated with toxic metals in street dust. The results will provide important insight into these trace metals in the urban environment in mining cities, and may be useful in informing the development of risk management measures.

2. Materials and methods

2.1. Study area

Huainan, a prefecture-level city located in the mid-northern part of Anhui Province, is located at 32°23.3′–33°0.5′N, 116°21.0′–117°12.5′E; it encompasses a total area of 5571 km^2 and has a population of 3,834,000 (PGHM, 2016). It is located along the Huaihe River bank, and the geomorphology is composed of piedmont slopes and alluvial plains. It has a warm, semi-humid climate, with the wind direction predominantly from the east, and annual average temperature, precipitation, and wind speed is 15.2 °C, 923–926 mm, and from 1.30 to 2.90 m/s, respectively (Fang et al., 2014). Coal-mining activities in Huainan began a century ago. Nine mines are currently active, and an additional 10 plants will be built in the near future. These mines are located mainly in Datong, Xiejiaji, and Panji Districts, and Fengtai County. As one of 14 large coal bases planned to develop by China, Huainan is the main industrial city that depends on coal-based industries in eastern China. In Huainan, raw coal production in 2015 reached 82 million tons (Mt) (HBS, 2016a), with coal gangue accounting for 10–15% of coal production (Zhou et al., 2012). There are six coal-fired power units with a total installed capacity of 14.2 million kilowatts and an annual generating capacity of 54.9 billion kilowatt hours in 2015 (HBS, 2016a). In 2015, Huainan's GDP reached 90 billion Yuan (includes Shouxian County) (HBS, 2016a, 2016b).

Rapid urbanization and economic development in Huainan have resulted in serious deterioration of the local environmental quality. In addition to mining and thermal power plants, Huainan contains other industries that have high energy consumption and produce significant pollution, such as coal chemical and cement manufacturing. Emissions of industrial dust were about 2.74×10^4 t in 2014 (HEPB, 2015). The total number of vehicles in Huainan has increased rapidly, at an annual rate of 14.9% in recent years, and reached 1.82×10^5 vehicles in 2015 (HBS, 2016a). In recent years, haze pollution has become common in Huainan. Mean Particulate Matter 10 (PM_{10}) (particle size < 10 μm) concentrations reached 107 μg/m^3 in 2014, which surpasses the Grade II value indicated by the Chinese Ambient Air Quality Standard (GB3095-2012) (HEPB, 2015). In the industrial district, researchers found that dust contained a high level of Hg, potentially derived from emissions of a nearby coal-fired power plant (Zheng et al., 2015). Although the levels of all heavy metals (except Cr) in groundwater are safe, elevated levels of heavy metals, especially for Cd, Cr, Pb and Hg, have been frequently reported in soils and surface water from the mines and their surrounding areas (Hu and Gao, 2009; Sun and Li, 2015; Fang et al., 2015; You et al., 2016; Zhang, et al., 2016a, 2016b). Such contamination have even resulted in metal concentrations in some vegetables or grains that exceed the Chinese maximum allowable concentrations (Qi et al., 2011; Fang et al., 2015; Sun and Li, 2015).

2.2. Sampling and chemical analysis

In this study, we sampled four sectors: a mining area, an industrial area, a mixed area (containing commercial residential land), and a new urban area. The mining areas include Panji and Xiejiaji Districts; Panji contains several large mines and coal-fired power plants; and Xiejiaji contains several active and some abandoned mines, many coal waste piles, and two industrial parks containing machinery and building materials industries. Many factories, including coal chemical, thermal power, metal processing, and family-run facilities, are located in the industrial area. The mixed area has the densest population, the busiest streets, and some factories in the eastern part. The new urban area is a developing region with minimal industrial activity.

We collected 70 composite samples of outdoor street dust in September 2014, in the cool and dry season. The sampling locations are shown in Fig. 1. During the 2-week period prior to sampling, the weather was sunny and windless. We chose to conduct sampling in September because the weather is more conducive to the accumulation of street dust on the ground during that time compared with the rainy season. Using a modified version of the procedure of Tang et al. (2016), we collected each sample by gently sweeping an area about 4–10 m^2 adjacent to the curb (within 1 m of the road) with clean plastic utensils (brush and dustpan) and transferred them into air-tight polyethylene bags for storage. Samples were air dried at room temperature, and coarse debris was removed. Samples were ground using a mortar and pestle, before being passed through a 150-mesh (about 100-μm) nylon sieve.

Though As and Sb are technically metalloids, we used the term "heavy metal" for all the elements measured in this study. We analyzed concentrations of eight heavy metals (As, Cd, Co, Cr, Cu, Hg, Pb, Sb) according to the HNO_3:HF:$HClO_4$ (V:V:V=5:10:2) digestion method described by Tang et al. (2016). We analyzed the digested solution using an inductively coupled plasma mass spectrometer (Agilent 7500a, Agilent Technologies, USA) for Cd, Co, Cr, Cu, Zn, Pb, and Sb, and an atomic fluorescence spectrometer (XGY-1011A, Langfang, China) for As and Hg. Quality control measures included the analysis of duplicate samples, a reagent blank, procedural blanks, and standard reference materials GSS-17 and GSS-25 (geochemical standard reference sample soils in China). We detected no contamination in laboratory or procedural blanks. Precision, determined by replicate analysis, was < 5% relative standard deviation (RSD) and accuracy, expressed as recovery of the reference material, was between 94.5% and 112% for all metals.