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Profiles of lead in urban dust and the effect of the distance to multi-industry in an old heavy industry city in China

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ABSTRACT

Lead (Pb) concentration in urban dust is often higher than background concentrations and can result in a wide range of health risks to local communities. To understand Pb distribution in urban dust and how multi-industrial activity affects Pb concentration, 21 sampling sites within the heavy industry city of Jilin, China, were analyzed for Pb concentration. Pb concentrations of all 21 urban dust samples from the Jilin City Center were higher than the background concentration for soil in Jilin Province. The analyses show that distance to industry is an important parameter determining health risks associated with Pb in urban dust. The Pb concentration showed an exponential decrease, with increasing distance from industry. Both maximum likelihood estimation and Bayesian analysis were used to estimate the exponential relationship between Pb concentration and distance to multi-industry areas. We found that Bayesian analysis was a better method with less uncertainty for estimating Pb dust concentrations based on their distance to multi-industry, and this approach is recommended for further study.

1. Introduction

In recent years, rapid industrialization and urbanization have been achieved with a large environmental sacrifice, especially in developing countries, such as China (Li et al., 2016). As one of the largest global producers and consumers, China is facing heavy metal pollution, linked to antimony (Sb), iron (Fe), lead (Pb) and zinc (Zn) among others (Gunson and Jian, 2001, Li et al., 2014). Metals emitted from various urban activities and industrial processes tend to accumulate in various media, especially in dust, soil, atmospheric particles, and urban runoff; they are difficult to remove from these media, even after many years (Lau and Stenstrom, 2005; Madarang and Kang, 2014; Liu et al., 2015; Maniquiz-Redillas and Kim, 2016). Urban dust is considered a good indicator of metal contamination from human and industrial activities in urban environments (Žibret, 2012; Žibret et al., 2013; Zhao and Li, 2013; Acosta et al., 2015; Song et al., 2015; Yu et al., 2016). High metal concentrations have often been found in urban dust, and numerous studies have focused on this metal pollution (Apeagyei et al., 2011; Li et al., 2013a; Huang et al., 2014). Urban dust also is an important source for human exposure to metals through inhalation, direct ingestion, and dermal contact (Zheng et al., 2010; Shi et al., 2011).

Metal exposure has a cumulative effect and can result in a wide range of health problems; it is especially problematic for children (De Miguel et al., 2007; Guney et al., 2010). For example, Pb, known as the "chemical time bomb" (Stigliani et al., 1991) and as a neurotoxin, is harmful to neurodevelopment, brain development, and kidney development in children, even at low concentrations (Kim et al., 2013). Therefore, there is an increasing need for information regarding Pb pollution status in urban dust to mitigate and control Pb health risks.

The United States Environmental Protection Agency's (USEPA) health risk assessment model was often used to estimate the potential risks related to exposure to Pb from urban dust (USEPA, 2011).

Normally, the sources of Pb in urban dust include industrial activities (Žibret and Šajn, 2008; Ordóñez et al., 2015; Qing et al., 2015), traffic-related activities (Lu et al., 2009; Yu et al., 2016), coal combustion (Cheng and Hu, 2010), atmospheric deposition (Li et al., 2016) and smaller, site-specific sources. Higher rates of Pb pollution have often been found around industrial areas, related to specific industries or activities (Al-Khashman, 2004; Chen et al., 2009).

Many studies have focused on the relationship between a single industry and its Pb pollution (Žibret and Šajn, 2008; Li et al., 2013c). Typically, the Pb in urban dust exponentially decreases with increasing distance from a given industry (Wang et al., 2003; Wang et al., 2006; Wu et al., 2011; Ordóñez et al., 2015). Therefore, the Pb pollution status at an unsampled site can be estimated using an exponential equation, based on the distance from this single industry. However, for many countries, such as China (Yang et al., 2010), Italy (Imperato et al., 2003), and Spain (Acosta et al., 2014), there are many industries

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located together, and identifying a specific source is difficult. Clearly, more research is needed to understand and estimate the combined influence of many industries on Pb concentration distributions. In this study, we used maximum likelihood estimation (MLE) and Bayesian analysis (BA) to develop a model for the relationship between multiple industrial sites and Pb pollution.

The objectives of this study were (1) to analyze the Pb spatial distributions in urban dust of Jilin City Center (JLC); (2) to assess the health risks of exposure to Pb in urban dust; (3) to show the influence on urban dust Pb concentrations from specific industries using MLE and BA methods, and (4) to determine the uncertainty of estimates based on MLE and BA methods. Results of this study will contribute to understanding the influence of multiple industrial sources on Pb distribution in urban dust and help identify measures that can reduce Pb exposure in local populations.

2. Materials and methods

2.1. Sample collection and pretreatment

Jilin City is the second largest city in Jilin Province, northeastern China, with a total area of 27,120 km^2 and a population of nearly 4.3 million (JLESSY, 2013). It plays an important part in the growing chemical industry of China. Since 2001, Jilin City's total industrial output has increased markedly, and continues to grow, having a 2013 output 9.7% higher than in 2012 (JLESSY, 2013). As a growing industrial city, there are many associated environmental challenges. This is compounded by the fact that there are many industries located in Jilin City Center (JLC) and also many people lived in JLC.

Fig. 1 presents a map of JLC showing the location of sampling sites and major heavy industries. A total of 21 urban dust samples were collected from 21 evenly distributed sites on October 19, 2012. At each sampling sites (1-21), the height of the column shown in Fig. 1 is proportional to the measured Pb concentration. Detailed information about these sampling sites is given in Supplementary Table ST1. Specifically industrial sites are numbered i1–i8 in Fig. 1. Given the large number of heavy industrial companies in Jilin City (with a listing of 1448 Industrial Enterprises above Designated Size in 2012) (JLESSY, 2013), only the top 20 prime operating revenue companies within the study area, along with the sampling sites (10 and 12) from industries are shown in Fig. 1. More information on these industries can be found in Supplementary Table ST2.

As described in our previous study (Li et al., 2016), urban dust samples were carefully collected within 0.5 m of the road curb or edge at each site, using a 15 cm brush and a plastic dustpan. Sweeping was repeated back and forth at least three times to collect surface particles. At least 300 g of particles were collected at each site. Sampling was carried out at least 7 days after rainfall. The collected samples were stored in self-sealing plastic bags and immediately transported to the laboratory. The samples were air-dried for 15 days in the laboratory and then sieved through a 500 μm opening nylon sieve to remove large particles, including stones, leaves, small pieces of bricks, cigarette butts, and other litter. The sieved dust samples were ground to powder, having a grain size less than 200 μm in diameter, to facilitate digestion, and stored at 4 °C prior to analysis.

2.2. Metal measurement, quality control and quality assurance

Approximately 0.5 g of the ground sample powder was digested using hydrofluoric acid, nitric acid, perchloric acid, and aqua regia according to the National Standard method for China (GB15618, 1995). Pb concentrations were measured using inductively coupled plasma-mass spectrometry (ICP-MS, American Thermo Electron Corporation X series II).

The detection limit of Pb was 2 μg/g. Three samples out of the overall 21 samples were selected to run as duplicate sample analyses for quality assurance. The recovery rate was determined by adding geochemical reference materials (e.g., GSS17, GSS25, GSS26) (three samples). The average recovery rate was calculated to be 100.6%.

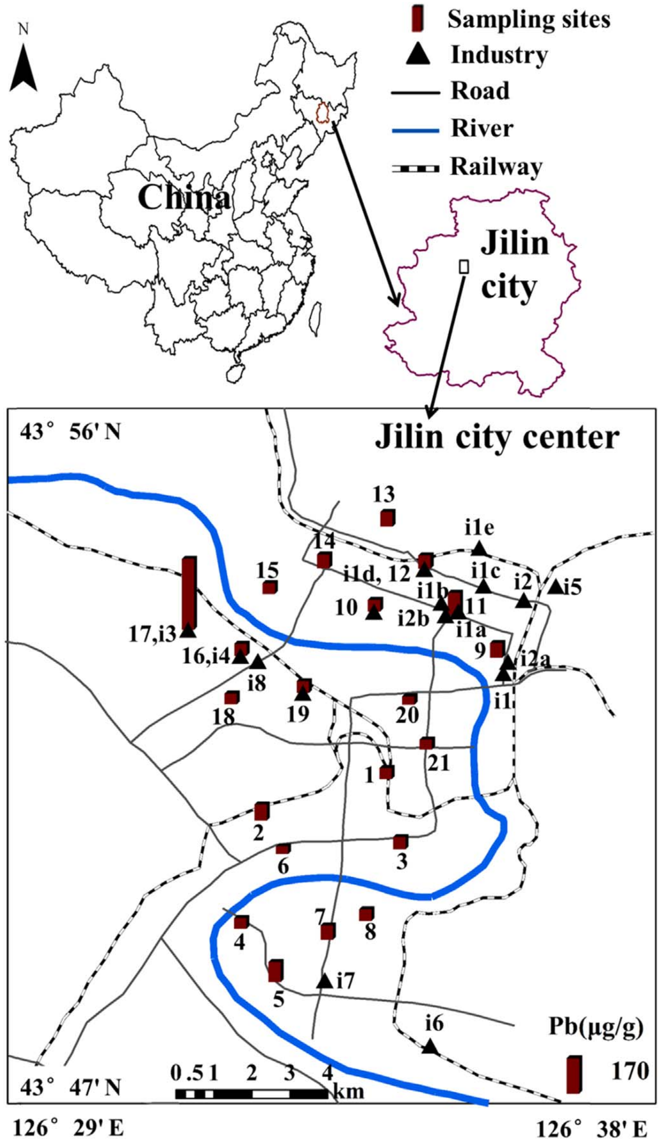

Fig. 1. Sampling site and major industry locations in Jilin City Center (JLC), China. (For interpretation of the references to color in this figure,the reader is referred to the web version of this article) .

2.3. Data analysis

Descriptive statistical analyses were performed using Microsoft Excel 2010 (Microsoft Corp., Albuquerque, NM, USA) and the freely available "R" statistical software package (R Core Team, http://www.r-project.org, accessed 09.11.16), version 3.2.4. The MLE and BA routines in R were used to test the influence of various industries on Pb concentration in urban dust. Both routines search for a set of parameters to maximize probability. ArcGIS 10.0 (Esri, Redlands, CA, USA, https://www.arcgis.com, assessed 09.11.16) was used for spatial calculations and to create Fig. 1. The health risk at each sampling site was estimated for ingestion, inhalation and dermal contact using USEPA methods described in the Section 2.3.1 belows. The health risk at locations other than sampling sites was estimated using ArcGIS 10.0's inverse distance weighting (IDW) function as shown in Fig. 2. Origin 8 (OriginLab Corp., Northampton, MA, USA) was used to estimate the lead concentration, as shown in Fig. 3. The data for Fig. 4 were