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Assessment of heavy metal pollution and human health risk in urban soils of steel industrial city (Anshan), Liaoning, Northeast China

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ABSTRACT

The purpose of this study was to determine the concentrations and health risk of heavy metals in urban soils from a steel industrial district in China. A total of 115 topsoil samples from Anshan city, Liaoning, Northeast China were collected and analyzed for Cr, Cd, Pb, Zn, Cu, and Ni. The geoaccumulation index (Igeo), pollution index (PI), and potential ecological risk index (PER) were calculated to assess the pollution level in soils. The hazard index (HI) and carcinogenic risk (RI) were used to assess human health risk of heavy metals. The average concentration of Cr, Cd, Pb, Zn, Cu, and Ni were 69.9, 0.86, 45.1, 213, 52.3, and 33.5 mg/kg, respectively. The Igeo and PI values of heavy metals were in the descending order of Cd > Zn > Cu > Pb > Ni > Cr. Higher Igeo value for Cd in soil indicated that Cd pollution was moderate. Pollution index indicated that urban soils were moderate to highly polluted by Cd, Zn, Cu, and Pb. The spatial distribution maps of heavy metals revealed that steel industrial district was the contamination hotspots. Principal component analysis (PCA) and matrix cluster analysis classified heavy metals into two groups, indicating common industrial sources for Cu, Zn, Pb, and Cd. Matrix cluster analysis classified the sampling sites into four groups. Sampling sites within steel industrial district showed much higher concentrations of heavy metals compared to the rest of sampling sites, indicating significant contamination introduced by steel industry on soils. The health risk assessment indicated that non-carcinogenic values were below the threshold values. The hazard index (HI) for children and adult has a descending order of Cr > Pb > Cd > Cu > Ni > Zn. Carcinogenic risks due to Cr, Cd, and Ni in urban soils were within acceptable range for adult. Carcinogenic risk value of Cr for children is slightly higher than the threshold value, indicating that children are facing slight threat of Cr. These results provide basic information of heavy metal pollution control and environment management in steel industrial regions.

1. Introduction

Heavy metals contamination in urban soils is of great concern issues due to their wide sources, toxicity, non-biodegradable properties and accumulative behaviors. Urban soils are generally regarded as being a sink of heavy metals and other pollutants from various sources of industrial activities, coal and fuel combustion, vehicle emissions and municipal waste disposal (De Kimpe and Morel, 2000; Luo et al., 2012; Paterson et al., 1996; Poggio et al., 2009; Wei and Yang, 2010; Wong et al., 2006). The excessive accumulation of heavy metals in the urban soils may lead to the deterioration of soil ecosystem, threaten human health, and create other environmental problem. Therefore, the contamination of heavy metals in soils is of increasing concern in urban environment management.

Numerous studies have reported on heavy metals contaminations in urban soils around the world (Aelion et al., 2009; Cannon and Horton, 2009; Daniela et al., 2002; Davydova, 2005; Kelly et al., 1996; Madrid et al., 2002; Morton-Bermea et al., 2009; Wilcke et al., 1998) and in China (Chen et al., 2005; Duzgoren-Aydin et al., 2006; Li et al., 2009, 2001; Li et al., 2013; Lu and Bai, 2006; Lu et al., 2003, 2007a, 2007b; Luo et al., 2012; Shi et al., 2008; Sun et al., 2010; Wei and Yang, 2010). Luo et al. (2012) reviewed studies of heavy metal contamination in urban soils of several Chinese cities and found that contamination with Cd, Hg, Cu, Pb, and Zn is widespread in urban soils. Different methods, such as enrichment factor (EF), geoaccumulation index (Igeo), pollution load index (PLI) and potential risk index, have been widely used to assess the contamination level of heavy metals in urban soils. The study on the distribution and source identification of heavy metals in different cities was also widely conducted (Chen et al., 2012; Sun et al., 2010; Wu et al., 2015; Zhao et al., 2014). The heavy metal pollution in urban soils and dusts has

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become significant threat to human health with the rapid industrialization and urbanization of China over the last two decades. Analysis of metal concentrations in soils, in particular, in old industrial regions, is critical for the making of policies aimed at reducing pollution level and improving soil ecosystem.

In recent years, urban soils have been evaluated as a diagnostic tool of environmental conditions that influence human health (Abrahams, 2002; Aelion et al., 2009; Chen et al., 2015; Chabukdhara and Nema, 2013; Loredo et al., 2003; Maanan et al., 2014; Li et al., 2014). Several studies have reported on health risk of heavy metals contaminations in soils and road dusts (Chen et al., 2015; Wei et al., 2015; Wu et al., 2015). The urban soil contaminated by heavy metals could enter the human body in three ways: ingestion, dermal contact and inhalation (Islam et al., 2015; Olawoyin et al., 2012; Wu et al., 2015). Therefore, children living in the industrial area may easily suffer from high health risk due to the contaminated urban soils. Many studies demonstrated the negative effects of heavy metals on human health (Islam et al., 2015; Mielke et al., 1999; Wei et al., 2015; Wu et al., 2015). However, study on possible health risk due to metal contamination in urban soils in old industrial region is still not reported.

Anshan city is the largest steel industrial base in China and has the reputation of the steel industry city. Established in 1948, the Anshan steel factory is one of the earliest large-sized iron and steel production factory in China and has made 658 million tons steel products and 375 million tons iron. The city also houses various types of highly polluting industries including metal smelting, metal casting, machinery manufacturing and etc. The environment of Anshan is facing serious threats from pollution caused by the industrial activities and urban rapid expansion. Increasing soil heavy metal pollution from steel industry and traffic activities is becoming a serious problem that adversely affects public health in the city. Therefore, the purposes of this study were (1) to determine the concentration and distribution of heavy metals (Cd, Cr, Cu, Zn, Pb and Ni) in soil from steel industrial districts, (2) to identify the potential source of heavy metals by multivariate analysis, and (3) to assess the pollution level, potential ecological risk and human health risk of heavy metals in urban soils.

2. Materials and methods

2.1. Study area

This study was carried out in the Anshan city, Liaoning Province, Northeast China, which has a total area of 624 km^2 and a population of more than 1.4 million. Anshan city is famous for its heavy industry and the biggest steel industrial district of northeast China. As an old industrial base with a long history, the heavy industry of Anshan city is mainly situated in the Anshan Steel Industrial Group Corporation, Tiedong and Tiexi districts (Fig. S1). The Anshan Steel Industrial Group Corporation made 31 million tons of steel products and 16 million tons of iron products each year. The sampling sites were located within 122°55′ to 123°00′E longitude and 41°04′ to 41°10′N latitude. The climate of studied area is a temperate continental monsoon climate, with an annual average temperature of 8.0–9.0 °C and annual rainfall of 640–880 mm. The soil of the study area is mainly Udalf. The main sources of pollution are the steel-related industry, vehicles, and human activities.

2.2. Soil sampling and chemical analysis

A total of 115 topsoil samples (0–10 cm) were collected from Anshan Steel Industrial Group Corporation (ASIGC) (23 samples), Tiedong district (46 samples) and Tiexi district (46 samples). The sampling sites of ASIGC are distributed in road and bare land around steel production factory. Many industrial enterprises related to steel industry, such as metal smelting, metal casting, and machinery industrial, are located in this area. The sampling sites of Tiedong and Tiexi districts are distributed in heavy traffic density roads, residential and industrial areas of urban areas. The location of sampling sites is given in Fig. S1. At each sampling site, three to five subsamples were collected from the topsoil (0–10 cm) using stainless steel shovel. These sub-samples were thoroughly mixed to form a composite sample. The samples were placed in self-lock polyethylene bags and transferred to the laboratory. The position of sampling sites was recorded using a hand-held global positioning system (GPS). The soil samples were collected in May 2014.

The soil samples were air-dried under room temperature and passed through a 2 mm nylon sieve to remove plant roots, debris, glasses and other materials. A portion of soil samples were passed through 0.149 mm sieves in order to completely dissolve the soil particles for heavy metal analysis (CNEMC, 1990). Soils (0.5 g) were digested with a mixture of concentrated $HF–HClO_4–HNO_3$ on a hot plate (CEPA, 1995). The digested solution was cooled, filtered, and finally diluted to 25 mL. The concentration of heavy metals (Cd, Cr, Pb, Cu, Zn, and Ni) was measured using inductively coupled plasma-atomic emission spectroscopy (ICP-AES, iCAP6300DUO, Thermo Electron Corporation). Quality assurance and control (QA/QC) included the procedural blank, duplicate analysis and standard reference materials. The accuracy, calculated from the relative error of the certified values of standard reference materials, was less than 10%. The relative standard deviation (RSD) of duplicate samples was under 5%.

2.3. Assessment of heavy metal pollution

Pollution level of heavy metals in soils was evaluated using the geoaccumulation index (Igeo), pollution index (PI), and potential ecological risk (PER) (Chen et al., 2015; Islam et al., 2015; Li et al., 2014; Wu et al., 2015). The geoaccumulation index (Igeo) was calculated according to the equation of Müller (1969).

$$\text{Igeo} = \log_2\left[\frac{C_n}{1.5B_n}\right] \tag{1}$$

where Cn represents the measured concentration of the element n and B_n is the background content of element n in Chinese soil (Liaoning) (CNEMC, 1990). Igeo was classified as follow (Chen et al., 2005; Wei et al., 2015; Wei and Yang, 2010): <0, practically unpolluted; 0–1, unpolluted to moderately polluted; 1–2, moderately polluted; 2–3, moderately to strongly polluted; 3–4, strongly polluted; 4–5, strongly to extremely polluted; and >5, extremely polluted.

The pollution index (PI) was defined as the ratio of element concentration in the soil sample to the background concentration of the corresponding element in the Chinese soil (Liaoning) (CNEMC, 1990). The PI of each element was calculated and classified as either low ($\text{PI} \le 1$), middle ($1 < \text{PI} \le 3$) or high ($\text{PI} > 3$) (Chen et al., 2005; Wu et al., 2015). In addition, to give an assessment of the overall pollution status for a sample, the pollution load index (PLI) of heavy metals was calculated using

$$\text{PLI} = (\text{PI}_1 \times \text{PI}_2 \times \text{PI}_3 \times \cdots \times \text{PI}_n)^{1/n} \tag{2}$$

According to contamination degree, the PLI is classified as unpolluted ($\text{PLI} \le 1$), unpolluted to moderately polluted ($1 \le \text{PLI} \le 2$), moderately polluted ($2 \le \text{PLI} \le 3$), moderately to highly polluted ($3 \le \text{PLI} \le 4$), highly polluted ($4 \le \text{PLI} \le 5$), or very highly polluted ($\text{PLI} > 5$) (Chen et al., 2015; Islam et al., 2015).