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# Reprint of: Metals in exposed-lawn soils from 18 urban parks and its human health implications in southern China's largest city, Guangzhou

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A B S T R A C T

The total concentrations, fractionation of metals and human health risk in surface-exposed lawn soils from 18 urban parks in Guangzhou were investigated. Cd was predominantly associated with the acid-soluble fraction and Pb mainly with the reducible fraction, whereas Cr, Ni, Cu, and Zn were strongly associated with the residual fraction. The hazard indices for the metals were <1, indicating that exposure to the urban park soil does not pose significant risks of non-carcinogenic effects from the metals analyzed. The probabilities of Cd, Cr, and Ni posing carcinogenic risks to children and adults were negligible (probability $<1 \times 10^{-6}$).



## 1. Introduction

The unprecedented rate at which urbanization and industrialization have occurred in China in the last few decades has been accompanied by increasing environmental pollution in urban areas because of the increasing intensities of anthropogenic activities in urban areas (Chen, 2007; Wei and Yang, 2010; Bai et al., 2014; Cheng et al., 2014). Human health in a town or city is strongly affected by the status of the soil in that area (Imperato et al., 2003; Wang et al., 2012a). Urban soils can be regarded as the sinks for metals and other pollutants, the main sources of which are industrial activities, vehicle emissions, the combustion of coal and other fuels, and the disposal of municipal solid waste (Wang et al., 2012b; Zhao et al., 2014; Karim et al., 2015). Excessive inputs of trace metals and other pollutants to urban soils may cause the urban soil ecosystem to deteriorate and other environmental problems to occur (Imperato et al., 2003; Zhao et al., 2014).

Metals have elicited much attention because they are toxic and non-degradable and can bio-accumulate (Järup, 2003; Sabine and Wendy, 2009; Gu et al., 2012). According to numerous studies, metals have been found to accumulate in fatty tissues, affect organ functions, and disrupt the nervous and endocrine systems of animals (Waisberg et al., 2003; Bocca et al., 2004; Zhao et al., 2014). Metals in urban soils can be transferred readily to humans through the ingestion, inhalation, and dermal absorption routes, and they will pose potential threats to urban residents, especially to children and senior citizens who are more susceptible to such threats and tend to use parks more often than other people (Miguel et al., 1997; Guney et al., 2010; Wei and Yang, 2010; Peña Fernández et al., 2014).

Analyzing total metal concentrations in soils can provide valuable information on overall pollution levels. However, total

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concentrations alone are not sufficient to allow the potential effects of contaminated soils on humans to be evaluated because the toxicity and mobility of a metal in the environment strongly depends on the specific chemical forms of the metal that are present and the states in which the metal is bound (Filgueiras et al., 2002; Gleyzes et al., 2002). Sequential extraction is a very important method that has been widely used to gain insights into the environmental behaviors of potentially toxic metals (Sutherland, 2010). Many sequential extraction schemes have been developed that depend on the Tessier procedure. Of these, the BCR procedure has been extensively accepted and used to fractionate metals in different types of environmental media (Gleyzes et al., 2002; Sutherland, 2010; Gu et al., 2014). However, performing a traditional extraction method is extremely tedious and time-consuming (Alonso Castillo et al., 2011). Microwave-assisted sequential extraction is less tedious and time-consuming than traditional extraction methods, and it has been used to analyze all types of solid environmental media, including sediment, soil, sewage sludge, and particulate matter (Jamali et al., 2009; Alonso Castillo et al., 2011; Kumar et al., 2013; Burt et al., 2014).

Guangzhou (112° 57′ to 114° 3′ E, 22° 26′ to 23° 56′ N) is the capital of Guangdong Province, and lies in the northern part of the Pearl River Delta. Guangzhou has existed for more than 2200 years, and has a population of more than 10 million (GZG, 2014). Guangzhou is one of the most important cities in the Pearl River Delta, which is the area with the fastest-growing economy in China. Exposed lawns in urban parks are the main areas used for outdoor recreation by children and adults in Guangzhou. However, to the best of our knowledge, very little information is available on total concentrations and the fractionation of metals and the health risks posed by metals in exposed-lawn soils in 18 urban parks in Guangzhou. The aims of this study were (1) to determine the total concentrations and fractionation of metals in soils under exposed lawns in urban parks in Guangzhou, and (2) to assess the health risks posed by metals in the soils.

## 2. Materials and methods

### 2.1. Topsoil sample collection

Topsoil samples (0–10 cm) were collected from exposed lawns that are the main areas used for outdoor recreation by children and adults. The samples were collected from 18 public parks in Guangzhou City (Fig. 1) in May 2014. Between 15 and 45 subsamples (the actual number depended on the area of the park lawn) of topsoil were collected from each park, and the subsamples were mixed thoroughly to get a representative sample for the whole park lawn. Each sample was then dried at 50 °C in an oven until it reached a constant weight, then the soil was gently disaggregated and sieved through a nylon sieve to give particles with diameters less than 150 μm and to homogenize the soil. Each prepared sample was then stored in a black self-sealing polyethylene bag until it was analyzed.

### 2.2. Analytical methods

The organic matter (OM) content was determined through losses on ignition to constant mass at 550 °C for 4 h (De Jonge et al., 2012). For soil pH, a 1: 2.5 (W/V) soil-water suspension was determined by a Single-Channel pH Meter (Mettler-Toledo International Inc. Switzerland) (Nanos and Rodríguez Martín, 2012). Pretreatments of particle size were implemented based on the China National Standards (GB/T12763.8–2007) and granulometry of each sample was determined using a Malvern Mastersizer 2000 (Malvern Instruments Co., Ltd. UK).

Each sample was sequentially extracted to give information on the metal fractionation following a method described by Rauret et al. (1999). In this method, the metals are separated into four operationally defined geochemical fractions, the acid-soluble, reducible, oxidizable, and residual fractions. The optimized microwave-assisted sequential extraction method used in this study has been described in detail elsewhere (Alonso Castillo et al., 2011). The metals remaining in a sample residue were digested following the United States Environmental Protection Agency (US EPA) method 3050B (microwave digestion). The total metal concentrations in soil samples were estimated by summing up the metal concentrations in the four fractions. The Chinese national standard sediment sample GBW07436 was analyzed to check the accuracy of the sequential extraction procedure and to monitor the performance of the analytical method. The Cd, Pb, Cr, Ni, Cu, and Zn recoveries were 87–103% in the acid-soluble fraction, 86–93% in the reducible fraction, 92–106% in the oxidizable fraction, and 89–104% in residual fraction. The concentrations of metals in the four chemical fractions were measured by a Hitachi Z2000 atomic absorption spectrophotometer (Hitachi High-Tech Instruments Co., Ltd. Japan). The instrument detection limits were calculated as 3σ/S (σ is standard deviation of blank signal, and S is the sensitivity) and the detection limits (mg/kg) were 0.04 for Cd, 0.1 for Pb, 0.2 for Cr, 0.1 for Ni, 0.05 for Cu and 0.6 for Zn, respectively.

### 2.3. Human health risk model

Children and adults are exposed to metals through three main pathways: ingestion, inhalation, and dermal contact. According to the US EPA (1997) and Lu et al. (2014a), the average daily dose (ADD in Eqs. (1)–(3)) (in mg/(kg d)) received via each of the three exposure routes can be estimated using Eqs. (1)–(3). Of the six metals that were studied, Cd, Cr, and Ni are known to be carcinogenic (Ferreira-Baptista and De Miguel, 2005; Xue et al., 2012). Slope factors for carcinogenic risks posed by these metals after exposure through ingestion and dermal contact have not been determined by the US EPA, so we only considered carcinogenic risks posed by the metals after exposure through inhalation. The lifetime average daily dose (LADD in Eq. (4)) was calculated using Eq. (4) (Xue et al., 2012) to allow the potential carcinogenic risk to be determined.

$$ADD_{ingestion} = \frac{C \times R_{ingestion} \times EF \times ED}{BW \times AT} \times 10^{-6} \tag{1}$$

$$ADD_{inhalation} = \frac{C \times R_{inhalation} \times EF \times ED}{PEF \times BW \times AT} \tag{2}$$

$$ADD_{dermal} = \frac{C \times SA \times SL \times ABF \times EF \times ED}{BW \times AT} \times 10^{-6} \tag{3}$$

$$LADD_{inhalation} = \frac{C \times EF}{AT \times PEF} \times \left( \frac{CR_{child} \times ED_{child}}{BW_{child}} + \frac{CR_{adult} \times ED_{adult}}{BW_{adult}} \right) \tag{4}$$

In Eqs. (1–4), a C value of $C_{UCL}$ (the exposure-point concentration, in mg/kg) is considered to give an estimate of the “reasonable maximum exposure”, which is the upper 95% confidence interval for the mean (US EPA, 2002; Sun et al., 2013). The upper 95% confidence limit (UCL) was calculated using the statistical software provided by the US EPA (ProUCL 5.0.00). The other parameters used in Eqs. (1)–(4) are defined in Table 1, and the real data for Chinese