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Distribution, source identification and health risk assessment of soil heavy metals in urban areas of Isfahan province, Iran

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ABSTRACT

The present study examines some heavy metals (As, Cd, Co, Cr, Cu, Ni, Pb and Zn) contents in urban soils of 23 cities in Isfahan province, central Iran. For this purpose, 83 topsoil samples were collected and analyzed by ICP-MS. Results showed that the concentrations of As, Cd, Cu, Pb and Zn are higher than background values, while Co, Cr and Ni concentrations are close to the background. Compared with heavy metal concentrations in selected cities around the world, As, Cd, Cu, Pb and Zn concentrations in urban soils of Isfahan are relatively enriched. Moreover, natural background concentrations of Co, Cr and Ni in Isfahan province soil are high and the apparent enrichment relative to other major cities of the world is due to this high background contents. Calculated contamination factor (CF) confirmed that As, Cd, Cu, Pb and Zn are extremely enriched in the urban soils. Furthermore, pollution load index (PLI) and Geoaccumulation index (I_{geo}) highlighted that highly contaminated cities are mostly affected by pollution from traffic, industries and Shahkuh Pb-Zn mine. Based on hazard quotients (HQ), hazard index (HI) and cancer risk (CR) calculated in this study, human health risk (particularly for Pb and Cd) have reached alarming scales. Results from principle component analysis (PCA) and positive matrix factorization (PMF) introduces three sources for soils heavy metals including mine and industries (mainly for Pb, Zn, Cd and As); urban activities (particularly for Cu, Pb and Zn); and geogenic source (Ni, Co and Cr).

1. Introduction

Soil as a natural component of the Earth serves a variety of vital functions in human societies including food production. During the last decades, the soil compartment has received a significant amount of pollutants from different sources including heavy metals due to rapid industrialization and urbanization (Wei and Yang, 2010). Soil is the most important environmental component because it acts not only as a geochemical sink for contaminants, but also as a natural buffer by controlling the transport of heavy metals to the atmosphere, hydrosphere and biosphere (Kabata-Pendias and Pendias, 2001). In contaminated soils, the contaminants will be transferred to the other environmental components, and indirectly threat human health (Zhang et al., 2007; Cui et al., 2005). Because of their persistence and toxicity, heavy metals are of major significance among the anthropogenic contaminants, (Adriano, 2001). Heavy metal pollution of soils is a severe problem in many parts of the world (Facchinelli et al., 2001; Solgi et al., 2012). Chemistry of parent rocks from which the soils are derived is the controlling factor for natural concentrations of trace metals in soils. Human activities may greatly increase metals concentrations in soil, particularly in urban areas (Guagliardi et al., 2013). Once contaminated, soils typically remain in this condition for a long period of time due to sorption of metals on particles and their limited mobility (Ferri et al., 2012; Peris et al., 2008). This fact produces a potential human cumulative exposure.

According to World Urbanization Prospects, over 3.5 billion of the world's 6.9 billion people now live in urban areas, likely making up to 68.7% of the population by 2050 (United Nations, 2009). Urbanization could affect soil physicochemical parameters such as their pH, texture, cation exchange capacity, and bulk density and also cause harmful substances to deposit in the soils (Liu et al., 2016; Amjadian et al., 2016). Urban ecosystem is defined as a

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complex composite of both natural (local climate, geology and the geographical characteristics) and anthropogenic (population and settlement patterns, use and misuse of resources, and the human inhabitants' behavior governed by their socio-economic conditions) factors (Karim et al., 2014). A wide range of anthropogenic activities including domestic heating, disposal of municipal and industrial wastes, heavy traffic, industrial emissions and past land use may increase the amount of heavy metals in urban soils (Kelly et al., 1996; Norm et al., 2001; Thornton, 1991; Wong et al., 2006) which have some specific characteristics such as poor structure, unpredictable layering and high concentrations of trace elements (Tiller, 1992; Manta et al., 2002). Heavy metals in urban soils may be transferred to humans through ingestion, inhalation, or dermal absorption pathways, and subsequently accumulate in fatty tissues, affect the nervous, endocrine and immune systems, hematopoietic function, and normal cellular metabolism. These contaminants are useful indicators to understand the environmental conditions, and can be used to monitor natural variability in the soil composition, and toxicological health risks associated with soil pollution (Zhao et al., 2014). Assessing the degree of metal contamination in urban soils presents a challenge to researchers because of the complexity of urban landscapes in nature and diversity of heavy metals sources (Yesilonis et al., 2008). Isfahan is the largest industrial Province in Iran and has the reputation of being the center of steel industry and many major mining activities. Overall, a total of 40 active industrial towns are located in this area. The Province also houses various types of highly polluting industries including petrochemical complexes, power plants, cement factories and machinery manufacture. These industrial activities, particularly steel industries and Pb-Zn mining, along with city expansion and inapplicable waste disposal caused serious threats by increasing soil heavy metal pollution and subsequently may cause serious health problem that adversely affects the population in the study area. Investigating the spatial distribution and source identification of heavy metals in urban soils can serve as a basis for soil remediation, risk assessment and effective management recommendations (Li and Feng, 2010; Zhao et al., 2010). The present study addresses the content, spatial distribution, health risk assessment and possible sources of selected heavy metals (As, Cd, Co, Cr, Cu, Ni, Pb and Zn) in urban soils of Isfahan province, central Iran. For these purpose, soil metal content in 23 cities were investigated and their possible sources were identified using not only common statistical approaches, but also positive matrix factorization (PMF) for the first time in the study area.

2. Material and methods

2.1. Study area

Isfahan is one of the large industrial cities in Iran, known for steel production and processing, chemical industries, and other industrial plants, in which intensive agricultural lands are surrounded by different industries such as steel and cement-making mills and lead mining. Isfahan province is located in central Iran with an area of about 106869 km^2 and lies between 32° 11' - 33° 6′ N and 51° 8' - 52° 12′ E. Mean annual precipitation in the study area is about 112.5 mm, and annual mean temperature is 16.2 °C, ranging from minimum 9.4 °C in winter to maximum 43 °C in summer. The study area includes some important cities of Isfahan province including Dorcheh, Chamgordan, Abrisham, Segzi, Najafabad, Zarrinshahr, Shahinshahr, Falavarjan, Mobarakeh, and the Centre of the province (Isfahan metropolis). Geologically, the study area is covered by sedimentary rocks (limestone, dolomite, evaporite, sandstone, and shale), along with Zayandehrud River alluvium (Fig. 1), and the soils in the study area are mostly composed of immature calcaric regosols, lithic teptosols, and haplic calcisols with undeveloped horizons (Keshavarzi et al., 2015).

2.2. Soil sampling, preparation and analysis

A total of 83 soil samples (0–5 cm deep) were collected from garden, park, roadside, residential area, and major cross way and squares of each city in July 2011 (Fig. 1). The sampling stations were chosen so as to cover evenly the whole study area. Due to the importance of Isfahan metropolis, its area, population, traffic, and diversity of land uses, the sampling sites are relatively denser. To create representative samples for each sampling site, composites samples were taken. This type of sampling yields homogenized samples for analyses. In each sampling site about 2 kg urban soil was collected using clean gloves, a stainless steel spade and a plastic scoop. The collected samples were transported to the laboratory for preparation and analysis.

In laboratory the soil samples were air dried at room temperature and sieved through a 63 μm sieve for the chemical analysis. A 0.5 g aliquot of each sample was digested in Aqua Regia, and concentrations of As, Cd, Co, Cr, Cu, Ni, Pb and Zn were determined using ICP-MS method in a certified commercial Canadian laboratory (Acme Analytical Laboratories, Ltd). Quality assurance and control (QA/QC) included the procedural blank, duplicate analysis and use of standard reference materials (STD OREAS24P and STD OREAS45C); the recovery percentages ranged from 88% to 106% indicating a good agreement between the measured and the certified values. Soil pH and electrical conductivity (EC) were determined using a pH meter and a conductivity meter with soil/water ratios of 1:2.5 and 1:5 in aqueous suspensions respectively. Also Soil organic matter was determined by potassium dichromate wet combustion procedure.

2.3. Data analysis

2.3.1. Assessment methods of heavy metal pollution

To assess soil contamination level, contamination factor (CF) and pollution load index (PLI) were calculated. Contamination factor can be calculated based on the equation presented by Tomlinson et al. (1980) as follows:

$$CF_i = \frac{C_{metal}}{C_{background}} \quad (1)$$

where $_{metal}$ is concentration of the concerned heavy metal in soil sample, and $C_{background}$ is the concentration in unpolluted soil (background value).

The mutual pollution effect at different stations by different metals can be calculated using pollution load index. PLI is the geometric mean of the CF values for the *n* metals (Madrid et al., 2002):

$$PLI = \sqrt[n]{CF1 \times CF2 \times \ldots \times CFn} \quad (2)$$

A PLI value close to 1 indicates heavy metals load near the background level, while values >1 indicate pollution (Cabrera et al., 1999).

To quantify the degree of heavy metals pollution the Geo-accumulation index (I_{geo}) was calculated as follow (Zhang et al., 2016):

$$I_{geo} = \mathrm{Log}_2[C_n/1.5B_n] \quad (3)$$

where, C_n is concentration of examined metal in soil, B_n is geochemical background value of given metal and factor 1.5 is used