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Health risk implications of potentially toxic metals in street dust and surface soil of Tehran, Iran

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ABSTRACT

In this study a total of 30 street dusts and 10 surface soils were collected in the central district of Tehran and analyzed for major potentially toxic metals. Street dust was found to be greatly enriched in Sb, Pb, Cu and Zn and moderately enriched in Cr, Mn, Mo and Ni. Contamination of Cu, Sb, Pb and Zn was clearly related to anthropogenic sources such as brake wear, tire dust, road abrasion and fossil fuel combustion. Spatial distribution of pollution load index in street dust suggested that industries located south-west of the city intensify street dust pollution. Microscopic studies revealed six dominant group of morphological structures in calculation of the exposurethe street dusts and surface soils, with respect to different geogenic and anthropogenic sources. The BCR (the European Community Bureau of Reference) sequential extraction results showed that Sb, Ni, Mo, As and Cr bonded to silicates and sulfide minerals were highly resistant to dissolution. In contrast, Zn, Cd, and Mn were mostly associated with the exchangeable phase and thus would be easily mobilized in the environment. Cu was the most abundant metal in the reducible fraction, indicating its adsorption to iron and manganese oxy-hydroxides. Pb was equally extracted from exchangeable and reducible fractions. Anthropogenic sources related to traffic apparently play a small role in Cr, Ni and Mo contamination and dispersed them as bioavailable forms but with reduced mobility and bioavailablity due to high potential of complexation and adsorption to organic matter and iron and manganese oxy-hydroxides. Calculated Hazard Index (HI) suggests ingestion as the most important pathway for the majority of PTMs in children and dermal contact as the main exposure route for Cr, Cd and Sb for adults. The HIs and fractionation pattern of elements revealed Pb as the sole element that bears potential health risk in street dust and surface soil.

1. Introduction

Potentially toxic metals (PTMs) are considered to be a major source of environmental pollution in urban areas (Al-Khashman, 2004; Batjargal et al., 2010). Street dust is a main reservoir for urban PTMs from surrounding areas (Tang et al., 2013). Displaced surface soil (Ferreira-Baptista and De Miguel, 2005) is one of the main sources of street dust and consequently trace elements therein. Furthermore, emissions from anthropogenic sources (vehicular traffic, heating systems, building deterioration, construction and renovation, corrosion of galvanized metal structures, etc.) contribute directly to the street-dust load in their proximity (Sutherland and Tolosa, 2000; Al-Khashman and Shawabkeh, 2006). Hence, the composition and quantity of settled dust in populated urban areas, are the most effective and sensitive environmental indicators (Tang et al., 2013).

Long-term exposure to street dust and surface soil could cause hazardous effects to human health through inhalation, ingestion, and dermal contact absorption, due to its accumulated PTMs (Yuan et al., 2014). Moreover, some PTMs are non-degradable with no-known homeostasis mechanism in human body (Tong and Lam, 2000). Hence, estimation of PTMs exposure via street dust and surface soil is a crucial issue. Since the toxicity of elements and their environmental mobility and tendency to be accumulated in living systems are greatly influenced by their chemical forms, it is important to identify chemical form of PTMS in human health risk assessment.

A sequential extraction approach can provide detailed information on the origin, mode of occurrence, biological and physicochemical availability, mobilization and transport of elements (Rao et al., 2007). Researchers have used several methods to assess bioavailability of elements mostly in soil and sediment samples. BCR sequential extraction method is already applied by several authors on urban soil and street dusts (e.g. Manta et al., 2002, Mielke et al., 1999, Isen et al., 2013, Delgado et al., 2011). As an example, Li et al. (2013) applied the modified BCR sequential extraction procedure on urban street dusts

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from a metropolitan city, Nanjing, SE China for partitioning and evaluating mobility, availability and persistence of 10 trace metals.

There are many published studies of the geochemical characterization of PTMs in street dust of industrialized and urban areas (e.g. Cao et al., 2012, Cai et al., 2013, Andersson et al., 2010, Shi et al., 2008). The perusal of related literature revealed that the few studies carried out in Iran were mostly focused on total PTMs concentration. Soltani et al. (2015) investigated human health hazards of heavy metals and polycyclic aromatic hydrocarbons (PAHs) in the street dust of the Isfahan metropolis. They found that Cd and Pb, pose high potential ecological risk in Isfahan street dust. Kamani et al. (2015) analyzed concentrations of Cd, Cr, Cu, Ni, Pb, and Zn in Zahedan street dust. They used various environmental indices to evaluate PTMs pollution in street dust and found that all samples are enriched in heavy metals (Kamani et al., 2015). Keshavarzi et al. (2015) evaluated the pollution and chemical speciation of selected heavy metals and their human health risk in the street dust of Shiraz metropolis. According to calculated hazard indices they recognized Hg, Pb, Zn and Mn as the most toxic elements in street dust samples. Saeedi et al. (2012) analyzed metals (Cu, Cr, Pb, Ni, Cd, Zn, Fe, Mn and Li) and polycyclic aromatic hydrocarbons in street dust samples from two districted areas of eastern and southern Tehran. The results of their study showed elevated concentrations of Pb, Cd, Cu, Cr, Ni, Zn, Fe and PAHs in the street dust samples.

Determination of toxic metal pollution in street dust of a highly populated megacity such as Tehran, which is highly industrialized with many nearby PTM emission sources is thought to be useful. The current population of Tehran is more than 8.2 M. The increasing number of vehicles and the daily increasing trend of fuel consumption has turned into a major environmental issue in Tehran. Based on the last estimates, around 17.4 million trips are made daily in Tehran (Tehran Municipality, 2012), which increased the daily gasoline fuel consumption in 2015 to 90 L, significantly higher than the mean global value of 15 L. Consequently, the central district of the Tehran metropolis with the heaviest traffic was selected as the study area to assess the potential environmental health risk of selected PTMs.

The main objectives of the present study were: 1) to determine total concentrations of PTMs in the street dust and surface soil of Tehran; 2) to discriminate the anthropogenic and geogenic sources of highly concentrated PTMs in the street dust and surface soil; 3) to evaluate the PTMs bioavailability in the street dust; and 4) to assess PTMs health risk for children and adults via different exposure pathways.

2. Materials and methods

2.1. Study area

Tehran is a mountainside city with an average altitude of 1300 m above the sea level, located on the southern slopes of Alburz mountain range. The climate of Tehran province varies from warm and dry in the south to cold and semi-humid in the mountain and cold with long winters in the higher regions. Average annual temperature varies from 0 °C to 37 °C. The mean annual precipitation for the period 2014–2015 was 245 mm with the maximum occurring in March. The prevailing wind direction throughout the year is from the west and southwest to east and northeast (Fig. 1). The land-use in Tehran includes residential (28.8%), commercial (35.8%), industrial (11.6%), green lands (17.1%) and wasteland (6.7%).

2.2. Sample collection and preparation

30 street dusts and 10 surface soils were collected from the central district of Tehran (Fig. 1) within two days in August 2015 covering an area of 100 km^2. A two month dry spell preceded the sampling campaign. Each street dust sample was collected by gently sweeping an area of about 30 m^2 adjacent to the curb of the two sides of the road using a plastic hand broom and pan to avoid metal contamination (Ordónez, 1997). Each collected sample was then transferred to a separate clean polyethylene bag. Soil samples were collected from each sampling point using a small plastic shovel. Each sample included at least two sub-samples collected from an area of 3 m^2 from top 0–5 cm soil.

2.3. Analytical methods

Extraneous matter such as paving stone and asphalt, small pieces of brick and concrete, leaves and other debris were removed from samples in laboratory. The samples were sieved through a 63 μm sieve, to remove other coarse debris. Then dust samples were dried at 30 °C for 7 days before analysis. A 0.5 g aliquot of sample was digested in aqua regia at 90 °C in a microprocessor controlled digestion block for 2 h. The digested sample was diluted and analyzed using inductively coupled plasma mass spectrometry (ICP-MS) in the Activation Labs, Canada.

Quality control was checked using certified reference material to assess accuracy, replicates to assess precision and quality control blanks to assess contamination. Multi-element standards, including Till-1 and Till-2 (Geochemical soil and till reference materials) and DH-1a (Uranium-Thorium ore) from Natural Resources Canada (NRCan); SdAR-M2, GXR1, GXR4 and GXR6 from USGS Geochemical Reference Materials and Certificates, OREAS45d from LGC standards, were used as certified reference material. The recovery percent varied from 87% for As to 115% for Sb, which is within the specified limits (Table 1). The analytical results showed no signs of contamination and the precision (n=3), expressed as relative standard deviation (RSD) %, is < 5% for all the studied elements except for Ni (RSD=5.5%).

Surface soils (< 2 mm) and 5 street dusts (< 2 mm) were analyzed for organic matter (OM) and organic carbon (OC) content gravimetrically by weight loss of the oven dried samples (105 °C) after ignition at 550 °C and 950 °C, respectively (Heiri et al., 2001). Electrical conductivity (EC) and pH were measured in 1:2.5 soil to distilled water w/w ratio, with a pH/EC meter (Cybershot PCD 6500 pH/EC meter, Eutech) (Ryan et al., 2007). Cation exchange capacity (CEC) was determined by ammonium acetate- sodium acetate (NH4OAc-NaOAc) method (Ryan et al., 2007). Dust and soil textures were determined by the hydrometry method (Hakanson, 1980) and classified according to USDA classification system.

2.4. Contamination assessment methods

Enrichment factor (EF) was determined by the following equation according to Yuen et al. (2014) to assess metal pollution level:

$$EF=(\frac{C_n}{C_{Sc}})_{sample}/(\frac{C_n}{C_{Sc}})_{background} \quad (1)$$

where, C_n is concentration of the target element, C_{Sc} is the concentration of scandium, as reference element. In this study, the worldwide average concentration of elements in soil was used as geochemical background (Table 1). According to Birch and Olmos (2008) an EF value less than 2 indicates deficiency to minimal enrichment. EF values greater than 10 indicate severe enrichment and EF values between 2 and 10 show moderate enrichment (Chen et al., 2007).

The pollution load index (PLI) in samples was calculated using the following formula:

$$PLI = \sqrt{CF_1 \times CF_2 \times \ldots \times CF_n} \quad (2)$$

where PLI is the pollution load index, CFs are contamination factors and n is the number of elements. A PLI value > 1 indicates polluted soil, whereas < 1 indicates no pollution (Tomlinson et al., 1980). CFs are calculated using the following formula:

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