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Human health risk assessment and riskiest heavy metal origin identification in urban soils of Yerevan, Armenia

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HIGHLIGHTS

- Lead is the primary pollutant of Yerevan soils.
- Single element non-carcinogenic risk was mainly detected for Pb and Cr.
- Heavy metals pose a non-carcinogenic risk to children.
- Low level of carcinogenic risk of As soil contents detected.
- Historical pollution was the main source for Pb riskiest contents.

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ABSTRACT

The pollution of urban soils by heavy metals remains a topical issue because of the risks it represents to human health. Heavy metal pollution levels of Yerevan's soils were evaluated using Pollution index and Enrichment factor, while associated health risk was assessed by US EPA model. The heavy metals with significant amount of PI > 1 values were observed for V (100%), Cr (95.4%), Ni (92.5%), Cu (95.6%), Zn (92.9%), Hg (89.0%), Pb (99.9%), As (72.0%), and Ba (61.6% of samples). EF showed that Yerevan topsoils were significantly contaminated with Hg, and moderately contaminated with V, Ni, Cu, Zn, Cr, and As. Topsoils near the smelting plants of molybdenum concentrate have moderately to extremely high contamination levels for Mo. Topsoils were moderate to extremely highly contaminated with Pb, too. The high amounts of samples with heavy metal contents greater than Maximum Acceptable Concentrations were observed for Pb, Cr, Zn, Ni, and Cu. Pb and Cr exceeded corresponding Soil Screening Levels in 3.39% and 2.43% of samples, correspondingly. The risk assessment showed children's multi-elemental non-carcinogenic risk and low level of arsenic carcinogenic risk in the whole Yerevan. The riskiest element was Pb which high contents in 72 risky sites correlate only with the metals having a natural origin. Moreover, its main source is historically polluted soils and Pb supposed to be redistributed in the city environment linked to the sorption complexes of Fe and Mn oxides.

1. Introduction

Cities are the centers of scientific-technological development and offer high-quality conditions for human life. At the same time, urbanization and industrialization affect urban environments in a unique way. A large number of studies of urban environment and especially urban soils (Alekseenko and Alekseenko, 2014; Charlesworth et al., 2011; Johnson et al., 2011; Meuser, 2010; Rouillon et al., 2013; Wong et al., 2006) showed that pollution by heavy metals is one of the most topical issues. Of particular concern is the health risk associated with heavy metal contents of the soils. Human health risk assessment was done in different cities around the world (Chabukdhara and Nema, 2013; Charlesworth et al., 2011; Ding and Hu, 2014; Filippelli et al., 2012; Grzetic and Ghariani, 2008; Gu et al., 2016; Jiang et al., 2017; Lee et al., 2006; Loredo et al., 2003; Poggio et al., 2008; Reis et al., 2013; Sahakyan et al.,

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2016; Sun et al., 2010; Zacháry et al., 2015) using the methodologies of health risk assessment developed by United States Environmental Protection Agency.

Although the first methodology of health risk assessment was developed in the 1980s, its core principles have undergone some modifications and are still valid (e.g (US EPA, 2009, 2008, 2005, 2004, 1997)). Risk assessment process consists of four basic steps, namely hazard identification, dose–response assessment, exposure assessment, and risk characterization (Pepper et al., 2011; US EPA, 1989a, 1989b). This model has been successfully used with soils (S. W. Lee et al., 2006; Lu et al., 2011; Rapant et al., 2010).

Yerevan has a total area of 223 km^2 and 1.06 million population (4782 persons per square km). Major land use types of the city are primarily residential, industrial, and commercial. Since Soviet time, being one of the industrialized (approx. 60% of republic's industry) cities of Armenia, Yerevan's territory is significantly polluted by heavy metals (Saghatelyan, 2004; Sahakyan, 2006; Tepanosyan et al., 2016). During the Soviet period, discharges from Aluminum plant, Electric bulb plant, Experimental plant of milling machines, Car and Worsted complex, Typography, Polygraphic complex, as well as from urban transport, led to the continuous accumulation of heavy metals in the soils of Yerevan (Saghatelyan, 2004; Sahakyan, 2006). After the collapse of the Soviet Union, major socioeconomic transformations had significant reflections on the quantitative and qualitative features of heavy metals geochemical streams. The quantities of heavy metal concentrations and priorities have changed over time, but being persistent pollutants, they still exist in the soils of Yerevan. Due to these socioeconomic transformations, the spatial distribution of industrial zones throughout Yerevan was changed as well and obtained a more mosaic character (Fig. 1) (Tepanosyan et al., 2016). In addition, uncontrolled constructive activities took place, and commercial and industrial enterprises were opened in residential areas, as well as many residential buildings, private houses and commercial units have been built in industrial zones (Supplementary materials Fig. 1). Since 1989, geochemical studies such as soil surveys, atmospheric and hydrochemical investigations were done systematically in the Center for Ecological-Noosphere Studies (CENS) of the National Academy of Sciences of the Republic of Armenia, but the human health risk has never been assessed by national or international standards. For this reason, this paper focuses on assessing: (1) heavy metals pollution levels and enrichment in Yerevan topsoil, (2) children's and adult's non-carcinogenic health risk, (3) arsenic lifetime carcinogenic risk, as well as (4) identifying the riskiest heavy metal sources of origin.

2. Materials and methods

2.1. Study site description

Naturally, in the territory of Yerevan (latitude 40°10′40″N, altitude 44°30′45″E) semi-desert, arid steppe and steppe landscapes are dominated. The climate is continental. The relief is represented by plains, foothills, plateaus and the River Hrazdan canyon. The parent rocks of the city territory consist of volcanic lavas, tuffs, and Quaternary sediments. The texture of the soil contained rubbly loam in a humic horizon. The soil profile is enriched by carbonates, and there is gypsum in the bottom lifts, indicating lack of processes of leaching of mineral substances in the deep horizons. This last process is conditioning the accumulation of heavy metals in the soil layer (Saghatelyan, 2004).

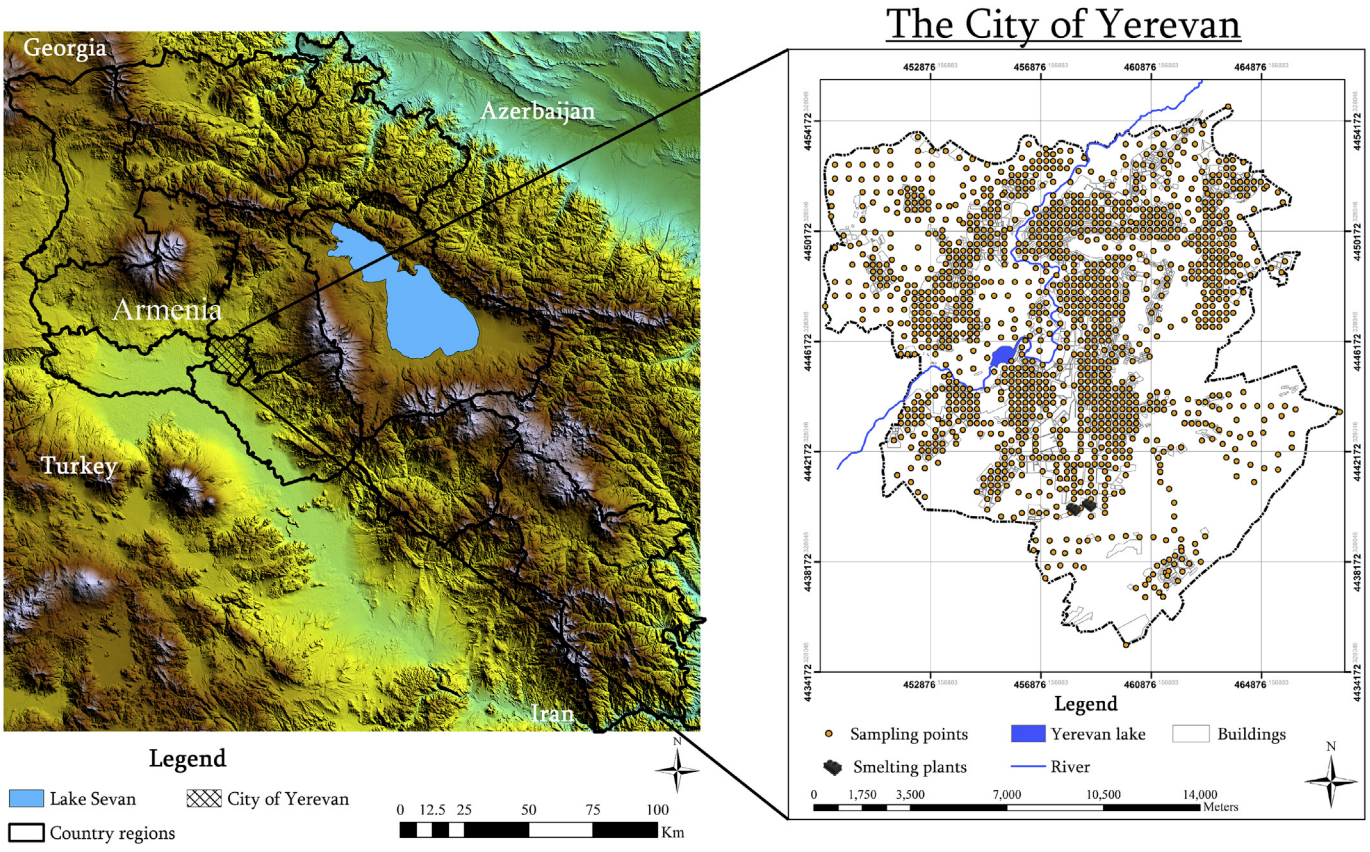

Fig. 1. Spatial distribution of topsoil samples in Yerevan territory.