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Origin identification and potential ecological risk assessment of potentially toxic inorganic elements in the topsoil of the city of Yerevan, Armenia

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ABSTRACT

The total concentrations of Ti, Fe, Ba, Mn, Co, V, Pb, Zn, Cu, Ni, Cr, Mo, Hg and As were determined in 1356 topsoil samples collected from the area of the city of Yerevan in order to: (1) determine the spatial distribution peculiarity and the origin of potentially toxic inorganic elements in Yerevan soils; and (2) assess the potential ecological risk of potentially toxic inorganic elements. The spatial distribution features of these elements were illustrated by environmental geochemical mapping. Pollution indexes (PIs) of As, Ti, Mn, Fe, Ba, and Co were between the range of 0.9–1.1, while PI of Cu, Zn, Ni, Cr, V, Hg, Mo (1.5–6.8) and especially Pb (22.9) was higher. Multivariate geostatistical analyses suggested that the concentrations of Pb, Cu, Zn, Hg, Cr, Ni and Mo observed in the topsoil bore the influence of anthropogenic and industrial activities. Moreover, according to the main findings of Principal component analysis (PCA) Pb and Zn have two distinct sources of origin: (1) vehicle emission and social activities (PC2); and (2) industrial activities (PC3). The potential ecological risk was quantitatively estimated for each sampling site and a risk map for the assessment was created. Among the investigated elements, Pb and Hg showed a higher potential ecological risk, than the others.

1. Introduction

Due to rapid industrialization and urbanization, significant concerns regarding urban soil pollution were raised in the past decades (Alekseenko and Alekseenko, 2014; Johnson et al., 2011; Morel and Heinrich, 2008; Wong et al., 2006). Being a complex mixer of soil parent materials and various inputs of exogenous materials (Morel and Heinrich, 2008), soils actually act as a pollutant sink and, if undisturbed, preserve the cumulative history of pollution. Especially topical in urban sites is contamination of soils by various potentially toxic inorganic elements (PTIE) (Charlesworth et al., 2011; Johnson et al., 2011; Luo et al., 2012; Wong et al., 2006). The long-term input of PTIE could result in a decreased buffering capacity of soil (Ljung et al., 2006) and groundwater contamination (Krishna and Govil, 2007; Ljung et al., 2006). Pollution of soils by PTIE has recently become a subject of many studies because of the risk both for the environment and human health (Albanese and Cicchella, 2012; Filippelli et al., 2012; Luo et al., 2011; Zhang et al., 2011). Highly polluted urban soils have an adverse effect on human health because of their easy transportation into human body from suspended dust or by direct contact (Madrid et al., 2002; Wang and Qin, 2005), as well as through the food chain (Charlesworth et al., 2011).

Geochemical studies in urban sites serve as an efficient tool to investigate peculiarities of the spatial distribution of PTIE in soils, to calculate geochemical baseline (Johnson et al., 2011), to reveal contaminated sites, to assess risk levels (Charlesworth et al., 2011; Johnson et al., 2011), to identify hot-spots and pollution sources (Acosta et al., 2011; Carr et al., 2008; Cicchella et al., 2005; Lee et al., 2006; Madrid et al., 2002), to control soil chemistry and safety, and to create a science based soil monitoring system.

Pollution with PTIE of the study area-city of Yerevan has been topical for many decades. Yerevan has a total area of 223 km^2, 1.06 million population (4782 persons per square km). The major land use types of the city are primarily residential, industrial and commercial.

Geochemical studies on the territory of Yerevan, among other Soviet Union cities, began in 1979 in the Institute of Mineralogy, Geochemistry and Crystal Chemistry of Rare Elements (IMGRE, Moscow). Later on, since 1989, the Center for Ecological-Noosphere Studies (CENS) of National Academy of Science of Armenia took up pace and continued all activities. PTIE were detected in Yerevan soils by the soils surveys implemented in last decades; particularly in 1979 and 1989–1990; during the Soviet Union (Saghatelyan, 2004); and in 2002–2003 after the economic collapse (Saghatelyan, 2004; Sahakyan, 2008). During the entire period of geochemical investigations existence of PTIE was also recorded in snow and leaf dust (Saghatelyan et al., 2014; Sahakyan, 2006), urban river waters (Nalbandyan and Saghatelyan, 2002; Nalbandyan et al., 2003; Saghatelyan and Nalbandyan, 2005) and vegetables grown in home gardens (Hovhannisyan et al., 2012; Hovhannisyan, 2004).

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The recorded high concentrations of PTIE are not typical for the territory of Yerevan, due to its natural and geological peculiarities (volcanic lavas, tuffs and the Quaternary sediments represent the geological base of the city (Saghatelyan, 2004)). Since Soviet time, being one of the industrialized (approx. 60% of the republics industry) cities of Armenia, Yerevan territory has remained significantly polluted by PTIE. Huge enterprises such as an Aluminum plant, the Electric bulb plant, the Experimental plant of milling machines, the Car and Worsted complex, Typography and a Polygraphic complex had operated in the city. Discharges from the abovementioned and other enterprises, as well as from urban transport, led to a continued stream of PTIE accumulating in the territory of the city (Nalbandyan and Saghatelyan, 2002; Saghatelyan, 2004; Saghatelyan et al., 2003; Sahakyan, 2006).

After the collapse of the Soviet Union and following socioeconomic transformations in 1990, radical changes occurred in the ecologically significant factors in the city's environment. Alongside the collapse, the level of industrial production simultaneously decreased and many of the industrial plants were closed (Saghatelyan, 2004; Sahakyan, 2008). Those socioeconomic transformations also have definite reflections on the quantitative and qualitative features of geochemical streams of PTIE. This manifested in changes of quantities of PTIE concentrations and priorities of pollutants, but being stable pollutants, they still existed in the territory of Yerevan.

Today, socioeconomic conditions are completely different: industry is in the recovery stage, with a wide range of industrial production in place. Spatial distribution of industrial units throughout the city has changed as well (Fig. 1) and obtained a more decentralized character, i.e. spread across the city irregularly.

The mosaic distribution of industrial enterprises, heavy traffic and historical pollution complicates the eco-geochemical status and reiterate the need to assess the present geochemical situation of the city's soils. To this end, the third geochemical soil survey was carried out in 2012. The present study is focused on determining the concentration levels and mapping of spatial distributions of PTIE in soils, revealing hot spots, and identifying the origin of PTIE in the soils. The potential ecological risk of PTIE for the first time in this territory is assessed as well.

2. Materials and methods

2.1. Study area

The natural landscape of Yerevan (latitude 40°10′40″N, altitude 44°30′45″E) territory is mainly semi-desert, arid steppe and steppe. The climate is continental with quite a broad amplitude of temperature (summer temperature ranges from +22 to +26 °C; winter temperature: −20 to -30 °C). Precipitation figures are 300–350 mm. The relief is rather diverse and is represented by plains, plateaus, foothills, and the River Hrazdan canyon. A geological composition of the territory is dominated by volcanic lavas, tuffs and Quaternary sediments. According to the geochemical classification of cities (Perelman and Kasimov, 1999), based on the lithogeochemical characteristics of parent rocks, Yerevan belongs to the background city type. The soil (mostly brown semi-desert) profile is rich in carbonates, to the lower horizon a presence of gypsum is common, thus evidencing a lack of chemical element washout and creating a good environment for PTIE accumulation on soil profiles (Saghatelyan, 2004).

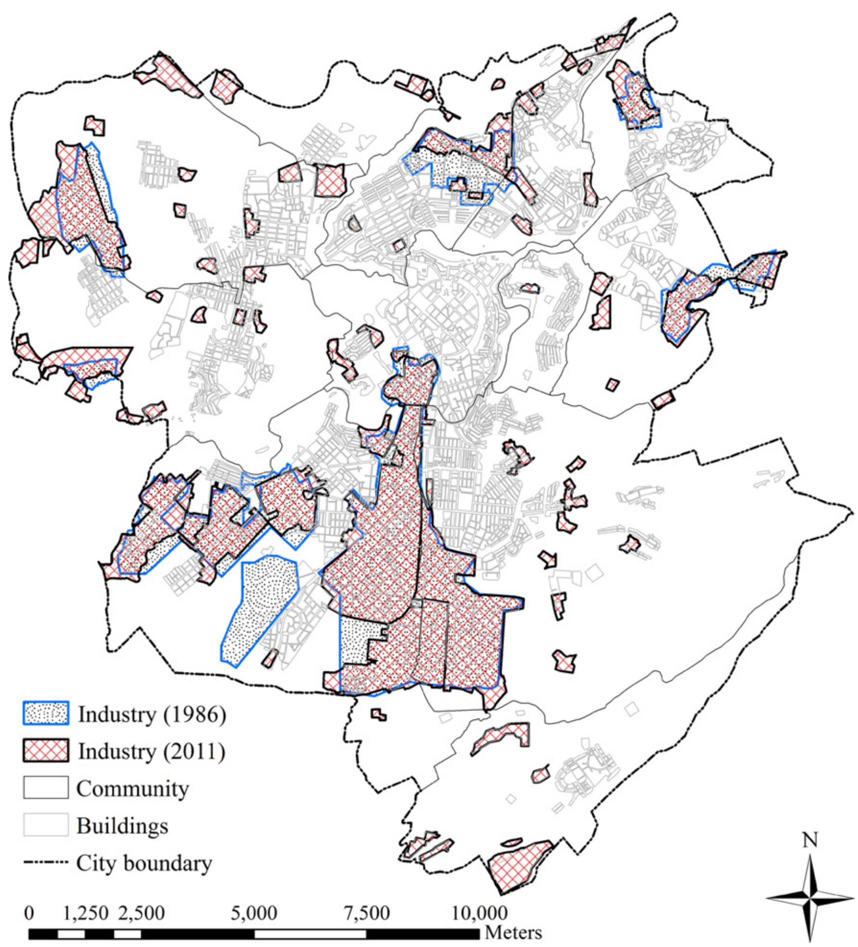

Fig. 1. Location of old (1986) and new (2011) industrial areas (Yerevan).