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Heavy metals pollution levels and children health risk assessment of Yerevan kindergartens soils

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A B S T R A C T

Children, the most vulnerable urban population group, are exceptionally sensitive to polluted environments, particularly urban soils, which can lead to adverse health effects upon exposure. In this study, the total concentrations of Ag, As, Ba, Cd, Co, Cr, Cu, Fe, Hg, Mn, Mo, Ni, Pb, Ti, V, and Zn were determined in 111 topsoil samples collected from kindergartens in Yerevan. The objectives of this study were to evaluate heavy metal pollution levels of kindergarten's soils in Yerevan, compare with national legal and international requirements on heavy metal contents in kindergarten soil, and assess related child health risk. Multivariate geostatistical analyses suggested that the concentrations of Ag, As, Ba, Cd, Cu, Hg, Mo, Pb, and Zn observed in the kindergarten's topsoil may have originated from anthropogenic sources, while Co, Cr, Fe, Mn, Ni, Ti, and V mostly come from natural sources. According to the Summary pollution index (Zc), 102 kindergartens belong to the low pollution level, 7 to the moderate and only 2 to the high level of pollution. Summary concentration index (SCI) showed that 109 kindergartens were in the allowable level, while 2 featured in the low level of pollution. The health risk assessment showed that in all kindergartens except for seven, non-carcinogenic risk for children was detected (HI > 1), while carcinogenic risk from arsenic belongs to the very low (allowable) level. Cr and multi-element carcinogenic risk (RI) exceeded the safety level (1.0E- 06) in all kindergartens and showed that the potential of developing cancer, albeit small, does exist. Therefore, city's kindergartens require necessary remedial actions to eliminate or reduce soil pollution and heavy metal-induced health risks.

1. Introduction

Cities are areas with a high level of anthropogenic impact and act both as pollution sources and bear the consequences of pollution. Urban soils are large "basins" for accumulation of various pollutants, thus also serving as informative media; therefore, urban soil is a focus of studies on environmental pollution (Chabukdhara and Nema, 2013; Li et al., 2004).

Among toxic and persistent pollutants found in urban soils, a special emphasis is placed on heavy metals (Li et al., 2004). When heavy metals enter the human organism via three major exposure routes, i.e., oral, dermal, and inhalation of soil particles (RAIS, 2017; US EPA, 2002, 1989), different disorders, depending on the element and its chemical form, may occur, thus, for instance, affecting hematogenesis and the central nervous, cardiovascular and urogenital systems (RAIS, 2017).

Depending on physiological, biological and social conditions, different groups in population respond individually to the impact of environmental pollution of heavy metals. In this respect children, especially the youngest, should receive a particular focus, as in early childhood the human organism and its immune system are still developing. During childhood, the demand for oxygen and food in the human organism is higher, which means that a child eats, drinks and breathes more intensively than an adult (Mielke et al., 2011; WHO, 2006). Children are restricted in movement, as they live, play outdoors, and attend kindergarten in the same residential area, which means in most cases they remain within a zone having almost the same level of pollution. Because of their short stature (when ≤1 m tall) children are impacted by secondary pollution from soil via the near-surface air layer. The vulnerability of children is also determined by their hand-to-mouth behavior (playing with or handling potentially polluted objects) with a high risk of direct penetration of pollutants into their organisms (Kumpiene et al., 2011; Mielke et al., 2011).

In children, exposure to heavy metals may cause allergic reactions, kidney damage, digestive system problems, and neurodevelopment disorders (WHO, 2006). Lead exposure in children results in fallback in their intellectual development (Han et al., 2012).

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To ensure the safety of children in cities, implementation of targeted investigations and monitoring of heavy metal contents in soils are required, especially in kindergartens areas. In many countries, surveys and monitoring of kindergartens are mandatory by public authorities (Johnson et al., 2011; RA Ministry of Health, 2010). Besides the assessment of soil pollution levels and identification of probable pollution sources, heavy metal pollution studies should place a particular emphasis on assessment of possible pollution-induced health risk to children (Lai et al., 2010; Wu et al., 2015).

Decade-long studies targeted the presence of heavy metals throughout the city of Yerevan (Saghatelyan, 2004; Sahakyan, 2008). However, neither the previous studies nor the state monitoring system assessed the status of kindergarten's soils. Therefore, the goal of this research was to evaluate heavy metal pollution levels of kindergarten soils in Yerevan, compare with national legal and international requirements on heavy metal contents in kindergarten's soils, and assess related child health risks.

2. Materials and methods

2.1. Study site

Yerevan (latitude 40°10'40"N, altitude 44°30'45"E) - Armenia's capital, covers an area of 223 Km^2, with a population of 1068.3 thousand people. The city has a dissected relief and is situated at the height of 850–1420 m. The climate is typically continental, the amount of annual precipitation ranges from 250 to 400 mm. The average air temperature range is from +22 °C to +26 °C in summer, and −4 °C to −6 °C in winter. Northeastern winds are dominant in the city round the year. Dry steppe and semi-desert natural landscapes are common. The geological base of the city territory includes volcanic lavas, tuffs, and Quaternary sediments.

Yerevan is an educational, cultural, economic and industrial center. The city houses some metallurgical plants, manufacturing enterprises (e.g., concrete, wood- and metal-ware, food, medicine, paper production and stone- and woodworking workshops). In the area of Yerevan and its outskirts, there are active basalt and crushed stone, tuff, clay quarries, and sandpits. Yerevan has a dense and extensive public transport network.

At present 162 kindergartens operate in Yerevan attended by approximately 32,000 children (RA National Statistical Servise, 2015). The studies covered 111 out of 162 kindergartens of Yerevan (Fig. 1). The remaining 51 kindergartens were not investigated because of asphalt covering, lack of soil and due to other technical reasons.

2.2. Topsoil sampling

Soil was sampled in 2012 within the frames of Yerevan's 3rd geochemical survey (Tepanosyan et al., 2016). 3–5 random sub-samples were collected from each kindergarten using a stainless steel hand auger (0–5 cm, including 'original' soil and artificial mounds) and then mixed thoroughly to obtain a bulk sample. The collected bulk samples were placed in polyethylene bags and labeled. Once taken to the lab, soil samples were air-dried, homogenized, sieved (< 2 mm), milled in compliance with ISO-11464 (ISO, 2006) and then stored in sealed bags until analyses.

2.3. Analytic methods and QA/QC

Kindergartens' topsoil samples were analyzed jointly with the whole geochemical soil survey samples bank. The total concentrations of Ag, As, Ba, Cd, Co, Cr, Cu, Fe, Hg, Mn, Mo, Ni, Pb, Ti, V, and Zn in the soils were determined by X-ray fluorescence spectrometry (Olympus Innov-X-5000 (USA)) according to EPA standard method 6200 (US EPA, 2007) in the Center for Ecological-Noosphere Studies (CENS). The detailed QA/QC of the database is presented in the Tepanosyan et al. (2016) publication. According to it, the accuracy error and precision of the dataset range constitutes 1.1–15.7% and 0.4–6.3%, respectively. Values below detection limits are observed for Ag, Cd, Hg, Mo and Ni in 15%, 11.7%, 5.4%, 1.8% and 13.5%, respectively. As the number of values below detection limit is relatively low (< 15% of all samples) (Johnson et al., 2011; Reimann et al., 2008), in the present study, element concentrations below detection limits are given a value of 1/2 of the detection limit.

2.4. Data analysis and geochemical mapping

Descriptive statistics (Table 1) were calculated for heavy metals concentrations. To identify the relationship between heavy metals in kindergartens' topsoil and their possible sources, principal component analysis (PCA) and cluster analysis (CA) were performed (SPSS 20.0). As environmental data are usually strongly right-skewed and are characterized by the existence of outliers (Reimann et al., 2008), for all studied elements, the raw data were log-transformed and standardized to the Z score before PCA and CA. Heavy metals with < 0.5 measures of the proportion of variance explained by the extracted components (communality values) were excluded from PCA. Monte Carlo PCA for Parallel Analysis (Ledesma, 2007) was used to determine an optimal number of components to remain. The software used for the mapping and spatial analysis was ArcGIS 10.1. Growing-dot maps of Zc levels and risk values were created to visualize summary pollution and show the kindergartens where health risk of children from heavy metals was detected.

2.5. Assessment of pollution with heavy metals in soil

For an integral description of heavy metal pollution, the contamination index (Johnson et al., 2011; Perelman and Kasimov, 2000) was calculated, according to the following formulas:

$$K_c = \frac{C_i}{C_f}, \tag{1}$$

$$Z_c = \sum_{i=1}^{n} K_c - (n-1), \tag{2}$$

where: Kc is the concentration coefficient, C_i is the content of the i^{th} metal in kindergartens' soils, C_f is the local background of the same element established based on 51 background samples from the unpopulated and unpolluted external part of the city (Tepanosyan et al., 2016), *n* is the number of elements in the same sample with $K_c > 1$. The summary pollution level was classified as $Z_c < 16$ –low level, $16 < Z_c < 32$ – mean i.e. moderately hazardous level, $32 < Z_c < 128$ – high i.e. hazardous level, $Z_c > 128$ – very high i.e. extremely hazardous level (Perelman and Kasimov, 2000).

The contents of the elements were compared with the Maximum acceptable concentrations (MAC) for soils accepted in Armenia (RA Government decree, 2005).

$$K_{MAC} = \frac{C_i}{C_{MAC}}, \tag{3}$$

where: K_{MAC} is the concentration coefficient based on MAC (Supplementary materials Table 1). In Armenia MAC values are set for As, Cd, Cr, Cu, Hg, Mn, Mo, Ni, Pb, V, and Zn (RA Government decree, 2005).

To describe poly-element pollution based on MAC a Summary Concentration Index (SCI) was calculated:

$$SCI = \sum K_{MAC}. \tag{4}$$

K_{MAC} and SCI classification levels are provided in the Supplementary Materials Table 1 (RA Government, 2005).