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Contamination of urban soils with heavy metals in Moscow as affected by building development

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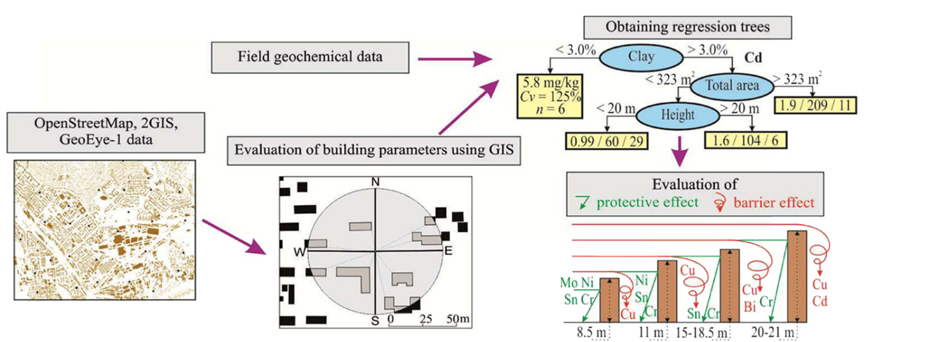
HIGHLIGHTS

- Urban development creates significant geochemical heterogeneity of depositing media
- Level of soil contamination depends on parameters and arrangement of the buildings
- Urban soils contamination is only manifested upon certain directions of air flows
- Buildings can form protective screens decreasing pollutant contents in urban soils
- Contamination depends on soil fractions that serve as the major carriers of metals

GRAPHICAL ABSTRACT



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ABSTRACT

Building development in cities creates a geochemical heterogeneity via redistributing the atmospheric fluxes of pollutants and forming sedimentation zones in urban soils and other depositing media. However, the influence of buildings on the urban environment pollution is poorly understood. The aim of this study is to evaluate the barrier functions of urban development by means of a joint analysis of the contents of heavy metals and metalloids in the upper horizon of urban soils, their physicochemical properties, and the parameters of the buildings. The soil-geochemical survey was performed in the residential area of the Moscow's Eastern Administrative District (Russia). The parameters of the buildings near sampling points were determined via processing data from the OpenStreetMap database, 2GIS databases and GeoEye-1 satellite image. A high level of soil contamination with Cd, W, Bi, Zn, As, Cr, Sb, Pb, Cu was revealed, depending on building parameters. A protective function of the buildings for yards is manifested in the decreasing concentrations of As, Cd, Co, Cr, Mo, Ni, Pb, Sb, Sn, W by 1.2–3 times at distances of <23–36 m from the buildings with their total area ≥660 m^2 and the height ≥7.5–21 m. An opposite effect which enhances concentrations of Bi, Cd, Co, Cr, Cu, Mo, Pb, Sb, Sn, W, Zn by 1.2–1.9 times is seen in "well-shaped" yards acting as traps under similar distances and heights, but at their average area ≥118–323 m^2, and total area ≥323–1300 m^2. The impact of these two building patterns on the soil contamination is only seen for certain directions of atmospheric flows. Buildings located in the northwestern sector relative to the sampling point protect the latter from the aerial pollution.

Abbreviations: HMMs, heavy metals and metalloids; EAD, Eastern Administrative District of Moscow; MRR, Moscow Ring Road; MPC, maximum permissible concentrations; TPC, tentatively permissible concentrations.

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1. Introduction

Cities have become the centers of intensive impact contamination of the environment because of high concentration of population and industry within relatively small areas. The ecological situation in many cities of Russia and other countries is close to the critical one (Kasimov et al., 2014). The strongest technogenic impact on the environment and humans is typical for multimillion megalopolises. According to the intensity and area of contamination, they represent specific technogenic geochemical and biogeochemical provinces (Saet et al., 1990; Johnson et al., 2011; Kasimov et al., 2014). Emissions from industrial enterprises and transport into the atmosphere are responsible for the development of geochemical anomalies in other components of urban terrain: snow cover, vegetation, soils, and hydrosphere.

A great number and uneven distribution of the technogenic emission sources in combination with diverse weather conditions create a complex and highly changeable pattern of geochemical fields and geochemical anomalies in the atmosphere of megalopolises. The content of contaminated aerosols in the air is highly variable, because particles of different sizes are transported by air flows to different distances (Hitchins et al., 2000; Baldauf et al., 2008; Hagler et al., 2009). Therefore, in order to assess the average level of contamination of the urban environments and the degree of ecological comfort in separate districts and quarters of the city, it is reasonable to test urban soils that accumulate pollutants for many years.

Distribution of atmospheric pollutants is controlled by the meteorological factors specifying the dispersing and accumulative capacities of the atmosphere (Baklanov et al., 2008; Glazunov, 2014; Demin et al., 2016). A significant influence on them is exerted by the topographical conditions and building patterns. High-rise residential blocks represent a complex system of air-blown multi-surfaces at different heights and with different slopes. Buildings considerably transform the wind regime of the atmospheric boundary layer creating "wind shades" in closed yards and "canyon effects" along large streets (Lifanov, 2006; Moussiopoulos et al., 2010; Samsonov et al., 2015). A decrease in wind speed in closed courtyards leads to the deposition of dust particles enriched in pollutants and their accumulation in the soils; in the well-ventilated areas, pollutants are carried away. Thus, depending on their orientation, buildings can either protect the area from pollution, or enhance it.

A multivariate statistical analysis of soil-geochemical data and parameters of building patterns in the cities makes it possible to describe the spatial geochemical heterogeneity of the urban environment and to delineate the zones of predominate accumulation of the pollutants in the soils and other depositing media (Dimopoulos et al., 2004; Tsiros et al., 2009). However, such studies are few in number, and the geometry of urban development in them is insufficiently considered.

The aim of our study was to evaluate barrier and protective functions of city buildings via a joint analysis of the contents of heavy metals and metalloids (HMMs) in the upper horizon of urban soils, physicochemical properties of the soils specifying their capacity to fix HMMs, and parameters of surrounding buildings. Residential area of the Eastern Administrative District (EAD) of Moscow was selected as the key object. This district is characterized by the high technogenic loads on the urban environment and various residential development with high-rise and low-rise buildings arranged in patterns of different densities.

The specific objectives of the study were as follows:

- to assess the physicochemical properties of urban soils and the intensity and spatial patterns of their pollution with HMMs;
- to determine parameters of building patterns – distance to the buildings, their height, and their area on different directions from soil sampling points – with the use of high-resolution satellite imagery and geoinformation analysis; and.
- to determine threshold parameters of the artificial relief of the city favoring an increase or a decrease in concentrations of HMMs in urban soils.

2. Study area

Soils in the southern part of the EAD within Sokolinaya gora, Perovo, Ivanovskoe, Novogireevo, Veshnyaki, Novokosino, and Kosino-Ukhtomskii municipalities (Fig. 1) were studied.

Low-rise (up to five storeys) houses are typical of the old quarters in Perovo, Ivanovskoe, Novogireevo, and Veshnyaki municipalities and of the zone of individual house construction in Kosino-Ukhtomskii municipality. Middle-rise (six–nine storeys) houses are typical of residential areas within the Moscow Ring Road (MRR), and high-rise houses (>ten storeys) are found beyond the MRR in Novokosino and Kosino-Ukhtomskii municipalities (Kasimov et al., 2016). Depending on the mutual arrangement of buildings, the following four development patterns can be distinguished: arranged (along perimeter, in groups, in lines), and isolated (manor-type) patterns.

Motor transport is the major source of pollution of the urban atmosphere and urban landscapes; it contributes to nearly 80% of total emissions (Kasimov et al., 2014). The largest highways are the MRR; Entuziastov and Nosovikhinskoe highways; Svobodnyi and Zelenyi avenues; and Perovskaya, Plekhanova, Yunosti, Veshnyakovskaya, and some other streets. Exhaust gases contain Cu, Pb, and Sr; engine oil is the source of Fe, Mo, Zn, Cu, Pb, and Sb; tire abrasion pollutes the environment with Cd, Mn, Fe, Zn, Pb, Co, Ni, Cr, Cu, and Sb; and wear of brake pads, with Fe, Cu, Sb, Mn, Zn, Ti, and Pb (Limbeck and Puls, 2011; Adachi and Tainosho, 2004; Iijima et al., 2007; Gietl et al., 2010; Quiroz et al., 2013). In the production of bearings, antifriction alloys based on Sn and Pb are used; these alloys also contain Sb, Cu, Cd, Ni, As (Vlasov et al., 2015).

Stationary sources of the anthropogenic pollution are the enterprises of heat power engineering, metal processing, machine building, chemistry and petrochemistry, production of building materials, pulp and paper, food, and some others industries, whose emissions contain HMMs. Emissions of thermal power plants contain V, Ni, Pb, Mo, Ge, Cr, Zn, W, Cu, Ag, and Sn; of incineration plants, Bi, Ag, Sn, Pb, Cd, Sb, Cu, Zn, Cr, Hg, and As; of chemical and petrochemical enterprises, W, Hg, Cd, Sb, Sn, Ag, Zn, Cu, Bi, Pb, Mo, and Co; and of mechanical engineering and metalworking plants, W, Mo, Zn, Sn, Sb, Ni, Cr, Cu, Mn, Pb, Co, V, and As (Saet et al., 1990; Demetriades and Birke, 2015). The enterprises are mainly found in the industrial zones, such as Sokolinaya gora, Prozhektor, Perovo, Rudnevo, Kosino-1, and Kosino-2.

The study area belongs to the marginal part of the Meshchera swampy and slightly dissected glaciolacustrine plain slightly inclined toward the southeast and covered by Quaternary glaciofluvial, alluvial, and anthropogenic sediments of considerable thickness (Shmidt, 2012). The soil cover of residential areas consists of the anthropogenic urbanozems (Urbic Technosols), sealed soils (Ekranic Technosols), replantozems (Urbic Technosols Umbric), and recreazems (Urbic Technosols Humic). In the recreation zone, both native and anthropogenically transformed soils are found: soddy-podzolic and soddy urbo-podzolic soils (Retisols) and their gleyed variants and soddy and mucky–peat alluvial soils (Fluvisols). In the postagrogenic zone (former cropland included in the urban territory), postagrogenic agrozems and agrosoddy-podzolic regraded soils are distinguished (Shmidt, 2012; Kasimov et al., 2016).

Southern, western, and eastern winds predominate in this area; thus, the EAD receives pollutants from industrial objects located to the west and southeast of its area. The frequency of calm days varies from 3 to 22%, which means that the EAD territory is sufficiently well blown through with the removal of the pollutants beyond its boundaries. Northeastern air flows predominate in the north and northeast of the studied area, northwestern air flows, in the center; and southwestern