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Functional city zoning. Environmental assessment of eco-geological substance migration flows

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ABSTRACT

One of the unsolved problems today is that of the division of the natural (geochemical background) and anthropogenic components of substance migration flows, such as complex integrated systems in the supergene zone. Not only qualitative, but also quantitative assessment of each component allows greater understanding of the correlation between the processes within the geological body and their impact on the environment. This study is based on academic knowledge in the field of geological sciences and study group research-developments aimed at the detailed examination of the migration of pollutants in anthropogenically modified city soils and the creation of a methodological framework in the field of the geochemical zoning of substance migration flows in the hypergenesis zone. We demonstrate that certain parameters of "zero-level" pollutant concentration for functional area land use can be developed for each city – the state of the environment before the beginning of a new stage of technogenesis.

1. Introduction

One of the major problems of megacities is surface geological environment violation and contamination. Geochemical effects are characteristic of all technogenesis types: they are pervasive, occur during the entire time of territory use, and affect all environment components. In turn, soils are of fundamental importance to human life, dynamically developing natural resources in the urban environment. Soil takes the major share of anthropogenic impact due to its matrix structure (Luo et al., 2007) and its composition is a reflection ("mirror") of accumulated ecological and geological damage. In this regard, technogenic soils and subsoils are formed on megacities' territories (Popova and Nakvasina, 2013) that demonstrate characteristic physical and chemical properties.

There are a large number of papers on the assessment of environmental risk to human health and the components of megacities' environmental pollution, but studies rarely take into account aspects of land use as indicators of the accumulation of heavy metals (Golovin et al., 1996). During the second half of the 20th century, with the development of the symbiosis of mathematics and geochemical methods in mineral searches, the direction of the theoretical and applied methods associated with the modelling of internal processes of ecological and geological systems also progressed appreciably. The communication problem of natural and technological substance flows in the light of thermodynamic and kinetic studies developed fruitfully in the work of V. Cvetkovic (Cvetkovic et al., 2006), M.A.N Anikwe (Anikwe and Nwobodo, 2002), A. Dube (Dube et al., 2001) and other researchers through the examination of specific examples of geological objects (for example, fuel and energy complex deposits). As for the space-geological approach, in most cases, works in this area are either fairly general, based on substance circulation principles, or are parts of solutions for specific applications (Van der Voet et al., 2013).

In this article, we try to use a new approach to understanding the connection between geochemical and territorial units that demonstrates characterizes the migration of substances as a dynamic component of ecological and geological systems using the example of St. Petersburg's urban areas. By considering the geochemical substance flow separation model proposed by V.V. Kurilenko (Fig. 1), this study is the first attempt to create a methodical approach to the quantification of individual

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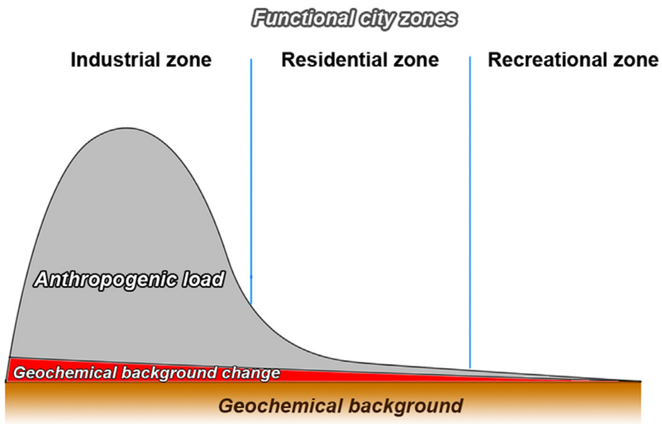

Fig. 1. Zone allocation of the geochemical components of substance migration flows.

components (technological, and the natural and resulting backgrounds) by analysing mathematical data matrices. This approach has strong potential, as it can be applied to all geological bodies by the method of zonal data sorting.

This article shows an interrelational model of city functional areas by mathematical modelling and the subsequent interpretation of geological spatial data. Such an approach is based on the difference between geochemical matrices and fully meets the needs of nature and subsoil management by the adoption of specific decisions. When considering the simplicity of the proposed method, it is relevant both to megacities' environmental authorities and to planning and surveying organizations in cases of the environmental assessment of geological objects (e.g., mineral fields).

The model presents an analysis of ecological geosystems by considering the natural characteristics (the geochemical specialization of source rocks – quaternary deposits and composition) and type of land use by functional ecological and geological zoning (Podlipskiy, 2013). The term "functional zoning", in the context of this article, is understood by the authors as the allocation of relatively homogeneous natural features and technogenic load areas within a city in order to develop further measures for the optimization, stewardship and usage process (the requirements of compactness and connectedness do not apply to functional zones). The various functions interact in different ways with the territories, elements of engineering and transport infrastructure, and with each other in terms of the rise in prices of construction costs, environmental damage risks, communication links, social relations, etc. Thus, the fine differentiation of functions is, in this case, necessary to justify the calculation of the solutions to problems in a complex urban assessment.

Differentiation of sites by the varying density of anthropogenic impact and its functional orientation is the basis of predicting the ecological environment's condition (Kosinova et al., 2002). Moreover, functional ecological and geological zoning is an essential tool for metropolis land resources management (Karim et al., 2014; Haykovich and Kurilenko, 2012). It allows the optimal ratio of use and/or protection measures to be set for a particular city site - the basic unit of a city territorial administration (Buyvolov, 2002).

2. Materials and methods

St. Petersburg is a federal city of Russia, the administrative centre of the North-West Federal District. It is located on the coast of the Gulf of Finland and in the mouth of the Neva River. St. Petersburg is an important economic, scientific and cultural centre of Russia and a major transport hub. It is the northernmost city in the world with a population exceeding five million, and is divided into 18 townships and 111 municipalities.

With regard to weather conditions, the study area is in a zone of excess moisture. The average rainfall is about 650–700 mm in most parts of Leningrad district. Approximately 70% of annual precipitation occurs during the warm season (i.e., from April to October).

2.1. The study area division and sampling

For the purposes of the present study, the isolation and characterization of the different types of "pure" anthropogenic impact (certain direction, intensity and nature), the study area of the city is divided into three groups according to the land use method (functional zoning):

- Industrial zone: an industrial enterprise area, a sanitary protection zone for industrial enterprises, and an area for transport infrastructure;
- Residential zone: a housing area and, to a lesser extent, public and business buildings;
- Recreational zone: a green area, including territories for recreational purposes.

The selection of study areas for each functional zone type was carried out on the basis of similar natural conditions (geomorphological, geological, hydrogeological and geobotanical), and on the type and extent of anthropogenic influence. Each study object group was selected depending on the underlying source rocks that are crucial in shaping the geochemical landscape type. These types are glaciofluvial and glaciolacustrine deposits (medium and coarse sand and sandy loam [H]), organogenic deposits (peat [H]), and marine and lacustrine deposits (layered clay and loam [m_1lN]). All source rocks were divided into three subgroups (two elementary sites in each) via dedicated functional areas (Fig. 2). Thus, geochemical data from 18 elementary areas, each with no fewer than 10 wells, were used. Overall, about 1000 soil samples were analysed for the determination of heavy metals (Zn, Cu, Pb, Cr, Cd, Ni, Hg, Mn, Co), metalloids (As), and the most common urban organic pollutants (petroleum products and benzo(a)pyrene). For better understanding, a database of only one elementary site group located on glaciofluvial and glaciolacustrine deposits will be used later in the article to demonstrate methodological consistency and provide a description of the results. This investigation uses research team data and the results of environmental surveys conducted by St. Petersburg GEO-companies, such as "LenStroyGeologiya" LLC, "Morion" LLC, and "TehnoTerra" LLC, in the period 2010–2014.

Soil sampling was conducted at the elementary sites layer by layer (0–0.2 m, 0.2–1.0 m, 1.0–2.0 m, 2.0–3.0 m) in accordance with the requirements of Russian National Standard 17.4.4.02–84 "Soils. Methods of sampling and samples preparation for chemical, microbiological, helminthological analysis" (National Standard 17.4.4.02–84, 1984; Haykovich and Kurilenko, 2012). Samples were analysed at accredited laboratories in the St. Petersburg and Leningrad region, as well as at the Environmental Geology Department Laboratory of St. Petersburg State University (SPSU) Earth Sciences Institute.

3. Data processing, evaluation and analysis

3.1. Geo-accumulation index

Functional zoning and management of the urban environment are impossible without a current ecological status assessment. In this respect, it is rational to use estimated coefficients, taking into account both the individual contributions and combined effect of a