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Landscape-geochemical mapping of the North-West of Kola Peninsula

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ABSTRACT

An ecological and radiochemical geo-information system was developed for studying the distribution features of technical radionuclides in tundra and taiga terrains. A series of landscape-geochemical maps was made at local (1:50 000) and regional (1:200 000) scales, and the radioecological conditions were determined in the study area. Landscapes have been identified according to the soil's physical and chemical properties, vegetation characteristics, natural moisture conditions, ground water level, the mineralogical composition of soil and underlying rocks, and the presence or absence of anthropogenic impact. This approach has allowed the conditions of migration and accumulation of radionuclides in the north-west of the Kola Peninsula to be revealed, and assisted in the understanding of migration and accumulation conditions of ^{137}Cs.

1. Introduction

Study of migration and accumulation processes of technical radionuclides in the north-west of the Kola Peninsula is a task for determining the potential influence of a number of facilities, which are currently or threatening pollution sources. Among these facilities is the *Nerpa* Shipyard, which has been focusing on disposal of nuclear submarines since 1992. The studies, described in this paper, covered an area of 50 km radius around the Shipyard, which is located on the western coast of the Kola Gulf to the north of Murmansk within the natural tundra zone.

Such studies, conducted after a series of radiation accidents, are of particular relevance as, for example, 'Mayak' in 1956, Chernobyl in 1986 and Fukushima 2011 (Andersson, 2009; Chesnokov et al., 2000; Korobova and Linnik, 1993; Korobova et al., 2007; Kurokawa et al., 2012; Linnick et al., 1991; Luykx and Frissel, 1996; Roed and Andersson, 1996). Geochemical mapping is the most informative way of presenting data of radiation conditions, and includes sampling points together with their values, thus providing information about the pollution process, factors and characteristics of the spatial distribution of technical radionuclides. The main concept of landscape-radionuclide geochemical mapping is to reveal the relations between radionuclide pollution and landscape aspects of a region (Kvasnikova and Golosov, 2002; Linnik, Brown, & Dowdall, 2006; Perelman and Kasimov, 1993). While, the main purpose of landscape-geochemical mapping is the representation of migration conditions of chemical elements and their compounds in soil (Klos et al., 2014). At the present time, regularities of accumulation and migration of technical radionuclides in landscapes have been thoroughly investigated within the areas affected by the Chernobyl and Fucusima disasters (Korobova and Romanov, 2011; Niimura et al., in press). There are, however, few studies on background values for ^{137}Cs distribution in soil (Glazovskaya et al., 1989; Isaksson et al., 2001; Korobova et al., 2007; Reimann et al., 1998).

In landscape-geochemical mapping of soil, the data are collected in a non-ideal sampling grid, where at each site some particulate deposition has occurred (Burenkov et al., 1999; Israel, 1996; Lis et al., 1997). This conceptual idea has been developed within the Chair of Landscape Geochemistry and Soil Geography of the Moscow State University Department of Geography under the guidance of M.A. Glazovskaya and A.I. Perelman. Their work on landscape-geochemical mapping has accumulated considerable data on the spatial distribution of chemical elements, their confinement to the specific soil types, and interrelations of their behaviour with the peculiarities of the landscape structure of an area (Bogdanova et al., 2008; Chiprés et al., 2009; Cicchella et al., 2013; Gavrilova, 1985; Kasimov et al., 2008; Kelepertzis et al., 2013; Rapant et al., 1999; Yuan et al., 2014). The Russian landscape scientific school is well known in the world, and investigators are using the theory (Fortescue, 1980, 1992; Klos et al., 2014; Polokhin et al., 2014).

2. Materials and methods

The study area is located within the tundra and tundra forest belts. The area's topography consists of folded blocky rises and depressions, formed as a result of tectonic movements, erosion, ice sheets, and repeated fluctuations in sea level. Atmospheric circulation is of

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monsoon character; in winter the south-western continental winds prevail, but in summer the prevailing winds are from the north-east, the Barents Sea. Soil in the north-western part of the Kola Peninsula is characterised by a broad variety and complexity, due to variability of soil formation with relief. The vegetation is sparse birch forest, forest of gnarled trees, shrubs, mosses and lichen.

Study of technical radionuclide migration and concentration in soil of the tundra belt has shown that the study area is not radioactively contaminated. The level of ^{137}Cs specific activity in soil, resulting from the global fallout, is 36 Bq/kg, which corresponds to 0.07 Ci/km^2 or 7% of the allowed limit in Russia. The area of the *Nerpa* Shipyard's influence on various environmental parameters was determined to be up to 14 to 16 km from the shipyard. The level of ^{137}Cs specific activity within the defined area (76 Bq/kg) exceeds the area's measured background value of 8–20 Bq/kg by more than three times. Most of the ^{137}Cs occurs in the 20-cm-thick O-horizon. There is little lateral redistribution of ^{137}Cs concentration (Kuzmenkova, 2009; Velichkin et al., 2012; Vorobyova et al., 2009).

The aim of the study was to determine in detail the migration and accumulation of technical radionuclides using ^{137}Cs as an example in the southern tundra of the Kola Peninsula. Large-scale landscape-geochemical mapping plays an important role in studying the distribution of radionuclides. The aims of this study included the following tasks:

- determination of factors and conditions, which facilitate migration and accumulation of technical radionuclides in the north-western part of the Kola Peninsula;
- development of a series of landscape-geochemical maps at various scales for the study area, and
- development of an integrated geo-information database on ^{137}Cs occurrence within the study area.

The field surveys were conducted in the summer of 2004 to 2009. Transverse sections were made and all pedogenic horizons were sampled, as well as lichens with a coverage of more than 50% of the 'autonomous' landscapes:

- within the industrial area of the *Nerpa* Shipyard close to the nuclear submarine disposal workshop and to the storage of spent reactor blocks, and
- beyond the industrial area at various distances and in different directions from the *Nerpa* Shipyard.

The criteria for selecting the sampling sites were (a) the distance from the *Nerpa* Shipyard, (b) dominant wind direction, and (c) the landscape geochemical structure. In total, there were 264 sampling profiles and 1056 soil samples.

The ^{137}Cs specific activity on the soil samples was determined by gamma-ray spectrometry using the HPGe detector by Canberra Industries (Fettweis et al., 2003). Other main physical and chemical properties, determined on the soil samples, were the pH with a pH-metre (pH340i/set) in aqueous extract, the grain-size distribution by the Kachinsky method, and the organic carbon content by the Turin method (Arinushkina, 1970; Kuzmenkova, 2009).

The data processing and map production used a variety of geoinformation technology (Auto CAD 3D map, ArcGIS). This approach allowed (1) a spatial analysis of technical radionuclide distribution in the tundra and tundra forest relief; (2) the extracted information to be summarised, and (3) different mapping layers and attribute data to be combined. For this purpose, a special object-oriented mapping database of relief data, environmental and radiochemical properties of the study area, and specifics of technical radionuclide migration and accumulation, were developed (see Table 1).

Table 1
Structure and content of the landscape mapping database.

Reference map	Digital map produced	Map content
Series of thematic maps: topography, geology, Quaternary deposits, geomorphology, vegetation, soil, and satellite images	Maps of geochemical landscapes, selected on the basis of relief	Landscape classification as 'autonomous', transeluvial, transaccumulative, superaquatic and aquatic landscapes with morphological characteristics of relief, soil and vegetation covers
Topographic maps, and geochemical landscapes maps, selected on the basis of relief; GPS data	Current material	Location of sampling points within the study area
Maps: soil (soil characteristics, soil formation factors), and Quaternary deposits. Field descriptions of sampling locations. Soil chemical analysis results	Elementary landscape maps	Soil and geochemical conditions of technical radionuclide migration and accumulation (alkali-acidic and redox properties, types of water regimes). Radial and lateral barriers
Maps: economic–geographical, industrial facilities, transport, power sector	Possible contamination sources	Location of sites that are potential sources of radioactive contamination
Maps: elementary landscapes; soil and geochemical, sample points. Results of radiometric analysis of soil and vegetation samples	Radioactive contamination of landscapes	Different levels of specific activity of industrial radionuclides in 'autonomous' and lower-elevation landscapes

The transport and accumulation of contaminants were analysed for selected objects at selected industrial sites and adjacent areas that have been exposed to contamination. Each level of the detailed analysis and its subsequent generalisation was presented on landscape-geochemical maps of different scales.

3. Results and discussion

3.1. Specifics of ^{137}Cs content distribution within the study area

The analysis of ^{137}Cs spatial distribution within the study area was conducted using the map of geochemical landscapes, selected on the basis of the relief conditions (Fig. 1); it shows that the ^{137}Cs content in soil decreases with increasing distance from the contamination source.

Depending on the relief, the landscapes were classified according to the catena from water divides to the river and lake valleys, and are represented by geochemical landscapes from 'autonomous' to subaquatic. The geochemical landscapes were determined by taking into account different soil types, vegetation cover, natural drainage conditions, ground water level, mineral content of soil and underlying bedrock, and presence or absence of industrial impact. The following results were derived after the analysis of landscapes in the area affected by the *Nerpa* Shipyard, which were selected on the basis of the relief conditions: transaccumulative landscapes (transeluvial (steep slope), transeluvial accumulative (smooth slope)) make up the largest percentage of the study area (about 40%); superaquatic and subaquatic landscapes make up around 50%, and only about 10% of the study area consists of 'autonomous' and transeluvial landscapes. This demonstrates that accumulation processes dominate over migration of elements within the study area.

The following ranking was adopted on the basis of analysis of ^{137}Cs specific activity at the sampling points: 0–50, 50–100, 100–150, 150–200, and >200 Bq/kg. The highest levels (>200 Bq/kg) of specific activity were observed near the Shipyard. The resulting