Geochemistry features of sediments of small urban arctic Lake Komsomolskoye, Murmansk region

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Abstract. First data of geochemistry and mineralogy of recent sediments of small Lake Komsomolskoye located in Monchegorsk town from Murmansk region (Russia) are presented. The high concentrations of heavy metals were found in surface layers of researched lake sediments. The most accumulation level is initialled for copper and nickel, which are entered to lake from copper-nickel plant complex situated near the arctic town. Other metals also can enter to waterbody in result of activity of this factory complex. In addition, lead, cadmium, antimony, thallium and other elements may be products of the atmospheric transport of pollutants from industries of North and East Europe. Moreover, we have studied main fractions of heavy metals from upper layers of Lake Komsomolskoye and morphology and composition of technogenic particles of nickel, copper, iron and other metals. The origin of these particles is directly associated with the different stages of processing technology of nickel and copper ore on the copper-nickel plant complex (crushing, flotation, roasting, and smelting).

1. Introduction

Essential global social, political, economic and environmental problems, such as urbanization and associated risks, have become more acute since the late 19th century. The trends described inevitably result in an increased impact on the environment and the diminished quality of its major constituents, such as water resources [1-4]. Water systems located in urban areas are commonly affected by various human activities that disturb hydrological and thermal regimes, result in water pollution, etc. The natural characteristics of water ecosystems are thus considerably changed, species composition is impoverished, communities are restructured and their self-cleaning abilities decline. In the northern latitudes, including the Arctic zone, natural ecosystems are most vulnerable to various kinds of anthropogenic pressure. Climate is a serious constraint for self-defense and ecosystem restoration, especially in the case of constant exposure to technogenesis. Many scientific studies on the ecological assessment of the current state of natural systems affected by human activities have been conducted. Yet, special integrated studies of water bodies in urbanized areas are scarce, as well as studies of the urban environment in the Arctic zone, where natural and climatic conditions contribute to the high sensitivity of its ecosystems to the human impact and considerably retard natural restoration after their damage.
For the territory of the Murmansk region, a particularly important problem is the pollution of water bodies due to heavy metals [1-3]. Moreover, the transfer of pollutants involves both local sources of pollution and from enterprises located in other regions of Russia and the world [5]. To establish the basic regularities of pollution of water bodies, the paleo reconstruction method is used. This method is based on the study of the consistent accumulation of heavy metals in the layers of recent sediments of lakes. For example, the investigations [4, 6] illustrate that an increase of metal concentrations in sediments is associated with the activity of copper-nickel plants and long-term atmospheric transport of pollutants. The beginning of the described trends dates back to the end of the 19th century and the beginning of the 20th century. Until now, similar work related to urban areas of the Murmansk region has not been carried out. The purpose of this work is to study the geochemical and mineralogical features of recent sediments of a small urban lake located in the city of Monchegorsk.

2. Materials and methods
Monchegorsk is a small town in the North-West of the Russian Federation (Murmansk region) with a population of 42 thousand people. Monchegorsk is located beyond the Arctic Circle, on the northern slope of the mountain range Monchetundra, on the shores of Lakes Imandra and Lumbolka (Figure 1). The leading enterprise in the city is the Kola Mining and Metallurgical Company, which produces nickel, cathode copper, cobalt and sulfuric acid.

The object of the study was a small lake named Komsomolskoye, located in the central part of the city (Figure 1). The lake is surrounded on the north, south and east by a park area, residential and administrative buildings adjoin the western shore of the lake. Metallurgov Street, the central street of the city, passes near the lake.

The Garmin Echomap Plus 42cv echo sounder chart plotter was used for analysis of the lake depths. Echo-data processing with depth mapping was performed using the Golden Software Surfer 13 program.

Sediments sampling was carried out using the Limnos sampler in April 2018, using ice from the lake. The sampling was performed at the maximum depth. Collected cores of sediments were divided into layers of 1 cm and 5 cm. Storage and transportation of samples was carried out using plastic containers and bottles and a cooler bag according with references [7]. The pH measurement was performed in the laboratory immediately after the delivery of the samples using the portable pH-420 pH millivoltmeter (made in Russia). All sediment samples were dried at a temperature is about 110 degrees above zero. Sediment samples were decomposed on the basis of acid dissection in the open system. The analysis used 0.1-g sample weights. Along with the samples being analyzed, blank samples and one standard (control) sample (the chemical composition of the bottom silt of Lake Baikal, BIL-1 – state standard number 7126-94) were subjected to decomposition. [8]. Elements concentrations in the bottom sediment samples were estimated using the mass-spectral method on a XSeries-2 ICP-MS instrument at the Analytical Centre of the Institute of Geology of the Karelian Research Centre of the Russian Academy of Science, Petrozavodsk. For the measurement error at the mass spectrometer, the value of the standard deviation S is taken when each element is determined thrice in the studied sample of sediments. The level of relative measurement error did not exceed the permissible values for all the trace elements defined in this study. To determine the various fractions of heavy metals, we used the technique (scheme) of sequential extraction of heavy metal [9]. The phases and composition of mineral particles in sediments were studied using a Vega II LSH scanning electron microscope (SEM) [10]. The particles were investigated using backscattered electron and secondary electron microscopy and quantitative chemical analysis obtained using energy-dispersive X-ray spectroscopy.

3. Results and discussion
Lake Komsomolskoye has a simple basin with a maximum depth 6.5 m in the center of the water body (Figure 1). The lake sediments represent brown organic silt or gyttja (sapropel), which contains about 43 % of organic matter calculated using data of LOI. The sediment pH values range from 4.92 to 5.94,
increasing from the upper slices to the lower layers. Acidification of water bodies is one of the main problems of the territories subject to pollution in the Murmansk region [2, 3].

Figure 1. Map of research area.

Geochemical analysis of Lake Komsomolskoye sediments showed that the water body is experiencing a significant anthropogenic load. An increased accumulation of Ni, Cu, Mn, Cr, Zn, Sr, Co, V, Pb, W, Mo, Cd, Sb, Tl was recorded in the upper layers of the sediments of the urban lake compared with the background layers of sediments (Figure 2). According to the distribution and level of accumulation of Ni and Cu, it can be concluded that the lake is experiencing the main load as a result of the activities of the copper-nickel plant, which has been operating since the 1930s [1, 2, 6]. Other metals could also enter to the lake over a long period of time as a result of emissions from this plant. This is indicated by work on the study of soil and sediments of lakes near the industrial zone [11]. On the other hand, the accumulation of Pb in recent sediments could have been associated with transportation emissions, given that before the 2000s gasoline containing tetraethyl lead was used in Russia [8]. In addition, many elements from the number of heavy metals are agents of long-range transport, which is recorded from the results of a study of sediments of lakes in the Murmansk region and neighboring regions.

The corresponding behaviour of Pb, Zn, Cd and Cu was shown for sediments from small lakes in Finland [12]. It has been noted that the heavy metal level in sediment cores began to rise in 1900s due to the impact of the far atmospheric transport of pollutants from the industrial areas of Finland, Russia and other former USSR countries [4, 13, 14]. Besides, the influence of the long-range atmospheric transport of heavy metals was already recognized as a pollution factor in small and large lakes in the Onega Lake watershed (southern Karelia) [15].
The similar surface enrichment of upper layers by Pb, Sb, Zn, Cd, Tl was noted in Asia region [7]. Authors showed that this process most likely resulted from increased atmospheric deposition since 1900s. Moreover this research implies that the enrichment of Sb, In, Sn, and Bi is not induced by their post-depositional redistributions associated with Fe/Mn hydroxides and decay of organic matter. On the other hand, Fe/Mn hydroxides and especially organic matter usually plays key role in accumulation of metals in sediments of polluted water bodies [16]. This is most relevant for small lakes in the humid zone of northern Russia, where the organic matter content of lake sediments may be up to 80%.

The analysis of the heavy metal fractions in the upper layers of Lake Komsomolskoye sediments has established that the mineral phase is the most characteristic phase of existence of metals in the lake sediments. In this case the mineral phase are not only natural minerals from primary rocks, but also mineral particles emitted from the plant’s pipe and representing the product of smelting or roasting of ore processed at an industrial enterprise (Figure 3-6). These particles vary from 10 to 80 μm, which is quite within the specified range of particle sizes found in the snow cover of the winter of 1995-1996 [6]. The technogenic particles were found up to a depth of 10 cm of Lake Komsomolskoye sediments that correlates with the Ni and Cu levels in the sediments under study. In addition to these metals, the composition of technogenic particles also includes Fe, S, O, Cr, Co and other elements. Similar particles are found in the upper soil horizons near the metallurgical plant in Sudbury, Canada [10]. According to the authors of this work, the soil polluted as a result of copper-nickel production may contain from 2 to 5% of technogenic particles relative to all sand and sludge particles in the soil cover.

Figure 2. Vertical distribution of heavy metals in sediments of lake Komsomolskoe, Murmansk region, Russia (concentrations are given in mg/kg).
The second most significant phase of the presence of heavy metals in Lake Komsomolskoye sediments is the phase associated with the organic matter of the sediments. Sb, Mo, and Cu have the highest similarity to organic matter in the lake sediments. The proportion of organic phases of these metals relative to the total content in the lake sediments is 35-36%. Least of all to this phase are metals such as Cd, Cr and Sn. It is also noted that a large proportion of water-soluble fractions of Pb, Cd, Zn and Tl in the layer of 0-5 cm of the sediments under study, which is a great danger because of the possibility of secondary pollution of the lake water.
4. Conclusions
At the present stage, Lake Komsomolskoye is experiencing a significant anthropogenic load. This is expressed in changes in the geochemical characteristics of the lake sediments. The upper sediment layers are significantly contaminated by heavy metals compared to the lower background layers. The main anthropogenic impact on the urban environment of Monchegorsk is the activity of the copper-nickel plant located near the city. In addition, we do not exclude the influence of long-range transport of heavy metals as one of the factors changing the sediment geochemistry. First of all, this refers to the behavior of lead in the recent lake sediment core.

Analysis of mineral particles containing iron, sulfur, nickel and copper in the upper sediment layers of Lake Komsomolskoye also indicates a significant influence of copper-nickel production. These technogenic particles have mostly spherical or irregular shapes. The origin of these particles is related to the processes of ore melting or roasting. In addition, it was found that various heavy metals are exposed to various fractions of existence in the arctic urban lake sediments. For example, Sb, Mo, and Cu have the greatest affinity to organic matter.

Heavy metal pollution causes great concern because of their toxicity, migration and accumulation abilities. Many of them including researched metals can be very toxic to the lake ecosystem. It is well-known that heavy metals are not degradable and getting in water systems they accumulate in bottom sediments for many years posing serious threat to aquatic communities. Most heavy metals are highly persistent and can easily enter a food chain until reach toxic levels forming serious threat to human health. Therefore, we are going to continue our research to assess the potential environmental risk caused by individual metals that is very important for implementing preventive measures in the future.

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