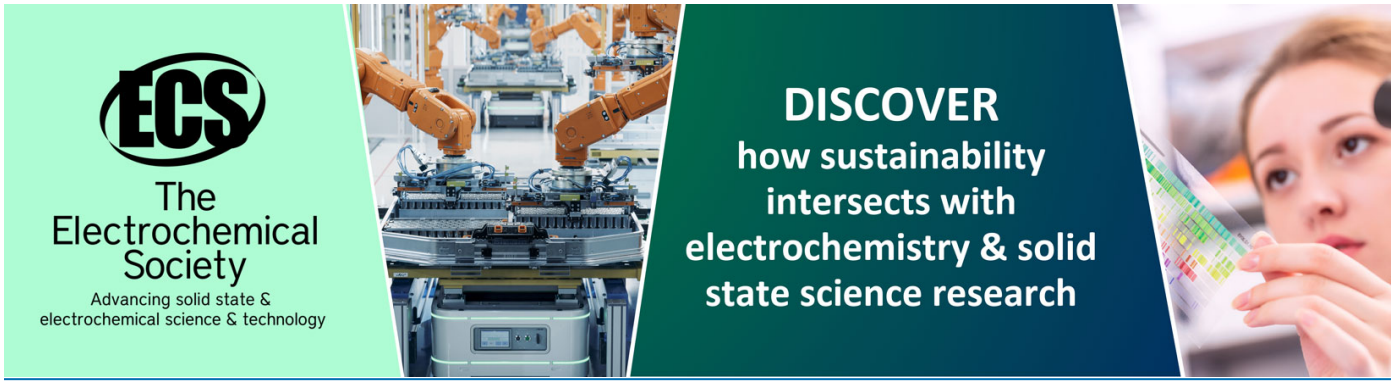
Transformation of Arctic ecosystems under impact of open-pit extraction of mineral resources



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Transformation of Arctic ecosystems under impact of open-pit extraction of mineral resources

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Abstract. The article considers the influence of open-pit mining of diamonds on the state of Arctic ecosystems outside of the zone of the direct impact of the enterprise. To assess changes in natural complexes, a retrospective analysis was carried out on the basis of the data from social surveys of the local population using adapted methodological approaches and comparing descriptions of the biodiversity of aquatic macrophytes made in 1969-1970 and 2018. The comprehensive studies of peat soils and the laboratory modeling of the flow of the saponite into the watercourse were carried out, in order to understand the possible ways of the impact of diamond mining on natural complexes. The shallowing of the river, the change in the nature of soils in the lower reaches of the river, the crowding out a number of native species of aquatic plants by invasive macrophytes were educed. It is shown that saponite interacts with components of bog ecosystems, changes its physicochemical properties and forms intermolecular associates with dissolved organic matter. This contributes to the transport of mineral particles over long distances, to its accumulation in bottom sediments, and to the prolonged desorption, which creates favorable conditions for the introduction of invasive species.

1. Introduction

Mineral resources are a significant potential of the Arctic. Therefore, extraction of mineral resources is actively developed in the Arctic zone of the Russian Federation. In particular, the industrial development of diamond deposits by open-pit mining is conducted in the Arkhangelsk diamondiferous province. The mining and processing plant, which is developing the kimberlite tube named after M.V. Lomonosov, is located in the upper course of the Zimnaya Zolotitsa River. This river serves as a spawning site for salmon and other fish, as well as the main source of water for the local population [1]. The river flows along the whole length in the deeply carved valley, the soils in the upper course are rocky, and in the lower course mostly sandy. The river has mixed feeding from snow, rain, and groundwater [2]. PJSC “Severalmaz” carries out regular environmental monitoring in the impact zone – close to the enterprise [3].

The mass media outlined an extremely negative forecast for the transformation of these territories after the start of mining in 2003 [4,5]. It was not confirmed. At the same time, the consequences of diamond mining by an open-pit method for the lower reaches of the Zimnaya Zolotitsa River were practically not studied. It is of great interest to scientists and members of the public; it is important for predicting the possible impact of further development of mineral resources in the northern territories of the Russian Federation on natural systems and the quality of human life. The multiplicity of the

factors of impact and the diversity of objects that are affected requires an integrated approach to assessing changes in the environment.

Therefore, the purpose of this study was to identify changes in the state of natural complexes as a result of open-pit mining of mineral resources (the case of the catchment area of the Zimnaya Zolotitsa River outside the official zone of impact of the diamond mining enterprise) using sociological and natural scientific methods.

2. Methods and materials

The studies were carried out in in the catchment area of the Zimnaya Zolotitsa River. The study area is situated in the north of the mainland part of the Arkhangelsk region, within the Belomorsko-Kuloisky plateau, in the zone of tundra forests. There is a quarry mining of a diamond deposit in the upper course of the Zimnaya Zolotitsa River. The main factors of the mining and processing plant direct impact on the environment are a decrease in the level of groundwater and a change in the hydrological regime, aeolian transfer of solid particles from terricones, water entering the riverbed from sedimentation ponds and quarry. Discharged waters containing finely dispersed clay mineral – saponite, according to the technological cycle of the enterprise, are treated on the filtration fields – plots of the high-moor sphagnum bogs, which occupy large areas in this territory [6].

Field materials were collected in 2018 in the lower course of the Zimnaya Zolotitsa River (at a distance of more than 100 km downstream) and in 2019 in its upper course (close to the plant).

A retrospective analysis of the changes that occurred during the industrial development of the quarry was made based on data from social surveys of the local population using questionnaire survey methods, expert and group interviews (focus groups) [7].

The main object of floristic studies was true water plants, which can serve as a reliable indicator of changes in the state of water bodies [8, 9]. Analysis of the transformation of plant communities in the region out based on data from 1969-1971 [10], and from field materials received in 2018-2019 was carried.

To understand the possible ways of mining developments affects natural complexes, field studies of peat deposits in the bogs of the catchment area and the laboratory modeling of entering the watercourse of the saponite suspension, both directly and through filtration fields (oligotrophic peat bogs), were carried out. Resistance to sedimentation was evaluated by changing the optical density of model waters of various concentrations, measured using a UV-spectrophotometer [11]. The changes in physicochemical parameters of peat deposits: active acidity, redox potential (ORP), total mineralization and degree of decomposition were studied [12].

3. Results and discussion

Results of surveys of the residents showed that most of them are not satisfied with the state of the environment. They noted that the water in the reservoirs is contaminated and the quality of drinking water is poor. At the same time, half of the residents use this water for food purposes due to the lack of other sources of water. Most respondents consider the mining and processing plant activity as the cause of water pollution. People in the survey noted overgrowing of the riverbank with shrubs and trees, erosion of coastal slopes, and a change in the composition of the vegetation cover. They associate these changes with a reduction in haying, grazing, etc. Figure 1 shows the results of surveys of the residents.

Participants in interviews and focus-groups noted shallowing of the river and lowering of groundwater levels; changes in the nature of soils in the lower course of the river; changing the terms of freezing and ice drift. Three cases, over the past seven years, have been noticed when water assumed a pronounced red-pink color. That is characteristic of kimberlite ore from the Arkhangelsk diamondiferous province containing saponite. It is significant that the villages of Verkhnaya and Nizhnaya Zolotitsa are 100-120 km away from the mining and processing plant. According to the population opinion, due to the deterioration in the water condition, salmon rarely spawn in the river, and the number of individual species of river fish decreases.

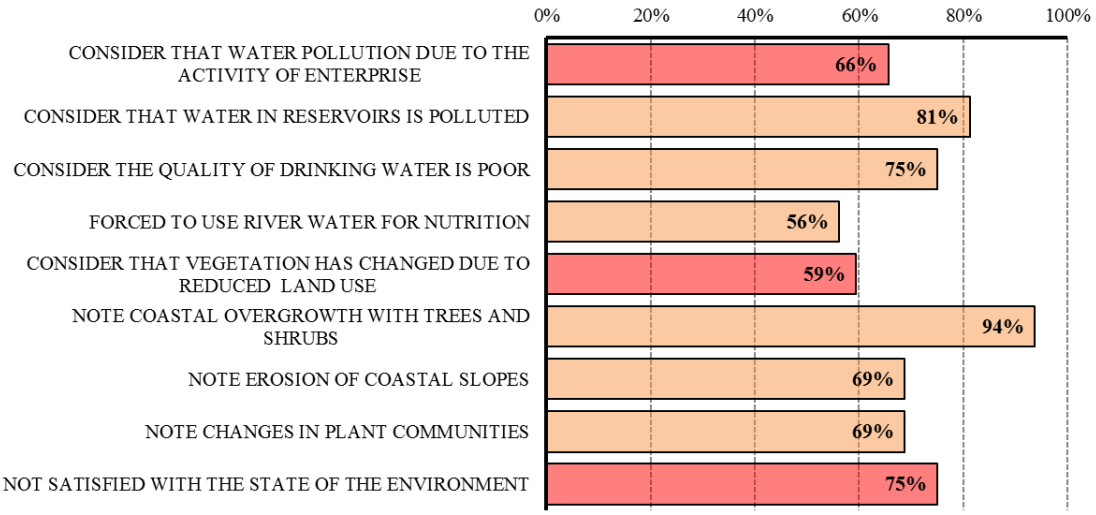

Figure 1. The results of a survey of the population of the Verkhnaya Zolotitsa village.

In witness whereof, there were recorded changes in the composition of aquatic macrophytes during the assessment of plant societies of studied territories. Their diversity, in comparison with the observations of 1969-1970, increased to 17 species in 2018. The specimens of *Myriophyllum spicatum L.* and *Persicaria amphibia (L.) Delarbre* were not found in the riverbed, but earlier these species were widespread. Four species of true aquatic vascular plants were noted for the first time: *Elodea canadensis Michx., Potamogeton lucens L., Stuckenia filiformis (Persoon) Börner* and *S. pectinata (L.) Börner*. The first of them forms dense thickets in some areas and is able to displace native species of aquatic macrophytes. For the European Plain, findings of these species in the surveyed area are located further to the north than all previously mentioned [13]. Most species whose frequency of occurrence has decreased are characteristic of weakly mineralized water bodies. Newly recorded species, on the contrary, prefer waters with increased salinity and hardness [14] and are demanding for nitrogen availability [15,16].

The active dispersal of new types of hydrophytes is probably facilitated by deoxidation of waters and an increase in their salinity. This can be caused by a strong decrease in water level in general, especially in the summer low water season, both due to natural climatic changes [17], due to a change in the species composition of forests as a result of fires and logging in the middle course of the river, as well as under the impact of mining.

Physico-chemical characteristics of peat deposits at different distances from the mining and processing plant are shown in Figure 2.

It should be noted that on the first and second plots between the tirr and the body of the peat deposit there is a thin (2-5 cm) highly oxidized black layer of weakly decomposed plant residues, and the peat itself has significantly higher density in comparison to the areas remote from the enterprise. Moreover, in the immediate vicinity of the enterprise, the consequences of the aeolian transfer of saponite are traced. The true mosses dominate in the moss layer of the plots which are situated near the terricones, and sphagnum mosses – in the distance. On the first plot (Figure 2 a) the deoxidizing effect of saponite introduction in the upper layers of peat (up to 15-25 cm) is manifested. On the other plots, the upper layer is characterized by the higher acidity (pH = 3.2-3.6), which decreases slightly with the depth of the deposit (Figure 2b, 2c).

The presence of saponite promotes the oxidation of peat components, which demonstrates the redox potential characteristic curves (Figure 2 d-f). At the same time, the barrier on the way of aeolian transport in the form of a tree belt area of 150-200 m width significantly reduces the impact of saponite on the bog massif.

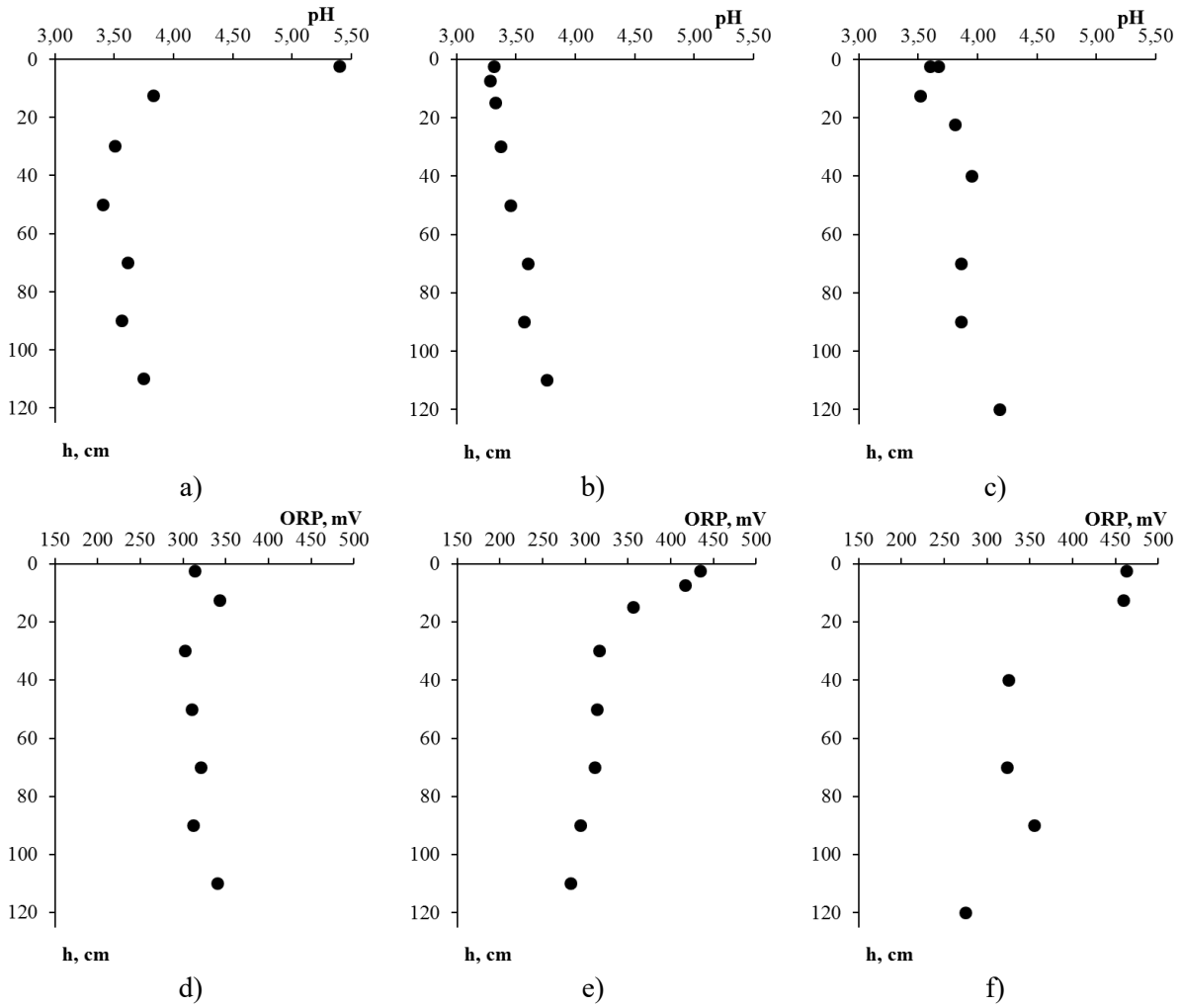

Figure 2. Physico-chemical characteristics of peat deposits: a), d) - in the immediate vicinity of the enterprise; b), e) - at a distance of 1 km from the enterprise on a site shielded by forest; c), f) - at a distance of 50 km from the enterprise.

According to laboratory studies, the deoxidizing effect of saponite is proportional to its addition to bog water. A decrease in active acidity (increase in pH value from 3.2-3.6 to 4.1-4.3) occurs already at short observation times. When filtering through peat, clarification of the suspension occurs due to the mechanical retention of saponite particles by parts of sphagnum mosses. During the first day, the peat under study provided a decrease in the total mineralization of water by 40-64 %, on the second day the degree of purification was 11-16 %, and on the third day it stabilized at a level of 2-6 %. By the end of the 5th day of the model experiment, a slight increase in total mineralization was observed. This indicates the exhaustion of the sorption capacity of peat. The optical density of bog water with saponite additives less than 0.01 % and subsequent sedimentation (5 days) increases by 1.2-1.5 times. An increase in saponite supplementation causes a proportional increase in the indicator. In this case, Springer's chromaticity coefficient (the ratio of optical densities at wavelengths $\lambda = 465$ nm and $\lambda = 665$ nm) increases slightly in the presence of saponite but does not depend on the weight of the additive. Saponite is characterized by a maximum optical density in the wavelength range $\lambda = 420$-470 nm [18]. The revealed effect is apparently due to the formation of sedimentation-resistant intermolecular organo-mineral associates of a certain composition. Such particles can be transported by the water stream at considerable distances from the source of pollution.

4. Conclusion

The result of the studies is that changes were recorded in the state of the natural complexes of the Zimnaya Zolotitsa River – outside the zone of the direct impact of open-pit mining. That is, first of all, a change in the level and composition of ground and river waters, changes in bog, land and aquatic plant communities, as well as in the physicochemical properties of peat deposits.

The change of plant communities occurs both under the influence of mining (aeolian and water transport), and other (climatic and anthropogenic) factors.

Peat has a high buffering ability with respect to saponite, but it significantly changes its physicochemical properties. Moreover, with a high degree of probability, it can be spoken of the formation of intermolecular associates of the mineral with humic substances, which contributes to the transfer of saponite particles over long distances, their accumulation in bottom sediments, as well as the prolonged desorption of mineral substances. This, in turn, creates favorable conditions for the introduction of invasive species.

The data obtained are important both for understanding the ongoing changes and for planning remediation activities.

Acknowledgments

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