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Abstract. The article deals with the problems associated with the anthropogenic impact of the mining and consentrating of apatite-nepheline ores on the environment in the Khibiny mountain massif, located in the central part of the Murmansk region. Mining company is one of the largest enterprises of the region and the largest European producer of phosphate raw materials for production of mineral fertilizers, but it is necessary to remember the fact that the activity of this enterprise causes significant damage to the environment, and the impact is complex. This impact is compounded by the low resilience of local ecosystems to human impacts. Mining leads to mechanical disturbance of soils, pollution of groundwater and surface water, atmosphere, soil and vegetation, and affectes negatively on the health of the local population. Negative features of production are low level of integrated use and consentrating of extracted ores, the presence of large amounts of unused waste of mining and consentrating industries. Priority pollutants are dust particles, strontium, lead, zinc, phosphorus, iron, etc. In this paper special attention is paid to bioindication research methods using Baltic sphagnum (Sphagnum balticum) and brown sphagnum (Sphagnum fuscum), due to their ability to accumulate aerotechnogenic pollutants.

1. Introduction

Nowadays, Russia's development depends on Arctic regions, for which the issues of comparing socio-economic development and preservation of the natural environment are relevant. The Murmansk region possesses not only rich raw material resources, but also unique natural opportunities for the development of recreation, traditional use of natural resources, as well as valuable biosphere resources, the importance of which can hardly be overestimated for future generations.

Extraction of apatite-nepheline ore in Khibiny has a complex negative impact on all components of ecosystems: there are changes in the terrain, geological, hydrological and geochemical conditions, soil, vegetation and animal habitats are disturbed, and the aesthetics of the landscape changes for the worse. Significant damage is also caused to the health of the population in the area affected by industrial facilities. This impact is exacerbated by the low resistance of local ecosystems to anthropogenic impacts.

From the point of view of long-term prospects, social and economic development, as well as due to natural factors, the majority of products of the mining and industrial complex of the Murmansk region have no alternatives in terms of their possible production in other regions of the country - for example, Apatit is Europe's largest producer of phosphate raw materials for the production of mineral fertilizers from apatite-nepheline ore from the Khibiny deposits. Apatit is the most important for the entire mining company of the Murmansk region: its products currently account is 56% of the total industrial output of the region [1].

The objects of the study includes current geo-ecological situation resulting from the activities of the mining and industrial complex in the Khibiny and foothills. In order to identify anthropogenic pollution during field routes at different distances from industrial sites, comprehensive descriptions of key areas were carried out at predetermined points, including the characteristics of natural features and environmental management, the nature and degree of anthropogenic impact, and samples of snow, water and soil were taken. The research was carried out taking into account the wind rose, relief and vegetation cover in the settlements, location of the residential quarters and peculiarities of the building.

2. Characteristics of the research area

The research area is located in the central part of the Kola Peninsula, 150 km north of the Arctic Circle, which determines its physical and geographical features, as well as specifics of nature use within it. The territory covers the south-eastern, south-western and southern parts of the Khibiny mountain massif and parts of foothills. Geographical location and history of development have determined the peculiarities of economic activity here. The studied area is located on the territory of the Murmansk region, which is a part of the Northern Economic District, and occupies a favorable economic and geopolitical position in relation to the industrially developed regions of the country. This advantageous position, as well as the availability of unique natural resources has led to the formation of a large industrial economy in a part of the study area. Currently, Khibiny are increasingly involved in the economic turnover, which causes complex reactions in natural landscapes [2].

Ore is extracted by open-pit mining at the Eastern excavation plant (the Koashva Mountains deposit, Njorkparkh), and the largest is the Tsentralnoye excavation plant (the Apatity Cirque deposit, Aikuaivenchorr mountain), which is closed. Underground mining takes place at Rasvumchorrsky (Rasvumchorr deposit) and Kirovsky (Kukis and Yuksporr mountains) mines. The total annual capacity of the mines is 28-30 million tonnes [1]. The company produces 8.5-9.0 million tons of apatite (39% P_2O_5) and 0.9-1.0 million tons of nepheline (28.5% Al_2O_3) concentrates annually. Apatite concentrate supplies Russian companies averaged up to 65% of the total volume or 5.9 million tonnes over the past six years. The volume of deliveries to the plants of the CIS countries is 4%, to the Baltic countries - 5%, to far abroad countries (China, Germany, Finland, Norway, Hungary, Romania, Slovakia and other countries) - 26% (2.2 million tons) (according to the data of the Apatit Museum). In the structure of product sales, the largest share of apatite concentrate is 85.2%, mineral fertilizers - 10.0%, nepheline concentrates - 1.5%, and other products - 3.2% [3].

Apatit is a city-forming enterprise for the cities of Kirovsk, Apatity, Koashva and Titan. Currently, Kirovsk, located in the mountains, is mainly affected by open-pit and underground mining, while Apatity and Titan - as a result of the activities of the factories ANOF-2 and ANOF-3, as well as dusting tailing dams. Ecological condition of the cities is affected by differences in physical and geographical conditions and location of anthropogenic sources. Kirovsk, in comparison with Apatity, built on the foothill plain, is located in a pit, less favorable conditions for purification of the atmosphere, but, compared with the data of the 1980s, we can say that the pollution from the activities of JSC "Apatity" facilities here has become less. This can be attributed to the termination of the ANOF-1 factory located in the basin of Lake Bolshoi Vudyavr within the city.

During the period of industrial development local nature has undergone anthropogenic changes, many of which have negative and often irreversible consequences. Currently development of the territory is mainly due to the activities of industry related to the extraction and concentrating of apatite-nepheline ores.

Significant parts of the territory located in the vicinity of Kirovsk, Apatity and industrial enterprises are subject to significant anthropogenic impact of the mining company and are in varying degrees of disruption. We can talk about the presence here of the so-called "impact" area - the territory, which has negative changes in the natural environment as a result of anthropogenic activity, resulting in the emergence and development of acute environmental situations [4, 5]. First of all, extraction and concentrating of raw mineral materials in Khibiny has led to significant mechanical disturbances of soils, pollution of underground and surface waters with industrial sites, dustiness of the air as a result of explosions for ore mining, dusting of tailing dumps. Chemical pollution of atmospheric air, surface waters, soil and vegetation cover with strontium, sulfur compounds and heavy metals is typical for this kind of industry [6]. Unfortunately, the health of the population suffers as well. People working at the enterprises of JSC "Apatit", along with unfavorable working conditions, typical for this industry, are affected by the constant impact of extreme natural conditions. The main indicative criterion of the unfavorable ecological situation in the region is the pathology of respiratory organs, diseases of which are almost 4 times higher than the average Russian indicators. Diagnosed malignant tumors are also higher than average in Russia - the main reason for their appearance is the pollution of the environment by strontium, which is the cause of development of bone cancer [7].

Negative features of production are: low level of integrated use and concentrating of extracted ores of most of the deposits and the presence of large amounts of unused waste of mining and concentrating industries. A significant part of nepheline, titanomagnetite (16-18% TiO_2), sphene (37% TiO_2, 0.4% SgO), aegirine annually in the amount of 15-20 million tons replenish the dumps of concentration plants. Over the entire development period of the Khibin, more than a third of the total reserves under development have been produced. By the middle of the nineties, the volumes of ore extraction and concentration output had tripled; at present, the main production at Apatit is stabilizing. Ore concentrating is carried out at the apatite-nepheline complex, which consists of two apatite-nepheline plants - ANOF-II (launched in 1963) and ANOF-III (operating since 1988) (ANOF-1, located within the city of Kirovsk, closed in 1992). Apatite-nepheline production waste is pumped and stored in tailings dumps with circulating water supply systems: for ANOF-2 which is located in Belaya Bay, a fenced dam from Lake Imandra, for AONF-3 - in the swampy area in the southern foothills of the Khibiny (river Chernaya, river Jemchujnaya) At present, apatite, partially nepheline and a small amount of sphene are completely extracted from the mined ore. A significant part of nepheline, titanomagnetite, sphene and aegirine (15-20 million tons per year) is added to the dumps of concentration plants (Figure 1).

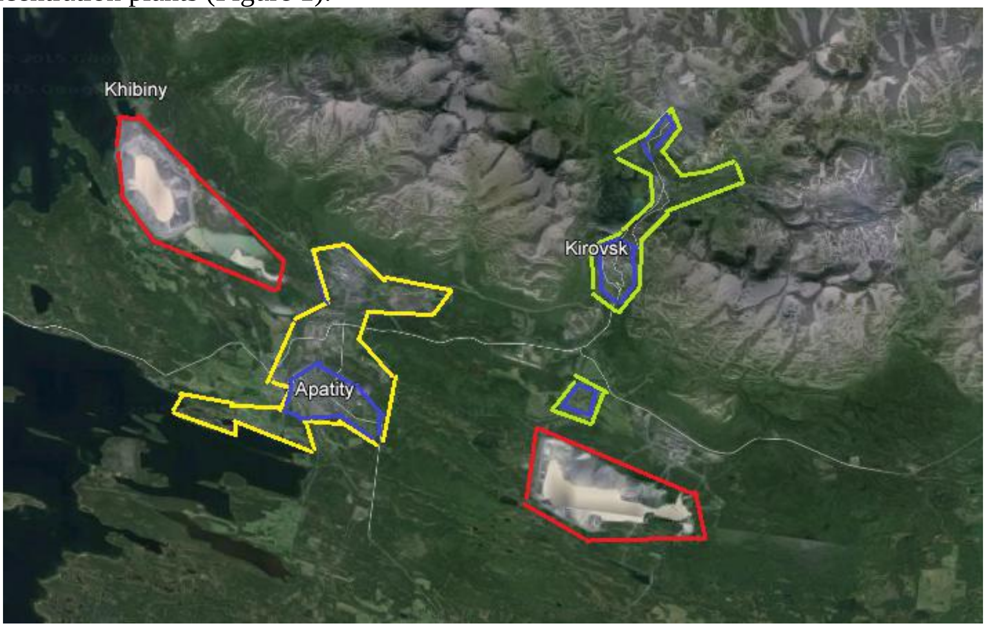

Figure 1. Location of Kirovsk, Apatity, Titan (highlighted in yellow) relative to the tailings dumps of ANOF-2 and ANOF-3 factories (highlighted in red)

At the end of 2017 total volume of production amounted to 33.4 million tons, while the volume of waste amounted to 84.5 million tons, of which 34.5 million tons were used or disposed of [3]. At the same time, 22.8 million tons of overburden formed as a result of open-pit mining at Apatit mines was involved in the construction of roads. Apatit emitted 11.5 thousand tonnes of pollutants into the atmosphere in 2016 [1]. Water consumption for production needs is 52.5 million cubic meters, and water discharge and waste water discharge is 189 million cubic meters.

Pollution of the environment occurs both in the process of ore extraction and concentrating. One of the main environmental impacts of Apatit's operations is mechanical - alienation and disturbance of the earth's surface. The impact on the subsoil should be considered as the formation of underground and quarry cavities. For example, for Apatit, specific land disturbances per 1,000 tonnes of extracted ore for underground and open-pit mines amount to 0.026 ha and 0.047 ha, respectively. [8]. The most noticeable changes in landscapes occur as a result of the formation of quarries and dumps. Their area grows every year without any recultivation. To get one ton of useful product every year it is required to extract more and more tons of ore, as the richest ores have already been extracted. Up to 400 kg of waste dumps are produced per 1 tonne of concentrate [1]. A significant part of the useful components of ores, which are not used for the production of concentrates, goes to tailings dumps. From the material of tailings dumps it would be possible to get a large number of valuable elements - nepheline, alumina, titanium, soda ash [9].

Air pollution occurs during the extraction of ores by explosive means, in the process of rock crushing at the factories and in the process of dusting waste rock dumps (tailing dumps). Localities and their surroundings are affected by the activities of industrial enterprises. Apatite concentrations of suspended solids and small suspended solids during the periods of the so-called unfavorable weather conditions are increasing on a one-time basis: winds of "unfavorable" directions - north-western, weak winds, and stilts at which harmful substances accumulate in the air [1]. In July, in northwestern winds, single concentrations of suspended solids reached 2 MACs in the city centre, and the frequency of exceedance of single concentrations exceeded 0.1%. In summer months there is an increase in average monthly concentrations compared to winter (May, June, July, August) [5]. In winter, suspended solids in the atmospheric air are practically not observed - most of the tailings dump at this time of year is covered with ice and snow.

Factories, tailing dams and quarries cause air pollution by aerosol particles. Priority pollutants are dust particles, strontium, lead, zinc, aluminium salts, phosphorus, iron, etc. Vegetation and soil cover suffer most from dusty particle emissions [10]. Dust particles emitted into the natural environment are alkaline in their chemical composition. They clog the stomata of plants, causing their death. The most dangerous pollutant contained in the emissions is strontium, which is enriched with apatite-nepheline ores, as well as compounds of phosphorus and aluminum salts. By settling on the soil surface, toxic substances and their compounds accumulate and create a horizon that prevents normal growth of plants. The content of toxic substances can reach 50% of the litter weight [11]. Dust particles also accumulate in river channels, silting them. The increase in the content of dust particles in the atmospheric air is most often associated with the dusting of tailings, which occurs at wind speeds of about 5 m/s. The deposition of such dust on the surface, such as Lake Imandra, has a negative impact on the development of aquatic organisms.

Tailings management facilities cause significant environmental damage. The ANOF-2 and ANOF-3 tailings dumps are sandy embankments where pulp waste is dumped into the tailings dump through a pipe leading from the plant. In the center of the embankment in the lowering of the relief is water. A significant problem is the fixation of the dusty tailings material, which begins to dust even at low wind speeds, polluting the vicinity Apatity, Titan, and the areas where the cottages are located. Physical and chemical impacts of tailings dumps on the natural environment are expressed in lithospheric, hydrospheric, air and biological pollution. Lithospheric pollution is the result of pulp leaks, construction waste, scrap metal, etc. Hydrosphere pollution is connected with the accidental inflow of industrial water and slurry into surface water bodies, discharge of waste water, washing off pollutants from slopes and dams by atmospheric precipitation. Air pollution is mainly caused by dusting of dry

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slopes and surfaces of tailing dumps. Biological pollution is manifested in the accumulation of macro- and microelements and is expressed in diseases and death of flora and fauna [12]. The maximum values of the polluting flow are observed near tailings dumps, where the concentration of dust in the air can reach 0.2-0.3 g/m^3. Dust mass flow to the Lake Imandra at a distance of several km is 4-8 g/m2 per day [13]. In spite of the fact that Apatit has the highest degree of purification of emissions into the atmosphere (according to Apatit, the efficiency of dust collectors here reaches 99%), the atmospheric air in Kirovsk and Apatity is polluted with dust containing toxic compounds (especially strontium) almost throughout the year [1]. Tailings dumps are recultivated by different methods. Thus, the biological method is widely used: to fix the sandy edges of the tailings dumps, the sand ryegrass that grows on the sandy shores of the Terek coast on the White Sea is used. However, with the help of this method it is not possible to fully fix the sides of tailings dumps. Therefore, chemical methods are also used for this purpose, for example, spraying latex emulsions and bitumen solutions on the surface of the sides. Unfortunately, these measures are not able to fully secure the slopes of tailings dumps. Currently, biologically isolated reagents have been used, the significant advantage of which is the fact that no hot water is required to apply new solutions (as in the case of bituminous solutions), they are only strengthened by moisture.

3. Bioindication of the research area

Studying the spread of technogenic pollutants by natural indication method additionally allows to estimate the level of concentration of individual ingredients in the air basin. In this case, the method of bioindication was used, in particular, brioindication (exposure of mosses). This method is actively used in Scandinavian countries and Finland. Moss for brioindication (Figure 2) was selected at a considerable distance from settlements and industrial sites - on the upper sphagnum bog behind the former Oktyabrsky settlement to the south-east of Khibiny on the basement plain. Then moss was laid out in a dry, well-ventilated room for drying, freed from inclusions and collected in portions in the net, which were hung in the study areas at predetermined points at a height of about 2 m. Control nets with background samples were sent to Moscow for analysis in the chemical-analytical laboratory of the Department of Environmental Management of Lomonosov Moscow State University. During half a year moss accumulated contaminants, in particular heavy metals, only from atmospheric air. In half a year the nets with moss were collected, moved into plastic bags, marked according to the labels and analyzed in the laboratory. The results were compared with the background sample data.

Figure 2. Baltic Sphagnum (Sphagnum balticum) and brown Sphagnum (Sphagnum fuscum) from the baseline

Collected samples of moss were thoroughly dried in the laboratorythen subjected to ashing [4]. Based on the results of the sample analysis, has been drawn up showing the content of contaminant elements (Cu, Zn, Ni, Pb, Sr) accumulated in the moss samples, indicating the concentrations of each element. Levels of accumulation of heavy metals in samples (compared to background value)

After analysis, the data were compared with the background values of heavy metal accumulation for each of the elements. The data obtained were reflected in the map (Figure 3).

According to the analysis, there was a significant excess of copper content in almost all 33 sample, except for two (in Kirovsk, the "23rd km" area and near the Saamskaya river and in the western part of the city of Apatity). Zinc concentration in any of the points did not exceed the background value. The accumulated concentrations of copper and nickel exceed the background values by more than 3-4 times - it can be assumed that the state of atmospheric air in Khibiny continues to be negatively affected by the activities of the Monchegorsk Copper and Nickel Plant. The analysis has shown that the content of strontium in the suspended sphagnum sorbents has already increased in six months compared to the control. The lifetime of these elements in the atmosphere is quite long and they easily penetrate into living organisms, including human body through the respiratory system. The accumulation of strontium causes special damage, which increases the risk of bone cancer, leukemia even in insignificant amounts, in children at the initial stages of its accumulation manifests rickets and bone fragility. The presence of heavy metals in the emissions into the atmosphere affects the fertility of women and embryonic development of the fetus. Thus, only 30-35% of children living in the research area are healthy [7].

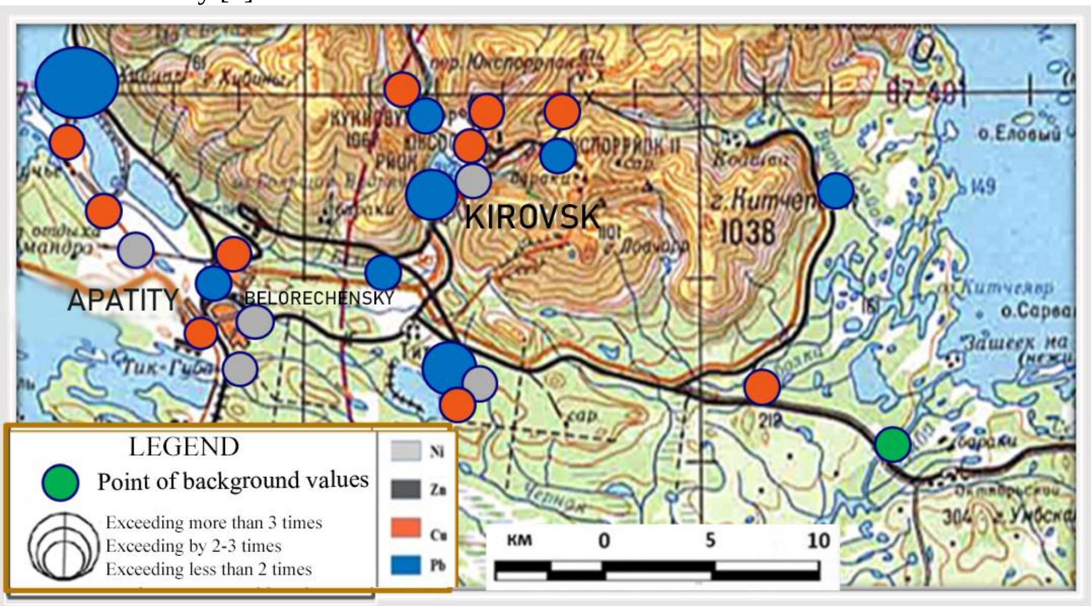

Figure 3. Excess content of heavy metals in samples of moss (fragment)

4. Nature conservation activities

At development of separate nature protection actions the standard nature protection requirements and restrictions at present should be considered [14]: works are made on the greatest possible distance from nature protection zones and territories; application of modern nature protection technologies and nature protection actions; planning and carrying out on the broken sites of a complex of recultivation works.

These measures have not been implemented on the proper scale, despite the fact that the declaration of such measures is sounded in the reporting documents of Apatit: tailings dumps are dusty, rock dumps are growing, the issue of their storage on popular tourist trails is not solved, the health of the population is deteriorating. The problems of quarry reclamation are not discussed.

During the work of the mills it is necessary not only to create projects for environmental protection and impact minimization, but also to strictly observe them. The following environmental protection measures should be taken at Apatit mines: in order to reduce harmful emissions into the air, hydro dusting of dump surfaces and roads during the warm season; restrictions on movement of machinery in areas prone to erosion (wind and water); creation of storm water runoffs from the industrial site along the non-destructible surface and directing them to the general system of wastewater treatment; use of existing facilities for collection, treatment and discharge of water, control over the chemical composition of mine waters sent to treatment facilities, elimination of industrial site littering with production and consumption waste, use of liquid vehicles for refueling equipment, establishment of a road watering regime for process vehicles for the purpose of dust suppression, performance of reclamation works after the end of operation of overburden dumps.

In order to streamline mining operations in the long term, it is necessary to address the issue of ore reuse - the extraction of elements from rock dumps and tailings dumps. Given the complexity of all mining factors, a rational approach to the use of mineral resources is becoming increasingly important. It presupposes technological improvement of subsoil development, application of more productive methods and methods of subsoil use. Today, the main task is to increase the completeness of the use of the subsoil potential, reduce losses during mining, concentration of ore. All this becomes possible only with the integrated use of mineral resources. Completeness of extraction of useful components increases due to improvement of enrichment of rock mass. It allows to reduce wastes and losses of raw materials and materials, to use more fully in manufacture by-products. It is possible to fill the worked out spaces of mines with waste rocks, they use them as a backfill material for filling of failures, thus not lifting them on a surface that considerably increases productivity of extraction and reduces expenses.

In terms of waste management, for example, decision to use 18.8 million tonnes of Apatit overburden from open pit mining for road construction can be cited as an example. In particular, 42,000 tonnes of phosphogypsum from the Balakovo branch of Apatit was used in 2015 to construct a 7-kilometre road section near the company and near Balakovo district of Saratov region [3].

In addition, it is important to take into account that tailings dumps in the technological scheme of mining and concentrating enterprises that develop apatite-nepheline ore deposits are very dangerous objects: during the period of development and operation of the Khibiny deposits they accumulated more than 800 million tons. One of the most dangerous variants of the accident development for the enterprise and environment is erosion of the ground fencing dam, as a result of which the liquid part of the tailings dump will be spilled [15]. In this connection, the development of apatite-nepheline ore enrichment technologies with the minimum possible waste storage in tailings dumps should also be considered as a priority area of research in the field of mineral raw materials concentrating. One of the ways to implement the solution of this problem is the use of technology of pre-concentration - separation of waste and weakly mineralized rocks after crushing before the processes of deep enrichment. According to the research [15], the use of pre-concentration apatite-nepheline ores by improving their quality reduces the volume of flotation tailings and increases the service life of the tailings dump.

In the course of development of measures to reduce air pollution at all enterprises of it is necessary to carry out an inventory of sources of air pollution, to determine the composition and amount of industrial emissions, the levels of pollution of the surface layer of air in the zones of emission dispersion. In order to reduce the gas content at Apatit, it is possible to recommend the use of gas fuel (the most common is a mixture of propane and butane - the engine running on propane-butane, at idling speed emits 4 times, and in the operating mode - 10 times less carbon monoxide than gasoline), synthetic alcohols, ammonia and hydrogen [16]. To reduce dustiness, it is necessary to create solid protective plantings of trees and shrubs between the source of pollution and other objects - such work is not carried out yet, there are separate plantings of trees and areas of natural plantings. Landscaping works should be carried out taking into account geographical and meteorological factors.

5. Conclusion

Environmental safety in the mining industry is possible only on the basis of a comprehensive solution to the problems of mining and consentrating of minerals, and the rational development of mineral resources should be carried out taking into account their ability to maintain the sustainability of the biosphere processes in the process of development. Therefore, enterprises should be required to reproduce the environmental potential at all stages of exploration and development of mineral resources and after the mining company is decommissioned.

Also it is not necessary to forget about decrease in recreational attractiveness of Khibiny which occurs as consequence of activity of the mining enterprises, and also - about "aesthetic" pollution which area in many times more than territory of industrial objects and is defined by possibility of the visual review. Meanwhile, it is assumed that the Kirovsko-Apatitsk industrial and transport hub will retain its economic significance in the future until 2050 and it has good economic and social prerequisites not only for the development of industry, but also for the development of a large recreational center of the Northern Economic District and the Barents region, which is promoted by the high attractiveness for tourists of the Khibiny massif with its diverse landscapes, a relatively high standard of living, compared to other cities of the Murmansk region. Unfortunately, the irrational use of natural capital leads to the fact that gradually, as a result of mining, overburden storage, the formation of tailings dumps and the lack of adequate measures for remediation, there is a limitation of the flow of recreational activities in many previously popular tourist areas of Khibiny.

The results of the analysis of the impact on the environment can be further used to monitor the level of pollution and rationalize the use of natural resources at the industrial facilities under consideration.

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