Application of the phytotesting method to assess the environmental impact of the waste of Lovozersky GOK LLC

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Abstract. For a comprehensive assessment of the negative impact of mining waste on environmental objects, the biotesting method was used; phytotesting is a special case of it. The test objects were the tailings of loparite ores, soil and lake water samples in the zone of influence of Lovozero Mining and Processing Plant LLC, located in the Murmansk region. Test cultures - seed oats \textit{Avena sativa} \textit{L.}, soft wheat \textit{Triticum aestivum} \textit{L.}, watercress \textit{Lepidium sativum}. Assessment of the impact of enterprise waste is given on the basis of the joint application of several test cultures and phytotesting methods. A decrease in test functions for a number of objects was found, but no toxic effect was detected. The V hazard class of the tailings of the enrichment of loparite ores stored by the enterprise has been experimentally confirmed, the low probability of overgrowing of the surface of the tailings has been demonstrated.

1. Introduction
The largest volume of production and consumption wastes in 2018 was the economic activity “mining” - 6.85 billion tons, and this volume increases every year [1]. The direct yield of the product in the process chain “raw materials - the target product” rarely exceeds 10%, that is, about 90% goes to waste, which leads to pollution of the ecosphere. According to [2], over 100 billion tons of mining waste has already accumulated in the territory of the Russian Federation, and about 40% can be involved as a source of mineral resources, but about 1% is actually used.

It is difficult to assess the environmental impact of production waste on the basis of analytical data alone. The maximum and approximate permissible concentrations of contaminants in soils are presented for a relatively small number of pollutants. Given the development of chemical synthesis technologies, many substances are simply not there. Also, the combined effect of several pollutants, which can be both antagonistic and synergistic, is not taken into account.

The aim of this work was to identify the negative impact of mining waste on environmental objects using the example of Lovozersky GOK LLC by phytotesting.

2. Objects and research methods
The objects of study were tailings of loparite ore beneficiation, samples of soils, lake waters taken near the Karnasurt processing plant of Lovozersky GOK LLC.
The Lovozero mining and processing plant is located in the center of the Kola Peninsula and is the city-forming enterprise for the village of Revda. The company is developing a deposit of niobium, tantalum and rare earth elements of the cerium group, the main marketable product is loparite concentrate. The total area occupied by two fields of tailings is 106 ha. The annual tail increment exceeds 400 thousand tons.

In the spring of 2018, the IPPES KSC RAS employees took samples of enrichment tailings from the second field of the tailing dump. Based on the results of determining the engineering-geological characteristics, the authors of [3] concluded that tails are classified as fine and medium-grained sands with a probability of dusting in the summer. The staff of the Institute of Chemical Physics and Technology, Kola Science Center, Russian Academy of Sciences, conducted radiometric studies, as a result of which the radium-thorium nature of radioactivity was established. The effective specific activity of natural radionuclides of the studied samples is in the range of 646 ± 21–1300 ± 24 Bq / kg [3]. In the summer of 2019, soil and lake water samples were taken near the enterprise (figure 1).

![Figure 1. Map diagram of sampling.](image)

Phytotesting, a special case of biotesting, is a tool for the integrated assessment of the toxicity of wastes and their pollution. This method has several advantages: expressness, accessibility and simplicity of experiments, profitability, reproducibility and reliability of the results [4]. Several methods have been developed in Russia and abroad that make it possible to experimentally determine the hazard class of waste [5], the degree of pollution of soils and industrial soils [6], chronic phytotoxicity [7], and others.

The Fitotest method [5] is used to establish the total toxicity and hazard class of production and consumption waste. The test object is the water extracts of the studied waste, the test object is the seeds of higher plants (oat sowing *Avena sativa L.*), distilled water with a pH of 6.3 is used as a reference (control), and the test function is the inhibition of seed root growth. The native extract and its dilutions (at least three) are tested in the experiment to determine the range of phytotoxic effects. Oat seeds are germinated in a Petri dish on paper filters moistened with distilled water, an aqueous extract from waste of various concentrations. All experiments are carried out three times. According to the results of measuring the length of the roots of seedlings, the inhibition effect is calculated: \( E_i = (L_{k} - L_{op}) / L_{k} \times 100 \), where \( E_i \) is the inhibition effect, %; \( L_{k} \) - the average length of the roots in the control, mm; \( L_{op} \) - the average length of the roots in the experiment, mm The phytotoxic effect is considered proven if the calculated indicator exceeds 20%. If only the native exhaust has a toxic effect, the hazard class IV is automatically assigned to the waste.

Phytotesting of soils under laboratory conditions is carried out in two possible versions: in aqueous extracts (eluate) and directly in the soil sample (contact). It is preferable to apply the second due to the fact that germination of seeds in extracts showed underestimated results due to the fact that only water-soluble substances pass into the extract [8].
According to [6], *Triticum* wheat is used as a test culture for assessing the contamination of soils and technogenic grounds. The test function is the germination energy and inhibition of the growth function of the roots of seedlings. All experiments are carried out in at least three times. The soil selected from the background territory, similar in physical and chemical characteristics to the studied samples (except for pollutants), acts as a reference substrate. Due to the complexity of the search for control, vermiculite with Knop nutrient solution [9], washed quartz sand, can be used as a reference. After the exposure of seeds, measurements and comparison of the germination and length of the roots of seedlings in the studied soils with control, the conclusions of the degree of the contamination of the objects are made. The toxicity level of contaminated soils is determined by reducing seed germination (N1, %) and root inhibition (N2, %) compared to the control sample. The values N1 and N2 are calculated according to the following formula: \( N = \frac{(M_k - M_i)}{M_k} \times 100 \), where N is the degree of change of the controlled parameter (length of seedling roots or seed germination) compared to the control sample (%); Mk is the average value of the parameter of the control sample; Mi is the average value of the parameter of the test sample.

In order to assess the environmental impact of enterprise waste by the phytotesting method, several series of experiments were carried out using the previously mentioned methods. Sowing oats (tails, lake water), wheat (soil) and watercress (for all test objects) were used as test cultures.

3. Results and discussion

In a previously published work, a preliminary assessment was made of the environmental impact of enterprise waste on the basis of analytical data. According to preliminary estimates, soils near the existing tailing dump are classified as moderately hazardous \( (Zc = 16.86) \). Manganese content increased by 1.2–1.6 times compared to the maximum permissible concentrations of chemical substances in the soil. The cont of nentsickel, copper, and zinc amount to 20, 33, and 55 mg / kg and exceed the estimated permissible concentrations of chemical substances in the soil by 1.5, 1.2, and 4.7 times (for maximum values), respectively [10].

To determine the phytotoxicity of water-soluble substances in the tailings of LGOK enrichment, an experiment was conducted according to the procedure [5] on aqueous extracts (T: W 1:10). Distilled water was used as a control, the native solution was taken in dilution 2, 5 and 10 times. The results of assessing the inhibition of the length of the roots of oats of inoculum and watercress depending on the dilution of the extraction of tailings of enrichment are presented in figure 2.

![Figure 2](image)

**Figure 2.** The relative decrease in the length of the roots of oats and watercress for various dilutions of the extraction of tailings enrichment.

The maximum decrease in root length for oats and watercress was recorded for the native solution, while the inhibition of root length was about 15% for both test cultures. For watercress, unlike oats, with tenfold dilution of the extract, hormesis is observed, that is, the stimulating effect of moderate or low doses of pollutants. The limiting value of the inhibition effect for the recognition of the phytotoxic effect in the experiment with aqueous extracts was not reached.

Soil contamination was determined by the contact method, germinating the seeds of test cultures - watercress and spring wheat directly in the studied samples - soil samples taken at a distance of 300 and...
600 m from the first field of the tailing dump. Quartz sand was used as a control. For comparison, the results of contact phytotesting in the tailings of enrichment of loparite ores are presented (figure 3).

**Figure 3.** Relative decrease in germination and length of roots and sprouts of wheat (1) and watercress (2) in control, tails, soils 300 and 600 m.

Germination turned out to be a more sensitive test function, wheat as a test culture. Since, in accordance with [5], two indicators are taken into account - germination and root length, we can conclude that the studied soil samples are classified as practically non-toxic.

For tail samples, there was a sharp decrease in seed germination, especially significant for wheat. This fact allows us to conclude about the low suitability of the soil without active reclamation work for natural and artificial overgrowing. For the representative of dicotyledonous plants - watercress, the decrease is less significant, but reaches a maximum level of 40-45% of the control.

Earlier, in samples of water from Lake Ilma, excesses of maximum permissible concentrations for water bodies of fishery value for fluorine and phosphates were revealed by 1.8 and 1.4 times, respectively [10]. In a series of experiments to assess the pollution of this water body by phytotesting, watercress and oats were selected as test cultures, the control was the water of Lake Revdozero, located at a considerable distance from the enterprise. Seeds of test cultures were germinated on paper filters moistened with water from the studied lakes. After the expiration of the exposure time, measurements and processing of two test functions were carried out - the length of the roots and seed sprouts.

The results are presented in figure 4. No acute toxicity was detected, but in some cases, a slowdown in the growth of roots and seed sprouts was noted.

**Figure 4.** Relative decrease in the length of roots and sprouts of watercress (1) and oats (2) in the water of the Revdozero (control) and Ilma lakes.

### 4. Conclusions

A comprehensive study of the effect of enrichment tailings of Lovozersky GOK LLC and contaminated soils and lake waters on the growth and development of higher plants (seed oats Avena sativa L., soft
wheat Triticum aestivum L., watercress Lepidium sativum) by eluate methods was carried out and contact phytotesting. The fifth hazard class of the tailings of enrichment of loparite ores has been experimentally confirmed.

Despite the classification by the calculated method of soils selected near the enterprise as moderately hazardous, the integrated assessment did not reveal significant pollution. Nevertheless, the effect of inhibition of the length of roots and seedlings was recorded for both the contact and eluate versions of the experiment. For sufficiently dilute solutions (low concentrations of pollutants) the hormesis effect for watercress was noted.

The phytotesting method allows not only to assess the degree of pollution of soils and industrial soils, but also to assess the potential for self-growth of the studied objects. According to the results, both natural and artificial overgrowing of the surface of the tailings site is unlikely without a significant amount of reclamation work.

Testing the waters of lakes (background and located near the enterprise) on two test cultures allows us to conclude that there is little pollution of the second object. Dicotyledonous plants (watercress) in this case showed a higher sensitivity to the level of pollution.

To conduct a comprehensive assessment of environmental pollution near mining enterprises, it is possible to use the phytotesting method, combining methods based on germination of test cultures both in water extracts of the studied objects and directly in the substrate. It is advisable to use at least two different test cultures for each object, and make a more sensitive conclusion.

Of course, phytotesting does not cancel chemical analyzes, but it saves time and money by identifying problem areas of the studied objects.

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