Use of organomineral sewage sludge for recultivation of disturbed by mining and processing industry lands

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Abstract. The paper is devoted to the study of the use of organic-mineral waste from the pulp and paper industry for the land and dumps restoration disturbed by the mining and processing industry. The examination of the chemical, agrochemical and toxicological properties of the dumps of the Verninsky GOK were carried out. It showed their toxicity to the environment and the need for restoration. It is proposed to use soil moisture obtained from frozen colloidal sediments of sludge-lignin of the Baikal PPM OJSC (BPPM) to intensify the restoration succession. It reduces the toxic effect of dumps on higher plants and introduces the necessary nutrients. At the same time, the use of the obtained soil moistures will make it possible not only to restore lands disturbed by the mining and processing industry, but also to utilize the accumulated waste of JSC BPPM, which creates a huge socio-ecological threat for Lake Baikal and the entire Southern Baikal region.

1. Introduction
The general dynamics of waste generation in the Russian Federation shows a steady tendency for an annual increase in their volume. From 2010 to 2019, the total mass of waste generated in the Russian Federation doubled from 3.7 billion tons to 7.8 billion tons [1]. In 2020 Russia set a record for the generation of industrial waste, i.e., about 8 billion tons, of which only 3.2 billion tons are subject to further processing, and the rest of the waste is disposed at landfills. The Siberian Federal District became a leader in the generation of industrial waste. In 2020 about 70% of the total Russian volume of waste was generated. It is primarily associated with the developed mining and processing industry. The Irkutsk region is included in the top of ten regions where the leading contribution to production is made by the developed deposits of gold-sulfide (Verninskoye), gold-quartz-sulfide (Nevskoye, GoletsVysochaishy) and gold-quartz (Ugakhan).

The largest contribution to the extraction of minerals in the Irkutsk region is made by the Verninskoye gold-sulfide deposit located in the central part of the Bodaibinsky district of the Irkutsk region, 146 km from the city of Bodaibo, 6 km from the settlement Kropotkin. The deposit was discovered in 1974, and in 2011 the Verninsky GOK was put into operation (figure 1). It is a part of the Polyus group, the largest gold mining company in Russia.
At the minerals extraction, about one-twentieth of the extracted raw material becomes a valuable product. The rest of the rock is transferred to dumps and tailings that affect the environment and significantly change and disrupt the natural landscape. The main technogenic load on the environment in the development of open pits is the mechanical destruction of the soil cover and vegetation. The current technology for the processing of mineral raw materials from the Verninskoye deposit is carried out according to gravity-flotation technology. Here a large amount of toxic heavy metals such as arsenic, cadmium, nickel, lead, copper, zinc, mercury, and also intake of cyanides. In this connection, self-healing of the disturbed natural environment is extremely slow, which creates serious negative social and environmental consequences. Thus, an extremely urgent task is the restoration of disturbed lands and the creation of conditions for self-overgrowing of the dumps of the mining industry. The paper discusses the possibility of using organic-mineral waste from the pulp and paper industry for the reclamation of lands in the mining and processing industry.

2. Material and research methods
In 2020-2021 the samples were taken and analyzed in an accredited laboratory for environmental monitoring of natural and man-made environments of the Federal State Budgetary Educational Institution of Higher Education "IRNITU" No. ROSS RU.0001.518897 to assess the chemical, agrochemical composition and toxicity of the dumps of the Verninsky GOK (table 1). Heavy metals were estimated by the method [2]. Their high content can inhibit the growth of plants, as well as cause their death. The main nutrients for plants as agrochemical indicators were determined, such as organic matter [3], phosphorus and potassium [4], total nitrogen [5], as well as the pH of salt and water extracts [6,7] and a solid residue for assessing dumps on the degree of salinity (tables 1,2).

| Indicators | Sample 1 | Sample 2 | Sample 3 | Sample 4 | Sample 5 |
|-----------|-----------|-----------|-----------|-----------|-----------|
| As, mg/kg | 1130 | 1120 | 1220 | 409 | 385 |
| Cd, mg/kg | 0.48 | 0.36 | 0.39 | 0.33 | 0.46 |
| Cu, mg/kg | 51.1 | 54.2 | 52.6 | 28.2 | 38.6 |
| Ni, mg/kg | 30.7 | 38.1 | 37.4 | 30.7 | 35.9 |
| Pb, mg/kg | 17.1 | 21.1 | 19.6 | 5.8 | 12.3 |
| Zn, mg/kg | 91.2 | 86.4 | 86.9 | 59.6 | 77.1 |
Table 2. Agrochemical structure of dumps in the Verninsky GOK.

| Indicators                              | Sample 1 | Sample 2 | Sample 3 | Sample 4 | Sample 5 |
|-----------------------------------------|----------|----------|----------|----------|----------|
| Mobile potassium, mg/kg                 | 154      | 147      | 112      | 136      | 144      |
| Mobile phosphorous, mg/kg               | 0.9      | 1.2      | 1.0      | 2.4      | 1.2      |
| Hydrogen index of water extract, units pH | 7.5       | 7.8      | 8.0      | 8.1      | 7.4      |
| Hydrogen exponent of salt extract, units pH | 7.2       | 7.2      | 7.6      | 7.6      | 7.2      |
| Organic matter, %                       | 4.0      | 3.6      | 4.2      | 2.3      | 3.6      |
| Total nitrogen, %                       | 0.3      | 0.2      | 0.3      | 0.2      | 0.2      |
| Solid residue of water extract, %       | 1.4      | 1.2      | 0.4      | 0.8      | 0.6      |

According to table 1, dumps of the Verninsky GOK contain a large amount of arsenic (from 30 APC to 120 APC). It is one of the most toxic elements of the mining and processing industry.

It is clear that the dumps can be attributed to alkaline, medium and highly saline organic and mineral soils with a low content of nutrients.

The dump toxicity studies have shown the III class of waste hazard. Thus, it is possible to draw conclusions about the need for reclamation of the dumps of the Verninsky GOK on the basis of the obtained information. It is proposed to use soil moisture obtained from frozen colloidal sediments of sludge-lignin of OJSC Baikalsky PPM (BPPM) to intensify the reclamation succession, since the area of the GOK is equated to the regions of the Far North, on the territory of which there is no fertile soil suitable for use in land restoration. Frozen sediments of sludge-lignin comply with GOST 54534-2011 “Resource saving. Sewage sludge. Requirements when used for reclamation of disturbed lands” [8-10]. Table 3 shows the structure of colloidal sediments of sludge-lignin, as well as the soil moisture obtained from them with the addition of sediments from the sewage treatment of Baikalsk city.

Table 3. The content of metals and the agrochemical composition of the obtained soil and frozen sludge-lignin in 2020 and 2021.

| Indicators                        | Produced soil moisture | Frozensludge-lignin | Standards according to GOST R 54534-2011 for biological restoration |
|-----------------------------------|------------------------|---------------------|---------------------------------------------------------------------|
|                                   | 2020 r. | 2021 r. | 2020 r. | 2021 r. |                                                    |
| Al, mg/kg                         | 21800   | 35190   | 54900   | 65400   | not standardized                                   |
| As, mg/kg                         | 1.2     | 2.0     | 1.6     | 2.1     | no more than 20                                    |
| Cd, mg/kg                         | 0.3     | 0.3     | 0.1     | 0.1     | no more than 30                                    |
| Co, mg/kg                         | 3.3     | 4.5     | 3.9     | 5.1     | not standardized                                   |
| Cr, mg/kg                         | 25.4    | 11.6    | 24.4    | 19.8    | no more than 1000                                  |
| Cu, mg/kg                         | 74.3    | 62.7    | 54.1    | 37      | no more than 750                                  |
| Fe, mg/kg                         | 8530    | 6660    | 3830    | 2250    | not standardized                                   |
| Mn, mg/kg                         | 235     | 308     | 232     | 323     | not standardized                                   |
| Ni, mg/kg                         | 15.4    | 11.7    | 15.2    | 19.3    | no more than 400                                  |
| Pb, mg/kg                         | 9.8     | 8.9     | 5.2     | 7.1     | no more than 500                                  |
| Zn, mg/kg                         | 191     | 112     | 69.0    | 70.0    | no more than 3500                                 |
| Total phosphorus, in terms of P2O5, % | 2.8    | 1.6     | 0.8     | 0.6     | no more than 1.5                                  |
| Total potassium, in terms of K2O, %| 0.2     | 0.1     | 0.07    | 0.05    | not standardized                                   |
| Mobile potassium, mg/kg           | 363     | 123     | 187     | 115     | not standardized                                   |
According to the information from the table, the chemical and agrochemical structure of sediments, with appropriate control, can be used for restoration of disturbed lands, while sewage sediments can be used both for the technical stage of reclamation and for the biological one.

The efficiency of the use of soil moisture from frozen colloidal sediments of sludge-lignin of JSC "Baikalsky PPM" for the intensification of reclamation succession of disturbed lands was studied. The toxicological properties of dumps of the Verninsky GOK were examined with the introduction of the obtained soil in the amount of 10%, by determining the effect on higher plants in accordance with GOST R ISO 22030-2009 Soil quality. Biological methods. The experiment took into account such parameters as the number of germinated seeds, the number of living plants, the length of the shoot, dry and wet weight of plants on the 14th day and at the end of the tests, the number of flowers. They were planted in vessels with 10 seeds of each plant species in four replicates, then, on the 14th day, 4 plants were left in each vessel. The final harvest of the remaining plants was seven, eight weeks for oats, and five to six weeks for oil radish. Soil moistures from uncontaminated areas near the territory of the Verninsky GOK were chosen as a background control. The average results of the experiment are presented in table 4.

**Table 4. Chronic phytotoxicity against higher plants.**

| Indicators                                      | Control | Dumps of the Verninsky GOK | Dumps of the "Verninsky" GOK + soil based on sludge-lignin sediments of JSC "BCBK" (10: 1) |
|------------------------------------------------|---------|----------------------------|---------------------------------------------------------------------------------|
|                                                | Oats    | Chineseradish              | Oats                             | Chineseradish                           | Oats      | Chineseradish |
| Number of germinated seeds (out of 10), pcs   | 10      | 9                          | 6                                | 5                                  | 9         | 8             |
| Number of living plants on the 14th day (out of 10), pcs | 10      | 9                          | 6                                | 5                                  | 8         | 8             |
| Average run length 14day (per plant), cm      | 17.1    | 13.6                       | 11.4                             | 6.6                                | 16.1      | 11.3          |
| Average raw mass of plants on the 14th day (per plant), g           | 0.23    | 0.21                       | 0.14                             | 0.11                               | 0.19      | 0.20          |
| Average dry weight of plants at the end of the test (per plant), g | 0.044   | 0.069                      | 0.028                            | 0.043                              | 0.041     | 0.065         |
| Average number of flowers at the end of the test (per plant), pcs  | 38      | 18                         | 26                               | 9                                 | 36        | 15            |
Table 4 proves that the dumps of the Verninsky GOK reduce seed germination by 40-50%. In comparison to the control, there is an inhibition of shoot growth by 1.5-2 times and a decrease in the dry weight of plants by 1.5 times, while the ability of plants to reproduce is reduced; the number of flowers decreases by 1.5-2 times. The obtained results can be substantiated by the fact that the high content of arsenic, the salinity of the dumps and the low content of nutrients have a detrimental effect on the growth and development of higher plants. After the introduction of soil from colloidal sediments of sludge-lignin of OJSC "Baikalsk PPM", an increase in seed germination is observed up to 80-90%, while there is an increase in the average length of shoots by 30-40%, dry weight of plants by 30-35% and the average number of flowers per one plant by 30-40%. The obtained information may be related to the fact that the introduction of soil moisture from colloidal sediments of sludge-lignin allows arsenic to be bound into water-insoluble forms, and also saturates the dumps with nutrients for plants.

3. Conclusion
The conducted studies have shown that the dumps of the mining and processing industry on the example of the Verninsky GOK negatively affect the environmental objects and require work on their restoration. It is possible to use soil moistures obtained from frozen colloidal sediments of sludge-lignin of the pulp and paper industry that reduce the toxic effect of dumps on higher plants and introduce the necessary nutrients to intensify the processes of reclamation succession. In this case, the vegetation layer is created for the subsequent planting of green spaces and turfing of the reclaimed area. After distribution of sediments in the recultivated area, they must be embedded in the soil.

Thus, the use of the obtained soil moistures from the frozen sediments of sludge-lignin of JSC "Baikalsk PPM" will help not only to restore the lands disturbed by the mining and processing industry, but also to utilize the accumulated waste of previous years at JSC "BPPM" (more than 8 million cubic meters), as they have a huge socio-ecological threat to Lake Baikal and the entire Southern Baikal region.

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