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Evaluation of Soil Toxicity of an Oil and Gas Condensate Field after Reclamation of Disturbed Lands on the Example of the Field of the Yamal-Nenets Autonomous District

Valentina M. Okmyanskaya[1*], Olga V. Bogdanova[1]

[1] Federal State Budget Educational Institution of Higher Education, Industrial University of Tyumen, Volodarskogo 38, 652000 Tyumen, Russia

* Corresponding author's e-mail: okmjanskajavm@tyuiu.ru

ABSTRACT

Oil pollution is a hazard both in terms of scale and toxicity. Oil and oil products cause poisoning, death of organisms and soil degradation. The natural self-purification of natural objects from pollution depends on the natural conditions of the region, the presence of moisture, heat and the activity of the vital activity of the soil biocenosis. Under the conditions of Siberia, where a low temperature regime is maintained for a long time, self-purification is a long process. As a result of the long industrial use of the Medvezhye oil and gas condensate field, the soils of this area have accumulated pollutants. Thus, it is required to assess the toxicity of the soil, as well as to provide the ways and methods to prevent its environmental pollution. One of the ways to restore disturbed landscapes is technical and biological reclamation, the features and results of which are considered in this study using the Medvezhye deposit sand pit as an example.

Keywords: environmental pollution, environmental monitoring, land reclamation, soil, heavy metals, oil and gas field.

INTRODUCTION

Intensive processes of oil and gas production lead to an increase in the scale of land pollution. Environmental problems begin already at the stage of extraction of raw materials and their delivery to enterprises. Equally acute problems arise during the transportation of natural resources to oil refineries (Ivanova 2015).

The main factors of the impact of oil and gas production complexes on the environment:

- emissions of pollutants into the atmosphere;
- noise pollution;
- change in the number of organisms, their resettlement, change in the habitat of the animal world;
- change in the geodynamic situation in the layers;
- change in the hydrological and hydrogeological regimes of the territory;
- violation of the conditions of heat and moisture exchange on the surface;
- thermal pollution of permafrost;
- mechanical disturbances of soils and ground covers of permafrost;
- chemical contamination of soils;
- wastewater discharges.

Depending on the source of pollution, there are three degrees of risk for each area of the environment (Table 1).

On the basis of the data presented in the table, it can be concluded that the most dangerous source of environmental pollution in the oil and gas fields are oil storage facilities and collection pipelines. They account for the largest amount of all emissions into the environment (Podvalov 2010).

In addition, if the degree of risk of pollution for various areas of the environment is analyzed, it can be said that the soil is exposed to various types of pollutants and their negative effect on the soil is high. After analyzing the main types of soil pollution at the fields, two main groups of anthropogenic impact can be distinguished: chemical

Table 1. Levels of risk of environmental pollution during oil and gas production

Type of pollution source	Risk of contamination		
	Earth	Water	Atmosphere
Wells and wellhead equipment	Low	Low	Low
Prefabricated pipelines	High	High	Low
Field oil processing units	Medium	Medium	High
Oil storage	High	High	High
Compressor equipment	Medium	Low	Medium

(soil pollution with chemical and toxic organic pollutants, oil sludge, radioactive contamination); and physical (complete or partial mechanical destruction of soils, changes in the hydrological and hydrogeological regime, the formation of new man-made landforms). The soil accumulates harmful production emissions, which subsequently also infiltrate other components of the environment (Ivasenko et al. 2010).

Currently, from 700 to 840 thousand hectares of land in Western Siberia are polluted. The oil and gas industry has 2064 sources of pollution, including 834 organized ones. Therefore, every year the indicator of degraded lands is growing.

Hence, the problem of cleaning the soil cover from pollution with toxic substances through reclamation work, as well as the issue of developing new and improving existing technologies for the restoration of oil-contaminated lands, is becoming extremely relevant.

The purpose of the study was to study the features of reclamation work on the example of the territory of the Medvezhye oil and gas condensate field located in the Yamalo-Nenets Autonomous Okrug, as well as to assess the toxicity of soils before and after the restoration of disturbed lands.

MATERIAL AND METHODS

The main criterion for determining the category of soil pollution by chemicals is the maximum allowable concentration (MPC) or approximate allowable concentration (APC) of chemicals in the soil.

The assessment of the degree of danger of soil contamination with chemicals was carried out in accordance with the Guidelines 2.1.7.730 – 99 of 02/07/1999 "Hygienic assessment of soil quality in populated areas" (Table 2).

The total pollution index (Zc) was calculated using the following formula:

$$Zc = \Sigma\ (Кc i + ... + Кc n) - (n\text{-}1) \quad (1)$$

where: n – number of determined chemical elements; $Кc i$ – concentration coefficient of the i-th pollution component.

The concentration factor for a given heavy metal in soil was calculated as follows:

$$Кc = Ci\ /\ Cfi \quad (2)$$

where: Ci – actual content of analyte in soil, mg/kg; Cfi – regional background content of a given substance.

Recommendations on the use of contaminated soils are contained in the Sanitary and Epidemiological Requirements for the Quality of Soil and Soils 2.1.7.1287 - 03 dated 16.04.2003 "Soil, cleaning of populated areas, domestic and industrial waste, sanitary protection of soil".

In 2018, soil samples were taken from the territory of the developed quarry No. 57, located within the boundaries of the Medvezhye oil and gas condensate field, prior to reclamation work for quality assessment. Soil sampling was carried out in accordance with GOST 28168-89 dated April 1, 1990 "Soils. Sampling", GOST 17.4.3.01

Table 2. Criteria for assessing the degree of soil contamination with inorganic substances

Content in soil mg/kg	Soil pollution category		
Substance hazard classes	1 class	2 class	3 class
$>K_{max}$	Very strong	Very strong	Strong
From MPC to K_{max}	Very strong	Strong	Medium
From 2 background values to MPC	Low	Low	Low

– 83 dated 01.07.1984 "Nature Protection. Soils. General requirements for sampling".

In accordance with these regulatory documents, the size of the trial plot should be from 1 to 5 ha, if the soil cover is homogeneous; otherwise, 0.5 to 1 ha. One combined sample should be taken from each site, the mass of which should not be less than 1 kg (GOST 28168-89, GOST 17.4.3.01 – 83). The quarry was divided into 13 sites, of which 12 were 4 ha and 1 was 3.7 ha.

The samples taken were numbered and registered in a journal, indicating the following data:

- serial number and place of sampling;
- terrain;
- soil type;
- purpose of the territory;
- type of pollution;
- date of selection.

Each sample had its own label indicating the place and date of sampling, the number of the soil section, soil difference, the horizon and depth of sampling, and the name of the researcher.

Further, the selected samples were sent for chemical analysis to the Center for Environmental Expertise in Novy Urengoy.

In 2020, after carrying out a set of works on the reclamation of disturbed lands of sand pit № 57, the soil samples were taken from the same sites as in 2018. The chemical analysis of these samples was carried out at the laboratory of the Tyumen Industrial University.

RESULTS

From 2007 to the present, the Medvezhye oil and gas condensate field has been under reconstruction, which is planned until 2030. This is due to the fact that its active development began in 1972, and only in the period from 1972 to 1990. The volume of accumulated gas production at the Medvezhye field exceeded 1 trillion m^3, which is 40% of its explored reserves (Big encyclopedia of oil and gas). The location of the deposit is shown in Figure 1.

As a result of the active development of natural resources, large-scale anthropogenic activities on the territory of the deposit, there have been significant changes in the landscape, the composition of the soil and vegetation cover.

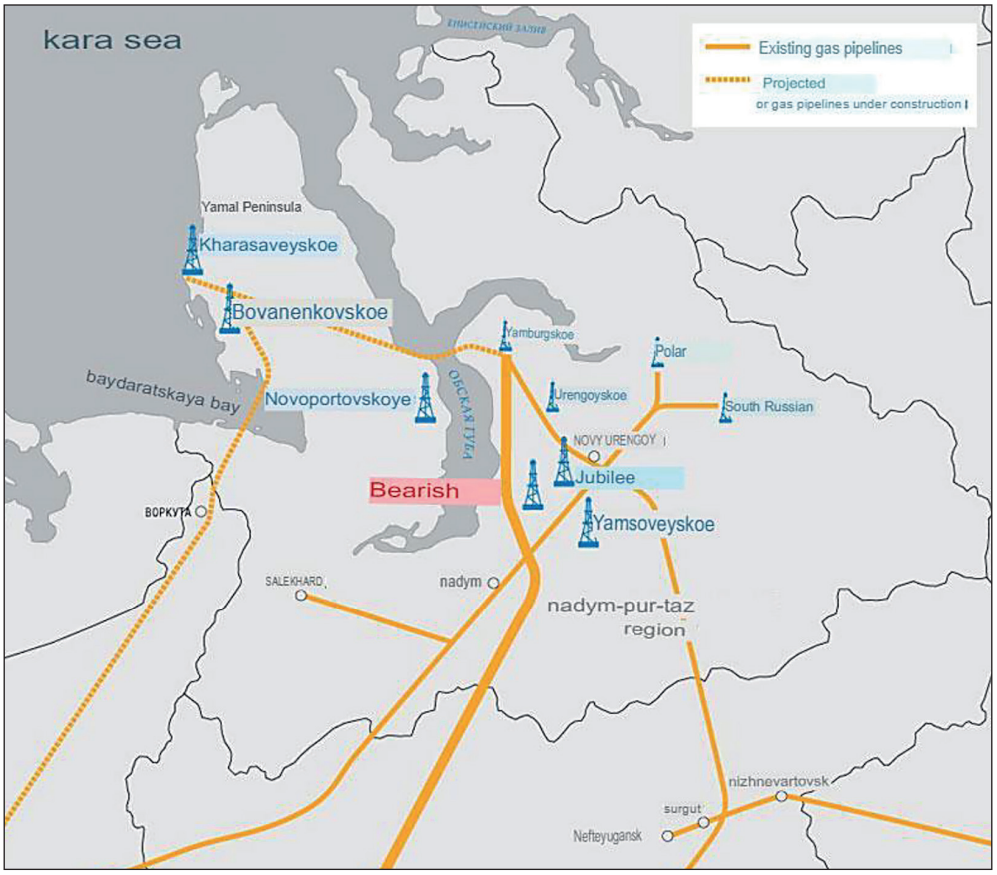

Figure 1. Location of the Medvezhye field

The most significant type of disturbance identified within the territory of the Medvezhye field is the disturbance of the soil and vegetation cover associated with the passage of heavy equipment. Moreover, at the field under consideration in the area of land allotment for gas pipelines, serious negative consequences of anthropogenic activity were revealed. These land plots are characterized by an increased content of heavy metals, as well as the presence of oily wastes resulting from accidental oil and gas spills. Moreover, in addition to contamination with hazardous toxic substances, the soil was subject to mechanical disturbances, resulting in the formation of quarries and dumps, many of which have not yet been subject to reclamation. Subsequently, the formation of quarries, the original natural complexes are often replaced by the same degraded lands with a low degree of restoration of the natural vegetation cover, as well as an increased erosion hazard, which determines the need for reclamation of such lands. In addition, the formation of man-made lakes is observed on the territory of the Medvezhye oil and gas condensate field. These are the consequences of peat extraction, in which technogenic excavations are formed within the landscapes of swamps and peat bogs.

According to the results of the study, the main soil pollutants on the territory of the Medvezhye field were identified:

- generated solid waste of construction industry;
- household waste;
- domestic effluents, which include the remains of oil products at the sites of fuel and lubricants;
- oily waste, oil sludge;
- heavy metals.

An assessment of the consequences of anthropogenic interference within the territory of the Medvezhye field allows drawing the following conclusions:

a) Of all types of mechanical disturbances, the maximum areas are occupied by lands with degraded soil and vegetation cover, which is due to the passage of heavy equipment and the construction of quarries for the extraction of building material.
b) The development of secondary technogenically provoked processes generally coincides with the regional trends of the territory towards progressive waterlogging, water and wind erosion, which must be taken into account when reconstructing and building new technical structures.
c) Untimely implementation of the reclamation of disturbed lands (the rate of reclamation does not correspond to the rate of formation of degraded lands).

Within the framework of this article, the authors thoroughly examined the reclamation work at open pit No. 57 of the Medvezhye field, which is used for the development of sand for backfilling well pads related to the complex gas treatment unit at the Nydinskaya area of the Medvezhye field (UKPG-N). The worked-out quarry at the Medvezhye deposit is a hollow with a maximum depth of 15 meters with stable sides. The maximum development width is up to 500 meters, the minimum is 150.

The area of the considered sand pit subject to reclamation is 51.7 ha. Figure 2 shows a diagram of the quarry boundaries. The device of this quarry led to negative consequences:

- change in geomorphological and geological conditions of the allotted territory;

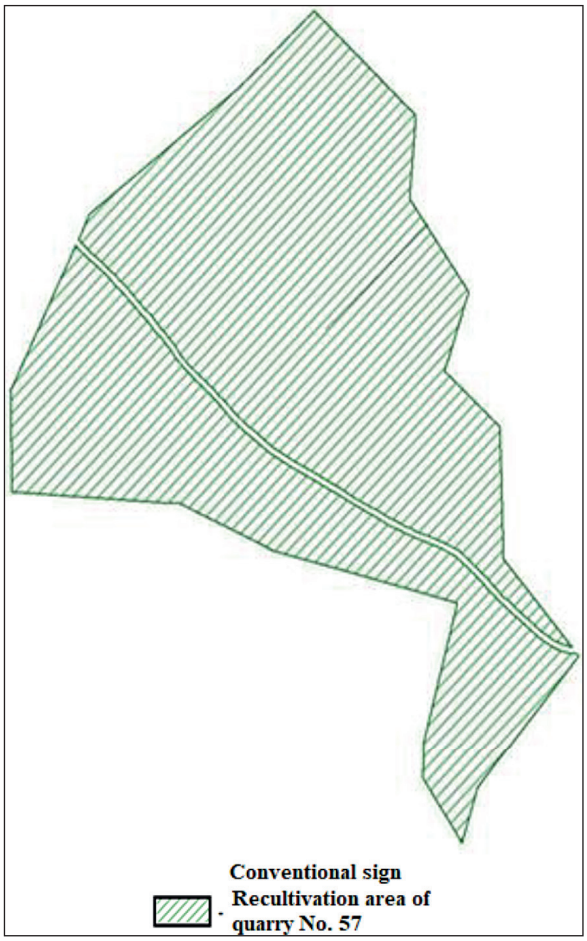

Figure 2. Scheme of the boundaries of quarry No. 57

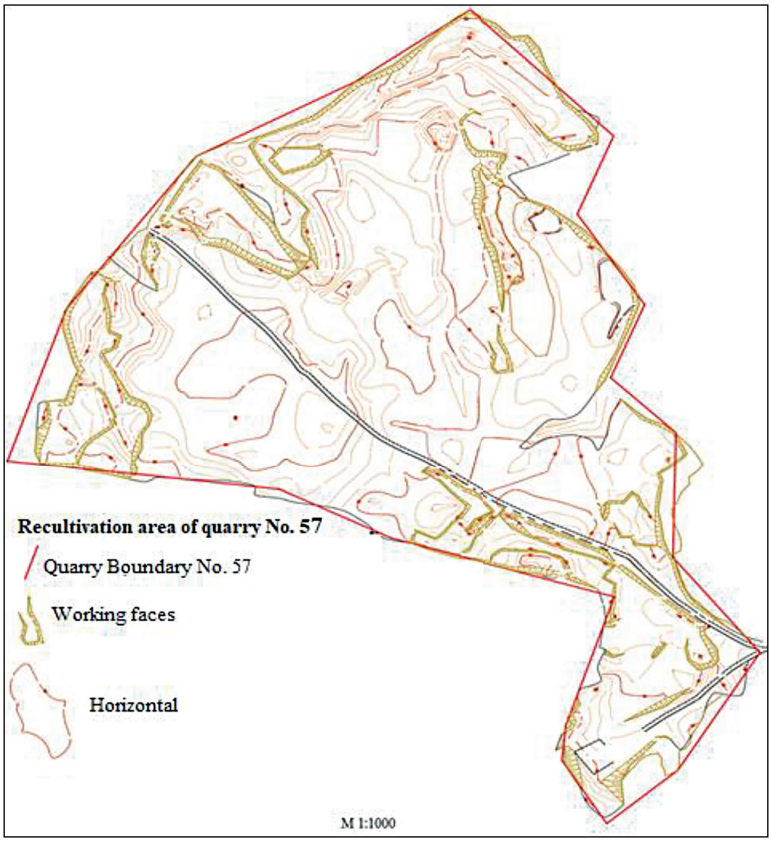

Figure 3. Topographic plan of the sand pit at the end of development

Figure 4. Developed sand pit № 57 as of 2018

Table 3. Types and volume of waste at sand pit No. 57

Waste types	Unit of measurement	Waste volume
Household waste	tons	9,996
Domestic drains	m³	5,000
Industrial waste	tons	14,144

- contamination of the territory of the quarry under consideration with industrial and household waste;
- complete destruction of the soil and vegetation cover;
- the emergence of a new technogenic relief form – a quarry excavation [Moskovchenko et al. 2014].

The topographic plan at the end of the development of quarry No. 57 is shown in Figure 3. Figure 4 shows a photo of the worked out quarry No. 57.

The primary task in the implementation of technical reclamation is the removal of all types of waste from the site. At quarry No. 57, as a result of sand extraction for the construction and reconstruction of Medvezhye oil and gas facilities, the following types of waste were generated, presented in Table 3.

Production waste was removed to scrap metal collection points for disposal in Novy Urengoy.

After clearing the reclaimed area from various wastes, it is necessary to lay rocks along the slopes of the dumps to a normal angle according to the requirements of landscape reclamation. The flattening of the slopes of the sides of quarry No. 57 was carried out by a B-10MB bulldozer. It should be noted that on the restored lands, it is necessary to provide for a slope angle not steeper than 18°, which corresponds to 1:3.

After the final planning work, before carrying out biological reclamation on disturbed lands, a fertile soil layer (peat-sand mixture) is created.

To prepare a peat-sand mixture and apply it with a layer of 10 cm, peat and sand were brought to the surface of the quarry in a ratio of 75% peat, 25% sand. It should be noted that sand and peat were used from local sources – peat quarries T1 and sand No. 3, located on the territory of the Medvezhye deposit. The brought peat and sand were leveled and mixed with a bulldozer (Fig. 5).

Since peat has an acidic pH of 4.5–5.5, it is necessary to provide for the liming of the peat-sand mixture by adding dolomite (lime) flour at a rate of 4 t/ha.

Application of peat-sand mixture is the final stage of technical reclamation. The soil prepared in this way will be the basis for sowing perennial grasses on disturbed land plots.

Planning work and the creation of a fertile layer are carried out in a warm, frost-free season – June – July. Under the conditions of the North, the gap between the technical and biological stages of reclamation should not exceed more than 2 years.

Biological reclamation is the final stage and is carried out to reduce and prevent the consequences of man-made disturbances. The main task of biological reclamation is the creation of an artificial vegetation cover, since the vegetation layer is practically absent in sand quarry No. 57. The creation of a grass cover consists in preparing the soil, applying fertilizers, selecting grass mixtures, sowing and caring for crops.

The criterion for choosing the period for the biological stage of reclamation work is the temperature of the soil and air, which ensures the normal growth and development of perennial plants.

The favorable period for biological reclamation is from mid-June to the third decade of

Figure 5. Applying a peat-sand mixture with a bulldozer

Table 4. Plants used for biological reclamation

Name of herbs	Plant photo
Meadow bluegrass	
Red fescue	
Meadow fescue	
Meadow foxtail	
Couch grass	
Filmy oats	

August. At the sand pit No. 57, from the beginning of July 2020, work was started to restore the soil and vegetation cover.

Taking into account previous studies, the following herbs were selected as reclamation plants, presented in Table 4.

Before sowing the grass mixture, the soil was harrowed in two tracks with special tooth harrows of the ZBZTS-1 brand, providing loosening with a depth of 4–5 cm with a working width of 25–30 cm.

In the upper layer, the soil should be crushed, which is achieved by cross-cultivation with light harrows ZBP-0.6 "A" to a depth of 2–3 cm.

The introduction of seeds of perennial grasses on the prepared soil was carried out with a seeding rate of 110 kg/ha.

Increasing the seeding rate by 10% will have a significant impact on the mass of roots in the first year of grass life, providing a short time for the onset of the tillering phase and the growth of the root mass. At a low seeding rate, the formation of the mass of roots takes longer, reaching its maximum by the end of the third year of life.

Seeding rates are shown in Table 5. The seeds were sown with a SZT-6 seeder, which made it possible to simultaneously sow the seeds and apply nitroammophoska.

Sowing grasses pursues the following goals: soil protection from water and wind erosion; restoration of fertility; increase in biodiversity.

To ensure closer contact of seeds with the soil, their rapid swelling and germination, post-sowing rolling was carried out with spur or ringed rollers of the KKSH-9.2G brand, weighing 75–100 kg.

The use of smooth water-filled rollers KVG-1.4 creates the conditions for better contact of seeds, which is the reason for the appearance of friendly seedlings on reclaimed lands.

The main purpose of rolling is:

- improving the contact of seeds with soil;
- pulling capillary moisture from the underlying soil layer to the seeds;
- partial incorporation of seeds that are on the surface of the site into the soil.

The depth of the seeds after rolling should be no more than 2–3 cm. When manually sowing, the seeds are planted with a rake, which is a long and labor-intensive approach.

As the sown soil dries out, it is necessary to irrigate with soil moisture to a depth of 20 cm. On average, water consumption is 20–30 m^3 per 1 ha.

Table 5. Grass seeding rate during reclamation

Name of herbs		Seeding rate (according to the project), kg/ha	Seeding rate (suggested), kg/ha
Perennial herbs	Meadow bluegrass	15	20
	Red fescue	40	40
	Meadow fescue	5	6
	Meadow foxtail	15	20
	Couch grass	5	5
Annual herbs	Filmy oats	30	30
Total seeding rate		110	121

As a result of sowing the grass mixture in June 2020, a continuous grass cover appeared on the territory of sand pit No. 57 by the end of summer of the same year, which indicates the use of effective methods of technical and biological reclamation. Figure 6 shows a photo of a reclaimed quarry.

When sowing grass seeds on sandy sloping soils, it is recommended to first feed them with nitrogen fertilizers in the amount of 50–100 kg/ha. According to the chemical analysis of slope soils, the application of nitrogen fertilizers is a mandatory measure.

Ammonium nitrate is used as a nitrogen fertilizer on the disturbed lands of the Medvezhye oil and gas field, in respect of which biological reclamation is being carried out. The dose of saltpeter, as well as complex fertilizers, for example, azofoska, is given in Table 6.

Biostimulants are used to grow plants on disturbed land plots. These are humic preparations obtained from peat and coal. The addition of humic preparations to the formulations, at least in the form of dusting grass seeds, gives a significant effect on their germination.

Dusting seeds with potassium or sodium humate is a very important procedure, since there is practically no humus in the soils of the quarries of the humus deposit. The seed treatment rate is 50 kg/ha. Before sowing the grass mixture, as well as planting trees, it is necessary to determine the acidity of the soil, as well as the values of the content of heavy metals.

On the territory of the Medvezhye field in 2017, comprehensive soil studies were carried out and soil acidity indicators were determined in various areas.

Figure 6. Creation of grass cover on reclaimed lands

Table 6. The dose of ammonium nitrate and complex fertilizers, depending on the type of soil

Soil type	Dose of ammonium nitrate, kg/ha	Application dose of azophoska, kg/ha
Loam	50	90–100
Technogenic sandy substrates	100	150

The acidity of local soils varies from 3.9 to 5.6 pH. This indicates the acidic nature of the soil. The soil acidity scale is shown in Figure 7.

Since the soil at the field is predominantly acidic, before sowing the grass mixture, it is necessary to produce liming, which will increase the fertility and efficiency of the use of mineral fertilizers.

Thus, reclamation was carried out on disturbed lands with an area of 51.7 hectares. Moreover, this set of measures made it possible to reduce the content of heavy metals and oil products in the soils of a separate reclaimed area of the Medvezhye field. This fact is confirmed by the results of laboratory studies conducted in 2018 before the start of reclamation and at the end of summer 2020 after the completion of the biological stage.

Table 7 shows the results of the chemical analysis of the soil from the sand pit No. 57, obtained during the research in 2018 and 2020.

The background content of pollutants is shown in Table 7 in accordance with the order of the Department of Natural Resource Regulation, Forest Relations and Development of the Oil and Gas Complex of the YaNAO dated 27.0.2017 No. 348 "On the establishment of environmental quality standards "The background content of pollutants in the snow cover, in the bottom sediments of the surface water bodies, in vegetation on the territory of the Yamalo-Nenets Autonomous Okrug". MPC of pollutants according to GN 2.1.7.2041-06 of 04/01/2006 "Maximum Permissible Concentrations (MPC) of chemicals in soil".

On the basis of the results of the analysis, it is necessary to determine the degree of contamination of the soils of the sand pit with heavy metals. The total pollution index (*Zc*) was calculated using the following formula:

Figure 7. Scale for assessing soil acidity

$$Z_c = \Sigma\,(K_{ci} + \ldots + K_{cn}) - (n - 1)$$

$$Zc\ (2018) = \Sigma\left(\frac{6,59}{7,62} + \frac{12,1}{10,33} + \frac{19,1}{18} + \frac{210,9}{211,38} + \frac{3,1}{2,76} + \frac{1,1}{0,76}\right) - (6-1) = 1,66$$

$$Zc\ (2020) = \Sigma\left(\frac{6,05}{7,62} + \frac{11,9}{10,33} + \frac{17,9}{18} + \frac{210,1}{211,38} + \frac{2,8}{2,76} + \frac{0,09}{0,76}\right) - (6-1) = 0,052 \quad (3)$$

Table 7. Results of chemical analysis of soil from sand pit No. 57 before and after reclamation

Name of pollutant	The content of pollutants in the soil in 2018, mg/kg	The content of pollutants in the soil in 2020 after reclamation, mg/kg	Background content of pollutants	MPC of pollutants
Heavy metals				
Copper	6.59	6.05	7.62	3
Nickel	12.1	11.9	10.33	4
Zinc	19.1	17.9	18	23
Manganese	210.9	210.1	211.38	400
Lead	3.1	2.8	2.76	32
Mercury	1.1	0.09	0.076	2.1
Oily waste				
Oil products	56	24	7.77	Not installed

In accordance with the Guidelines MU 2.1.7.730 - 99 of 02/07/1999, with the resulting value of total pollution up to 16, the category of soil pollution is permissible. That is, the content of chemical elements in the soil exceeds the background, but not higher than the MPC.

Figure 8 shows the graphs that clearly indicate the change in the concentration of toxic pollutants in the soil of the area under consideration.

Thus, after the reclamation, the total pollution of the soil of the sand pit No. 57 significantly decreased, which indicates the effectiveness of the work on the restoration of disturbed landscapes. Figure 9 shows a graph of changes in the total pollution index.

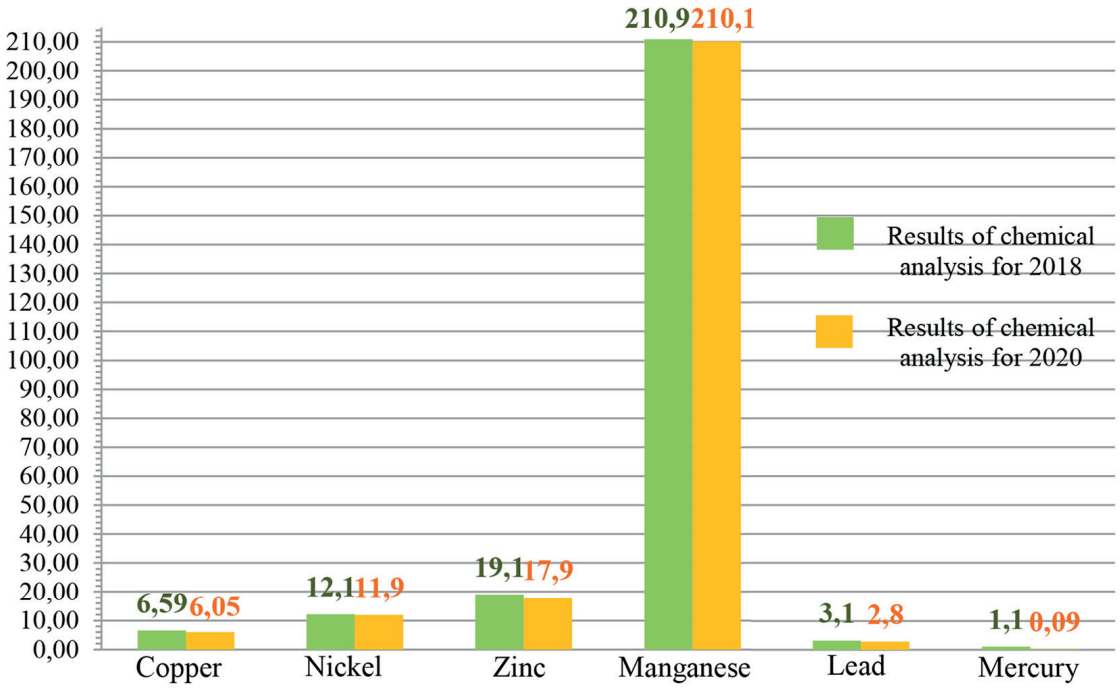

Figure 8. Change in the concentration of toxic pollutants in the soil after reclamation

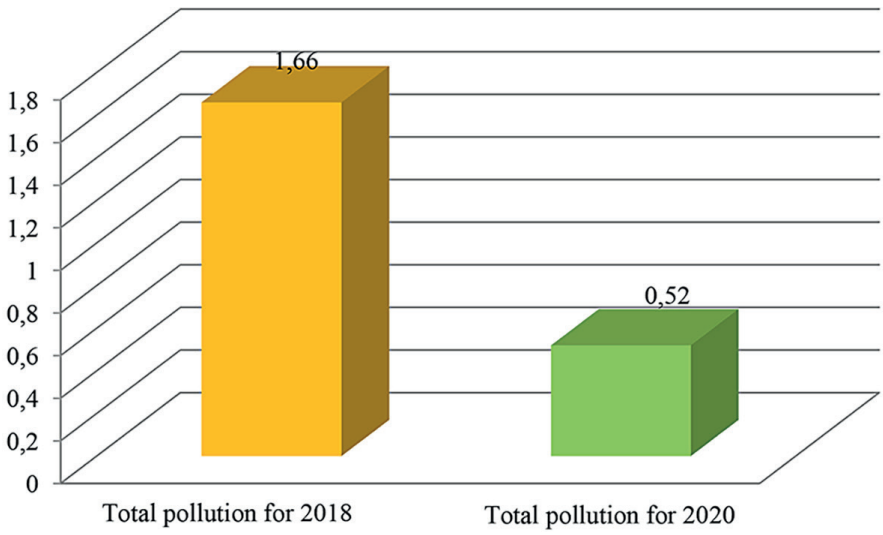

Figure 9. Change in the total indicator of soil pollution

CONCLUSIONS

The problem of reclamation of technogenic territories in the Far North is the relationship between the technical and biological stages. According to the study, carrying out a technical stage alone is not enough for a quick and sustainable restoration of a disturbed natural ecosystem.

The reclamation of disturbed lands of the Medvezhye oil and gas condensate field has its own characteristic features. Thus, in order to provide effective measures to restore disturbed landscapes, it is necessary to study the territory comprehensively, as well as to determine the degree of pollution.

Each of the stages of reclamation is important and significant in its own way; however, they must be interconnected and complement each other, because the ecological situation in the given territory depends on their efficiency and sophistication.

The Medvezhye deposit occupies a vast territory, so the objects of reclamation are individual well clusters, quarries, trenches, individual land plots and their parts.

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