Assessment of environmental damage from oil sludge to land resources in the Irkutsk Region

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Abstract. In Russia, the problem of sustainable development is most acute and representative. For the vast territories and rich natural subsoil resources, the environmental issue becomes the most acute. In Russia, from an environmental point of view, there are many territories of concern which make it clear that theoretical issues gain practical importance. The Central Siberian Plateau with its large reserves of raw hydrocarbons - the Lena-Tunguska oil and gas province with a total area of about 2.8 million km² - is a region of intensive oil and gas production. The amount of ecosystem transformations has no analogues in Russia; all transformations were formed in a short period of time (30-50 years). To maintain this industry, linear and non-linear structures were built, which transformed the landscape and territories not only superficially: the exploration and well construction transformed the geology of the region. This article addressed the damage caused to the soils of the Irkutsk Region in oil and gas production by the three most promising fields: the Yarakta, Markovo and Dulisma fields. The calculation was made in accordance with the methodology for calculating the amount of damage caused to the soil as an object of environmental protection. The calculated damage without taking into account possible emergencies at oil and gas production facilities amounted to almost 100 million rubles.

1. Introduction
Industrial production of hydrocarbons in the Irkutsk Region is becoming one of the basic industries in the mining sector of Eastern Siberia. This is primarily due to the discovery and successful development of the Lena-Tunguska oil and gas province located in the western part of Yakutia, in the northern and central areas of the Krasnoyarsk Territory, and in the western and northern areas of the Irkutsk Region. More than 40 fields were discovered in the territory of the province; industrial oil and gas inflows were obtained in more than 30 separate wells, mainly from subsalt terrigenous and carbonate sediments. The most significant identified fields are: the Dulisma, Danilovskoye, Verkhnechonsk, Markovo, and Yarakta fields. The Eastern Siberia-Pacific Ocean oil pipeline was built and is successfully operated; the Power of Siberia gas pipeline is being built [1].

But along with the growth of oil production and an increase in the volume of its processing and transportation, environmental problems are aggravating, among which one of the most significant, apart from the impact on the atmosphere and water resources, is the problem of soil pollution by oil waste. Among all oil wastes that have a detrimental effect on the components of the environment, so-called oil sludge (drilling sludge) is of particular danger. Drilling sludge is a water suspension, the solid part of which consists of the spalls formed in the destruction of rock of the bottom and walls of
the well, products of abrasion of the drilling string and casing, and clay minerals (when flushed with clay mud) [2].

The rocks contained in drilling sludge, depending on the geological conditions, can be represented by sandstones, clays, limestones and others, i.e. poorly soluble chemical compounds that do not have any pronounced toxicity [5] and therefore do not represent a hazard to ecological systems. However, when drilling oil and gas wells, flushing fluids (drilling fluids) are used, which perform a number of functions during the drilling process [6], including transfer of energy to the drilling tool, compensation of reservoir pressure, formation of a waterproof crust on the surface of the well, removal of the crushed rock formed in the drilling process up to the surface [7], etc.

Suspensions of clays with a number of components, that provide the necessary complex of physicomechanical characteristics of the drilling mud, are predominantly used flushing liquids [8]. The driller’s guide lists almost 50 reagents that can be conveniently classified into soluble inorganic compounds (sodium and potassium hydroxides and carbonates, alkali and alkali-earth chlorides), which are used primarily to ensure the stability of the dispersion phase, and organic substances [9] (oil, flotation reagents, polymer dispersions, etc.) [10]. The purpose of these reagents is to regulate such characteristics as water loss, reduction of friction coefficient, defoaming, etc. The use of these reagents, which are part of drilling fluids, leads to contamination of the rock cut during drilling [11], with the result that the contaminated rock on the surface becomes drilling sludge of hazard class IV [12]. 1 m³ of drilling sludge contains up to 68 kg of polluting organic substances, not including oil (petroleum products) and mineral pollutants [13]. When drilling a well with a depth of 2,600 m, the pit contains on average about 65% of water, 30% of sludge (cuttings), 5.5% of oil, 0.5% of bentonite and 0.5% of various additives that ensure optimal operation of the drilling rig [14].

Sludge pits occupy significant areas. Their overflow, especially during the rainy season, contaminates soils, which is accompanied by changes in their physicochemical composition, bituminization, tarification, soil cementation, loss of the ability to absorb moisture and other undesirable consequences, i.e. environmental risks [15]. Environmental risks can be assessed through environmental and economic damage, which is a monetary estimate of negative changes in the environment as a result of its pollution, reduction of the quality and quantity of natural resources, as well as the likely consequences of such changes [16].

The aim of this paper is a comparative assessment of the environmental risk (environmental and economic damage to the soil) in the extraction and development of oil fields operated by Irkutsk Oil Company.

2. Materials and methods

As the objects of research, we chose the Yarakta, Dulisma and Markovo fields.

The Dulisma oil and gas condensate field is located in the Katangsky Municipality, 90 km northwest of the city of Kirensk. The design capacity of the Dulisma field amounts to 400-450 thousand tons of oil per year. The license for the development of the field belongs to NK Dulisma CJSC.

The Yarakta oil and gas condensate field is geographically located 140 km north-east of the city of Ust-Kut, closer to the northern part of the Ust-Kut Municipality and the southern part of the Katangsky Municipality of the Irkutsk Region. The oil and gas potential of the field is associated with sediments of the Vendian and Cambrian ages, namely, sandstones of the Yarakta horizon with a total thickness of up to 40 m. The resource oil reserve is estimated at 102.5 million tons, and its density is 0.830 g/cm³ or 34° API. The density of the condensate corresponds to a value of 0.67-0.71 g/cm³. The license holder for the development of the Yarakta field is a subsidiary of INK LLC – Ust-Kutneftegaz OJSC [17].

The Markovo oil and gas condensate field is located 160 km south-west of the city of Kirensk, near the village of Verkhemarkovo in the Irkutsk Region. The oil and gas potential is associated with sediments of the Vendian and Cambrian ages. The first gas-oil (emergency) release with an open flowing with flow rate of about a thousand tons per day was obtained in evaluation well No.1 laid down in the crest position of the Markovo anticline, from a depth of 2162-2164 m (lime-sand-clay
porous fractured reservoir rock of the Osinsky reservoir). The initial reservoir pressure is not less than 216 atm. Oil reserves amount to 20 million tons. The density of oil is 0.850 g/cm$^3$ or 34° API. The operator of the field is Irkutsk Oil Company.

Environmental risk assessment is carried out according to the Methodology for Calculating the Amount of Damage Caused to the Soil as an Object of Environmental Protection. This methodology was approved by Order No. 238 of the Ministry of Natural Resources and Environment of the Russian Federation dated July 8, 2010 (as amended on July 11, 2018) [3].

The damage to the soil as a protected element of the environment, expressed in monetary form, is calculated according to the following formula:

$$DA = DA_{cont} + DA_{was} + DA_{cov} + DA_{rem} + DA_{dest},$$  \hspace{1cm} (1)

where $DA$ is the total amount of damage caused to land resources (in rubles);
$DA_{cont}$ is the amount of damage as a result of soil contamination, the impact of which occurred when contaminants entered the soil, leading to non-compliance with environmental quality standards for the soil, including standards for the maximum (approximately) allowable concentrations of contaminants in the soil (in rubles);
$DA_{was}$ is the amount of damage as a result of soil deterioration when used to place household and industrial waste on its surface (in rubles);
$DA_{cov}$ is the amount of damage as a result of land divestment for construction objects in the form of buildings and structures for various purposes (in rubles);
$DA_{rem}$ is the amount of damage as a result of soil deterioration during the removal of the fertile surface layer (in rubles);
$DA_{dest}$ is the amount of damage as a result of destruction of the fertile soil layer (in rubles).

The damage as a result of soil contamination, the impact of which occurs when contaminants enter the soil, leading to non-compliance with environmental quality standards for the soil, including standards for the maximum (approximately) allowable concentrations of contaminants in the soil, expressed in monetary terms, is calculated according to the following formula:

$$DA_{cont} = CD \cdot S \cdot C_d \cdot C_{us} \cdot T_x,$$  \hspace{1cm} (2)

where $DA_{cont}$ is the amount of damage (in rubles);
$CD$ is the contamination degree depending on the ratio of the actual content of the i-contaminant in the soil to the maximum permissible value for the soil;
$S$ is the area of the contaminated territory (m$^2$);
$C_d$ is the coefficient taking into account the depth of contamination, soil deterioration when its surface is covered with artificial surfaces and (or) objects (including linear ones);
$C_{us}$ is the coefficient taking into account the land category and the type of permitted use of the land;
$T_x$ is the value of the tariff for damaging the soil as a protected element of the environment in the form of its contamination (rub/m$^2$).

The damage to the soil as a result of using it to place household and industrial waste on its surface, expressed in monetary form, is calculated according to the following formula:

$$DA_{was} = \sum (M_i \cdot T_{was}) \cdot C_{us},$$  \hspace{1cm} (3)

where $DA_{was}$ is the amount of damage (in rubles);
$M_i$ is the mass of waste with the same hazard class (t);
$n$ is the sum of the waste types grouped according to hazard classes within the same zone where unauthorized disposal of production and consumption waste have been registered;
$C_{us}$ is the coefficient taking into account the land category and the type of permitted use of the land;
$T_{was}$ is the value of the tariff for damaging the soil as a protected element of the environment as a result of soil deterioration when littered (rub/ton).

The cost of waste disposal was calculated in accordance with the Decree of the Government of the Russian Federation dated September 13, 2016 No. 913 “On the rates of payment for the negative impact on the environment and additional factors”.

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Accordingly, after carrying out an assessment using these methodologies, we determined the monetary estimate of damage from secondary pollution of field soils by organic substances.

3. Results and discussion

Based on data from the results of production control and draft standards, we calculated the damage to the soil as a protected element of the environment according to the Methodology for Calculating the Amount of Damage Caused to the Soil as an Object of Environmental Protection.

Table 1 presents the main characteristics of the studied fields by the main factors of the formation of polluting organic substances. Figure 1 shows the result of the calculation of the damage to the soil as a protected element of the environment, expressed in monetary form.

| Factor                        | Yarakta field | Markovo field | Dulisma field |
|-------------------------------|---------------|---------------|---------------|
| Field area; ha                | 9500          | 155.86        | 1131.08       |
| The fields are located in the Ust-Kut forest district S = 4,535,116 ha |
| Number of cluster wells       | 16            | 8             | 20            |
| Waste composition             | Sludge. Composition: water, petroleum products, carbon, barite, betonite, carbonates, Na, Mg, K | Sludge. Composition: water, petroleum products, carbon, barite, betonite, carbonates, Na, Mg, K | Sludge. Composition: water, petroleum products, carbon, barite, betonite, carbonates, Na, Mg, K |
| Waste disposal method         | Disposal in a drilling mud pit at cluster sites | Disposal in a drilling mud pit at cluster sites | Disposal in a drilling mud pit at cluster sites |
| Hazard class                  | 4             | 4             | 4             |
| Amount of pollutants, tons   | 530.53        | 261.43        | 711.62        |
| Area of polluted land; m²     | 1263.15       | 622.45        | 1694.3        |

Average density of drilling sludge = 2100 kg/m³

Figure 1. Result of the calculation of the damage to the soil as a protected element of the environment, expressed in monetary form (in rubles).
As a result of the study, we obtained data confirming that the greatest damage was caused by the Dulisma field, it had the largest territory and the largest number of cluster wells. This load can be considered significant for the region of Baikal.

4. Conclusion
Taking into account the fact that it is cluster foundations that account for the main part of infrastructure sites built at the fields, it follows that well clusters are ecologically the most hazardous oil production objects that require constant monitoring. Without taking into account possible emergencies, we calculated damage amounting to almost 100 million rubles caused to land resources of the Irkutsk Region. Therefore, we would like to note the importance of monitoring and checking the cases of leaks at oil and gas production facilities, in order to prevent additional load on land resources.

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