ASSESSMENT OF TECHNOGENIC SOIL CONTAMINATION AND ECOLOGICAL RISK AT THE SURGIL GAS FIELD

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Annotation. The article examines the features of technogenic pollution of the soil and groundwater of the Surgil gas field, located in the Aral Sea region - a region with a pronounced ecological crisis dynamic. The purpose of the work is to assess the degree and spatio-temporal dynamics of gas production activity's impact on environmental components. The research is based on a hierarchical approach, including local and translocal monitoring of the physicochemical parameters of soil and groundwater. Particular attention is paid to the pollution of heavy metals as the most dangerous pollution agents. For quantitative assessment, the gradient indication method, the analysis of the total concentration of polluents, and the methodology for assessing potential environmental risk were used. The obtained results indicate a progressive nature of soil technogenic pollution in 2011-2022. It has been established that lead and cadmium contribute the most to environmental risk. It is necessary to apply comprehensive quantitative methods and GIS technologies to improve the effectiveness of environmental assessments of gas production facilities.

Key words: technogenic pollution, Surgil gas field, heavy metals, local and translocal monitoring, gradient indication, environmental risk, GIS technologies.

Introduction. Environmental pollution is one of the most important environmental problems of our time. The dangerous growth rates of pollution in all spheres of the Earth's natural environment threaten to significantly worsen the ecological conditions of human life. Global problems such as climate warming, drinking water quality problems, soil degradation problems, and biota in general are emerging.

In the Aral Sea region, the problem of industrial pollution of the environment has worsened with the discovery of the Western Aral Sea natural gas field with preliminary estimates of 11 billion cubic meters and the Surgil field (Figure 1), whose reserves are about 120 billion cubic meters of natural gas. In the near future, the construction of a 110-kilometer pipeline for delivering natural gas from the developed Surgil field for the Kungrad soda plant is planned [1, 2, 3], which is fraught with additional environmental stress to the Aral crisis in the form of soil and vegetation cover destruction.

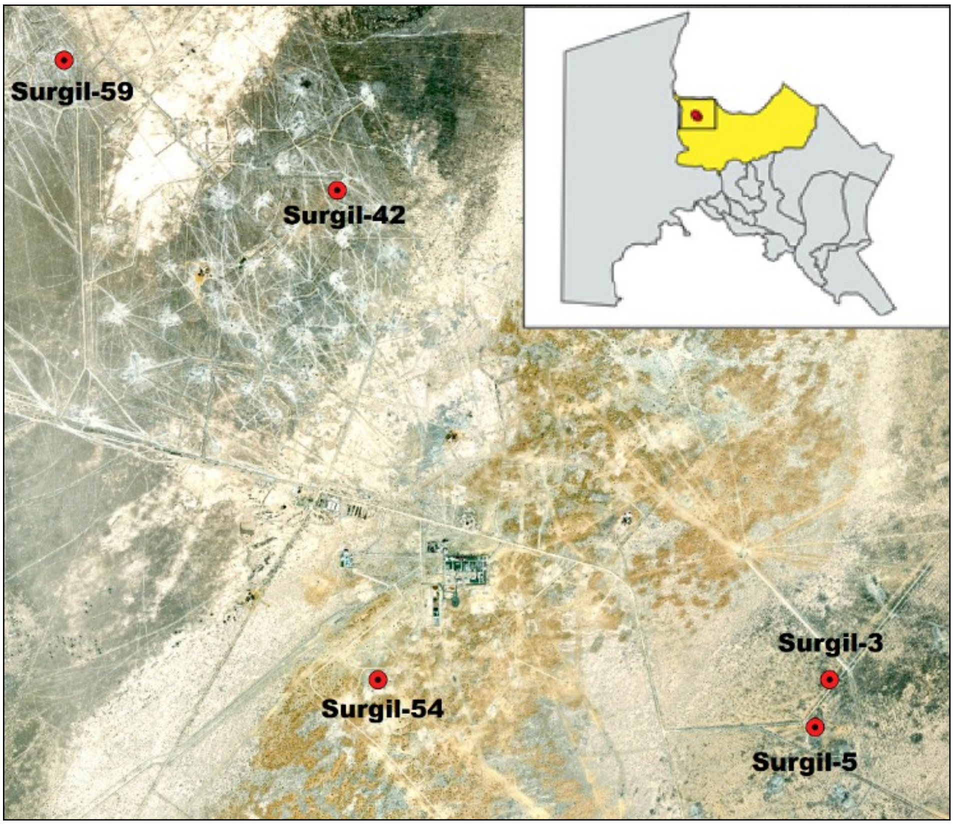

Fig.1. Surgil Gas Field

The complexity of the environmental impact structure at the oil and gas production stage is related to the deployment of complexes of technological facilities connected by pipeline systems, highways, power transmission lines, and work organization. When developing oil and gas condensate fields, the sources of technogenesis are: disruption (erosion) of the embankment of shaft areas and individual wells of production facilities, reservoir parks, etc.; construction of highways, power transmission lines, etc.; airtightness of the collection system and within the production transport; discharge of oil-contaminated storm runoff during underground and major repairs of production wells; disruption (breakage) within production collectors and pipelines; discharge of underground water; system for increasing reservoir pressure; flame "utilization".

Sources of pollution during well drilling can be conditionally divided into permanent and temporary [4]. The first includes the filtration and leakage of liquid drilling waste from sludge storage facilities. The second group includes sources of temporary action - absorption of the drilling fluid during drilling; emissions of reservoir fluid to the bottom surface; disruption of the tightness of the cemented column-back space, leading to inter-layer flows and column-back manifestations; flooding of the drilling area due to precipitation. The greatest danger to natural environment objects is posed by production and technological drilling waste, which accumulates and is stored directly in the drilling area. In their composition, they contain a wide range of pollutants of mineral and organic nature, represented by materials and chemical reagents used for the preparation and treatment of drilling fluids (for example: polyacrylamide, condensed sulfite-alcohol barde, carboxymethylcellulose, highly viscous gel, high-viscosity synthetic fluid, dk drill, DKS-extender, sypan, T-80) [5].

Emissions from comprehensive gas treatment plants (CGTP) are enriched in SO_2 (46.0–60.8%) and CO (24.4–32.6%), which are formed during the combustion of natural gas in flares. Flare gas combustion products constitute the main portion of emissions from the comprehensive gas treatment plant into the atmosphere (over 70%). The share of emissions from unorganized sources – leaks through wellhead fittings (3.0–6.1%) and from separation equipment (2.0–3.5%) – is insignificant. Up to 68 kg of polluting organic substances per 1 m^3 of waste is generated, not counting oil [5].

When drilling wells, the wastewater storage facility contains about 65% water, 30% sludge (drilled rock), 5.5% oil, 0.5% bentonite, and 0.5% various additives that ensure the optimal operation of the drilling rig. Warehouses are emptied of the liquid phase. Water from the liquid phase is usually removed by evaporation. Then, the thickened drilling waste is covered with mineral soil [5].

Since the evaporation process is quite long, during it, sludge microelements are released into the atmosphere, which are carried by the wind and deposited outside the drilling sites. Towards the end of evaporation, the wind removal of solid waste intensifies. Therefore, there is a need for translocal monitoring.

Environmental pollution is defined as an undesirable effect by introducing various substances - polluents - into it. Two types of environmental pollution can be distinguished: a) exceeding the background values of existing polluents above the level of maximum permissible concentration (MPC); b) the appearance of new substances in the environment, the concentration of which over time, due to accumulation, can reach and even exceed the MPC. The negativity or positivity of the processes of introducing various substances into the environment is determined by their ecological significance. It is known that any substance can be beneficial or harmful within the appropriate concentration ranges.

If, during the operation of an industrial facility, the emissions of a certain substance not only do not exceed the MPC, but also supplement its content in the soil, air, or water to a normal value, then the impact of the industrial facility can be considered even positive. The MPC of any substance is a concentration that does not cause pathological changes (anomalies) during prolonged exposure to the environment and does not lead to the accumulation of toxic elements dangerous to human health and life. Obviously, the MPC is the upper limit of normal values of the substance content. Technogenic pollution exists if, during the operation of an industrial facility, the content of any ingredient in its emissions exceeds the MPC.

Although the level of chemical pollution of Surgil gas fields is significantly lower than that of oil fields, it leads to barely noticeable environmental changes, which are poorly recorded using existing local monitoring methods. For the latter, there is no unification of approaches and work methods: production specifics and, most importantly, regional features and differences in natural-territorial complexes are not taken into account. Furthermore, the observation methods used are not always sufficiently justified and tested. As a result, the current procedures, principles, and methods for carrying out local monitoring prove ineffective in a number of cases.

The imperfection of methods for assessing technogenic pollution (empirical determination of MPCs, background values, their regional differences, measuring instrument errors) makes it difficult to obtain a realistic conclusion about the environmental safety of industrial facilities.

In this regard, this work proposes a complex of methods for studying the technogenic pollution of soils and groundwater at the Surgil gas field, which significantly increases the effectiveness of environmental assessment.

Materials and methods. The general methodology is the method proposed by academician V.N. Sukachev [6], which consists of "sequential narrowing of the perspective on the object under study," i.e., the sequential increase in the degree of research detail. At the first hierarchical level, local monitoring of the physical and chemical indicators of soil and groundwater is carried out throughout the Surgil field, in the immediate vicinity of drilling wells and wastewater storage facilities (Figure 2).

Fig.2. Wastewater depot.

At the second level of research, the degree of detail increases due to the inclusion of spatial dynamics of soil and groundwater physicochemical indicators. Translocal monitoring is due to the fact that chemical elements and compounds can move through geochemical processes such as horizontal infiltration, adsorption, and wind erosion.

Finally, at the third level, the viewing angle narrows to considering only heavy metals as the main pollutants of gas deposits and the quantitative assessment of their distribution in soil and air.

According to the hierarchical structure of the research, the objects of research are:

At the first stage of local monitoring of the Surgil territory - soil and groundwater in the immediate vicinity (5-10m) of wells No. 3, 5, 42, 54 and 59 and wastewater reservoirs;

At the second stage of translocal monitoring, the area of influence of a specific comprehensive gas treatment plant and the individual Surgil-54 well was studied — including soils and groundwater at distances of 100, 500, and 1000 meters in various directions. This particular well was selected for more detailed examination because it is located near the comprehensive gas treatment plant and situated on the crest of the Arkhangelsky ridge, thereby having the largest zone of influence due to favorable conditions for horizontal migration of contaminants, both in soil and in air.

In the third stage of studying the spatio-temporal dynamics of the distribution of technogenic heavy metals, the object of research is the concentration of heavy metals in soil and air.

Referring to the application of background values in the ecological assessment of environmental pollution, it should be noted that in the context of the spatial-temporal dynamics of the dried-up bottom of the Aral Sea, it is quite controversial. According to the definition, background values of the state of the natural environment are indicators characterizing the natural state of environmental components (air, water, soil) that are not directly subjected to technogenic or anthropogenic impact. They serve as a basis for assessing pollution and changes caused by economic activity and are determined in zones where human influence is minimal, for example, in reserves. It is clear that comparing the state of the natural environment in the Surgil gas fields with its state, for example, in the Baday-tugai Reserve, would lead to an unrealistic assessment of the ecological impact of the Surgil gas fields, as these are completely different ecosystems. The physical and chemical indicators of the soils of the equivalent ecosystem in the north of the dried-up Arkhangelsk valley could be used as background values, but they are practically absent. Therefore, to assess the degree of technogenic pollution of the Surgil gas field area, temporal-background values, i.e., the "pre-industrial" physicochemical indicators of this area obtained during preliminary monitoring of the natural environment of this area in [7], are used in the work.

Due to the particular importance of the problem of environmental pollution by heavy metals by the gas-producing industry, noted in many publications [8, 9, 10, 11, 12], in this work, along with the qualitative methods described above, quantitative methods in combination with GIS technologies and information technologies were used to determine the distribution of heavy metals.

Quantitative methods include the methods developed by the authors for gradient indication of the degree of pollution, based on the analysis of spatial dynamics [13], assessment of the total concentration of polluents, and comparative statistical analysis of soil technogenic pollution in different years.

The method of gradient indication of the degree of contamination by a particular ingredient, based on the analysis of spatial dynamics, consists in calculating the average gradient G of the relative value $P=C(x_i)/\Phi$ (excess of the background concentration value) in the radial direction from the source:

$$G=\frac{1}{n}\sum_{i=1}^{n}\frac{C_i-C_{i-1}}{\Phi} \tag{1}$$

where Φ is the temporal-background value of the pollute, $C(x_i)$ is the pollute concentration obtained at the i-th sampling point, the numbering increases with the removal of the point from the source.

The method of gradient indication of the degree of pollution serves to quantitatively classify the impact of an industrial facility on the environment. In addition, the gradient indication method allows for the determination of R_D - soil contamination radius, i.e., the impact zone of the industrial facility for the $G<0$ case. For this, the linear trend $f(x)$ of the series of relations $C(x_i)/\Phi$ is constructed, the point X is found, where $F(X)=0$, and it is evident:

$$R_D=max\{X\} \tag{2}$$

Many pollutants accompanying gas extraction technologies have a summation effect. For the first time, the normative characteristic - the total concentration of polluents [14] - was used to assess the ecological state of the soils of the southwestern dried-up bottom of the Aral Sea:

$$q=\frac{C_1}{MPC_1}+\frac{C_2}{MPC_2}+\frac{C_3}{MPC_3}+\ldots+\frac{C_k}{MPC_k} \tag{3}$$

where C_k is the average concentration of the k -th polluent in the influence zone.

According to Le Chatelier's law [15], this value must be less than or, in extreme cases, equal to 1 ($q\le 1$), if it exceeds this value, the pollution is considered excessive.

The methodology for assessing environmental risk has been applied to determine technogenic pollution from especially hazardous pollution agents - heavy metals [16]. The environmental risk index characterizes the toxicological, ecological, and environmental impact of soil contamination with metals [17, 18, 19]. The environmental risk is calculated using equation (4):

$$E_r^i = T_r^i \times (C_i / C_0) \quad (4)$$

where C_i is the metal concentration in the sample, and C_0 is the metal background concentration [20]. $T_r^i -¿$ represents the toxic response coefficient of a specific metal. Toxic response factors (TRF) for Cu (5), Cr (2), Pb (5), Zn (1), Ni (5) and As (10) were obtained from the literature [16, 21, 22]. Risk index (RI) can be calculated using equation (5).

$$RI = \sum_{i=0}^{n} E_r^i \quad (5)$$

Based on the assessment, the values of $E_r < 40$, $RI < 150$ indicate low environmental risk, $40 \leq E_r < 80$, $150 \leq RI < 300$ indicate moderate environmental risk, $80 \leq E_r < 160$; $300 \leq RI < 600$ indicate a significant environmental risk, $160 \leq E_r < 320$; $RI \geq 600$ indicates a high environmental risk and $E_r \geq 320$ is considered a very high environmental risk.

Results. Calculations of the total concentration showed that with the presence of a summation effect for the indicated metals, soil contamination is significant, as it is greater than 1 in all directions: N - 1.7; NE - 2.4; S - 1.8, SW - 1.9.

Table 1

Total concentration values for heavy metals

Directions	Soil pollution (mg/kg)	
	2011y.	2022y.
North	1.7	2.2
North-East	2.4	3.0
South	1.8	3.1
South-West	1.9	2.0

The table shows a significant increase in the total concentration of heavy metals in the soil during the period 2011-2022, which indicates a significant positive trend in technogenic pollution in the Surgil gas field.

Calculations using the proposed gradient indication method are illustrated in Figure 3 using the example of the heavy metal lead (Pb).

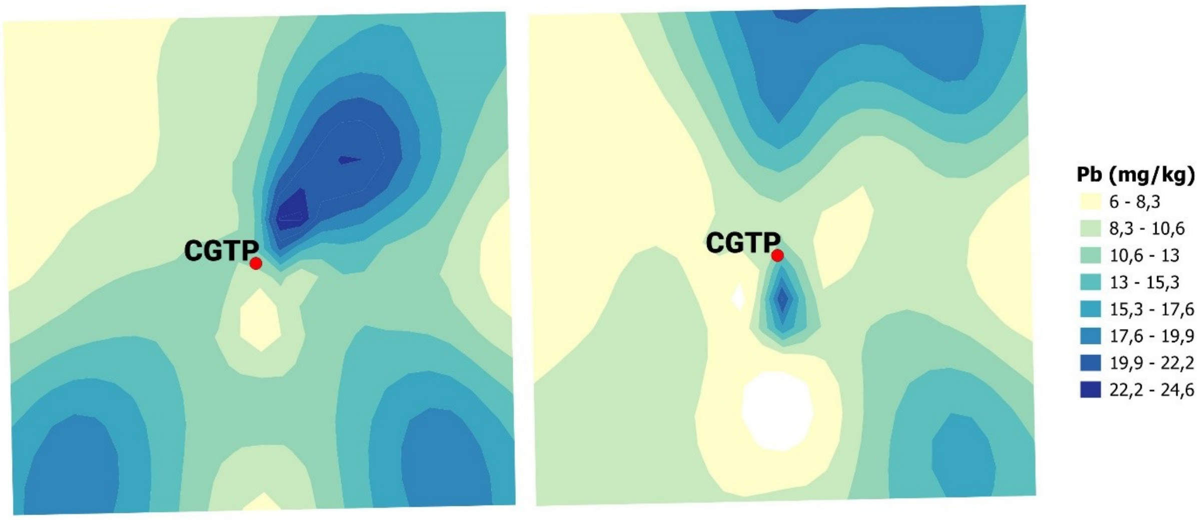

Fig. 3. Spatial dynamics of lead in 2011 (left) and 2022 (right).

The diversity of the dynamics of heavy metal content in the soil along route directions is explained by the intersection of the relief of the area that was the former bottom of the Aral Sea (Archangelsk valley). The south and southeast represent elevated terrain, while the north and northeast represent descending terrain from the source. As is known from soil physics, the terrain is of great importance for horizontal infiltration, and since the agent of heavy metals in our case is water (drilling fluid discharge), the northern flow is greater than the southern flow. Therefore, the spread and accumulation of heavy metals occurs more and faster in the northern and northeastern directions. The heterogeneity of the terrain's orography determines the formation of local M_i concentration maximums in the lowlands and local N_i minimums in the elevations of the relief (Figure 3).

The dynamics of the average content of heavy metals in the soil for 2006-2022 clearly indicates the progressive nature of technogenic pollution at the Surgil gas field.

Assessment of potential environmental risk, performed based on individual risk coefficients (E_r) and risk indicators (RI), showed a heterogeneous contribution of the studied heavy metals.

It was established that the values of E_r for Pb (107.26) and Cd (239.38) correspond to a significant environmental risk ($80 \leq E_r < 160$) for lead (Pb) and a high environmental risk ($160 \leq E_r < 320$) for cadmium (Cd).

At the same time, the values of Er for Ni (10.48), Zn (12.74), and Cu (13.80) are in the range of low ecological risk ($E_r < 40$), indicating their relatively insignificant impact on the ecological state of soils.

The potential environmental risk (RI) indicator, equal to 383.66, belongs to the category of significant environmental risk ($300 \leq RI < 600$), which indicates the cumulative adverse impact of heavy metals on the studied territory.

Conclusion. Based on the above material, the following conclusions can be drawn.

1. It is necessary to distinguish between assessing environmental pollution and assessing technogenic pollution. When assessing pollution, one can limit oneself to the physical and chemical indicators obtained by sampling soil, water, and air samples and subsequently analyzing them and comparing them with the REM. To assess the technogenic pollution of the environment by any industrial facility, it is necessary to compare the "pre-industrial" physical and chemical indicators of the area surrounding the industrial facility with the physical and chemical indicators at the existing industrial facility. The difference in these indicators indicates the degree of impact of the industrial facility on the environment, i.e., technogenic pollution.

2. Assessment of technogenic pollution in regions experiencing ecological crisis with pronounced destructive dynamics is complicated by the presence of

poorly studied processes accompanying the ecological crisis and numerous noises (preceding anthropogenic pollution, soil and air migration of pollutants, processes of pollutant absorption by microorganisms and vegetation, etc.).

3. Determining technogenic pollution by individual substances is a specific task for assessing the ecological state of the natural environment when industrial elements are introduced into it. Assessment of the ecological state involves the quantitative expression of complex pollution using pollution indices, as well as assessing risks to human health and the local biota as a whole.

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