Ecological state of alluvial soils of floodplain landscapes under conditions of local pollution by hydrocarbons (Western Siberia)

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Abstract. The paper presents an analysis of field and experimental studies of the main physicochemical parameters of oil-contaminated soils of floodplain ecosystems of the middle taiga subzone of Western Siberia. The features and main regularities of their change in different pollution zones (epicenter - impact zone) are revealed. The state of the physicochemical parameters of technogenically contaminated soils is compared with background analogs. The most important groups of chemical compounds and elements that pose an environmental hazard are considered - oil and oil products, technogenic readily soluble salts (including their toxic compounds), the ways of their migration, transformation and accumulation in contaminated soils. General recommendations are given on the use of the discovered regularities in the technical maps of reclamation measures and the system for monitoring contaminated soils.

1. Introduction

For an objective assessment of the environmental consequences of anthropogenic changes in ecosystems, reliable quantitative characteristics are required that reflect the impact of human economic activity on the soil cover [1-5]. At the same time, special attention should be paid to identifying changes in soil processes and soil properties in the most common form of chemical pollution - a burst of oil, as well as assessing the nature, degree and consequences of soil disturbance as a result of exposure to pollutants and the organization of soil-ecological monitoring. It should be noted that an increase in the intensity of environmental exploitation naturally leads to an increase in the number of accidental oil spills and necessitates the development and implementation of new scientific and practical developments in existing production processes. One of these developments is the scientific and methodological substantiation of changes in the main parameters of oil-contaminated soils - physicochemical parameters (pH of the water extract, the ratio of cations and anions of readily soluble salts, the amount of Corg), water-physical properties, particle size distribution (Kstructuralnays soil structure).
Despite a significant number of works devoted to the study of the impact of oil pollution on the ecological state of soils in taiga eluvial landscapes of Western Siberia [5-11], few data is available on oil products typical behavior, as well as practical aspects of floodplain ecosystems soil reclamation. In this regard, the purpose of this study is to analyze the features of the influence of oil pollution on the properties of alluvial soils and the possibility of using the obtained data for carrying out restoration work.

2. Material and Methods
The study covered the soils of the territory of the crude oil spill in Alexandrovski and Kargasokski Districts of the Tomsk Region, and of Nizhnevartovsk District of the Khanty-Mansi Autonomous Area of Yugra. Soil contamination resulted from the field pipeline rupture in the central part of the Ob River floodplain. In each zone of different technogenic load (epicenter, impact zone, oil spill periphery), a soil cross section and a number of pits were made, and soil was classified based on the reference data. Soil sampling was carried out in accordance with GOST 28168-89, taking into account the thickness of the horizons of the described sections to a depth of 100 cm. Pit samples were taken from 0–10 and 10–20 cm layers. Biocenoses are represented by pine, larch, pine and birch forests; steppe cereal, forb cereal and leguminous cereal communities, as well as meadow forb associations of river valleys and interplanar depressions. For field studies of soils of the landscapes under study, soil-morphological, pedolithological, botanic, geological-geomorphological and comparative-geographic study methods were applied. Within the area, 5 soil cross sections and 25 soil pits were made and described. To identify the specific features of contaminated soil transformation, a cross-spectrum analysis of reference soils and soils contaminated with oil emulsions was carried out. Undisturbed soils are located in the immediate vicinity of the reference target and are represented by various types of alluvial soils. Diagnostics and classification was carried out in accordance with modern concepts of industrially transformed soil classification.

Air-dry soils samples were used for laboratory studies of properties of the main types of soils as per applicable State Standarts, and with the help of statistical methods and STATISTICA 6.0 software.

3. Results
Comparison of the profiles of the background and hydrocarbon-contaminated soils showed that a number of features are revealed in the chemozems that have arisen as a result of oil impact, which led to the transformation of the morphological appearance of the soil: the appearance of an oily film in the soil mass, an intense smell of oil and cementation of individual soil aggregates.

Fluorimetric analysis data indicate that the content of oil products in contaminated soils ranges from 11.34 to 6.53 g / 100 g of soil, decreasing with distance from the epicenter of pollution to the pollution boundary in the lateral direction, and in the radial direction with increasing depth of soil horizons (figure one). Thus, the input of petroleum carbon significantly increases the total organic carbon content of soils. In the background soil, this figure is 5.4%, while in technogenically polluted soils, it varies up to 10.7% (figure 2). At the same time, the amount of organic carbon decreases down the soil profile; however, in the technogenic soil, this parameter always multiply exceeds its values in the background analogs. These observations indicate the need for deep agrotechnical processing, which will ensure the restoration of aboriginal soil microflora, improve aeration, its water-physical properties, and activate the processes of natural detoxification of the pollutant. Deep cultivation is necessary due to the fact that in the process of reclamation work on contaminated soils is carried out only in the root layer. Thus, during surface agrotechnical works, toxic compounds of oil hydrocarbons will remain in the soil layer and cannot be treated with a biological product, which in the future can create unfavorable conditions for self-healing and self-cleaning of soils.
The agrotechnical complex of works is necessary to prepare the soil for the final stage of reclamation - phyto-reclamation sowing of oil-resistant grasses. However, the negative consequences of oil pollution for soil biota are manifested not only in a toxic effect, but also in a sharp change in an unfavorable direction in most water-physical indicators, which is one of the most important parameters for a favorable growth and development of plants. For the purpose of an accessible demonstration of trends in changes in the main physicochemical and physical parameters, Table 1 presents the averaged values for the upper root-inhabited ones.

In particular, the plant wilting moisture significantly increases in the background samples, this parameter is an order of magnitude lower (10.3%) than in the freshly contaminated soil of the epicenter of the oil slick (25.46%) and on the periphery of the oil spill (impact zone - 22.32%; pollution boundary - 21.59%). Oscillations of this parameter occur against the background of a sharp reduction in the range of active moisture in the lower part of the soil profile (from 1.97% to 2.52%) of contaminated soils and its complete absence in the root layer. The difference in these parameters indicates a moisture deficit in contaminated soils. In particular, the moisture content of wilting of plants increases significantly. These changes indicate the minimal ability of oil-contaminated soils to absorb and retain moisture, which contributes to the transformation of the initial lumpy-granular soil structure into a blocky one and worsens the structural coefficient (Kstructurality = 0.53, unsatisfactory).

Extraction of hydrocarbon raw materials under conditions of humid soil formation is accompanied by specific, unparalleled in natural conditions, phenomena of technogenic halogenesis. The presence and development of this process in soils is important when planning the biological stage of reclamation work. The analysis of the geochemical distribution of salts indicated that the peak of the salt content falls on the upper horizons of the pollution halo of the epicenter of the spill (0.54%), and on the periphery at the spill boundary, in the impact zone (0.48%). It should be noted that there are no readily soluble salts in the background alluvial soils, which indicates the technogenic nature of the pollutant.
Table 1. Physicochemical and physical parameters of oil-contaminated soils

| Soil sampling area | Contamination source | Impact zone | Pollution boundary | Uncontaminated soil |
|--------------------|----------------------|-------------|--------------------|---------------------|
| Depth, cm          | 0–10 10–30 0–10 10–30 0–10 10–30 0–10 10–30 | 0–10 10–30 0–10 10–30 0–10 10–30 0–10 10–30 |
| WM, %              | 25.46 21.28 22.32 18.68 21.59 20.06 10.3 7.3 |
| AMR, %             | - - - - - - - - |
| pH                 | 7.6 7.3 6.9 6.2 6.2 6.1 4.6 4.9 |
| Dense residue, %   | 0.54 0.48 0.48 0.24 0.32 0.24 - - |
| Salinity           | medium low low low low non–saline non–saline non–saline |
| salinity type      | Sulfate/sodium chloride Sulfate/sodium Sulfate/sodium Sulfate/sodium Sulfate/sodium Sulfate/sodium - - |
| (Anionic/cationic)  | - - |

Note: "-" is below the detection threshold

The introduction of Na⁺ into the soil absorbing complex and its displacement of cations, which determine the acidity of alluvial soils (4.6), causes a noticeable increase in pH values in chemozems to 7.6, and a shift in the reaction towards the alkaline side. The type of chemistry in the radial direction of the contaminated soil profiles remains equally weak and sulphate-sodium. In the absence of reclamation measures, these changes can cause inhibition of plant growth and development, which will not allow completing the process of reclamation on these soils. It should be noted that the practice of reclamation of saline lands on an industrial scale at the oil fields of Western Siberia is currently absent, which determines the relevance and significance of the data obtained, and the possibility of their use to predict changes in the state of soils in the future.

The results of statistical data processing demonstrate a close relationship (r = 0.5-0.9) between the content of oil products and the physicochemical (pH, C org, water extract analysis) and water-physical parameters of soils subject to transformation. The T-test results indicate, testify to the significant significance of the studied parameters and their close relationship with the content of oil products in the soil, and also allows us to characterize the general ecological state of soils as unsatisfactory.

4. Discussion

In humid areas, the formation of solid bituminous crusts on the surface, as well as in the soil profile, under conditions of oil pollution, all soil characteristics change dramatically.

The intensity of lateral migration and accumulation of hydrocarbons depends on the composition of the pollutant and the distance to the source of pollution. The radial migration of the pollutant is due to the presence of sorption barriers in the soil (heavy loamy and gley horizons - AYC, x, IC1g, IIC2g, IIC3g), as well as from the geochemical position of soils in the landscape. The analysis of the geochemical distribution of salts indicated that the peak of the salt content falls on the upper horizons of the pollution halo at the epicenter of the spill (0.54%), in the impact zone (0.48%), and at the periphery at the spill boundary (0.32%). The type of chemistry in the radial direction of the contaminated soil profiles is sulphate-sodium, varies from weak to medium salinity. The introduction of Na⁺ into the soil absorbing complex and its displacement of cations, which determine the acidity of alluvial soils, causes a noticeable increase in pH values in chemozems up to 8.52, and a shift of the reaction towards the alkaline side. In the absence of reclamation measures, these changes can cause inhibition of plant growth and development, which will not allow completing the process of reclamation on these soils.

Unfavorable soil and hydrological properties of contaminated soils (DAV, VZ) indicate the acquisition of hydrophobic properties by the soil, the appearance of moisture in the humus horizons that is inaccessible to plants, and indicate the need for additional reclamation work that is not provided for in standard projects for reclamation of disturbed lands - deep loosening of soils for improving the flow of moisture to the root systems of plants at the phytomeliorative stage of sowing oil-resistant grasses.
5. Conclusion

As a result of the impact of a hydrocarbon pollutant on the soils of floodplain ecosystems, changes in the morphological, water-physical, physicochemical properties of soils occur. This is manifested in a change in the color of the entire soil profile to a darker one, the appearance of an intense specific smell of oil, cementation of soil aggregates with heavy oil fractions, and the formation of a bituminous crust on the soil surface, which, in turn, leads to dramatic changes in water-physical properties. Salt compounds and high content of hydrocarbons create a phytotoxic environment during phytomeliorative sowing of herbs at the biological stage of restoration work. The sodium chloride variety of salinization and the presence of toxic salts in the soil profile determine the development of the saline process, which is not typical for soils of the alluvial type of soil formation, and indicate the initial stage of the processes of technogenic halogenesis. The ecological consequence of this is either the complete absence of vegetation in the oil-contaminated area, or it is in a state of extreme oppression. Consequently, oil pollution of soils is accompanied not only by the disruption of natural landscapes and changes in the most important ecological functions and genetic parameters of soils, but also by the loss of agricultural land. Therefore, the study of the patterns of which is important for establishing the main parameters of reclamation systems when carrying out measures to clean up soils from oil and oil products.

On soils contaminated with man-made products, the main task of biological reclamation is to increase their self-cleaning ability. The solution to this problem is possible through the joint functioning of technical and biological systems operating with a wide range of activities. In the humid conditions of Western Siberia, unfavorable conditions for self-recovery are characteristic of all technogenically contaminated soils; however, in the soils of floodplain ecosystems, where the phytotoxicity of the soil persists for a long period, interfering with the normal functioning of the entire biogeocenosis, these processes are most complex and time-consuming. Therefore, alluvial soils need a special approach to the implementation of the biological stage of the remediation process, since the currently existing standards for carrying out restoration work cannot fully ensure the full restoration of its properties by the soil.

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