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Main Trends in Morphological Properties of Alluvial Soils under Conditions of Local Pollution with Oil Emulsions (Western Siberia)

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Abstract. This paper discusses materials of studying the morphological properties of alluvial soils in the floodplain ecosystems of Western Siberia. It reveals the peculiarities and main regularities of their changes in different pollution zones (the Contamination source being an impact zone). The state of the morphological peculiarities of technogenically polluted soils is compared with background analogs. The article describes the technogenic signs in the upper horizons of chemical-contaminated soils at different levels of oil hydrocarbon (OHC) pollution. There have been identified correlations between the content of total oil hydrocarbons (OHC) in horizon AY $_{v, x}$ and its color parameters measured in the Munsell system.

1. Introduction

Continuously increasing human intervention leads to the increase of contaminants emission to ecosystems. Among numerous environmental contaminants (EC), oil and oil products (OP) shall be mentioned as sufficiently hazardous, quickly propagating, slowly decomposing in natural conditions and capable of exerting a toxic effect on soil that is the central component of the ecosystem.

Deep and often irreversible changes occur in the entire complex of soil properties under the influence of oil flows. At the same time, morphological properties of soils are the most representative signs of pollution, indicators of changes in the ecological state of soils. These changes are especially informative in the soils developed under the conditions of humid soil formation of Western Siberia where the soil self-restoration processes are most complex and long-term [1-5].

Technogenic gleying, salinization and alkalinization processes [6-11] may develop in oil-producing areas due to soil regime disturbances and the impact of oil and mineralized oil field waters, which leads to soil structure transformation. A description of the morphological structure of their profiles is necessary to identify technogenic pedogenesis factors in the studied region. Soil pollution is controlled during an industrial environmental monitoring in the territory of oil fields, in the oil pipeline impact zone, at oil refineries, and oil storage facilities. An inspection of the areas of impact pollution with oil and oil products includes identification of sections and a description of the morphological properties of soils. The purpose of studying such sections is to determine the depth of oil seepage, presence of subsurface flows and the nature of soil profile transformation. Reconnaissance route studies based on a visual inspection of the upper soil horizons can help identify and delineate contaminated lands as well as determine and specify the configuration and dimensions of oil spills. Therefore, the determination of the morphological parameters of soils in background and oil-contaminated areas is an urgent production problem.

2. Materials and methods

The study targets were soils found in the territory of a crude oil spill in Aleksandrovsky and Kargasoksky Districts of Tomsk Region and in Nizhnevartovsky District of Khanty-Mansi Autonomous Okrug-Yugra. A pollution focus appeared as the result of a field pipeline rupture in the central part of the River Ob floodplain. A section and a number of soil pits were formed and soil was classified according to the background in each zone with a different technogenic load (Contamination source, impact zone). Soil sampling complied with GOST 28168-89 with due account for the thickness of the horizons in the described sections up to the depth of 100 cm. Samples from the pits were taken at the depths of 0-10 and 10-20 cm. Vegetation is represented by forest pine biocenoses, larch, pine and birch biocenoses, steppe cereal, forb cereal and leguminous cereal communities, as well as meadow forb associations of river valleys and interplanar depressions. Simultaneously, a requirement of the maximum homogeneity of soil formation factors, i.e. parent rocks, relief elements and vegetation nature, was observed. Five soil sections and 25 soil pits were formed and described in the territory. To identify the regularities of contaminated soil transformation, the authors made a cross-spectrum analysis of background soils and soils contaminated with oil emulsions. Undisturbed soils are located in the immediate vicinity of the control study target and are represented by various types of alluvial soils. Diagnostics and classification were based on the modern concepts of anthropogenically transformed soil classification [12-13]. A test for the normalcy of signs distribution was made using the Kolmogorov-Smirnov, Shapiro-Wilk criteria, and histograms. As most signs have an abnormal distribution, nonparametric statistical methods were used in this paper. Statistical data processing was performed via the Microsoft Excel 2010 spreadsheet processor and the STATISTICA 6.0 package.

3. Results and Discussion

The morphological structure of the profile objectively reflects the direction of the soil-forming process and gives a clear idea of the soil ecological state. Therefore, the primary indicator of soil oil pollution is the transformation of its overall look. It should be noted that, according to the engineering and environmental survey standards, the determination of the visual signs of pollution is an integral and necessary stage of an area field survey.

The morphological structure of the background soils quite clearly reflects the alluvial process development. Accumulative humus horizon $AY_{v,x}$ with a thickness of up to 13 cm and a fine lumpy structure is formed under a well-decomposed underlayer. The underlying layers of the alluvial soil, being independent genetic formations, are not pronounced; the middle part of the profile has no pedogenic structural organization. The root layer is not very thick: the bulk of the roots is concentrated in the upper part of the profile – in the organogenic and accumulative humus horizon; single roots lay deeper than 30-40 cm. According to the Russian Soil Classification [13], common alluvial pratal dirt/gley heavy loamy soil formed in the central part of the floodplain land was used as a reference material. The alluvial soil profile (section 1) in the background area has the following morphological structure: $AY_{v,x}$-AY_x-$AYC_{g,x}$-IC_{1g}-IIC_{2g}-$IIIC_{3g}$ (table 1).

In the study targets, the dispersion of hydrocarbons occurred in two directions: lateral (flat runoff) and radial (vertical runoff), which made it difficult to differentiate the soil profile horizons (table 2). In this regard, soil samples were taken layer by layer (0-10, 10-20, 20-40 cm, etc.).

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Table 1. Morphological structure of the alluvial soil profile in the background area (Section 1).

Horizon, depth, cm	Morphological signs
$AY_{v,x}$ (1-10 cm)	The color is uniform, gray-brown , 10YR5/2 according to the Munsell scale. Consists of the remains of herbaceous vegetation having a varying degree of decomposition. Densely penetrated by meadow vegetation root systems. The transition is clear in terms of soil mass composition, the boundary is even.
AY_x (13-23 cm)	The color is brown with gray bloom on the edges of structural units, uniform, 10YR5/2 according to the Munsell scale. Compacted, fresh, having a fine crumbly structure, light-loamy. The transition is gradual in color, the boundary is even. The horizon is laced with perennial grass roots.
$AYC_{g,x}$ (30-40 cm)	The color is brown with gray bloom on the edges of structural units, nonuniform, 10YR5/2 according to the Munsell scale. Ochery spots of iron oxide (D: about 2 cm), dark gray deposits of weakly decomposed organic matter and roots of perennial herbaceous vegetation. Compacted, fresh, having a fine crumbly structure, medium-loamy. The transition is clear in color, the boundary is even.
IC_{1g} (45-55 cm)	The color is nonuniform, light blue, 10YR5/2 according to the Munsell scale. Present Individual living roots are identified. The horizon is compacted, fresh, with a heavy grain size distribution. The border is rendered as clear in color and density. Ochery spots of iron oxide, dark gray deposits of weakly decomposed organic matter and roots of perennial herbaceous vegetation. Compacted, fresh, having a fine crumbly structure, medium-loamy. The transition is clear in color, the boundary is even.
IIC_{2g} (60-70 cm)	The color is heterogeneous, varying from light gray to dark gray, 7.5YR4/1 according to the Munsell scale. Ocher spots of iron oxide (D: 0.7-1.5 cm). Visible thin roots. Compacted, fresh, structureless, sandy loam. The transition is clear in color and density, the boundary is even.
$IIIC_{3g}$ (90-100 cm)	The color is heterogeneous, varying from light gray to dark gray, 7.5YR4/1 according to the Munsell scale. The horizon comprises alternating layers of brown, rusty and bluish colors having varying intensity and thickness (the thickness of the light gray stripes is significantly lower vs. the brown stripes). Loose, fresh, structureless sand.

Technogenically contaminated soils are defined as oil-contaminated chemical-contaminated soils occurring within the areas of gray-humic typical-gley medium fine soils [13]. The study of oil-contaminated soils involves the registration of additional morphological signs (oiliness, irisation, hydrophobic properties of soil aggregates, formation of technogenic inclusions and neoplasms, such as crusts, drips, films, nodules). The color of the humus horizons of the contaminated soil ($AY_{v,x}$, $AYC_{g,x}$) is unnaturally dark compared to the background, which is explained by the inwash of organic pollutants. The OHC content in the contaminated soils varies from 16.23 to 3.98 g/100 g of soil (figure 1) decreasing with distance from the Contamination source towards the impact zone in the lateral direction and increasing with the depth of soil horizons in the radial direction.

In the areas of crude oil spills, a dense bituminous layer is formed in the upper part of the soil profile, and brown-black tarry-asphaltene crusts are formed on the soil surface itself. Frontal seepage of oil that completely saturates the soil mass is characteristic of the upper horizons in heavily contaminated soils (the Contamination source of pollution). The oily film found on the soil knife surface shows the depth of OHC seeping along the soil profile. The first stages of pollution are characterized by the signs of soil horizon iridescence due to silvery-rainbow oil film. All horizons of soils comprise bituminous, organic-mineral, organic-ferruginous and ferruginous films, sinters, concretions. In gley horizons, the surface of aggregates and plant residues is enveloped with black films, and black spots of pollutant appear on the walls of cracks.

In chemical-contaminated soils, horizons IC_{1g}, IIC_{2g}, $IIIC_{3g}$ are of gray color with various shades (light gray, dark gray, gray). Rusty, ocher and gley spots appear in oil-contaminated soils; the color of the horizons is much darker vs. the background soils. The dark color of the oil-contaminated horizons is largely determined by resinous asphaltene substances that leave a characteristic oily trace. The light oil fractions are almost colorless.

Table 2. Morphological structure of chemical-contaminated soil (Sections 2, 3).

Horizon, depth, cm	Morphological signs	
	Contamination source (Section 2)	Impact zone (Section 3)
$AY_{v,x}$ (1-10 cm)	Horizon of uniform color, the color is dark gray, almost black, due to the fact that it is completely saturated with oil - color 5YR2/1 on the Munsell scale; has no structure, there are established inclusions formed by chemogenic cementation of soil aggregates. Soil aggregates (D: 3.5-5 cm) with oil films along the edges with a sharp characteristic smell of oil. The horizon is heavy loamy, with a bituminous crust on the surface, viscous, moist, compacted, with multidirectional roots from perennial herbal residues. The transition in color and structure is weak, the boundaries are not identified	The horizon is uniform in color, the color is dark gray, due to the fact that it is completely saturated with oil - color 2.5Y5 / 3 on the Munsell scale; has no structure, there are established inclusions formed by chemogenic cementation of soil aggregates. Soil aggregates (D: 2.5 cm) with oil films along the edges with a sharp characteristic smell of oil. The horizon is heavy loamy, viscous, moist, compacted, with multidirectional roots from perennial herbal residues. The transition in color and structure is weak, the borders are not identified.
AY_x (10-20 cm)	Uniform, dark gray, almost black, 5YR2/1 according to the Munsell scale; structureless, heavy-loamy, viscous, wet, compacted, with roots of plant residues, blocky aggregates (D: 3-5 cm); saturated with oil with a strong characteristic odor, no noticeable color transition, no differentiated boundaries.	Uniform, gray horizon color, 2.5Y5/3 according to the Munsell scale; structureless with cemented blocky inclusions, heavy-loamy, viscous, wet, compacted, with roots of plant residues, saturated with oil; blocky aggregates (D: 3.5-4 cm); no noticeable color transition, no differentiated boundaries.
$AYC_{g,x}$ (20-40 cm)	Heterogeneous, dark gray with a slight brownish tint, 2.5Y7/3 according to the Munsell scale; structureless with cemented blocky inclusions, heavy-loamy, viscous, wet, compacted, lower degree of oil contamination vs. the previous horizons, no noticeable color transition, no differentiated boundaries.	Heterogeneous, dark gray with a slight brownish tint and gleying spots, 2.5Y7/3 according to the Munsell scale; structureless, heavy-loamy, viscous, wet, compacted, lower degree of oil contamination vs. the previous horizons, noticeable color transition, slightly differentiated boundaries.
IC_{1g} (40-60 cm)	Heterogeneous, dark gray with ocher and gray gleying spots, 2.5Y8/3 according to the Munsell scale; structureless with cemented blocky inclusions, heavy-loamy, wet, compacted, contamination determined visually and by smell, slightly noticeable color transition, slightly differentiated boundaries.	Heterogeneous, dark gray with ocher and gray gleying spots, 2.5Y8/3 according to the Munsell scale; structureless, heavy-loamy, wet, compacted, with blocky aggregates (D: 2-3 cm), contamination determined visually and by smell, slightly noticeable color transition, slightly differentiated boundaries.
IIC_{2g} (60-80 cm)	Heterogeneous, dark fawn and brown with ocher and gray spots of gleying, 2.5Y8/3 according to the Munsell scale; structureless, medium-loamy, wet, compacted, with blocky aggregates (D: 3 cm), contamination determined visually and by smell, noticeable color transition, slightly differentiated boundaries.	Heterogeneous, dark fawn and brown with ocher and gray spots of gleying, 2.5Y8/3 according to the Munsell scale; structureless, medium-loamy, wet, compacted, contamination determined visually and by smell, noticeable color transition.
$IIIC_{3g}$ (80-100 cm)	Heterogeneous, dark fawn with ocher and gray spots of gleying, 2.5Y8/3 according to the Munsell scale; structureless, heavy-loamy, wet, compacted, with blocky aggregates (D: 2-5 cm), contamination determined visually and by smell.	The horizon was not surveyed. The section was formed down to the depth of 70 cm.

Categorical and quantitative estimates were obtained using the Munsell color measurement system for the oil-contaminated soil samples taken from the oil spill sections and site. Correlation and regression analyzes were carried out to study the relationship between the level of hydrocarbon pollution and the color indices of the chemical-contaminated soil. The Spearman correlation coefficient was calculated; the relationship is close, inverse. The ranges of color characteristics variation corresponded to the values typical of horizon $AY_{v,x}$, chemical-contaminated soils in natural conditions, but were displaced due to its coloring with oil. An increase in the OHC content in the gray humus horizon of chemical-contaminated soils was marked with a change in color tones from 2.5Y to 5YR according to the Munsell scale. The oil-contaminated horizons demonstrate a decrease in lightness and color saturation parameters according to the Munsell scale, which is observed in the chemical-contaminated soil profiles (table 3). Oil films on the surface of soil aggregates may lead to soil color haziness with an increase in an OHC content.

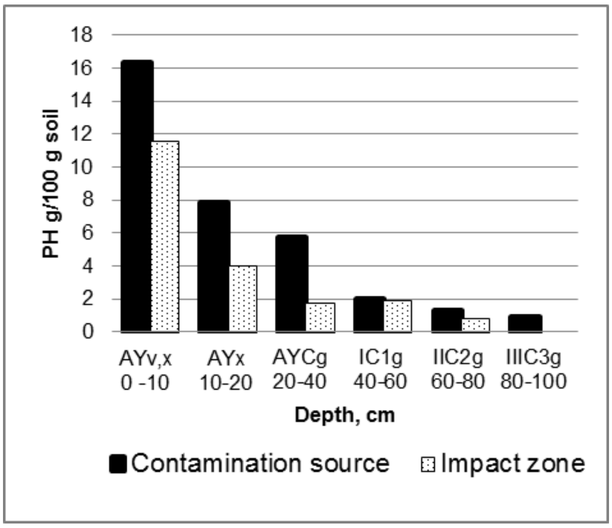

Figure 1 PH content in oil-contaminated soils

Table 3. Spearman coefficients of correlation between the content of the total OHC (g/100 g of soil) and color characteristics in horizon $AY_{v,x}$, chemical-contaminated soils (according to the Munsell system)

Parameters	**Variation range**	R^S
color tone	5YR-2.5Y	-0.89
lightness	2-5	-0.97
color saturation	1-3	-0.85

The degree of soil compaction varies from moderately cemented to highly cemented ($AY_{v,x}$, AY_x, $AYC_{g,x}$), overcompaction is predominantly artificial. The humus horizons contain artifacts (> 20%) in the form of construction waste, synthetic solid waste, and crude oil. Compacted dark brown and finely lumpy technogenic microaggregates were found. The oiliness and “soaping” of their edges are chemogenic signs reflecting an increase in the hydrophobicity of contaminated soil particles, which makes it possible to reliably classify the soils as Technosols [12].

The lower hydromorphic horizons of the oil-contaminated soils under study ($IC1_g$, $IIIC2_{g,x}$, $IIIC3_{g,x}$) are characterized by an increase in the grain size distribution and in the number of ocher spots confirming gley process strengthening. In background soils, K_d (dispersion coefficient) is at its peak in humous soil horizons (8%), while in chemical-contaminated soil its values reach 22%, which indicates the high water resistance of the control samples. Such changes cannot be attributed to positive phenomena, since the unnatural growth in the agronomically valuable fraction of soil structure owing to the adhesion of microaggregates with oil not related to soil genesis is accompanied by a number of very negative properties and processes deteriorating soil bonitet.

According to the FAO rating method, the index of assessing background alluvial soils calculated as the geometric mean of the total number of points (indices) LUI = 67 (Land Unit Index) makes it possible to refer the soil as soil suitability class II (moderately suitable), thus the lands are suitable for hayfields. Oil-contaminated soils with LUI = 14 are classified as category IV (subclass a) of lands (unsuitable). The further use of soils requires reclamation work; there are severe restrictions on 2/3 of the area under study.

Thus, alluvial soils experienced dramatic changes in their morphological parameters caused by oil pollution. The most characteristic changes are those associated with the color of the horizons and the sign of oiliness in the oil-contaminated soil mass. Chemogenic transformation is most clearly traced in the upper horizons of the Contamination source described in Section 2 where the level of OCH contamination was 16.23 g/100 g of soil, while the contamination level is lower in the impact zone.

4. Conclusion

The morphological appearance of soils changes significantly under the influence of technogenic oil flows: the color becomes darker, the nature of the boundaries between the horizons changes, and gleying processes intensify due to the disturbance of water and air exchange in the soils. Changes in morphological signs are determined by the depth of oil seepage that depends on the type of soil and its granulometric composition. Geochemical barriers of organogenic horizons are a means of protection against penetration of the bulk of oil into the lowest parts of a soil profile. The color of the horizons contaminated with oil becomes darker, the parameters of lightness and color saturation decrease (5YR-2.5Y according to the Munsell scale). The nature of the boundaries between the horizons changes: waviness, tongued shapes, potentially blurred boundaries in case of a severe pollution. Typical profile differentiation weakens and gleying processes intensify in technogenically contaminated soils. Prolonged exposure to oil spills, especially under reducing environmental conditions, contributes to the destruction of coarse particles, which manifests itself in a decrease in sand fractions and coarse dust and an increase in the amount of fine particles.

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