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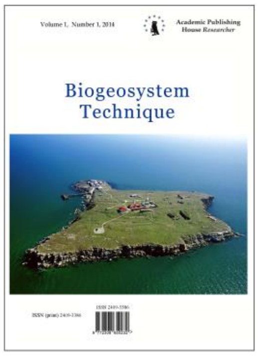

Biogeochemical Characteristics of Soils in the Dzunbayan Oil-Producing Area (Eastern Mongolia)

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Abstract

For balances approach to Sustainable Development Goals, the physical and chemical degradation of soils, biological degradation of soil organic matter in result of oil pollution were studied. The data on the particle-size distribution, the content of chemical components and the number of microorganisms in the soils of the Dzunbayan (East Gobi) oil-producing area are presented. The studied soils are characterized by a bimodal distribution of particles: the main fraction is coarse sand (200–2000 μm), it ranges from 40 to 60 %. It is accompanied by fine silt (2–20 μm), its content reaches 17 %. A high content of chromium, copper, strontium, rubidium, cesium and arsenic was identified in soils, which reflect the geochemical specificity of the geological province. Due to arid climate of the study area soils are characterized by an alkaline reaction pH 8.2–8.7. Soils initially non-saline near the well are highly saline (salinity up to 0.7–1.2 %), due to the mining technologies used. The content of petroleum hydrocarbons (HC) in the soils of the study area varies from 9 to 60 mg/kg with a maximum in the vicinity of the operating well. The microbial community of soils is characterized by a high degree of adaptation to the conditions of the arid zone, salinity, high pH values, at the same time these conditions limit the development of typical representatives of soil microbiocenoses – actinomycetes and, to a greater extent, microscopic fungi. The total number of heterotrophic bacteria (TNH) in the studied soil samples varied within 1.22–3.49 10^6 CFU/g of dry soil, the share of hydrocarbon oxidizing bacteria (HOB) was 12.6–18.9 % of TNH. The content of hydrocarbon oxidizing bacteria (HOB) in the microbial community of soil (within 20 %) corresponds to the concentration boundary of pollution by hydrocarbons for the studied soils (up to 60 mg/kg), which indicates that the microbial community is on the verge of fulfilling the ability to self-purification of the soil. The identified physico-chemical characteristics of the studied soils of the desert zone (dominance of sand fractions, high pH values, salinity) in combination with specific climatic conditions and features of

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the oil composition of the Dzunbayan deposit (prevalence of heavy paraffin fractions) characterize their low potential for self-purification from pollution by hydrocarbons. For sustainable solutions planning of the oil production, transportation, and pollution prevention the transcendental Biogeosystem Technique methodology will be helpful for Land Degradation Neutrality implementation.

Keywords: oil production, soil, salinity, pollution, hydrocarbons, bacteria, Mongolia.

1. Introduction

Aspiration to achieve the Sustainable Development Goals (SDGs) in 2015 adopted by the United Nations (UN) is of high importance to avoid further land degradation and to achieve the lofty goals of Land Degradation Neutrality (LDN) by 2030 is a base of the current and strategic world development framework agendas (Keesstra et al., 2018). Physical and chemical degradation of soils, biological degradation of soil organic matter in result of oil pollution are the worldwide environment and high cost problems (Villacís et al., 2016). The Dzunbayan oil deposit is located in the southeastern part of Mongolia in the province of Eastern Gobi, 440 km east of Ulaanbaatar. It belongs to the central part of the Dzunbayan depression and is located at an altitude of 760 m above sea level. The first geological studies of the Mongolia territory aimed at the exploration and assessment of oil reserves were carried out in the 1920s by American specialists N. Berkeley and S. Morris in the Gobi Desert. On the basis of these and other materials, in 1931, the American geologist D. Tenner predicted the existence of oil deposits in the country (Serebriakov, Kondratiev, 2012). Planned geological exploration at oil deposits in Mongolia began in 1934, with the help and participation of USSR specialists. Two oil deposits were discovered in the south and in the south-east of the country with estimated reserves of 45 million barrels.

By 1941, a geological survey was carried out in south-eastern Mongolia with the participation of the Mongolian geologist J. Dugersuren and the Soviet geologist Yu. Zhelubovsky. Signs of oil-bearing were identified in the Eastern Gobi in the Dzunbayan area, which subsequently led to the discovery of the Dzunbayan oil deposit, which was commissioned in 1948. In terms of their physicochemical properties, Dzunbayan oil is very viscous, heavy, with a high content of resinous components and paraffins, the yield of light fractions is only 5–6 %.

During the operation, more than 260 wells were drilled to a depth of 3 km. New structures favorable for oil and gas accumulations were established. The operation of wells is carried out by subsurface oil pumps. Currently, oil is produced by 168 wells with a flow rate of 30–100 barrels per day. The reserves of the Dunbayan deposit are estimated at 160 million barrels. The extracted oil (550 thousand barrels per month) is transported by tank wagons for processing to China.

Today in Mongolia there is a tendency to worsening conditions for the development of oil deposits associated with the formation depletion with easily recoverable oil reserves. In this regard, there is an increasing interest in technologies that increase the efficiency of deposit development. To increase oil recovery at the Dzunbayan field, it is planned to use the method of water-gas impact.

The aim of this work is to assess the state of the soil in the area of the Dzunbayan deposit, their lithological and mineral composition, as well as the state of the soil microbial complexes involved in the processes of soil self-purification from pollutants. In this paper, we focus on the SDG, and land restoration (Keesstra et al., 2016, 2018).

2. Objects and methods

The study area is located 45 km south of Sainshanda, East Gobi aimak. The exploration area of the Dzunbayan deposit is 5321 km^2, the operational area is 239.5 m^2. Soil samples were taken in December 2018 near one (44°27'07" N and 110°05'17" E) of the 168 wells along the perimeter at a distance of 2 m (polluted sample sites M1–M3), as control we used "unpolluted" sample sites M4 and M5 5 and 30 m from the well, because the main soil contamination occurs when oil is taken. Soil sampling and chemical analysis was carried out in accordance with IS 17.4.3.01-83.

For chemical and microbiological analyzes, soil samples (0.5 kg), from a depth of 0–20 cm, were selected by the envelope method. For particle size analysis, soil samples, dried to the air-dry state, were ground in a porcelain mortar with a pestle with a rubber tip and passed through a 2 mm mesh sieve. The granulometric composition of the samples as a whole was determined by the sieve method (fine earth fraction <2 mm) by laser diffraction (particle size distribution from 0.01 to

2000 μm) on a size analyzer particles (SALD-2300, SHIMADZU, Japan) (Fraunhofer, 1817; Vadjunina, Korchagina, 1973; Shein et al., 2017; Wolform, 2011). The total composition was determined by the X-ray fluorescence method (Pioneer S4, Bruker AXS, Germany) using the silicate analysis technique. The XRF analysis was carried out in the Analytical Centre at the Institute for Tectonics and Geophysics, Khabarovsk, Far East Branch of the Russian Academy of Sciences. Hydrogen test, determination of electrical conductivity (EC) and salinity (S) of soil water extract (1:5) was carried out using a combined meter (Seven Multi S-47k, Mettler-Toledo, Switzerland).

Determination of the mass fraction of hydrocarbons (HC) in the soils was performed according to the method (END F 16.1:2.2.22–98). The hydrocarbon fraction was isolated by extraction with carbon tetrachloride, purified from accompanying polar compounds on a column with aluminum oxide of the 2nd degree of Brockman activity. The measurements were carried out on the concentration meter (KN-2M, Sibekopribor, Russia).

The number of ecological-trophic groups of microorganisms in the soil was determined by methods generally accepted in soil microbiology (Netrusov et al., 2005).

3. Results and discussion

Particle size analysis

The studied soils are friable sandy formations of yellow-orange color. For the particle size distribution significant differences between the samples was not identified. The degree of granulometric differentiation associated with the morphostructural features of the area can be judged from the distribution of particles by volume and the number of particles of a certain size. Figure 1 shows typical particle distribution curves. Evaluation of the particle size distribution in soil by volume criterion showed that the studied soils are characterized by a bimodal particle distribution (Figure 1a). The main fraction is coarse sand (particles with a diameter of 200–2000 μm), it makes up from 40 to 60 % of the volume of particles. It is accompanied by a fine silt (particles with a diameter of 2–20 μm), the content of which reaches 17 %. Its content suggests a rather high ability of soils to adsorb hydrocarbons.

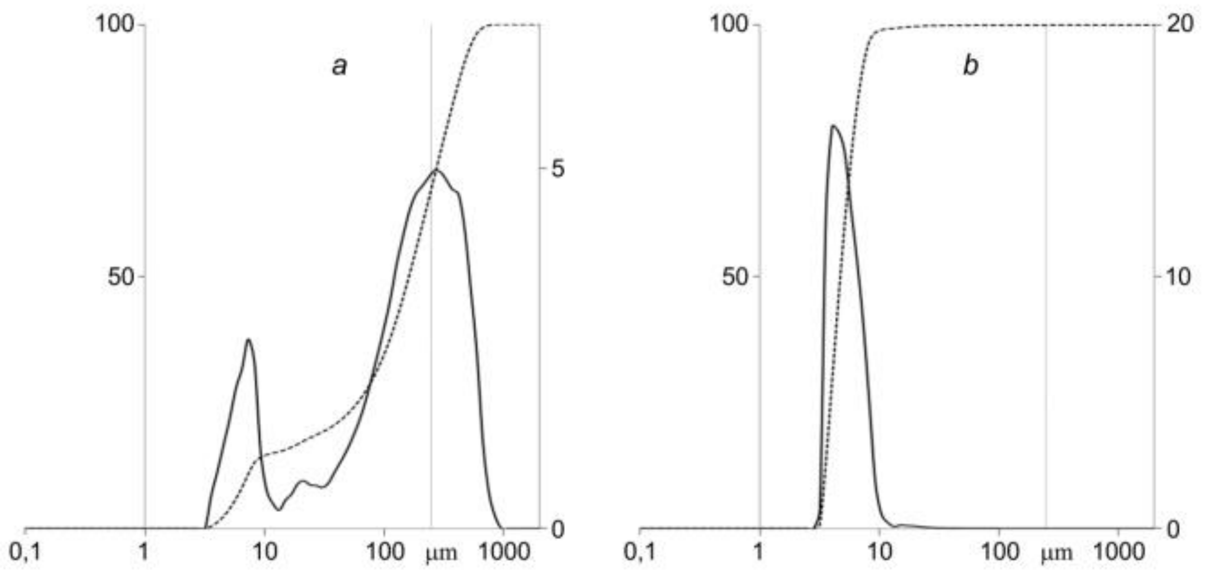

Fig. 1. Particle size distribution in the soils of the Dzunbayan deposit: *a* – by volume of particles; *b* – by the number of particles of a certain size. The solid line is the differential curves (auxiliary axis of ordinates), the dotted line is the integral curves (the main axis of ordinates)

Chemical content of soil

The study of the gross chemical composition of the soil showed the relative uniformity of distribution of the studied chemical components in them. Only in the M2 sampleincreased calcium content in comparison with other samples was revealed (Table 1). The content of iron oxide, which gives the soil an orange color, varied slightly – from 1.8 to 2.4 %, the content of aluminum oxide varied from 11.5 to 11.9 %. All samples revealed an elevated content of sodium oxides (3.6–4.3 %) and potassium (3.6–4.1 %), which is typical of sandy soils in this region (Liu et al., 2016).

The increased sodium content is reflected in the pH of the soil water extract, which is characterized by an alkaline condition and varies from 8.15 to 8.67 (Table 2) as in arid soils and in soils having a marine genesis (He et al., 2014). The alkaline reaction of the soil extract may also be due to the salinity of the soil. The salinity of the soil extract of the studied soil samples ranged from 0.13 to 2.37 ‰ and from 0.07 to 1.19% in soils correspondingly. The maximum salt content 0.7–1.2% is noted near the well (sample sites M1–M3). Such high salinity indicates soils as highly saline ones. With distance from the well salinity drops sharply and at a distance of 30 m is 0.07 % (M5), which corresponds to non-saline soils. Last with a high degree of confidence allows to assert that salinization is associated with mining technologies used.

Table 1. Gross chemical composition of soils in the Dzunbayan deposit (%)

M_xO_y	Sample				
	M1	M2	M3	M4	M5
SiO_2	81.74	75.93	80.16	79.61	82.17
TiO_2	0.37	0.40	0.36	0.32	0.39
Al_2O_3	11.83	11.59	11.70	10.90	11.90
Fe_2O3	2.03	2.43	2.09	1.87	1.83
MnO	0.08	0.08	0.07	0.07	0.06
CaO	0.72	1.75	0.88	0.86	0.89
MgO	0.60	0.84	0.65	0.55	0.60
Na_2O	4.09	4.27	4.01	3.64	3.82
K_2O	3.91	3.60	3.82	3.76	3.93
P_2O_5	0.05	0.06	0.06	0.05	0.06

It is known that electrical conductivity (EC) correlates with such soil properties as the cation exchange capacity of the soil, the content of organic matter and salinity (Li et al., 2011; He et al., 2014). In the studied samples, the EC of the water extract varied more significantly than the pH. Its maximum values were found in sample M2, where the EC was 4.5 mS/cm, as the EC removed from the well, the EC value decreased and at a distance of 30 m it was 0.3 mS/cm. Apparently, such a decrease in the EC value demonstrates a decrease in the HC content in the soil and its salinity.

The content of HC in soils varied from 9 to 60 mg/kg with the maximum content in samples taken at a distance of 2 m from the well (53–60 mg/kg, sampling site M1–M3). It should be noted that the problem of the maximum allowable concentration (MAC) on the content of hydrocarbons for the soil is practically not solved. Therefore, in the work of E.A. Rogozina (2006) it's proposed to assess the degree of pollution of soils by hydrocarbons by the excess of the content of HC over the background value in a specific area and in a specific territory. At the same time, in particular, it is indicated that for areas that do not produce oil, the background content of HC in the soil is 40 mg/kg, and for oil-producing areas – 100 mg/kg.

Under the classification of V.I. Uvarova (1989) according to the content of petroleum hydrocarbons (mg/kg of dry soil) soils can be divided into: clean – 0–5.5, slightly polluted – 5.5–25.5, moderately polluted – 25.6–55.5, polluted – 55.6–205.5, dirty – 205.6–500, very dirty > 500. If to adhere to this classification, then among the samples of the studied soils there are the following: clean – 0; slightly polluted – 2 samples (M4 and M5); moderately polluted – 1 sample (M3); polluted – 2 samples (M1 and M2). As in the case of soil salinization with distance from the well soil pollution by oil drops sharply and at a distance of 5 and 30 m are 15 and 9 mg/kg (M4 and M5), which corresponds to slightly polluted soils. The differences in the content of oil products at sampling sites M1 – M3 are statistically insignificant, which is due to the *a priori* conventionality of the classification boundaries.

Table 2. Physicochemical properties of soils in the Dzunbayan deposit

Sample	Description of soil sample	HC, mg/kg	Water extract		
			EC*, mS/cm	pH	S**, ‰
M1	Clay-sandy, yellow	60	3.09	8.15	1.63
M2	Clay-sandy, bright yellow	58	4.50	8.15	2.37
M3	Clay-sandy, yellow	53	2.68	8.16	1.41
M4	Sandy-clay, light yellow	15	0.74	8.67	0.30
M5	Sandy, light yellow	9	0.32	8.16	0.13

*– electrical conductivity, ** – salinity (salt content)

The content of heavy metals in the studied soil samples is presented in Table 3. According to the standards established for sandy and loamy soils (HS 2.1.7.20.41-06), the excess of chromium at average was 4.2 and arsenic – 9.5 MAC. It should be noted that data on As require clarification: RFA analysis does not give a strictly quantitative assessment of its content in soils. However, the tendency of its accumulation in the soils of Mongolia is noted by many authors. The content of other rated metals did not exceed the MAC limits. The content of strontium, rubidium and cesium, which are in large quantities in the studied soil samples, is not subject to rationing and reflects the characteristics of the mineral composition of the soils of the studied geological province.

Table 3. The content of heavy metals in the soils of the Dzunbayan deposit, mg/kg

Element	M1	M2	M3	M4	M5	MAC
Cr	26	27	27	24	24	6.0
Cu	1	5	4	3	0	3.0
Zn	32	34	32	30	31	23.0
Pb	36	34	35	35	34	32.0
Co	0	2	0	0	0	5.0
Ni	8	9	9	7	7	4.0
Sr	146	186	159	148	155	–
V	21	28	21	16	18	150.0
Rb	159	146	155	157	155	–
Sn	3	3	3	3	3	–
Zr	715	834	837	747	423	–
As	19	20	19	19	17	2.0

Microbiological studies

The full functioning of the soil and its biotic functions are largely determined by the microbial community. Microbiocenoses react very quickly to anthropogenic influences, which makes it possible to quickly identify the most vulnerable ecological zones. Therefore, soil microbial indicators are used for the purposes of environmental monitoring and assessment of the stability of the ecosystem as a whole, especially under various anthropogenic loads.

The microbial community of soils and desert sands is poorly studied, and little attention is paid to their role in self-purification of soil and sand of desert from petroleum hydrocarbons (Kharusi et al., 2016; Joy et al., 2017). Due to the low content of moisture and organic matter, a large temperature range, intensive solar irradiation and high alkalinity, the soil and sands of the desert are a severe environment for the life of microorganisms (An et al., 2013; Baubin et al., 2019; Pointing, Belnap, 2012; Schulze-Makuch et al., 2018; Quoreshi et al., 2019). Therefore, hydrocarbons in desert soils become even more resistant for degradation by microorganisms (Kharusi et al., 2016).

For the studied areas, the dependence of the total number of heterotrophic bacteria (TNH) and hydrocarbon oxidizing bacteria (HOB) on the content of HC in soils was noted (Figure 2). With the distance from the oil well and the decrease in the content of petroleum hydrocarbons (PH), the number of microorganisms in the soil decreased. This is probably due to the fact that in sandy soils that contain little organic matter, PH is practically the only source of organic matter, to whose content bacteria react with a change in abundance. Regular intake of small amounts of PH stimulates the development of the hydrocarbon oxidizing ability of microorganisms (Alrumman et al., 2015; Ebadi et al., 2018; Khan et al., 2018), at the same time, the salinity of soils polluted with hydrocarbons may, on the contrary, suppress the activity of bacteria (Gao et al., 2015). In order to undergo the processes of biodegradation of PH, the number of bacteria in the soil must be at least 10^3 CFU/g (Khan et al., 2018). A smaller number of bacteria indicates a high content of HP, which have a toxic effect, blocking their enzymatic activity (Alrumman et al., 2015; Khan et al., 2018). Bacterial communities clearly reveal the "concentration limit" of pollution of hydrocarbons, below which microbial cenoses still cope with incoming hydrocarbons and stabilize the situation at 40–60 mg/kg of dry soil (Kuznetsova, Dzuban, 2001).

In the case of the studied saline soils, it can be assumed that the microbial community is on the verge of realizing the ability to self-purifying the soil and even a slight increase in the level of PH in the soil can lead to irreversible changes in the composition of the microbial community and, as a result, to chronic soil pollution.

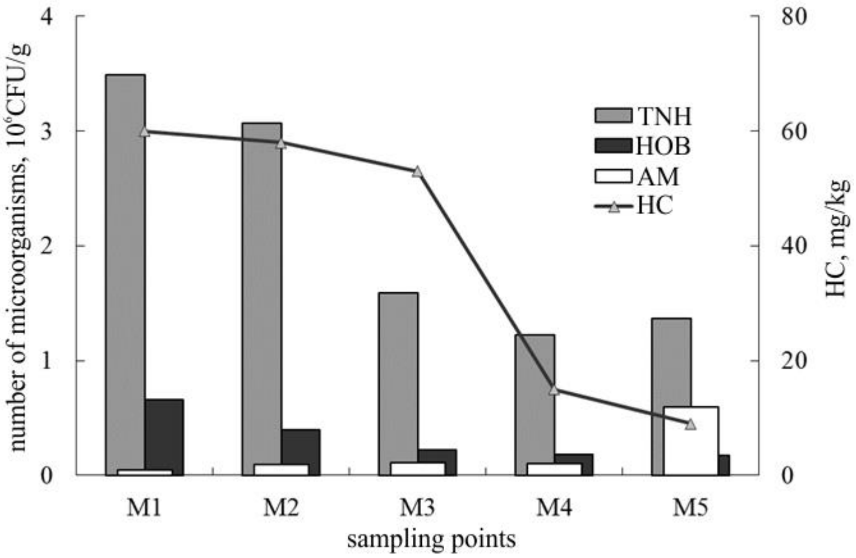

Fig. 2. The number of bacteria and the content of petroleum hydrocarbons (PH) in the soils of the Dzunbayan deposit: TNH – total number of heterotrophic bacteria, 1×10^6 CFU/g; HOB –number of hydrocarbon oxidizing bacteria, 1×10^6 CFU/g; AM – actinomycetes number, 1×10^4 CFU/g

An important indicator of the potential activity of microbial communities involved in the processes of soil self-purification is the content of HOB in it. It is believed that the proportion of HOB in the community of heterotrophic bacteria of background natural objects does not exceed the conditional level of 10 % (Patin, 2001). The proportion of HOB in the microbial communities of the studied soils ranged from 12.6 % in the soil sample M5 to 18.9 % in sample M1, which indicates their adaptation to pollution by hydrocarbons (Atlas, 1993; Peressutti et al., 2003; Zhang et al., 2012).

In addition to changes in the number of bacteria, soil microbiocenoses respond to environmental conditions by changing the ecological and trophic structure (Alrumman et al., 2015). The microbial community of the studied soils was distinguished by an abundance of pigmented colonies (Figure 3) and spore-forming bacteria. Bacteria pigments are secondary metabolites, they protect them from the action of visible light and UV rays (Órdenes-Aenishanslins et al., 2016). Pigmented forms of halophilic bacteria are often found in salt waters and soils (Rekadwad et al., 2017). Bacterial spores allow microorganisms to survive in unfavorable living conditions, they are resistant to elevated temperatures, radiation, chemicals, and tolerate the absence of moisture.

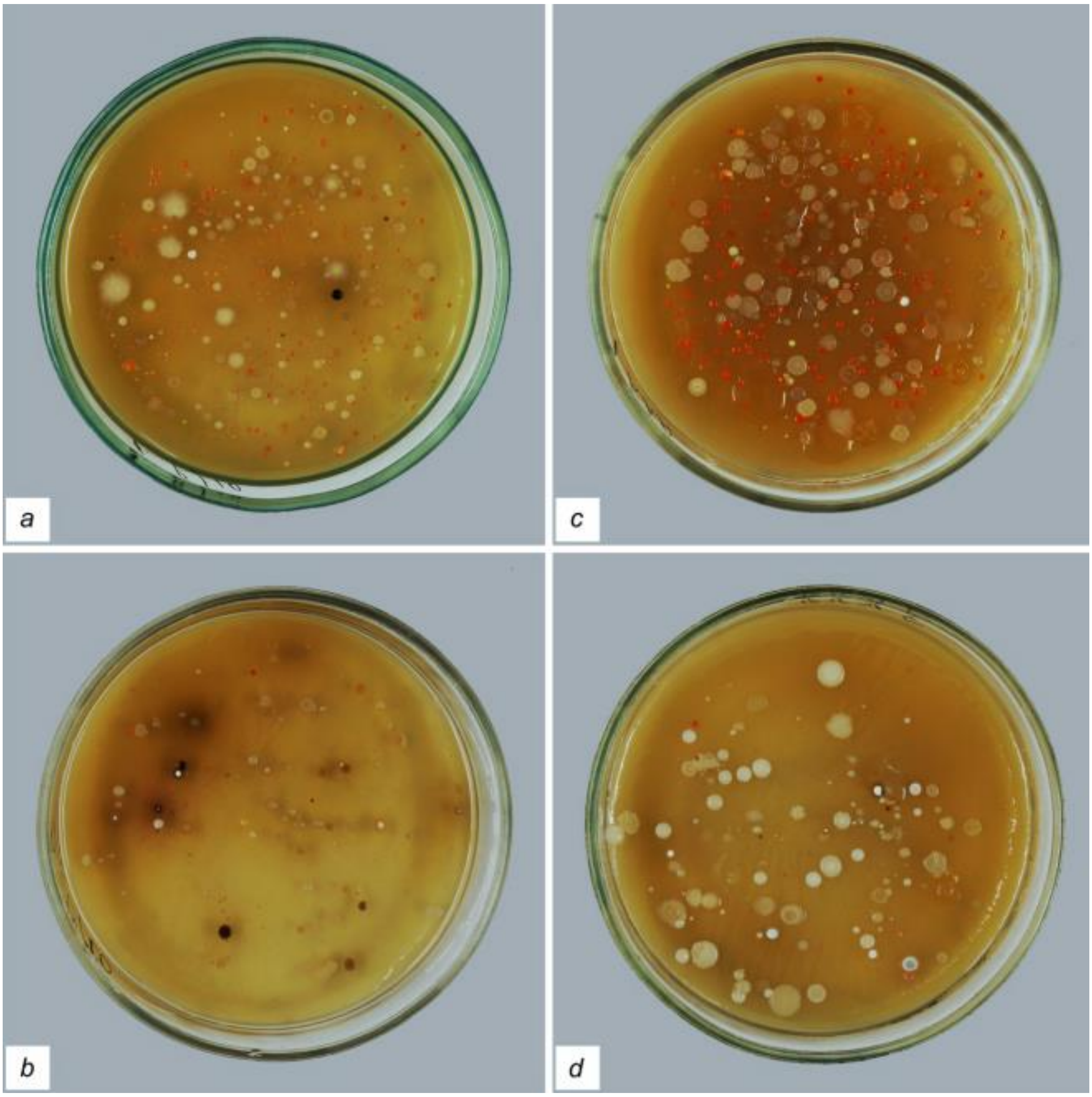

Fig. 3. Pigmented forms of heterotrophic soil microorganisms of the Dzunbayan deposit - carotenoids (pink, orange color), melanin (black, brown): *a*, *b* – colonies of microorganisms assimilating organic forms of nitrogen; *c*, *d* – colonies of microorganisms assimilating the mineral forms of nitrogen (5 and 30 m from the well, respectively)

Typical representatives of soil microbiocenosis are actinomycetes (AM). They predominate in dry alkaline soil (Bhatti et al., 2017). This group of microorganisms is actively developing in soils rich in organic matter, they do not tolerate changes in humidity, temperature and pollution by hydrocarbons (Bao et al., 2019). The number of AM in the studied soils was relatively small (on average 10^4 CFU/g). As we approach the operating well, the number of actinomycetes in the soil decreased from a maximum of 11.9 10^6 CFU/g in sample M5 to a minimum of 0.97 10^6 CFU/g in sample M1, which indicates the inhibitory effect of hydrocarbons on actinomycetes. Microscopic fungi that are typical representatives of soil microbiocenosis of all climatic zones were not detected in the studied soil samples (Bao et al., 2019; Dighton, 1994; Grishkan, Nevo, 2010). Most likely, the main factor affecting the absence of micromycetes in soils is the pH of the environment. The pH values in the studied soils ranged from 8.15 to 8.67. Such pH values do not limit the development of most ecological-trophic groups of bacteria, but they are extremely unfavorable for micromycetes, preferring a slightly acid environment.

According the data of this paper, sustainable solutions need to embed short-term management in long-term landscape planning of oil production, transportation, and pollution prevention. It is necessary to move from excessive exploitation in combination with environmental protection, to sustainable use and management of the soil-water system (Keesstra et al., 2018) via transcendental Biogeosystem Technique methodology (Kalinitchenko et al., 2016). The proposed approach will help to implement LDN and to make a contribution to strategic world development (Keesstra et al., 2018).

4. Conclusion

The identified physico-chemical features of the studied soils of the desert zone (particle size, high pH values, salinity) together with specific climatic conditions and peculiarities of the oil composition of the Dzunbayan deposit (prevalence of heavy paraffin fractions) characterize their low potential for self-purification from pollution by hydrocarbons. However, a microbial community has developed in the soils, adapted to specific conditions: increased insolation, salinity, alkaline reactions of the environment and the presence of petroleum hydrocarbons. The content of hydrocarbon oxidizing bacteria in the microbial community of the soil (within 20 %) corresponds to the concentration boundary of pollution by hydrocarbons for the studied soils (up to 60 mg/kg) and even a slight increase in the level of petroleum hydrocarbons entering the soil can lead to irreversible changes in the composition of the microbial community and as a result – to chronic soil pollution. Sustainable solutions for planning the oil production, transportation, and pollution prevention will help to implement LDN and refine the currently not effective strategic world development principles.

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Биогеохимическая характеристика почв района нефтедобычи Дзунбаян (Восточная Монголия)

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Аннотация. Представлены данные по гранулометрическому составу, содержанию химических компонентов и численности микроорганизмов в почвах участка нефтедобычи Дзунбаян (Восточное Гоби). Исследуемые почвы характеризуются бимодальным распределением частиц: основная фракция – грубый песок (200–2000 мкм), она составляет от 40 до 60 %. Ей сопутствует фракция тонкой пыли (2–20 мкм), содержание которой достигает 17 %. В почвах выявлено повышенное содержание хрома, меди, стронция, рубидия, цезия и мышьяка, отражающее геохимическую специфику данной геологической провинции. Вследствие аридного характера климата исследуемые почвы имеют щелочную реакцию среды pH 8.2–8.7. Незасоленные на контрольных участках рядом со скважиной они сильно засолены (содержание солей достигает 0.7–1.2%), что обусловлено используемыми технологиями добычи нефти. Содержание нефтяных углеводородов (НУ) в почвах исследуемого участка варьирует от 9 до 60 мг/кг при максимуме вблизи эксплуатационной скважины. Микробное сообщество почв по ряду признаков характеризуется высокой степенью адаптации к условиям аридной зоны, солености, высоким значениям pH, в то же время эти условия ограничивают развитие типичных представителей почвенных микробоценозов – актиномицетов и в большей степени микроскопических грибов. Общая численность гетеротрофных бактерий (ОЧГ) в исследованных почвенных образцах варьировала в пределах 1.22–3.49 10^6 КОЕ/г сухой почвы, доля нефтеокисляющих бактерий (НОБ) составляла 12.6–18.9 % от ОЧГ. Содержание НОБ в микробном сообществе почвы (в пределах 20 %) соответствует концентрационной границе нефтяного загрязнения для исследованных почв (до 60 мг/кг), что указывает на то, что микробное сообщество находится на грани реализации способности к самоочищению почвы. Выявленные физико-химические особенности исследованных почв пустынной зоны (доминирование песчаных фракций, высокие значения pH, соленость) в совокупности со специфическими климатическими условиями и особенностями состава нефти месторождения Дзунбаян (преобладание тяжелых парафиновых фракций) характеризуют их низкую потенциальную способность к самоочищению от нефтяного загрязнения.

Ключевые слова: нефтедобыча, почвы, осолоненность, загрязнение, углеводороды, бактерии, Монголия.

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