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The Impact of Natural Resources on the Ecological State of the Environment

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Abstract. *This study investigates the environmental impact of oil contamination on soil properties in the Muradkhanli oil and gas field located in the Imishli region of Azerbaijan. The aim of the research was to determine the levels of petroleum hydrocarbons and selected heavy metals in contaminated soils and to evaluate their ecological significance. Soil samples were collected from different locations and analyzed using standard physicochemical methods and ICP-MS techniques. The results revealed that petroleum hydrocarbon content ranged from 5.3% to 9.2%, indicating a high level of contamination. The soil reaction was slightly alkaline (pH 7.84–8.0). Elevated concentrations of Zn, Cu, and Fe were detected, while most heavy metals remained within permissible limits. The findings demonstrate that hydrocarbon pollution represents a major environmental concern in the study area, whereas heavy metal contamination is comparatively moderate. The results also indicate the limited natural self-remediation capacity of the soils, highlighting the need for effective remediation strategies.*

Keywords: *oil pollution, soil contamination, heavy metals, bioremediation, environmental assessment*

Introduction

In the new millennium, the preservation of ecological balance, the efficient use of natural resources, the protection of water, soil and atmospheric air from pollution have become a universal problem. Along with demographic growth in the world, such worrying issues as a sharp increase in consumption, global warming, ozone layer damage, and depletion of natural resources have also had their impact on environmental thinking and activity. In the context of a global ecological crisis, the preservation of the necessary balance between the economy, society and the environment can be achieved only by forming a new environmentally safe and economically optimal development model-sustainable development. In this context, the main priority at present is the coordination of global, regional and national instruments for the implementation of sustainable development goals. Currently, the international community is applying progressive methods to protect environmental components and solve existing ecological problems.

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Until Azerbaijan regained its independence, no attention was paid to environmental issues in our country for 70 years. Against the backdrop of the constant increase in production, the plants and factories operating in our country emitted an excessive amount of toxic gases into the atmosphere, dumped harmful waste into the environment, polluted the territories of Azerbaijan, and our citizens suffered ecologically, and measures to prevent this were taken. Even at that time, Great Leader Heydar Aliyev emphasized the importance of the plants and factories operating in Azerbaijan operating with minimal damage, causing as little damage to the environment as possible, operating with as little waste as possible, and building and operating them with the latest technologies in order to minimize pollution of nature (Aliyev & Huseynov, 2020).

In recent years, against the backdrop of global warming, agriculture has faced a dangerous risk factor – drought – for important crops. Thus, the sector most affected by climate change is agriculture. Agriculture is largely a field of activity dependent on climate and weather conditions, and is therefore more affected. These effects manifest themselves in the form of an increase in diseases and pests, crop losses, low productivity, and a decrease in water resources. Frequent recurrence of events such as floods and droughts causes great damage to agricultural products. Rising temperatures, humid weather, and an increase in carbon dioxide levels in the atmosphere lead to an increase in many weeds, pests, and diseases. The impact of climate change on agriculture in our country and in the world is most often manifested in the following ways.

• Decrease in productivity
• Increase in demand for irrigation water
• Change in planting and harvesting times
• Increase in diseases and pests (Hajiyeva et al., 2023).

In modern times, the proper use of land and obtaining high productivity from agricultural crops are among the main issues facing specialists. As we know, as a result of successful reforms, land has passed into state, private and municipal ownership (Aslanov, 2004).

For each zone, it is necessary to determine the lower limit of the amount of oil substances in the soil-rocks, above which the soil itself cannot cope with pollutants, its self-cleaning potential is reduced to the required level. This limit can be called the upper limit of the self-cleaning potential of the soil. The notion of the hydrocarbon status of soils involves the proportions of the gas, bitumen, and polyarene components of the total hydrocarbons and their radial and lateral variations. The following types of soil hydrocarbon status were identified: (1) the background (reference) type (2) the first kind of emanation type related to soil degassing (most probably, in an oilfield); (3) the technogenic type developed in the areas of oil spills, contaminated surface runoff, and industrial waste storage; and (4) the emanation type of the second kind related to the degassing and evaporation of spilled oil and other substances in underground karst caves (Pikovskii et al., 2008).

Thus, in order to identify oil pollution, develop effective methods for cleaning disturbed lands, assess quality of measures taken, it is necessary to know the geochemical background, especially the background hydrocarbon components, to study the microbial activity of soils and bottom sediments, to research the response of soil ecosystems to oil pollution, and assess the ability of soils to self-remediation. Furthermore, a comprehensive study of the geochemical background and microbial activity of soils and bottom sediments has a great theoretical and practical importance, since it allows assessing the current state of soils in the cryolithic zone prior to intensive technogenic interference. “In addition, the historical data for the region do not provide reliable baselines to assess current environmental or ecosystem states, presenting challenges to those tasked with measuring impacts” (Lifshits et al., 2021).

Widespread soil contamination with oil and the toxicity of petroleum hydrocarbons to soil biota make it extremely important to study microbial responses to oil stress. Soil metabolites reflect the main metabolic pathways in the soil microbial community. The examination of changes in the soil metabolic profile and metabolic function is essential for a better understanding of the nature of the pollution and restoration of the disturbed soils. The present study aimed to assess the long-term effect of oil on the ecological state of the soil, evaluate quantitative and qualitative differences in metabolite composition between soil contaminated with oil and non-contaminated soil, and reveal biologically active metabolites that are related to oil contamination and can be used for contamination assessment. A long-term field experiment was conducted to examine the effects of various oil concentrations on the biochemical properties and metabolic profile of the soil (Polyak et al., 2024).

One of the main environmental problems in the fuel and energy complex is the breakdown of oil pipelines, their wear and tear, as well as accidents caused by the transportation of crude oil and petroleum products by various means of transport. In recent years, the increase in the export of petroleum products through oil pipelines has led to environmental stress. As a result, the total volume of oil-contaminated land per 1–2 hectares reaches from 3,000 to 10,000 m^2, and the degree of soil contamination varies between 100–400 g/kg. Several factors affect the occurrence of waste: the drilling technology used to conduct drilling operations, the depth of the well, the water system used and the removal of water, natural and climatic factors, etc. During the construction of a 4500–5200 m well, 6-8 thousand cubic meters of drilling waste are generated (Ismailov, 2007).

The environmental consequences of crude oil pollution on soil properties are enormous. Oil pollution is of a great concern the world over. Even at the micro-level, contamination of the environment by crude oil is a global problem in that it leads to loss of vegetation, food insecurity and biodiversity. Based on the detrimental effects of crude oil pollution on soil and plants and its negative effects on food security as well as the environment, this study evaluates the effects of various levels of crude oil pollution grown with different plant species on soil physic-chemical properties (Ijah et al., 2018).

In recent years, projects implemented in the fields of improving the ecological situation in the country, including the efficient use of natural resources, restoration of polluted areas, protection of water resources, expansion of specially protected natural areas, forests and greenery, etc. have played their role in the restoration of ecological components. The soil cover, together with its microworld, is a very complex system that performs universal biological, absorbing, decomposing and neutralizing functions of various pollutants. The composition of the soil block consists of uncontrollable parameters (granulometric composition) and parameters that are practically difficult to control (organic and chemical composition), which allows determining the level of soil fertility and increasing fertility (Mammadov & Hakimova, 2003).

The application of low-emission technologies, restoration of oil-polluted areas, restoration of the ecological condition of water basins, and implementation of greening works have resulted in the improvement of the ecological situation, especially on the Absheron Peninsula, in the cities of Baku and Sumgait. Recently, one of the most demanded strategic products in all countries of the world is oil.

Depending on the degree of contamination, soils are classified as weakly, moderately and heavily contaminated. Oilfield areas are considered to be completely contaminated. In these areas, oil products are absorbed into the soil up to 100 cm along the profile, and the amount of oil varies between 7.8–9% (Mammadov & Khalilov, 2005).

It should be noted that oil loss during extraction, processing and transportation from the soil accounts for 5% of the total production. Comparative studies show that pollution with oil and its products has the greatest impact on the soil ecosystem. Thus, oil pollution has a very strong impact on the biodiversity and biological balance of the soil ecosystem, causing irreversible changes (Banks & Schultz, 2005; Dawson et al., 2007).

Methods

The research was conducted using generally accepted scientific methods. The study focused on the investigation of physicochemical, agro-physical, and biological properties of reclaimed soils. The main parameters analyzed included soil pH, salinity, salt migration, residual hydrocarbon content and its decomposition, as well as the number of microorganisms, which are important indicators of soil productivity. The following chemical analyses were performed on the collected soil samples: hygroscopic moisture content; granulometric and micro-aggregate composition (according to N.A. Kachinsky); absolute water density (D.V. Ivanov); carbonation; humus content (according to Tyurin); and pH measured in water suspension. The degree of contamination of oil-polluted soils was determined under laboratory conditions using the decantation method with benzene. The conducted chemical analyses provided a basis for assessing the current condition of the soils and ensured the scientific validity of the research.

Results and Discussion

The State Oil Company of Azerbaijan is currently implementing pilot projects aimed at the remediation of oil-contaminated lands. It is recommended to carry out greening and restoration measures in the area of an old oil field affected by oil waste contamination. The study area is a flat terrain with smooth relief, located inland from the sea and heavily polluted by oil. The soils are characterized by a light granulometric composition, low nutrient content, and salinity, and are located in the vicinity of oil fields. It should be noted that oil wells in the area were previously drilled using traditional methods. The depth of soil contamination ranges from 10–15 cm, and in some locations reaches 70–120 cm. Spilled oil remains in the soil for many years without complete degradation. The study area is the Muradkhanli Oil and Gas Field located in the Imishli region, which is affected by pollution resulting from oil production, processing, and transportation activities (Figure 1).

Figure 1
Oil-contaminated area

Soil samples were collected from the study area, and their coordinates were recorded for chemical analysis. To determine the concentrations of hydrocarbons and heavy metals, the samples were transferred to the soil analysis laboratory of “AzLab” LLC under the Ministry of Ecology and Natural Resources of the Republic of Azerbaijan. The sampling coordinates were: No. 3 400 4 3.072 and No. 4 47 51 2189. The samples were analyzed using an ICP-MS 7700 inductively coupled plasma mass spectrometer. The results, including the hydrocarbon content, are presented in Table 1.

Table 1
Amount of hydrocarbons (%)

	N3	N4
Petroleum hydrocarbons (%)	9,2	5.3

The soil samples collected from the experimental area were found to be alkaline based on the soil solution analysis. The average pH ranged between 7.84 and 8.0. The concentrations of trace elements are presented in Table 3. According to Clark's standards, the levels of heavy metals in these soils are within permissible limits.

Previous studies have shown that microelements are predominant in some oil-contaminated soils. Among heavy metals, the most toxic elements for humans and animals include Hg, Pb, Cd, Zn, Cr, Ni, and Cu.

Soil contamination with heavy metals may originate from various sources, leading to the accumulation of toxic substances in the soil. Studies indicate that the concentrations of microelements vary among different soil types, resulting in a wide range of fluctuations. Therefore, biological responses to microelements also differ. Heavy metals, as major environmental pollutants, play a significant role in soil contamination processes.

Figure 2
Determination of toxic substances in soil and plant samples

The sampling was not conducted by "AzeLab". The samples were delivered to the laboratory by a representative of the customer. All analyses were performed at the "AzeLab" laboratory. These results apply only to the specified samples. Unsigned results are not valid. The laboratory reports may not be reproduced, distributed in incomplete form, or used for commercial or advertising purposes.

Table 2
Soil sample analysis results

No.	Indicators	Unit of measure	Sample name and quantity of components			
			N-1	N-2	N-3	N-4
1	Zn	mg/kg	326.6	47.4	232.7	58.3
2	Co	mg/kg	13.2	10.8	<LOD	8.4
3	Ni	mg/kg	15.7	30.2	<LOD	23.2
4	Cr	mg/kg	63.7	29.9	47.6	19.0
5	Mo	mg/kg	6.9	<LOD	19.3	2.6
6	Cd	mg/kg	0.75	<LOD	<LOD	2.9
7	Cu	mg/kg	85.4	98.1	85.9	47.2
8	Fe	mg/kg	140 800	36 400	110 600	25 880

9	Mn	mg/kg	953	749	810	836
10	Petroleum hydrocarbons	mg/kg	3 280	445	9 600	53

Table 3
Plant sample analysis results

No.	Indicators	Unit of measure	Sample name and quantity of components
			Plant
1	Na^+	mg/kg	24.5
2	K^+	mg/kg	2.72
3	Ca^{2+}	mg/kg	5.04
4	Mg^{2+}	mg/kg	18.5
6	Mo	mg/kg	0.013
7	B	mg/kg	0.79
8	Cu	mg/kg	0.002
9	Fe	mg/kg	0.23
10	Mn	mg/kg	0.09
11	Zn	mg/kg	0.02

Table 4
Amount of hydrocarbons in contaminated soil

No.	Indicators	Unit of measure	Sample name and quantity of components	
			N3	N4
1	Na^+	mg/kg	232.7	58.3
2	K^+	mg/kg	<LOD	8.4
3	Ca^{2+}	mg/kg	<LOD	23.2
4	Mg^{2+}	mg/kg	47.6	19.0
6	Mo	mg/kg	19.3	2.6
7	B	mg/kg	<LOD	2.9
8	Cu	mg/kg	85.9	47.2
9	Fe	mg/kg	110 600	25 880
10	Mn	mg/kg	810	836
11	Zn	mg/kg	9 600	53

Conclusion

The results of this study show that soils in the Muradkhanli oil and gas field are significantly affected by petroleum contamination. The hydrocarbon content (5.3–9.2%) indicates a high level of pollution, while the slightly alkaline pH (7.84–8.0) reflects changes in soil properties under contamination conditions. Although elevated levels of Zn, Cu, and Fe were detected, most heavy metals remained within permissible limits, suggesting that hydrocarbon pollution is the main environmental concern. However, the presence of these elements may pose potential ecological risks in the long term. The findings also indicate the limited natural self-remediation capacity of the soils, highlighting the need for effective remediation strategies such as bioremediation and phytoremediation. Further studies with expanded sampling and long-term monitoring are recommended.

Declaration of Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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