UDC 911.52 DOI 10.52578/2305-9397-2024-4-2-145-157
IRSTI 39.19.31

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ANALYSIS OF THE LANDSCAPE AND ECOLOGICAL STATE OF THE ATYRAU REGION

ANNOTATION

The arid landscape of the Caspian Lowland (Atyrau region) is a very fragile natural geosystem of interrelated components. The transformation of arid landscapes due to the scale of anthropogenic impact leads to desertification processes. The research is devoted to the analysis of the landscape-ecological state of the Atyrau region, characterized by arid landscapes subject to significant anthropogenic impact. The relevance of the study is due to the need to develop effective methods for monitoring and managing natural resources for the sustainable development of the region. The purpose of the study is to assess the state of natural and anthropogenically disturbed landscapes, identify the main factors of their transformation and offer recommendations for improving the ecological situation of the region. Research methods included the use of a system of general scientific methods, such as landscape analysis, synthesis and cartographic tools. The main materials of the study consisted of landscape and other maps of the territory, as well as statistical data. The research results showed the significant influence of oil production, agriculture and other anthropogenic factors on the ecological state of the region's landscapes. The main problems associated with soil, water and air pollution, vegetation degradation and erosion processes have been identified. Measures have been proposed to improve the landscape and ecological condition of territories exposed to anthropogenic activities.

Key words: *arid landscapes, technogenic impact, petroleum products, agricultural impact, ecological state.*

Introduction. The swift growth of human activities has led to a significant increase in land use, altering landscape structures and creating substantial ecological risks. These risks are crucial considerations for ecosystem conservation and the pursuit of sustainable development [1,2]. Natural landscapes play a vital role in ecosystems, where their stability and diversity are fundamental to sustaining regional ecological functions. A scientific and well-founded assessment of ecological risks within regional landscapes is essential for tasks such as evaluating ecosystem safety, optimizing functional zoning, and developing landscape safety models [3].

In this regard, landscape-ecological data is gaining importance for the scientific justification of natural resource management and sustainable territorial development. This is facilitated by the capabilities of landscape ecology and geography, which offer a detailed examination of the structure, dynamics, and functions of contemporary landscapes. Comprehensive geo-ecological landscape studies serve as a crucial mechanism for optimizing natural resource usage and should be grounded in an understanding of the interactions between humans and nature, as well as the natural-economic systems shaped by anthropogenic impacts on natural complexes and environmental components [4]. In addition, a comprehensive landscape-ecological analysis necessitates multi-faceted geographical research that addresses four key aspects: the natural environment, the structure of landscapes and their transformation due to anthropogenic influences from industrial and agricultural activities, and socio-economic conditions [5].

The alteration of landscapes in the area under study is closely associated with activities such as the development of oil and gas fields, the construction of roads, power lines, and pipelines, as well as deforestation and widespread livestock grazing. According to researchers [6,7], landscapes altered by economic activities are termed anthropogenic modifications, representing a series of transformations of the original structures, which vary based on the intensity and duration of human influence.

Research examining the spatial and temporal changes in landscape-ecological risks and ecosystem services emphasizes the need for integrated approaches in environmental monitoring and management, particularly in areas with high levels of human and socio-economic activity [8]. Evaluating and forecasting the impacts of land use and climate change on landscape-ecological risks through models like the landscape loss index relies on quantitative assessment and modeling, supporting sustainable land resource management [9].

Utilizing open data to develop thematic maps that evaluate key ecological features of landscapes highlights the importance of geospatial information in supporting nature conservation initiatives and the preservation of ethno-ecosystems in the face of growing human impact. This method demonstrates the valuable potential of such data in tackling a range of environmental challenges [10].

Based on Earth remote sensing data from various years and field studies, a comprehensive assessment of the dynamics of the ecological situation at oil fields was conducted. Research has shown the negative anthropogenic impact of oil extraction on the environment and identified the relationship between oil production distribution and the main soil types of the studied area [11].

Due to the large-scale contamination of soils with oil and petroleum products, studies on the quantitative and qualitative changes in rock properties are extremely relevant. It is known that the transformation of oil begins almost immediately after it reaches the ground surface. Its movement and transformation processes occur at different rates depending on numerous factors. However, the result of this transformation is not simple oil decomposition but the formation of new compounds, some of which may be more toxic [12].

The development of hydrocarbon resources in the Atyrau region dates back more than 110 years. The initial oil discovery occurred in 1899 at the Karashungul site, located in the Zhylyoi district. During the following decade, 21 wells were drilled, producing approximately 5,000 tons of oil annually. From 1911 to 1915, several other fields, including Dossor, Makat, and later Kulsary, Koschagyl, Karaton, Baishonas, Iskene, Sagiz, Koshkar, and Shubarkuduk, were brought into production. By 1970, exploration had led to the identification of 42 hydrocarbon deposits across the region, comprising 32 oil fields, 7 oil and gas combined fields, and 3 gas fields [13]. The discoveries made during the 1970s and 1980s were pivotal in shaping the hydrocarbon industry that became the backbone of independent Kazakhstan's economy.

Beyond oil and gas, significant reserves of uranium and shell limestone were uncovered along the Caspian Sea's coast and continental shelf. This prompted a surge in extraction activities, which in turn fueled the establishment of new towns, expansion of settlements, and the development of infrastructure including railroads, highways, and pipelines. Alongside these developments, agricultural activities also saw considerable growth.

Overall, around 70 oil and gas fields have been explored, prepared, and are currently operational in the region. The annual oil production exceeds 29 million tons, with plans to potentially double this amount in the future. Forecasts indicate that oil production from the Kazakhstani shelf alone could reach up to 150 million tons per year [14].

Since the initial discoveries, over 100,000 wells have been drilled across the region, leading to the development of extensive infrastructure. This includes pipelines for transporting oil, gas, and water, as well as power and communication lines, road networks, quarries, and the establishment of work settlements and urban areas. It is noteworthy that in 1990, the region had no gas industry, and oil production made up only 13% of total output.

During the 1990s, there was a slight dip in production levels, which contributed to a temporary reduction in environmental pressures from industrial activities. However, this trend has since reversed, with rising demand for resources leading to increased emissions, wastewater discharge, and the release of toxic waste, thereby exacerbating the region's environmental challenges [13].

In recent years, research has underscored the importance of a systematic, multi-level approach to analyzing and managing landscape-ecological risks. For instance, it has been shown that effective restoration and resource allocation can be achieved by prioritizing areas based on ecological benefits and cost-effectiveness [15]. Studies also highlight that the complexity of landscapes, particularly in regions with diverse ecological functions, necessitates scale-sensitive approaches that consider spatial and temporal dynamics to capture the intricate interactions among landscape elements [16]. Moreover, evaluating the ecological risks associated with human activity and climate change provides valuable insights into managing landscapes sustainably and mitigating degradation [17].

Integrated frameworks, such as the patch-matrix model, enhance the assessment of habitat quality, connectivity, and biodiversity, which is crucial in regions with high ecological potential [18]. GIS-based approaches have proven indispensable for mapping and analyzing ecological states, offering spatial precision in evaluating the impacts of industrial and development activities on ecosystems [19]. Additionally, ecological networks and risk assessments further support sustainable landscape management by enhancing landscape connectivity and minimizing fragmentation [20].

Such comprehensive approaches allow for a thorough assessment of ecological risks and the development of targeted conservation and restoration strategies, ultimately supporting the resilience of landscapes impacted by both human and natural factors.

Materials and research methods. For assessing the landscape and ecological state of the Atyrau region, a comprehensive methodological framework was developed based on approaches that analyze landscape ecological risks, complex landscape structures, and multi-factor interactions. Studies on similar regions underscore the importance of employing multi-level, integrative methods to accurately assess ecosystem changes influenced by anthropogenic and climatic factors.

Research demonstrates that prioritization methods which balance cost-effectiveness and ecosystem benefits can effectively identify areas in need of ecological restoration. This approach allows for efficient resource allocation and can be adapted for regions facing significant human impact, such as Atyrau [15]. Scaling and complexity analysis further reveal the necessity of considering spatial and temporal scales for examining large, heterogeneous landscapes. Methods such as “coarse-graining” enable the aggregation of fine-scale information to reveal broader landscape patterns, which is essential for understanding the overall function and structure of ecosystems in complex landscapes [16].

Moreover, findings indicate that human activity and climate significantly elevate ecological risks. By using metrics such as population density and temperature variation, researchers have identified how these factors intensify ecological stress, aiding in the identification of critical zones for ecological protection and informed management practices [17]. In terms of resilience, studies show that modeling landscape response to disturbances is valuable for assessing the capacity of ecosystems to recover from anthropogenic impacts, which is crucial for developing strategies that ensure long-term ecological stability [21].

Approaches that use spatial landscape metrics, such as the patch-matrix model, have proven effective in evaluating habitat structure, fragmentation, and biodiversity. This is especially relevant for analyzing habitat quality and connectivity in regions like Atyrau [18]. GIS-based methods for indicating landscape-ecological states are also highlighted as essential for assessing spatial distribution of ecological conditions, providing valuable data for managing landscapes impacted by both tourism and urban development [19].

Landscape ecological risk assessments further support the development of ecological networks, emphasizing the importance of landscape connectivity and ecological corridors in mitigating ecological risks. These networks are especially valuable in both rural and urbanized settings, helping to preserve connectivity and reduce ecological fragmentation [20].

Finally, research in landscape ecological health assessment proposes several frameworks, such as pressure-state-response models, which examine ecosystem structure, function, and resilience. These frameworks are effective for comprehensive ecosystem health assessments across diverse landscapes, providing a structured approach to understand the interplay between human activities and natural processes [22].

Integrating these methodologies enables a comprehensive landscape-ecological assessment for the Atyrau region, identifying interactions between human influence, climate variables, and landscape structure. This holistic approach is critical for pinpointing high-risk areas and formulating targeted conservation and restoration strategies.

A system of general scientific methods was used to conduct landscape-ecological research, including systematic, descriptive, statistical methods, as well as special methods, such as landscape-ecological research techniques: primary landscape analysis and synthesis, and landscape-structural analysis [23]. For the creation of the landscape-ecological information system, cartographic tools from the ArcGIS 10.8 desktop GIS package were applied. The research materials included landscape and other thematic maps of the territory at scales of 1:1,500,000 and 1:2,500,000, as well as statistical data.

Results and discussion. The geological-geomorphological characteristics of the territory, combined with the arid conditions shaping the main landscape-forming factors and the development of zonal physical-geographical processes, have determined the homogeneity of the spatial organization of this area. Atyrau Region is predominantly located in the desert zone. It contains 177 types of landscapes, 7 of which are semi-desert, 161 are desert types, and 9 are intrazonal (valley) landscapes. The primary structure of the landscapes is composed of marine lowland plains of the semi-desert and desert types, formed by hydrological agents along with zonal differentiation factors and landscape-forming processes. These natural-territorial complexes cover about 70% of the territory. The dominant landscapes consist of marine plains with aeolian reworking, accounting for 33% of the entire landscape diversity. Subdominant natural-territorial complexes include marine gently sloping and sloped plains, which form 26.5% of the landscape diversity. Marine primary plain landscapes cover 6%. Alluvial, lake-alluvial, and deluvial-proluvial lowland plains of the semi-desert and desert types are less widespread, accounting for about 18% of all natural-territorial complexes. Lake-alluvial and alluvial-proluvial lowland desert plains constitute 0.5% and 1% of the landscape diversity, respectively (Figure 1) [24].

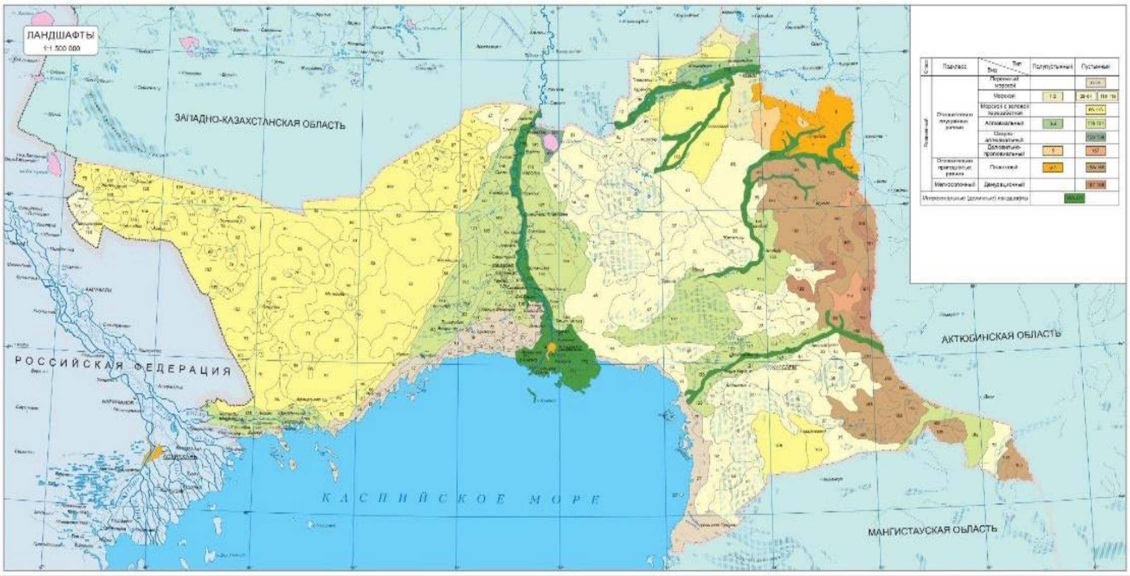

Figure 1 – Landscape Map of Atyrau Region

One of the key indicators of the current environmental state of the region is the anthropogenic factor and its associated negative consequences. These include air pollution, radiation conditions, pollution of underground and surface waters, the state of drinking water supply, soil pollution, and degradation of the soil and vegetation cover.

The Atyrau Region hosts more than 250 industrial enterprises, spanning sectors such as oil refining, chemical production, and machinery, among others. These industries collectively operate over 5,000 stationary sources that contribute to environmental pollution. While oil and gas extraction activities occur throughout most of the region, the primary hub of production is concentrated in the Zhylyoi district. Enterprises involved in oil and gas extraction and refining are responsible for the majority of air pollution in the region, accounting for over 80% of the emissions. Figure 2 illustrates the various sources of anthropogenic environmental impact.

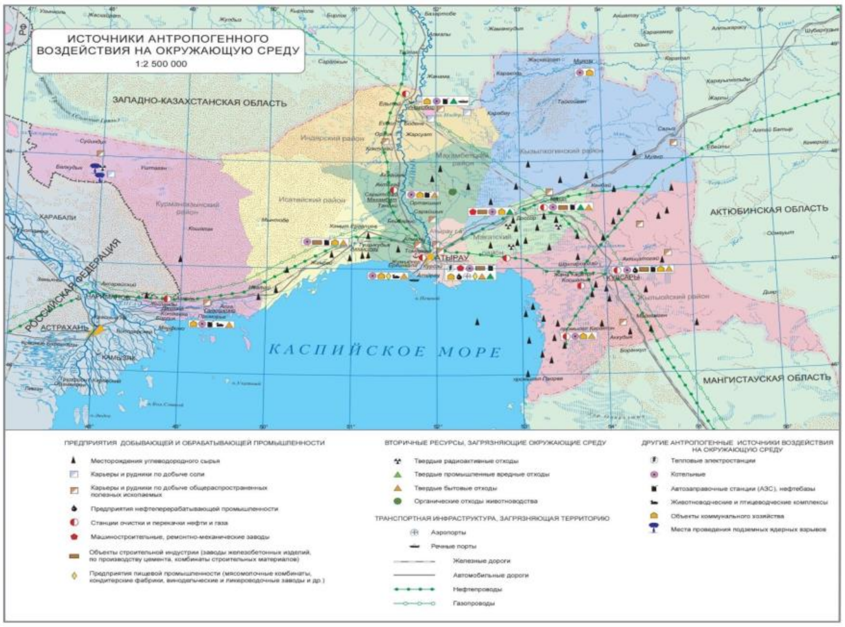

Figure 2 – Sources of Anthropogenic Impact on the Environment [24]

The primary source of anthropogenic pressure in the region is linked to the extraction and processing of hydrocarbon resources. The majority of these deposits are situated in the eastern and southeastern parts of the area. By 2002, several active oil fields had reached their peak production capacity. Future expansion in onshore output is expected to be driven by intensified efforts in developing key fields, such as Tengiz.

Studies suggest that the largest growth in discovered reserves and hydrocarbon production will likely originate from the Caspian Sea basin. In the Kazakh sector of the Caspian Sea, more than 400 geological structures have been identified, with over 120 showing potential for oil and gas extraction. Although these structures are distributed throughout the basin, the northern part, known as the Pre-Caspian Depression, is considered the most promising area, believed to hold up to 75% of the region's total geological resources. Another significant area is the North Caspian Uplift, located near the western coastline of the Atyrau region, which is estimated to contain around 20% of the oil and gas resources within the Kazakh sector of the Caspian Sea (Figure 3).

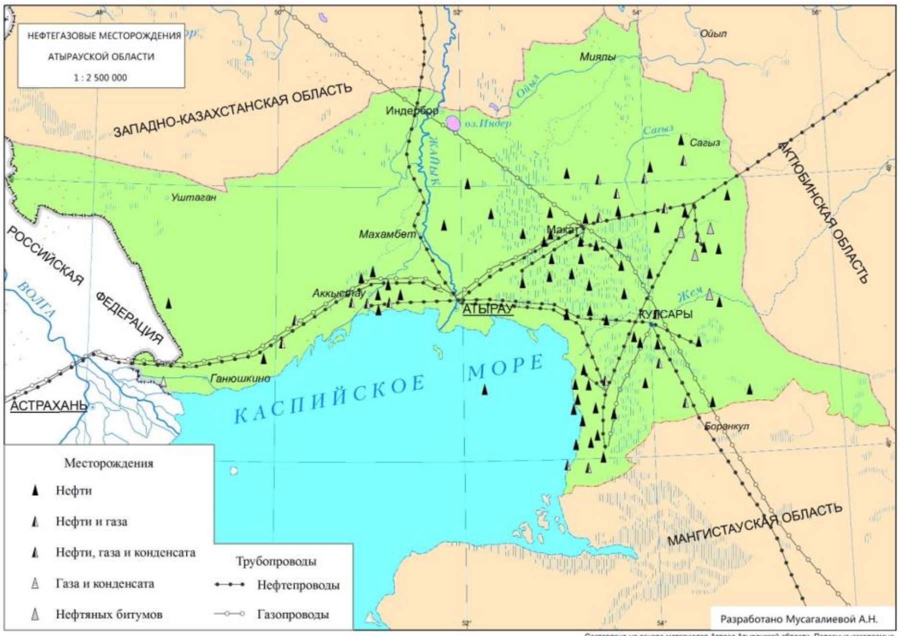

Figure 3– Oil and Gas Deposits in Atyrau Region

The Kashagan field is one of the largest and most complex offshore oil fields ever discovered, making it a critical hydrocarbon deposit. This vast reservoir has estimated geological reserves of 4.65 billion tons (equivalent to 36.6 billion barrels) and covers an area roughly 75 km in length and 45 km in width [25].

Economic growth in the Atyrau Region is heavily reliant on the mining sector, particularly the extraction and partial processing of hydrocarbon resources. According to statistics [26], the region produced 47.8746 million tons of oil (including gas condensate) in 2021, contributing to 55.7% of Kazakhstan's total output of 85.8794 million tons. From 2012 to 2021, oil production in the region, including gas condensate, increased by 18.7851 million tons, marking a growth of more than 1.5 times (Figure 4).

Figure 4– Dynamics of Oil Production, Including Gas Condensate, in Atyrau Region from 2012 to 2021

The air quality in the Atyrau Region is primarily influenced by the volume of pollutant emissions from oil and gas operations, energy and utility sectors, transportation, and other industrial activities. Data from the Department of Ecology of Atyrau Region indicates that 80-85% of these emissions are generated by enterprises in the oil and gas sector. Key contributors to air pollution include major companies such as Tengizchevroil LLP, Intergas Central Asia JSC, North Caspian Operating Company N.V., KazTransOil JSC, Atyrau Oil Refinery LLP, and Embamunaigas JSC.

In 2021, the number of stationary pollution sources in the region increased to 28,904 units, resulting in total emissions of 160.2 thousand tons [27]. The primary pollutants released by these facilities include carbon monoxide, particulate matter, sulfur dioxide, hydrogen sulfide, and nitrogen oxides.

Table 1 – Emissions of Key Pollutants for 2020-2021, thousand tons

Year	Sulfur dioxide	Hydrogen sulfide	Nitrogen oxides	Particulate matter	Carbon monoxide
2020	41,2	0,2	20,4	6,3	44,9
2021	49,5	0,2	20,2	2,8	39,2

In addition to stationary sources, a significant contribution to air pollution comes from mobile sources, namely motor vehicles. According to the Bureau of National Statistics of the Republic of Kazakhstan, in 2021, there were 97.9 thousand passenger vehicles and 20.0 thousand trucks registered in Atyrau Region.

Monitoring of radioactive contamination in the near-surface atmospheric layer of Atyrau Region was conducted at 3 meteorological stations (Atyrau, Peshnoy, Kulsary) and 1 automatic post by taking five-day air samples using horizontal tablets. The average gamma radiation levels in the region's near-surface atmosphere ranged from 0.08 to 0.33 μSv/h. On average, the gamma radiation level across the region was 0.12 μSv/h, which was within acceptable limits.

There are currently 840 closed-type ionizing radiation sources distributed across 31 industrial enterprises in the region. Once these sources reach the end of their service life, they will be transferred to specialized disposal sites. In addition, the region is home to 55 medical facilities.

Furthermore, the former Azgir nuclear test site, previously referred to as "Galit," is located within the Azgir rural district of the Kurmangazy district. This site covers an area of 300 hectares and comprises 10 technological platforms as well as the "Yava" facility.

Furthermore, the test site area was a location for the fall of rocket stages, leading to contamination of the territory with rocket fuel components (heptyl, benzo[a]pyrene, hydrocarbon and nitrogen compounds). All these factors have had a negative impact on the environment and living conditions in the region.

The ecological condition of surface waters in Atyrau Region is influenced by the water flow regime of rivers, the development of the industrial and agricultural sectors, the presence of water treatment facilities, and the dynamics of water intake, consumption, and discharge of wastewater.

Table 2 – Surface Water Quality in Atyrau Region for 2021 and 2023, mg/dm³ [27]

Name of Water Body	Water Quality Class		Parameters	Concentration, mg/dm³
	2021	2023		
Jaiyk	4 class	4 class	Magnesium	30,7
Emba	5 class	4 class	Suspended Solids	152,3
Peretaska	4 class	4 class	Magnesium	30,5
Iaik	4 class	4 class	Magnesium	37,6
Kigash	5 class	3 class	Suspended Solids	26,4
Sharanova	5 class	3 class	Suspended Solids	26

Within the period from 2021 to 2023, the quality of water of the Ural River, Peretaska channels, and Yaik changed insignificantly and corresponded to the 4th class of quality according to the levels of pollution. In the Kigash River and Sharonova channel, the range of substantial improvement of surface water quality happened and passed from the 5th to the 3rd pollution category. This transition represents a significant reduction in water pollution, reflecting a general improvement in the ecological status of those waters.

The main pollutants influencing the aquatic ecosystems of Atyrau Region include magnesium and suspended particulate matter. The mentioned trend of this pollutants can be explained by several facts, one of which is an increase in the quality of wastewater management system. More sophisticated treatment methods adopted both by industrial sectors and municipal institutions have likely played a role in reducing the amount of pollutants discharged into the water bodies. Besides that, industrial emissions control and increased regulation have been the supporting factors for this change [28]. Soil cover disturbances are technogenic, which is the influence of industrial enterprises on extraction and processing of hydrocarbon resources, construction materials such as sand, stone, and clay, among others, along with transport.

Table 3 – Heavy Metal Content in Soils of Atyrau Region, mg/kg [27]

Settlement |	Zinc	Copper	Chromium	Lead	Cadmium	Petroleum Products
Atyrau city	0,062-0,118	0,07-0,113	0,004-0,018	0,001-0,004	-	-
village of Zhanbai, Zaburun'e, Jammansor	1,6-2,75	0,01-0,58	0,0-0,1	0,04-0,16	0,06-0,18	-
Deposits: Dossor, Makhat, Koshagyl, village of Zhanbai, village of Zaburun'e	1,7-4,0	0,22-3,0	0,947-2,49	0,06-3,39	0,1-0,35	1,45-2,35

The contamination of soils by oil and chemical pollutants related to the extractive industry is considered to be of danger class 3-4 regarding the area of its impact, while its areal distribution is still scattered and limited. This type of soil pollution is widely found in areas of exploited oil fields, both within the area of production and primary pipelines, and is related to the unsustainable exploitation of natural resources. Soil contamination is a concern throughout every phase of oil field development, beginning with exploratory drilling and extending through the construction and operation of oil and gas wells, as well as the transportation and storage of raw materials. The primary pollutants include crude oil and mineralized wastewater generated by production processes.

The high content of paraffin and resin-silica hydrocarbons in crude oil is the main factor contributing to the formation of bitumen crusts in the soil profile. These compounds are low in mobility, creating hotspots of persistent environmental pollution. The toxic substances from oil that contaminate the soil include carbon monoxide, hydrogen sulfide, nitrogen oxides, carbon oxides, phenol, ammonia, and various mineral salts. They accumulate in the soil profile and affect plant development, both through direct action of naphthenic acids and other hydrocarbons and mineral salts.

The utilized agricultural land fund covers an area of 322.7 thousand hectares, governed by specific legal regulations designed to safeguard it from conversion to other uses. This framework aims to preserve and enhance soil fertility. The agricultural land is categorized as follows: 7.0 thousand hectares of arable land, 6.7 thousand hectares of fallow land, 50.5 thousand hectares of meadows, 3,031.3 thousand hectares of pastures, and 0.3 thousand hectares allocated for perennial crops and orchards [29].

Soil erosion is the most widespread type of degradation in the region. The development of soil erosion processes is influenced by a combination of natural conditions (climate, topography, soil composition, etc.) as well as the degree of anthropogenic impact and the intensity of land use. The area of eroded land totals 3,133.9 thousand hectares.

Deflation processes are evident in the destruction of the soil-vegetation cover, changes in microrelief, and the development of deflation hotspots. The causes of degradation include overgrazing and the cutting of shrubs.

The analysis of the ecological consequences of oil and gas extraction has revealed potential environmental issues arising from the interaction between oil and gas industry facilities and the surrounding environment. It has also allowed for the categorization of the main anthropogenic impact factors according to their influence on landscapes and the overall natural environment.

The map of the current ecological state of the landscapes in the Atyrau region presents subclasses and dominant types of landscapes, along with their current ecological conditions. Large areas are occupied by landscapes in satisfactory ecological condition, primarily located in the southeastern, western, and central regions. In the eastern part of the area, marine and alluvial landscapes, used for industrial purposes, predominate. This region hosts hydrocarbon deposits, including Dossor, Makhat, Eskene, Baishonas, Koshagyl, Kulsary, Karaton, and Prorva.

In the oil and gas extraction areas along the northeastern coast of the Caspian Sea and in the eastern part of the region, there is a high density of aboveground and underground pipelines, which alters the morphological structure of the landscapes and contributes to deflation, water erosion, and salinization processes. Aeolian plains dominate these landscapes, which are heavily used for grazing. Uncontrolled livestock grazing and high load levels lead to significant pasture degradation, disrupting the vegetation cover, promoting deflation processes, and creating exposed sands and shifting dunes. The landscapes of primary marine and coastal plains, particularly in areas of hydrocarbon extraction and transportation, exhibit a tense ecological state (Figure 5).

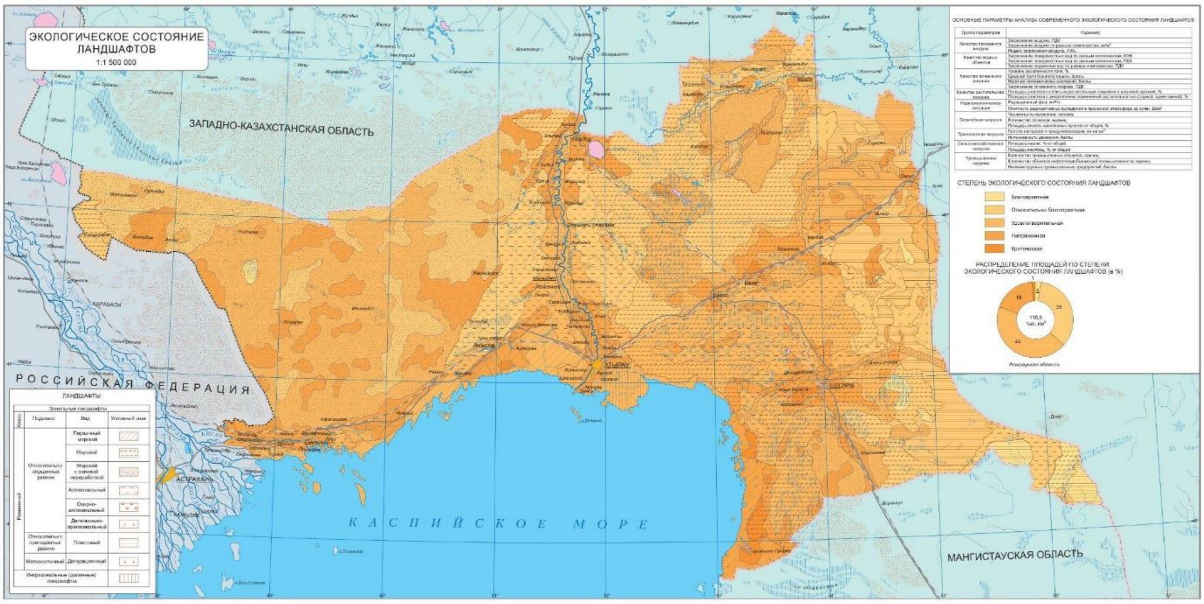

Figure 5 – Ecological Condition of Landscapes [24]

The overall destruction and pollution of natural systems resulting from the extraction and transportation of hydrocarbon resources are therefore the primary causes that have given rise to such a positive ecological condition in the area. This perturbation is responsible for the pollution of air, soil, and groundwater, apart from the rise in the level of the Caspian Sea and hence the destruction of its shelf area. Except for the negative impacts related to the extraction of oil and gas and transportation of raw materials, in the western part of the region, basic causes of deterioration of the general state of the environment include excessive grazing by livestock.

Human activities of different directions play a great role in the ecological status of the Atyrau region. The main ecological hazardous human activities contributing to environmental degradation of the above-mentioned regions include oil extraction, agricultural practices, hydrocarbon transportation, and excessive grazing. The after-effects include air, soil, and water pollution, as well as vegetation reduction and soil salinization. The results point to the necessity of elaboration and implementation of an integrated approach to mitigate the negative effects of anthropogenic factors on the ecosystem of the region.

Due to industrial sources and agriculture, the discharges of pollutants are continuously going on, and because of that, the general ecological condition of surface waters in the catchment remains unsatisfactory. Despite this fact, the research indicates that structural upgrade of effluent treatment facilities and increases in industrial emissions standards have, in many instances, improved water quality. This investigation confirms the high level of anthropogenic soil pollution, especially those areas used for oil production. The presence of heavy metals and hydrocarbons in soils negatively modifies their properties, worsening the conditions for plant development and promoting erosion processes. From the point of view of pollution sources, the main polluters are wells, pipelines, and production structure in districts of active oil production.

Additionally, the findings emphasize the need for sustainable natural resource management to ensure the region's sustainable development. Specifically, proposed measures include improving wastewater treatment technologies, enforcing stricter controls on industrial emissions, rehabilitating degraded lands, and developing programs to combat soil erosion.

Suggestions for improvement of the ecological situation include strengthening monitoring and regulatory measures on emissions from the oil, gas, and chemical industries. It is also necessary to create continuous air, water, and soil quality monitoring systems using modern technologies. Upgrading and expanding current treatment plants to more effectively treat wastewater, especially in areas of industrial pollution, is also crucial. Prohibition of cattle grazing on degraded pasture and implementation of land rehabilitation activities are needed to prevent further ecological disturbance.

The findings from the Atyrau region reveal traces of a strong influence of various anthropogenic activity on the state of the landscape and ecological health of the territory. The intensive industrial activities of the region disturb the structural constituency of the landscapes and deposit pollutants in the soil, water, and atmosphere, which encourages cascading environmental degradations like soil erosion, deflation, and loss of vegetation. Particularly, the fact that hydrocarbon deposits are concentrated and are accompanied by infrastructural development in the form of pipelines and roadways creates "hot spots" of ecological disturbance, further heightening the risk of land degradation and habitat fragmentation.

Apart from that, the high level of pollutants found-soil heavy metals and petroleum derivatives-points to the future of the soil quality and health of plants for supporting biodiversity in this region. Among others, paraffin and resinous hydrocarbons have shown that pollution from oil extraction is not only sustained but it also forms new chemical compounds within the soil that could be more toxic to the flora and fauna. This indicates that the effect of the pollution on the soil profile also calls for soil remediation techniques considering high hydrocarbon and heavy metal contamination.

In aquatic systems within the region, though certain improvements in water quality can be realized with regard to some regulatory efforts, high levels of substances like magnesium and suspended solids still predominate. The state of continued contamination affects not only local bodies of water but also the broader ecological health of the region, further underlining the need for better management of water resources, particularly from the industrial sectors.

The findings justify the necessity for sustainable management that might reduce adverse environmental impacts of economic activities in this region. This includes enhanced regulatory control over emissions, higher-order treatment of wastewater, soil remediation, afforestation to revive degraded lands, and continuous ecological monitoring through geospatial technologies in order to make environmental management responsive and adaptive. Integration of measures mentioned above can rehabilitate the affected areas, protect the remaining natural ecosystems, and ensure further sustainable development of the Atyrau region.

This study underlines the urgent need for a multilevel approach to landscape management, which, besides immediate ecological risks, would develop and realize long-term activities aimed at ecological resilience and sustainable resource use. The given comprehensive landscape-ecological assessment forms a sound basis for elaboration of measures that could balance the economic activities of the region with the environmental conservation efforts and thus contribute to the sustainable development of the Atyrau region.

Conclusion. The analysis of the landscape-ecological state in the Atyrau Region has shown that anthropogenic activities have a substantial impact on the area's ecological health. The primary contributors to these negative effects include oil extraction, agricultural practices, transportation of hydrocarbons, and overgrazing. These activities result in soil, water, and air pollution, as well as vegetation loss and erosion, all of which drive the desertification of the region's arid landscapes.

The findings of the research emphasize the necessity of creating and applying efficient strategies for the monitoring and management of natural resources to reduce the adverse effects of human activities. Essential actions include enhancing wastewater treatment facilities, enforcing stricter regulations on industrial emissions, and promoting the sustainable use of land resources.

To ensure the sustainable development of the region, comprehensive landscape and geo-ecological studies must continue, aimed at a detailed examination of the structure, dynamics, and functioning of modern landscapes. This will not only help identify and minimize ecological risks but also provide strategic recommendations for the protection and restoration of natural ecosystems in Atyrau Region.

To enhance the landscape-ecological condition of the Atyrau Region, it is recommended that local authorities intensify monitoring and regulatory efforts, particularly targeting industrial emissions from the oil, gas, and chemical sectors. Implementing stricter controls on these enterprises is essential. Developing and deploying continuous monitoring systems for air, water, and soil quality, utilizing advanced technologies, will also be necessary. Furthermore, upgrading and expanding existing treatment facilities to improve the efficiency of wastewater management is critical, especially in areas with a high concentration of industrial activities.

The rational use of land resources should include the development and implementation of programs for the restoration of degraded lands, including afforestation and soil erosion control measures. Limiting and regulating livestock grazing, especially in areas prone to erosion, will help prevent further degradation of pastures. To reduce water pollution, measures should be introduced to protect water bodies from industrial discharges, agricultural chemicals, and household waste, as well as to develop and implement water resource management systems, including the protection and restoration of aquatic ecosystems.

A thorough evaluation of the ecological risks linked to the development of oil and gas fields, along with the formulation of effective mitigation strategies, should be an essential component of the planning and decision-making process. This approach is crucial for promoting the sustainable development of the region.

Acknowledgements. This research was funded by the Science Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan (Grant " Sustainable development of natural-industrial and socio-economic systems of the West Kazakhstan region in the context of green growth: a comprehensive analysis, concept, forecast estimates and scenarios" No. BR21882122)

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ТҮЙІН

Каспий маңы ойпатының құрғақ ландшафты (Атырау облысы) бір-бірімен байланысқан компоненттерден тұратын өте нәзік табиғи геожүйе болып табылады. Антропогендік әсердің ауқымына байланысты құрғақ ландшафттардың өзгеруі шөлдену процестеріне әкеледі. Зерттеу антропогендік әсерге ұшыраған құрғақ ландшафттармен сипатталатын Атырау облысының ландшафты-экологиялық жағдайын талдауға арналған.

Зерттеудің өзектілігі аймақтың тұрақты дамуы үшін табиғи ресурстарды бақылау мен басқарудың тиімді әдістерін әзірлеу қажеттілігімен түсіндіріледі. Зерттеудің мақсаты болып табиғи және антропогендік бұзылған ландшафттардың жағдайын бағалау, олардың өзгеруінің негізгі факторларын анықтау және аймақтың экологиялық жағдайын жақсарту бойынша шаралар ұсыну табылады. Зерттеу әдістеріне ландшафттық талдау, синтез және картографиялық құралдарды қолдану сияқты жалпы ғылыми әдістер жүйесін пайдалануды қамтиды. Зерттеудің негізгі материалдары аумақтың ландшафттық және басқа да карталарынан, сондай-ақ статистикалық мәліметтерден тұрды.

Зерттеу нәтижелері мұнай өндірудің, ауыл шаруашылығының және басқа да антропогендік факторлардың аймақ ландшафтарының экологиялық жағдайына елеулі әсерін көрсетті. Топырақтың, судың және ауаның ластануымен, өсімдіктердің деградациясымен және эрозия процестерімен байланысты негізгі мәселелер анықталды. Антропогендік әрекетке ұшыраған аумақтардың ландшафтық-экологиялық жағдайын жақсарту бойынша шаралар ұсынылды.

РЕЗЮМЕ

Аридный ландшафт Прикаспийской низменности (Атырауской области) представляет собой очень хрупкую природную геосистему взаимосвязанных компонентов. Преобразование аридных ландшафтов из-за масштабов антропогенного воздействия ведет к процессам опустынивания. Исследование посвящено анализу ландшафтно-экологического состояния Атырауской области, характеризующейся аридными ландшафтами, подверженными значительному антропогенному воздействию. Актуальность исследования обусловлена необходимостью разработки эффективных методов мониторинга и управления природными ресурсами для устойчивого развития региона. Цель исследования заключается в оценке состояния естественных и антропогенно-нарушенных ландшафтов, выявлении основных факторов их трансформации и предложении рекомендаций по улучшению экологической ситуации региона. Методы исследования включали использование системы общенаучных методов, таких как ландшафтный анализ, синтез и картографический инструментарий. Основные материалы исследования состояли из ландшафтных и других карт территории, а также статистических данных. Результаты исследования показали значительное влияние нефтедобычи, сельского хозяйства и других антропогенных факторов на экологическое состояние ландшафтов региона. Выявлены основные проблемы, связанные с загрязнением почв, воды и воздуха, деградацией растительного покрова и эрозионными процессами. Предложены меры по улучшению состояния ландшафтно-экологического состояния территорий, подверженных воздействию антропогенной деятельностью.

УДК 639.3.338.45:63 *DOI 10.52578/2305-9397-2024-4-2-157-166*
МРНТИ 69.25.15

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