

Article

Assessment of Anthropogenic Disturbances of Landscapes: West Kazakhstan Region

Aigul Tokbergenova ¹, Irina Skorintseva ², Aizhan Ryskeldiyeva ^{1,*}, Damira Kaliyeva ¹, Ruslan Salmurzauly ^{3,4} and Aizhan Mussagaliyeva ¹

¹ Department of Geography, Land Management and Cadastre, Al-Farabi Kazakh National University, Almaty 050040, Kazakhstan

² Institute of Geography and Water Security, Almaty 050000, Kazakhstan

³ Space Technology and Remote Sensing Center, Al-Farabi Kazakh National University, Almaty 050040, Kazakhstan

⁴ Department of Biodiversity and Bioresources, Al-Farabi Kazakh National University, Almaty 050040, Kazakhstan

* Correspondence: aiganris_81@mail.ru

Abstract: The study analyzes anthropogenic disturbances of landscapes in Western Kazakhstan, which occupies 27% of the country's territory. The main focus is on the impact of industry and agriculture, especially pasture use and the development of oil and gas fields. The application of remote sensing data and field surveys allowed us to identify the degree of landscape disturbance and to propose their classification into five levels of disturbance, from virtually undisturbed to severely disturbed. Cartographic analysis revealed that pastures occupy 53.83% of the territory, while industrial-technogenic impact accounts for 23.12%. This indicates a significant level of landscape transformation. The findings of this study can serve as a foundation for environmental monitoring and the formulation of recommendations aimed at reducing anthropogenic impacts. The study underscores the necessity for the sustainable management of natural resources in the context of industrial development in the region and provides crucial insights for maintaining ecological balance.

Keywords: West Kazakhstan region; assessment; anthropogenic impact; landscape transformation; landscape disturbance; field study; remote sensing



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1. Introduction

Worldwide, landscape fragmentation and changes in heterogeneity are predominantly driven by increasing human activities, particularly agriculture [1].

In recent decades, the increasing level of anthropogenic impact has become the main cause of loss of biodiversity at local, regional, and global levels [2–4]. Chronic anthropogenic disturbances (CRF) resulting from activities including cattle grazing, firewood harvesting, and the utilization of non-wood forest products represent the predominant types of environmental changes in developing countries [5,6]. Globally, landscapes typically represent a synthesis of human activity and biodiversity, characterizing them as biocultural landscapes [7,8]. This study conceptualizes the cultural aspect of landscapes as a broad spatial manifestation of human activity, encompassing agriculture, urbanization, industrial development, road infrastructure, and any modifications or replacements of the original natural soil cover by anthropogenic influences. This process is termed «anthropization» [9]; landscape modification as a result of human activity results in anthropogenic landscapes dominated by man-made elements and the original natural site types are often reduced to a disjointed pattern [10].

The arid lands of Kazakhstan and degraded landscapes negatively impact the economy and quality of life of the country's population, particularly affecting the poorest segments of the rural population who directly depend on what the land can provide for their sustenance and livelihood. Economic losses from land degradation are estimated at 3–11% of GDP, while the losses from inaction are five times higher than the costs of implementing measures [11]. The strong degree of anthropogenic disturbance of the territory of the Republic of Kazakhstan is associated with extensive industrial development, as the oil and gas industry is one of the most environmentally hazardous sectors of the economy [12].

By the end of 2022, 246.3 thousand hectares of land were disturbed throughout the republic as a result of the development of mineral reserves, their processing and geological investigation, as well as the construction of industrial facilities, linear structures, and other businesses. Only 53.0 thousand hectares have undergone work and are currently subject to reclamation.

The largest amount of disturbed land is located in the regions of Mangistau, Karaganda, Kostanay, Akmola, Eastern Kazakhstan, Aktobe, and Pavlodar. In all industrial regions there are ecologically dangerous impact zones, slag heaps, dumps, quarries, boreholes, and mining wastes, comprising a total area of more than sixty thousand hectares, which constantly pollute the soil [13].

Western Kazakhstan has been and remains the most difficult region of the republic in terms of natural and climatic conditions. These difficulties have become particularly acute during the last decades of intensive development of the region by oil and gas producing enterprises and military organizations. Of all the riverside zones, only the basin of the Ural River, the largest in the region, remains suitable for more or less tolerable existence. The rivers such as Emba (Zhem), Wil, and Temir, formerly full-flowing and ecologically safe rivers, are disappearing [14].

One of the main principles for the protection of natural landscapes is the preservation of their structure and character of functioning; therefore, under conditions of intensive nature management and as a result of anthropogenic pollution, the constructive geographical methodology combines approaches—the landscape approach (type, structure, character of functioning, state of geosystem) and the ecological approach (interrelations between living organisms and their habitat) [15].

This study aims to evaluate the extent of human-induced disturbances in the landscapes of the West Kazakhstan region. This work presents the first complete map of anthropogenic disturbance in the landscapes of the West Kazakhstan region, developed at a scale of 1:1,500,000, serving as a tool for analyzing the effects of human activity on the region's natural systems. This map enables the identification of regions with differing levels of disturbance, facilitating a deeper comprehension of anthropogenic effects and highlighting places necessitating prioritized restoration and conservation efforts. A copyright certificate has been issued for this developed map [16].

The obtained results provide a foundation for further research and development of a strategy for sustainable land management, making this study a relevant and significant contribution to the scientific and practical communities. The results of the assessment can contribute to the development of recommendations for optimizing subsurface use in the study area, preventing possible negative consequences and ensuring the environmental safety of the region.

2. Study Area

This study considers the West Kazakhstan region, which covers an area of 736.2 thousand km², equivalent to 27% of the total territory of Kazakhstan (Figure 1). Administratively, it covers the districts of Aktobe, Atyrau, West Kazakhstan, and Mangis-

tau oblasts (Figure 1) [17]. It occupies a vast territory stretching from the Caspian Sea in the south to the borders of the Russian Federation in the north and west. The relief is represented by various forms, from plateaus and lowlands to table plateaus and aeolian plains, which form a complex natural landscape. The climate of the region is strongly continental due to its landlocked position in the centre of the Eurasian continent, its openness to the north, and its orographic conditions. There is a pronounced latitudinal zonality and significant variations in temperature, precipitation, and humidity from north-west to south-east. The region comprises several natural climatic zones: steppe, dry-steppe, semi-desert, and desert. Each zone is characterized by a specific hydrothermal regime, which affects the soil and vegetation cover. Large areas of the region, including the Solonchak massif and salt domes, are subject to significant anthropogenic impacts, resulting in landscape degradation, soil salinization, and changes in ecosystem structure.

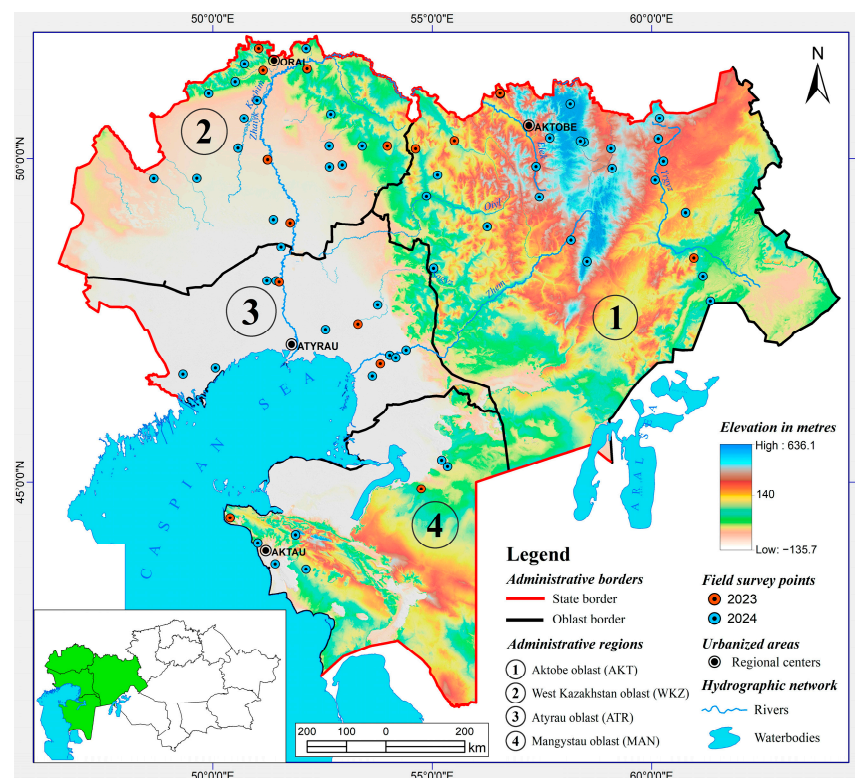


Figure 1. The object of the study and the location of the descriptive points on the territory.

3. Materials and Methods

Methodological issues of studying the ecological state of landscapes and assessing the anthropogenic impact are highlighted in the works of authors such as Antipova [18], Isachenko [19], Milkov [20], Kochurov [21], Dyakonov et al. [22], and others. Nonetheless, a unified methodology for evaluating the landscape–ecological condition of the territory remains absent, hindering such studies at both regional and local levels.

A map of the contemporary landscapes of the West Kazakhstan region, scaled at 1:1,500,000, served as the foundation for the creation and assessment of the anthropogenic disturbance map. This map was developed using many methodologies, including systemic, regional, genetic, typological, historical, and landscape–ecological techniques [23–27]. The map model of contemporary landscapes illustrates the structural organization and spatial differentiation of modern natural–territorial complexes, their transformation, and facilitates the evaluation of the territory’s natural resource potential, along with the dynamics of changes in its components. Cartographic and GIS methodologies, field research, quantita-

tive evaluations, and classification were employed in the development process. Modern remote sensing data and methods of processing and interpretation were also widely used in the analysis of anthropogenic disturbances to landscapes. The detailed step-by-step information of the RS data processing applied in this study is presented in Table 1.

Table 1. Remote sensing data processing sequence.

Comprehensive Indicators of Anthropogenic Disturbances					
Agrogenic		Forestry	Industrial-Technogenic	Linear-Technogenic	Residential
Remote sensing data: Landsat 5–9; Sentinel-2; Multispectral sensors; Sentinel-1; Alos Palsar; Synthetic Aperture Radar	Remote sensing data: MODIS LAND/AQVA Google Earth and Bing map	Remote sensing data: LULC Landsat (NASA); LULC Sentinel (ESA)	Remote sensing data: LULC (NASA, ESA); Geology.kz; Open Street map, Google map	Remote sensing data: Open Street map, Google map; NextGIS; DivaGIS, IIRF, gROADSv1	RS data: LULC Landsat (NASA); LULC Sentinel (ESA)
Remote Sensing Data Processing: computing VI: NDVI; NDSI; BSI; data classification MLC; SAR data clustering	Remote Sensing Data Processing: calculating VI: NDVI, EVI; determining the location of trusses	Remote sensing data processing: selecting representative years; downloading LULC products; selecting the study region	Database creations: collection of vector and raster data on man-made objects; database creation; SAR data clustering	Database creations: collecting vector data on linear-technogenic sites; database creation	Remote sensing data processing: selecting representative years; downloading LULC products; selecting the study region
Determination of the degree of ploughing: calculations of multi-year trend in VI; calculation of the degree of ploughing based on the VI trend	Determination of the degree of degradation: calculations of the multi-year trend of VI; calculations of degradation degree of farm buffer zones	Reclassification: reclassification of LULC data; extractions of forest ecosystem contours for the last 20 years	Systematization of collected data: classification and vectorisation of raster data; systematization of vector data	Systematization of collected data: classification and vectorisation of raster data; systematization of vector data	Reclassification: reclassification of LULC data; extractions of urbanized areas over the last 20 years
Data post-processing: obtaining ploughability contours; classification of contours by degree of ploughing in %	Data post-processing: grading by degradation; KDE analysis of density of farms in number per km ²	Data post-processing: comparative analysis of forest contours over the last 20 years. Determining the extent of deforestation in %; farm density analysis (KDE)	Data post-processing: verification of obtained results; determination of the degree of industrial-technogenic disturbance in %	Data post-processing: validation of results obtained; determination of road network density in km per km ²	Data post-processing: comparative analysis of the contours of the populated over the last 20 years. Determining the number of settlements; analyzing the density of farms (KDE)

Landscapes were classified on the basis of a typological system including morphostructural and bioclimatic characteristics. Within this classification, morphostructural and bioclimatic features are used to define taxonomic units of modern natural–territorial complexes. The primary units in the landscape classification hierarchy were organized as class, subclass, type, subtype, and landscape type. The highest level of classification—landscape class—covers natural–territorial complexes with common morphostructural characteristics. In this study, the main mapping unit was the landscape subclass. The map of anthropogenic

landscape disturbance was generalized according to the scale, using landscape types as the lowest taxonomic unit to differentiate the degree of disturbance.

Verification of the remotely sensed data was conducted during field surveys through the visual inspection of photo and video recordings using DJI Mavic 3 Pro and DJI Mavic 3 Multispectral drones, as well as ground surveys. This approach allowed us to assess the extent of landscape disturbance, natural regeneration, and the impact of anthropogenic factors such as quarries, water management structures, and the density of unpaved roads.

Field points for landscape description were selected based on areas with intensive economic impacts and anthropogenically modified landscape types. A total of 67 landscape description points were planned, distributed as follows: steppe zone—4 points (a narrow strip north of Oral and Aktobe), dry-steppe—18, semi-desert—23, and desert zone—22. The selection of points also focused on areas with industrial-technogenic impacts, including zones of oil and gas extraction as well as agricultural impacts. Particular attention was given to severely disturbed sites, such as open-pit mining areas and oil and gas fields.

The methodology relies on the classifications established by Milkov [28], Marcinkevich et al. [29], and Geldyeva [23], facilitating the identification of impact types on regional landscapes. The examination of anthropogenic disturbances in the landscapes of the West Kazakhstan region was conducted according to the types of impacts: agricultural (agrogenic, pasture), forestry, industrial-technogenic, linear-technogenic, and residential. The impacts were evaluated through a set of parameters to ascertain the complex indicator of anthropogenic landscape disturbance (Table 2).

Table 2. Parameters for assessing complex indicator of anthropogenic landscape disturbance.

Type of Landscape Impact	Parameter System
Agricultural	degree of ploughing (% of area); degree of concentration of farms (units)
Forestry	degree of forest management (% of deforestation of the total forest area)
Industrial-technogenic	degree of disturbance of the territory due to development of mineral deposits (% of territory area)
Linear-technogenic	road network density (km per km ²)
Residential	number of settlements per unit area

In addition to the map, a matrix was developed to systematize and organize information on classes, subclasses, types, and degree of anthropogenic disturbances of landscapes in the study region (Table 3).

An analysis of changes in the vertical and horizontal structures of landscapes, influenced by anthropogenic factors—including various types of economic activities and population dynamics—was conducted, considering the extent of their spread and employing the methodologies of Geldyeva [23] and Plyusnin [30]. Based on this, a classification system was developed to assess the degrees of disturbance within the territory of the West Kazakhstan region.

Practically undisturbed landscapes—resembling background landscapes—are limited to unused lands and protected areas.

Weakly disturbed landscapes appear in areas designated for grazing and hay production, experiencing minimal agrogenic impacts without intensive technology or chemical fertilizers, along with selective logging.

Moderately disturbed landscapes are those affected by agrogenic activities, unsustainable grazing practises, and areas of intensive logging of forests and shrubs.

Table 3. The layout of the matrix for the map of anthropogenic disturbances of the West Kazakhstan region.

Class	Subclass	Type	Disturbance				
			Practically Undisturbed	Weakly Disturbed	Moderately Disturbed	Significantly Disturbed	Severely Disturbed
Plain area	Elevated	Steppe		8	20	31	42
	Shallow			9	21		
	Lowland	Dry-steppe	1	10	22	32	43
	Elevated		2	11	23	33	44
	Shallow		3		24	34	45
	Lowland	Semi-desert	4	12	25	35	46
	Elevated		5	13	26	36	47
	Shallow			14	27	37	48
	Lowland	Desert	6	15	28	38	49
	Elevated			16	29	39	50
	Shallow		7	17	30	40	51
Mountainous	Lowland mountain	Dry-steppe		18		41	
	Lowland mountain	Desert		19			

Significantly disturbed landscapes include areas impacted by industrial-technogenic, linear-technogenic, and residential development, with some localized effects from grazing and agricultural activities.

Severely disturbed landscapes are characterized by industrial, agro-technogenic, and some localized forestry impacts.

The total score of the degree of anthropogenic disturbance was calculated according to the Formula (1) based [23].

$$Ld = Ai_1(1i + 2i) + Ai_2 + Ai_3 + Ai_4 + Ai_5 \quad (1)$$

where Ld —landscape disturbance; Ai_1 , Ai_2 , etc.—degree and type of anthropogenic impact (Table 2); and $1 + 2$ —number of parameters (criteria) for assessing a specific type of anthropogenic impact.

The quantitative assessment of anthropogenic disturbances of the landscapes is shown in Table 4.

Table 4. Quantitative assessment of anthropogenic disturbances of landscapes.

Anthropogenic Disturbance of Landscapes	Sum of Values
Practically undisturbed	Less than 20
Weakly disturbed	21–30
Moderately disturbed	31–40
Significantly disturbed	41–50
Severely disturbed	More than 51

4. Results

In the West Kazakhstan region, we have identified 115 types of modern landscapes, which demonstrate spatial differentiation, complex regional structural organization, and significant species diversity of modern natural complexes. These features are due to the

geographical location of the region, geological and geomorphological history, as well as the influence of unfavourable natural and anthropogenic processes caused by long-term economic activity.

The landscape structure of the region is represented by plain and mountain landscape classes. Flat landscapes occupy 99.7% of the area of the region, while mountainous landscapes occupy only 0.3% of the area. The flat part is dominated by low-lying and elevated plains, which together make up more than 89% of the region's area, while small-scale landscapes and intrazonal natural–territorial complexes occupy smaller areas (9.9%). Upland stratified plains (17.8%), structural plateaus (14.6%), low-lying secondary marine plains (15.3%), and aeolian plains (11.4%) dominate. Less significant are the landscapes of low-lying alluvial, lacustrine–alluvial and deluvial–proluvial plains, accounting for 4.7%, 3.9%, and 5.4%, respectively. The smallest areas are occupied by tectonically denudation shallow sand and low mountains—0.2% and 0.3% of the region.

The climatic and bioclimatic conditions of the region determine the predominance of natural complexes characteristic of arid zones (72.9%), including desert and semi-desert landscapes. In contrast, steppe and dry-steppe zones occupy only 25.9% of the territory. The diversity of natural ecosystems gives rise to a complex structural organization of landscapes, which demands an integrated approach to research and monitoring.

However, the West Kazakhstan has been a region of industrial and agricultural nature management for many years. The problems of the landscape and ecological state of the Western Kazakhstan region caused by anthropogenic impacts on the natural environment are becoming more urgent due to the development of new mineral deposits and the development of extractive and processing industries.

Research has identified that the majority of natural and anthropogenic landscapes within regions associated with hydrocarbon extraction and processing are subject to processes such as erosion, deflation, salinization, soil fertility decline, humus depletion, soil structure degradation, and other adverse impacts [23].

As the result shows, there is an agricultural impact in the study area, which covers 60% of the territory, represented by pasture and agrogenic types of impacts (Figure 2).

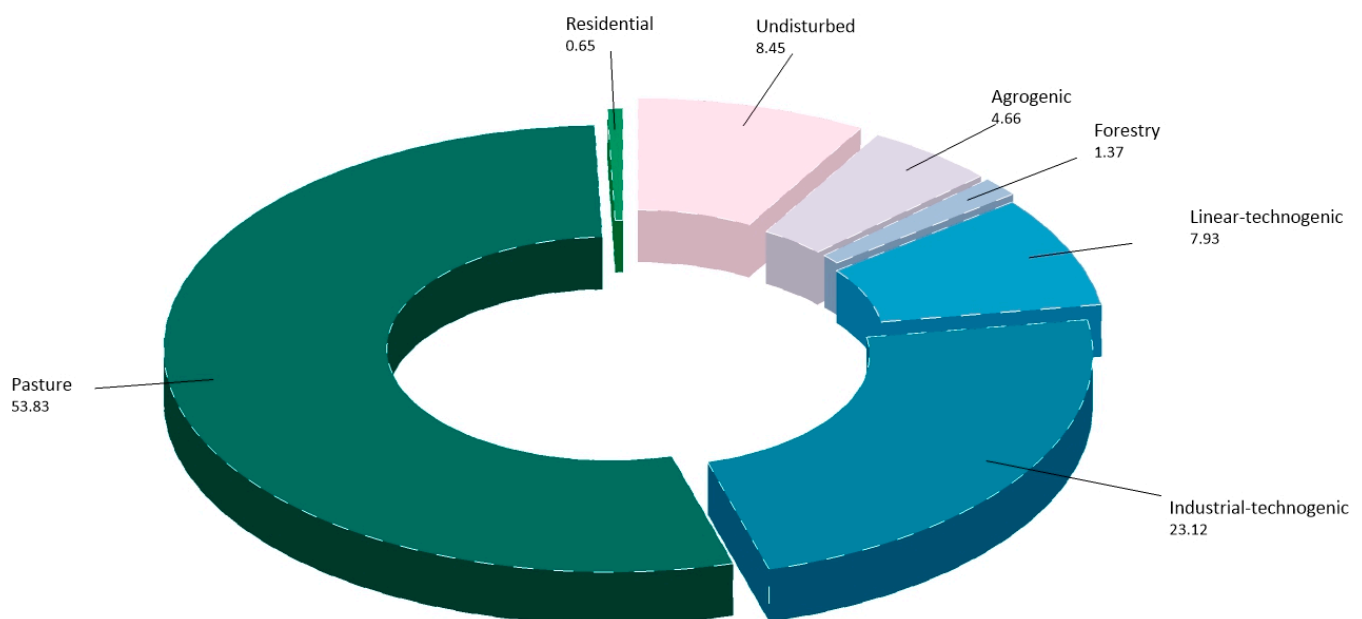


Figure 2. Ranking of type of impact on landscapes of West Kazakhstan region by occupied area, %.

The impact of pasture types in the region is evident in the vast majority of landscapes, amounting to 39,602.7 km² (53.83%). The prevalence of pasture impacts in the territory

represents one of the leading factors of anthropogenic impacts on ecosystems, characterized by the massive use of land for agriculture, particularly for grazing. This type of impact indicates a significant share of livestock agriculture as the main source of economic activity and livelihood for rural communities.

To gain an in-depth understanding of rangeland dynamics, a long-term assessment was conducted using multi-year NDVI data from the MODIS satellite. The study relied on 16-day NDVI composites covering the period from 2000 to 2024 to assess changes in the condition of rangeland ecosystems. This approach allowed for a comprehensive analysis of rangeland conditions and the identification of long-term trends under the influence of anthropogenic pressures and climatic factors. The analysis employed the Vegetation Condition Index (VCI), calculated according to Formula (2).

$$VCI = \frac{NDVI - NDVI_{min}}{NDVI_{max} + NDVI_{min}} \times 100 \quad (2)$$

where NDVI is the current value of the Normalized Difference Vegetation Index; NDVI_{min} is the minimum value of NDVI for the growing season; and NDVI_{max} is the maximum value for the growing season.

The results of the VCI calculation were systematized and categorized into five categories reflecting the vegetation condition for each year: «very good», «good», «fair», «poor», and «very poor» (Figure 3).

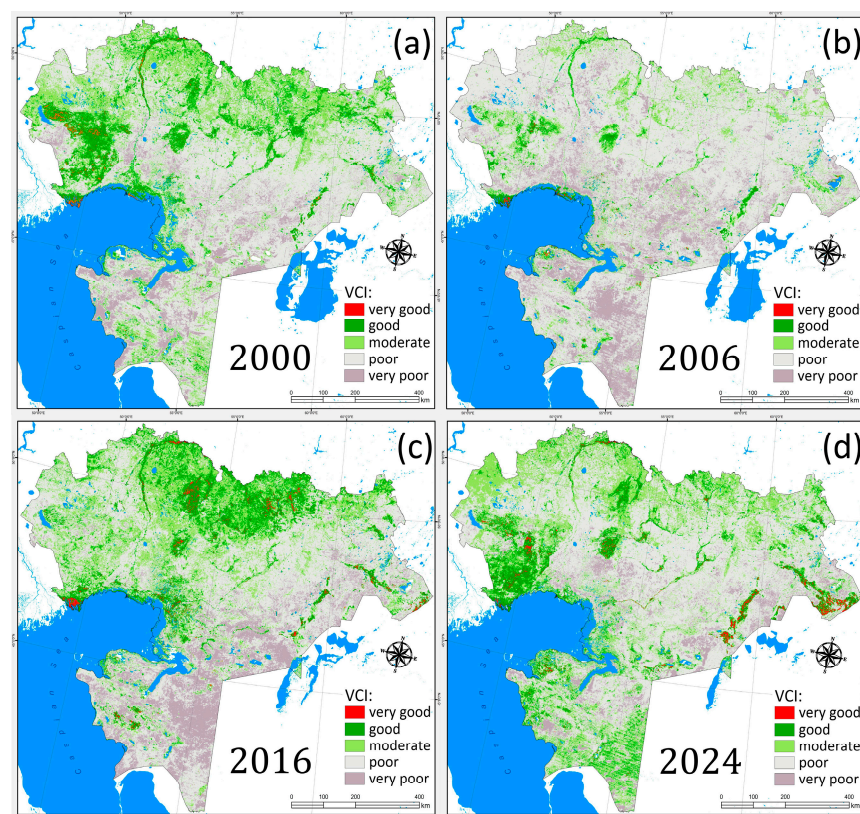


Figure 3. Assessment of vegetation cover condition in West Kazakhstan based on the Vegetation Condition Index (VCI) for the years (a) 2000, (b) 2006, (c) 2016, and (d) 2024.

The long-term trend of changes in rangelands was analyzed on the basis of the NDVI values calculated for each VCI class over the entire observation period. Considering the arid climate and the desert and semi-desert landscapes of the region, the long-term VCI data revealed a significant proportion of areas with scarce vegetation cover. The long-term

averages showed that 66% of the region's area fell into this category, of which 10.8% were characterized with increased degradation. Areas suitable for use as pastureland, with vegetation cover characterized by VCI ranging from 'very good' to 'fair' conditions, show significant dynamics, covering 34% of the total area of the region. At the same time, the share of areas with vegetation cover in 'very good' and 'good' conditions average 7.08 and 0.65% of the total WKR area, respectively (Figure 4). The obtained contours of the obtained VCI classes were used in the design of the map of anthropogenic disturbances of the landscapes of the West Kazakhstan region.

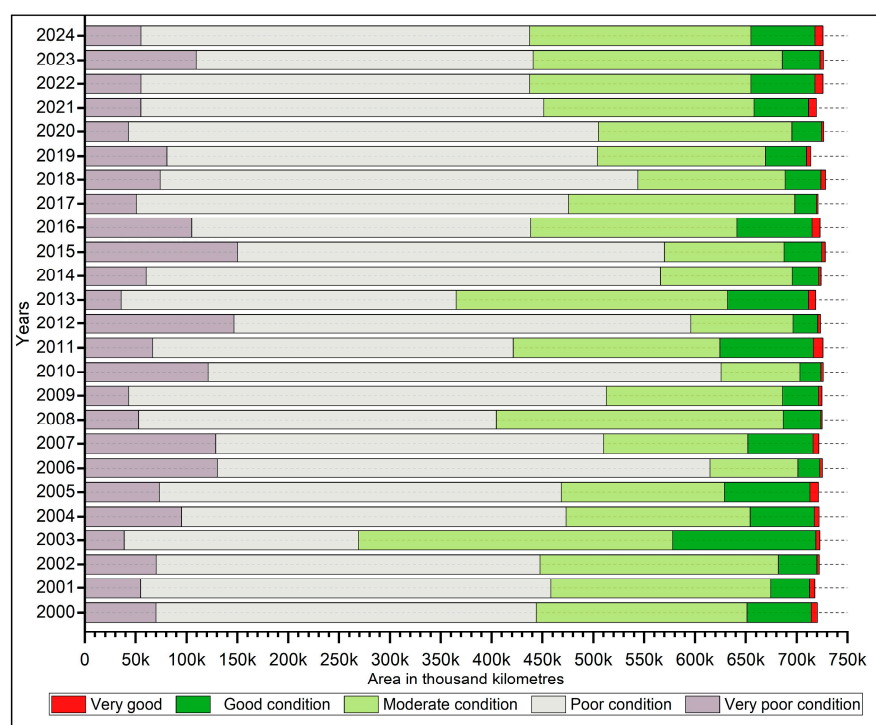


Figure 4. Area distribution of VCI classes (in thousands of square kilometres) over last 25 years.

The impact of degradation processes is particularly evident in rangelands within regions of intensive livestock farming. Overgrazing and increased grazing pressure have led to a reduction in humus content by up to 30%, a loss of 20–50% of essential plant nutrients, and a decrease in soil absorption capacity by up to 10%. The most extreme manifestation of this phenomenon is the formation of loose sands. For instance, the vegetation of the hilly ridge sands of Bolshie Barsuki, predominantly located in the Aktope region, were locally degraded under the influence of grazing. On wind-eroded sands, a reduction in *Koelpinia* plant groupings, with only isolated psammophilous plants remaining, was observed. Following the degradation of these communities, the projective vegetation cover has decreased to 15–20%.

The banks of the Oiyl River in the Aktope region are characterized by severe pasture degradation, primarily caused by the grazing of domestic cattle and horses. Nearly all plant species within the phytocenosis in this area were grazed or are in a suppressed state. However, the intensity of degradation varies, as, in some locations, signs of moderate and low levels of pasture degradation prevail. These changes are manifested in the form of livestock trails, where soil turfing has diminished, the number of indicator plant species of degradation has increased, and their projective cover has expanded. Such areas are predominantly found near settlements. For example, overgrazed rangelands are observed near the rural settlement of Dolinnoye in the Terekty district of the West Kazakhstan region.

The agrogenic impact is most prevalent in the steppe and dry-steppe landscapes of the region, where agricultural activity is extensively practised (4.66%). In the region, extensive areas of steppe are subject to ploughing and intensive agriculture, which results in a transformation of soil structure and a decline in soil fertility. This type of impact is mainly represented on the territory of the Obshchij Syrt, the Podural'skij plateau, and the Torgajskoe stolovoe plateau.

Multi-year analyses of agricultural land were performed using LULC (Land Use and Land Cover) data developed by the GLAD (Global Land Analysis and Discovery) research group at the University of Maryland. These data, based on Landsat satellite images, have a spatial resolution of 30 m. The results show a decrease in agricultural land areas by 25.2% in the West Kazakhstan region and 38% in the Aktobe region (Figure 5).

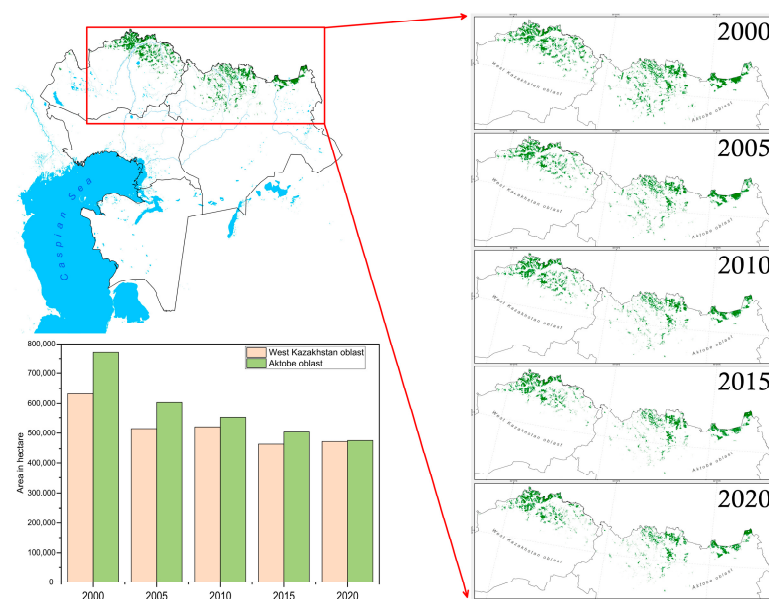


Figure 5. Changes in agricultural land in Western region of Kazakhstan over last 20 years.

The second largest area of impact, following grazing activities, is the industrial-technogenic impact (3425.1 km^2 —23.12%), which reflects the substantial development of extraction and processing facilities. The West Kazakhstan region is one of the primary centres for oil and gas production in Kazakhstan. Extraction is conducted through both open-pit and underground mining methods, exerting significant impacts on natural landscapes. Oil refining and petrochemical production in the region are concentrated at major facilities such as the Atyrau, Karazhanbas, Kenkiyak, and Mangystau refineries, contributing to infrastructure development but also causing emissions of pollutants into air and water. A location map of the industrial-technogenic objects is shown in Figure 6.

The active development of extractive and processing industries in the West Kazakhstan region is accompanied by significant environmental impacts.

According to the Ministry of Energy of the Republic of Kazakhstan, the area contaminated with oil and oil products is more than 1.5 million hectares. The largest share of soil and environmental pollution is in the Atyrau region—59%, Aktobe region—19%, West Kazakhstan region—13%, and Mangystau region—9%, where most (80%) of the fields are located [13]. For example, the total area of oil pollution in Western Kazakhstan is 194 thousand hectares and the volume of spilled oil is more than five million tonnes, especially in the Atyrau region, which is part of the Pre-Caspian oil and gas province [31] and borders the same oil-bearing regions as Mangystau, Western Kazakhstan, and Aktobe regions [32].

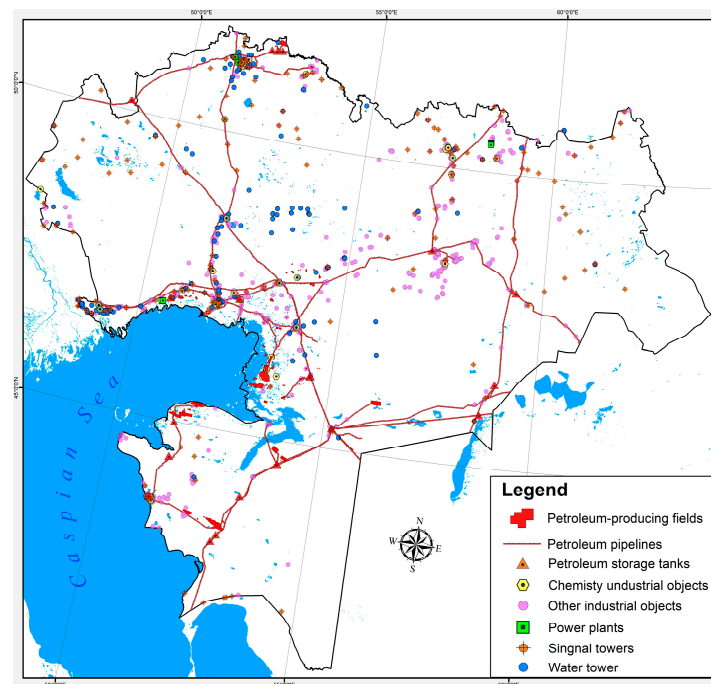


Figure 6. Location map of industrial-technogenic objects.

During the extraction of deposits as a result of the use of multi-tonne machines and mechanisms, these lands have undergone varying degrees of technogenic degradation, lost their fertility, and have not yet been studied either genetically or economically [33].

The linear-technogenic impact covers 5837.4 km² or 7.93% of the total area. In this region, the development of transportation infrastructure—including highways, railways, pipelines, and power lines—plays a crucial role in supporting industrial activities. This type of impact places significant strain on landscapes through the construction and operation of these networks. Major highways, such as the Uralsk–Aktobe route, pass through key population centres in the area. Another significant transport artery, the Uralsk–Atyrau road, supports the transport of goods and passengers, provides access to various industrial facilities and agricultural areas, and serves as a primary route for the shipment of oil, gas, and other industrial products.

The Uralsk–Atyrau railway is vital for transporting cargo, including oil, gas, and industrial goods, as well as for passenger services. Pipelines exert the greatest pressure on natural landscapes. Pipeline construction alters the natural terrain, as the formation of embankments and trenches disrupts natural structures, potentially altering the area's hydrological conditions, damaging soil cover, and destroying vegetation. Construction activities also intensify soil erosion, making it more vulnerable to degradation. Pipeline leaks pose further risks, potentially contaminating soil and rendering it unsuitable for agriculture or natural regeneration.

According to the results of cartographic analysis and traditional methods (direct observation, manual data collection, and processing), the area occupied by residential zones was identified as relatively small, about 475.34 km² (0.65%). However, this analysis does not indicate a low degree of urbanization in the region. Residential zones in the Aktobe, West Kazakhstan, Atyrau, and Mangystau regions are important centres of economic and social activity in Western Kazakhstan. The administrative centres of Aktobe, Atyrau, and Aktau exhibit high levels of urbanization, with major cities including Khromtau, Kandyagash, Kulsary, Makat, Zhanaozen, and Fort Shevchenko. The administrative centre of Uralsk, along with primary cities such as Aksai, Chingirlau, Kaztalovka, Zhanibek, and Bokeyorda, reflects moderate urbanization levels.

However, significant industrial development in cities like Aktobe, Atyrau, Aktau, and Zhanaozen has led to a predominance of industrial impacts, which, in turn, has reduced the area of residential zones in the study region. Cartographic analysis confirms that industrial activities have a substantial influence on the allocation of land resources, making residential zones less prominent compared to industrial territories.

The area impacted by forestry activities is 1007.6 km² or 1.37%, indicating a limited distribution of forestry within the region. In the West Kazakhstan oblast, forests occupy small areas, mainly concentrated along the floodplains of the Ural (Zhayyk) and Shagan rivers. Forested areas in the Aktobe oblast are also limited, primarily located along the floodplains of the Zhem (Emba) and Irgiz rivers. In the Atyrau oblast, forests are extremely scarce, mostly found along the Ural (Zhayyk) river, while in the Mangystau oblast, forests are nearly absent. Natural conditions, such as arid climate and a lack of water resources, restrict forest distribution. Vegetation in this area mainly consists of shrubs and semi-shrubs. Forests serve as pastures for livestock and provide wood resources for local needs.

In recent years, deforestation processes have intensified significantly, including continuous deforestation covering large areas. These changes have led to an increase in hillslope erosion due to the loss of forest cover. In the Zhayyk River valleys, the effects of deforestation were particularly noticeable, resulting in significant disturbances to ecological balance. Mass deforestation in the region stimulated a sharp acceleration of the processes of mass and energy exchange in the «nature-human» system, exacerbating environmental problems and reducing the stability of natural complexes.

The analysis of the dynamics of forest biocenoses was carried out on the basis of Sentinel LLC data for the period from 2017 to 2023. The results show that the area of floodplain forests in the middle reaches of the Zhayyk River has decreased by 34% in the last seven years (Figure 7).

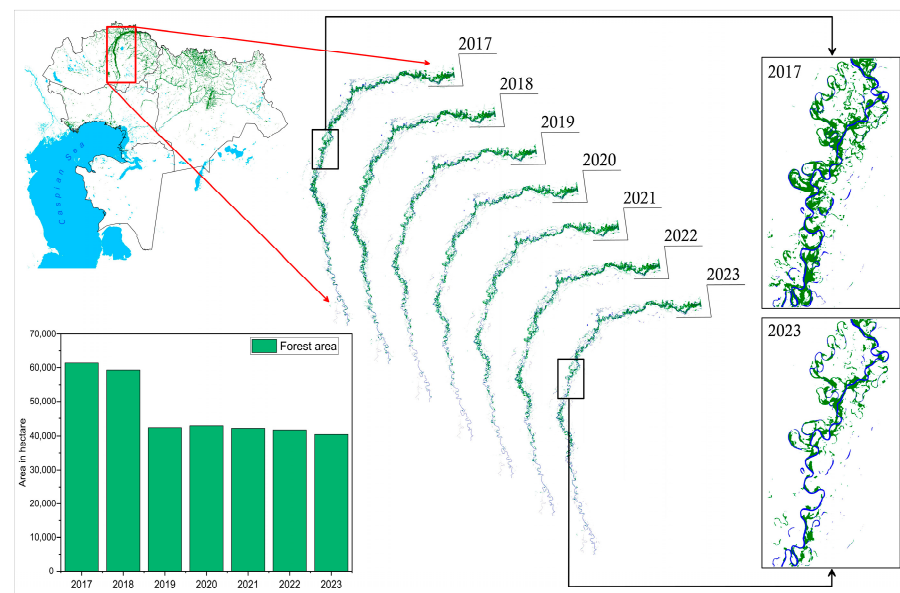


Figure 7. The dynamics of the floodplain forests of the middle reaches of the Zhayyk River for the period (2017–2023).

Approximately 6212.9 km² or 8.45% of the territory remains free from anthropogenic impacts, highlighting the importance of these lands for preserving the natural state of ecosystems and biological diversity. These areas represent unique natural sites, including erosion escarpments, salt flats, chink zones, and sand massifs. Erosion escarpments can be observed along the Shagan River and in the foothills of the Ural Mountains. Extensive salt

flats are found in the Mangystau region, such as Olikoltyk Sor, Kaidak Sor, and Bolshoy Sor, as well as in the Atyrau region with salt flats like Aralsor, Zhamansor, and other unnamed ones. The chink zone is located in the Ustyurt area and on the Mangyshlak Plateau. Sand massifs in the region include Bolshoy and Malyi Barsuki, predominantly located in the southeastern part of the Aktope region. Nature reserves and protected areas consist of forests, steppes, water bodies, and other ecosystems. The Ustyurt Reserve and locally designated reserves are present within the region.

In order to analyze the consequences of anthropogenic impacts, the next stage of the study provides an assessment of the degree of disturbance of landscapes, carried out on five levels from virtually undisturbed to severely disturbed (Figure 8).



Figure 8. Map of anthropogenic disturbance.

The area of anthropogenic impacts by type in the West Kazakhstan region as a percentage is presented in Figure 9.

Practically undisturbed landscapes within the study area are preserved mainly in the territories of nature reserves, wildlife sanctuaries, and unused lands (legend numbers 1–7). The practically undisturbed landscapes of the region are concentrated within low-lying and elevated desert territories and cover an area of 1218.7 km², which is 1.7% of the total area. The state of natural complexes is already being monitored in these territories through the activities of nature reserves and reserves, which play a key role in preserving natural heritage.

Landscapes of a weak degree of disturbance, occupying an area of 27,420.9 (37.3%), are represented on various types of relief, including upland and lowland areas (legend numbers 8–19). These landscapes retain a relatively high degree of natural preservation and minimal impact of anthropogenic factors. Landscapes with a weak degree of disturbance on the map have the largest areas of pasture impact (70.0%), where monitoring is required

to prevent further increases in anthropogenic pressure, especially from grazing activities. Here, it is important to introduce rotational grazing and control the number of livestock.

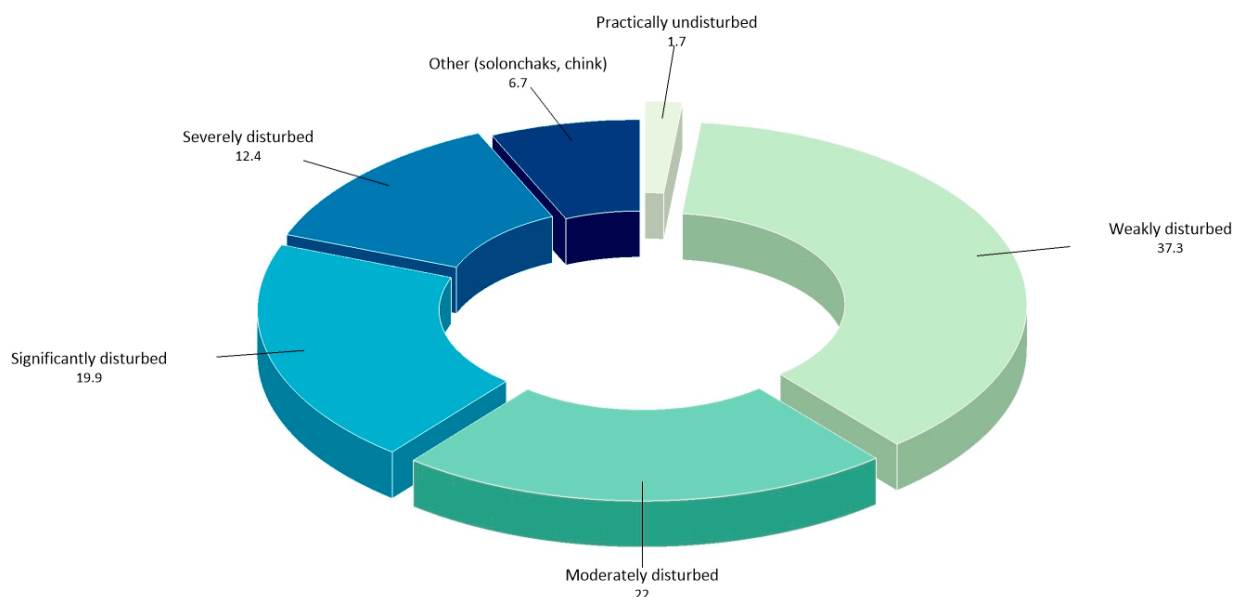


Figure 9. Ranking of anthropogenic landscape disturbance in West Kazakhstan by area, %.

Landscapes with a moderate degree of disturbance, covering an area of 16,190.2 km² (22.0%), are localized within lowland and upland areas characteristic of dry-steppe and desert zones (legend numbers 20–30). Landscapes with a moderate degree of disturbance on the map show the largest areas of pasture (32.9%) and linear-technogenic (27.0%) types of impacts. These areas require measures to limit linear-technogenic changes, such as road and communication construction, with minimal damage to ecosystems. Pasture impacts also require regulation, including the revegetation of degraded areas.

Landscapes with significant disturbances, covering an area of 14,659.2 km² (19.9%), are concentrated on lowland, elevated, and partially hilly plains located within desert, dry-steppe, and semi-desert zones (legend numbers 31–41). Significant landscape disturbance is represented on the map by grazing (46.91%), industrial-technogenic (26.48%), agricultural (14.85%), and linear-technogenic (11.76%) impacts. Priority restoration measures here include land reclamation efforts for areas affected by industrial and agricultural activities. For grazing lands, reclamation activities aimed at soil and vegetation restoration are necessary. Additionally, strengthening the environmental oversight of industrial activities is critical.

Landscapes with severe disturbances, covering 9085.8 km² (12.4%), are located on lowland and elevated plains typical of desert and semi-desert zones (legend numbers 42–51). Severe landscape disturbance is represented on the map by industrial-technogenic (90.2%), agricultural (7.41%), and forestry (2.3%) impacts. Landscape transformation is driven by intensive logging in the floodplain of the Ural River, oil and gas extraction, and agricultural expansion. These areas require the highest priority in reclamation programmes.

The use of remote sensing data provided a spatial understanding of the predominant anthropogenic impacts and landscape disturbance levels.

For example, in the Khromtau area, field observations identified large quarries where landscapes are entirely altered, vegetation cover is destroyed, and dust emissions are evident (Figure 10a). Observation point No. 62 revealed impacts from linear-technogenic features like unpaved roads and industrial zones, which were also confirmed by remote

sensing. Drone imagery shows abandoned quarries naturally revegetating with shrubs (Figure 10b,d).

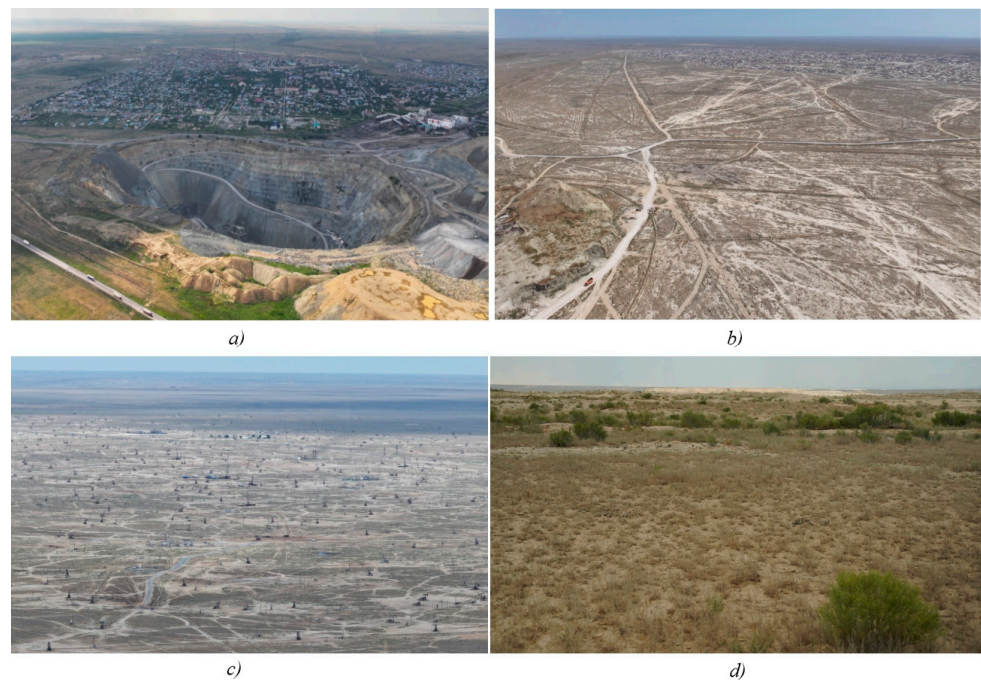


Figure 10. Field research materials: (a) Mirny quarry. Southeastern outskirts of city of Khromtau, Aktobe region. Description point Pw 11. (b) Linear-technogenic impacts, east of Aktau city, Mangistau oblast. Description point Pw 62. (c) Fields of oil rigs to east of Zhetibay settlement, Karakiyan district, Mangistau region. Description point Pw 63. (d) Vegetation cover near quarry east of Aktau, Mangystau region. Description point Pw 62.

At point No. 63, near oil facilities, heavy oil spills and compacted soils from vehicular traffic have eradicated vegetation. This area is classified as severely disturbed, dominated by industrial-technogenic impacts (Figure 10c).

As described above, the remote sensing imagery provided a spatial representation of the predominance of impact types and degrees of disturbance, which enabled their assessment.

The analysis of all images confirmed the consistency in the classification of landscape types and their degrees of disturbance thereby validating the reliability of the remote sensing method. Consequently, the data obtained through remote sensing were successfully verified by the results of the field research, allowing them to be confidently used in subsequent ecological assessments and spatial analyses of landscapes in the West Kazakhstan region.

5. Discussion

In recent decades, researchers have sought to rationalize and standardize methods for assessing landscape disturbances and ecological integrity. This has involved the development of geospatial models to evaluate the impact of anthropogenic structures. These models employ impact levels to determine landscape composition, structure, and fragmentation, as well as to establish metrics for analyzing landscape connectivity [34,35]. Incorporating GIS layers with anthropogenic disturbances as resistance or cost factors in habitat suitability models enables the visualization of these effects at the surface level [36]. Hobbs and Hopkins [37], as referenced in McIntyre and Hobbs [38], identify four levels of impact, ranging from minimal changes to complete landscape destruction, emphasizing the importance of accounting for impact intensity. To illustrate, Gorokhov [39] devised

a methodology for mapping landscape transformation in Southern Yakutia across three levels of analysis (regional, local–regional, and local), categorizing disturbance levels to account for the diverse types of land use and their impact on the landscape.

Density and distance models based on geospatial data are also effective at representing the cumulative impacts of disturbances that extend beyond the immediate footprint of impacts. These models facilitate the identification of «hotspots», which are areas of high disturbance, allowing for the assessment of the overall impact on habitat quality [40]. It is essential to understand the accuracy with which these models capture the influence of anthropogenic interference on habitat quality, as such data form the basis for developing conservation measures.

The article by Akhmetzhanova [41] analyzes the land status of the Atyrau region from the perspective of an ecological–economic balance, based on the categorization of land by economic use. The author critically evaluates existing methodologies, highlighting their shortcomings in accounting for anthropogenic pressures, and proposes an alternative approach for a more accurate assessment of land condition, which is particularly important for the sustainable development of the region.

In subsequent research, Akhmetzhanova [42] expands her analysis by focusing on the migratory pathways of pollutants within the ecological–landscape geochemical systems of Kazakhstan’s Caspian region. The primary sources of pollution are industrial discharges and highly mineralized technogenic waters, which contribute to soil salinization and groundwater contamination, thus impacting the geochemical stability of ecosystems. The author emphasizes that, to ensure the region’s sustainable development, it is essential to consider both local and long-distance pollution flows and to develop effective conservation measures that minimize anthropogenic impacts on landscapes.

Additionally, Geldyeva et al. [43] highlight the importance of conducting landscape–ecological assessments and monitoring arid zones subject to intensive impacts from the oil extraction industry. These measures include «landscape-ecological assessment of the area at the project planning stage for hydrocarbon resource development, establishment of landscape-ecological monitoring, and development of conservation recommendations aimed at preserving the natural-resource potential of landscapes».

According to data provided by E.V. Lobikova [44], the projective vegetation cover on disturbed sites rarely exceeds 40–50%. Around drilling rigs, within a radius of 150–500 m, up to 70–80% of vegetation cover is destroyed, even after biological reclamation efforts. These findings highlight the significant challenges in restoring natural vegetation in areas subjected to intensive technogenic impacts.

Analysis of Landsat-TM5 satellite images from 2002 to 2022, conducted by N.I. Rudik [45], revealed that the coastal areas of the Atyrau region are characterized by intensive secondary salinization processes. These areas often contain solonchak salt flats, which serve as natural accumulators of petrochemical pollution originating from nearby oilfields. These observations align with the findings of this study, underscoring the substantial impact of hydrocarbon extraction on soil degradation.

The severity of anthropogenic impacts is further supported by the research of Abrosimov et al. [46], who reported that, in certain oilfields, the thickness of oil-contaminated soils reaches up to 10 m. Particularly high levels of soil contamination with petroleum products were recorded near the Makat, Dossor, Komsomolskoye, Tanatar, Tenteksor, and Iskene oilfields. In some cases, petroleum product concentrations reached 172,480 mg/kg, significantly exceeding Kazakhstan’s maximum allowable concentration of 100 mg/kg [47].

Furthermore, the authors emphasize the need to establish patterns of landscape transformation during exploitation and to understand the impact of hydrocarbon extraction, processing, and transportation on regional ecosystems. Accounting for anthropogenic changes

within natural–territorial complexes, as part of natural–economic systems (NESs), «allows for determining the resilience of natural complexes», which is essential for formulating effective conservation strategies and maintaining balanced natural resource management.

The results of studies such as those described above were applied in density-based geospatial models to represent the cumulative impact of anthropogenic disturbances that extend beyond the immediate footprint of the disruption. Disturbance density is expressed as a measure of impact per unit area, relevant to the study’s objectives, while density-based models smooth the precise location of disturbances, transforming them into «hotspot» estimates (i.e., areas of concentrated disturbance). Distance- and density-based approaches offer different methods for aggregating the impact of disturbances on the landscape [48]. Regardless of the method used, it is essential to assess how effectively such models capture the influence of anthropogenic disturbances on habitat quality.

6. Conclusions

Results of the Study

1. A total of 115 types of contemporary landscapes were identified in the West Kazakhstan region, illustrating the spatial differentiation, complex regional structural organization, and significant diversity of natural complexes.
2. A map of anthropogenic landscape disturbance was developed based on a contemporary landscape map at a scale of 1:1,500,000. Additionally, a matrix was created to systematize and organize information on classes, subclasses, types, and levels of anthropogenic disturbances in the region.
3. An assessment of anthropogenic disturbances was conducted, identifying five types of impacts: agricultural (60%, including grazing 53.83% and agrogenic 4.66%), industrial-technogenic (23.12%), linear-technogenic (7.93%), residential (0.65%), and forestry (1.37%). Landscape disturbance was categorized into five levels: virtually undisturbed (1.66%), low disturbance (37.27%), moderate disturbance (22.01%), significant disturbance (19.93%), and severe disturbance (12.35%).
4. A long-term analysis of rangeland dynamics was performed using NDVI data from the MODIS satellite, while arable land was analyzed using LULC (Land Use and Land Cover) data.
5. The remote sensing data were validated through field observations, demonstrating high reliability and effectiveness in evaluating landscape conditions and conducting spatial analyses.

This study highlights the critical importance of regular landscape monitoring in the region to promptly identify changes caused by anthropogenic impacts. Based on the data obtained, it is essential to develop systemic measures aimed at reducing anthropogenic pressure, preventing further ecosystem degradation, and rehabilitating disturbed territories. Priority should be given to restoring oil extraction and forested areas.

A comprehensive approach is necessary to address these challenges, including the following:

Measures to Prevent and Mitigate Soil Pollution from Industrial and Technogenic Activities:

- Establishing monitoring systems to control soil pollution near industrial facilities and oilfields, such as Dossor, Makat, and Iskene in the Atyrau region, as well as in the Aktobe, West Kazakhstan, and Mangystau regions.
- Improving the management of oil and gas pipelines and implementing measures for the safe storage and transportation of chemical substances.

- Reclaiming disturbed lands in mining areas, managing industrial waste, and developing methods and technologies for hazardous waste treatment.
- Creating green sanitary zones and protective forest belts using local woody and shrub species around settlements, fields, industrial complexes, water bodies, roads, pipelines, and transmission lines.

Measures to Prevent the Degradation of Riparian and Forest Ecosystems:

- Inventorying and zoning riparian and forest ecosystems to establish usage regimes, define water protection zone boundaries, and identify areas requiring conservation.
- Restricting and prohibiting deforestation in the middle reaches of the Ural River, conducting sanitary clearing, and planting saplings in degraded landscapes.
- Implementing environmentally friendly technologies in hydrocarbon extraction areas to protect woody and shrub vegetation from chemical pollution.

Measures to Prevent Degradation of Soil–Vegetative Cover in Agricultural Lands:

- Inventorying arable lands and conducting agrochemical monitoring to assess soil fertility and optimize fertilizer application.
- Introducing advanced cultivation technologies tailored to soil and climatic conditions, including minimum tillage, mulching, and the use of combined soil processing equipment.
- Addressing land degradation through anti-deflation and anti-erosion measures, the reclamation of degraded arable lands, and the adoption of soil-protective crop rotations.
- Regulating livestock grazing based on landscape characteristics, pasture types, and permissible loads. Restoring degraded pastures through replanting and phytomelioration.
- Prohibiting haymaking in significantly degraded natural complexes.

Measures to Minimize Degradation Processes in Agricultural Complexes:

- Implementing forest reclamation and moisture retention measures on pastures and light soils, creating windbreaks and seasonal enclosures.
- Conducting water management and operational measures on irrigated lands to optimize water use, prevent water loss, and create reservoirs at artesian wells.

The data obtained in this study are of substantial practical value for developing sustainable land use strategies and planning conservation measures in the West Kazakhstan region. The comprehensive approach used here can be applied to other arid regions to support sustainable development and biodiversity conservation.

The successful implementation of these measures requires the integration of policy, advanced technologies, and community participation. Developing environmental programmes, ensuring legal compliance, and providing financial incentives for ecological initiatives will form the foundation for effective implementation. Engaging local communities through educational projects and restoration activities will further enhance the sustainability of these measures.

The integration of these approaches will ensure ecological sustainability and support the long-term socio-economic development of the region.

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