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**Assessment of the contribution of oil and gas production complex to the
formation of the ecological state of Mangystau region**

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DEFINITIONS

Oil field – a collection of oil accumulations located within one or more traps, governed by a single structural feature and situated within the same local area.

Gas field – a group of gas accumulations located within a common surface area, controlled by a single structural feature.

The intensity of the pollution – the overall level of speed or pollutants entering the environment.

Evaluation – the process of determining the state of the object in relation to the desired state or another entity, including correlation with the accepted criteria, sample rate.

The ecological situation – a spatio-temporal combination of different, including positive and negative in terms of human living and the state of the conditions and factors that create a certain environmental situation on the territory of a different degree of well-being or distress.

Grid model – the imposition of a grid of elementary blocks with characteristic boundaries to better align with the actual set of geoecological material maps.

Integrated Environmental Assessment (IEA) – a comprehensive form of environmental evaluation that considers the influence of various factors on ecosystems, as well as the resilience of those ecosystems. The term "integrated" reflects the need to account for a wide range of measured variables used to assess impacts either on specific environmental components (referred to as partial integrated assessments) or on the environment as a whole (referred to as overall or summary integrated assessments).

The objective function – in IEA, the proposal presented by R. Pentla as a linear multiple regression equation:

$$OF(IEA) = a_1 \cdot f_1 + a_2 \cdot f_2 + \dots + a_n \cdot f_n,$$

where OF (IEA) – calculated value of the objective function (integrated environmental assessment, assess the degree of favorable or unfavorable environmental situation with

the position of the object, which is the impact);

f_i – value of a given environmental factor ($i = 1, 2, \dots, n$) at the observation point;

a_i – weighting factor that takes into account the net (plus or minus) and importance (weight) of this factor in the formation of the total level of exposure.

The return tasks of the IEA – an independent assessment of the contribution of the individual sources of the environmental situation of the region in its comprehensive environmental assessment for an objective implementation of the principle of "the polluter pays".

SYMBOLS AND ABBREVIATIONS

PGEC	Petroleum gas of extraction complex
PGE	Petroleum gas extraction
GIS	Geographic information system
JSC	Joint-stock company
LLP	Limited liability partnership
JV	Joint venture
IEA	Integrated environmental assessment
MPC	Maximum permissible concentration
IAP	Index of atmospheric pollution
IWP	Index of water pollution
IDB	International development bank
POF	Private objective function
PSRT	Particular solution of the return tasks
IOF	Integral objective function
ISRT	Integral solution for the return tasks

INTRODUCTION

This scientific study utilizes the "Atlas of Mangystau Region" from the Institute of Geography, Ministry of Education Science of the Republic of Kazakhstan as its primary input material. The study aims to provide a comprehensive analysis of the natural, economic, and social conditions of the area, focusing on the assessment of environmental impacts. The research incorporates system-wide and eco-geographical laws to understand the relationships between natural components and to transform cartographic information into quantitative data for mathematical models. One of the key objectives of the study is to develop a method for solving the inverse problem related to environmental impact assessment. Expert estimates map of human impact on environmental components in the Mangystau region are used as a basis for this research. The study aims to address new theoretical challenges related to environmental issues in the region.

Relevance of the research topic. Management decisions aimed at reducing environmental stress in regions are typically based on the principle of "the polluter pays," which involves imposing fees or penalties on those who are responsible for environmental damage. However, in the field of waste management, this principle is often undermined by the practice of outsourcing waste removal and recycling to specialized companies on a contractual basis.

To truly assess the environmental impact of different industries and companies in a region, an independent evaluation of environmental data is necessary. This evaluation should consider the overall impact of all enterprises in all sectors of the economy, as well as the specific contributions of individual industries or companies to overall pollution levels.

In the case of the oil and gas extraction industry in the Mangystau region, addressing environmental challenges requires innovative solutions that take into account the complex interplay of factors affecting the local environment. This may involve

conducting comprehensive environmental assessments and developing strategies to mitigate the industry's impact on the region's ecosystem.

Purpose of Research: The purpose of this research is to evaluate the impact of oil and gas extraction on the environment in the Mangystau region. The goal is to assess the overall anthropogenic disturbance in the area and determine the extent to which the oil and gas industry contributes to this disturbance. The research aims to provide an independent evaluation that can be used to implement the "polluter pays" principle, requiring those responsible for environmental damage to bear the costs. This evaluation will be based on existing peer-reviewed maps that assess the level of human impact on various environmental components.

To achieve this purpose the following tasks were identified and solved:

Assess the environmental and socio-economic impacts of oil and gas production in the Mangystau region, with a focus on biodiversity, water resources, and the well-being of local communities.

Examine the current environmental conditions in the region, including air, water, and soil quality, the effectiveness of waste management practices, and the overall ecological footprint of industrial activities.

Develop a comprehensive methodology for integrated environmental assessment, incorporating the findings of previous studies and addressing the specific challenges posed by anthropogenic impacts.

Quantify the contribution of the oil and gas industry to environmental degradation through the use of advanced analytical tools and techniques.

Propose sustainable development strategies and mitigation measures to reduce the environmental impact of oil and gas activities in the Mangystau region.

The object and subject of study. Additionally, field research will be conducted to collect data on the current ecological state of the region. Interviews with local

residents, government officials, and experts in the field will also be conducted to gather information on the factors influencing the environment in Mangystau region.

Methods of research. The data collected through these various methods will be analyzed using statistical and qualitative research techniques to identify trends, patterns, and correlations in the data. The results of the research will be used to assess the current ecological state of the region, identify the main factors contributing to anthropogenic transformation, and make recommendations for sustainable development and environmental conservation in Mangystau region.

Scientific novelty of research. The novelty of the research is determined by the development of new methods for solving theoretical problems - “inverse” problems traditionally used in complex environmental assessment. The fundamental difference between the ideas for studying existing methods of integrated environmental assessment is the use of multidimensional models (the objective function as a linear multiple regression equation). The capabilities of these models are significantly superior to those traditionally used in GIS overlay operations, since areas of intersection can be identified by no more than three parameters, while environmental engineering methods show that to achieve acceptable accuracy of estimates, there must be at least five important parameters.

Theoretical significance. This study’s theoretical value lies in the creation of quantitative methodologies aimed at identifying the specific role of the oil and gas industry in altering the anthropogenic elements of the Mangistau region’s environment. It offers a novel theoretical framework for addressing complex issues in integrated environmental assessment.

Practical significance. The practical importance of the research is demonstrated through its capacity to independently evaluate the impact of low-concentration pollutants on the overall environmental condition of the region and on specific environmental components—tasks that are inherently difficult to quantify. By applying

inverse problem-solving techniques within the context of expert analysis, the study introduces innovative assessment approaches. These methods support the implementation of environmental policy, particularly the “polluter pays” principle, by providing measurable data on the oil and gas sector’s additional influence on human-induced environmental change.

Validity and reliability of results, conclusions and recommendations.

The reliability of the results justified the use of well-known mathematical models, which confirmed the correctness of the theoretical basis, the objectivity of the original cartographic material, as well as comparison of models based on a set of weight options and changes in sets of score maps. To confirm the results of particular solutions to return problems, a comprehensive environmental assessment uses the results of natural analyzes of terrain and vegetation samples taken near operating wells and with the exception of the sanitary protection zone of the Zhetybai field in 2015 and 2016.

Implementation of the results. The dissertation research was conducted within the framework of the project funded by the Ministry of Education and Science of the Republic of Kazakhstan, No. 0589/GF-4 (2015–2017), titled "Development of a Method for Objectifying Expert Assessments of the Contribution of Specific Pollution Sources to the Overall Environmental Situation of a Territory."

Personal contribution of the author's work

The author’s individual contribution to this research includes the identification of key problems, the development of appropriate methods for their resolution, the formulation of principal conclusions, preparation of input data for differential modeling, and the execution of all computational procedures. During 2015, preparatory and analytical stages of the study—focused on soil contamination, landscape features, and vegetation patterns in the vicinity of active wells and within the Zhetybai sanitary protection zone—were conducted in the United Kingdom at Middlesex University

(Faculty of Science, School of Science and Technology). In 2016, the outcomes of a specific inverse solution were validated through comprehensive expert analysis.

Sources of research.

The thesis is grounded in an established Integrated Environmental Assessment, which is based on expert evaluations presented in the form of an atlas map. This map illustrates the zoning of the Mangystau region according to varying levels of anthropogenic impact on the landscape, soil, vegetation, and groundwater. It synthesizes an extensive body of factual data reflecting the natural, economic, and social characteristics of the region.

Approbation of the work.

Report the results and sections of dissertations, discussed at various conferences during 2014-2016 at international conferences, including: Tempus I-Web Kazakh National University. Al-Farabi “Integrating water cycle management: building capacity, capacity and influence in education” (Almaty, 2015), “Modern problems of hydrometeorology and geoecology”, dedicated to the 75-year-old professor, Doctor of Geology. Cherednichenko V.S. (Almaty, 2015); “Ecological safety of territories and water areas: international and global problems” (Kerch, 2016) “Nature – Society – Human”: Designing the future world Dubna, December 19 – 20, 2016 (Moscow, 2006-2008).

Publications. 1 monograph, 16 articles in scientific journals, 3 articles in collections of international conferences, 3 thesis on international scientific conferences.

Volume and structure of the thesis. The thesis consists of pages 170, number of tables 18, figures 10.

1..... MODERN ENVIRONMENTAL PROBLEMS OF MANGYSTAU REGION

1.1 Brief physical and geographical characteristics of Mangystau region

The Mangystau region, formerly known as Mangyshlak, was established on March 20, 1973, from the southern part of the Guryev region. In 1988, the region was abolished, but it was reinstated in 1990 under the name Mangystau. It is located east of the Caspian Sea, on the Mangyshlak (Mangystau) Plateau. The region borders Atyrau and Aktoobe regions to the northeast, Turkmenistan to the south, and Uzbekistan to the east.

The land of Mangystau is a treasure trove of ancient civilization, an archaeological reserve, and an open-air museum. It is home to 11,000 historical monuments protected by the state, as well as thousands of petroglyphic "poems"—ancient drawings. This region is renowned for its unique sacred structures and mosques, including Beket-Ata, Shakpak-Ata, Shopan-Ata, and Masat-Ata, which attract pilgrims not only from Kazakhstan but also from Turkmenistan, Uzbekistan, Russia, the Caucasus, Iran, and Turkey.

A thousand years ago, the territory of present-day Mangystau was a vital part of the Great Silk Road, which linked Khwarezm and Khiva with Europe and the Middle East. The Ustyurt Plateau was once dotted with fortresses, caravanserais, and settlements of artisans, herders, and hunters. Archaeological evidence suggests that life in these communities was relatively prosperous. However, waves of migration and repeated wars disrupted this ancient trade route. Eventually, the Mongol invasions of the region in later centuries led to the complete disappearance of the Silk Road through Ustyurt. For centuries afterward, Mangystau remained isolated, a distant frontier on the edge of the known world. Windswept and scorched by the sun, the land became a harsh environment where nomadic tribes struggled to survive. Today, Mangystau is often

referred to as the "peninsula of treasures," a region rich in historical landmarks and ancient paths. These roads now lead to the regional capital, Aktau—a coastal city and one of the youngest in Kazakhstan. The prominent Kazakh geologist and first president of the Academy of Sciences of the Kazakh SSR, Academician Kanysh Satpayev, once viewed the region from the sky and noted that the shape of the peninsula resembled a veiled woman. He famously called it "the sleeping beauty." That "sleeping beauty" was awakened in the 1950s, when geologists discovered significant reserves of uranium, rare earth elements, oil, and gas beneath the land. These findings spurred rapid development, leading to the establishment of cities and industrial settlements, including Aktau, Zhanaozen, and the oil-producing towns of Zhetybay, Kalamkas, and Karazhanbas. Today, Mangystau is a major industrial hub, accounting for approximately 25% of Kazakhstan's oil production. The Aktau–Zhetybay–Uzen oil pipeline runs through the region, and Aktau serves as the country's primary maritime gateway. Mangystau also hosts five museums that celebrate its rich cultural and historical legacy. In which funds there are archeological and paleontological finds confirming that the region once was the place of ancient Euroasian civilizations function. Local inhabitants carefully store certificates of those of far years. On Mangyshlak old times and the present get on. Melodies, songs and kyu of Mangystau always differed in the originality and beauty. Seven national singers – composers, great – the akyn-zhyrau and many other geniuses of national spirit – left after themselves the richest heritage. These cultural traditions find the continuation in creativity of our talented contemporaries.

Original creations of national architects of the 19th century when architectural art of Mangystau has reached the blossoming, have absorbed in themselves many centuries the experience developed by many generations of masters. This period dates the richest mausoleums on registration. Their harmonious forms, magnificence of a rare ornament, the internal colourfully painted walls are worthy admiration of the most captious viewer. In 1980 the Mangystau National historical and cultural park has been created. In the area

there are over 12 thousand monuments of history and culture. 139 objects taken under protection of the state are under authority of the reserve. From them 20 monuments of republican value. It is investigated and processed scientifically over 12000 monuments. They display all periods of development of culture and religion of the Caspian people.

One of especially esteemed and visited monuments of Mangystau is the rocky mosque Beket-Ata in the area Oglandy (the Southern Ustyurt). The mosque is located in 100 km from Shopan-Ata. In depth of the mosque in a crypt it is buried itself Beket-Ata. Beket Myrzagululy philosopher and educator of the Kazakh people. In youth he has become famous as the brave and skillful soldier and the commander. In the middle of life, dreaming of the world and a consent on the homeland, he addresses religion, becomes the follower of the Sufi doctrine of Islam. In places of seasonal movements he suits the mosques-medrese where educates people and preaches a just image of life, will organize training of children in the diploma. For the life he has built several underground rocky mosques. They are located in lower reaches of the river Emba, on the Aral coast, about a well old Beyneu and in the area Oglandy.

1.1.1 Short physiographic characteristic

The area is located on South-West of the Republics of Kazakhstan in a desert zone and includes the peninsula of Mangyshlak, the Ustyurt plateau, the peninsula Buzachi, quarrels Dead Kuluk and Kaydak. The area of the territory of the region makes 165,6 thousand sq.km.

As of December 1, 2024, the population of the Mangystau region was 803.6 thousand people. This included 369.7 thousand urban residents (46%) and 433.8 thousand rural residents (54%)."

The area is characterized by sharply-continental arid desert climate which is formed in bigger degree under the prevailing influence Iranian and Arctic masses.

Rather big extent of area on longitude significantly affects the temperature mode, especially in winter time.

Considerable impact on the temperature mode of area is exerted by the Mangystau region lies between the Caspian Sea and the western edge of the Siberian anticyclone, whose climatic axis extends westward through central Kazakhstan. Winters in the region are generally mild and brief, especially in the southern parts where thaws are common. Average January temperatures range from -4°C to -9°C , though in particularly harsh winters, extreme lows can drop to -26°C or even -43°C . Summers are long and hot, but unlike winter, temperature variations across the region are relatively small. In July, average temperatures remain above 24°C , with maximums reaching up to 45°C .

Annual precipitation is low, typically around 100–150 mm. Most of this (60–70%) falls during the colder months, while only 30–40% occurs in the warmer period. However, summer precipitation often evaporates before reaching the ground due to high atmospheric dryness, resulting in the phenomenon known as "dry rain." A stable snow cover forms only in late December in northern and some central areas; in most of the region, snow remains on the ground for less than a month. Snow depth rarely exceeds 10–15 cm, as strong winds often blow it into low-lying areas like ravines and gullies, where it accumulates and facilitates effective snowmelt infiltration.

The combination of low precipitation and high evaporation rates leads to low relative humidity, typically between 30–60%. The region is also known for its strong winds and frequent storms. During winter, eastern and southeastern winds dominate, while in summer, winds shift to the west and northwest. Average annual wind speeds range from 3 to 7 meters per second, with peak speeds reaching 10–26 m/s. The highest average monthly wind speeds, between 4.8 and 7.1 m/s, are recorded in January and February. Coastal areas often experience storm-force winds exceeding 15 m/s during winter months.

Meteorological Conditions of Aktau

The average air temperature in the region for the first quarter was -4.0 to $+2.5^{\circ}\text{C}$, which is 2°C above the norm (norm: -6.2 to $+0.6^{\circ}\text{C}$).

Precipitation fell across most of the region within the normal range (7–20 mm). However, some locations recorded above-normal precipitation:

- Automatic Weather Stations Bolashak: 20.1–37.5 mm
- Automatic Weather Stations Zhetibay: 16.0–27.4 mm
- Automatic Weather Stations Ushtagan: 20.3 mm
- Automatic Weather Stations Kuryk: 33.4 mm
- Fort Shevchenko: 20.0 mm
- weather stations Beineu: 17.9 mm
- weather stations Sam: 26.7 mm
- Automatic Weather Stations Akkudyk: 14.5 mm
- weather stations Aktau: 35.6 mm This represents 149–250% of the norm.

Near the ground, frequent changes in pressure fields caused unstable weather. Fluctuations in air temperature, along with precipitation, fog, ice, blowing snow, and dust storms, were observed. Wind gusts reached 15–25 m/s.

Weather conditions also influenced air pollution levels. In the 2024, two days of low wind (light wind) were recorded. "Observations of the chemical composition of atmospheric precipitation involved sampling rainwater at two weather stations: Aktau and Fort Shevchenko. The sediment samples were primarily composed of hydrocarbonates (25.49%), sulfates (17.67%), chlorides (23.0%), sodium ions (12.90%), calcium ions (11.25%), nitrates (1.41%), magnesium ions (2.19%), potassium ions (5.16%), and ammonium (0.94%) The lowest total mineralization was recorded at the weather stations Aktau (130.31 mg/L), while the highest was at the Fort Shevchenko MS (232.95 mg/L). The specific electrical conductivity of atmospheric precipitation ranged from $199.9\ \mu\text{S}/\text{cm}$ (Aktau MS) to $432.5\ \mu\text{S}/\text{cm}$ (weather stations Fort Shevchenko). The

acidity (pH) of precipitation ranged from 7.3 (Fort Shevchenko) to 7.5 (weather stations Aktau)

The relief of the territory of the area is various. The northern part consists of the Caspian Lowland, which includes low mountains such as Zheltau (221 m) and Mynsualmas (148 m), as well as sandy deserts like Kara Kum and Itself, and large saline areas such as Olykoltyk, Kaydak, Karatuley, and Karakeshu. This area also encompasses the Buzachi Peninsula.

The central part is dominated by the Mangystau Peninsula, home to the Mangystau Mountains (including Aktau and Karatau, rising up to 556 meters), the Mangystau Plateau, and the Karakiya Depression—the lowest point in the CIS at –132 meters. To the southwest lies the Kendyrly-Kayasansk Plateau, and to the south is the Karynzharyk Depression. The eastern portion of the region is taken up by the expansive Ustyurt Plateau.

Much of the region is characterized by arid wormwood deserts with patches of shrub vegetation on brown soils. The surface is partially covered with saline flats and sand dunes, supporting extremely sparse plant life. Due to the harsh climate and minimal soil development, the region's landscapes are highly sensitive to human impact.

The western boundary of the region is bordered by the Caspian Sea, which covers a basin area of 3.6 million square kilometers. The sea's surface area is approximately 424,000 square kilometers, with a total water volume of 77,000 cubic kilometers and an average salinity of 12.6%.

Mangystau has no permanent river network. Instead, it is characterized by enclosed depressions surrounded by numerous dry streambeds, ravines, and channels that only carry surface runoff during spring and autumn. The highest concentration of dry riverbeds, wells, and springs is found in the mountainous areas of Mangyshlak, where some springs are abundant enough to support irrigation of vegetable crops. The Ustyurt Plateau also has a significant number of wells.

The largest area – Karakiyansk – has the area of 64,836 thousand sq.km, the largest city on number – the administrative center of area of Aktau, with the population of 181,7 thousand persons. [2] (table 1).

Table 1 – Administrative-territorial division of the Mangystau region

Name of the area	Area, one thousand sq.km
Aktau a.	-
Aktau	0,299
Zhanaozen a.	-
Zhanaozen	0,515
Area Beyneusky	40,519
village Beyneu	-
Area Karakiyansky	64,836
village of Kuryk	-.....
Mangystau district	46,022
village of Shetpe	-
Area Munaylinsky	4,922
village of Mangystau	-
Area Tupkaragansky	8,528
Fort-Shevchenko	-
In total on area:	165,642

The Mangystau region shares its northeastern borders with the Atyrau and Aktobe regions, while to the west it is bounded by the Caspian Sea, across which lie Russia, Azerbaijan, and Iran. To the south, it borders Turkmenistan, and to the east, Uzbekistan. The region's internal borders stretch for 319 km, while its external borders extend 1,173 km, including 810 km along the Caspian Sea.

Since Soviet times, Mangystau has been a major center for industrial development, primarily driven by its substantial reserves of hydrocarbon resources. The region produces approximately 25% of Kazakhstan's total oil output. Additionally, it is home to the country's key maritime gateway—the port city of Aktau.

Between 2010 and 2014, the region demonstrated strong socio-economic performance, with Mangystau contributing about 5.5% to Kazakhstan's gross regional product. The vast oil and gas reserves have attracted significant financial interest from both domestic and international companies, making Mangystau one of the main hubs for the extraction and export of hydrocarbon resources in the country.

From January to December 2024, the total volume of industrial production in the Mangystau region reached 3,035,657 million tenge at current prices, reflecting a 3.3% increase compared to the same period in 2023. In the mining sector, output grew by 2.7%, while the manufacturing sector experienced a significant rise of 12.8%. Conversely, the supply of electricity, gas, steam, hot water, and air conditioning saw a slight decline of 0.9%. Meanwhile, activities related to water supply, waste management, treatment, and environmental cleanup recorded a 12.9% increase.

Agricultural output for the same period totaled 40,380 million tenge, which is 101.9% of the volume recorded in the corresponding period of 2023.

As of January 1, 2025, the number of registered legal entities in the region stood at 17,553, marking a 4.4% increase compared to the same date the previous year. Of these, 17,171 are small enterprises employing fewer than 100 people. The number of registered small and medium-sized enterprises (legal entities) grew by 5%, reaching 15,346.

Labor and income

In the third quarter of 2024, the region reported 18.3 thousand unemployed individuals, resulting in an unemployment rate of 5% of the labor force. As of January 1, 2025, 12,694 people were registered as unemployed with employment authorities,

representing 3.5% of the workforce. In the third quarter of 2024, the average monthly nominal wage in your region was 570,233 tenge, reflecting a 9.8% increase compared to the same period in 2023. In the third quarter of 2024, the region's real wage index was 99.7%, indicating a slight decrease in purchasing power compared to the same period in 2023. The average per capita nominal monetary income was 243,627 tenge, representing a 12.4% increase from the third quarter of 2023. The growth rate of real cash income for this period was 2.1%.

Economy

The calculation of the short-term economic indicator is carried out to ensure efficiency and is based on changes in output indices for basic sectors: agriculture, industry, construction, trade, transport and communications, accounting for over 60% of GDP. In the period from January to September 2024, the Gross Regional Product (GRP) of your region amounted to 3,654,775.7 million tenge in current prices, reflecting a 3.7% real-term increase compared to the same period in 2023. Within the GRP structure, the production of goods accounted for 55.7%, while services contributed 36.7%. In December 2024, the Consumer Price Index (CPI) in your region increased by 9.2% compared to December 2023. This regional inflation rate is slightly higher than the national average of 8.6% for the same period. According to preliminary data, from January to November 2024, Kazakhstan's mutual trade with Eurasian Economic Union (EAEU) countries amounted to \$19.65 million, reflecting a 15.3% decrease compared to the same period in 2023. Exports stood at \$19.4 million, a significant 65.5% decline, while imports were \$177 million, marking a 0.8% increase.

The main exporters of oil – AO "Ozenmunaygaz", AO "Investigation Production KazMunaiGas, AO "Mangistaumunaygaz", AO "Karazhanbasmunay", TOO SP "Arman", ZAO "Karakudukmunay". Oil goes generally to Switzerland, to the Virginia islands, Italy, Great Britain, Gibraltar, the Bahama islands [4].

Kazakh oil exports in 2025 are focused on the following areas:

Italy: remains the largest consumer of Kazakh oil.

- The Netherlands: increased purchases of oil from Kazakhstan.
- Greece: increased imports of Kazakh oil.
- Germany: continues to receive supplies through the Druzhba oil pipeline.

In addition, Kazakhstan is considering increasing exports through alternative routes, such as the Baku-Tbilisi-Ceyhan pipeline, to diversify export routes.

As of 2025, Kazakhstan continues to actively advance its oil industry, solidifying its role in the global energy market and broadening the reach of its export destinations.

Within the Mangystau region, approximately 70 hydrocarbon fields have been explored, with total recoverable reserves estimated at 702.5 million tons of oil, 157.7 billion cubic meters of natural gas, and 4.7 million tons of gas condensate. Currently, 27 of these fields are under development. Over the years, the region has produced 426.8 million tons of oil—accounting for 73% of Kazakhstan’s total oil production since the inception of the national oil extraction industry.

Among the most significant fields are Uzen, with estimated reserves of around 500 million tons of oil; the Zhetybay oil and gas-condensate field with approximately 150 million tons; and other major deposits such as Karazhanbas, Northern Buzachi, and Kalamkas, which collectively hold over 350 million tons of initial reserves.

One of the most promising areas for future exploration is the central sector of the Caspian Sea. Forecasts suggest that the Caspian shelf, to depths of up to 600 meters, may contain up to 500 million tons of oil and gas—more than four times the estimated reserves in Azerbaijan’s sector. A key confirmation of the shelf’s potential was the discovery of oil and gas at the offshore Pearl field. In total, there are 14 hydrocarbon sites within the Mangystau sector of the Caspian Sea.

Despite its relatively compact size, the region is also rich in other natural resources, including phosphorites, various salts and minerals, and iron ore. In the early 1950s, some of Kazakhstan’s largest uranium and rare-earth element deposits were

identified in Mangystau. One notable example is the Beck deposit, located 40 km east of the Zhetybay settlement, with approved reserves of 60 million tons.

Mangystau is also abundant in construction materials, particularly limestone, which is found on the surface across much of the region. This limestone is widely used and highly valued not only within the GIS but also internationally. The estimated reserves of limestone (shell rock) amount to several billion cubic meters, with around 100 deposits already explored. Additionally, the region contains deposits of other construction materials such as crushed stone, raw materials for brick production, building lime, sand-gravel mixtures (SGM), and construction sands and other [4].

The main priorities are preserving jobs, preventing unemployment, and meeting social obligations. To achieve this, an action plan has been developed, which includes both public and private investment projects. To achieve this, an action plan has been developed, which includes both public and private investment projects. Measures to monitor the labor market are being implemented, and memorandums have been signed with enterprises. A key step was the reduction of export customs duties on oil. Efforts continue in close collaboration with the government and businesses to stimulate domestic consumption and support key industries[8-9].

To ensure the economic and social sustainability of the Mangistau region for the period 2021–2025, a Comprehensive Plan for the Social and Economic Development of the Region has been developed. The key priorities of this plan include:

Economic Diversification: Reduce dependence on the oil and gas sector by developing other industries and services.

Development of Human Capital: Improve the quality of education and healthcare, while also promoting employment and increasing the incomes of the population

Infrastructural development: Modernization of transport and utility infrastructure to improve the quality of life and attract investment.

Source: adilet.zan.kz

Environmental sustainability: Conservation of the environment and rational use of natural resources.

Social support: Providing social protection for vulnerable segments of the population and improving their well-being.

The Mangistau region is effectively adapting to changing economic conditions, particularly in the oil and gas sector. With accumulated experience, strategic planning, and supportive measures, the region ensures socio-economic sustainability. To support further development, a Comprehensive Socio-Economic Growth Plan for 2021–2025 was approved, outlining key priorities: economic diversification, human capital development, infrastructure modernization, environmental sustainability, and support for socially vulnerable groups. The implementation of these initiatives aims to create a sustainable economic model, reduce dependence on the oil and gas sector, and improve the quality of life for the population.

1.2 Characteristics of environmental conditions and factors of its formation

The section is written on materials of the statistical reporting of Department of statistics of the Mangystau region and Management of natural resources and regulations of environmental management of the Mangystau region (The information bulletin about a condition of the surrounding environment of the Mangystau region for 2010-2014).

1.2.1 Atmospheric air

For the period of 2009-2013 growth of number of the industrial enterprises influencing the atmosphere [3] (table 3) was noted.

Table 3 - The number of the enterprises of the Mangystau region performing emissions of the contaminating substances [3]

Cities and regions	Years				
	2009 year.	2010 year.	2011 year.	2012 year.	2013 year.
Aktau c.	209	249	261	177	166

Zhanaozen c.	22	34	34	43	47
Beineu town	19	25	28	49	52
Karakiyak town	9	14	11	48	48
Mangistau town	3	5	7	28	36
Munaily town	25	29	27	41	57
Tupkaragan town	14	17	11	60	77
Total of the region	306	373	379	446	483

Most the enterprises is concentrated in Aktau (166 enterprises) and to Zhanaozen (47 enterprises) that makes 44,1% of all enterprises of area.

Pollution of atmospheric air in the Mangystau region was caused by emissions of the enterprises of the industry relating, the main image, to an oil and gas complex, the chemical industry, power, pits on extraction of nonmetallic materials, to construction, the processing industry and motor transport.

Between 2009 and 2013, total emissions from enterprises in the Mangystau region increased by 22%, rising from 67.1 thousand tons to 82.4 thousand tons. Of this amount, only 4.9 thousand tons were captured and treated at air purification facilities, while the remaining 77.1 thousand tons were released directly into the atmosphere without any filtration.

The majority of pollutants from industrial emissions are discharged into the air untreated, highlighting the urgent need for pollution sources to be equipped with appropriate dust and gas cleaning technologies.

Additionally, at the Dunga field, a valve malfunction at the gas treatment facility led to excess flaring of associated gas beyond regulated limits.

The highest contributors to air pollution in the region are industrial enterprises located in Aktau, the regional center, which account for 20% of total emissions. This is followed by Zhanaozen and Beyneu district, each contributing 17% to the overall volume of pollutants

According to the Department of Statistics of the Mangystau Region, the chemical composition of pollutant emissions reveals that hydrocarbons make up approximately 38%, with carbon monoxide and volatile organic compounds accounting for 25% and 22%, respectively [2]. Despite ongoing efforts by major oil and gas companies in the region to implement programs for the utilization of associated petroleum gas, the issue of substantial atmospheric emissions—particularly from gas flaring during oil extraction—remains a significant environmental concern.

The structure of atmospheric pollutant emissions varies across the districts of the Mangystau region. The highest concentrations of sulfur dioxide and hydrocarbons are found in emissions from enterprises located in Zhanaozen, while hydrogen sulfide is most prevalent in the Karakiyan district. Carbon monoxide emissions are dominant in the Munaylin district, nitrogen oxides and ammonia in Aktau, and volatile organic compounds in the Mangystau district [10].

According to available data, the composition of emissions from industrial enterprises across cities and districts in 2013 was as follows: hydrocarbons were the dominant pollutants in Aktau, Zhanaozen, and the Tupkaragan district; sulfur dioxide prevailed in Beyneu, Karakiyan, and Mangystau districts; and carbon monoxide was the main contaminant in Munaylin.

Overall, hydrocarbons constituted the largest portion of total emissions in the region (38%), followed by carbon monoxide (25%) and sulfur dioxide (22%).

To address atmospheric pollution, the region has introduced advanced oil and gas production technologies. In recent years, three gas processing plants have been commissioned—two by JSC "MNK Kazmunayteniz" and one by LLC "Karakudukmunay." Additionally, a mini gas processing facility operated by LLC "Emir Oil" is currently in operation. In the latter half of 2012, a gas treatment unit was launched at the Northern Buzachi field by FC "Buzachi Operating Ltd."

Modern gas reinjection technologies have also been adopted. For instance, LLC "Com-Munay" has implemented a system to inject associated gas back into underground reservoirs. This approach allows part of the gas to meet internal production demands, while excess gas is reinjected to reduce emissions.

As of January 1, 2013, several enterprises had achieved full utilization of associated gas, including: JSC "Mangystau Munaygaz," JSC "Ozenmunaygaz," LLC "Hazar-Munay," LLC "SP Arman," LLC "Karakudukmunay," AF JSC "MNK Kazmunayteniz," FC "Maersk Oil Kazakhstan GmbH," LLC "Buzachi Neft," LLC "Tasbolat Oil Corporation," and FC "Buzachi Operating Ltd."

By 2014, atmospheric monitoring at the Dunga and Zhetybay oil fields showed that pollutant levels—including suspended particulate matter, sulfur dioxide, carbon monoxide, nitrogen dioxide, ammonia, sulfuric acid, and total hydrocarbons—did not exceed maximum allowable concentrations (MACs).

Between 2009 and 2010, concentrations of total hydrocarbons at all monitoring points at these fields ranged from 1.0 to 3.2 times the MAC. However, levels of sulfur dioxide, carbon monoxide, nitrogen dioxide, ammonia, and sulfuric acid remained within regulatory limits. From 2011 to 2014, all monitored pollutants consistently stayed within established safe thresholds [2].

Aside from industrial sources, motor vehicles represent a major contributor to air pollution in cities and densely populated areas. Data from the Road Traffic Police of the Mangystau Region's Department of Internal Affairs indicate a steady annual increase in vehicle numbers, leading to a corresponding rise in emissions.

In 2013, over 140,000 vehicles were registered in the region—an increase of 30,000 compared to 2009. The problem is worsened by the fact that a significant portion of these vehicles are between 6 and 25 years old, which contributes to high levels of exhaust emissions with a complex chemical composition [3].

Assessment of Atmospheric Air Quality in the Mangystau Region (2020-2024)

Main Sources of Air Pollution

According to the Republican State Institution “Department of Ecology for the Mangystau Region,” 70 large enterprises emit pollutants into the environment. The total actual emissions from stationary sources amount to 79.04 thousand tons.

General conclusion on changes in the level of atmospheric air pollution for 2020–2024.

Aktau City:

Pollution levels in 2022, 2023, and 2024 were assessed as elevated. In 2020, pollution levels were very high, while in 2021, they decreased to high levels. The highest number of exceedances of maximum one-time MPCs was recorded for carbon monoxide (5 cases) and hydrogen sulfide (62 cases). Average daily concentrations were exceeded for PM10 suspended particle

Zhanaozen City:

Pollution levels in March have remained stable over the past five years and are assessed as elevated. The highest number of exceedances of maximum one-time MPCs was recorded for hydrogen sulfide (4 cases). No exceedances of average daily concentration standards were recorded.

Beineu village:

Overall, pollution levels in the first quarter have remained unchanged over the past five years and are rated as elevated, with the exception of 2020 when they were low. The largest number of exceedances of maximum one-time MPCs was recorded for suspended particles PM_{2.5} (37 cases), PM₁₀ (64 cases) and ammonia (1 case).

Excess of average daily concentrations was observed for ground-level ozone.

Conclusion:

Overall, during 2020–2024, the level of air pollution in the settlements in question remains high, especially in Aktau and Beineu. In Zhanaozen, the situation is relatively stable but still assessed as elevated. The main pollutants are suspended particulate matter (PM_{2.5}, PM₁₀), hydrogen sulfide, carbon monoxide, and ammonia, which require further monitoring and pollution reduction measures. In Zhanaozen, the level of pollution in March has remained unchanged over the past five years and was assessed as elevated. The highest number of exceedances of maximum one-time MPCs was recorded for hydrogen sulfide (4 cases). Exceedances of the standard daily average concentrations were not observed.

The level of pollution in the 1st quarter over the past five years has remained unchanged and was assessed as elevated, except for 2020, when the level was low. The highest number of exceedances of maximum one-time MPCs was recorded for suspended particles PM_{2.5} (37 cases), suspended particles PM₁₀ (64 cases), and ammonia (1 case). Exceedances of the average daily concentration standards were observed for ground-level ozone.

1.2.2 Land resources and soils

Ecologically reasonable and balanced land use, which promotes the preservation of land and soil resources, is of significant importance for sustainable development, both at the national level and within specific regions. One of the key activities in land and soil protection is the formation of an optimal land fund structure for the region.

According to the 'Management of Land Relations of the Mangystau Region,' as of April 29, 2014, the total area of land in the region is 16,564.2 thousand hectares.

In 2014, the largest areas of land were dedicated to agricultural purposes and land reserves, comprising 31% and 59% of the total land area, respectively. Residential areas occupied 6% of the land. Forest lands and specially protected natural areas covered 241.3 thousand hectares (1.3%) and 223.7 thousand hectares (1%), respectively. Industrial and transportation lands accounted for 274 thousand hectares (2%).

Changes in the distribution of land categories within the Mangystau region's land fund are largely associated with rapid industrial development and challenging conditions for rural economic growth. Notably, throughout the period under review, the area allocated to specially protected natural zones of national significance has remained static. These areas account for only 1.4% of the total land fund—an amount insufficient to ensure comprehensive protection of the region's biodiversity.

Soil Degradation: The Mangystau region is exposed to a range of environmental challenges, including desertification driven by human activity, frequent dust storms, and the decline of vegetation cover. Desertification—particularly the spread of mobile sands—has become an increasingly critical issue across many arid zones of Kazakhstan. In Mangystau, vulnerable areas include the sandy regions near the villages of Senek (Karakiyay district), Ushtagan, and Tushchykuduk (Mangystau district). The most prevalent form of desertification in the region is complex in nature, resulting from a combination of human-induced factors and the progressive degradation or complete loss of the soil-vegetation layer. In many areas, these processes are primarily linked to the transportation and operation of oil extraction machinery. In addition, regions near the Caspian Sea coastline and the eastern parts of the region bordering Kyzylorda are particularly prone to dust storms, which further accelerate environmental degradation.

As part of efforts to combat desertification in the region, a number of actions have been implemented. In 2013, the 'Management of Natural Resources and Environmental Management Regulation of the Mangystau Region' signed an agreement with GKP 'Zhasylalem' for the 'Restoration of Vegetation Cover' project in the Bostankum and Tuyesus sandy areas, with a budget of 26.0 million tenge. Additionally, an agreement with GKP 'Zhasylalem' for a sand stabilization project in the village of Tushchykuduk was signed for 24.9 million tenge. The allocated funds were fully utilized. As a result of these efforts, 1,800 hectares of land were stabilized. Currently, an estimate is being developed for works aimed at creating barriers and restoring vegetation cover on 1,000 hectares of land in the Senek and Ushtagan areas. [3].

Soil Pollution: The soil cover of the Mangystau region faces high technogenic pressure due to the operations of industrial enterprises in the oil and gas sector.

The factors contributing to soil pollution and degradation include the use of powerful drilling and construction equipment with a high destructive impact, extensive transport networks for raw material export, insufficient reliability of operated trade equipment and transportation means, the formation of oil and drilling sludges, high hydrogen sulfide content in raw materials, oil spills, and both organized and unauthorized waste dumps [13].

Petrochemical soil pollution is widespread across all operating oil and gas fields and areas near main oil pipelines due to the irrational development of natural resources. Oil pipeline ruptures, emergency spills from exploratory wells, technological violations during the transportation and storage of raw materials, and the use of outdated, worn-out equipment are key contributors to soil pollution. As a result, soils acquire new, negative properties that differ from natural soil formation, which requires significant financial investments for restoration.

When oil spills occur, a surface bitumen layer forms in the soil profile. These layers oxidize when exposed to air and have a high density, making them impermeable to air, microorganisms, water, and plant roots. This leads to slow decomposition and long-lasting contamination in the soil, creating persistent pollution hotspots in the surrounding environment. The bituminous layers contain carcinogenic heavy hydrocarbons, with 3,4-benzopyrene being particularly toxic and dangerous [14].

In soils polluted by oil, key genetic indicators are disrupted: the content of humus, nitrogen, phosphorus, and minerals changes; bulk density increases; and aeration and water penetration decrease. As a result, the soil's morphological profile collapses, its genetic properties change, and wind and dust carry away small particulate matter, among other effects [15].

During oil extraction, soil salinization occurs due to the waste trade water. Many oil fields are heavily flooded and exhibit high levels of mineralization. The lack of an effective wastewater disposal system at oil production facilities leads to the creation of lifeless reservoirs containing brine water and toxic chemical substances on the production sites [3].

Soil quality monitoring in the Mangystau region is regularly conducted by ASE 'Mangystau Center for Hydrometeorology,' which collects soil samples from the territories of Aktau, Zhanaozen, Fort-Shevchenko, the settlement of Beyneu, SEZ 'Seaport-Aktau,' and four oil and gas fields (Dunga, Zhetybay, Armand, Karazhanbas), and analyzes them.

At the Dunga (3 points) and Zhetybay (3 points) fields, the concentration of oil products ranged from 0.014% to 0.04%, and the content of chromium (Cr6+), manganese, lead, zinc, nickel, and copper did not exceed the permissible limits (see Table 6) [2].

At the Karazhanbas and Armand fields, the concentration of oil products ranged from 0.03% to 0.065%, and the content of chromium (Cr6+), manganese, copper, lead, nickel, and zinc did not exceed the permissible

In 2013, the LLC "Republic Scientific Research Center for Air Protection" carried out an environmental assessment of the soil cover in Zhanaozen as part of the research project titled *"Development of the GIS-Based Ecological Passport for the City of Zhanaozen."* The study focused on evaluating soil contamination by heavy metals (lead, cadmium, copper, zinc) and petroleum products.

At present, the area of soils in Zhanaozen that have been affected to varying degrees by human economic activity is expanding rapidly. The soil cover in the city is primarily impacted by mechanical and chemical factors, while biological and complex factors play a lesser role. Mechanical disturbances are especially pronounced in the urban landscape, particularly within residential and industrial zones [16].

In the urban setting of Zhanaozen, anthropogenic influences now outweigh natural soil-forming processes. This has led to the emergence of anthropogenically modified soils that possess characteristics distinct from those of undisturbed, natural soils.

To determine the natural background levels of heavy metals in regional soils, two reference sites were selected: one located along the Aktau–Zhanaozen highway and the other along the Zhanaozen–Turkistan route. Research conducted in 2013 mapped the distribution of heavy metals in Zhanaozen soils, including areas earmarked for future urban development [17].

Conclusions to Section 1:

The role of the oil and gas sector in the region's economy will not decrease and has real potential for growth.

The existing state ecological monitoring network cannot provide a comprehensive view of the region's ecological condition due to the limited number of observation points.

No monitoring has been conducted on vegetation pollution.

Although the review highlights the significant role of the oil and gas sector in the region's ecological situation, the available data on soil pollution show only minor excesses in industrial centers. For example, at observation points in oil and gas fields, the concentration of oil products ranged from 0.03% to 0.065%, while the levels of chromium (Cr⁶⁺), manganese, copper, lead, nickel, and zinc did not exceed permissible norms.

This situation underscores the importance of independent ecological research, which would provide a comprehensive ecological assessment of the region and the role of the oil and gas sector in its development."

2 METHODS FOR SOLVING THE INVERSE PROBLEM IN INTEGRATED ENVIRONMENTAL ASSESSMENT

The ecological condition of a territory is assessed based on the outcomes of various environmental monitoring components. These monitoring tools measure the impact of multiple anthropogenic sources on key environmental elements, including air, soil, vegetation, terrain, surface water, and groundwater. The data collected from these measurements form the basis for conducting either comprehensive (multi-component) or individual (component-specific) environmental assessments.

Due to the complexity involved in developing both types of assessments, there is currently no universally standardized methodology. Nonetheless, the "polluter pays" principle remains a fundamental concept, requiring an independent evaluation of the contributions made by specific pollution sources to the overall or component-specific ecological condition. Within this context, the inverse problem of environmental assessment—whether comprehensive or targeted—must be addressed. This study considers a comprehensive ecological assessment following the approach proposed by R. Pentl.

Two methods for resolving the inverse problem of integrated environmental assessment have been developed using pre-existing expert maps. These maps provide detailed evaluations of anthropogenic changes to environmental components. The methods include both generalized and differentiated approaches and were created as part of a research grant from the Ministry of Education and Science of the Republic of Kazakhstan (grant No. 0589/GF-4), titled *"Development of a Methodology for Objectifying Expert Evaluations of the Contribution of Individual Pollution Sources to the Overall Environmental Situation in a Territory."*

2.1 Methods of constructing the objective function

The high level of anthropogenic impact in the Republic of Kazakhstan is largely attributed to the intensive development of the oil and gas sector, which is considered one of the most environmentally hazardous industries. In the Mangystau region, specific climatic conditions—such as susceptibility to deflation and the presence of sparse vegetation with limited ability to buffer anthropogenic effects—intensify the need for strict adherence to environmental safety standards [23, 24, 44].

Studies evaluating environmental risks associated with different extractive industries have demonstrated that relying solely on the maximum permissible concentrations (MPC) of harmful substances is inadequate for assessing ecological impact, especially in the case of heavy metals. A comprehensive assessment must consider not only the initial concentration of pollutants in the environment but also their migration, accumulation, and transformation within key ecosystem components. These processes can lead to the emergence of secondary concentrations and byproducts with toxic properties. Therefore, environmental safety standards for the biosphere should be based on the behavior of pollutants within ecosystems—including their distribution, buildup, degradation, and transformation—along with their movement through different environmental media at local, regional, and global scales [33–34, 41, 1].

Because these processes differ across ecosystem types, a uniform application of standards is not feasible. This makes integrated environmental assessment essential, as it incorporates the diverse factors influencing ecosystem stability and resilience [32–34]. The concept of integrated assessment addresses the need to evaluate numerous variables to assess the impact on individual environmental components (referred to as partial or private assessments), or on the environment as a whole (referred to as integrated or summary assessments) [32, 33].

The concept of 'integrated environmental assessment' is now multifaceted, as the evaluation object may refer to individual components, their collective set, or a set of parameters describing these components. The diversity of integrated environmental assessments also arises from differences in objectives, techniques, the scope of evaluated components, and the nature of the parameters and objects involved. In the absence of standardized methods, developers often assess the complexity of the concept, its informational depth, and create methods for obtaining a comprehensive evaluation of interrelations between parameters and their classification. Accounting for the spatial distribution of parameters in a comprehensive environmental assessment leads to a geoecological approach, establishing new criteria for environmental zoning based on anthropogenic impacts in the study area, with the potential for landscape self-restoration. [48, 50].

Traditionally, the assessment of natural systems has relied on comparing current environmental conditions to established reference standards, evaluating the degree of deviation in environmental factors from normative values. These benchmarks often represent optimal conditions for natural systems. However, when analyzing environmental influences, it is essential to understand the interaction between these influencing factors and the responses of geosystems [32, 42, 51–54]. A key challenge

lies in identifying the threshold at which biotic components begin to respond negatively. As L.I. Mukhin observed in 1973 [51], this is complicated by the fact that many studies use a limited set of indicator values that may not reach critical limits. As a result, rating scales often capture only one-sided trends in indicator behavior—either rising or falling along the tolerance spectrum.

The most common thresholds used in environmental assessments are maximum allowable emission and discharge limits, which are established annually for specific enterprises. Exceeding these thresholds results in violations of maximum permissible concentration (MPC) standards for pollutants in air, soil, and water bodies [32, 42, 51, 54].

Every organism occupies an ecological niche defined by a specific set of optimal environmental conditions. Deviations—whether above or below the optimal range—can lead to adverse effects. Therefore, a key element of environmental impact assessment is the development of private rating scales. These scales align two groups of indicators: one that characterizes the state of an environmental factor, and another that reflects the response of biotic components in the geoecosystem. According to [32], this process involves: identifying relevant factors and indicators → gathering data on environmental relationships and biotic responses → selecting evaluation criteria and creating rating scales → assessing factor influence and mapping its spatial variation.

Thus, the core of environmental impact evaluation lies in choosing the most representative parameters for each factor and constructing appropriate rating scales. In comprehensive assessments, it is not only the intensity of each factor that must be considered but also its significance in shaping favorable or unfavorable conditions for biological systems. The importance and direction (positive or negative) of each factor depend on the objective of the integrated assessment—whether evaluating beneficial or harmful impacts on the environment. R. Pentl proposed the concept of an *evaluation function target*, which enables such assessments. The simplest form of this integrated evaluation is expressed as a linear multiple regression equation [43]:

$$\text{OF(CEA)} = \mathbf{a_1 \cdot f_1} + \mathbf{a_2 \cdot f_2} + \dots + \mathbf{a_n \cdot f_n} \quad (2.1)$$

Where:

- **OF(CEA)** represents the outcome of the integrated environmental assessment;
- **f_i** is the value of the *i*-th environmental factor at the observation site;
- **a_i** is the weighting coefficient that reflects the influence and significance of that factor in determining overall environmental quality.

In this model, the objective function doesn't serve its traditional mathematical purpose (as a criterion for optimization), but rather functions as a tool for guiding the evaluation. The structure remains formally similar, as the procedure involves optimizing the selection and weighting of coefficients (a_i), often based on expert judgment within the conditions of the study.

A persistent challenge with integrated assessments is the reliance on expert opinions, which introduces subjectivity. In response, international conventions and recommendations—such as those by the International Development Bank—have promoted the development of standard guidelines for regional evaluations [25–26]. The increasing economic implications of strict environmental regulations have emphasized the need to integrate economic considerations into environmental assessments, especially in light of the dynamic nature of ecosystem changes [27–31].

Following Kazakhstan's adoption of former USSR environmental conventions, most major international environmental agreements from the late 20th century have played a role in advancing methodologies for integrated ecological assessments. In Kazakhstan, including by the present authors, various methods for integrated evaluation have been developed based on the objective function model [35–38, 3–7]. One recurring issue in such assessments is the lack of precise quantitative data regarding the effects of environmental factors. In these cases, expert reviews are often used, synthesizing past research on environmental impacts. However, the use of such expert-derived evaluations limits the possibility of establishing universal, quantifiable benchmarks.

Equation (2.1) does not consider interactions between environmental factors, meaning that assessment accuracy improves with the number of factors included. According to [42]—which explains environmental engineering through systems theory and quantitative information theory [52, 53–55]—the required number of parameters (n) to achieve a desired level of accuracy (Δ) can be calculated using a simplified formula (2.2):

$$\Delta = 1 / l^n \quad (2.2)$$

Where:

- l is the level of quantization (i.e., the number of divisions on the assessment scale);
- n is the number of environmental factors considered.

Even with a coarse binary rating scale ($l = 2$, such as "yes"/"no"), using just five parameters results in an error of only about 3.1% ($\Delta = 1/2^5 = 0.03125$). Thus, the reliability of assessments depends more on the number of expert evaluations (n) than on the detail of the rating scale (l).

Despite this, the selection of significant factors and construction of relevant rating scales remains a key task, requiring careful consideration of the geographic, environmental, and economic specifics of the studied area.

Internationally, numerous handbooks and manuals have been developed to guide integrated environmental assessments. These include a wide range of indicators reflecting individual and cumulative environmental effects [56]. In post-Soviet literature, the term *indicator* is often synonymous with *criterion*, and encompasses broader dimensions. For example, the concentration of heavy metals in soils is not only an indicator of metal presence but also of the region's overall toxic burden. Composite indicators such as water quality indexes or greenhouse gas indexes consolidate multiple variables into a single metric. Multivariate models—including factor analysis, cluster analysis, and other statistical techniques—are used to create these summary indicators [57–60].

A critical element of objective assessment remains the development of private rating scales. When each factor is independently assessed across its entire range of variation, the resulting evaluation can be considered objective within the framework of the integrated function [32, 51].

However, analysis of formula (2.2) from the standpoint of systems and information theory suggests that while scale differentiation and parameter range completeness are important, they are secondary in multidimensional models. Increasing the number of relevant factors selected to describe the system reduces concerns about potential non-linear interactions and enhances the objectivity of the overall assessment.

2.2 The method of solving the inverse problem using generalized objective functions.

The initial, simplified approach to addressing the inverse problem of integrated environmental assessment relies on pre-existing expert maps that provide private evaluations of anthropogenic impacts on natural systems. This method includes two main approaches. The first approach involves the use of concrete empirical data, formatted for integration into targeted evaluation functions, thereby ensuring a reasonable level of objectivity in the resulting assessments (Section 2.2.1). The second approach centers on the development and comparison of generalized objective functions, which offer a weighted average representation of human impact on various environmental components throughout the Mangystau region of the Republic of

Kazakhstan, with a particular emphasis on areas affected by oil and gas activities (Section 2.2.2).

2.2.1. Methods of Obtaining and Using Data for Generalized Objective Functions

Given that the goal of this research is to address the *inverse* problem—one that presupposes the existence of prior integrated expert assessments of the ecological state of the Mangystau region—the study utilizes evaluation maps depicting anthropogenic impacts on various environmental components as its primary data sources. These maps are part of the *Atlas of the Mangystau Region* [39] and include expert-based assessments of factors such as *Anthropogenic Impact on Relief, Vegetation Transformation, Soil Degradation, Groundwater Disturbance, and Natural Groundwater Protection*. They were developed by the Institute of Geography under the Ministry of Education and Science of the Republic of Kazakhstan, using expert evaluations, expedition-based fieldwork, and interpretations of remote sensing data.

To evaluate the influence of the oil and gas sector on the environment, the atlas's *Human-Caused Sources of Influence* inventory map was used. The legend of this map highlights the Mangystau region as a significant industrial hub, which also experienced nuclear testing—factors that have severely affected both environmental conditions and public health. Ongoing legacy pollution continues to have negative consequences.

Major sources of anthropogenic pressure are concentrated near industrial enterprises, urban areas, workers' settlements, and oil and gas fields. The region is home to 218 quarries and active sites for the exploration and extraction of a wide range of minerals, including materials such as drilling clay, rock salt, gravel, chalk, sand, limestone, marl, and construction stone. In addition, ongoing oil and gas operations contribute to the region's industrial footprint.

The map features special symbols indicating locations of air, water, and soil pollution sources. These include extraction sites (for oil, gas, non-metallic minerals, salt, construction materials, etc.), as well as production facilities involved in engineering, metalworking, chemicals, food processing, and nuclear energy. Also indicated are communal infrastructure facilities, road-building operations, transport infrastructure (airports, seaports, pipelines, roads, and railways), and designated sites for environmental hazards—such as radioactive waste disposal areas (e.g., the *Koshkarata* tailings pond), storage areas for contaminated soil, sewage lagoons, and industrial and

municipal landfills. The map additionally marks areas affected by soil contamination and past underground nuclear explosions.

This wide range of anthropogenic impact sources reinforces the credibility and comprehensiveness of the expert evaluation maps. However, since the types and intensity of environmental pressures vary across different natural components, each evaluation map reflects distinct characteristics. Therefore, the zoning criteria indicated in the legends—defining the degree of anthropogenic impact—must be carefully considered for each individual map.

Therefore, it can be stated with confidence that all map-based evaluations correspond to objective criteria as defined in equation (2.2). However, when constructing objective functions to address the inverse problem, it is essential that these criteria reflect a generalized representation of the effects of anthropogenic sources. The analysis presented in the previous section (2.1) indicates that a five-level classification of impact intensity—used as generalized variables within the objective functions—is sufficient to achieve the required level of accuracy.

The subsequent step in preparing the initial dataset for constructing objective functions using the simplified approach involves delineating areas with varying degrees of anthropogenic pressure, as defined in the evaluation maps. These zones are visually differentiated using distinct colors according to the legends of the respective maps.

Figures 2.1 through 2.3 illustrate the process of compiling the initial data necessary for solving the inverse environmental assessment problem, using the Anthropogenic Transformation of Vegetation map as an example. Specifically, Figure 2.1 displays a segment of the map highlighting changes in vegetation due to human activity. Figure 2.2 overlays this same section with symbols representing the Oil and Gas Complex. It is important to emphasize that, in assessing the oil and gas sector's contribution to environmental transformation, all relevant activities—such as oil extraction, gas extraction, and combined operations—are included, as detailed in the inventory map. Finally, Figure 2.3 shows the resulting composite map, created by integrating the data from Figures 2.1 and 2.2.

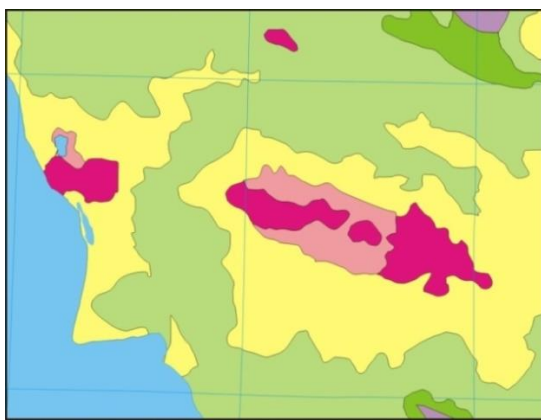


Figure 2.1 – Detail of the map showing the anthropogenic transformation of vegetation.

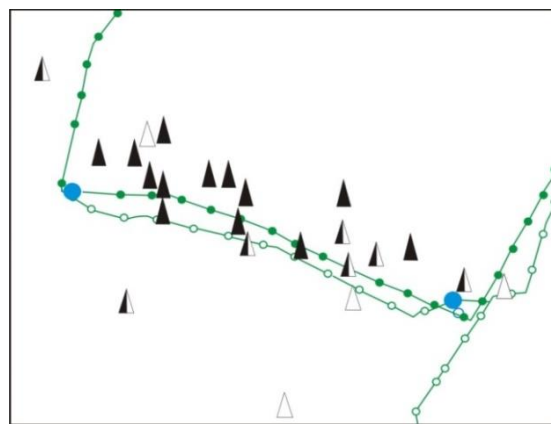


Figure 2.2 - Oil and Gas icons (for the fragment in Figure 2.1.)



Figure 2.3 – Scheme of the allocation of hydrocarbon fields in zones with varying degrees of anthropogenic transformation of vegetation

The use of ArcGIS software greatly streamlines the process, as converting the assessment map into a vector format enables the automatic identification of the spatial distribution of five levels of anthropogenic impact on environmental components throughout the region. By overlaying this vector map with the boundaries of the oil and gas industry infrastructure, it becomes possible to assess the extent of environmental impact specifically within the oil and gas complex zones.

This approach utilizes individual thematic maps from the *Atlas of the Mangystau Region*, which depict the anthropogenic transformation of natural components. These maps were digitized using the ArcMap component of the ArcGIS system. During digitization, vector shapefiles were generated, allowing for the automatic calculation and display of area values for each delineated zone (see Fig. 2.4).

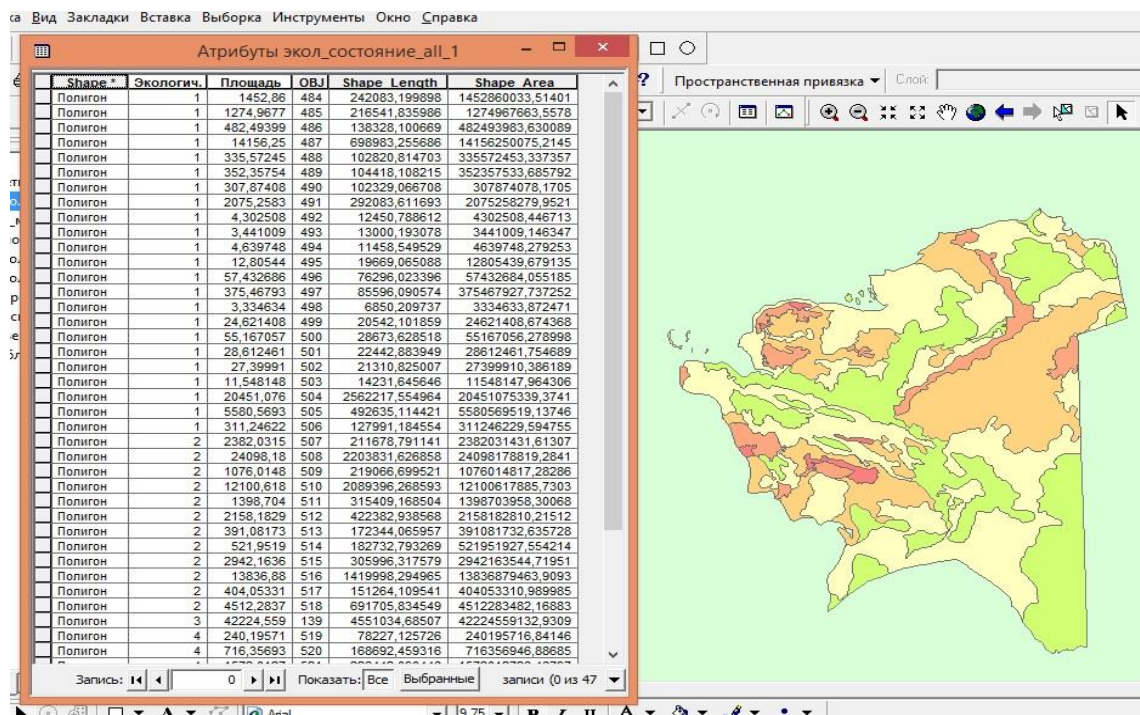


Figure 2.4 – Demonstration of the procedure for obtaining areal values of individual boundaries using vector shapefiles.

The final stage in obtaining initial data for the objective functions using the simplified method is the summation of all circuits with the same color (polygons labeled 'environment' – ecological levels of human impact, ranging from 1 to 5). The areas for each level of the circuits are first calculated for the entire region and then for the circuits within the zones of the oil and gas complex.

2.2.2 Methods of construction Grid model and obtaining a matrix of input data for objective function

The final stage of the simplified method for solving the inverse problem involves constructing and comparing generalized objective functions using the source data, which represent the total area of contours with the same color. This is first done for the entire area and then for areas containing the oil and gas complex.

The subsequent phase involves validating the computational procedure used to define the objective functions. Given that the input data comprises verified evaluation maps (scorecards), the reliability and impartiality of the expert assessments are assumed to be high. The primary task at this stage lies in interpreting and quantifying

the parameters—specifically, the five color-coded classification levels on the map, each corresponding to a specific degree of anthropogenic impact on various components of the environment.

Accordingly, the number of *fif_ifi* variables used in the objective function, which reflect varying levels of human influence, is fixed at five, matching the five-tier classification of environmental impact adopted in the evaluation maps.

The next step is to define the characteristics of the weighting coefficient *aia_iai*, which incorporates both the **direction** (positive or negative) and the **magnitude** (relative importance) of each factor in assessing overall anthropogenic load. Since the analysis aims to determine the specific contribution of the oil and gas sector to environmental degradation, a positive value for *aia_iai* will correspond to a negative impact on natural components, as indicated in the thematic maps.

The weighted influence of each parameter in the objective function is determined in accordance with its alignment to one of the five impact levels, as evaluated on a traditional expert-based ten-point scale. On this linear scale, each classification step spans 2 points, so that any increase in transformation severity correlates directly with an increase in score.

This methodology is justified by both the complexity and costliness of environmental restoration efforts, particularly land remediation. Since the financial and logistical demands of environmental protection grow proportionally with the degree of human-induced disturbance—reflecting a reduced capacity of natural systems for self-recovery—a separate environmental impact assessment is conducted for each zone. These assessments employ weighting factors that correspond to the respective transformation levels on the grading scale.

Accordingly, the five categories in the objective function are assigned the following score intervals:

- Minimal or no transformation: 0–2 points
- Weak transformation: 2–4 points
- Moderate transformation: 4–6 points
- Significant transformation: 6–8 points
- Strong transformation: 8–10 points

To quantify the oil and gas sector’s average weighted contribution to vegetation transformation, mid-range values from each category are used. This leads to the following form of the **private objective function** for the environmental component at the regional level:

$$POF_{CNEReg} = f_{CNEReg1} + 3 \cdot f_{CNEReg2} + 5 \cdot f_{CNEReg3} + 7 \cdot f_{CNEReg4} + 9 \cdot f_{CNEReg5} \quad (2.3)$$

Where $f_{CNERegi}$ is the function representing the level of anthropogenic disturbance of a component of the natural environment for the entire region. It is computed as the ratio of the total area covered by polygons corresponding to a specific transformation level to the total area of the entire region.

(2.3)

Where $f_{CNERegi}$ is the function representing the level of anthropogenic disturbance of a component of the natural environment for the entire region. It is calculated by dividing the total area of polygons with a certain level of anthropogenic transformation of this component by the total area of the entire region.

In this context, the variable fif_ifi (also written as $fiff_{\{if\}fif}$) represents the **proportion of the area** (i.e., the fraction of the sum of polygons) subjected to a specific level of anthropogenic disturbance relative to the total area of the region. Each term in the function reflects the contribution of a particular transformation level to the overall assessment of environmental degradation for one natural component.

As expressed in equation (2.3), the weight coefficients (expressed in points on the expert scale) are multiplied by the corresponding area fractions (measured in square kilometers). This results in a **cumulative score**, expressed in units of "points $\times$ km²," which quantifies the overall anthropogenic impact on the natural environment either across the entire region or within the boundaries of the oil and gas complex.

However, this formulation introduces **spatial dependency**: the magnitude of the objective function is influenced not only by the severity of environmental impact but also by the physical extent of the evaluated area (i.e., total regional area or area occupied by oil and gas activities). To ensure spatial comparability and derive a **normalized assessment**, the final value must be divided by the total area of the corresponding zone—either the entire region or the total area affected by oil and gas production.

It is important to clarify that the function $f_{CNERegion}$ is not variable-based; instead, it operates on fixed values. These values correspond to the aggregate areas of all map contours of the same color (derived from five classification categories), as extracted from the shapefile attribute table for the entire study region. Therefore, solving equation (2.3) results in a **single scalar value** that represents the **weighted average level** of anthropogenic transformation across the region.

To solve the inverse problem of **integrated environmental assessment** using a generalized approach, a similar objective function must be constructed for the zones influenced by oil and gas activities. These zones are also identified on the same expert-based evaluation maps. In this case, the structure of the objective function remains consistent with equation (2.3), but the fif_ifi values are replaced with

f_{OGECi} , denoting the share of each transformation level within the **oil and gas exploitation zones**.

Each f_{OGECi} is calculated as the ratio of the total area corresponding to the i -th level of anthropogenic disturbance within all oil and gas zones to the combined area of these zones. The **weighting scheme remains unchanged**, ensuring consistency with the previous formulation:

$$POF_{CNE\ OGEC} = f_{CNE\ OGEC1} + 3f_{CNE\ OGEC2} + 5f_{CNE\ OGEC3} + 7f_{CNE\ OGEC4} + 9f_{CNE\ OGEC5}, \quad (2.4)$$

As in equation (2.3), equation (2.4) involves variables and the sum of all loops of the same color (Table 5, samples from shapefile attributes) in the oil and gas producing zones, which refer to the total area of all oil and gas complex zones. Therefore, the result of solving equation (2.4) yields only one value — a number that describes the average weighted level of anthropogenic transformation of the natural environment across all areas influenced by the oil and gas complex.

The role of the oil and gas complex in the transformation of each component of the natural environment in the Mangystau region as a whole is determined by subtracting the value of $POF_{CNEOGEC}$ from POF_{CNEReg} . The resulting ten-point scale score is the outcome of the inverse problem solution and represents the additional contribution of oil and gas production to the anthropogenic disturbance of the natural environment in the Mangystau region across all levels of human transformation.

Thus, the result of the inverse problem solution is an optional contribution (as reflected in $POF_{CNE\ area}$ reflected, which shows the net effect of the main factors according to the legends of the estimated map) of the oil and gas complex in the anthropogenic transformation of each natural component.

It remains to derive the integral objective functions for all components of the natural environment, both for the entire Mangystau region and for areas with the presence of an oil and gas complex. These integral objective functions are constructed similarly to the partial functions, but with the replacement of $f_{CNE\ area}$ by $POF_{CNE\ area}$ in equation (2.3) and $f_{CNE\ OGECi}$ by $POF_{CNE\ OGECi}$ in equation (2.4). When constructing these functions, a new justification for the weighting values is required, as the integral factors in the objective function now include the individual trust functions constructed for all components of the natural environment of the Mangystau region (relief, soil, vegetation, and groundwater), both across the entire area and within areas

with oil and gas complexes. As a result of changes in the semantic content of the factors, we obtain the equations (2.5) and (2.6)

$$IOF_{AREA} = a_{rel}POF_{rel\ area} + a_{soil}POF_{soil\ area} + a_{plant}POF_{plant\ area} + a_{GW}POF_{GW\ area} \quad (2.5)$$

$$IOF_{OGC} = a_{rel}POF_{rel\ OGC} + a_{soil}POF_{soil\ OGC} + a_{plants}POF_{plants\ OGC} + a_{GW}POF_{GW\ OGC} \quad (2.6)$$

The justification for assigning weight coefficients in equations (2.5) and (2.6) must take into account the functional significance of each environmental component in the anthropogenic transformation of the Mangystau region. This rationale is grounded in both empirical data and theoretical frameworks established in the field of geosystem studies by prominent scientists such as V.I. Vernadsky, V.V. Dokuchaev, M.I. Budyko, V.R. Williams, V.A. Kovda, D.L. Armand, A.G. Isachenko, O.A. Alekin, V.N. Solntsev, D.M. Akhmedsafin, J.S. Sydykov, V.B. Sochava, among others [1–11]. Further contributions to understanding the structure and evolution of landscapes, soil systems, and groundwater regimes have been made by F.N. Milkov, B.G. Rozanov, A.V. Chigarkin, G.V. Geldyeva, G.M. Dzhanaleeva, E.V. Ostrovsky, V.N. Dostay, I.K. Gavich, A.I. Perelman, S.L. Schwartz, M. Goldberg, and many others [33–46]. The interactions between environmental components and the factors shaping the natural environment have been extensively studied and described in scientific literature [47–67, etc.].

In General Geography, F.N. Milkov [12]—whose work is widely regarded as a comprehensive source on landscape formation—emphasized the pivotal role of the lithogenic base (which includes geological structure and relief, as defined by R.I. Abolina) in the spatial differentiation of landscapes. Milkov supported the idea originally proposed by N.A. Solntsev in 1960 that the lithogenic base is the most stable and inert component within a landscape system. However, Milkov also critiqued this view, advocating instead for the relative equivalence of all landscape-forming factors. He referenced the foundational works of V.V. Dokuchaev (1899), who emphasized the significance of soil, and L.S. Berg (1947), who introduced the concept of geographical landscapes. Nevertheless, Milkov consistently acknowledged relief as a particularly conservative factor—one that maintains influence over climatic processes—and noted that nearly all major schools of geographic thought consider relief a fundamental determinant of landscape patterns [33].

The role of soil within the ecosystem is equally well-established. It is not only the cornerstone of agricultural productivity but also a key natural resource and an essential part of the human habitat. Soil emerges from complex interactions among the atmosphere, hydrosphere, lithosphere, flora, and fauna. The environmental functions of soil have been widely studied by scholars such as V.V. Dokuchaev, J. Liebig, V.R. Volobueva, E.D. Russell, L.G. Ramensky, V.R. Williams, and V.A. Kovda. Contemporary soil science views soil not merely as a product of natural formation processes, but as a multifaceted ecological entity critical to ecosystem sustainability. Its ecological stability is now recognized as a prerequisite for the overall stability of the biosphere [33–37, 47–49]. Therefore, incorporating soil as a primary indicator of anthropogenic pressure in the Mangystau region is both scientifically justified and methodologically sound.

Vegetation, as an integral and responsive component of the landscape system, also holds significant weight in environmental assessments. Among the most dynamic environmental elements, vegetation responds readily to variations in soil, topography, hydrological regimes, and air pollution [37–39, 50–55]. It performs several vital ecological functions, including contributing to pedogenesis (soil formation), facilitating nutrient and energy cycling, and acting as a bioclimatic indicator. Vegetation absorbs solar radiation, synthesizes organic compounds, and helps regulate the atmospheric gas balance, making it indispensable for sustaining life [53]. By analyzing changes in vegetation structure and floristic composition, researchers can infer both the intensity and direction of anthropogenic processes and track changes in associated components such as soil, groundwater, and surface water.

Although climate is a fundamental factor in shaping the natural environment, its spatial variability across the Mangystau region is limited due to its zonal characteristics, making it difficult to incorporate as a differentiating factor in regional analysis. Instead, the influence of climate is captured indirectly through its interactions with relief, soil, vegetation, and water resources. For the purposes of this study, the analysis focuses specifically on four key components: relief, soil, vegetation, and groundwater. Assessing anthropogenic changes in air quality across the Mangystau region presents challenges due to the limited availability of monitoring infrastructure. The regional network of weather and atmospheric monitoring stations is sparse, with air pollution data available only from six measurement points—three each at the Dunga and Zhetybai oil fields. Given the strong interconnection between atmospheric conditions and vegetation health, vegetation can be employed as an indirect indicator (or proxy) for assessing air quality within the framework of constructing anthropogenic impact maps.

Mangystau's distinctive climatic features—particularly the complete absence of permanent surface watercourses—highlight the region's acute water scarcity, especially with respect to potable water. According to expert estimates, the daily deficit in drinking water reached 40,000 m³ and was projected to increase to 70,000 m³ by 2020 [24–26].

Data from the regional government (akimat) indicate that out of 60 villages in Mangystau, only 17 are connected to centralized water supply systems. The remaining 35 settlements rely on decentralized sources, and due to low population density and high infrastructure costs, nine villages are forced to use imported bottled water. Major urban centers such as Aktau and Zhanaozen, along with oil-producing enterprises, account for approximately 93% of the region's total water consumption, leaving only 7% for rural settlements [24, 26].

Water supply in the region is derived from three main sources:

- **Desalinated seawater**, produced by LLP "MAEC-Kazatomprom", which covers 47–50% of demand.
- **The Astrakhan–Mangyshlak pipeline**, delivering approximately 40% of water from the Volga River.
- **Groundwater resources**, contributing an estimated 11–13% of the total supply, depending on the source [24, 27].

Mangystau possesses 65 known groundwater deposits, with total daily reserves amounting to 522,000 m³. Major deposits include Tuyesu, Sauyskan, Kuyulus, Tonirekshyn, Janajol, and Ketikskoye [24–26]. These groundwater sources provide for approximately 17.5% of the population's drinking water needs [24, 27–28].

Consequently, the issue of high-quality drinking water is primarily resolved through desalination of Caspian seawater and water imports from the Russian Federation via the Volga. While urban and industrial consumers use water from these sources, rural communities largely depend on local groundwater reserves, emphasizing the need for comprehensive environmental evaluation of these aquifers.

Such evaluations are critical for two main purposes: (1) localized assessments that focus specifically on the condition of groundwater, and (2) broader integrated assessments that consider the interactions and cumulative impacts on all components of the natural environment.

To quantify environmental impacts effectively, initial assessments can be carried out using expert judgment, assigning relative weights to the different environmental components. These results are then normalized—excluding directional (positive or negative) effects—on a common scale (e.g., 1, 10, or 100) to account for disparities in the influence of oil and gas activities on different ecological elements.

Given the systemic interdependencies within the geoecosystem, where each component both affects and is affected by others, this analysis adopts a geoecological approach [37–39, 49–50, 54–55]. This methodology recognizes the regulating functions of vegetation and soil, as well as the structural role of relief, though each component exerts its influence through distinct mechanisms.

In arid environments such as Mangystau, water is a critical ecological factor. Due to the absence of surface runoff, the region's groundwater reservoirs are prone to salinization. In areas with unconsolidated sediments, evaporation from shallow groundwater tables (up to 3 meters deep) leads to further salinity accumulation. Consequently, only vegetation with deep root systems—particularly halophytic (salt-tolerant) species—can effectively utilize this water, as reflected in the area's floral composition.

Taking these interactions into account, the formula for calculating integrated environmental impact can be revised by normalizing the weights so that their sum equals 1. This yields the following generalized models for the entire region and for the areas influenced by the oil and gas sector:

$$IOF_{area} = 0,2POF_{rel\ area} + 0,2POF_{soil\ area} + 0,4POF_{plant\ area} + 0,2POF_{GW\ area} \quad (2.7)$$

$$IOF_{OGC} = 0,2POF_{relOGC} + 0,2POF_{soil\ OGC} + 0,4\ POF_{plantOGC} + +0,2POF_{GWOGC} \quad (2.8)$$

It is important to note that these integral assessments are based on previously computed private environmental scores, which represent average impact ratings. Thus, equations (2.7) and (2.8) should not be interpreted as precise mathematical formulas, but rather as conceptual models designed to provide an aggregated view of anthropogenic pressure.

Ultimately, the solution to the inverse problem of integrated environmental assessment involves determining the specific contribution of the oil and gas industry to the ecological state of the Mangystau region. This is achieved by calculating the difference between the regional impact index (IOF_{area}) and the index for oil and gas complex zones (IOF_{OGC}). The resulting value, expressed as a percentage, indicates the additional anthropogenic burden attributable to the oil and gas sector across all environmental components. IOF_{area} , in this context, reflects the cumulative baseline impact from all major factors as illustrated in the legend of the environmental assessment map.

2.3 The method for solving the inverse problem involves the use of objective functions differentiated across the territory.

The second method for solving the inverse problem of integrated environmental assessment aims to obtain a differentiated assessment of the territory. This approach is based on using pre-existing expert maps of anthropogenic transformation of natural environment components and is implemented through two methods.

The first method focuses on obtaining differentiated data in a form suitable for multivariate statistical analysis. It involves converting spatial (map-based) data into point-based (numerical) data using a grid model (see subsection 2.3.1).

The second method follows the generalized approach of subject area contour replacement. It aggregates areas with the same level of anthropogenic transformation (represented by the same color on the Mangystau Region Assessment Map Atlas) across the entire region, including oil and gas extraction zones. This method integrates these values into equations (2.3), (2.4), (2.7), and (2.8), ensuring consistency in the sum of areas within each block of the grid model of the Mangystau region.

As a result, equations (2.9), (2.10), (2.11), and (2.12) are derived through this substitution process.

2.3.1 Method for Constructing the Grid Model and Obtaining the Original Data Matrix for Use in Multidimensional Statistical Component Analysis

2.3.1.1 General Scheme for Constructing the Grid Model

With the advent of GIS technology, cartographic modeling has become widespread. This approach allows for the automatic generation of new spatial data through overlay and intersection operations based on existing digital terrain models. The foundation of GIS-based automated cartography lies in digital models, which represent geographical objects using structured data. According to [27], a digital model is a structured representation of geographical data that enables the reconstruction of objects through interpolation, extrapolation, or approximation.

The Department of Cartography at Moscow State University has contributed significantly to the generalization of spatial modeling, developing both the theoretical

foundations and practical methods for cartographic research [28] as well as mathematical and cartographic modeling techniques [29,30].

However, mapping methods alone are insufficient for assessing and predicting environmental changes caused by economic activity. As a result, there is a growing need to integrate simulation modeling within GIS environments. As noted by the authors in [31]:

"The dual application of mapping and simulation of basin-landscape systems in a GIS environment forms the basis for optimizing natural resource management."

Studies [32–34] emphasize that modeling complex natural systems requires a shift towards deterministic and statistical models. Such models enhance the accuracy of systematic representations of environmental objects and processes, offering several approaches to building more reliable predictive models.

Currently, methods for mathematical and cartographic modeling of complex systems are being developed independently. The integration of these methods remains at the stage of individual (artisanal) simulations, where large databases must reconcile the complexities of mapping data and simulation models.

For example, in [35], six types of databases are identified as necessary for the quantitative description of a three-dimensional dynamic environment, where parameters vary across space and time:

1. Factual data – Results from measurements of parameters that describe the past and present state of an object, typically recorded at specific observation points.
2. Object (generalized) data – Parameters aggregated for entire objects or their structural elements.
3. Profile data – Parameters describing the structure and variability of an object's properties in vertical cross-sections of its three-dimensional depth.
4. Map data – Information that describes the geometry and variability of process parameters in a plan view.
 - Grid data – Parameters describing the properties of a three-dimensional object at selected nodal points within a defined grid.
 - Spatial (three-dimensional) data – Parameters describing the properties of a three-dimensional object in a fully spatial context.

A three-dimensional representation provides a clearer understanding of objects, making it particularly useful for dynamic models that simulate a single process within a single environment. However, while these models are effective for controlled simulations, they face significant limitations when applied to scenarios involving qualitative changes in the medium (e.g., catastrophe theory) or when accounting for

multiple interacting processes. Studies [37, 38] highlight the practical challenges of using dynamic models in real-world, multidimensional environments where numerous operating factors interact.

Modern GIS systems primarily focus on enhancing spatial visualization rather than on capturing interdependencies among factors that drive spatial variations in environmental parameters. As noted in [35], this limitation arises from the emphasis on displaying spatial structures (positions 4–6 in the database classification) rather than on modeling complex relationships.

For subject-centered systems (such as those focused on humans or biota), this approach is inadequate. The reason is that in such models, the subject itself is often oversimplified or excluded, leading to a purely schematic and generalized representation that fails to account for its dynamic interactions with the environment.

Reflection on actions based on the specifics of the recipient (the object) can be assumed in the second type of database, where generalization (grouping by certain criteria) is possible only if the object's response to one or a group of factors is uniform or similar in meaning. The first type of database, factual data, is entirely aligned with geo-ecological assessments. Specifically, the "parameters of measurement results that describe the past and present state of the object, typically observed at specific points" form the foundation for identifying factors and indices in IA Absalom's framework [39].

Moving to geo-ecological assessments, which are purely environmental, the key is to reflect the spatial aspects of an object's response to environmental impacts. This requirement is addressed in the final stage of IA Absalom's estimation algorithm: the "assessment of impact factors and the establishment of spatial variation," which can then be represented in separate maps.

Thus, the comparison of database types in the GIS implementation stages of IA Absalom's estimation algorithm shows a bias in GIS toward the spatial aspects of physical factors (environmental, etc.), while IA Absalom's algorithm emphasizes factual aspects. However, it is this emphasis on factual data that is key to a substantive understanding of complex natural systems.

There is a natural desire to unify these two approaches, and their comparison clearly reveals the common foundation: a unified data presentation that binds parameters describing the properties of a three-dimensional object to a selected set of nodal (bearing) points.

To generate baseline data, we suggest using various cartographic materials, which are based on expert generalization of a large volume of original factual data (centered around observation points). To determine the location of the initial observation points on

offline maps, each map can be divided into an equal number of identical blocks, with each block linked to the information centers scattered across the area. This approach creates a grid model map.

This technique has long been used in hydrogeology for modeling groundwater flow in continuous media. Thus, applying the hydrogeological method of constructing a grid model for continuous media in environmental and geographical (geo-ecological) investigations allows for the conversion of dispersed (map-based) information into concentrated (matrix-based) data.

The key difference is that in hydrogeodynamics, this technique is typically used for areal features when creating water conductivity maps. In our case, the data may include marketplace information (measured in units such as the area percentage occupied by a certain parameter, often represented by color or shading), as well as linear and point data. For linear data, we use traditional eco-informatics methods—linear features (e.g., rivers, transportation routes, etc.) are converted into numeric expressions of length in arbitrary units. The grid model as a whole is a superposition of elementary grid units with distinct boundaries (such as the seashore, lakes, contours, towns, etc.), designed to closely match the actual set of geo-environmental maps. All maps are standardized to a single scale, which is a key condition for constructing the grid model. This is important because, in many cases, parameters need to be derived from different maps. Each grid unit is then numbered and assigned an alphanumeric code.

For processing the grid model using numerical methods, the database should take the form of a matrix of input data, in which each block's number is listed sequentially for each row of the grid model, with the original data stored in the first column. As a result, the blocks in the grid network model are developed into one column of the original data. These columns are populated with the coded values corresponding to the features selected for analysis (such as area, length, number of icons, etc.).

2.3.1.2 Partial automation of constructing a grid model using ArcGIS.

As noted on the official website [<http://www.arcgis.com/features/>], ArcGIS is a comprehensive system that enables users to collect, organize, manage, analyze, share, and distribute geographic information. As one of the world's leading platforms for building and using geographic information systems (GIS), ArcGIS is utilized globally in fields such as public administration, business, science, education, and media. The ArcGIS platform allows for the publishing of geographic information, making it

accessible and usable by a wide range of users. The system is available anywhere that supports web browsers, as well as on mobile devices like smartphones and desktop computers (Fig. 2.5)



Figure 2.5 – Diagram of possible ArcGIS connections with other devices and software systems.

The **ArcGIS system** is a suite of software products and tools designed for professional GIS tasks. It includes software, interactive cloud infrastructure, professional tools, and customized resources such as **application templates, ready-to-use web and mobile applications, basemaps, and reliable content**, which help extend the user community. Support for server and cloud platforms enables collaborative processing and data exchange, ensuring that critical information for planning and decision-making is immediately available to all users.

Section 2.2 of this document describes the procedures within the ArcGIS system for delineating areas of contours, which serve as the initial data for constructing objective functions. In this section, we present an approach to **partially automate** the construction process outlined in Section 2.3.1, which covers the general scheme for constructing the grid model used in the aforementioned project, funded by a grant.

The grid model's core concept involves transforming information from a map into a new type of distributed data—focused information. This means that information about any given area is tied to the center of a regular grid block.

To create a regular grid, we use the connection between ArcGIS and the QGIS Desktop system [<http://www.qgis.org/ru/site/>] as shown in Figure 2.5. This grid, when integrated with ArcGIS (using the shapefiles module), solves the problem of converting distributed marketplace information (within each block of the regular grid) into concentrated data (represented by the centers of the grid blocks).

Below is a detailed algorithm for obtaining concentrated information in regular grid blocks for one level of anthropogenic transformation of vegetation, as discussed in Section 2.2. This transformation is not based on the area of polygons, but on the values stored in each block of the regular grid. If we had previously calculated the sum of the areas of the polygons, now we have a column of original data, which we will process using a program (Factor Complex) implementing one of the methods of multivariate statistical analysis—component analysis.

The algorithm for constructing the grid model for areal information was developed by Iztaeva A.M., a master's student in the Geoecology specialty, as part of the grant-funded project. The algorithm includes work with two GIS systems and consists of the following steps:

Work in QGIS Desktop

Step 1. Launch the QGIS Desktop program. In the upper right corner, click on the "Add Vector Layer" icon. Select the shapefile from the working project area. In the Edit panel, under "Vector", choose "Selection" and then select "Regular Grid" (Fig. 2.6).

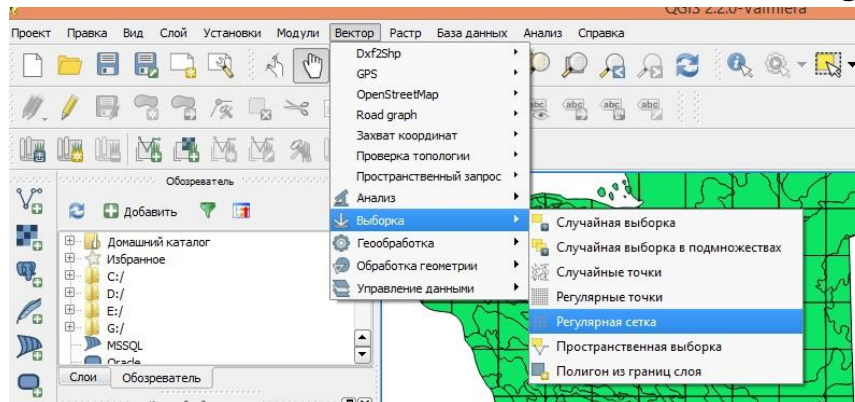


Figure 2.5 – Mapping display in Step 1 implementation.

Step 2. In the window that opens, under "Boundaries grid", click on the "Get the map" button. In the "Settings" section, set the grid frequency intervals (in this case, the grid should have intervals of 50 km or 50,000 meters). Next, save the regular grid in the appropriate folder and export the grid shapefile to ArcGIS.

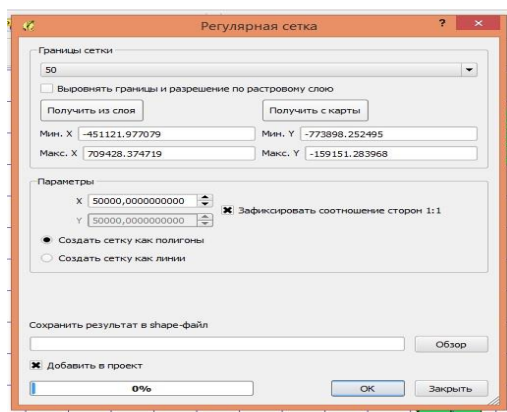


Figure 2.6 – Mapping display during the implementation of Step 2.

Next, continue working in ArcGIS:

Step 3. Start the ArcMap program. On the toolbar, under the "Editor" menu, select "Start Editing". In the display panel, leave only the polygons that need to be cut by the grid (50×50 grid lines) and the contamination area enabled.

In the display panel, right-click on the polygon layer to be cut, then go to Selection and select "Make this layer available for sampling". (If there are multiple shapefiles that need to be cut, this must be done one by one.)

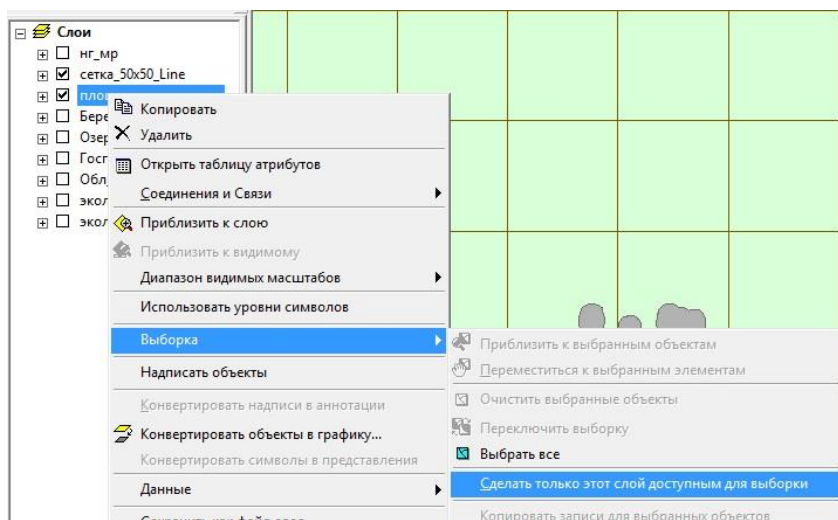
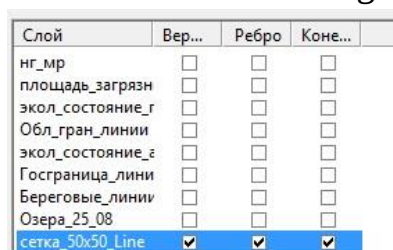


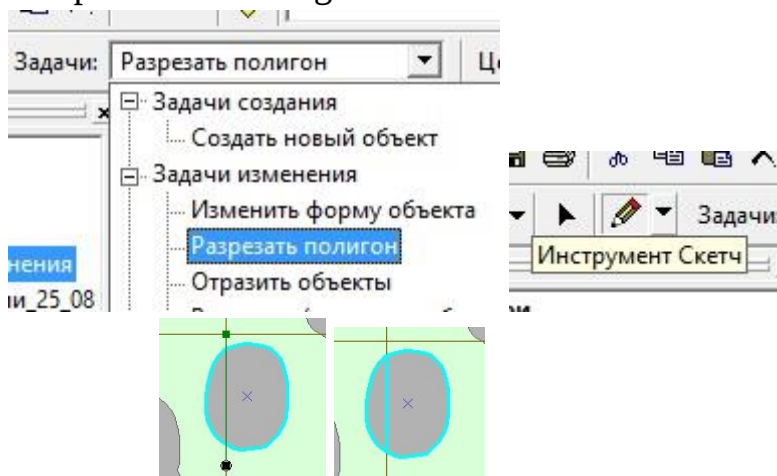
Figure 2.7 – Screen display during the implementation of Step 3.

Step 4. On the toolbar, under "Edit", select "Short". In the window that appears, check the box next to the grid shapefile (line) for which you want to cut the



objects.

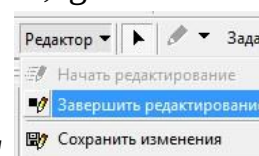
Step 5. Select the "Select Objects" tool and choose the desired object. In the "Tasks" panel, select "Cut Polygon". On the toolbar, choose the "Sketch" tool. Click next to the selected object at the location where the grid line intersects; the sketch will "snap" to the grid lines. Make sure to click outside the polygon.



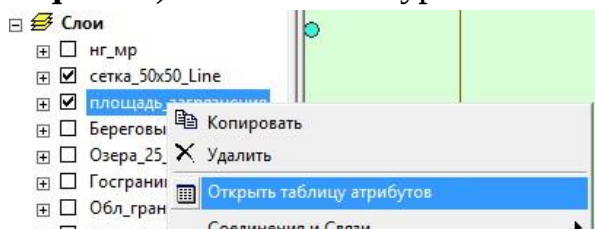
To complete the polygon partition, double-click.

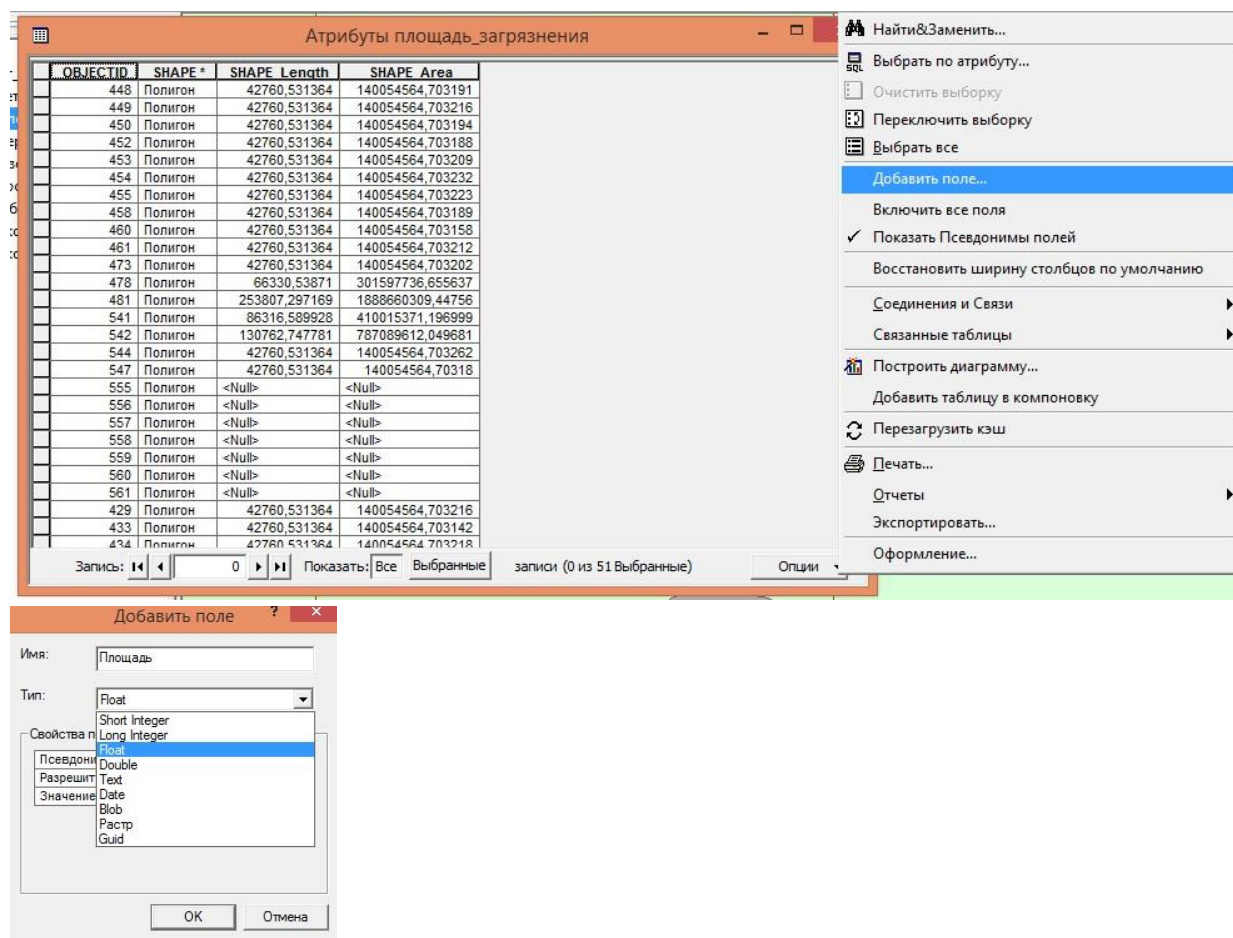
Step 6. After completing all necessary polygon partitions, go to the "Editor"

toolbar, select "Save Changes", and then click "Stop Editing".

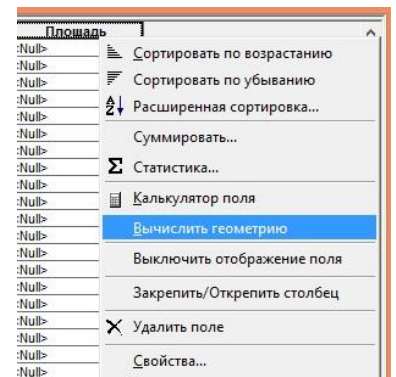


On the display panel, right-click on the layer that was cut, then select "Open Attribute Table". In the "Options" menu, choose "Add Field". Name the new field (e.g., "Square") and select the type "Float". Click "OK".

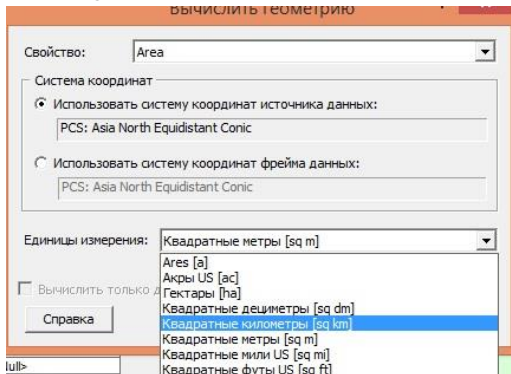




Step 7: Right-click on the header of the added field, then select "**Calculate Geometry**". In the units section, select "**Square Kilometers**", then click "**OK**".

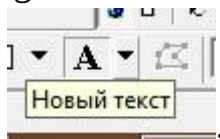


Finally, close the attribute table window.

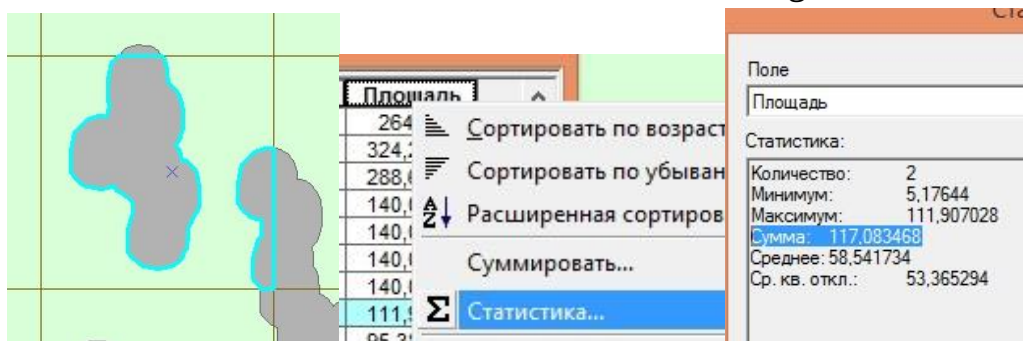


On the toolbar, under the "**Editor**" menu, select "**Start Editing**".

Step 8. On the toolbar, select the "**New Text**" tool. Then, by clicking on the map, assign alphabetic and numeric names to each row and column of the grid (for example, use English letters for columns and numbers for rows).



Then, select the "**Select Objects**" tool and highlight the polygons within each grid cell on the map. Next, expand the attribute table window. Right-click on the "**Area**" field header and select "**Statistics**". In the window that opens, copy the value under "**Sum**". Write down the values of all areas according to the name of each column.



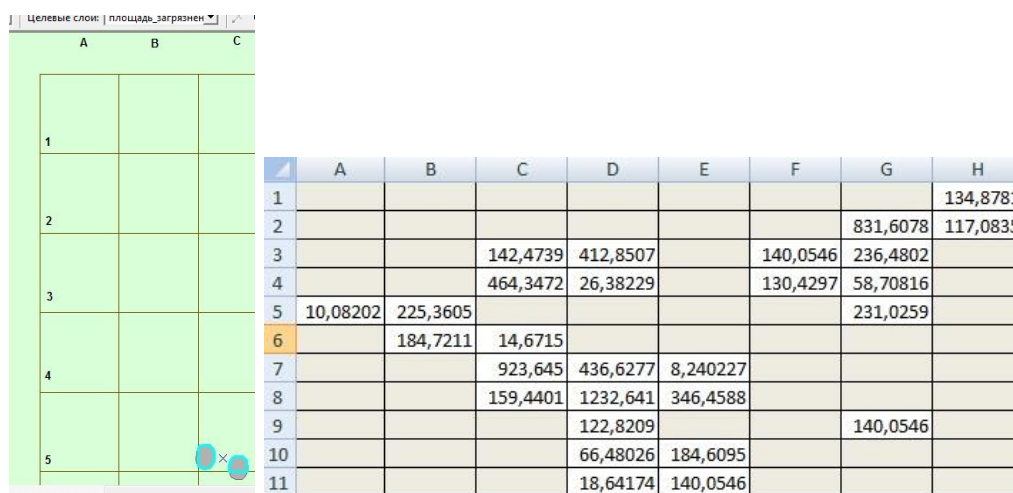


Figure 2.8 – The final result of implementing step 5 shows the areas corresponding to one of the levels of anthropogenic disturbance in the natural environment, measured in units of the grid model.

As seen from the description of the algorithm, it involves a significant number of operations even for a single parameter taken from the map. However, the use of a regular grid with coordinate referencing allows for more precise grid overlay across all maps and facilitates direct interaction with other ArcGIS software modules, providing greater accuracy compared to the "manual" method of determining the area of contours in each block of the grid model.

2.3.2 The methods of constructing territorially differentiate private and integral objective functions

As a result, the application of the network model to all estimated maps, with superimposed levels of anthropogenic disturbance zones and the oil and gas mining complex map, produces more quantitative information. This can be used to build both private and integral objective functions according to the procedure described in subsection 2.2.2. However, now the information about the areas, which we previously had to take from a wide region or the areas where the oil and gas mining complex is located, is broken down into blocks of the grid model. This enables the application of the objective function equations to each block, allowing for a differentiated assessment of the territory.

In other words, the second method aligns with the generalized method of replacing the contours of subject areas with the same level of anthropogenic

transformation (represented by the same color on the evaluation map of the Mangystau region) throughout the region, including all areas with oil and gas extraction complexes. The equations (2.3) and (2.4) are applied to the sum of the areas within each block of the grid model across the Mangystau region. As a result, we obtain the following equations (2.9) and (2.10) for the partial objective functions within the ij -th block of the grid model for each component of the natural environment—first for the units (30), and then for the blocks with oil and gas extraction complexes (31):

$$POF_{CNERegj} = f_{1ij} + 3 \cdot f_{2ij} + 5 \cdot f_{3ij} + 7 \cdot f_{4ij} + 9 \cdot f_{5ij}, \quad (2.9)$$

$$POF_{CNEOGECij} = f_{OGEC1ij} + 3 \cdot f_{OGEC2ij} + 5 \cdot f_{OGEC3ij} + 7 \cdot f_{OGEC4ij} + 9 \cdot f_{OGEC5ij} \quad (2.10)$$

The role of $OGECij$ in the transformation of each component of the natural environment in every ij -block grid model for the Mangistau region is determined by subtracting the value of $POFCNE\ OGECij,ij$ (calculated from equation 2.10) from the value of $POFCNE\ Regij$ (calculated from equation 2.9). The result is expressed as a percentage and represents the additional contribution of $OGECij$ to the anthropogenic transformation of each natural component. This is because the $POFCNE\ Reg$ reflects the net effect of the main factors according to the legends of the estimated map.

Thus, we have differentiated the contribution of the oil and gas extraction complex to the anthropogenic transformation of each component of the natural environment across the region. To visualize this differentiation, it is possible to construct contour lines for the results of the inverse problem solution for each component of the natural environment in three versions: $POFCNE\ Regij$ contour lines, $OGECij$ contour lines, and their combined contour lines.

$$POF_{CNEOGECij} - POF_{CNE\ Regij}.$$

Similarly, the differentiated integral objective functions (2.11) and (2.12) are calculated for the territory by replacing $IOFReg$ with $IOFRegij$ in equation (2.7) and $IOFOGEC$ with $IOFOGECij$ in equation (2.8). This calculation takes into account $POFCNERegij$, calculated according to equation (2.9), and $POFCNEOGECij$, calculated according to equation (2.10), for all components of the environment (relief, soil, vegetation, and groundwater).

$$IOF_{Regij} = 0,2POF_{relRegj} + 0,2POF_{soil\ Regij} + 0,4POF_{Veg\ Regij} + 0,2POF_{GW\ Regij} \quad (2.11)$$

$$IOF_{OGECij} = 0,2POF_{relOGECij} + 0,2POF_{SOILOGECij} + 0,4POF_{VegOGECij} + 0,2POF_{GWOGECij} \quad (2.12)$$

Again, the role of OGE_{Cij} in the total transformation of all components of the natural environment in each ij -block grid model for the Mangistau region is determined by subtracting the value of $IOFOGE_{Cij}$ (calculated from equation 2.12) from the value of $IOFReg_{ij}$ (calculated from equation 2.11). The resulting value, expressed as a percentage, represents the additional contribution of OGE_{Cij} to the total anthropogenic transformation of all natural components. This is because $IOFReg$ reflects the net effect of all the main factors influencing all the components of the natural environment.

Conclusions to the Section

The primary goal of this research was to develop a method for the quantitative determination of the contribution of the oil and gas extraction complex to the transformation of the anthropogenic components of the environment in the Mangistau region. This goal was achieved as a result of new solutions to theoretical problems in the field of integrated environmental assessments. Through solving the inverse problem, new types of assessments were obtained, addressing practical issues related to the economic support of environmental measures. These measures implement the principle of "the polluter pays" by quantifying the additional contribution of the oil and gas extraction complex to the anthropogenic transformation of the natural environment.

Two methods for solving the inverse problem of integrated environmental assessment were developed, using pre-existing expert maps for private environmental assessments of the anthropogenic transformation of environmental components. These methods led to the development of generalized and differentiated assessments as part of the project funded by a grant.

The first method, which is a simplified approach, is based on the use of pre-existing expert maps of the anthropogenic transformation of natural environment components. It is implemented through two steps. The first method aims to obtain concrete evidence that is adapted for use in the objective function, ensuring sufficient objectivity for the objective functions.

The second method is based on constructing and comparing generalized objective functions that reflect the average (weighted) assessment of human impact on environmental components throughout the Mangistau region and areas with oil and gas extraction activities. The pressures on transformation levels in the objective function account for the complexity of environmental activities for each natural component, with justifications provided in the assessment map legends. This simplified approach involves comparing generalized evaluations, where trust functions encompass areas with varying levels of anthropogenic disturbance, and the numeric values correspond to each level.

The second method for solving the inverse problem—providing a differentiated assessment of the territory—is also based on the use of expert environmental assessment maps. This method is realized through two steps. The first method focuses on obtaining differentiated evidence, which is then adapted for use in a differentiated assessment. It represents the territory's grid model and transforms data from maps (dispersed) into points (numerical).

The second method, similar to the generalized evaluation method, involves constructing and comparing objective functions that reflect human impact on environmental components in the Mangistau region and areas with oil and gas extraction activities. While the equations for the objective functions are similar to those in the generalized evaluation method, they are now calculated separately for each block, providing a differentiated view of the oil and gas extraction complex's role in the territory. The advantage of this method lies in its simplicity and speed, especially when working with vectorized evaluation maps in GIS.

The generalized objective function used for individual and environmental assessments is not understood in the classical mathematical sense, such as a criterion for comparing alternatives using different optimization methods. Instead, it serves as a function that implements the purpose of the evaluation—assessing the contribution of oil and gas production to the anthropogenic disturbance of the natural environment. In this context, the optimization procedure is reduced to the average point evaluation of each of the five classes, as shown in the color legend. These classes are assessed using a conventional 10-point scale in the expert procedure, where, in accordance with the objective (the level of disturbance of environmental components), the maximum points are assigned to the fifth class, which represents the highest level of anthropogenic disturbance to the relief.

The objectification of the objective function previously included justifying the selection of the most significant factors based on specific geographical, environmental, and economic conditions of the evaluated area. It also involved ensuring the completeness of the rating scale, which was considered the most challenging problem.

Environmental engineering methods, viewed through the lens of general systems theory and quantitative information theory, enabled the linkage of the completeness of the rating scale range (quantization levels in information theory) with a number of parameters (the effect of intra-bonds). This was done by calculating the minimum number of parameters necessary to achieve the desired level of accuracy in the description, using the simple formula (2.2). Thus, the objectification problem was reduced to justifying the selection of the most important factors.

The large amount of cartographic material, summarizing a variety of information in the form of inventory and evaluation maps collected in the Atlas of Mangistau region, makes these maps essential for addressing a range of environmental challenges.

3 EVALUATION OF THE IMPACT OF THE OIL AND GAS INDUSTRY ON THE ECOLOGICAL SITUATION IN THE MANGYSTAU REGION USING A GENERALIZED METHOD FOR SOLVING THE INVERSE PROBLEM OF INTEGRATED ENVIRONMENTAL ASSESSMENT

This section presents the results of solving the inverse problem of integrated environmental assessment for the Mangystau region using a generalized estimation approach. This method relies on ready-made expert maps for private environmental assessments of the anthropogenic transformation of natural environment components. The components considered in the assessment include relief, soil, vegetation, and groundwater. For each of these components, a separate task was constructed with private objective functions to estimate the contribution of the oil and gas complex to the anthropogenic transformation of relief, soils, vegetation, and groundwater.

These results were then used to construct integral objective functions and obtain a generalized assessment of the oil and gas complex's contribution to the overall ecological situation throughout the Mangystau region. This approach ensures the implementation of the "polluter pays" principle across the entire industry and region.

Since these issues are approached through a generalized method, specific methods were required to obtain evidence in a form adapted for use in partial trust functions. Justification of the objectivity of the objective functions is provided in the first part of each subsection.

To assess the accuracy of the developed methodology, the section also presents results comparing the accuracy of the inverse problem solution. This includes comparative calculations for different sets of estimate maps and different sets of loads on the natural environment components within the objective integrated functions.

3.1 Assessing the Impact of the Oil and Gas Complex of Mangystau Region on the Anthropogenic Modification of the Relief

Choosing a Relief as an Indicator of the Intensity of Human Impact on Ecosystems in the Mangystau Region

The theoretical generalizations of renowned scientists in the fields of geography, soil science, geochemistry, and geology have substantiated the use of relief as the primary factor for differentiating landscape areas [17-75, 102-104]. Currently, due to the advancement of digital technologies and the widespread availability of remote sensing data, it is possible to conduct a detailed assessment of human impact on the relief. This is carried out by the Geography Institute [56]. The results are presented in Figure 3.1 of the map.

The map reflects an evaluation based on expert generalizations. However, it should be examined from the perspective of selecting the primary processes that destabilize the relief. The number of parameters considered fully meets the criteria of objectivity outlined in Section 2, as represented by the equation (2.2).

As indicated in the map legend, the assessment of relief disturbances accounts for five types of anthropogenic impacts: residential, industrial, transport, agricultural, and the presence of military test sites. Each impact type is further differentiated into various forms of human-induced relief alterations, with a quantization scale rating of level 2. The assessment takes into account at least five factors.

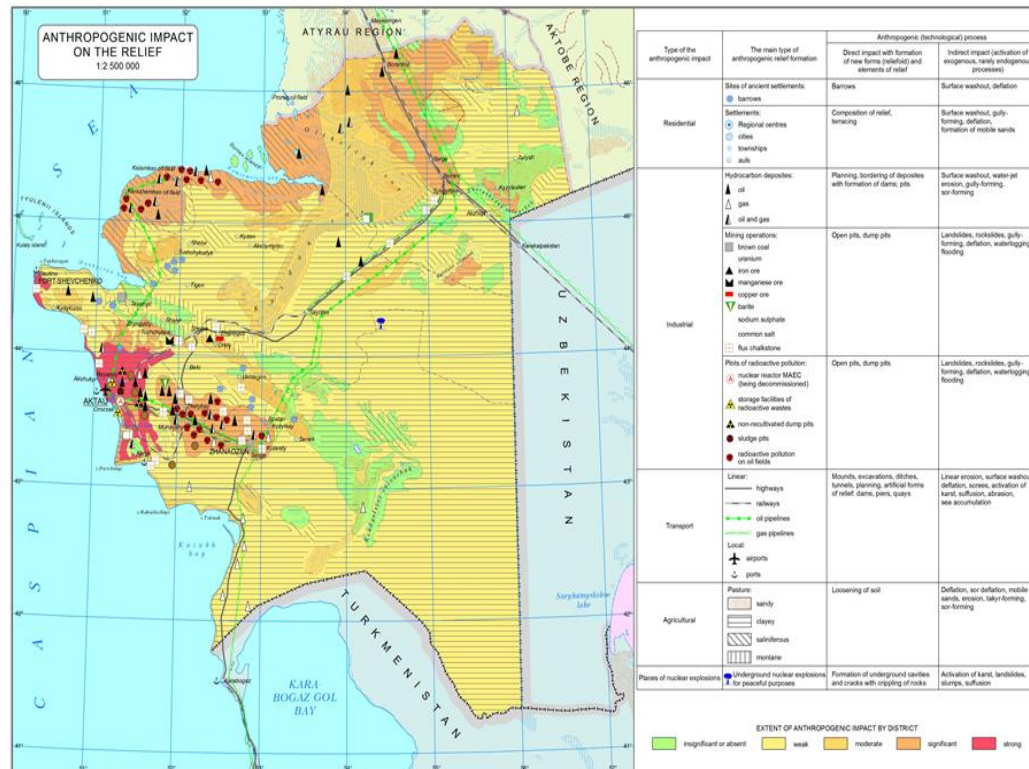


Figure 1 - Anthropogenic Impact on the Relief of the Mangystau Region [56]

This map presents expert zoning of the Mangystau region based on the level of anthropogenic destabilization, with five classes identified:

- **Red:** Strong degree of transformation
- **Brown:** Large degree of transformation
- **Golden:** Moderate degree of transformation
- **Light yellow:** Weak degree of transformation
- **Green:** Little or no transformation

Thus, to address the inverse private task (focused solely on the relief) within Integrated Environmental Assessment, there is sufficient reason to consider the accuracy of the initial data adequate for assessing the role of the oil and gas complex in the anthropogenic transformation of the relief in the Mangystau region. The data source is

based on the areas of polygons representing each level of anthropogenic transformation of the relief, covering both the entire region and the areas affected by the oil and gas complex.

The summary of all degrees of anthropogenic disturbance, within the context of the private objective function, should account for the weighted contribution of each region, considering the complexity and cost of environmental protection measures, particularly those for the remediation of the territory. This analysis is carried out in the methods section of the research, with equations (2.3) and (2.4) used to calculate the target values of the private functions for both the region and the zones influenced by the oil and gas complex.

For the recording of a specific component of the natural environment (CNIj), it should be replaced with the component under consideration—namely, the relief (rel).

$$POF_{rel\ region} = f_{1relReg} + 3f_{2relReg} + 5f_{3relReg} + 7f_{4relReg} + 9f_{5relReg} \quad (3.1)$$

$$POF_{relOGC} = f_1 + 3f_{2\ relOGC} + 5f_{3\ relOGC} + 7f_{4\ relOGC} + 9f_{5\ relOGC}, \quad (3.2)$$

Where:

f_{irel_reg} – Function of the i-th level of anthropogenic disturbance of the relief for the entire region. It is calculated by dividing the total area of the polygons corresponding to a certain level of anthropogenic relief transformation in the whole region by the total area of the entire region.

In this case, f_{irel_reg} represents the proportion of the area affected by the i-th level of anthropogenic disturbance of the relief relative to the total area of the region. In other words, it reflects the actual contribution of this level to the overall assessment of the anthropogenic disturbance of the relief.

firel_OGC – Function of the i-th level of anthropogenic disturbance of the relief in the areas of oil and gas field locations. It is calculated by dividing the total area of the polygons corresponding to a certain level of anthropogenic transformation of the relief in the zones with the oil and gas complex by the total area of all zones with the oil and gas complex.

The role of the oil and gas complex in the overall transformation of the Mangystau region's relief is determined by subtracting the value of POF_{rel_OGC} from POF_{rel_Region} , by analogy with the equation provided.

(2.5).

$$PSIP_{rel} = POF_{relOGC} - POF_{relReg} \quad (3.3)$$

The resulting score on a ten-point scale represents the outcome of a particular solution to the inverse problem and indicates the additional contribution of the oil and gas production complex to the anthropogenic disturbance of the relief in the Mangystau region across all levels of human transformation. For clarity, this value can also be expressed as a percentage.

Thus, the result of solving the inverse problem provides an optional contribution (as reflected in **POFrelReg**, which shows the net effect of the primary factors on the relief, according to the legend of the estimated map) of the oil and gas complex to the anthropogenic transformation of the relief. The results, based on areas with different levels of anthropogenic transformation across the entire Mangystau region, including the zones with the oil and gas complex, were processed in ArcGIS and calculated using equations (3.1) - (3.3), as shown in Table 3.1.

Table 3.1 - Results of the Calculation of Generalized Partial Objective Functions and Generalized Solutions to the Private Inverse Problem for the Relief

Function	Type	The extent of anthropogenic transformation	Total
----------	------	--	-------

and Unit of Measurement	Little or no	poor	moderate	greatly	strong	
for relief						
Total Area of the i-th Level of Anthropogenic Disturbance Contours, km ²	12800	94362	21647	33317	3519	165645,00
$F_{rel\ Regi}$ – the Ratio of the Area of i-th Level Transformation Contours to the Area of the Region, Dimensionless	0,077	0,570	0,131	0,201	0,021	
POF_{relReg} – private objective function for the region, scores						4,039
Total Area of the i-th Level Transformation Contours within Oil and Gas Complex Zones, km ²	230,9	1990,2	675,4	3609,8	704,7	7211,00
$f_{relOGCi}$ – The ratio of the area of i-th level transformation contours within the zones of the oil and gas producing complex to the	0,032	0,276	0,094	0,501	0,098	

Function and Measurement	Type of Unit	The extent of anthropogenic transformation					Total
		Little or no	poor	moderate	greatly	strong	
total area of all oil and gas complex zones, dimensionless							
$POF_{rel\ OGC}$ – Particular Objective Function for Areas with the Oil and Gas Complex, Score							5,712
$PSIP_{rel}$ – Private Solution to the Inverse Problem (Additional Contribution of the Oil and Gas Complex to the Anthropogenic Disturbance of the Relief in the Mangystau Region), Score							1,67
$PSIP_{rel}$ – Private Solution to the Inverse Problem (Additional Contribution of the Oil and Gas Complex to the Anthropogenic Disturbance of the Relief in the Mangystau Region), %							16,73

Thus, the weighted average rating of anthropogenic disturbance of the relief in the areas of the oil and gas complex was 5.71 points on the scale, which is 1.67 points higher than the average estimation of anthropogenic disturbance for the Mangystau region as a whole. The oil and gas complex contributes an additional burden to the relief, exceeding the average contribution of all anthropogenic sources by 16.73%. These results are presented in the publication. [105]

3.2 Generalized Evaluation of the Role of the Oil and Gas Complex in Soil Degradation in the Mangystau Region

Generalized evaluation of the role of the oil and gas complex in the degradation of soil in the Mangystau region

On the Role of Soil as One of the Components of the Ecosystem: Soil is the foundation of agricultural production, one of humanity's most valuable resources, and a vital part of the human environment. It results from the complex interactions between the atmosphere, hydrosphere, lithosphere, flora, and fauna. The numerous environmental functions of soil were explored by scholars such as V.V. Dokuchaev, J. Liebig, V.R. Volobueva, E.D. Russell, L.G. Ramensky, V.R. Williams, V.A. Kovda, and others. Modern soil science views soil not only as a product of the soil-forming process but also as a multifunctional natural structure that plays a critical role in the ecosystem [103-106]. It is now widely accepted that the stability of soil's ecological functions is crucial for the overall stability of the biosphere. Therefore, using soil as an indicator of human impact on the ecosystem of the Mangystau region is a reasonable choice. To achieve the objectives of this subsection, the data source used is the published map of soil degradation [56], shown in Figure 3.2.

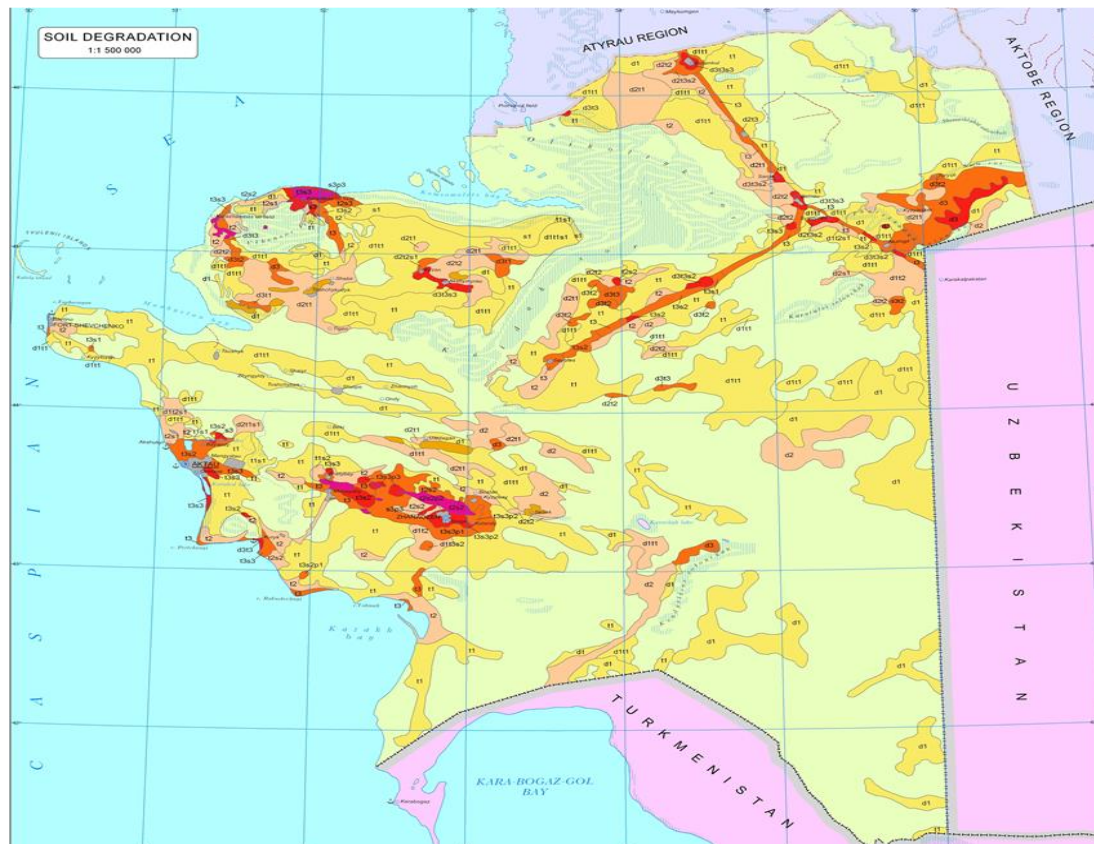


Figure 3.2 - Map of Soil Degradation([34])

This map provides a privacy impact assessment (integrated environmental assessment for one component of the natural environment) of the anthropogenic impact on the soil cover of the Mangystau region, based on expert generalizations and a large amount of diverse information. The map legend indicates that the soil degradation map is derived from the soil map of the Mangystau region and uses remote sensing data.

Gray and crimson colors on the map represent areas characterized by total destruction of the soil cover (residential, residential-industrial zones, oil fields, and loose barchan sands). Alphanumeric encoding is used to indicate types of anthropogenic soil degradation:

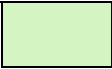
- **T** – Mechanical soil disturbance
- **P** – Pasture degradation
- **3** – Secondary salinization
- **H** – Petrochemical pollution

The numbers following the indexes of anthropogenic soil degradation represent the degree of manifestation of the process:

- **1** – Slightly disturbed
- **2** – Moderately disturbed
- **3** – Severely disturbed

The current status of the soil (as assessed by direct peer review) is represented by five colors.

The current state of soil

				
undisturbed	slightly disturbed	moderately disturbed	greatly disturbed	greatly disturbed

In the legend of the estimated map, from which we derived the raw data, there is a detailed rationale for selecting anthropogenic factors of soil degradation, which are exacerbated by the climatic conditions of the area. For example, [56] notes that residential and industrial soil degradation, in addition to the establishment of residential

areas and industrial facilities, affects vast adjacent areas. This extensive area of human impact is characterized by the formation of man-made relief features, both positive (embankments, mounds) and negative (excavations, trenches, pits), as well as salt marshes and deflated areas.

In addition to mechanical soil disturbance, areas surrounding settlements inevitably become contaminated by household and industrial waste. The oil and gas complex is credited with even more severe consequences for soil health. In addition to the total destruction of soil due to mechanical effects, it also causes intensive petrochemical pollution. This pollution is linked to technological issues in petroleum storage, emergency wells and pipelines, delayed remediation of these issues, and contamination from mineralized wastewater and drilling waste. These factors contribute to a deterioration in the water-physical properties of the soil, a change in the redox potential, secondary salinization, and concomitant anthropogenic alkalization. Additionally, there has been an increase in groundwater salinity and contamination from toxic substances in the fields and surrounding areas.

In large areas of pasture degradation, moderate and mild signs are visible, such as poor cattle trails, reduced grass cover, and an increase in the number and types of cover plants indicative of pasture degradation. The construction of the evaluation map also accounts for soil and road degradation, which is an inevitable component of any human impact. [56] Expert assessments are generally considered to have a higher degree of subjectivity, so using this map for theoretical constructions with multivariate models requires substantiation of the objectivity of the zoning results, which are based on expert estimations. [25] However, an analysis conducted in Section 2 of the research, using formula (2.2) and applying the general theory of systems and quantitative information theory, has shown that the degree of differentiation in scale and the completeness of the range of all possible states accounted for by the parameter plays a subordinate role in the use of multidimensional evaluation functions.

Thus, concerns regarding the objectivity of rating scales, due to the complexity of accounting for nonlinear effects of interactions with other factors, can be mitigated by increasing the number of factors chosen as important for description. While Figure 3.2, with alpha-digital encoding, can represent the approximate area impacted by the oil and gas complex in terms of these types of anthropogenic soil degradation, **N** – petrochemical pollution can clearly be attributed to the oil and gas complex. However, **T** – mechanical soil disturbance could be caused by various factors, one of which is the oil and gas complex. To more definitively highlight the role of the oil and gas complex in soil degradation, the ArcGIS vector map layers were overlaid. This map shows the "Oil and Gas Production Complex" layer (the same data is also available on other inventory maps from [56], such as "Human-caused Sources of Influence"). The result of this overlay is shown in Figure 3.3.

Regarding the construction of private environmental assessments for the Mangystau region, this map includes only five variables (levels of soil environmental condition) that are mandatory for checks against environmental engineering criteria and expert environmental assessments [40]. These variables are sufficient to provide baseline data for further theoretical constructions and precision. In other words, to address the inverse private (soil cover only) objectives of integrated environmental assessment, there is ample justification to consider the accuracy of the initial data as sufficient for assessing the role of the oil and gas complex in the anthropogenic degradation of the soil cover in the Mangystau region.

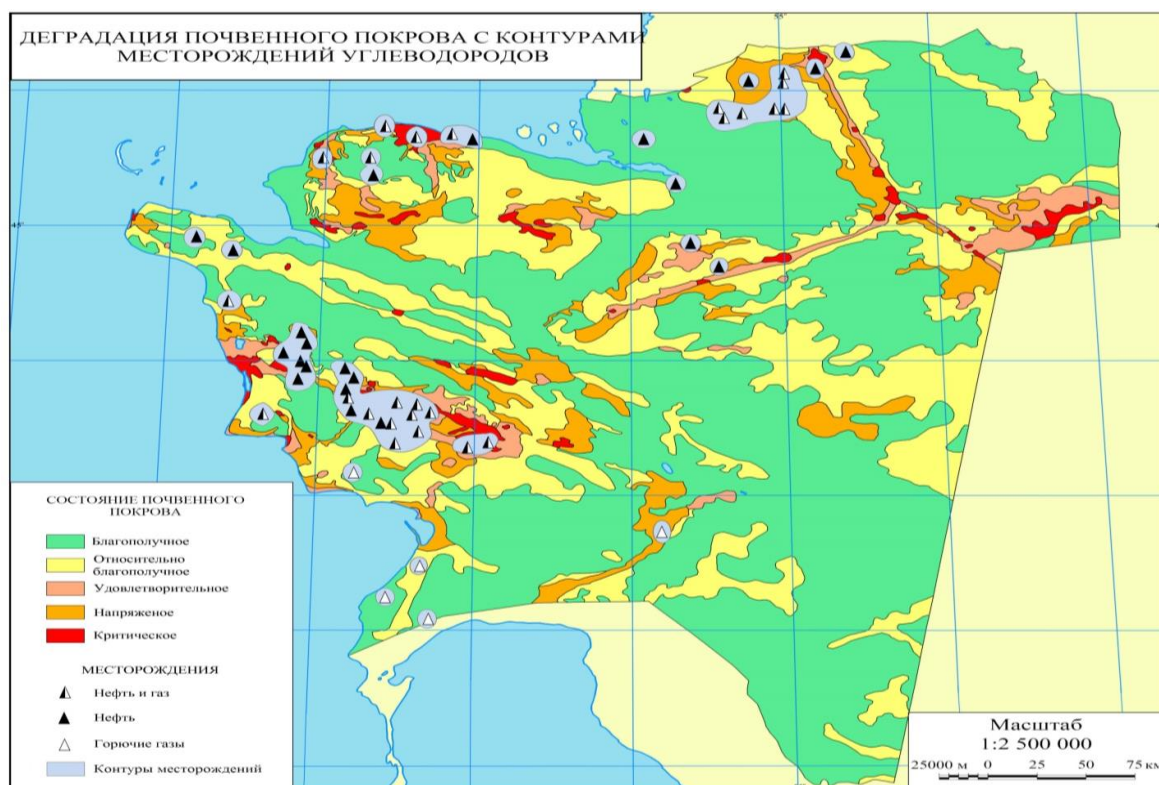


Figure 3.3 - Diagram of Edge Enhancement of Hydrocarbon Deposits in Zones with Varying Degrees of Soil Cover Degradation in the Mangystau Region.

As shown in Figure 3.3, the oil and gas fields fall within zones of varying levels of degradation, with a predominance of the highest degradation levels. In addition to the theoretical assessments of the objectivity of expert estimates, the theoretical conclusions derived from the quantitative theory of information [40] are supported by direct methods that confirm their objectivity. One example is the collection of evidence during field research.

The first example is the dissertation research of Musaeva J.K. [107], which focuses on the development of environmental foundations for modeling microbiological contamination of oil-polluted soils. In this work, the ecological state of the soils at the Zhetybai oil field, one of the major fields in the Mangystau region, is described: "The soil cover of the territory is primarily composed of gray-brown and saline soils. Large areas consist of gray-brown eroded soils and underdeveloped soils, as well as salt licks,

takyr, and salt marshes. The ecological state of the vegetation is considered satisfactory, though the degree of negative changes (degradation) in the morphological status of the vegetation cover increases year by year, and the area of technogenically disturbed land is expanding." Statistical data on the background and chemical properties of oil-contaminated soils in areas of oil and gas industries are presented in Table 3.2.

Table 3.2 - Agrochemical Properties of Original Undisturbed Soil and Oil-Contaminated Soil in Oil and Gas Fields ([107]).

Properties of Background and Oil-Contaminated Soils	Gray-brown soil	Gray-brown alkaline-saline soil	Solonetz or solonchaks soils	Alkaline soils	Takyr soils (salt-crusted soils)
The content of organic carbon, which is part of humus%	0,48±0,06	1,06±0,14	0,34±0,04	0,25±0,03	0,76±0,11
	5,36±0,91	6,33±0,88	6,51±0,93	2,8±0,44	5,88±0,94
pH of the aqueous suspension (pH value in water)	8,2±0,39	8,5±0,47	8,9±0,51	9,1±0,47	8,7±0,42
	7,5±0,4	8,4±0,38	7,6±0,39	8,4±0,41	7,5±0,36
Content of carbonates (CO ₂), %	10,3±0,9	13,3±0,67	10,9±0,81	7,7±0,65	15,0±0,59
	9,1±0,72	12,5±0,54	9,8±0,73	6,9±0,67	14,3±0,61
Total nitrogen or Gross nitrogen content, %	0,035±0,003	0,075±0,002	0,026±0,003	0,020±0,002	0,066±0,003
	0,066±0,005	0,079±0,004	0,078±0,005	0,12±0,01	0,069±0,002
Total phosphorus or Gross phosphorus content, %	0,14±0,01	0,11±0,001	0,09±0,1	0,07±0,006	0,08±0,006
	0,09±0,008	0,14±0,001	0,12±0,009	0,07±0,005	0,1±0,009

The content of HCO_3 , %	0,015±0,00 1	0,015±0,001	0,05±0,00 4	0,019±0,0 01	0,06±0,00 4
	0,018±0,00 1	0,017±0,001	0,021±0,0 01	0,027±0,0 02	0,02±0,00 1
Cl^-	0,024±0,00 3	-	0,184±0,0 2	0,15±0,00 2	0,305±0,0 3
	0,093±0,00 7	0,028±0,003	0,199±0,0 01	1,021±0,1 1	0,213±0,0 1
SO_4	0,061±0,00 5	0,023±0,001	0,052±0,0 2	0,182±0,0 1	0,301±0,0 2
	0,353±0,02 9	0,387±0,031	0,063±0,0 1	0,638±0,0 4	0,059±0,0 04
Heavy residue	0,178±0,02	0,086±0,006	0,435±0,0 1	0,619±0,0 5	0,987±0,0 4
	0,893±0,06	1,019±0,09	0,447±0,0 1	2,556±0,1 9	0,407±0,0 3

Note: Numerator – control; denominator – oil-contaminated soil.

The conclusion regarding the strong degradation of soil in the territory of the oil fields, as presented in the cited work, was made by comparing the concentrations of key agrochemical indicators in the zonal soils and oil-contaminated gray-brown soils, which form the main background of the soil cover in the Zhetybai field area.

In the Mangystau region's fields, environmental monitoring data from RSE "Kazgidromet" ME RK are also available. Since the number of monitoring parameters used for soil contamination assessment [85-86] includes several heavy metals (Mn, Cu, Cr^{6+} , Pb, Zn, Ni), which are not covered in Table 3.2, Table 3.3 presents monitoring results for two of the four observed fields, each of which had sampling conducted at three points.

Table 3.3 - Characteristics of Soil Contamination in the Fields of Mangystau Region (according to [86])

Field	Impurities	1 point		2 point		3 point	
		Q mg/kg	Q/EAC	Q, mg/kg	Q/ EAC	Q, mg/kg	Q/ EAC
Spring period 2014 y.							
Dunga	Petroleum products, %	0,016		0,035		0,025	
	Manganese, mg / kg	0,2	0,0001	0,15	0,0001	0,16	0,0001
	Copper, mg / kg	0,75	0,25	1,45	0,48	1,22	0,41
	Cr (6+), mg / kg	0,02	0,4	0,01	0,2	0,01	0,2
	Lead, mg / kg	0,001	0,00003	0,002	0,00006	0,001	0,00003
	Zinc, mg / kg	0,1	0,004	0,07	0,003	0,15	0,007
	Nickel, mg / kg	0,26	0,0650	0,19	0,05	0,2	0,05
Zhetybai	Petroleum products,, %	0,027		0,03		0,025	
	Manganese, mg / kg	0,2	0,0001	0,17	0,00011	0,14	0,00009
	Copper, mg / kg	1,18	0,39	1,2	0,40	1,15	0,38
	Cr (6+), mg / kg	0,01	0,2	0,03	0,6	0,02	0,4
	Lead, mg / kg	0,001	0,00003	0,002	0,0000	0,001	0,00003

					6		
	Zinc, mg / kg	0,11	0,005	0,14	0,0061	0,15	0,007
	Nickel, mg / kg	0,28	0,07	0,23	0,058	0,32	0,08
The autumn period 2014 y.							
Dunga	Petroleum products, , %	0,025		0,028		0,020	
	Manganese, mg / kg	0,67	0,00045	0,1	0,0000	0,08	0,0001
	Copper, mg / kg	1,25	0,42	1,5	0,50	1,32	0,44
	Cr (6+), mg / kg	0,03	0,6	0,04	0,8	0,03	0,6
	Lead, mg / kg	0,002	0,00006	0,002	0,00006	0,002	0,00006
	Zinc, mg / kg	0,1	0,004	0,07	0,003	0,15	0,007
	Nickel, mg / kg	0,26	0,07	0,19	0,05	0,2	0,05
Zhetybai	Petroleum products, , %	0,030		0,024		0,035	
	Manganese, mg / kg	0,128	0,0001	0,135	0,0000	0,16	0,0001
	Copper, mg / kg	1,54	0,51	1,25	0,42	1,3	0,43
	Cr (6+), mg / kg	0,02	0,4	0,04	0,8	0,04	0,8
	Lead, mg / kg	0,002	0,00006	0,001	0,00003	0,001	0,00003
	Zinc, mg / kg	0,11	0,005	0,14	0,006	0,15	0,007
	Nickel, mg / kg	0,28	0,07	0,23	0,0575	0,32	0,08

Spring period 2015 y.							
Dunga	Petroleum products, , %	0,019		0,024		0,02	
	Manganese, mg / kg	0,58	0,0004	0,4	0,0003	0,42	0,0003
	Copper, mg / kg	0,95	0,32	1,1	0,37	1,27	0,42
	Cr (6+), mg / kg	0,02	0,4	0,02	0,4	0,03	0,6
	Lead, mg / kg	0,001	0,00003	0,002	0,0001	0,001	0,00003
	Zinc, mg / kg	0,2	0,009	0,16	0,007	0,08	0,003
	Nickel, mg / kg	0,31	0,0775	0,28	0,07	0,22	0,06
Zhetybai	Petroleum products, , %	0,034		0,026		0,036	
	Manganese, mg / kg	0,64	0,0004	0,48	0,0003	0,5	0,0003
	Copper, mg / kg	2	0,67	1,45	0,48	1,6	0,53
	Cr (6+), mg / kg	0,03	0,6	0,02	0,4	0,02	0,4
	Lead, mg / kg	0,003	0,0001	0,003	0,0001	0,002	0,0001
	Zinc, mg / kg	0,3	0,013	0,18	0,0078	0,24	0,010
	Nickel, mg / kg	0,45	0,11	0,36	0,090	0,42	0,11

Note: Q, mg/kg – the impurity concentration in mg/kg; Q/MAC – the impurity concentration in terms of the MAC shares.

As seen in Table 3.3, the results of the state environmental monitoring indicated no exceedances of the Maximum Permissible Concentrations (MPC) for heavy metals in

the soils at all observation points. The same results were observed in the 2015 observations [108].

As part of the project grant funding in 2015, soil and vegetation samples were taken near the existing wells and outside the sanitary protection zone of the Zhetybai deposit. The results of heavy metal determinations in the soils are presented in Table 3.4 [109].

Table 3.4 - Results of Chemical Analysis of Heavy Metals in Soil Samples Collected During Fieldwork in the Summer of 2015

Sampling Point Locations	№ sample	Concentrations of Total Forms of Pollutants in the Soil (mg/kg)				Concentrations of Total Forms of Pollutants in the Soil as MPC Shares for Zn – in Fractions of Clarke			
		Cd	Cu	Zn	Pb	Cd	Cu	Zn	Pb
Near the production well	1	0,15	8,19	39,6	5,54	0,3	0,248	0,48	0,173
	2	0,15	6,26	41,05	9,09	0,3	0,19	0,49	0,284
	3	0,18	7,63	26,9	9,04	0,36	0,231	0,32	0,282
	4	0,28	6,45	26,1	6,97	0,56	0,195	0,31	0,218
	5	0,96	4,66	17,1	8,72	1,92	0,141	0,21	0,272
	6	0,62	5,06	33,9	7,03	1,24	0,153	0,41	0,22
	7	0,2	3,73	15,2	8,04	0,4	0,113	0,18	0,251
	8	0,25	4,74	17,8	7,41	0,5	0,144	0,21	0,232
	9	0,24	3,97	32,9	6,33	0,48	0,12	0,40	0,198
sanitary protection zone of the	10	0,2	5,01	24,8	6,51	0,4	0,152	0,30	0,203
	11	0,77	10,2	42,3	4,61	1,54	0,309	0,51	0,144

Sampling Point Locations	№ sample	Concentrations of Total Forms of Pollutants in the Soil (mg/kg)				Concentrations of Total Forms of Pollutants in the Soil as MPC Shares for Zn – in Fractions of Clarke			
		Cd	Cu	Zn	Pb	Cd	Cu	Zn	Pb
	12	0,23	8,4	38,5	3,83	0,46	0,2545	0,46	0,12
	13	0,32	8,1	41,5	4,03	0,64	0,2455	0,50	0,126
	14	0,25	9,13	69,5	4,29	0,5	0,277	0,84	0,134
	15	0,29	9,26	66,1	4,75	0,58	0,281	0,80	0,148
	16	0,27	9,1	80,7	3,98	0,54	0,276	0,97	0,124
	17	0,41	9,8	43,4	4,29	0,82	0,297	0,52	0,134
	18	0,31	9,4	30,7	3,58	0,62	0,2858	0,37	0,112
	19	0,26	7,9	58	3,71	0,52	0,239	0,70	0,117
	20	0,23	7,4	59,8	3,23	0,46	0,224	0,72	0,101

As seen in Table 3.4, exceeding the maximum permissible concentration (MPC) of heavy metals is observed only for cadmium (Cd). In the monitoring program of Mangystau region, conducted by "Kazgidromet," there are no cadmium deposits. It is worth noting that the excess was found both near the production well and outside the buffer zones, with the average cadmium content in these two sampling areas being practically the same (0.67 and 0.64 mg/kg). For all other heavy metals, as well as in the data from the state soil monitoring at the Zhetybai deposit, no exceedance of the MPC was observed at any test point. Similar results were obtained in the field studies conducted in 2016 [110].

Such a distribution of heavy metal concentrations in the soil confirms the findings of many studies regarding the uninformative nature of exceeding the MPC for total

heavy metal content in environmental monitoring. The total concentration may not accurately reflect the level of anthropogenic soil degradation. As indicated on the estimated map [56] and supported by the humus content data in [107], a strong degradation of soil at the Zhetybai field was confirmed. The research of the project authors funded by grants confirmed a radical change in the quantitative distribution of the plant species composition.

Analysis of the presence of certain species in selected vegetation samples showed that near the oil well, 95% of the total plant mass was dominated by *Garman* (also known as burial, adraspan, prairie root, or Turkish paint), a toxic weed that clogs pastures and severely degrades grazing land in southern steppes and deserts. Other species (e.g., *Artemisia terrae-albae*, *Anabasis salsa*, and *Suaeda acuminata*) were rare in these samples. The situation changed entirely for samples taken outside the sanitary protection zone. In these samples, *Garman* was replaced by a variety of species, with *Garman* representing only a small portion (less than 2%) of the samples.

Thus, in addition to theoretical studies, direct confirmation of the objectivity of the expert zoning map for soil degradation as part of independent research in 2009, presented in the paper [108], was provided by the field studies conducted in the summer of 2015. This map can be used as a private environmental assessment (comprehensive environmental evaluation for one of the environmental components). It serves as a reliable source of information for solving the inverse problem and building a multidimensional expert model for the objective function.

The methods for obtaining the initial data for solving the inverse problem using GIS technologies are outlined in Section 2 of the research. The method for determining the generalized assessment involves calculating the sum of areas throughout the region and in the areas with hydrocarbon fields for each level of anthropogenic soil transformation. The areas for different levels of anthropogenic soil degradation in the

region and in zones with the oil and gas complex are defined using polygons in the ArcGIS system, similar to the method used for assessing relief [105].

The solution to the private inverse problem for integrated environmental assessment is outlined in Section 2.2, with specific applications for relief in Section 3.1. For the soil, applying the estimated equations should not be problematic—equations (3.1)–(3.3) will require only a change in the environmental component being assessed.

In this case, calculations will be carried out according to equations (3.4)–

$$POF_{soil\ Region} = f_{1soilReg} + 3f_{2soilReg} + 5f_{3soilReg} + 7f_{4soilReg} + 9f_{5soilReg} \quad (3.4)$$

$$POF_{soilOGC} = f_{1soilOGC} + 3f_{2soilOGC} + 5f_{3soilOGC} + 7f_{4soilOGC} + 9f_{5soilOGC}, \quad (3.5)$$

$$PSIP_{soil} = POF_{soilOGC} - POF_{soilReg} \quad (3.6)$$

where $f_{i\ soil\ region}$ – This is the function of the i-th level of anthropogenic disturbance of soil cover for the entire region. It is calculated by dividing the total area of polygons representing the level of anthropogenic transformation of the soil cover across the entire area by the total field area.

In this case, $f_{i\ soil\ reg}$ represents the sum of the areas corresponding to a specific level of anthropogenic disturbance of the soil, relative to the total area of the entire region. In essence, it reflects the contribution of this area to the overall assessment of anthropogenic disturbance of the soil cover—this is the function of the i-th level of anthropogenic disturbance of soils.

$f_{i\ soilOGC}$ – This is the function of the i-th level of anthropogenic disturbance of soil in the zones where deposits are located. It is calculated by dividing the total area of polygons representing a certain level of anthropogenic transformation of the soil cover within the zones of the oil and gas complex by the total area of all zones within the oil and gas complex.

PSIPsoil – This represents the result of the private solutions to the inverse problem. It is an optional function (with POFsoilReg and POFsoilOGC reflecting the net effects of the main factors according to the descriptions in the evaluation map). This value contributes to the oil and gas complex's impact on the transformation of anthropogenic soil, as shown in Table 3.5.

Table 3.5 - Results of the calculation of generalized partial objective functions and the generalized solution of the inverse problem for soil degradation.

Thus, the weighted average evaluation anthropogenic disturbance soil Mangystau

Type of Function and Unit of Measurement	The degree of anthropogenic transformation					Total
	Little or no disturbance	Slightly disturbed	Moderately disturbed	Heavily disturbed	Very heavily disturbed	
for soil						
Total area of the contours at the i-th level of anthropogenic disturbance (in km²)	89992	49239	17974	6908	1953	166066
$f_{i\text{soilReg}}$ – Ratio of the area of the i-th level of transformation contours to the total area of the region	0,542	0,297	0,108	0,042	0,012	

(dimensionless)						
$POF_{soilReg}$ – private objective function for the region, scores						2,370
The total area of the contours outlining the i-th level of transformation within the zones of the oil and gas complex, in km ² .	1733,50	2189,44	1879,65	633,82	751,56	7187,98
$f_{i\ soil\ OGC}$ – The ratio of the area of contours of the i-th level of transformation within the zones of the oil and gas extraction complex to the total area of all zones of the oil and gas extraction complex, dimensionless.	0,241	0,305	0,261	0,088	0,105	

$POF_{soilOGC}$ – Private objective function for areas within the oil and gas extraction complex, on a point scale.	4,02
$PSIP_{soil}$ – Private solution to the inverse problem (the additional contribution of the oil and gas extraction complex to the anthropogenic disturbance of the soil in the Mangystau region), on a point scale.	1,65
$PSIP_{soil}$ – private solution of the inverse problem (an additional contribution of oil and gas extraction complex in the anthropogenic disturbance of the soil on the territory of Mangystau region),%	16,51

The region with the oil and gas complex scored 2.37 points on the scale, which is 1.65 points higher than the average estimation of anthropogenic disturbance of soils in the Mangystau region as a whole. The oil and gas complex contributes an additional burden on the soil, exceeding the average impact of all anthropogenic sources by 16.51%.

3.3 Assessment Role of the Oil and Gas Complex in Anthropogenic Changes to Vegetation in the Mangystau Region

Within the interconnected structure of landscape components, vegetation plays a central role as one of the core functional units of ecosystems. It is highly sensitive and reactive to fluctuations in environmental conditions such as soil composition, topography, water availability, and air quality. Because of this responsiveness, both the condition of vegetation and its floristic diversity are widely recognized as effective indicators for tracing the intensity, pace, and direction of anthropogenic and technogenic processes. These indicators also mirror the ongoing changes in other environmental components, including soil, groundwater, and surface water systems [25–26, 28, 111–115].

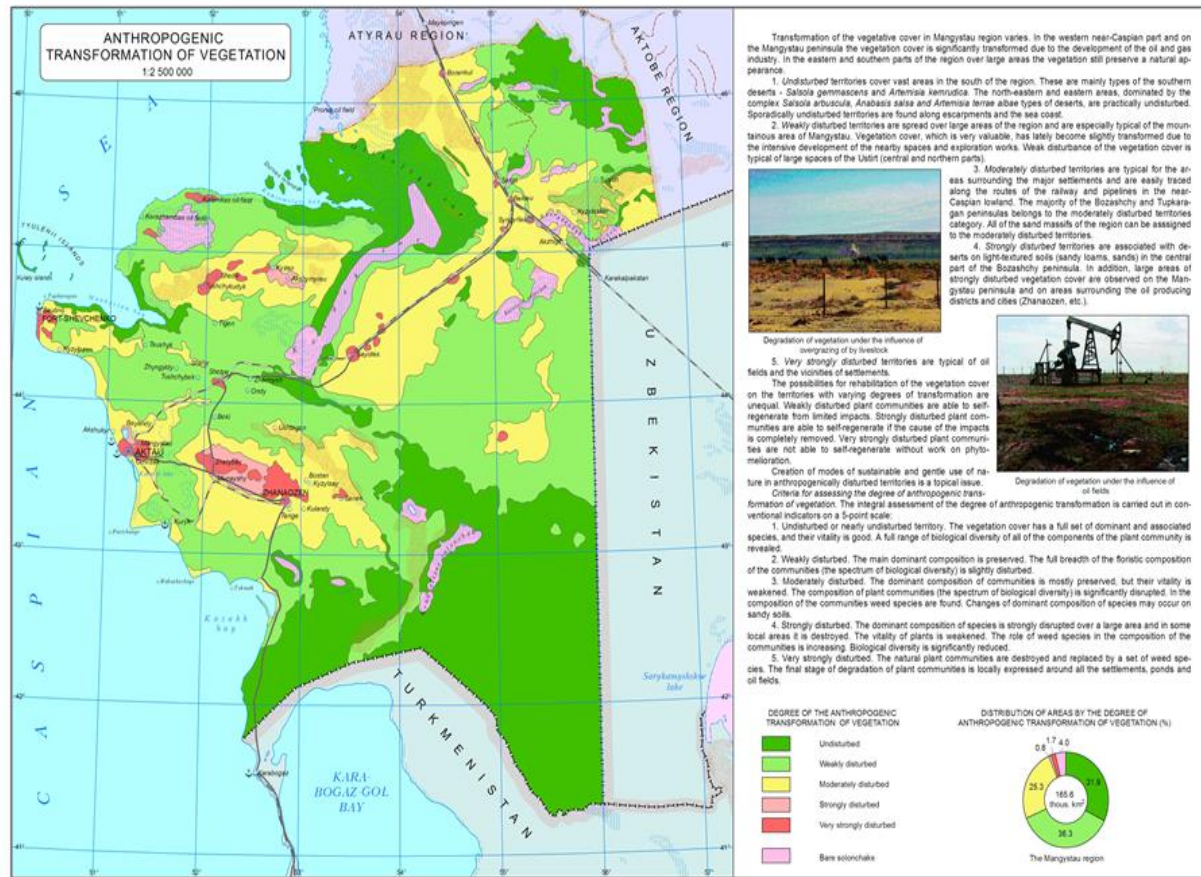
A field-based study on vegetation monitoring conducted at the Karazhanbas oil field in the Mangystau region [94] underscores the diagnostic significance of vegetation

in detecting and characterizing human-induced environmental disturbance. The research highlights that the region's vegetation cover has evolved under extreme natural conditions, including arid climate, pronounced temperature variability, persistent humidity deficits, and saline soils. As a result, the vegetative landscape exhibits uniform spatial patterns, sparse species composition, and low biodiversity. Furthermore, the study documents notable vegetation degradation in areas adjacent to technogenic structures such as oil wells, access roads, and other infrastructure [116].

To support the resolution of the inverse problem of integrated environmental assessment, which necessitates robust expert analysis, the anthropogenic transformation map of vegetation from the *Atlas of the Mangystau Region* [56] was utilized as a primary analytical resource. This map, presented in Figure 3.4, was developed by the Institute of Geography of the Ministry of Education and Science of the Republic of Kazakhstan. It is based on expert evaluations, field expedition data, and remote sensing interpretation.

The map legend categorizes the landscape into zones characterized by varying degrees of anthropogenic transformation. Specifically:

Undisturbed Territory: Vast areas in the south of the region remain largely untouched. The north-eastern and eastern parts, dominated by complex boyalych,



Anabasis salsa, and

Figure 3.4 – Map of Anthropogenic Transformation of Vegetation [17]
white land sagebrush desert, also show little disturbance. Undisturbed areas are found on the escarpment and along the sea coast. These areas are characterized by a low level of transformation, or its complete absence, and are shown in green on the map.

1. **Slightly disturbed areas** are distributed across large spaces in the region and are particularly common in the mountainous Mangystau. The surface vegetation, which is highly valuable, has recently been slightly transformed due to the intensive

development of surrounding areas and geological exploration activities. Weak disturbance of vegetation is typical for large areas in Ustyurt (central and northern parts). These areas are characterized by low levels of transformation and are represented on the map in light green.

2. **Medium disturbed areas** are common in sites surrounding large settlements and are easily traced along railways and pipelines in the Caspian depression. Medium disturbed areas also include large parts of the Bozaschy and Tupkarangan peninsulas. All sandy areas in the region are classified as medium disturbed. These areas are characterized by a moderate level of transformation and are shown on the map in yellow.

3. **Heavily disturbed areas** are associated with deserts on light-textured soils (sandy loam, sands) in the central part of the Bozaschy peninsula. Additionally, large areas of heavily disturbed vegetation are observed on the Mangystau Peninsula, particularly in sites surrounding oil production areas and cities (e.g., Zhanaozen). (Insert Fig. 7 here). These areas are characterized by a significant level of transformation and are shown on the map in pink.

4. **Very heavily disturbed areas** are primarily found in oil fields and the surrounding settlements. These areas are characterized by a high level of transformation and are represented on the map in red. [56]

In addition to the factors identified in the descriptions of zones with varying degrees of human-induced vegetation change, the legend includes photo sites that illustrate the most prevalent drivers of disturbance in the region—namely, oil and gas production and overgrazing. These images help substantiate the classification of areas based on different levels of anthropogenic impact. Six primary human activity factors were taken into account: oil and gas extraction, geological exploration, pipeline infrastructure, residential settlements, transportation networks, and overgrazing.

It is important to highlight that the evaluation of these factors was not limited to a simple inventory of human activities (which is also mapped in the Atlas), but was supported by classical landscape assessment criteria. These include shifts in species composition (such as changes in the ratio between dominant and weedy species or the replacement of dominant species) and indicators of plant health and vitality. While the legend does not detail specific dominant and associated species, a review of the 2011 Atlas of the Mangystau Region vegetation maps—featuring various vegetation types—confirms that the anthropogenic transformation map was constructed using expert interpretations of multiple thematic maps. One of these is the vegetation map that identifies 32 complexes of arid and semi-arid plant communities across 82 ecosystem types.

As a result, the expert-generated anthropogenic transformation map incorporates at least 32 plant community types and considers no fewer than six key anthropogenic factors. Based on the selection of impactful drivers and the range of ecological parameters assessed, the vegetation transformation map can be considered objective and scientifically grounded. Its development aligns with principles from environmental engineering, systems analysis, and information theory, supporting both the relevance and credibility of its findings.

In addition to outlining key types of human activity, the legend plays a crucial role in shaping the objective function used in assessment. It indicates that levels of transformation are defined not only by the presence and proportion of dominant, associated, and weedy species but also by indicators such as plant vitality and self-regeneration capacity. Thus, the degree of vegetation transformation is inversely related to the ecosystem's ability to recover, while the cost of ecological restoration is directly proportional to the severity of disturbance. This relationship provides an economic rationale for assigning weight coefficients in the objective function.

Therefore, in addressing the inverse problem—here focused on vegetation—there is strong justification to consider the input data sufficiently accurate for evaluating the role of the oil and gas sector in altering natural vegetation in Mangystau.

To more precisely account for the influence of the oil and gas industry, the "Oil and Gas Complex" inventory map from the Atlas [56] was used. This map shows the distribution and development of hydrocarbon fields across the region and includes relevant information in its legend. Due to its scale alignment and inventory-based nature, the accuracy of this map is considered reliable and does not require additional validation.

Following the methodology outlined in Section 2, the total areas corresponding to each level of anthropogenic vegetation transformation were calculated both for the entire region and specifically within zones affected by oil and gas activity. These results are presented in Table 3.6.

The next step is to validate the computational procedure of objective functions, as outlined in section 2 of the research, and apply it to the relief and soils discussed earlier. To do this, the vegetation icon in the equations (3.4)–(3.6) should be replaced with the soil component. The result will be as follows:

$$POF_{plantReg} = f_{1plantReg} + 3f_{2plantReg} + 5f_{3plantReg} + 7f_{4plantReg} + 9f_{5plantReg} \quad (3.7)$$

$$POF_{plantOGC} = f_{1plantOGC} + 3f_{2plantOGC} + 5f_{3plantOGC} + 7f_{4plantOGC} + 9f_{5plantOGC}, \quad (3.8)$$

$$PSIP_{plant} = POF_{plantOGC} - POF_{plantReg} \quad (3.9)$$

Where:

$f_{iplantReg}$ – Function representing the i-th level of anthropogenic disturbance of vegetation cover for the entire region. It is calculated by dividing the total area of

polygons representing a certain level of anthropogenic transformation of vegetation by the total area of the entire region.

In this case, $f_{i\text{plantReg}}$ is the sum of the areas at each level of anthropogenic disturbance of vegetation across the entire region. Essentially, it represents the contribution of this area to the overall assessment of anthropogenic disturbance of vegetation at the i -th level.

$f_{i\text{plantOGC}}$ – Function representing the i -th level of anthropogenic disturbance of soil in areas where deposits are located. It is calculated by dividing the total area of polygons with a certain level of anthropogenic transformation of vegetation in zones containing the oil and gas complex by the total area of all oil and gas complex zones.

$PSIP_{\text{plant}}$ – The result of solving the inverse problem, which represents the cumulative effect of all major factors in $POF_{\text{plantRegion}}$ and POF_{plantOGC} , as shown in the legend of the estimated map. This contribution reflects the impact of the oil and gas complex on the anthropogenic transformation of vegetation (Table 3.6).

Table 3.6 – Results of the calculation of generalized partial objective functions and the generalized solution of the inverse problem for individual plants.

Type of Functions and Units	The degree of anthropogenic transformation					Total
	Little to No Disturbance	Weakly Disturbed	Medium Disturbance	Heavily Disturbed	Very heavily disturbed	
For vegetation (plants)						
Total Area of the Contours at the i-th Level of Anthropogenic	52562	31411	63561	9264	8629,6	165427,6

Type of Functions and Units	The degree of anthropogenic transformation					Total
	Little to No Disturbance	Weakly Disturbed	Medium Disturbance	Heavily Disturbed	Very heavily disturbed	
Disturbance, km ²						
$f_{i\text{ veg}}$ region – Ratio of the area of the contours at the i-th level of transformation to the total area of the region, dimensionless.	0,318	0,190	0,384	0,056	0,052	
$POF_{Veg\ Region}$ – Partial objective function for the region, in scores.						3,670
Total area of the contours outlining the i-th level of transformation within the zones of the oil and gas extraction complex, in km ² .	420	436	1642,1	1466	3232	7196,1

Type of Functions and Units	The degree of anthropogenic transformation					Total
	Little to No Disturbance	Weakly Disturbed	Medium Disturbance	Heavily Disturbed	Very heavily disturbed	
Ratio of the area of the contours at the i-th level of transformation within the oil and gas extraction complex zones to the total area of all oil and gas extraction complex zones, dimensionless.	0,058	0,061	0,228	0,204	0,449	
$POF_{VEG\ OGEC}$ – Partial objective function for areas with oil and gas extraction complexes, on a point scale.						6,849
$PSIP_{VEG}$. – Partial solution of the inverse problem (additional contribution of the oil and gas extraction complex to the anthropogenic disturbance of vegetation in the Mangystau region), in scores.						3,18
$PSIP_{VEG}$. – Partial solution of the inverse problem (additional contribution of the oil and gas extraction complex to the anthropogenic disturbance of vegetation in the Mangystau						31,79

Type of Functions and Units	The degree of anthropogenic transformation					Total
	Little to No Disturbance	Weakly Disturbed	Medium Disturbance	Heavily Disturbed	Very heavily disturbed	
region), in percentage (%).						

The weighted average score for anthropogenic disturbance of vegetation in areas influenced by the oil and gas complex in the Mangystau region was calculated at 3.67 points. This figure is 3.18 points higher than the regional average, indicating a significant localized impact. Additionally, the oil and gas sector contributes an extra environmental burden on soils, surpassing the average influence of all anthropogenic sources by 31.79%.

Field research conducted by the project team in 2015 provided clear evidence of severe vegetation degradation near the Zhetybai oil and gas field. Specifically, in the zone surrounding the production well, a marked shift in plant composition was observed, with native vegetation largely replaced by disturbance-tolerant weed species—unlike the comparatively undisturbed flora outside the field’s sanitary protection zone [95].

3.4 Evaluation of the Role of the Oil and Gas Complex in Groundwater Pollution in the Mangystau Region

The unique climatic conditions of the Mangystau region, coupled with the complete absence of permanent river systems, significantly aggravate issues related to water scarcity—particularly the shortage of potable water. Experts estimate that the region currently experiences a daily deficit of 40,000 m³ of drinking water, a figure projected to increase to 70,000 m³ per day by 2020 [88–92].

According to the regional Akimat, Mangystau is home to 60 rural settlements. Of these, only 17 are equipped with centralized water supply systems, while 35 rely on decentralized sources. Due to low population densities and the high cost of developing

water infrastructure, nine rural communities depend on imported bottled water. In contrast, urban centers such as Aktau, Zhanaozen, and nearby towns—along with oil-producing enterprises—consume 93% of the region’s total water supply, leaving only 7% for the remaining settlements [89, 91].

Water provision in the region comes from three principal sources: LLP "MAEC-Kazatomprom," which accounts for 47–50% of the supply through desalination of Caspian seawater; the “Astrakhan–Mangyshlak” pipeline, delivering approximately 40% of water from the Volga River; and regional groundwater reserves, which contribute around 11–13% [88, 90]. Mangystau possesses 65 known groundwater deposits, collectively holding reserves of up to 522,000 m³ per day. The largest among these are Tuyesu, Sauyskan, Kuyulus, Tonirekshyn, Janajol, and Ketik [66–68], which meet the domestic water needs of about 17.5% of the region’s population [88, 90–92].

Hence, the primary strategy for addressing water shortages involves reliance on desalinated water from the Caspian Sea and water from the Volga River, supplied by the Russian Federation. While urban areas and industrial facilities rely entirely on these external sources, rural villages depend on local groundwater deposits. This reliance underscores the importance of assessing the ecological state of these groundwater systems, both for localized evaluations and broader integrated environmental assessments, which form the basis for planning targeted environmental management strategies.

According to earlier works referenced in [56], partial environmental assessment maps—such as those for anthropogenic impacts on topography, soil degradation, and vegetation transformation—were produced based on expert synthesis of diverse datasets. These maps categorize territories into five impact levels, with more severe impacts associated with greater complexity and cost of environmental mitigation.

However, the Atlas [56] does not contain a five-level classification for groundwater disturbance; instead, it features a map with only three levels of

anthropogenic impact (Figure 3.5). The legend describes these levels as indicators of groundwater status, accounting for both the availability of proven and probable reserves and the extent of human-induced effects on the subsurface hydrosphere. The map highlights how factors such as sea-level changes in the Caspian and industrial activities influence the hydrogeodynamic and hydrogeochemical conditions of groundwater. Green indicates low disturbance, yellow represents moderate disturbance, and red marks areas of high anthropogenic impact. Horizontal shading illustrates hydrogeological effects due to sea-level fluctuations and technogenic activities, while inclined shading identifies zones affected by pollution and groundwater abstraction.

Pollution—particularly its implications for drinking water safety—is considered the main anthropogenic stressor in groundwater evaluations. The degree of contamination is determined through observations from the national groundwater monitoring system, supplemented by occasional inspections. A total of 19 pollution sources have been identified: seven through continuous monitoring and twelve via episodic surveys. Key contaminants include petroleum products (exceeding maximum permissible concentrations by 10–15 times), fluorides (3–5 times the limit), and ammonia (2–4 times the limit). Overall, the contamination levels in affected zones are classified as moderately hazardous [56].

In summary, the thematic analysis of groundwater disturbance maps and their legends demonstrates that human activities—including oil and gas extraction, mining, power generation, chemical processing, and animal husbandry—have measurable effects on groundwater dynamics and quality. The assessment is based on seven standardized indicators, such as sulfates, chlorides, surfactants, fluorides, oils, phenols, radionuclides, and uranium. These factors meet the requirements for accuracy and objectivity [56].

To enable a more comprehensive evaluation, it is necessary to adopt a five-tier scale for assessing groundwater disturbance. A foundational element for such an

expanded assessment is the groundwater protection map (Figure 3.6). The map legend outlines the criteria used to evaluate groundwater vulnerability, which include both natural and anthropogenic influences. Natural factors involve the depth to groundwater, the presence of impermeable geological layers, lithological characteristics, and interactions between aquifers. Anthropogenic factors encompass the nature of surface pollutants and their potential to infiltrate and contaminate groundwater.

Groundwater protection is evaluated through both qualitative and quantitative methods. In the context of Mangystau, the assessment is predominantly qualitative. It is based on moisture conditions within the vadose zone and the way pollutants interact with surrounding rock formations and groundwater systems. The region's hydrogeological context—such as the extent of aquifer confinement and the influence of technogenic activities on subsurface water—is also considered in the evaluation.

An analysis of the groundwater protection map—similar to the one used for mapping anthropogenic disturbance—reveals that the classification of protection levels incorporates more than five parameters. As such, this map meets the criteria for both accuracy and objectivity [40]. Consequently, the final map, generated in ArcGIS by integrating vector layers from Figures 1 and 2, achieves the required level of detail and reliability [40]. This composite map is presented in Figure 3.7. It visually distinguishes four natural groundwater protection levels using various colors, while three degrees of anthropogenic disturbance are represented through distinct hatching styles.

For the purpose of calculating an integrated objective function that captures the impact on all environmental components, a dual-scale framework is employed to establish a five-level classification system.

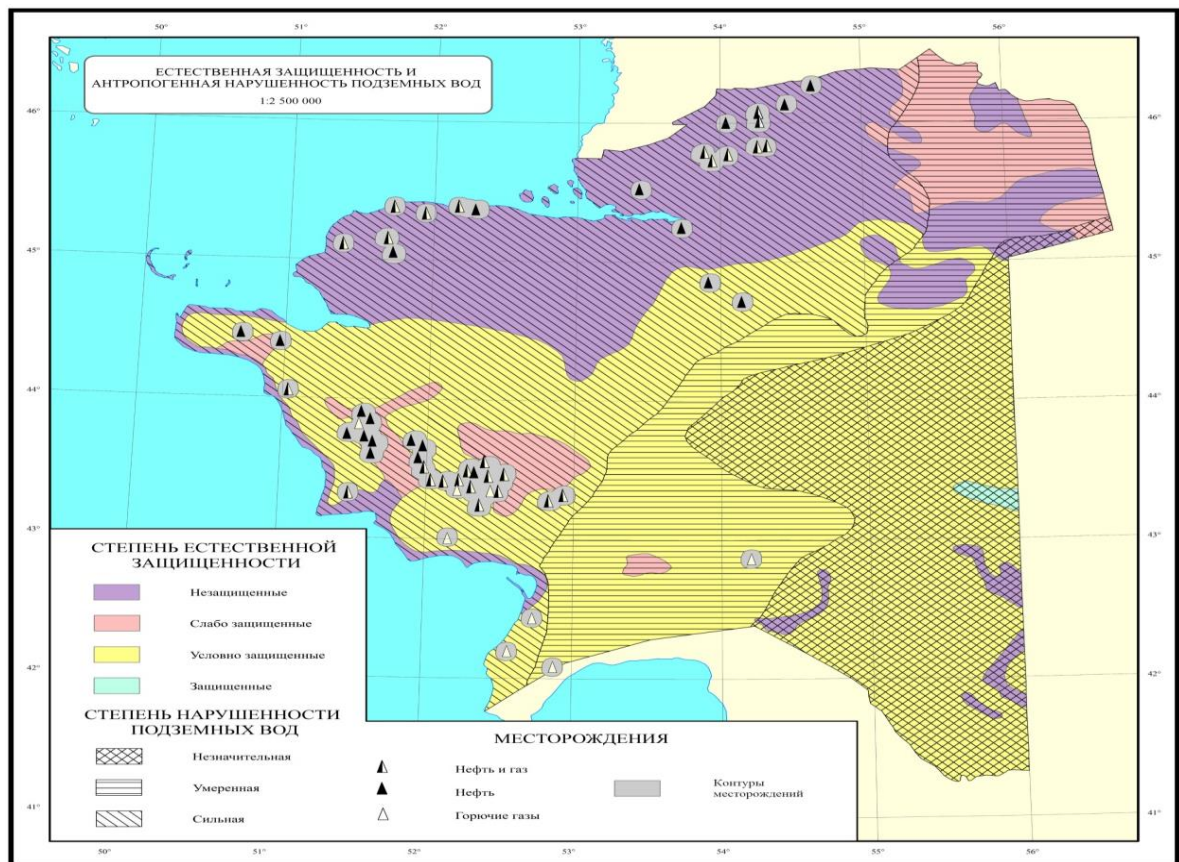


Figure 3.7 - Diagram of combining hydrocarbon field circuits in zones of various degrees of natural protection and groundwater disturbance in the Mangystau region.

The map legend for assessing the degree of natural protection of groundwater indicates that this evaluation considers both natural factors (such as hydrogeological conditions and the degree of coverage of groundwater by loamy and clayey layers) and anthropogenic factors (particularly the movement of moisture in the aeration zone and the interaction of pollutants with rocks and groundwater). The logical approach to establishing protection levels takes into account the specifics of anthropogenic disturbance of groundwater, as described in the legend for Figure 3.5. The result is a combination presented in **Table 3.7**.

Table 3.7 – Correspondence of assessment scales for the degree of protection and disturbance of groundwater with the generally accepted five-level scale of anthropogenic disturbance of environmental components in the Mangystau region.

Three-level scale of anthropogenic disturbance of groundwater (indicated by three species)	The four-level scale of the degree of protection of groundwater (Indicated by 4 colors)	A five-level scale of levels of anthropogenic disturbance of components of the natural environment (a legend for constructing a new map - Figure 3.11)	Combination of colors of the degree of protection (4 colors) and Types of hatching - 3 types (In a box, horizontal lines, inclined lines)
Little or no (shading in the box)	Protected	undisturbed	Hatching in a box
	Conditionally protected	(Does not mean / absence)	Hatching in a box
	Poorly protected	Slightly disturbed (Weak)	Hatching in a box
	unprotected		Hatching in a box
Moderate (shading horizontal lines)	Protected	Moderately disturbed (Moderate)	There is no such zone on the map
	Conditionally protected		Hatching with horizontal lines
	Poorly protected		Hatching with horizontal lines
	unprotected		Hatching with horizontal lines
Strong (shading	Protected	Strongly Disturbed	There is no such zone on the map
	Conditionally		Hatching with

horizontal lines)	protected	(Significant)	inclined lines
	Poorly protected	Very strongly disturbed (Strong)	Hatching with inclined lines
	unprotected		Hatching with inclined lines

Thus, **Table 3.7** essentially provides a description (algorithm) detailing the conversion of a three-level scale for assessing groundwater disturbance ("finished" integrated environmental assessment of human impact on groundwater) to a standard five-level scale for anthropogenic disturbance of environmental components. This is achieved through additional zoning of groundwater security on the map, with the appropriate combination of color contours and shaded areas. As a result, a map with a three-level assessment of anthropogenic disturbance to groundwater is transformed into the classical five-level evaluation format (Fig.3.8).

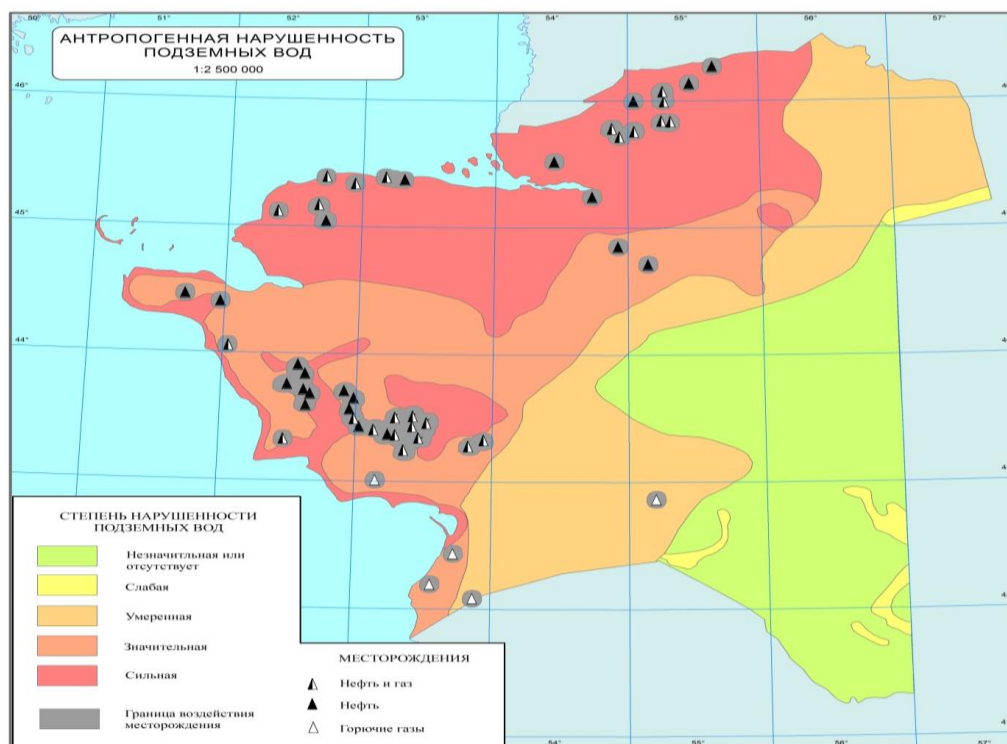


Figure 3.8 - Map of anthropogenic disturbance of groundwater, converted to a five-level evaluation.

The schematic of the circuit area can be created by analogy with the schemes for estimating anthropogenic disturbance of relief, soils, and vegetation. This procedure is implemented in ArcGIS to generate vector shapefiles.

Thus, the first part of the method for solving the inverse problem in integrated environmental assessment using GIS technologies and objective function models, based on the maps from the Atlas of Mangystau region with pre-integrated environmental assessments, has been completed. At the same time, a specific method for obtaining evidence in the traditional manner, using a five-level scale, has been developed. This method is applicable to polygons in the region as a whole as well as for areas with the oil and gas complex.

The second method involves mapping areas at different levels of human exposure to a specific component of the natural environment (in this case, groundwater) throughout the Mangystau region of Kazakhstan, as well as for areas with the oil and gas complex. The objective function remains unchanged and is described in the previous section. By analogy with the previous subsection, we replace the term "vegetation" (veg) with "groundwater" (GW) in equations (3.7) - (3.9).

As a result, we obtain equations (3.10) - (3.12):

$$POF_{GWReg} = f_{1GWReg} + 3f_{2GWReg} + 5f_{3GWReg} + 7f_{4GWReg} + 9f_{5GWReg} \quad (3.10)$$

$$POF_{GWOGE} = f_{1GWOGE} + 3f_{2GWOGE} + 5f_{3GWOGE} + 7f_{4GWOGE} + 9f_{5GWOGE}, \quad (3.11)$$

$$PSIP_{GW} = POF_{GWOGE} - POF_{GWReg} \quad (3.12)$$

where f_{iGWReg} – the function representing a certain level of anthropogenic disturbance of groundwater status for the entire region. It is calculated by dividing the total area of polygons with a specific level of anthropogenic transformation of groundwater status by the total area of the region.

In this case, f_{iGWReg} represents the proportion of the region affected by a particular level of anthropogenic groundwater disturbance, effectively indicating the contribution of these areas to the overall assessment of groundwater disturbance.

$f_{iGWOGEC}$ the function representing a certain level of anthropogenic disturbance of groundwater status in areas with oil and gas extraction. It is calculated by dividing the total area of polygons with a specific level of anthropogenic transformation of groundwater in oil and gas extraction zones by the total area of all oil and gas extraction zones.

The impact of the oil and gas complex on groundwater status in the Mangystau region is determined by subtracting the value of POF_{GWOGEC} from POF_{GWReg} . The resulting value, expressed on a ten-point scale, represents the outcome of the inverse problem solution and quantifies the additional contribution of the oil and gas sector to anthropogenic groundwater disturbance across all levels of human transformation.

For better clarity, this value can be converted into percentages.

Thus, the result of the inverse problem solution represents an additional contribution of the oil and gas extraction complex to the anthropogenic transformation of groundwater status, as POF_{GWReg} . already reflects the net effect of the primary factors in accordance with the legend of the estimated map.

Thus, the weighted average evaluation of anthropogenic disturbance of groundwater in the Mangystau region with the oil and gas extraction complex was 5.51 points on the scale, which is 2.46 points higher than the average estimation of anthropogenic disturbance of groundwater in the Mangystau region as a whole. The oil

and gas extraction complex creates an additional burden on the state of groundwater, exceeding the average for all anthropogenic sources by 24.55%.

The resulting value indicates that the impact of the oil and gas extraction complex on the state of groundwater extends beyond its specific areas and surpasses the effects of all other components of the natural environment. This situation underscores the need for changes in the methods of organizing production environmental control, as current results usually do not show exceedances of environmental standards.

3.5 Integral Generalized Assessment of the Role of the Oil and Gas Extraction Complex in the Environmental Stress of the Mangystau Region

The Policy Section 2: Integrated Grounded View of Objective Functions for Integrated Environmental Assessment

This section presents a comprehensive analysis of the objective functions employed in the integrated environmental assessment, grounded in the evaluation of anthropogenic impacts on the key components of the natural environment both across the region as a whole and in areas specifically influenced by oil and gas activities. To substantiate the assigned weights of individual trust functions, a literature review was conducted to explore the interconnections among environmental components. Given the interconnected nature of geoecosystem elements—where each component affects and is affected by others—the methodology draws upon previous geo-ecological assessments of these interactions [68–72, 78, 81–82, 96]. These studies highlight the regulatory functions of vegetation, soil, and topography, though the underlying mechanisms vary considerably. In arid environments, water holds particular significance; however, due to the absence of surface watercourses, groundwater becomes a vital ecological resource. In this context, groundwater is typically saline and located at depths where evaporation is only feasible in loose substrates deeper than 3 meters. Consequently, only deep-rooted plants—mainly halophytes—are capable of utilizing this water, a fact reflected in the species composition of vegetation samples collected.

Considering these estimates, the equation for calculating the integrated environmental assessment (cumulative impact) in Section 2, as well as the corresponding objective functions, is recorded in its final form (subject to load rationing) as equations (3.13) - (3.15), which are a repeat of equations (2.8) - (2.10):

$$IOF_{Reg} = 0,24POF_{RelReg} + 0,24POF_{SoilReg} + 0,28POF_{vegReg} + 0,24POF_{GWReg} \quad (3.13)$$

$$IOF_{OGEC} = 0,24POF_{RelOGEC} + 0,24POF_{SoilOGEC} + 0,28POF_{vegOGEC} + 0,24POF_{GW OGEC} \quad (3.14)$$

$$ISIP = IOF_{OGEC} - IOF_{Reg} \quad (3.15)$$

Once again, it is important to emphasize a key point: while private environmental assessments were obtained in the form of generalized (average) ratings of influence, the current assessment provides a generalized integral estimate. Equations (3.13) - (3.15) are not strict formulas but rather a framework for understanding the overall environmental impact.

The final result of the generalized solution to the inverse problem of integrated environmental assessment (which determines the contribution of the oil and gas complex to the overall environmental situation) in Mangystau region is obtained by subtracting the value of IOF_{OGEC} from IOF_{Reg} The resulting value is then converted into a percentage and represents the additional contribution of the oil and gas extraction complex to the total anthropogenic transformation of all natural components as a whole (see Table 3.9).

Table 3.9 – Results of the calculation of generalized integral objective functions and the generalized integral solution to the inverse problem of integrated environmental assessment for the environmental situation in the Mangystau region.

Type of Functions and Units	The values of the calculated functions
<i>IOF_{Region}</i> – The integrated objective function for the anthropogenic disturbance of the natural environment in the Mangystau region, score.	3,89
<i>IOF_{OGE}</i> – The integrated objective function for the anthropogenic disturbance of the natural environment in the Mangystau region within areas with oil and gas extraction complexes, score.	6,17
<i>ISIP</i> – Generalized solution of the inverse problem (additional contribution of the oil and gas extraction complex to the anthropogenic disturbance of the natural environment in the Mangystau region), score.	2,28
<i>ISIP</i> – Generalized solution of the inverse problem (additional contribution of the oil and gas extraction complex to the anthropogenic disturbance of the natural environment in the Mangystau region), %.	22,77

As shown in Table 3.9, the overall assessment of anthropogenic disturbance to the natural environment across the entire Mangystau region amounted to 3.89 points (equivalent to 38.88%). In comparison, the aggregated score for areas impacted by oil and gas extraction activities reached 6.17 points (or 61.66%). Therefore, the final outcome of the generalized inverse problem solution in the integrated environmental

assessment indicates that the oil and gas extraction complex contributes an additional 22.77% to the total anthropogenic disturbance within the Mangystau region.

This result was obtained using weighted loads on environmental components, which were based on averaged data from literature and expert analysis of intersystem interactions within natural systems across different climatic zones. From this, we selected a set of loads considering the high regulatory role of vegetation.

Since all expert assessments are inherently subjective, we will verify the specificity of the effect in the semi-desert areas of Mangystau region. Additionally, we will account for possible changes in the relationship characteristics in areas of intensive anthropogenic impact. The next subsection will explore experimental calculations of the integral objective functions using different sets of weighting coefficients for environmental components.

To assess the accuracy of the generalized solution to the inverse problem of integrated environmental assessment, experimental testing of all stages of calculation was carried out using various compositions of the original cartographic material.

3.6 Checking the Accuracy and Objectivity of the Generalized Method for Solving the Inverse Problem in Integrated Environmental Assessment of the Territory

To avoid the risk of tailoring integrated solutions by arbitrarily adjusting the weights of environmental components in the objective function and the inverse problem's final solution using the generalized method, we verify outcomes using different sets of weights. Initially, we compare our results (which inherently involve subjectivity) with alternative sets of subjective weightings found in existing literature.

Ideally, to rigorously validate the significance of component interrelations, one would construct a dynamic model based on a weighted graph that incorporates the

delayed response of Mangystau's natural system, represented by four vertices. This is because the system's interconnections are governed by differential equations, reflecting the complexity of environmental dynamics. However, dynamic models remain largely undeveloped due to the challenges in defining transition criteria within these equations [43]. Even graph-based approaches are rarely used, as they demand extensive data on the behavior of every component of the environment.

Given that we approach the inverse problem using an already completed integrated environmental assessment, we acknowledge that comprehensive tasks—like developing a full-scale environmental Atlas of the Mangystau region—are not feasible on a routine basis. Therefore, we rely on subjective selections from existing subjective weight justifications. As discussed in Section 2, expert assessments are kept minimal—either using uniform weightings or a first-approximation method with slight emphasis on vegetation.

Subsequently, we perform calculations under the assumption of equal weighting. Experimental tests with different weight sets proceed without issue, as weights are only applied in the final step—when computing generalized integral objective functions using equations (3.16)–(3.17), which replicate (3.13)–(3.14) but incorporate adjusted weights across all environmental components. Equation (3.15) remains unchanged. For easier comparison with inverse problem outcomes, the total weight is normalized to 1, meaning all components are assigned equal weights.

$$0.25IOF_{Reg} = 0,25 POF_{Rel Reg} + 0,25 POF_{Soil Reg} + 0,25 POF_{vegReg} + 0,25 POF_{GWReg} \quad (3.16)$$

$$IOF_{OGEC} = 0,25POF_{RelOGEC} + 0,25POF_{soilOGEC} + 0,25POF_{vegOGEC} + 0,25POF_{GWOGE} \quad (3.17)$$

Values POF_{RelReg} , $POF_{SoilReg}$, POF_{VegReg} , POF_{GWReg} and $POF_{RelOGEC}$, $POF_{SoilOGEC}$, $POF_{vegOGEC}$, POF_{GWOGEC} have already been calculated and do not change when the weight loads are altered. Therefore, these values should be removed from Tables 3.1, 3.5, 3.6, and 3.8. After substituting the numerical values, we obtain the experimental results, which are shown in Table 3.10:

Table 3.10 - Results of the experimental calculation of generalized integral objective functions and the generalized integral solutions to the inverse problem of integrated environmental assessment for a set of equivalent weight loads.

Type of Functions and Units	The values of functions
IOF_{Region} – the integrated of objective functions anthropogenic disturbance the natural environment of Mangystau region, score	3,90
IOF_{OGEC} – the integrated objective function anthropogenic disturbance of the natural environment of Mangystau region in areas with oil gas of extraction complex score	6,17
ISIP – generalized integral solution of the inverse problem, the score	2,27
ISIP – generalized integral solution of the inverse problem, %	22,69

A comparison between the results in Tables 3.9 and 3.10 reveals that the generalized integral values derived from the inverse problem using equivalent weight loads differ by just 0.01 points, or 0.08%. The same minimal difference of 0.01 points is observed in the values of the integral objective functions, and it appears only when

evaluating the entire region; for the areas associated with oil and gas extraction complexes, the solutions are identical.

To further support the objectification of the selected weight sets, an additional experiment was carried out. In this case, the justification for the weights is not based on references from literature but instead on the calculated normalized values of partial objective functions. These functions represent the average anthropogenic impact on each individual component of the natural environment.

Since the partial objective functions for the overall transformation of the j -th component of the natural environment (CNE_j) differ between the entire region ($POFCNE_jReg$) and areas with the oil and gas extraction complex ($POFCNE_jOGEC$), normalization of the loads will be performed separately by determining the proportion of each private objective function relative to the sum of all the component values, both for the entire region and for the oil and gas extraction complex. The results of these calculations are presented in Table 11.3.

Table 3.11 - The results of calculations of normalized loads on components of the natural environment for the private values objective functions

The component of the natural environment	The values of partial objective functions		The values of weight loads	
	$POF_{CNE_j}^{Reg}$	$POF_{CNE_jO}^{GEC}$	POF_{CNE}^{jReg}	$POF_C^{NE_jOGEC}$
Relief	4,0388	5,712	0,2591	0,2327
Soil	2,3696	4,022	0,1520	0,1638
Vegetation	3,67	6,8493	0,2355	0,2790
Ground water	5,508	7,9645	0,3534	0,3244

The total Value	15,5864	24,5478		
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In this case, the equation used to calculate the integrated functions will be as follows

$$IOF_{Reg} = 0,2591POF_{rel\ reg} + 0,152POF_{soilReg} + 0,2255POF_{veg\ Reg} + 0,3534POF_{GW\ Reg} \quad (3.16)$$

$$IOF_{OGEC} = 0,2327POF_{RelOGEC} + 0,1638POF_{soilOGEC} + 0,279POF_{VegOGEC} + 0,3244POF_{GWOGE} \quad (3.17)$$

Accounting for the specific characteristics of the territories in terms of human impact intensity resulted in only a small increase (about 4%) in the value of the integral objective function. This had almost no effect on the generalized solution of the inverse problem for the entire region, with a reduction of less than 0.5%.

Thus, the generalized approach proposed for solving the inverse problem in the integrated environmental assessment of the region proves to be largely robust against variations in the weighting of environmental components. This stability is primarily due to the compensatory effect of subtracting the integral objective function for the entire region from that of the zones associated with oil and gas extraction.

3.6.2 Checking the accuracy of the generalized method for solving the inverse problem of integrated environmental assessment using cartographic material of different compositions

The preceding sections have outlined the outcomes of both partial and comprehensive solutions to the inverse problem of integrated environmental assessment for the Mangystau region, utilizing a generalized methodological approach. This approach is based on cartographic data derived from the *Atlas of Mangystau Region*,

which provides integrated environmental evaluations of four key components: relief, soil, vegetation, and groundwater. The specific maps used include "Anthropogenic Impact on Relief," "Anthropogenic Transformation of Vegetation," "Soil Degradation," "Anthropogenic Disturbance of Groundwater," and "Natural Protection of Groundwater." These were developed by the Institute of Geography under the Ministry of Education and Science of the Republic of Kazakhstan, based on expert field assessments and remote sensing data interpretation.

To reflect the influence of the oil and gas sector on each environmental component, the inventory map titled "Anthropogenic Sources of Exposure" from the Atlas is also employed. The information and legend from this map are instrumental in substantiating the credibility of the evaluation map used in solving the inverse problem.

To facilitate the verification of the generalized method's accuracy, an experimental calculation of the integral solution is carried out using a simplified set of source maps. For this purpose, we retain the maps "Anthropogenic Impact on Relief," "Anthropogenic Disturbance of Groundwater," and "Natural Protection of Groundwater," which already incorporate synthesized private assessments (see Tables 3.1, 3.8, and 3.9). In place of the "Anthropogenic Transformation of Vegetation" and "Soil Degradation" maps, we substitute cartographic data representing the oil and gas industry's impact on surface layers. Since no dedicated map exists in the Atlas for this purpose, we instead use five-level contour data from the map titled "Ecological State of Soil and Vegetation Layer" along with industry-specific symbols from the map "Impact of the Oil and Gas Industry on the Natural and Economic System." [34]

(Fig.3.9).

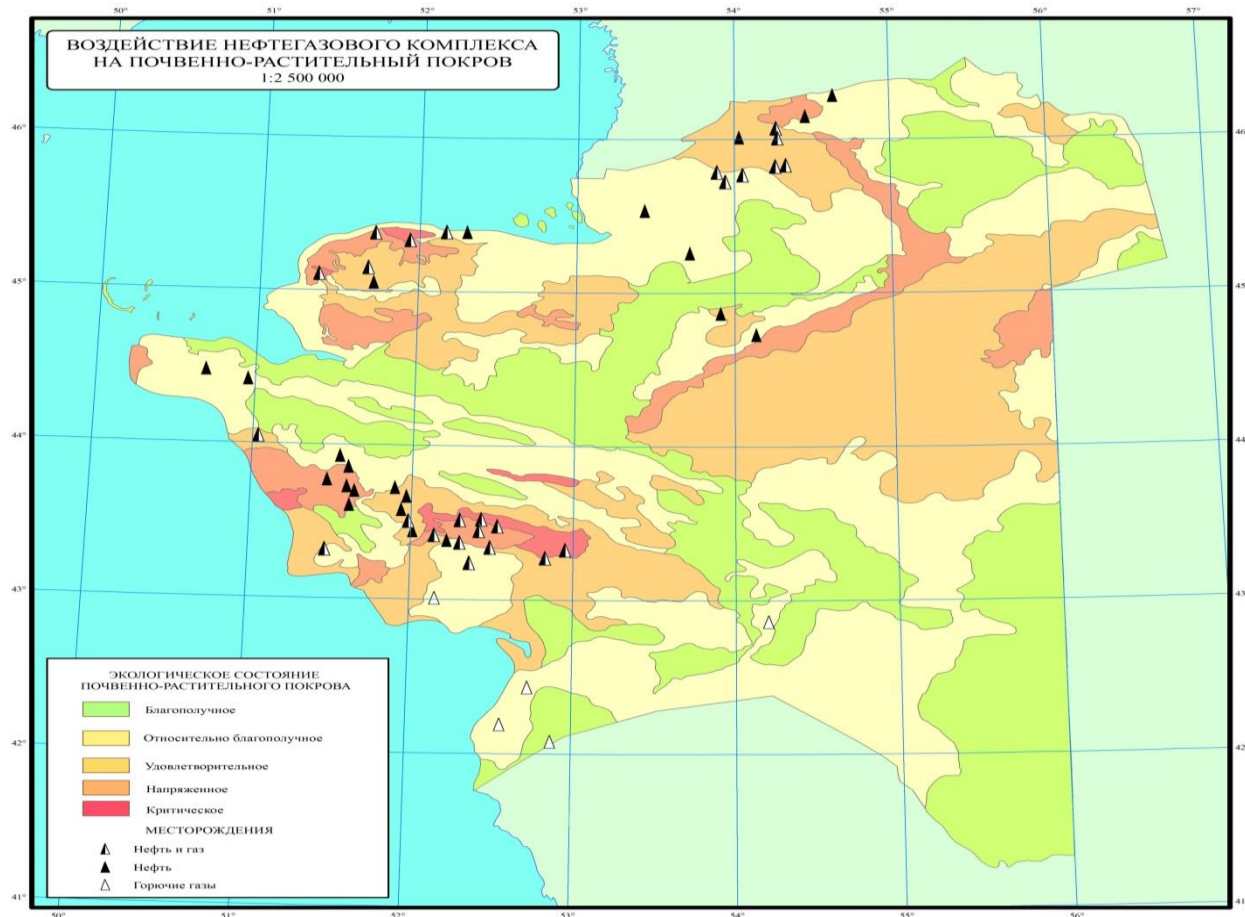


Figure 3.9 - Map of the Impact of the Oil and Gas Extraction Complex on Soil-Vegetation Cover

The selection of the map for experimental calculations is based on the common information framework used by the Institute of Geography for constructing expert appraisal maps. This framework already considers the impact factors that were tested in the previous sections.

The methods for obtaining initial data for the generalized method remain unchanged. Therefore, the results of determining the contours for areas with the same ecological state of the soil and vegetation layer—both for the entire region and for areas with the oil and gas extraction complex—are presented in the general table 11 (first and fourth rows). As before, reference is made to the inverse problem method for private

solutions and integrated environmental assessment, as outlined in Section 2.2, with specific examples for relief, soils, vegetation, and groundwater provided in Sections 3.1–3.4. Integral estimates are given in Section 3.5.

Consequently, we will again use the calculated values and equations for the soil and vegetation layer, replacing the environmental component labels as needed. The calculations will follow equations (3.18) - (3.20).

$$POF_{SVLReg} = f_1_{SVLReg} + 3f_2_{SVLReg} + 5f_3_{SVLReg} + 7f_4_{SVLReg} + 9f_5_{SVLReg} \quad (3.18)$$

$$POF_{SVLOGEC} = f_1_{SVLOGEC} + 3f_2_{SVLOGEC} + 5f_3_{SVLOGEC} + 7f_4_{SVLOGEC} + 9f_5_{SVLOGEC}, \quad (3.19)$$

$$PSIP_{SVL} = POF_{SVLOGEC} - POF_{SVLReg}, \quad (3.20)$$

where $f_{iSVLReg}$ – Function representing the i-th level of anthropogenic disturbance of the soil and vegetation layer across the entire region. It is calculated by dividing the total area of polygons with the i-th level of anthropogenic transformation of the soil and vegetation layer by the total area of the region.

In this case, $f_{iSVLReg}$ represents the fraction of the area with the i-th level of anthropogenic disturbance of the soil and vegetation layer relative to the entire area of the region. This indicates the actual contribution of the zone to the overall assessment of the anthropogenic disturbance of the soil and vegetation layer for the region.

$f_{iSVLOGEC}$ – Function representing the i-th level of anthropogenic disturbance of the soil and vegetation layer in the oil and gas extraction zones. It is calculated by dividing the total area of polygons with the i-th level of anthropogenic transformation of the soil and vegetation layer within the oil and gas extraction complex by the total area of all the zones of the oil and gas extraction complex.

PSIPSVL – Function representing the i-th level of anthropogenic disturbance of the soil and vegetation layer within the oil and gas extraction zones. It is calculated by dividing the total area of polygons with the i-th level of anthropogenic transformation of the soil and vegetation layer in these zones by the total area of all the zones of the oil and gas extraction complex.

Table 3.13 – Calculation of the average contribution of the oil and gas extraction complex to the anthropogenic disturbance of the soil and vegetation layer in the Mangystau region

Type of functions and unit	The degree of anthropogenic transformation					Total
	Little or no	Weakly	Moderate	Heavily disturbed	Very heavily disturbed	
for soil and vegetation layer						
The total area of the contours of i-th level of anthropogenic disturbance of, km2	4564 1,44	670 68,46	41 649,56	9 997,87	16 32,16	165 989,49
$f_{SVLRegi}$ – the ratio of the amount of contours of areas of i-level of transformation to the area of the	0,275 4	0,40 4	0, 251	0, 060	0, 010	

region, dimensionless						
POF_{SVLReg} – private objective function for soil and vegetation layer by territory of the region, scores						3,2 52
The total area of the contour outlines the i-th level of transformation within the zones with oil gas of extraction complex km2	6	192,1 2,98	128	23 22,62	1 638,46	15 72,14 700 8,35
$F_{SVLOGEC\ i}$ – the ratio of area circuits i-th level of transformation within the zones with oil gas mining complex in the area of all zones with oil gas of extraction complex, dimensionless		0,027 3	0,18	0, 331	0, 234	0, 224
$POF_{SVLOGEC}$ - private objective functions for soil vegetation layer by zones of oil gas extraction complex, score						5,8 9
$PSIP_{SVL}$ – decision private the inverse problem (optional						2,6

contribution of oil gas of extraction complex in the anthropogenic disturbance of soil and vegetation layer in the Mangystau region), score	4
$PSIP_{SVL}$ — private the inverse problem solution (additional contribution oil gas of extraction complex in the anthropogenic disturbance of soil and vegetation layer in the Mangystau region),%	26, 37

According to the results, it is difficult to assess the accuracy of the solution because it should be compared with the separate estimates for the soil and vegetation. These estimates are shown in Tables 3.5 and 3.6, from which it can be concluded that the result of the separate solutions to the inverse problem for soil $PSIP_{soil}$ is 1.65 points, while for vegetation it is 3.18 points. Thus, the combined result of 2.64 points lies within the range of individual assessments for soil and vegetation, making sense in the context of the resulting estimates.

We now verify the integrated solution results for sets of four and three evaluation maps. To do this, we use an analogy with subsection 3.5 and justify the inclusion of equations for the integral impact on all components of the natural environment evaluations. Initially, the four main components are represented by a set of three components — relief and groundwater remain the same, but instead of soil and vegetation, we now use their combined characteristic, the soil-vegetation layer.

In this case, the equations for the integrated impact assessments for the entire region and zones with oil and gas mining complexes are no longer based on four terms, but on three. Therefore, the distribution of loads in the integral objective functions must be substantiated once more.

As discussed earlier in Section 2, we once again draw upon the literature to support our analysis. Following the concept of stronger internal linkages within natural systems, we represent the system as a graph, where each component is a vertex—four vertices for four components, and three vertices forming a triangle for a three-

component model. In this framework, relationships can be represented along both the sides and diagonals of the geometric figure.

Diagonal links may differ in significance from side connections, often being longer and potentially representing weaker or more indirect interactions. In the case of a triangle, where only side connections exist, it becomes challenging to determine which of the three component interactions is dominant. For simplification, we initially assume that all connections are equally weighted. Thus, if the total environmental load is distributed as two loads of 0.33 and one of 0.34, we attribute the slightly higher value of 0.34 to the soil–vegetation layer, maintaining consistency with the earlier choice of vegetation as the dominant component in the four-component model.

The equations can be written in the form of (analogous to equations (3.13) - (3.15) in subsection 3.5) for the integral objective functions and the generalized solution of the inverse problem:

$$IOF_{Region}=0,33POF_{RelReg} + 0,34POF_{SVLReg} + 0,33POF_{GWReg} \quad (3.21)$$

$$IOF_{OGEC}= 0,33POF_{relOGEC} + POF_{SVLOGEC} + 0,33 POF_{GWOGEC} \quad (3.22)$$

$$ISIP= IOF_{OGEC} - IOF_{Reg} \quad (3.23)$$

The results of the solutions to these equations are provided in Table 3.14. As seen in the table, the results of the generalized solutions to the integrated inverse problems (ISIP), along with the additional contribution of the oil and gas extraction complex (OGEC) to anthropogenic changes in the environmental situation in the Mangistau region, are based on three original maps. These contributions amounted to 22.59%, compared to 24.28% when assessed using four maps. Thus, the difference in estimates is 1.69%, which is considered an acceptable error.

Table 3.14 – Results of calculations of the integral objective functions for the three components of the natural environment, assessing the contribution of the oil and gas extraction complex to the formation of the ecological situation in the Mangystau region

Types of Functions and Units	Function value
POF_{relReg} – private objective function for the relief of the territory of the region, scores	4,039
$POF_{relOGEC}$ – private objective function for the relief by the zones with the oil gas extraction complex, score	5,712
$POF_{SVL Reg}$ – private objective functions for soil and vegetation layer by territory of the region, scores	3,252
$POF_{SVLOGEC}$ – private objective functions for soil vegetation layer by zones with oil gas of extraction complex, score	5,89
POF_{GWReg} – private objective function for groundwater on the territory of the region, scores	5,508
$POF_{GW OGEC}$ – private objective function for groundwater in zones with oil gas of extraction complex, score	7,964
results the inverse problem solution integrated environmental assessment for all components the natural environment	
$IOF_{Reg.}$ – the integrated objective function anthropogenic disturbance of the natural environment of Mangystau region, the score	4,26
IOF_{OGEC} – the integrated objective function anthropogenic disturbance of the natural environment of Mangystau region in areas	6,52

with oil gas producing complex scores	
<i>ISIP</i> – generalized solution the inverse problem (additional contribution oil gas of extraction complex in the anthropogenic disturbance the natural environment of Mangistau region), score	2,26
<i>ISIP</i> – generalized the inverse problem solution (an additional contribution of oil gas of extraction complex in the anthropogenic disturbance the natural environment of Mangystau region),%	22,59

Good matches can be obtained by using maps from a single source, created with uniform methods and a large, consistent database. This approach allows for the integration of a vast amount of diverse information, covering many effects on each factor in expert-based generalizations of the source-estimated map.

As a result, ensuring the accuracy of the solution to the inverse problem depends on the precision and objectivity of the integrated environmental assessment.

Complex environmental evaluation is based on the "ready" maps, which serve as the foundation for the initial data and the "ready" solutions to the direct problem.

Conclusions of the Section

Anthropogenic pressure on fragile ecosystems leads to varying degrees of environmental transformation, depending on the scale and duration of economic activity. This chapter introduces new theoretical advancements in integrated environmental assessment. By addressing the inverse problem, new models have been developed to enhance the practical implementation of environmental management, particularly through the “polluter pays” principle. These models enable quantification of the additional environmental burden caused by oil and gas extraction, both on individual ecosystem components and the overall ecological state of the region.

The analysis draws upon data from the *Atlas of the Mangystau Region*, which includes maps reflecting anthropogenic disturbance. These maps were developed using traditional expert evaluation methods, supported by a combination of conventional and modern cartographic tools. The weighted average disturbance to the region's relief caused by oil and gas activities was calculated at 5.75 points—1.83 points higher than the regional norm—representing a 6.14% contribution from the sector. Soil degradation associated with oil and gas operations averaged 4.02 points, which is 1.93 points (or 19.31%) above the regional baseline of 5.22 points. This translates to a 40.21% share of total soil degradation. The average vegetation disturbance across the region was 3.55 points. Field studies conducted by the project team in 2015 confirmed severe vegetation degradation near oil wells at the Zhetybai field, where native species were almost entirely replaced by disturbance-tolerant weeds.

Groundwater showed an average disturbance level of 6.72 points in oil and gas zones, exceeding the regional average of 6.14 points. This reflects ongoing high levels of anthropogenic pressure on groundwater resources and highlights the need for investment in water infrastructure upgrades.

The integrated environmental disturbance score for the Mangystau region as a whole was 3.77 points (or 37.67%). In contrast, within areas impacted by oil and gas development, this value rose to 5.39 points, indicating that oil and gas activities account for 53.87% of overall environmental degradation. The additional burden specifically attributed to the oil and gas sector was determined to be 16.19%.

To test the reliability of the methodology, two versions of the inverse problem were explored. One variation involved adjusting environmental weightings and input maps. For example, increasing the weight assigned to vegetation led to a marginal difference of only 0.01 points (0.08%) in the integrated score compared to the equal-weight model, with identical outcomes observed in oil and gas-affected zones. This supports the internal consistency of the model. The results also demonstrated that soils

and vegetation are more vulnerable in oil and gas zones, whereas relief and groundwater showed relatively less impact.

Further testing involved altering the set of cartographic inputs. In one scenario, the four-component model (vegetation, soil, relief, groundwater) was simplified by replacing vegetation and soil maps with a composite map reflecting the oil and gas industry's impact on the soil-plant system. This map was derived from contour data on the ecological condition of soil and vegetation, and included information from the "Map of Oil and Gas Industry Impact on the Natural and Economic System" [34] (Figure 3.9). Using this simplified three-map model, the calculated impact of the oil and gas sector was 22.59%, compared to 24.28% from the four-map model. The 1.69% difference lies within acceptable error margins.

The consistent results across different configurations confirm that accurate and dependable assessments can be achieved when maps are developed under a unified methodological framework and supported by coherent, high-quality data.

This approach facilitates the integration of diverse information sources, capturing a wide range of environmental effects through expert generalization of initial assessment data. Ultimately, the reliability of the inverse problem solution hinges on the objectivity and precision of the "direct" problem—that is, the quality of the initial environmental assessments derived from the selected maps. Moreover, the interconnectedness of natural environment components is inherently reflected in each evaluative map, as these maps synthesize all expert data available. Each map represents a consolidated expert interpretation of factual environmental information gathered through monitoring networks, research expeditions, and remote sensing. They also account for inventory maps that describe various factors influencing environmental components, including their interactions with both natural and economic systems.

In summary, regardless of which evaluation map is selected, all maps from the established set maintain a high level of accuracy and objectivity, ensuring reliable outcomes in solving the inverse problem of integrated environmental assessment

4. EVALUATION OF THE CONTRIBUTION OF THE OIL AND GAS EXTRACTION COMPLEX TO THE ECOLOGICAL SITUATION IN THE MANGYSTAU REGION THROUGH A DIFFERENTIATED TERRITORIAL APPROACH, USING AN INVERSE PROBLEM SOLUTION FOR INTEGRATED ENVIRONMENTAL ASSESSMENT.

This section presents the results of the inverse problem solution for an integrated environmental assessment of the Mangystau region. The assessment is conducted through a differentiated territorial evaluation using a ready-made map with expert-based environmental assessments of anthropogenic transformations in natural environment components. These components include relief, soil-vegetation layers, and groundwater.

In the previous section, the research demonstrated a strong correlation between the generalized solution of the inverse problem and the anthropogenic disturbance maps of soil and vegetation. This allowed for the replacement of multiple maps with a single comprehensive map—depicting anthropogenic impacts on the soil-vegetation layer.

A key conclusion from the previous section is that the accuracy and objectivity of the inverse problem solution in an integrated environmental assessment depend heavily on the reliability of the "ready-made" direct problem evaluation maps. These maps were used as the foundational dataset for our analysis.

This conclusion is supported by the use of unified methodologies for constructing different evaluative maps, incorporating a shared evidence base, such as inventory maps of anthropogenic impact sources. Additionally, a single framework was employed for recording ecological conditions across the territory, integrating data from monitoring networks, remote sensing interpretation, and field research results. This approach significantly reduces the extensive effort required to translate initial cartographic materials into quantitative data for each grid block in the Mangystau region.

For each of the three evaluative maps—reflecting human impact on the relief, soil-plant layer, and groundwater—a separate problem was addressed by constructing differentiated partial objective functions. These functions were used to determine specific contributions of the oil and gas extraction complex to the anthropogenic transformation of natural environment components.

The obtained results were then used to build integrated functions for differentiated targets, allowing for a comprehensive assessment of the oil and gas extraction complex's contribution to the overall environmental situation in blocks where such activities are present. This approach ensures the enforcement of the 'polluter pays' principle across the entire industry in the region.

The method for obtaining quantitative data to support the differentiated assessment is based on a unified grid model applicable to all maps. Details of this methodology are provided in the methods section of the research, while an example of its specific application is presented in the first part of this section.

4.1 Construction of the Initial Data Matrix Based on the Grid Model for the Mangystau Region

As noted in the methods section of this dissertation research, the second method for solving the inverse problem in complex environmental evaluation—used to obtain a differentiated territorial assessment—is also based on ready-made maps containing expert private environmental assessments of anthropogenic transformations of natural environment components. This method is implemented through three approaches.

The first approach is designed to obtain differentiated data in a format adapted for use in the differentiated assessment method. It involves using a grid model of the territory to convert dispersed (map-based) information into point-based (quantitative, numerical) data. As a result of this conversion, cartographic information is transformed into a quantitative data matrix. In this matrix, the columns represent the areas classified under each of the five levels of human impact on different components of the natural

environment across the Mangystau region—both as a whole and specifically within areas where the oil and gas extraction complex is present.

The key difference in this approach is that the total area within the boundaries of each block in the grid model is now considered. The entire region is divided into a system of 91 square blocks. Previously, the sum of the areas of polygons at each level of human impact on each environmental component was represented by five values for the entire region and five values for areas with oil and gas extraction activities. Now, this results in a dataset consisting of ten columns.

This matrix can be processed using any software package that supports multi-dimensional mathematical modeling. It also facilitates computational procedures for calculating both private and integral objective functions, enabling the implementation of the inverse problem solution algorithm for each block.

Additionally, in Section 3, we evaluate the accuracy of the generalized inverse problem solution by testing different sets of weight loads and varying numbers of evaluative maps. The accuracy of differentiated solutions will be verified by comparing the results of generalized solutions against total values for each area or weighted averages for each column, where the equations for private or integrated function calculations are applied.

The step-by-step algorithm for building a grid model to convert areal information into point data involves a combination of work with two GIS systems—QGIS Desktop and ArcGIS. This algorithm was developed by the project grant recipient, Iztayeva A.M., who graduated with a master's degree in geoecology in 2016. Figure 4.1 illustrates the visual results of Step 5 of this algorithm

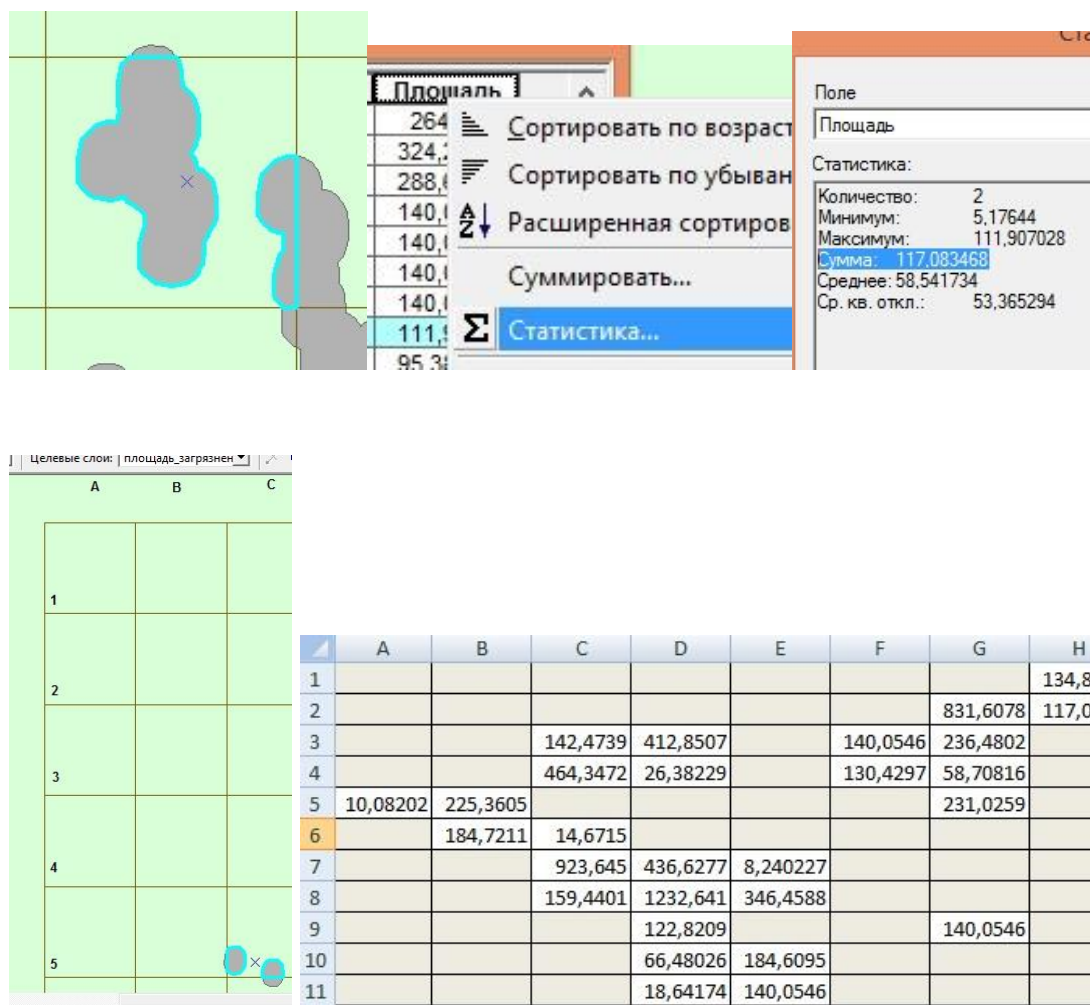


Figure 4.1 – The final result of Step 5 of the algorithm, showing one area's levels of anthropogenic disturbance in the natural environment, represented in units of the grid model

As shown in the subsection '*Partial Automation of Building a Grid Model Using ArcGIS*', the algorithm involves a significant number of operations, even for a single parameter map. However, the use of a regular grid enables more precise overlay alignment across all maps and ensures direct integration with ArcGIS software. This provides greater accuracy compared to the manual method for determining the area of contours within each block of the grid model.

Figure 4.2 displays the grid model map of human impact on the relief. As seen in the figure, the adopted grid model uses an alphanumeric block numbering system—horizontal columns are labeled alphabetically, while vertical columns are numbered.

According to the notation accepted in matrix calculus, the matrix element f_{ij} has indices that indicate its position in the i -th row and j -th column of the numerical matrix. In the grid model, this corresponds to a combination of input data that reflects the geographical position of the block center, located at the intersection of the i -th row and j -th column. This positioning links the information to the area of the

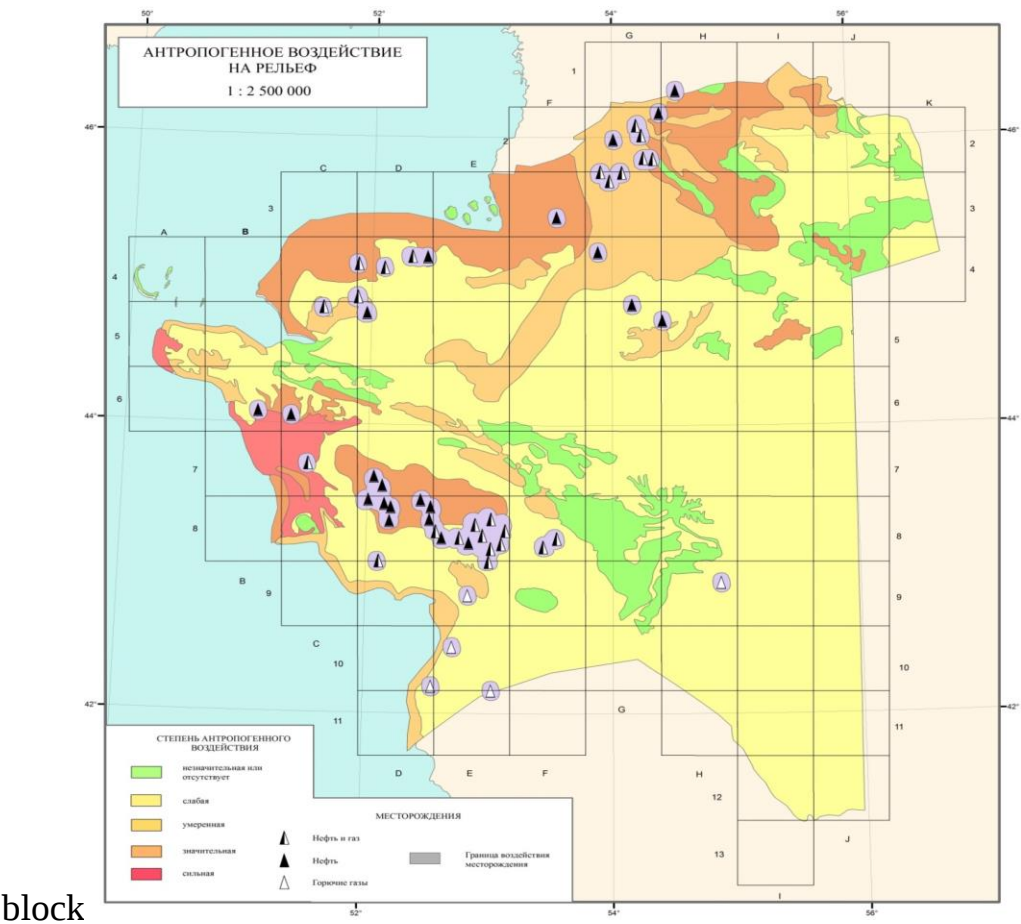


Figure 4.2 – Grid Model of Human Impact on the Relief"

It is important to emphasize that when determining the areas of contour segments for each level of anthropogenic disturbance across all blocks in the grid pattern shown in Figure 4.1, we have only one column of the original data. To obtain the full data matrix for all five disturbance levels, the procedure in the algorithm for constructing the grid

model from areal data needs to be repeated five times for each grid unit across the entire area and five times for each estimated map block within the oil and gas extraction complex. Afterward, the matrix grid pattern, similar to that shown in Figure 4.1, is expanded into columns of the original data, creating a conventional numerical matrix.

The concept behind this operation is illustrated in Figure 4.3. This figure shows a screenshot of the matrix, which integrates the five "matrices" similar to the one in Figure 4.1, applied to the map of human impact on the relief (see. Fig. 4.2).

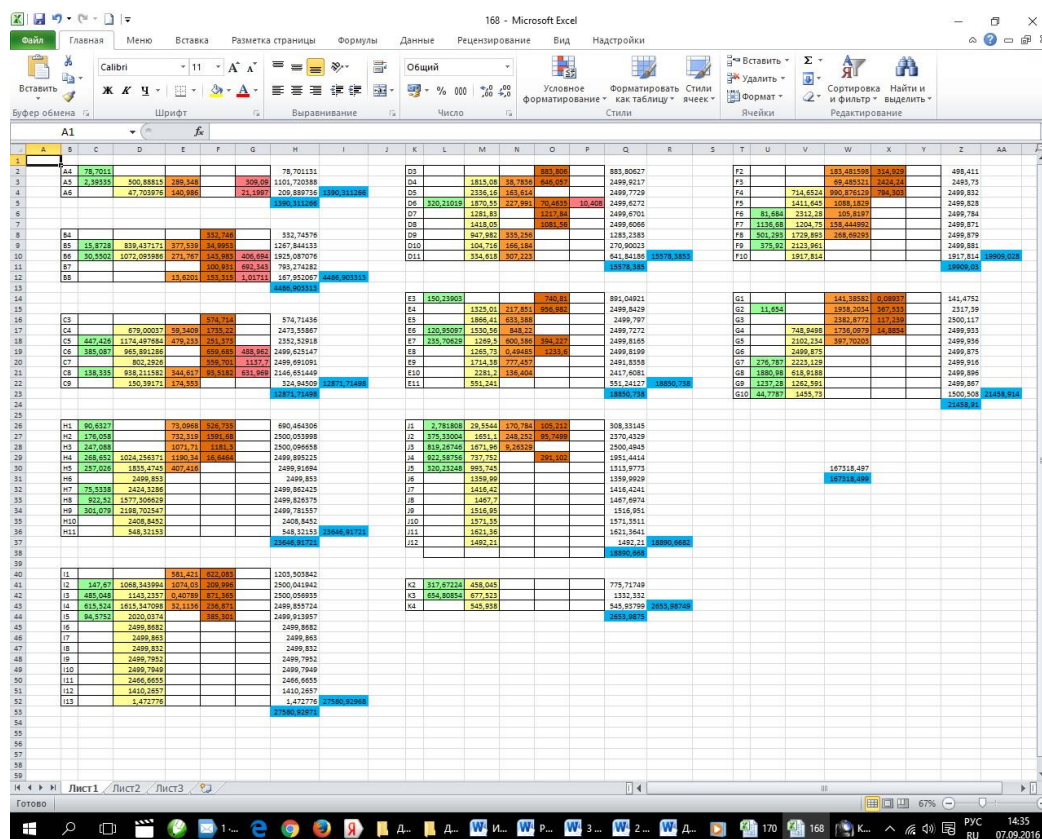


Figure 4.3 – A visual representation of the matrix obtained after combining five matrices, similar to the one presented in Figure 4.1.

These 'pieces' were then deployed into the data matrix for all blocks of the grid model and for the blocks with the presence of the oil and gas extraction complex. The results of this 'reversal' are presented in Tables 4.1 and 4.2, which show the source of the

quantitative data matrix for blocks across the entire area and for those areas affected by oil and gas extraction activities.

These matrices are then used for calculating the private and integral target functions in the implementation of the second and third methods for differentiated territorial evaluation of the impact of the oil and gas extraction complex on the anthropogenic modification of the relief, soil and vegetation layer, and groundwater. This leads to integrated, differentiated estimates of the contribution of the oil and gas extraction complex to the ecological situation in areas where such activities occur in the Mangystau region.

Table 1 (Appendix A) presents the results of determining the contours of areas with different levels of anthropogenic impact on the relief, soil-vegetation layer, and groundwater in the grid blocks throughout the region. Table 2 (Appendix A) shows the same data for the blocks in the grid model where the oil and gas extraction complex is present.

The comparison of the area sums for different levels of human exposure, using the generalized estimates method, was determined by summing the shapefiles for the entire region or for all areas with the presence of the oil and gas extraction complex. In the case of differentiated assessments, the respective columns were summed. This comparison showed that the area calculated in the differentiated assessment was 425 km² larger than in the generalized assessment (approximately 5 km² per block). However, considering the total area of 2,500 km², this difference represents a negligible error—total error for block 91 was only 0.19%.

Thus, while constructing the grid model involved considerable effort, even with partial automation, the result was very satisfactory. Unfortunately, such procedures require not only patience but also a solid understanding of GIS

4.2. Differentiated assessment of the impact of the oil and gas extraction complex on the anthropogenic modification of the relief in the mangystau region

The result of applying the methods for preparing the initial grid data model map of human impact on the relief [75] was the deployment of the initial data matrix, which was then used to calculate partial objective functions reflecting the effect on the relief across all blocks of the grid model, throughout the region, and in blocks containing areas with the oil and gas extraction complex. The calculations were performed using Method 2 from Subsection 2.3.2, *'Methods of Building Territorial Differentiated Private and Integrated Objective Functions.'*

As noted in that subsection, the second and third methods align with Methods 2 and 3 of the generalized assessment method. However, in this case, these constructions were carried out for the area of each grid block. Such differentiation, as an integral measure of human impact on all components of the natural environment, and the solutions to the inverse problem in integrated environmental assessment, allow for the visualization of the role of the oil and gas extraction complex across the region through contouring of the solutions.

Thus, while the equations for the objective function are similar to those in the generalized evaluation method, they are now calculated separately for each block. This provides differentiation of the oil and gas extraction complex's role across the territory. Referring to equations (2.11) and (2.12), which are specific to the components of the natural environment (relief), we obtain equations (4.1) and (4.2) for calculating the partial objective functions within the ij -th block of the grid model: first for relief in equation (4.1), and then for the blocks with oil and gas extraction complex in equation (4.2):

$$POF_{ijrelReg} = f_{1ijrelReg} + 3f_{2ijrelReg} + 5f_{3ijrelReg} + 7f_{4ijrelReg} + 9f_{5ijrelReg}, \quad (4.1)$$

$$POF_{ijrel OGEC} = f_{1ijrel OGEC} + 3f_{2ijrel OGEC} + 5f_{3ijrel OGEC} + 7f_{4ijrel OGEC} +$$

$$+ 9f_{5ij\ rel\ OGEC},$$

Where $f_{kij\ relReg}$ is the function that defines the (K-th) level of anthropogenic disturbance to the relief in the ij -th block of the grid model across the entire area. It is calculated by dividing the total area of polygons for that level of anthropogenic transformation of the relief in the block by the total area of all polygons within the block, which represents the total area of the block. It is important to note that the boundaries of the Mangystau region may only occupy part of the blocks, and the boundaries of the blocks may extend into adjacent areas or regions. When dividing by the total area of the block, significant errors may occur in incomplete blocks. Therefore, for the calculation of the target function, only the part of the block area that is within the Mangystau region is considered.

$f_{kijrel\ OGEC}$ is the function that defines the (K-th) level of anthropogenic disturbance to the relief in the ij -th block of the grid model, but only for blocks containing areas with the oil and gas extraction complex. It is calculated by dividing the total area of polygons for that level of anthropogenic transformation of the relief in the block by the total area of the oil and gas extraction complex in that block.

The role of the oil and gas extraction complex in the transformation of each component of the natural environment in each ij -th block of the grid model in the Mangystau region is determined by subtracting the values of the private objective function $f_{ijrelOGEC} - f_{ij}^{\text{relOGEC}}$, obtained from solving equation (4.2), from the values of $POF_{ijrel\ Reg}$ which are the results of the calculations from equation (4.1) in each block of the grid model

$$(4.2)$$

where $f_{kij\ relReg}$ – function of defined (K-th) level anthropogenic disturbance relief in the ij -th block grid model over the entire area, which is calculated by dividing the total area of the polygons for that level of anthropogenic transformation of the relief in the block on the total area of all polygons, in fact this area of the block. Here we should

pay attention to the fact that the boundaries of the territory of Mangystau region land can occupy only a portion of the blocks, and on the borders of the area of the blocks may occur in the surrounding area or state. When divided by the total area of the block, you can get significant errors in incomplete blocks, so to calculate the target function is calculated only the part of the block area, which is part of the land or part of the territory of Mangystau region.

f_{kijrel} *OGEC* – function of definition (k-th) level of anthropogenic disturbance of the relief in the ij-that block net model in blocks with zones of oil gas production complex, which is calculated by dividing the total area of the polygons for that level of anthropogenic transformation of the relief on the block on the total area of all oil gas of extraction complex in this block.

The role of the oil gas production complex in the transformation ij each component natural environment each ij-how block grid model Mangystau region determined subtracting values of private objective function ij rel oil gas of extraction complex obtained as a result of the settlement of the equation (4.2), $POF_{ijrel Reg}$ values resulting from calculations according to the equation (4.1) in each block net model.

$$PIP_{ijrel} = POF_{ijRel OGEC} - POF_{ijRel Reg} \quad (4.3)$$

Table A3 lists the results of calculations using equations (4.1) to (4.3). Since the blocks with the presence of the oil and gas extraction complex are much fewer than the total number of blocks in the region (24 out of 91), the column values for the private inverse problems related to the relief show many negative values for the private solutions in these blocks. This indicates, even without contour mapping, that intense manifestations of the impact of the oil and gas extraction complex can be identified.

We now estimate the accuracy of the solution to the inverse problem of differentiation. The matrix representation in Table A3 makes it easy to perform this procedure in Excel. To compare with the results from the generalized assessment method, we calculated the average values for the number of blocks. Specifically, the

sum of the values for $POF_{Rel\ Region}$ is divided by 91 (the total number of units in the entire territory), and $POF_{Rel\ OGEC}$ is divided by 24 (the number of units with the oil and gas extraction complex).

We should immediately clarify that in this case, we are not comparing the accuracy of the methods themselves, but rather comparing the private and integrated objective functions. The rationale for the coefficients used remains the same as in the generalized assessment method. Here, we are estimating the accuracy of building the grid model, which is largely determined by the precision with which the grid model is aligned with the coordinates of the evaluation maps, as well as the significant patience required for this meticulous operation.

Table A4 presents a comparison of the averaged data over blocks to provide an indicative estimate of the accuracy of the two methods used to solve the inverse problem of integrated environmental assessment.

As shown in the last column of Table A4, the relative error of the two methods in assessing the contribution of the oil and gas extraction complex to anthropogenic relief transformation does not exceed 3%. In the case of differentiated assessments, satisfactory accuracy was achieved when comparing the results of the generalized and averaged values of the differentiated solutions for the private inverse problem concerning the relief.

Now, we will analyze the benefits of the differentiated assessment method, which requires significantly more time during the step of obtaining quantitative information from cartographic material compared to the generalized evaluation method.

We will also attempt to justify the physical meaning of the results derived from the solution to the inverse problem. According to equation (4.3), a particular solution of the inverse problem, $ijrel_{ijrel}$, represents the difference in the partial objective functions describing the level of anthropogenic impact on the relief in blocks with oil and gas extraction zones, as compared to blocks across the entire area. In the

part of the territory where the oil and gas extraction complex is absent, the value of the private inverse problem related to the relief will be determined by the influence of all factors recorded in the evaluation map, but with a negative sign. This is because the private objective function $f_{5ijrelReg}$ for oil and gas extraction complex units is 0.

Judging by the purpose of equations (4.1) and (4.2), the maximum values for these (equal to 9) will be achieved when the entire unit area or the oil and gas extraction complex zones are represented by a single color corresponding to the maximum exposure level ($k = 5$). The reasoning is as follows: $f_{5ijrelReg}$, which is obtained by dividing the sum of the fifth-level contours in the block (in this case, the entire block), by the total block area, results in 1. Since the weighting factor for the fifth level is equal to 9, multiplying 1 by 9 gives a result of 9. A similar reasoning applies to $f_{5ijrelOGEC}$.

As with the generalized solution, it must be noted that $f_{kijrelOGEC}$ is calculated only within the zones with the presence of the oil and gas extraction complex, not over the entire unit area. Thus, a partial solution of the inverse problem $ijrel=0$ indicates that the impact of the oil and gas extraction complex has been fully accounted for. This is the upper limit of the action, fully in line with the "polluter pays" principle. Consequently, a negative value of a particular solution of the inverse problem, $ijrel$, ranging from 0 to the value of the inverse problem solution $ijrelReg$ with a negative sign, means that there is no additional contribution of the oil and gas extraction complex to the anthropogenic disturbance of the relief. It simply reflects the area covered by the "polluter pays" principle

$$-POF_{ijrelReg} \leq PSIP_{ijrel} < 0 \quad (4.4)$$

The principle is violated only in the case of positive values of $PSIP_{ijrel}$, as these values exceed the recorded impact of all relevant factors, including the oil and gas mining complex. This represents a potential violation of the "polluter pays" principle:

$$PSIP_{ijrel} \geq 0$$

(4.5)

Since the increased values compared to the average values for all the blocks of $POF_{jRELReg}$ occur in the absence of the oil and gas production complex, Table 4.1 highlights a selection of such units alongside all units containing the oil and gas extraction complex to demonstrate the application of inequalities (4.4) and (4.5)

To facilitate interpretation, the highlights in yellow the blocks where oil and gas extraction facilities are absent. This visual cue suggests that significant anthropogenic transformation of the relief in these areas may be attributed to alternative sources of environmental pressure, as identified in the legends of both the inventory and assessment maps. These instances represent cases of “*influence from other exposure sources.*”

For blocks that do contain oil and gas infrastructure, color coding has been applied to reflect the nature of the inequalities described in expression (4.4)—indicating situations where the impact of other environmental stressors surpasses that of the oil and gas sector. According to Table 4.1, only 5 out of 24 such blocks fall into this category. The remaining 19 blocks fall under the scope of inequality (4.5), meaning that the oil and gas sector has a greater-than-average impact in these locations. These are areas where the “polluter pays” principle may not be adequately enforced.

This differentiated evaluation thus provides qualitatively richer insights into the role of oil and gas activities in altering the region’s relief. In the generalized assessment model, an average impact is calculated either for the entire study area or collectively for all zones with oil and gas facilities. The specific solution to the inverse problem offers an average measure of the oil and gas sector's influence within those zones, attributing an additional 16.73% contribution to relief disturbance. However, it is important to

emphasize that this figure applies exclusively to areas where oil and gas extraction infrastructure is present and does not account for adjacent regions.

By contrast, the differentiated evaluation reveals that in 4 out of the 24 blocks, non-oil-and-gas factors have a more significant effect on relief modification than the extraction activities themselves. These localized variations in partial inverse solution values—especially the positive differences—can serve as a basis for implementing differentiated environmental payments based on actual emissions and impacts in each block.

4.3. Estimation of the Influence of the Oil and Gas Extraction Complex on Soil and Vegetation Degradation and Groundwater Using the Differentiated Assessment Method

As a result, the execution sequence described in the previous subsection for operations on the original data for the soil-vegetation layer and groundwater tables (A1 and A2) led to the calculation of the corresponding partial objective functions. The values of these partial objective functions for each block in the grid model are shown in Tables A5 and A6 (for the soil-vegetation layer and groundwater, respectively). Tables A7 and A8 show the averaged block values for different levels of human impact, partial objective functions, and the private solutions to the inverse problem for the soil-vegetation layer (Table A7) and groundwater (Table A8). These tables provide an indicative estimate of the accuracy of the two methods used for solving the inverse problem of integrated environmental assessment.

As in the previous section, when comparing the inverse solutions between the differentiated and generalized assessments, it is important to note that we are not comparing the accuracy of the models themselves, but rather the accuracy of the grid model construction. This is because both methods implement the same approach to comparing private and integral objective functions, with the same study factors as in the generalized estimation method. The accuracy of the grid model construction is primarily

determined by the precision of aligning the grid model with the coordinates of the evaluation maps and by the significant effort required for this detailed work.

As seen from the last column of Table A7, the relative error for the two methods in assessing the contribution of the oil and gas mining complex to the anthropogenic transformation of the soil-vegetation layer is somewhat higher compared to relief. The maximum error, as expected, is observed in POFijSVLOGEC (due to many small loops within one block) and amounts to 4.14%, compared to 2.55% in the relief task. Nevertheless, the differentiated assessments show satisfactory accuracy when comparing the generalized and averaged values of the differentiated solutions for the private inverse problem for the soil-vegetation layer.

A similar estimation of the comparability of the solutions for groundwater (Table A8) shows that the loops of one color are much smaller than in the soil-vegetation layer map, resulting in a lower maximum error of 3.25%. This again confirms that the error in both the generalized and differentiated assessment methods is largely due to the accuracy in converting the original map (dispersed data) into quantitative point data.

This emphasizes cases where a high level of anthropogenic disturbance to the soil-vegetation layer is caused by other sources. These “other sources of impact” are clearly indicated in the legend of the inventory map, which includes both descriptions and icons, making it easy to correlate them with the respective blocks.

In the blocks where the oil and gas extraction complex is present, color coding is used to differentiate the impact based on inequalities (4.4). These represent situations where “the influence of other sources surpasses the impact of the oil and gas complex.” As shown in Table 4.2, only one out of the 24 blocks containing oil and gas operations falls into this category. The remaining 23 blocks correspond to inequality (4.5), indicating that “the oil and gas extraction complex has a greater impact than the block’s average level of disturbance”—suggesting a potential violation of the “polluter pays” principle.

This differentiated assessment method, therefore, provides qualitatively new insights into the role of the oil and gas extraction complex in the anthropogenic alteration of the soil-vegetation layer. Unlike the generalized model, the differentiated approach reveals that only a single block out of 24 experiences stronger impacts from other factors than from oil and gas activities. This indicates that the oil and gas complex exert a greater influence on the soil-vegetation layer than on the terrain. The observed positive difference in the localized solutions of the inverse problem may serve as a basis for implementing differentiated environmental emission charges.

The blocks with oil and gas extraction complexes are highlighted in green to show the scope of inequality (4.4) related to groundwater. This corresponds to cases where "the influence of other sources of exposure exceeds the impact of the oil and gas extraction complex." As shown in Table 4.3, such units for groundwater account for 9 out of the 24 blocks with the presence of oil and gas extraction complexes. The remaining 15 units fall under inequality (4.5), where "the effect of the oil and gas extraction complex in the block exceeds the average," indicating areas where the "polluter pays" principle for groundwater pollution might be violated.

Thus, differentiated evaluation in this case provides new insights into the role of the oil and gas extraction complex in the anthropogenic transformation of groundwater status. In nine of the 24 units, there is no need to increase fees for groundwater pollution. Still, the difference in positive values of particular solutions to the inverse problem may form the basis for establishing differentiated payments for environmental emissions.

4.4. Assessing the Impact of the Oil and Gas Extraction Complex on the Environment as a Whole Using the Differentiated Assessment Method

The calculation of the integral objective function and the solution to the inverse problem for the integrated environmental assessment of the Mangystau region using the differentiated evaluation method was carried out in full accordance with the procedure outlined in Section 2.3.2. However, since we are using a variant that combines maps of anthropogenic degradation and transformation of soils and vegetation into a single map—namely, the anthropogenic impact on the soil and vegetation layer—the number of terms in equations (2.14) and (2.15) is reduced from four to three. In this case, the normalized load on the components of the environment will be 0.33, 0.34, and 0.33, respectively. Thus, we effectively use equations (3.21) - (3.23), assuming these are written for the ij -th block of the grid model. As a result, we obtain the following equations (4.4) - (4.6):

$$IOF_{ijReg} = 0,33POF_{ijRelReg} + 0,34POF_{ijSVLReg} + 0,33POF_{ijGWReg} \quad (4.4)$$

$$IOF_{ijOGEC} = 0,33POF_{ijrel OGEC} + 0,34POF_{ijSVL OGEC} + 0,33POF_{ijGW OGEC} \quad (4.5)$$

$$ISIP_{ij} = IOF_{ijOGEC} - IOF_{ijReg} \quad (4.6)$$

The results of solving these equations, differentiated by blocks of the grid model, over the entire range of objective function values for the private assessment of human impact on the relief, soil-vegetation layer, and groundwater, as well as the corresponding solutions for units with oil and gas extraction complexes, are presented in Table A9. A comparative evaluation, averaged over blocks for integrated objective functions and

integral solutions to the inverse problem, alongside similar functions obtained by the generalized assessment method, is shown in Table A10.

Since the calculations of the integral objective functions are not directly tied to specific area circuits within the blocks, the comparability of results between the generalized and differentiated methods is higher for integral objective functions than for the private objective functions. The maximum relative error was 1.72%, which was observed for IOF_{OGEC} (the integral objective function for anthropogenic disturbance of the natural environment in the Mangystau region in areas with oil and gas extraction complexes).

To provide better visibility of the results of the inverse problem solution for the integrated environmental assessment, Table 4.4 shows a selection from Table A9. This table presents the results of calculating the integral objective functions of human impact on the natural environment of Mangystau region across the entire territory of the blocks with a high level of impact, as well as for all blocks with oil and gas extraction complexes.

Table 4.4 - Differentiated Assessment of the Contribution of the Oil and Gas Extraction Complex to Anthropogenic Disturbances of the Natural Environment

Designation of blocks	IOF_{ijReg}	IOF_{ijOGEC}	$ISIP_{ij}$	Differentiated Evaluation of the Level of Exposure to the Oil and Gas Extraction Complex
A-5	5,438	0,000	-5,438	Influence of Other Sources of Exposure Only
A-6	5,424	0,000	-5,424	Influence of Other Sources of Exposure Only
B-4	6,300	0,000	-6,300	Influence of Other Sources of Exposure

Designation of blocks	IOF_{ijReg}	IOF_{ijOGEC}	$ISIP_{ij}$	Differentiated Evaluation of the Level of Exposure to the Oil and Gas Extraction Complex
				Only
B-5	4,470	5,052	0,583	The Impact of the Oil and Gas Extraction Complex Exceeds the Block Average
B-6	5,011	6,993	1,982	The Impact of the Oil and Gas Extraction Complex Exceeds the Block Average
B-7	7,854	0,000	-7,854	Influence of Other Sources of Exposure Only
B-8	6,930	0,000	-6,930	Influence of Other Sources of Exposure Only
C-3	7,166	7,958	0,792	The Impact of the Oil and Gas Extraction Complex Exceeds the Block Average
C-4	6,602	6,808	0,205	The Impact of the Oil and Gas Extraction Complex Exceeds the Block Average
C-5	5,111	0,000	-5,111	Influence of Other Sources of Exposure Only
C-6	4,616	5,803	1,187	The Impact of the Oil and Gas Extraction Complex Exceeds the Block Average
C-7	6,343	8,112	1,769	The Impact of the Oil and Gas Extraction Complex Exceeds the Block Average
C-8	5,717	6,711	0,994	The Impact of the Oil and Gas Extraction Complex Exceeds the Block Average
C-9	5,625	0,000	-5,625	Influence of Other Sources of Exposure Only

Designation of blocks	IOF_{ijReg}	IOF_{ijOGEC}	$ISIP_{ij}$	Differentiated Evaluation of the Level of Exposure to the Oil and Gas Extraction Complex
D-3	6,320	6,588	0,268	The Impact of the Oil and Gas Extraction Complex Exceeds the Block Average
D-4	5,806	0,000	-5,806	Influence of Other Sources of Exposure Only
D-5	5,104	0,000	-5,104	Influence of Other Sources of Exposure Only
D-7	5,525	6,345	0,820	The Impact of the Oil and Gas Extraction Complex Exceeds the Block Average
D-8	5,523	7,084	1,561	The Impact of the Oil and Gas Extraction Complex Exceeds the Block Average
D-9	4,838	4,674	-0,165	The influence of other sources of impact exceeds the impact of the oil gas extraction complex
D-10	4,725	5,680	0,955	The Impact of the Oil and Gas Extraction Complex Exceeds the Block Average
D-11	4,407	0,000	-4,407	Influence of Other Sources of Exposure Only
E-3	5,163	0,000	-5,163	Influence of Other Sources of Exposure Only
E-4	5,124	0,000	-5,124	Influence of Other Sources of Exposure Only
E-5	5,152	0,000	-5,152	Influence of Other Sources of Exposure Only

Designation of blocks	IOF_{ijReg}	IOF_{ijOGEC}	$ISIP_{ij}$	Differentiated Evaluation of the Level of Exposure to the Oil and Gas Extraction Complex
E-7	5,181	0,000	-5,181	Influence of Other Sources of Exposure Only
E-8	6,227	7,149	0,922	The Impact of the Oil and Gas Extraction Complex Exceeds the Block Average
E-9	4,302	0,000	-4,302	Influence of Other Sources of Exposure Only
E-10	3,733	5,063	1,330	The Impact of the Oil and Gas Extraction Complex Exceeds the Block Average
E-11	3,669	3,798	0,128	The Impact of the Oil and Gas Extraction Complex Exceeds the Block Average
F-2	6,242	0,000	-6,242	Influence of Other Sources of Exposure Only
F-3	6,282	6,980	0,698	The Impact of the Oil and Gas Extraction Complex Exceeds the Block Average
F-4	5,442	5,660	0,218	The Impact of the Oil and Gas Extraction Complex Exceeds the Block Average
F-5	4,587	0,000	-4,587	Influence of Other Sources of Exposure Only
F-6	4,597	0,000	-4,597	Influence of Other Sources of Exposure Only
G-1	6,512	0,000	-6,512	Influence of Other Sources of Exposure Only

Designation of blocks	IOF_{ijReg}	IOF_{ijOGEC}	$ISIP_{ij}$	Differentiated Evaluation of the Level of Exposure to the Oil and Gas Extraction Complex
G-2	6,418	7,765	1,347	The Impact of the Oil and Gas Extraction Complex Exceeds the Block Average
G-3	5,486	6,994	1,507	The Impact of the Oil and Gas Extraction Complex Exceeds the Block Average
G-4	4,814	6,519	1,705	The Impact of the Oil and Gas Extraction Complex Exceeds the Block Average
G-5	5,012	5,566	0,554	The Impact of the Oil and Gas Extraction Complex Exceeds the Block Average
G-9	3,003	5,259	2,256	The Impact of the Oil and Gas Extraction Complex Exceeds the Block Average
G-10	3,294	0,000	-3,294	Influence of Other Sources of Exposure Only
H-1	6,053	6,980	0,927	The Impact of the Oil and Gas Extraction Complex Exceeds the Block Average
H-2	6,271	6,813	0,542	The Impact of the Oil and Gas Extraction Complex Exceeds the Block Average
H-3	6,157	0,000	-6,157	Influence of Other Sources of Exposure Only
H-4	5,016	0,000	-5,016	Influence of Other Sources of Exposure Only
H-5	4,861	0,000	-4,861	Influence of Other Sources of Exposure Only
I-3	4,979	0,000	-4,979	Influence of Other Sources of Exposure

Designation of blocks	IOF_{ijReg}	IOF_{ijOGEC}	$ISIP_{ij}$	Differentiated Evaluation of the Level of Exposure to the Oil and Gas Extraction Complex
				Only
I-4	4,773	0,000	-4,773	Influence of Other Sources of Exposure Only
J-1	4,536	0,000	-4,536	Influence of Other Sources of Exposure Only

As before, in the last column of Table 4.4, yellow blocks are marked to indicate the absence of the oil and gas extraction complex, where the level of human exposure is above average. The blocks with the presence of the oil and gas extraction complex are color-coded to highlight the scope of the inequalities (4.4), representing the case where "the influence of other sources of exposure exceeds the impact of the oil and gas extraction complex." As seen in Table 4.14, only one unit out of 24 blocks with the oil and gas extraction complex falls under this category. The remaining 23 blocks fall within the scope of inequality (4.5), where "the impact of the oil and gas extraction complex on the block exceeds the average," representing an area of potential violations of the "polluter pays" principle.

The range of positive values for the integral solution of the inverse problem, from 0.128 to 2.256, not only reflects the excess impact of the oil and gas extraction complex on the environment in these blocks, but also forms the basis for establishing differentiated fees for emissions into the environment.

The differentiated assessment method requires significantly more time at the stage of obtaining quantitative information from cartographic material compared to the generalized evaluation method, but it offers several clear advantages. In the generalized evaluation model, the particular solution to the inverse problem resulted in an estimate

that exceeded the average assessment of the oil and gas extraction complex's role in human impact on natural environmental components. As a result, all areas with oil and gas extraction complexes were deemed "guilty" of contributing to further environmental impacts.

The differentiated assessment method, however, allows for the identification of areas where the anthropogenic impacts of the oil and gas extraction complex are less than those of other sources. Additionally, analyzing a range of integrated solutions in areas affected by oil and gas extraction could form the basis for the differentiated application of the "polluter pays" principle. The maximum values of the partial objective functions cannot exceed a value of 9, due to their composition (the quotient of the sum of squares of contours of the same color within a block unit area) as well as the values of their respective weighting factors. For example, when the function at the 5th level of anthropogenic disturbance is equal to 1, this, when multiplied by the weighting factor of 9, yields a maximum value of 9.

As with the generalized solutions, it is important to remember that the partial objective function $f_{kijCE\ OGEC}$ is calculated only within the zones of oil and gas extraction activity, rather than over the entire unit area. Therefore, $PSIP_{ijCEnv} = 0$ means that the impact of the oil and gas extraction complex has been fully accounted for and is the upper limit of action in full compliance with the "polluter pays" principle. Consequently, a negative value for $PSIP_{CEnv}$, ranging from 0 to $POF_{ijCEReg}$ with a minus sign, would indicate no additional contribution from the oil and gas extraction complex to the anthropogenic disturbance of a given environmental component, reaffirming the area under the principle of "polluter pays."

Only in the case of positive values for a particular solution to the inverse environmental problem is the principle violated, as these values exceed the recorded impact of all relevant factors, including the oil and gas extraction complex. This situation represents a potential violation of the "polluter pays" principle.

Higher-than-average values for the private solution to the inverse environmental problem occur in areas without an oil and gas extraction complex. In such cases, there may be a high level of anthropogenic transformation of the relief, driven by other sources, as indicated in the legends of the inventory and assessment maps. This scenario exemplifies the "influence of other sources of exposure." Therefore, the differentiated assessment has provided qualitatively new insights into the role of the oil and gas extraction complex in the anthropogenic transformation of the relief.

In contrast to the generalized evaluation model, the differentiated assessment model showed that in four of the 24 blocks, the anthropogenic disturbance of the relief was higher due to other factors than the effects of the oil and gas extraction complex. The impact of the oil and gas extraction complex on the soil-vegetation layer was higher than on the relief in all but one of the 24 blocks. The additional impact of the oil and gas extraction complex on groundwater was less than its impact on the relief—in nine of the 24 units, there was no need to increase fees for groundwater pollution.

The integral solution to the inverse problem (i.e., the additional contribution of the oil and gas extraction complex to the anthropogenic disturbance of the natural environment in the Mangystau region) provides an overall picture of the spatial distribution of the oil and gas production complex's role in shaping the region's ecological situation. The range of positive values for the integral solution to the inverse problem, from 0.128 to 2.256, not only indicates an excess of exposure from the oil and gas extraction complex on the environment in the blocks with the complex but can also serve as the basis for establishing differentiated fees for emissions into the environment.

CONCLUSION

The ecological condition of a region is evaluated through data obtained from various environmental monitoring efforts, targeting different components of the ecosystem. These monitoring tools capture the effects of diverse anthropogenic activities on air, soil, vegetation, relief, surface water, and groundwater by measuring specific indicators. These indicators serve as the foundation for building both comprehensive (multi-component) and component-specific environmental assessments.

Due to the complexity of creating such assessments, there are no universally accepted methods for their implementation. Nevertheless, the “polluter pays” principle necessitates an independent evaluation of the contribution of individual pollution sources to both comprehensive and component-level environmental impacts. This requirement underpins the development of inverse problem-solving approaches in environmental assessment. Within this context, we apply a comprehensive assessment approach based on the methodology of R. Pentl.

A significant contribution of this work lies in developing a method to quantitatively determine the role of the oil and gas extraction complex (OGEC) in the anthropogenic alteration of environmental components in the Mangystau region. This marks a theoretical advancement in integrated environmental assessment. By solving inverse problems, new forms of assessment have been established, allowing for practical applications—such as calculating compensation aligned with the “polluter pays” principle—by quantifying the OGEC’s additional impact on ecosystem components.

This thesis presents the methodology and application of two approaches to solving inverse problems in integrated environmental assessment: one based on generalized objective functions and the other on differentiated evaluations. Both rely on expert maps of private environmental assessments of anthropogenic transformation. These methods were developed under the grant project of the Ministry of Education and Science of the Republic of Kazakhstan, No. 0589/GF-4, titled “*Development of a Method for Expert*

Estimations of the Contribution of Pollution Sources to the Overall Environmental Situation of the Territory.”

The **generalized assessment method** uses data from the *Atlas of the Mangystau Region*, which includes pre-constructed maps of integrated environmental assessments. These maps incorporate the impact of all known sources on key components—relief, soil, vegetation, and groundwater—and are applied through three distinct methods:

Method 1 ensures the objectivity of the objective function by converting raw, spatial map data into quantitative values through GIS tools. This transformation enables the generation of partial objective functions suitable for further analysis.

Method 2 addresses the inverse problem for component-level environmental assessments. It computes the difference between generalized private objective functions that describe the region-wide average anthropogenic impact and the cumulative impact across all zones with OGECS. The degree of impact is interpreted using legend-based justifications provided in the assessment maps.

Method 3 deals with the fully integrated inverse problem. It calculates the difference between region-wide integral objective functions (representing average total anthropogenic pressure) and that of areas affected by OGECS. These calculations take into account interrelationships among environmental components, with a literature review supporting the theoretical model.

To validate the developed methods, results from the inverse problem solutions were cross-checked. In the generalized approach, comparative calculations used varying sets of maps and weight distributions for partial objective functions. For the differentiated approach, average values for each spatial block were compared with corresponding generalized results.

The **differentiated assessment method** also employs expert maps to evaluate anthropogenic transformation, but with a more localized focus. This approach, like the generalized method, uses three core techniques:

Method 1 generates a spatially explicit grid model for quantitative analysis. The region is divided into a matrix of square blocks, with each block containing data on human impact levels across all five categories for each environmental component. This transformation produces a numeric database that enables spatial comparison across the entire Mangystau region and within OGEC zones.

Methods 2 and 3 mirror the structure of their generalized counterparts, using similar objective function equations. However, in this case, they are calculated individually for each spatial block, enabling a detailed understanding of OGECs' local impact

To evaluate the accuracy of the differentiated solutions, the results are compared with the generalized assessment method. The values for the private objective functions (POFCOE R) are averaged across all units (the sum of POFCOE R values divided by the number of units—91 for the whole territory, and POFCOE OGEC for the 24 zones with oil and gas extraction complexes).

Since both methods implement the same approach—comparing the private and integral objective functions using the same rationale—the actual accuracy of constructing the grid model can be estimated. The accuracy of the grid model construction is largely determined by how carefully the grid model is aligned with the coordinates of the evaluation maps and by the diligence of the person performing this painstaking task.

The differentiated assessment method requires significantly more time during the stage of obtaining quantitative information from cartographic material compared to the generalized evaluation method, but it has a number of clear advantages. In the generalized evaluation model, the particular solution to the inverse problem exceeds the average estimate of the role of the oil and gas extraction complex in human impact on the natural environment components. As a result, all areas with oil and gas extraction

complexes are equally considered "guilty" of further impacting the environmental components.

The differentiated assessment method makes it possible to pinpoint areas where the anthropogenic impact from oil and gas extraction complexes is lower than that from other sources. Analyzing the range of integrated solutions in zones influenced by changes in oil and gas operations can provide a foundation for implementing a differentiated interpretation of the "polluter pays" principle.

The partial objective functions are capped at a maximum value of 9. This upper limit stems from how these functions are calculated—specifically, as the ratio of the sum of squared values of same-level disturbance contours within a block's area—and from the assigned weight coefficients. For example, if a block exhibits a fifth-level anthropogenic disturbance (the highest level), its function value would be 1; when this is multiplied by the corresponding weight factor of 9, the resulting value is 9.

Here, as in the case of the generalized solution, it must be remembered that $f_{kijCOE_{OGEC}}$ calculated only within the zones with the presence of oil gas the extraction complex, rather than in the entire unit area. Thus, $PSRT_{ijCOE} = 0$ would mean that the effect of oil gas of extraction complex fully taken into account, the upper limit of the action full compliance with the principle of "the polluter pays". Consequently, a negative value $PSRT_{COE}$, ranging from 0 to $POF_{ijCOE} R$ with a minus sign would mean the absence of additional contribution in oil gas of extraction complex anthropogenic disturbance component of the natural environment, an area just of the principle of "polluter pays".

Only in case of positive values $PSRT_{ijCOE}$ this principle is violated, because they were higher than the recorded impact of all relevant factors, including oil gas extraction complex. This is the realm of the possible violation of the principle of "polluter pays":

Higher than average values for all blocks $POF_{ijCOEnR}$ occur in the absence of oil and gas of extraction complex, there may be cases a high level of anthropogenic

transformation of the natural environment with the effects of other components of the sources listed in the legends of the inventory and assessment maps. This is a case of "the influence of the only other sources of exposure." Thus, differentiated assessment allows to obtain qualitatively new information about the role of OGEC in anthropogenic transformation of the natural environment components.

The developed method, based on a differentiated evaluation grid model, effectively and clearly solves the problem of delimiting the zones of influence from various anthropogenic sources. This method not only highlights areas with excess exposure to the oil and gas extraction complex (OGEC) in regions with its presence but can also serve as a foundation for applying differentiated fees for environmental emissions.

However, these advantages are realized only when "ready" Integrated Environmental Assessments (IEA), primarily from the expert evaluation maps in the Mangystau region Atlas, are available. To extend the application of the developed methods, it is necessary to create a method for solving both the direct and inverse tasks of integrated environmental assessments without relying on evaluation maps.

Main Results of the Research:

Formulated algorithms for the generalized and differentiated methods to solve the inverse tasks of integrated environmental assessment, aimed at objectifying expert estimates of the contribution of pollution sources to the overall ecological situation of the territory.

Developed a three-level differentiation grading scale for groundwater status, using a classical five-level system with maps for groundwater protection against pollution.

Constructed generalized partial objective functions to assess the contribution of the oil and gas extraction complex to violations of relief, soil, vegetation, and groundwater in the Mangystau region. Integral solutions to the inverse tasks were derived for all natural environment components using generalized methods.

Calculated partial solutions for the inverse tasks of integrated environmental assessment, enabling the determination of the additional contribution of the oil and gas extraction complex to the anthropogenic disturbance of the natural environment components in the Mangystau region. The contributions in the presence of the oil and gas extraction complex were:

16.73% for anthropogenic disturbance of relief

16.51% for soil degradation

31.79% for anthropogenic disturbance of vegetation

24.55% for anthropogenic disturbance of groundwater

The integral solution to the inverse problem (OGEC's additional contribution to anthropogenic disturbance in the Mangystau region's zones with OGEC) was 22.77%.

Conducted numerical experiments to assess the accuracy of the generalized estimation model for OGEC's integral contribution to environmental conditions. The difference in the integral objective function did not exceed 1.6% across different sets of loads and evaluation maps (actual difference: 1.69%).

Concluded that the close match between results can be attributed to the use of a single source map, constructed using uniform methodology and a comprehensive database, which supports generalizations from expert use of diverse information on many factors impacting each source of the evaluated maps. Thus, the accuracy and objectivity of the "finished" IEA maps used as initial data ensure the accuracy of solving the inverse tasks.

Conducted soil sampling and vegetation analysis near existing wells and outside the sanitary protection zone of the Zhetybai deposit in 2015 and 2016. Sample preparation and analysis were done at the UK Faculty of Natural Sciences at Middlesex University.

As a result it was confirmed a high degree of anthropogenic transformation of vegetation in the oil well site area of the Zhetybai oil and gas deposit compared to the

vegetation outside the sanitary protection zone. The analysis also found no significant soil pollution from the operating OGEC, as measured by Kazhydromet's heavy metal monitoring list. The transformation involved nearly complete replacement of palatable plant species by weeds.

Justified the selection criteria for areas with excess OGEC influence on the ecological situation based on a comparative analysis of the integral values of the objective functions across blocks in the region and OGEC zones.

Identified, based on calculations of the particular solutions for the inverse tasks of integrated environmental assessment, that anthropogenic disturbance components in OGEC zones associated with other sources of exposure were greater than from OGEC in the following cases (zones where there is no need to increase fees for environmental emissions):

Relief: 4 of 24 blocks

Soil-vegetation: 1 of 24 blocks

Groundwater: 9 of 24 blocks

Based on the integral solution calculations, it was found that in one of the 24 blocks with OGEC, the influence of other sources of exposure exceeded that of OGEC. In the remaining 23 blocks, the impact of OGEC was greater than the average, potentially violating the "polluter pays" principle.

Determined the relative error of the differential and generalized methods for assessing OGEC's contribution to anthropogenic transformation of environmental components, which did not exceed:

3% for relief

4.14% for soil-vegetation layers (due to small circuits within a unit)

3.25% for groundwater

In the case of differentiated evaluations, satisfactory accuracy was achieved by comparing generalized and differentiated solutions, with errors determined by the accuracy of the initial mapping conversion (from dispersed to quantitative data).

Showed that the comparability of the integral objective function results for generalized and differentiated methods is higher than for the private objective functions, as the latter are not directly linked to the defined contour areas of the blocks. The maximum relative error was 1.72%, referring to the IOFOGEC (integral objective function for anthropogenic disturbance of the natural environment in the Mangystau region with OGEC).

Concluded that the integral solution of the inverse tasks (OGEC's additional contribution to the anthropogenic disturbance in the Mangystau region) provides a general picture of the spatial distribution of OGEC's role in the ecological situation of the region. The range of positive ISRTij values from 0.128 to 2.256 not only indicates excess exposure to OGEC in the blocks with OGEC but can also serve as a basis for applying differentiated fees for environmental emissions.

By scaling the evaluation maps, the second method enables a more detailed assessment of OGEC's additional contribution to the formation of ecological stress in areas with OGEC presence.

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APPENDIX A

Table A1 – Matrix of Initial Data Representing Anthropogenic Impact Levels on Environmental Components Across Grid Model Blocks for the Entire Regional Territory

Block designation	Areas of contours with different degrees of anthropogenic transformation in all blocks of the region's territory for														
	relief					soil and vegetation layer					groundwater				
	insignificant or absent	weak	moderate	significant	strong	insignificant or absent	weak	moderate	significant	strong	insignificant or absent	weak	moderate	significant	strong
A4	78,70					76,12									78,93
A5	2,39	500,89	289,35		309,09	69,79	890,42		183,35					658,23	316,57
A6		47,70	140,99		21,20		258,44		0,38					79,23	181,15
B4				332,75			324,10								362,88
B5	15,87	839,44	377,54	35,00		558,30	729,63							729,92	363,94
B6	30,55	1072,09	271,77	143,98	406,69	601,57	1061,54	298,69	54,37					1470,35	458,38

Block designation	Areas of contours with different degrees of anthropogenic transformation in all blocks of the region's territory for														
	relief					soil and vegetation layer					groundwater				
	insignificant or absent	weak	moderate	significant	strong	insignificant or absent	weak	moderate	significant	strong	insignificant or absent	weak	moderate	significant	strong
B7				100,93	692,34		33,93	59,46	630,59	183,70				505,69	280,09
B8			13,62	153,31	1,02			190,19							130,77
C3				574,71			187,65	15,64	207,69	53,57					367,09
C4		679,00	59,34	1735,22			611,61	1303,26	518,07	47,86					2485,65
C5	447,43	1174,50	479,23	251,37		869,10	604,71	147,12	783,20					956,20	1493,00
C6	385,09	965,89		659,68	488,96	1422,38	1077,62							2307,02	185,50
C7		802,29		559,70	1137,70	280,27	965,75	352,47	887,05	14,45				1323,68	1188,98
C8	138,33	938,21	344,62	93,52	631,97	261,49	816,68	875,28	240,20					991,46	1145,26
C9		150,39	174,55					313,03						175,06	121,57

Block designation	Areas of contours with different degrees of anthropogenic transformation in all blocks of the region's territory for														
	relief					soil and vegetation layer					groundwater				
	insignificant or absent	weak	moderate	significant	strong	insignificant or absent	weak	moderate	significant	strong	insignificant or absent	weak	moderate	significant	strong
D3				883,81		374,21	83,06		36,49	106,39					506,95
D4		1815,08	38,78	646,06			1024,26	1206,40	269,34						2499,21
D5		2336,16	163,61			400,86	782,56	1171,96	144,62					802,77	1746,59
D6	320,21	1870,55	227,99	70,46	10,41	1327,65	1172,35							2382,70	158,81
D7		1281,83		1217,84		270,14	1167,72	762,62	31,97	267,55				1807,13	744,53
D8		1418,05		1081,56			1159,67	735,36	522,64	82,32				2203,18	306,63
D9		947,98	335,26				977,13	301,00						898,33	351,65

Block designation	Areas of contours with different degrees of anthropogenic transformation in all blocks of the region's territory for														
	relief					soil and vegetation layer					groundwater				
	insignificant or absent	weak	moderate	significant	strong	insignificant or absent	weak	moderate	significant	strong	insignificant or absent	weak	moderate	significant	strong
D10		104,72	166,18				166,05							190,75	
D11		334,62	307,22			159,95	314,93							494,37	
E3	150,24			740,81		150,68	563,36							716,61	
E4		1325,01	217,85	956,98			1672,81	768,23	58,96					2499,16	
E5		1866,41	633,39			956,16	630,43	757,59	155,82					98,67	2400,69
E6	120,95	1530,56	848,22			1930,60	569,40							1945,17	552,34
E7	235,71	1269,50	600,39	394,23		78,55	1679,64	528,77		213,04				1512,98	986,68
E8		1265,73	0,49	1233,60			243,61	1431,37	161,74	663,28			617,05	375,16	1515,59

Block designation	Areas of contours with different degrees of anthropogenic transformation in all blocks of the region's territory for														
	relief					soil and vegetation layer					groundwater				
	insignificant or absent	weak	moderate	significant	strong	insignificant or absent	weak	moderate	significant	strong	insignificant or absent	weak	moderate	significant	strong
E9		1714,38	777,46			906,89	418,53	1058,49					1384,60	703,54	411,46
E10		2281,20	136,40			902,49	1374,49	102,43					1484,80	766,30	85,64
E11		551,24				338,23	294,22						291,54	378,97	
F2			183,48	314,93			395,63	147,59							540,63
F3			69,49	2424,24			2476,16								2499,27
F4		714,65	990,88	794,30		1032,36	1111,66	355,98						131,01	2368,10
F5		1411,64	1088,18			1492,90	899,18	69,19	38,72					1189,37	1309,98

Block designation	Areas of contours with different degrees of anthropogenic transformation in all blocks of the region's territory for														
	relief					soil and vegetation layer					groundwater				
	insignificant or absent	weak	moderate	significant	strong	insignificant or absent	weak	moderate	significant	strong	insignificant or absent	weak	moderate	significant	strong
F6	81,68	2312,28	105,82			873,34	150,78	1010,59	465,29				201,69	2170,86	126,96
F7	1136,68	1204,75	158,44			600,28	1235,38	664,33			24,20		1633,70	841,75	
F8	501,29	1729,89	268,69			429,92	348,33	1721,76					2456,80	42,98	
F9	375,92	2123,96				563,93	1632,23	303,84					2497,90		
F10		1917,81				391,79	1573,69						1988,30		
G1			141,39	0,09				111,31	43,66						253,35
G2	11,65		1938,20	367,53			221,28	1909,78	221,57						2393,41

Block designation	Areas of contours with different degrees of anthropogenic transformation in all blocks of the region's territory for														
	relief					soil and vegetation layer					groundwater				
	insignificant or absent	weak	moderate	significant	strong	insignificant or absent	weak	moderate	significant	strong	insignificant or absent	weak	moderate	significant	strong
G3			2382,88	117,24		791,72	1594,91	113,38							2499,05
G4		748,95	1736,10	14,89		1759,81	674,78	65,41						648,78	1850,43
G5		2102,23	397,70			5,98	663,51	1217,23	613,28				288,08	2211,28	
G6		2499,87						2496,85	3,15		704,88		1577,30	217,32	
G7	276,79	2223,13				843,40	942,73	713,87			2217,38		282,27		
G8	1880,98	618,92				1653,38	788,36	58,25			352,43		2147,40		
G9	1237,28	1262,59				1248,61	1176,8	74,54			19,90		2480,0		

Block designation	Areas of contours with different degrees of anthropogenic transformation in all blocks of the region's territory for														
	relief					soil and vegetation layer					groundwater				
	insignificant or absent	weak	moderate	significant	strong	insignificant or absent	weak	moderate	significant	strong	insignificant or absent	weak	moderate	significant	strong
							4						0		
G10	44,78	1455,73				182,66	1322,27				249,16	121,00	1178,40		
H1	90,63		73,10	526,73			683,69		44,37						744,07
H2	176,06		732,32	1591,68		252,75	1330,59	464,86	451,80						2499,90
H3	247,09		1071,71	1181,30		23,02	1613,49	469,91	393,58						2499,05
H4	268,65	1024,26	1190,34	16,65		497,23	1301,81	228,55	472,41					1516,11	983,09
H5	257,03	1835,47	407,42				20,31	2174,37	305,32				968,98	1530,38	

Block designation	Areas of contours with different degrees of anthropogenic transformation in all blocks of the region's territory for														
	relief					soil and vegetation layer					groundwater				
	insignificant or absent	weak	moderate	significant	strong	insignificant or absent	weak	moderate	significant	strong	insignificant or absent	weak	moderate	significant	strong
H6		2499,85					75,56	2424,44			1940,22		559,29		
H7	75,53	2424,33				143,75	1964,88	391,37			2499,65				
H8	922,52	1577,31				1655,98	844,02				1425,47		1094,30		
H9	301,08	2198,70				823,87	1676,13				1750,12	99,50	650,32		
H10		2408,85					2391,61				2122,34	292,00			
H11		548,32					475,31				473,70				
I1			581,42	622,08		309,45	926,10						725,38		536,13

Block designation	Areas of contours with different degrees of anthropogenic transformation in all blocks of the region's territory for														
	relief					soil and vegetation layer					groundwater				
	insignificant or absent	weak	moderate	significant	strong	insignificant or absent	weak	moderate	significant	strong	insignificant or absent	weak	moderate	significant	strong
I2	147,67	1068,34	1074,03	210,00		2041,40	454,29	4,31					1818,30		683,58
I3	485,05	1143,24	0,41	871,37		23,02	1613,49	469,91	393,58				1266,30		1232,78
I4	615,52	1615,35	32,11	236,87			153,60	1813,28	533,13				1543,60	556,90	400,68
I5	94,58	2020,04		385,30				2370,93	129,07		615,43		1875,80	10,14	
I6		2499,87					4,76	2495,24			2490,70		8,81		
I7		2499,86				8,51	925,68	1565,80			2499,66				
I8		2499,83				762,57	1737,4				2499,8				

Block designation	Areas of contours with different degrees of anthropogenic transformation in all blocks of the region's territory for														
	relief					soil and vegetation layer					groundwater				
	insignificant or absent	weak	moderate	significant	strong	insignificant or absent	weak	moderate	significant	strong	insignificant or absent	weak	moderate	significant	strong
							3				0				
I9		2499,80				1026,73	1473,27				2459,53	20,40			
I10		2499,79				1773,44	726,56				2499,08				
I11		2466,67				1367,42	1077,40				2434,90	24,40			
I12		1410,27				1273,01	15,49				1285,16				
I13		1,47				0,05					0,95				
J1	2,78	29,55	170,78	105,21			258,13	27,92					285,59		
J2	375,33	1651,10	248,25	95,75		1060,27	785,45	537,72					2375,2		

Block designation	Areas of contours with different degrees of anthropogenic transformation in all blocks of the region's territory for														
	relief					soil and vegetation layer					groundwater				
	insignificant or absent	weak	moderate	significant	strong	insignificant or absent	weak	moderate	significant	strong	insignificant or absent	weak	moderate	significant	strong
													0		
J3	819,27	1671,96	9,26			164,24	1672,66	663,10					2499,10		
J4	922,59	737,75		291,10			144,84	1559,42	201,48		262,37	392,00	1270,90		
J5	320,23	993,74					394,85	98,59	801,00		1242,46		78,65		
J6		1359,99					680,53	677,07			1372,24				
J7		1416,42				348,36	792,61	293,79			1449,00				
J8		1467,70				1507,36	1,23				1547,88				

Block designa- tion	Areas of contours with different degrees of anthropogenic transformation in all blocks of the region's territory for														
	relief					soil and vegetation layer					groundwater				
	insignific- ant or absent	weak	moderate	significant	strong	insignific- ant or absent	weak	moderate	significant	strong	insignifi- cant or absent	weak	moderate	significant	strong
J9		1516,95				1531,88	49,17				1033,61	559,00			
J10		1571,35				1652,05					1431,55	236,00			
J11		1621,36				1728,84					1170,94	567,00			
J12		1492,21				1580,92					1595,06				
K2	317,67	458,05				515,94	221,92						734,51		
K3	654,81	677,52				237,40	634,35	422,64				2,74	1285,90		
K4		545,94				300,65	192,13					360,00	162,26		

Table A2 – Matrix of initial data (levels of anthropogenic impact on components of the natural environment) for blocks of the grid model for zones with the presence of OGPC

Block designation	Areas of contours with different degrees of anthropogenic transformation by blocks with the presence of an oil and gas production complex for														
	relief					soil and vegetation layer					groundwater				
	insignificant or absent	weak	moderate	significant	strong	insignificant or absent	weak	moderate	significant	strong	insignificant or absent	weak	moderate	significant	strong
A4															
A5															
A6															
B4															
B5		66,95				6,97	228,47							198,89	36,55
B6		66,72		12,11	34,27	27,59	57,56	99,57						172,07	12,65

Block designation	Areas of contours with different degrees of anthropogenic transformation by blocks with the presence of an oil and gas production complex for														
	relief					soil and vegetation layer					groundwater				
	insignificant or absent	weak	moderate	significant	strong	insignificant or absent	weak	moderate	significant	strong	insignificant or absent	weak	moderate	significant	strong
B7															
B8															
C3		83,30	28,53	60,46			57,70		74,29	10,49					142,47
C4		75,74	58,00				29,41	314,35	73,98	46,42					464,35
C5															
C6		0,83		103,77	35,45		14,67							14,67	
C7		2,20		0,63	137,85	37,33	260,66	114,41	525,91					347,13	576,51
C8		5,11		1,01			87,66	71,78						100,32	59,12
C9															
D3		468,62	145,52	137,17			266,08	42,04	29,31	73,37					439,23

Block designa tion	Areas of contours with different degrees of anthropogenic transformation by blocks with the presence of an oil and gas production complex for														
	relief					soil and vegetation layer					groundwater				
	insignific ant or absent	weak	moderate	significant	strong	insignific ant or absent	weak	moderate	significant	strong	insignific ant or absent	weak	moderate	significant	strong
D4								1,27	25,11						
D5															
D6															
D7		236,56		359,30			6,52	281,91	25,15	123,05				336,63	88,00
D8		71,19		693,00			446,53	218,53	505,39	62,19				996,82	235,82
D9		60,13	56,96				116,92	5,90						122,82	
D10		44,30					85,12							85,12	
D11															
E3															
E4															

Block designa tion	Areas of contours with different degrees of anthropogenic transformation by blocks with the presence of an oil and gas production complex for														
	relief					soil and vegetation layer					groundwater				
	insignific ant or absent	weak	moderate	significant	strong	insignific ant or absent	weak	moderate	significant	strong	insignific ant or absent	weak	moderate	significant	strong
E5															
E6															
E7															
E8		902,26	22,97	566,57				116,70	36,55	201,44				282,09	72,61
E9															
E10		213,48	22,25			0,80	183,81							183,57	1,04
E11		83,03				140,05	10,38						140,05	10,38	
F2															
F3				140,05			140,05								140,05
F4		314,56					130,43								130,43

Block designation	Areas of contours with different degrees of anthropogenic transformation by blocks with the presence of an oil and gas production complex for														
	relief					soil and vegetation layer					groundwater				
	insignificant or absent	weak	moderate	significant	strong	insignificant or absent	weak	moderate	significant	strong	insignificant or absent	weak	moderate	significant	strong
F5															
F6															
F7															
F8															
F9															
F10															
G1															
G2	8,48		594,14	237,54			137,32	632,46	61,83						801,61
G3			279,12				231,71	4,77							226,48
G4		40,14	140,05			7,93	9,62	41,15						49,08	9,62

Block designation	Areas of contours with different degrees of anthropogenic transformation by blocks with the presence of an oil and gas production complex for														
	relief					soil and vegetation layer					groundwater				
	insignificant or absent	weak	moderate	significant	strong	insignificant or absent	weak	moderate	significant	strong	insignificant or absent	weak	moderate	significant	strong
G5		148,77	8,81				121,99	50,85	58,19					231,03	
G6															
G7															
G8															
G9			73,64	82,42		14,23	125,82						140,05		
G10															
H1			5,40				134,88								124,88
H2		194,83		27,61			60,49	56,59							107,08

Table A3 – Results of Calculations of Partial Objective Functions and Partial Solutions to the Inverse Problem for Relief Using the Differentiated Assessment Method

Block designation	Blocks throughout the region							Blocks with the presence of an oil and gas production complex							$PSIP_{rel}$
	Area in block	functions of the i-th level of anthropogenic disturbance of the relief in the region					POF_{RelReg}^g	Area of oil and gas production complex in the block	functions of the i-th level of anthropogenic disturbance of the relief by zones with an oil and gas production complex					POF_{RelOGP}^C	
		$f_{1ijRelReg}^g$	$f_{2ijRelReg}^g$	$f_{3ijRelReg}^g$	$f_{4ijRelReg}^g$	$f_{5ijRelReg}^g$			$f_{1ijRelOGP}^C$	$f_{2ijRelOGP}^C$	$f_{3ijRelOGP}^C$	$f_{4ijRelOGP}^C$	$f_{5ijRelOGP}^C$		
A4	78,70	1,000	0,000	0,000	0,000	0,000	1,000								-1,000
A5	1101,7	0,002	0,455	0,263	0,000	0,281	5,204	0							-5,204

Block designation	Blocks throughout the region							Blocks with the presence of an oil and gas production complex							$PSIP_{rel}$
	Area in block	functions of the i-th level of anthropogenic disturbance of the relief in the region					POF_{RelReg}	Area of oil and gas production complex in the block	functions of the i-th level of anthropogenic disturbance of the relief by zones with an oil and gas production complex					POF_{RelOGP}	
		$f_{1ijRelReg}$	$f_{2ijRelReg}$	$f_{3ijRelReg}$	$f_{4ijRelReg}$	$f_{5ijRelReg}$			$f_{1ijRelOGP}$	$f_{2ijRelOGP}$	$f_{3ijRelOGP}$	$f_{4ijRelOGP}$	$f_{5ijRelOGP}$		
	2														
A6	209,89	0,000	0,227	0,672	0,000	0,101	4,949	0							-4,949
B4	332,75	0,000	0,000	0,000	1,000	0,000	7,000	0							-7,000
B5	1267,84	0,013	0,662	0,298	0,028	0,000	3,681	66,94	0,000	0,000	1,000	0,000	0,000	5,000	1,319
B6	1925,0	0,016	0,557	0,141	0,075	0,211	4,817	113,10	0,000	0,000	0,590	0,107	0,303	6,426	1,609

Block designation	Blocks throughout the region						Blocks with the presence of an oil and gas production complex							$PSIP_{rel}$	
	Area in block	functions of the i-th level of anthropogenic disturbance of the relief in the region					POF_{RelReg}	Area of oil and gas production complex in the block	functions of the i-th level of anthropogenic disturbance of the relief by zones with an oil and gas production complex						POF_{RelOGP}
		$f_{1ijRelReg}$	$f_{2ijRelReg}$	$f_{3ijRelReg}$	$f_{4ijRelReg}$	$f_{5ijRelReg}$			$f_{1ijRelOGP}$	$f_{2ijRelOGP}$	$f_{3ijRelOGP}$	$f_{4ijRelOGP}$	$f_{5ijRelOGP}$		
	9							2							
B7	793,27	0,000	0,000	0,000	0,127	0,873	8,746	0							-8,746
B8	167,95	0,000	0,000	0,081	0,913	0,006	6,850	0							-6,850
C3	574,71	0,000	0,000	0,000	1,000	0,000	7,000	172,29	0,000	0,000	0,483	0,166	0,351	6,735	-0,265
C4	2473,56	0,000	0,275	0,024	0,702	0,000	5,854	133,74	0,000	0,000	0,566	0,434	0,000	5,867	0,013

Block designation	Blocks throughout the region							Blocks with the presence of an oil and gas production complex							$PSIP_{rel}$
	Area in block	functions of the i-th level of anthropogenic disturbance of the relief in the region					POF_{RelReg}	Area of oil and gas production complex in the block	functions of the i-th level of anthropogenic disturbance of the relief by zones with an oil and gas production complex					POF_{RelOGP}	
		$f_{1ijRelReg}$	$f_{2ijRelReg}$	$f_{3ijRelReg}$	$f_{4ijRelReg}$	$f_{5ijRelReg}$			$f_{1ijRelOGP}$	$f_{2ijRelOGP}$	$f_{3ijRelOGP}$	$f_{4ijRelOGP}$	$f_{5ijRelOGP}$		
C5	2352,53	0,190	0,499	0,204	0,107	0,000	3,454	0							-3,454
C6	2499,63	0,154	0,386	0,000	0,264	0,196	4,921	140,048	0,000	0,000	0,006	0,741	0,253	7,494	2,573
C7	2499,69	0,000	0,321	0,000	0,224	0,455	6,626	140,68	0,000	0,000	0,016	0,004	0,980	8,929	2,302

Block designation	Blocks throughout the region							Blocks with the presence of an oil and gas production complex							$PSIP_{rel}$
	Area in block	functions of the i-th level of anthropogenic disturbance of the relief in the region					POF_{RelReg}^g	Area of oil and gas production complex in the block	functions of the i-th level of anthropogenic disturbance of the relief by zones with an oil and gas production complex					POF_{RelOGP}^C	
		$f_{1ijRelReg}^g$	$f_{2ijRelReg}$	$f_{3ijRelReg}^g$	$f_{4ijRelReg}$	$f_{5ijRelReg}^g$			$f_{1ijRelOGP}^C$	$f_{2ijRelOGP}^C$	$f_{3ijRelOGP}^C$	$f_{4ijRelOGP}^C$	$f_{5ijRelOGP}^C$		
C8	2146,65	0,064	0,437	0,161	0,044	0,294	5,133	6,11	0,000	0,000	0,835	0,165	0,000	5,330	0,197
C9	324,95	0,000	0,463	0,537	0,000	0,000	4,074	0							-4,074
D3	883,81	0,000	0,000	0,000	1,000	0,000	7,000	751,31	0,000	0,000	0,624	0,194	0,183	6,118	-0,882
D4	2499,92	0,000	0,726	0,016	0,258	0,000	4,065	0							-4,065

Block designation	Blocks throughout the region							Blocks with the presence of an oil and gas production complex							$PSIP_{rel}$
	Area in block	functions of the i-th level of anthropogenic disturbance of the relief in the region					POF_{RelReg}^g	Area of oil and gas production complex in the block	functions of the i-th level of anthropogenic disturbance of the relief by zones with an oil and gas production complex					POF_{RelOGP}^C	
		$f_{1ijRelReg}^g$	$f_{2ijRelReg}^g$	$f_{3ijRelReg}^g$	$f_{4ijRelReg}^g$	$f_{5ijRelReg}^g$			$f_{1ijRelOGP}^C$	$f_{2ijRelOGP}^C$	$f_{3ijRelOGP}^C$	$f_{4ijRelOGP}^C$	$f_{5ijRelOGP}^C$		
D5	2499,77	0,000	0,935	0,065	0,000	0,000	3,131	0							-3,131
D6	2499,63	0,128	0,748	0,091	0,028	0,004	3,064	0							-3,064
D7	2499,67	0,000	0,513	0,000	0,487	0,000	4,949	595,85	0,000	0,397	0,000	0,603	0,000	5,412	0,463

Block designation	Blocks throughout the region							Blocks with the presence of an oil and gas production complex							$PSIP_{rel}$
	Area in block	functions of the i-th level of anthropogenic disturbance of the relief in the region					POF_{RelReg}^g	Area of oil and gas production complex in the block	functions of the i-th level of anthropogenic disturbance of the relief by zones with an oil and gas production complex					POF_{RelOGP}^C	
		$f_{1ijRelReg}^g$	$f_{2ijRelReg}^g$	$f_{3ijRelReg}^g$	$f_{4ijRelReg}^g$	$f_{5ijRelReg}^g$			$f_{1ijRelOGP}^C$	$f_{2ijRelOGP}^C$	$f_{3ijRelOGP}^C$	$f_{4ijRelOGP}^C$	$f_{5ijRelOGP}^C$		
D8	2499,61	0,000	0,567	0,000	0,433	0,000	4,731	764,19	0,000	0,000	0,093	0,000	0,907	8,627	3,897
D9	1283,24	0,000	0,739	0,261	0,000	0,000	3,523	117,09	0,000	0,514	0,486	0,000	0,000	3,973	0,450
D10	270,90	0,000	0,387	0,613	0,000	0,000	4,227	44,30	0,000	1,000	0,000	0,000	0,000	3,000	-1,227
D11	641,84	0,000	0,521	0,479	0,000	0,000	3,957	0							-3,957

Block designation	Blocks throughout the region							Blocks with the presence of an oil and gas production complex							$PSIP_{rel}$
	Area in block	functions of the i-th level of anthropogenic disturbance of the relief in the region					POF_{RelReg}^g	Area of oil and gas production complex in the block	functions of the i-th level of anthropogenic disturbance of the relief by zones with an oil and gas production complex					POF_{RelOGP}^C	
		$f_{1ijRelReg}^g$	$f_{2ijRelReg}^g$	$f_{3ijRelReg}^g$	$f_{4ijRelReg}^g$	$f_{5ijRelReg}^g$			$f_{1ijRelOGP}^C$	$f_{2ijRelOGP}^C$	$f_{3ijRelOGP}^C$	$f_{4ijRelOGP}^C$	$f_{5ijRelOGP}^C$		
E3	891,05	0,169	0,000	0,000	0,831	0,000	5,988	0							-5,988
E4	2499,84	0,000	0,530	0,087	0,383	0,000	4,706	0							-4,706
E5	2499,80	0,000	0,747	0,253	0,000	0,000	3,507	0							-3,507
E6	2499,7	0,048	0,612	0,339	0,000	0,000	3,582	0							-3,582

Block designation	Blocks throughout the region						Blocks with the presence of an oil and gas production complex							$PSIP_{rel}$	
	Area in block	functions of the i-th level of anthropogenic disturbance of the relief in the region					POF_{RelReg}^g	Area of oil and gas production complex in the block	functions of the i-th level of anthropogenic disturbance of the relief by zones with an oil and gas production complex						POF_{RelOGP}^C
		$f_{1ijRelReg}^g$	$f_{2ijRelReg}^g$	$f_{3ijRelReg}^g$	$f_{4ijRelReg}^g$	$f_{5ijRelReg}^g$			$f_{1ijRelOGP}^C$	$f_{2ijRelOGP}^C$	$f_{3ijRelOGP}^C$	$f_{4ijRelOGP}^C$	$f_{5ijRelOGP}^C$		
	3														
E7	2499,82	0,094	0,508	0,240	0,158	0,000	3,923	0							-3,923
E8	2499,82	0,000	0,506	0,000	0,493	0,000	4,974	1491,81	0,000	0,000	0,605	0,015	0,380	6,550	1,576
E9	2491,8	0,000	0,688	0,312	0,000	0,000	3,624	0							-3,624

Block designation	Blocks throughout the region						Blocks with the presence of an oil and gas production complex								$PSIP_{rel}$
	Area in block	functions of the i-th level of anthropogenic disturbance of the relief in the region					POF_{RelReg}	Area of oil and gas production complex in the block	functions of the i-th level of anthropogenic disturbance of the relief by zones with an oil and gas production complex					POF_{RelOGP}	
		$f_{1ijRelReg}$	$f_{2ijRelReg}$	$f_{3ijRelReg}$	$f_{4ijRelReg}$	$f_{5ijRelReg}$			$f_{1ijRelOGP}$	$f_{2ijRelOGP}$	$f_{3ijRelOGP}$	$f_{4ijRelOGP}$	$f_{5ijRelOGP}$		
	4														
E10	2417,61	0,000	0,944	0,056	0,000	0,000	3,113	235,73	0,000	0,906	0,094	0,000	0,000	3,189	0,076
E11	551,24	0,000	1,000	0,000	0,000	0,000	3,000	83,03	0,000	1,000	0,000	0,000	0,000	3,000	0,000
F2	498,41	0,000	0,000	0,368	0,632	0,000	6,264	0							-6,264
F3	2493,7	0,000	0,000	0,028	0,972	0,000	6,944	140,05	0,000	0,000	0,000	1,000	0,000	7,000	0,056

Block designation	Blocks throughout the region						Blocks with the presence of an oil and gas production complex							$PSIP_{rel}$	
	Area in block	functions of the i-th level of anthropogenic disturbance of the relief in the region					POF_{RelReg}	Area of oil and gas production complex in the block	functions of the i-th level of anthropogenic disturbance of the relief by zones with an oil and gas production complex						POF_{RelOGP}
		$f_{1ijRelReg}$	$f_{2ijRelReg}$	$f_{3ijRelReg}$	$f_{4ijRelReg}$	$f_{5ijRelReg}$			$f_{1ijRelOGP}$	$f_{2ijRelOGP}$	$f_{3ijRelOGP}$	$f_{4ijRelOGP}$	$f_{5ijRelOGP}$		
	3														
F4	2499,83	0,000	0,286	0,396	0,318	0,000	5,064	314,56	0,000	1,000	0,000	0,000	0,000	3,000	-2,064
F5	2499,83	0,000	0,565	0,435	0,000	0,000	3,871	0							-3,871
F6	2499,7	0,033	0,925	0,042	0,000	0,000	3,019	0							-3,019

Block designation	Blocks throughout the region						Blocks with the presence of an oil and gas production complex						$PSIP_{rel}$		
	Area in block	functions of the i-th level of anthropogenic disturbance of the relief in the region					POF_{RelReg}^g	Area of oil and gas production complex in the block	functions of the i-th level of anthropogenic disturbance of the relief by zones with an oil and gas production complex					POF_{RelOGP}^C	
		$f_{1ijRelReg}^g$	$f_{2ijRelReg}^g$	$f_{3ijRelReg}^g$	$f_{4ijRelReg}^g$	$f_{5ijRelReg}^g$			$f_{1ijRelOGP}^C$	$f_{2ijRelOGP}^C$	$f_{3ijRelOGP}^C$	$f_{4ijRelOGP}^C$			$f_{5ijRelOGP}^C$
	8														
F7	2499,87	0,455	0,482	0,063	0,000	0,000	2,217	0							-2,217
F8	2499,88	0,201	0,692	0,107	0,000	0,000	2,814	0							-2,814
F9	2499,8	0,150	0,850	0,000	0,000	0,000	2,699	0							-2,699

Block designation	Blocks throughout the region						Blocks with the presence of an oil and gas production complex							$PSIP_{rel}$	
	Area in block	functions of the i-th level of anthropogenic disturbance of the relief in the region					POF_{RelReg}	Area of oil and gas production complex in the block	functions of the i-th level of anthropogenic disturbance of the relief by zones with an oil and gas production complex						POF_{RelOGP}
		$f_{1ijRelReg}$	$f_{2ijRelReg}$	$f_{3ijRelReg}$	$f_{4ijRelReg}$	$f_{5ijRelReg}$			$f_{1ijRelOGP}$	$f_{2ijRelOGP}$	$f_{3ijRelOGP}$	$f_{4ijRelOGP}$	$f_{5ijRelOGP}$		
	8														
F10	1917,81	0,000	1,000	0,000	0,000	0,000	3,000	0							-3,000
G1	141,48	0,000	0,000	0,999	0,001	0,000	5,001	0							-5,001
G2	2317,39	0,005	0,000	0,836	0,159	0,000	5,297	840,16	0,010	0,000	0,000	0,707	0,283	7,505	2,208

Block designation	Blocks throughout the region							Blocks with the presence of an oil and gas production complex							$PSIP_{rel}$
	Area in block	functions of the i-th level of anthropogenic disturbance of the relief in the region					POF_{RelRe_g}	Area of oil and gas production complex in the block	functions of the i-th level of anthropogenic disturbance of the relief by zones with an oil and gas production complex					POF_{RelOGP_C}	
		$f_{1ijRelRe_g}$	$f_{2ijRelReg}$	$f_{3ijRelRe_g}$	$f_{4ijRelReg}$	$f_{5ijRelRe_g}$			$f_{1ijRelOGP_C}$	$f_{2ijRelOGP_C}$	$f_{3ijRelOGP_C}$	$f_{4ijRelOGP_C}$	$f_{5ijRelOGP_C}$		
G3	2500,12	0,000	0,000	0,953	0,047	0,000	5,094	279,11	0,000	0,000	0,000	1,000	0,000	7,000	1,906
G4	2499,93	0,000	0,300	0,694	0,006	0,000	4,413	180,19	0,000	0,223	0,000	0,777	0,000	6,109	1,696
G5	2499,94	0,000	0,841	0,159	0,000	0,000	3,318	157,57	0,000	0,944	0,000	0,056	0,000	3,224	-0,095

Block designa- tion	Blocks throughout the region							Blocks with the presence of an oil and gas production complex							$PSIP_{rel}$
	Area in block	functions of the i-th level of anthropogenic disturbance of the relief in the region					POF_{RelRe_g}	Area of oil and gas production complex in the block	functions of the i-th level of anthropogenic disturbance of the relief by zones with an oil and gas production complex					POF_{RelOGP_C}	
		$f_{1ijRelRe_g}$	$f_{2ijRelReg}$	$f_{3ijRelRe_g}$	$f_{4ijRelReg}$	$f_{5ijRelRe_g}$			$f_{1ijRelOGP_C}$	$f_{2ijRelOGP_C}$	$f_{3ijRelOGP_C}$	$f_{4ijRelOGP_C}$	$f_{5ijRelOGP_C}$		
G6	2499,87	0,000	1,000	0,000	0,000	0,000	3,000	0							-3,000
G7	2499,92	0,111	0,889	0,000	0,000	0,000	2,779	0							-2,779
G8	2499,90	0,752	0,248	0,000	0,000	0,000	1,495	0							-1,495

Block designation	Blocks throughout the region							Blocks with the presence of an oil and gas production complex							$PSIP_{rel}$
	Area in block	functions of the i-th level of anthropogenic disturbance of the relief in the region					POF_{RelReg}^g	Area of oil and gas production complex in the block	functions of the i-th level of anthropogenic disturbance of the relief by zones with an oil and gas production complex					POF_{RelOGP}^C	
		$f_{1ijRelReg}^g$	$f_{2ijRelReg}^g$	$f_{3ijRelReg}^g$	$f_{4ijRelReg}^g$	$f_{5ijRelReg}^g$			$f_{1ijRelOGP}^C$	$f_{2ijRelOGP}^C$	$f_{3ijRelOGP}^C$	$f_{4ijRelOGP}^C$	$f_{5ijRelOGP}^C$		
G9	2499,87	0,495	0,505	0,000	0,000	0,000	2,010	156,06	0,000	0,000	0,000	0,472	0,528	8,056	6,046
G10	1500,51	0,030	0,970	0,000	0,000	0,000	2,940	0							-2,940
H1	690,46	0,131	0,000	0,106	0,763	0,000	6,001	5,40	0,000	0,000	0,000	1,000	0,000	7,000	0,999
H2	2500,0	0,070	0,000	0,293	0,637	0,000	5,992	222,45	0,000	0,000	0,876	0,000	0,124	5,497	-0,495

Block designation	Blocks throughout the region						Blocks with the presence of an oil and gas production complex						$PSIP_{rel}$		
	Area in block	functions of the i-th level of anthropogenic disturbance of the relief in the region					POF_{RelReg}^g	Area of oil and gas production complex in the block	functions of the i-th level of anthropogenic disturbance of the relief by zones with an oil and gas production complex					POF_{RelOGP}^C	
		$f_{1ijRelReg}^g$	$f_{2ijRelReg}^g$	$f_{3ijRelReg}^g$	$f_{4ijRelReg}^g$	$f_{5ijRelReg}^g$			$f_{1ijRelOGP}^C$	$f_{2ijRelOGP}^C$	$f_{3ijRelOGP}^C$	$f_{4ijRelOGP}^C$			$f_{5ijRelOGP}^C$
	5														
H3	2500,10	0,099	0,000	0,429	0,472	0,000	5,550	0							-5,550
H4	2499,90	0,107	0,410	0,476	0,007	0,000	3,764	0							-3,764
H5	2499,90	0,103	0,734	0,163	0,000	0,000	3,120	0							-3,120

Block designation	Blocks throughout the region						Blocks with the presence of an oil and gas production complex							$PSIP_{rel}$	
	Area in block	functions of the i-th level of anthropogenic disturbance of the relief in the region					POF_{RelReg}^g	Area of oil and gas production complex in the block	functions of the i-th level of anthropogenic disturbance of the relief by zones with an oil and gas production complex						POF_{RelOGP}^C
		$f_{1ijRelReg}^g$	$f_{2ijRelReg}^g$	$f_{3ijRelReg}^g$	$f_{4ijRelReg}^g$	$f_{5ijRelReg}^g$			$f_{1ijRelOGP}^C$	$f_{2ijRelOGP}^C$	$f_{3ijRelOGP}^C$	$f_{4ijRelOGP}^C$	$f_{5ijRelOGP}^C$		
	2														
H6	2499,85	0,000	1,000	0,000	0,000	0,000	3,000	0							-3,000
H7	2499,86	0,030	0,970	0,000	0,000	0,000	2,940	0							-2,940
H8	2499,8	0,369	0,631	0,000	0,000	0,000	2,262	0							-2,262

Block designation	Blocks throughout the region						Blocks with the presence of an oil and gas production complex						$PSIP_{rel}$		
	Area in block	functions of the i-th level of anthropogenic disturbance of the relief in the region					POF_{RelReg}	Area of oil and gas production complex in the block	functions of the i-th level of anthropogenic disturbance of the relief by zones with an oil and gas production complex					POF_{RelOGP}	
		$f_{1ijRelReg}$	$f_{2ijRelReg}$	$f_{3ijRelReg}$	$f_{4ijRelReg}$	$f_{5ijRelReg}$			$f_{1ijRelOGP}$	$f_{2ijRelOGP}$	$f_{3ijRelOGP}$	$f_{4ijRelOGP}$			$f_{5ijRelOGP}$
	3														
H9	2499,78	0,120	0,880	0,000	0,000	0,000	2,759	0							-2,759
H10	2408,85	0,000	1,000	0,000	0,000	0,000	3,000	0							-3,000
H11	548,32	0,000	1,000	0,000	0,000	0,000	3,000	0							-3,000

Block designation	Blocks throughout the region							Blocks with the presence of an oil and gas production complex							$PSIP_{rel}$
	Area in block	functions of the i-th level of anthropogenic disturbance of the relief in the region					POF_{RelReg}^g	Area of oil and gas production complex in the block	functions of the i-th level of anthropogenic disturbance of the relief by zones with an oil and gas production complex					POF_{RelOGP}^C	
		$f_{1ijRelReg}^g$	$f_{2ijRelReg}^g$	$f_{3ijRelReg}^g$	$f_{4ijRelReg}^g$	$f_{5ijRelReg}^g$			$f_{1ijRelOGP}^C$	$f_{2ijRelOGP}^C$	$f_{3ijRelOGP}^C$	$f_{4ijRelOGP}^C$	$f_{5ijRelOGP}^C$		
I1	1203,50	0,000	0,000	0,483	0,517	0,000	6,034	0							-6,034
I2	2500,04	0,059	0,427	0,430	0,084	0,000	4,077	0							-4,077
I3	2500,06	0,194	0,457	0,000	0,349	0,000	4,006	0							-4,006

Block designation	Blocks throughout the region							Blocks with the presence of an oil and gas production complex							$PSIP_{rel}$
	Area in block	functions of the i-th level of anthropogenic disturbance of the relief in the region					POF_{RelReg}^g	Area of oil and gas production complex in the block	functions of the i-th level of anthropogenic disturbance of the relief by zones with an oil and gas production complex					POF_{RelOGP}^C	
		$f_{1ijRelReg}^g$	$f_{2ijRelReg}^g$	$f_{3ijRelReg}^g$	$f_{4ijRelReg}^g$	$f_{5ijRelReg}^g$			$f_{1ijRelOGP}^C$	$f_{2ijRelOGP}^C$	$f_{3ijRelOGP}^C$	$f_{4ijRelOGP}^C$	$f_{5ijRelOGP}^C$		
I4	2499,86	0,246	0,646	0,013	0,095	0,000	2,912	0							-2,912
I5	2499,91	0,038	0,808	0,000	0,154	0,000	3,541	0							-3,541
I6	2499,87	0,000	1,000	0,000	0,000	0,000	3,000	0							-3,000

Block designa- tion	Blocks throughout the region							Blocks with the presence of an oil and gas production complex							$PSIP_{rel}$
	Area in block	functions of the i-th level of anthropogenic disturbance of the relief in the region					POF_{RelRe} g	Area of oil and gas produc- tion comple x in the block	functions of the i-th level of anthropogenic disturbance of the relief by zones with an oil and gas production complex					POF_{RelOGP} C	
		$f_{1ijRelRe}$ g	$f_{2ijRelReg}$	$f_{3ijRelRe}$ g	$f_{4ijRelReg}$	$f_{5ijRelRe}$ g			$f_{1ijRelOGP}$ C	$f_{2ijRelOGP}$ C	$f_{3ijRelOGP}$ C	$f_{4ijRelOGP}$ C	$f_{5ijRelOGP}$ C		
I7	2499,86	0,000	1,000	0,000	0,000	0,000	3,000	0							-3,000
I8	2499,83	0,000	1,000	0,000	0,000	0,000	3,000	0							-3,000
I9	2499,80	0,000	1,000	0,000	0,000	0,000	3,000	0							-3,000

Block designation	Blocks throughout the region							Blocks with the presence of an oil and gas production complex							$PSIP_{rel}$
	Area in block	functions of the i-th level of anthropogenic disturbance of the relief in the region					POF_{RelReg}	Area of oil and gas production complex in the block	functions of the i-th level of anthropogenic disturbance of the relief by zones with an oil and gas production complex					POF_{RelOGP}	
		$f_{1ijRelReg}$	$f_{2ijRelReg}$	$f_{3ijRelReg}$	$f_{4ijRelReg}$	$f_{5ijRelReg}$			$f_{1ijRelOGP}$	$f_{2ijRelOGP}$	$f_{3ijRelOGP}$	$f_{4ijRelOGP}$	$f_{5ijRelOGP}$		
I10	2499,79	0,000	1,000	0,000	0,000	0,000	3,000	0							-3,000
I11	2466,67	0,000	1,000	0,000	0,000	0,000	3,000	0							-3,000
I12	1410,27	0,000	1,000	0,000	0,000	0,000	3,000	0							-3,000

Block designation	Blocks throughout the region							Blocks with the presence of an oil and gas production complex							$PSIP_{rel}$
	Area in block	functions of the i-th level of anthropogenic disturbance of the relief in the region					POF_{RelReg}	Area of oil and gas production complex in the block	functions of the i-th level of anthropogenic disturbance of the relief by zones with an oil and gas production complex					POF_{RelOGP}	
		$f_{1ijRelReg}$	$f_{2ijRelReg}$	$f_{3ijRelReg}$	$f_{4ijRelReg}$	$f_{5ijRelReg}$			$f_{1ijRelOGP}$	$f_{2ijRelOGP}$	$f_{3ijRelOGP}$	$f_{4ijRelOGP}$	$f_{5ijRelOGP}$		
I13	1,47	0,000	1,000	0,000	0,000	0,000	3,000	0							-3,000
J1	308,33	0,009	0,096	0,554	0,341	0,000	5,455	0							-5,455
J2	2370,43	0,158	0,697	0,105	0,040	0,000	3,054	0							-3,054
J3	2500,49	0,328	0,669	0,004	0,000	0,000	2,352	0							-2,352

Block designation	Blocks throughout the region							Blocks with the presence of an oil and gas production complex							$PSIP_{rel}$
	Area in block	functions of the i-th level of anthropogenic disturbance of the relief in the region					POF_{RelReg}^g	Area of oil and gas production complex in the block	functions of the i-th level of anthropogenic disturbance of the relief by zones with an oil and gas production complex					POF_{RelOGP}^C	
		$f_{1ijRelReg}^g$	$f_{2ijRelReg}^g$	$f_{3ijRelReg}^g$	$f_{4ijRelReg}^g$	$f_{5ijRelReg}^g$			$f_{1ijRelOGP}^C$	$f_{2ijRelOGP}^C$	$f_{3ijRelOGP}^C$	$f_{4ijRelOGP}^C$	$f_{5ijRelOGP}^C$		
J4	1951,44	0,473	0,378	0,000	0,149	0,000	2,651	0							-2,651
J5	1313,98	0,244	0,756	0,000	0,000	0,000	2,513	0							-2,513
J6	1359,99	0,000	1,000	0,000	0,000	0,000	3,000	0							-3,000

Block designation	Blocks throughout the region							Blocks with the presence of an oil and gas production complex							$PSIP_{rel}$
	Area in block	functions of the i-th level of anthropogenic disturbance of the relief in the region					POF_{RelReg}^g	Area of oil and gas production complex in the block	functions of the i-th level of anthropogenic disturbance of the relief by zones with an oil and gas production complex					POF_{RelOGP}^C	
		$f_{1ijRelReg}^g$	$f_{2ijRelReg}^g$	$f_{3ijRelReg}^g$	$f_{4ijRelReg}^g$	$f_{5ijRelReg}^g$			$f_{1ijRelOGP}^C$	$f_{2ijRelOGP}^C$	$f_{3ijRelOGP}^C$	$f_{4ijRelOGP}^C$	$f_{5ijRelOGP}^C$		
J7	1416,42	0,000	1,000	0,000	0,000	0,000	3,000	0							-3,000
J8	1467,70	0,000	1,000	0,000	0,000	0,000	3,000	0							-3,000
J9	1516,95	0,000	1,000	0,000	0,000	0,000	3,000	0							-3,000

Block designation	Blocks throughout the region							Blocks with the presence of an oil and gas production complex							$PSIP_{rel}$
	Area in block	functions of the i-th level of anthropogenic disturbance of the relief in the region					POF_{RelRe_g}	Area of oil and gas production complex in the block	functions of the i-th level of anthropogenic disturbance of the relief by zones with an oil and gas production complex					POF_{RelOGP_C}	
		$f_{1ijRelRe_g}$	$f_{2ijRelReg}$	$f_{3ijRelRe_g}$	$f_{4ijRelReg}$	$f_{5ijRelRe_g}$			$f_{1ijRelOGP_C}$	$f_{2ijRelOGP_C}$	$f_{3ijRelOGP_C}$	$f_{4ijRelOGP_C}$	$f_{5ijRelOGP_C}$		
J10	1571,35	0,000	1,000	0,000	0,000	0,000	3,000	0							-3,000
J11	1621,36	0,000	1,000	0,000	0,000	0,000	3,000	0							-3,000
J12	1492,21	0,000	1,000	0,000	0,000	0,000	3,000	0							-3,000

Block designation	Blocks throughout the region							Blocks with the presence of an oil and gas production complex							$PSIP_{rel}$
	Area in block	functions of the i-th level of anthropogenic disturbance of the relief in the region					POF_{RelReg}	Area of oil and gas production complex in the block	functions of the i-th level of anthropogenic disturbance of the relief by zones with an oil and gas production complex					POF_{RelOGP}	
		$f_{1ijRelReg}$	$f_{2ijRelReg}$	$f_{3ijRelReg}$	$f_{4ijRelReg}$	$f_{5ijRelReg}$			$f_{1ijRelOGP}$	$f_{2ijRelOGP}$	$f_{3ijRelOGP}$	$f_{4ijRelOGP}$	$f_{5ijRelOGP}$		
K2	775,72	0,410	0,590	0,000	0,000	0,000	2,181	0							-2,181
K3	1332,33	0,491	0,509	0,000	0,000	0,000	2,017	0							-2,017
K4	545,94	0,000	1,000	0,000	0,000	0,000	3,000	0							-3,000

APPENDIX B

Table A4 – Comparison of Calculation Results for Particular Solutions to the Inverse Problem for Relief Using Generalized and Differentiated Assessment Methods

Function type and unit of measurement	Generalized assessment method					Average differentiated assessment for all blocks					Relative error, %		
	Degree of anthropogenic transformation					Total	Degree of anthropogenic transformation					Total	
	insignificant or absent	weak	moderate	significant	strong		insignificant or absent	weak	moderate	significant			strong
F_{relReg} , dimensionless quantity	0,077	0,57	0,131	0,201	0,021		0,086	0,584	0,147	0,157	0,027		
POF_{RelReg} point						4,039						3,910	1,292
$F_{relOGPCi}$, dimensionless quantity	0,032	0,276	0,094	0,501	0,098		0,000	0,249	0,261	0,310	0,179		
$POF_{RelOGPC}$, point						5,712						5,835	1,230
$PSIP_{Rel}$, point						1,67						1,93	2,552
$PSIP_{Rel}\%$						16,73						19,25	2,522

Table A5 – Results of calculations of partial objective functions and a partial solution of the inverse problem for the soil-vegetation layer (SVL) using the differentiated assessment method

Block designation	Blocks throughout the region							Blocks with the presence of OGPC							$PSIP_{ijSVL}$
	Area in block	functions of the k-th level of anthropogenic disturbance of the SVL in the region					POF_{ijSVL}	Area of zones with OGPC in the block	functions of the k-th level of anthropogenic disturbance of the SVL in zones with OGPC					$POF_{ijSVLOGPC}$	
		$f_{1ijSVLReg}$	$f_{2ijSVLReg}$	$f_{3ijSVLReg}$	$f_{4ijSVLReg}$	$f_{5ijSVLReg}$			$f_{1ijSVLOGPC}$	$f_{2ijSVLOGPC}$	$f_{3ijSVLOGPC}$	$f_{4ijSVLOGPC}$	$f_{5ijSVLOGPC}$		
A4	76,124	1,000	0,000	0,000	0,000	0,000	1,000	0							0,000
A5	1143,5	0,061	0,779	0,000	0,160	0,000	3,519	0							0,000
A6	258,81	0,000	0,999	0,000	0,001	0,000	3,006	0							0,000
B4	324,10	0,000	1,000	0,000	0,000	0,000	3,000	0							0,000
B5	1287,9	0,433	0,567	0,000	0,000	0,000	2,133	235,44	0	0,97039	0	0	0	2,911	-4,059

Block designation	Blocks throughout the region							Blocks with the presence of OGPC							$PSIP_{ijSVL}$
	Area in block	functions of the k-th level of anthropogenic disturbance of the SVL in the region					POF_{ijSVL}	Area of zones with OGPC in the block	functions of the k-th level of anthropogenic disturbance of the SVL in zones with OGPC					$POF_{ijSVLOGPC}$	
		$f_{1ijSVLReg}$	$f_{2ijSVLReg}$	$f_{3ijSVLReg}$	$f_{4ijSVLReg}$	$f_{5ijSVLReg}$			$f_{1ijSVLOGPC}$	$f_{2ijSVLOGPC}$	$f_{3ijSVLOGPC}$	$f_{4ijSVLOGPC}$	$f_{5ijSVLOGPC}$		
B6	2016,1	0,298	0,527	0,148	0,027	0,000	2,807	184,72	0	0,31158	0,539048	0,539048	0	7,403	-20,189
B7	907,67	0,000	0,037	0,066	0,695	0,202	7,124	0							0,000
B8	190,19	0,000	0,000	1,000	0,000	0,000	5,000	0							0,000
C3	464,54	0,000	0,404	0,034	0,447	0,115	5,548	142,47	0	0,40498	0,521398	0,521398	0,073615	8,134	8,134
C4	2480,7	0,000	0,247	0,525	0,209	0,019	5,002	464,15	0	0,06335	0,677249	0,159383	0,100012	5,592	5,592
C5	2404,1	0,362	0,252	0,061	0,326	0,000	3,702	0							0,000
C6	2500	0,569	0,431	0,000	0,000	0,000	1,862	14,671	0	1	0	0	0	3,000	3,000

Block designation	Blocks throughout the region							Blocks with the presence of OGPC							$PSIP_{ijSVL}$
	Area in block	functions of the k-th level of anthropogenic disturbance of the SVL in the region					POF_{ijSVL}	Area of zones with OGPC in the block	functions of the k-th level of anthropogenic disturbance of the SVL in zones with OGPC					$POF_{ijSVLOGPC}$	
		$f_{1ijSVLReg}$	$f_{2ijSVLReg}$	$f_{3ijSVLReg}$	$f_{4ijSVLReg}$	$f_{5ijSVLReg}$			$f_{1ijSVLOGPC}$	$f_{2ijSVLOGPC}$	$f_{3ijSVLOGPC}$	$f_{4ijSVLOGPC}$	$f_{5ijSVLOGPC}$		
C7	2500	0,112	0,386	0,141	0,355	0,006	4,512	938,36	0,039785	0,21351	0,121927	0,121927	0,560453	7,188	-30,145
C8	2193,6	0,119	0,372	0,399	0,109	0,000	3,998	159,44	0	0,549783	0,450217	0,450217	0	7,052	7,052
C9	313,02	0,000	0,000	1,000	0,000	0,000	5,000	0							0,000
D3	600,14	0,624	0,138	0,000	0,061	0,177	3,060	437,18	0	0,608615	0,099059	0,124491	0,167835	4,703	4,703
D4	2500	0,000	0,410	0,483	0,108	0,000	4,396	0							0,000
D5	2500	0,160	0,313	0,469	0,058	0,000	3,848	0							0,000
D6	2500	0,531	0,469	0,000	0,000	0,000	1,938	0							0,000

Block designation	Blocks throughout the region							Blocks with the presence of OGPC							$PSIP_{ijSVL}$
	Area in block	functions of the k-th level of anthropogenic disturbance of the SVL in the region					POF_{ijSVL}	Area of zones with OGPC in the block	functions of the k-th level of anthropogenic disturbance of the SVL in zones with OGPC					$POF_{ijSVLOGPC}$	
		$f_{1ijSVLReg}$	$f_{2ijSVLReg}$	$f_{3ijSVLReg}$	$f_{4ijSVLReg}$	$f_{5ijSVLReg}$			$f_{1ijSVLOGPC}$	$f_{2ijSVLOGPC}$	$f_{3ijSVLOGPC}$	$f_{4ijSVLOGPC}$	$f_{5ijSVLOGPC}$		
D7	2500	0,108	0,467	0,305	0,013	0,107	4,087	436,62	0	0,014940	0,645646	0,057595	0,281818	6,213	6,213
D8	2500	0,000	0,464	0,294	0,209	0,033	4,622	1232,6	0	0,362254	0,177286	0,410008	0,050452	5,297	5,297
D9	1278,1	0,000	0,765	0,235	0,000	0,000	3,471	122,82	0	0,951989	0,048011	0	0	3,096	3,096
D10	166,05	0,000	1,000	0,000	0,000	0,000	3,000	85,122	0	0	0	1	0	7,000	7,000
D11	474,87	0,337	0,663	0,000	0,000	0,000	2,326	0							0,000
E3	714,04	0,211	0,789	0,000	0,000	0,000	2,578	0							0,000
E4	2500	0,000	0,669	0,307	0,024	0,000	3,709	0							0,000

Block designation	Blocks throughout the region							Blocks with the presence of OGPC							$PSIP_{ijSVL}$
	Area in block	functions of the k-th level of anthropogenic disturbance of the SVL in the region					POF_{ijSVL}	Area of zones with OGPC in the block	functions of the k-th level of anthropogenic disturbance of the SVL in zones with OGPC					$POF_{ijSVLOGPC}$	
		$f_{1ijSVLReg}$	$f_{2ijSVLReg}$	$f_{3ijSVLReg}$	$f_{4ijSVLReg}$	$f_{5ijSVLReg}$			$f_{1ijSVLOGPC}$	$f_{2ijSVLOGPC}$	$f_{3ijSVLOGPC}$	$f_{4ijSVLOGPC}$	$f_{5ijSVLOGPC}$		
E5	2500	0,382	0,252	0,303	0,062	0,000	3,090	0							0,000
E6	2500	0,772	0,228	0,000	0,000	0,000	1,456	0							0,000
E7	2500	0,031	0,672	0,212	0,000	0,085	3,871	0							0,000
E8	2500	0,000	0,097	0,573	0,065	0,265	5,996	354,69	0	0	0,329024	0,103046	0,56793	7,478	7,478
E9	2493,9	0,392	0,168	0,440	0,000	0,000	3,098	0							0,000
E10	2379,4	0,379	0,578	0,043	0,000	0,000	2,328	184,60	0	0,004320	0,995679	0	0	4,991	4,194
E11	632,44	0,535	0,465	0,000	0,000	0,000	1,930	150,43	0	0,931014	0,068986	0	0	3,138	-136,917

Block designation	Blocks throughout the region							Blocks with the presence of OGPC							$PSIP_{ijSVL}$
	Area in block	functions of the k-th level of anthropogenic disturbance of the SVL in the region					POF_{ijSVL}	Area of zones with OGPC in the block	functions of the k-th level of anthropogenic disturbance of the SVL in zones with OGPC					$POF_{ijSVLOGPC}$	
		$f_{1ijSVLReg}$	$f_{2ijSVLReg}$	$f_{3ijSVLReg}$	$f_{4ijSVLReg}$	$f_{5ijSVLReg}$			$f_{1ijSVLOGPC}$	$f_{2ijSVLOGPC}$	$f_{3ijSVLOGPC}$	$f_{4ijSVLOGPC}$	$f_{5ijSVLOGPC}$		
F2	543,22	0,000	0,728	0,272	0,000	0,000	3,543	0							0,000
F3	2496,1	0,000	1,000	0,000	0,000	0,000	3,000	140,05	0	0	1	0	0	5,000	5,000
F4	2500	0,413	0,445	0,142	0,000	0,000	2,459	130,42	0	0	1	0	0	5,000	5,000
F5	2500	0,597	0,360	0,028	0,015	0,000	1,923	0							0,000
F6	2500	0,349	0,060	0,404	0,186	0,000	3,854	0							0,000
F7	2500	0,240	0,494	0,266	0,000	0,000	3,051	0							0,000
F8	2500	0,172	0,139	0,689	0,000	0,000	4,033	0							0,000

Block designation	Blocks throughout the region							Blocks with the presence of OGPC							$PSIP_{ijSVL}$
	Area in block	functions of the k-th level of anthropogenic disturbance of the SVL in the region					POF_{ijSVL}	Area of zones with OGPC in the block	functions of the k-th level of anthropogenic disturbance of the SVL in zones with OGPC					$POF_{ijSVLOGPC}$	
		$f_{1ijSVLReg}$	$f_{2ijSVLReg}$	$f_{3ijSVLReg}$	$f_{4ijSVLReg}$	$f_{5ijSVLReg}$			$f_{1ijSVLOGPC}$	$f_{2ijSVLOGPC}$	$f_{3ijSVLOGPC}$	$f_{4ijSVLOGPC}$	$f_{5ijSVLOGPC}$		
F9	2500	0,226	0,653	0,122	0,000	0,000	2,792	0							0,000
F10	1965,4	0,199	0,801	0,000	0,000	0,000	2,601	0							0,000
G1	154,97	0,000	0,000	0,718	0,282	0,000	5,563	0							0,000
G2	2352,6	0,000	0,094	0,812	0,094	0,000	5,000	831,60	0	0	0,165125	0,760527	0,074348	6,818	6,818
G3	2500	0,317	0,638	0,045	0,000	0,000	2,457	236,48	0	0	0,979835	0,020165	0	5,040	5,040
G4	2500	0,704	0,270	0,026	0,000	0,000	1,644	58,708	0	0,135079	0,163945	0,700976	0	6,132	-1,798
G5	2500	0,002	0,265	0,487	0,245	0,000	4,950	231,02	0	0	0,528044	0,220093	0,251863	6,448	6,448

Block designation	Blocks throughout the region							Blocks with the presence of OGPC							$PSIP_{ijSVL}$
	Area in block	functions of the k-th level of anthropogenic disturbance of the SVL in the region					POF_{ijSVL}	Area of zones with OGPC in the block	functions of the k-th level of anthropogenic disturbance of the SVL in zones with OGPC					$POF_{ijSVLOGPC}$	
		$f_{1ijSVLReg}$	$f_{2ijSVLReg}$	$f_{3ijSVLReg}$	$f_{4ijSVLReg}$	$f_{5ijSVLReg}$			$f_{1ijSVLOGPC}$	$f_{2ijSVLOGPC}$	$f_{3ijSVLOGPC}$	$f_{4ijSVLOGPC}$	$f_{5ijSVLOGPC}$		
G6	2500	0,000	0,000	0,999	0,001	0,000	5,003	0							0,000
G7	2500	0,337	0,377	0,286	0,000	0,000	2,896	0							0,000
G8	2500	0,661	0,315	0,023	0,000	0,000	1,724	0							0,000
G9	2500	0,499	0,471	0,030	0,000	0,000	2,061	140,05	0,101604	0,898396	0	0	0	2,797	-11,433
G10	1504,9	0,121	0,879	0,000	0,000	0,000	2,757	0							0,000
H1	728,05	0,000	0,939	0,000	0,061	0,000	3,244	134,87	0	0	1	0	0	5,000	5,000
H2	2500	0,101	0,532	0,186	0,181	0,000	3,893	117,08	0	0	0,51665	0,48335	0	5,967	5,967

Block designation	Blocks throughout the region							Blocks with the presence of OGPC							$PSIP_{ijSVL}$
	Area in block	functions of the k-th level of anthropogenic disturbance of the SVL in the region					POF_{ijSVL}	Area of zones with OGPC in the block	functions of the k-th level of anthropogenic disturbance of the SVL in zones with OGPC					$POF_{ijSVLOGPC}$	
		$f_{1ijSVLReg}$	$f_{2ijSVLReg}$	$f_{3ijSVLReg}$	$f_{4ijSVLReg}$	$f_{5ijSVLReg}$			$f_{1ijSVLOGPC}$	$f_{2ijSVLOGPC}$	$f_{3ijSVLOGPC}$	$f_{4ijSVLOGPC}$	$f_{5ijSVLOGPC}$		
H3	2500	0,009	0,645	0,188	0,157	0,000	3,987	0							0,000
H4	2500	0,199	0,521	0,091	0,189	0,000	3,541	0							0,000
H5	2500	0,000	0,008	0,870	0,122	0,000	5,228	0							0,000
H6	2500	0,000	0,030	0,970	0,000	0,000	4,940	0							0,000
H7	2500	0,058	0,786	0,157	0,000	0,000	3,198	0							0,000
H8	2500	0,662	0,338	0,000	0,000	0,000	1,675	0							0,000
H9	2500	0,330	0,670	0,000	0,000	0,000	2,341	0							0,000

Block designation	Blocks throughout the region							Blocks with the presence of OGPC							$PSIP_{ijSVL}$
	Area in block	functions of the k-th level of anthropogenic disturbance of the SVL in the region					POF_{ijSVL}	Area of zones with OGPC in the block	functions of the k-th level of anthropogenic disturbance of the SVL in zones with OGPC					$POF_{ijSVLOGPC}$	
		$f_{1ijSVLReg}$	$f_{2ijSVLReg}$	$f_{3ijSVLReg}$	$f_{4ijSVLReg}$	$f_{5ijSVLReg}$			$f_{1ijSVLOGPC}$	$f_{2ijSVLOGPC}$	$f_{3ijSVLOGPC}$	$f_{4ijSVLOGPC}$	$f_{5ijSVLOGPC}$		
H10	2391,6	0,000	1,000	0,000	0,000	0,000	3,000	0							0,000
H11	475,30	0,000	1,000	0,000	0,000	0,000	3,000	0							0,000
I1	1235,5	0,250	0,750	0,000	0,000	0,000	2,499	0							0,000
I2	2500	0,817	0,182	0,002	0,000	0,000	1,370	0							0,000
I3	2500	0,009	0,645	0,188	0,157	0,000	3,987	0							0,000
I4	2500	0,000	0,061	0,725	0,213	0,000	5,304	0							0,000
I5	2500	0,000	0,000	0,948	0,052	0,000	5,103	0							0,000

Block designation	Blocks throughout the region							Blocks with the presence of OGPC							$PSIP_{ijSVL}$
	Area in block	functions of the k-th level of anthropogenic disturbance of the SVL in the region					POF_{ijSVL}	Area of zones with OGPC in the block	functions of the k-th level of anthropogenic disturbance of the SVL in zones with OGPC					$POF_{ijSVLOGPC}$	
		$f_{1ijSVLReg}$	$f_{2ijSVLReg}$	$f_{3ijSVLReg}$	$f_{4ijSVLReg}$	$f_{5ijSVLReg}$			$f_{1ijSVLOGPC}$	$f_{2ijSVLOGPC}$	$f_{3ijSVLOGPC}$	$f_{4ijSVLOGPC}$	$f_{5ijSVLOGPC}$		
I6	2500	0,000	0,002	0,998	0,000	0,000	4,996	0							0,000
I7	2500	0,003	0,370	0,626	0,000	0,000	4,246	0							0,000
I8	2500	0,305	0,695	0,000	0,000	0,000	2,390	0							0,000
I9	2500	0,411	0,589	0,000	0,000	0,000	2,179	0							0,000
I10	2500	0,709	0,291	0,000	0,000	0,000	1,581	0							0,000
I11	2444,8	0,559	0,441	0,000	0,000	0,000	1,881	0							0,000
I12	1288,4	0,988	0,012	0,000	0,000	0,000	1,024	0							0,000

Block designation	Blocks throughout the region							Blocks with the presence of OGPC							$PSIP_{ijSVL}$
	Area in block	functions of the k-th level of anthropogenic disturbance of the SVL in the region					POF_{ijSVL}	Area of zones with OGPC in the block	functions of the k-th level of anthropogenic disturbance of the SVL in zones with OGPC					$POF_{ijSVLOGPC}$	
		$f_{1ijSVLReg}$	$f_{2ijSVLReg}$	$f_{3ijSVLReg}$	$f_{4ijSVLReg}$	$f_{5ijSVLReg}$			$f_{1ijSVLOGPC}$	$f_{2ijSVLOGPC}$	$f_{3ijSVLOGPC}$	$f_{4ijSVLOGPC}$	$f_{5ijSVLOGPC}$		
I13	0,0521	1,000	0,000	0,000	0,000	0,000	1,000	0							0,000
J1	286,05	0,000	0,902	0,098	0,000	0,000	3,195	0							0,000
J2	2383,4	0,445	0,330	0,226	0,000	0,000	2,562	0							0,000
J3	2500	0,066	0,669	0,265	0,000	0,000	3,399	0							0,000
J4	1905,7	0,000	0,076	0,818	0,106	0,000	5,059	0							0,000
J5	1294,4	0,000	0,305	0,076	0,619	0,000	5,628	0							0,000
J6	1357,6	0,000	0,501	0,499	0,000	0,000	3,997	0							0,000

Block designation	Blocks throughout the region							Blocks with the presence of OGPC							$PSIP_{ijSVL}$
	Area in block	functions of the k-th level of anthropogenic disturbance of the SVL in the region					POF_{ijSVL}	Area of zones with OGPC in the block	functions of the k-th level of anthropogenic disturbance of the SVL in zones with OGPC					$POF_{ijSVLOGPC}$	
		$f_{1ijSVLReg}$	$f_{2ijSVLReg}$	$f_{3ijSVLReg}$	$f_{4ijSVLReg}$	$f_{5ijSVLReg}$			$f_{1ijSVLOGPC}$	$f_{2ijSVLOGPC}$	$f_{3ijSVLOGPC}$	$f_{4ijSVLOGPC}$	$f_{5ijSVLOGPC}$		
J7	1434,7	0,243	0,552	0,205	0,000	0,000	2,924	0							0,000
J8	1508,5	0,999	0,001	0,000	0,000	0,000	1,002	0							0,000
J9	1581,0	0,969	0,031	0,000	0,000	0,000	1,062	0							0,000
J10	1652,0	1,000	0,000	0,000	0,000	0,000	1,000	0							0,000
J11	1728,8	1,000	0,000	0,000	0,000	0,000	1,000	0							0,000
J12	1580,9	1,000	0,000	0,000	0,000	0,000	1,000	0							0,000
K2	737,86	0,699	0,301	0,000	0,000	0,000	1,602	0							0,000

Block designation	Blocks throughout the region							Blocks with the presence of OGPC							$PSIP_{ijSVL}$
	Area in block	functions of the k-th level of anthropogenic disturbance of the SVL in the region					POF_{ijSVL}	Area of zones with OGPC in the block	functions of the k-th level of anthropogenic disturbance of the SVL in zones with OGPC					$POF_{ijSVLOGPC}$	
		$f_{1ijSVLReg}$	$f_{2ijSVLReg}$	$f_{3ijSVLReg}$	$f_{4ijSVLReg}$	$f_{5ijSVLReg}$			$f_{1ijSVLOGPC}$	$f_{2ijSVLOGPC}$	$f_{3ijSVLOGPC}$	$f_{4ijSVLOGPC}$	$f_{5ijSVLOGPC}$		
K3	1294,3	0,183	0,490	0,327	0,000	0,000	3,286	0							0,000
K4	492,78	0,610	0,390	0,000	0,000	0,000	1,780	0							0,000

Table A6 – Results of Calculations of Partial Objective Functions and Partial Solutions to the Inverse Problem for Groundwater (GW) Using the Differentiated Assessment Method

Block designa- tion	Blocks throughout the region							Blocks with the presence of an oil and gas production complex							$PSIP_{GW}$
	Areas in blocks	functions of the k-th level of anthropogenic disturbance of the SVL in the region					POF_{GWReg}	Areas of zones with OGPC in blocks	functions of the k-th level of anthropogenic disturbance of the SVL in zones with OGPC					POF_{GWOGP} C	
		F_{GWReg} 1	F_{GWReg2}	F_{GWRe} g3	F_{GWReg} 5	F_{GWReg}			F_{GWOGP} C1	F_{GWOGP} C2	F_{GWOGP} C3	F_{GWOGP} C4	F_{GWOGP} C5		
A4	78,93	0,000	0,000	0,000	0,000	1,000	9,000	0							-9,000
A5	974,79	0,000	0,000	0,000	0,675	0,325	7,650	0							-7,650
A6	260,39	0,000	0,000	0,000	0,304	0,696	8,391	0							-8,391
B4	362,88	0,000	0,000	0,000	0,000	1,000	9,000	0							-9,000
B5	1093,86	0,000	0,000	0,000	0,667	0,333	7,665	235,4421	0,000	0,000	0,000	0,845	0,155	7,310	-0,355
B6	1928,73	0,000	0,000	0,000	0,762	0,238	7,475	184,7211	0,000	0,000	0,000	0,932	0,068	7,137	-0,338
B7	785,78	0,000	0,000	0,000	0,644	0,356	7,713	0							-7,713

Block design ation	Blocks throughout the region							Blocks with the presence of an oil and gas production complex							$PSIP_{GW}$
	Areas in blocks	functions of the k-th level of anthropogenic disturbance of the SVL in the region					POF_{GWReg}	Areas of zones with OGPC in blocks	functions of the k-th level of anthropogenic disturbance of the SVL in zones with OGPC					POF_{GWOGP} C	
		F_{GWReg} 1	F_{GWReg2}	F_{GWRe} g3	F_{GWReg} 5	F_{GWReg}			F_{GWOGP} C1	F_{GWOGP} C2	F_{GWOGP} C3	F_{GWOGP} C4	F_{GWOGP} C5		
B8	130,77	0,000	0,000	0,000	0,000	1,000	9,000	0							-9,000
C3	367,09	0,000	0,000	0,000	0,000	1,000	9,000	142,4739	0,000	0,000	0,000	0,000	1,000	9,000	0,000
C4	2485,65	0,000	0,000	0,000	0,000	1,000	9,000	464,3472	0,000	0,000	0,000	0,000	1,000	9,000	0,000
C5	2449,20	0,000	0,000	0,000	0,390	0,610	8,219	0							-8,219
C6	2492,52	0,000	0,000	0,000	0,926	0,074	7,149	14,67149	0,000	0,000	0,000	1,000	0,000	7,000	-0,149
C7	2512,66	0,000	0,000	0,000	0,527	0,473	7,946	923,645	0,000	0,000	0,000	0,376	0,624	8,248	0,302
C8	2136,73	0,000	0,000	0,000	0,464	0,536	8,072	159,4401	0,000	0,000	0,000	0,629	0,371	7,742	-0,330

Block design ation	Blocks throughout the region							Blocks with the presence of an oil and gas production complex							$PSIP_{GW}$
	Areas in blocks	functions of the k-th level of anthropogenic disturbance of the SVL in the region					POF_{GWReg}	Areas of zones with OGPC in blocks	functions of the k-th level of anthropogenic disturbance of the SVL in zones with OGPC					POF_{GWOGP} C	
		F_{GWReg} 1	F_{GWReg2}	F_{GWRe} g3	F_{GWReg} 5	F_{GWReg}			F_{GWOGP} C1	F_{GWOGP} C2	F_{GWOGP} C3	F_{GWOGP} C4	F_{GWOGP} C5		
C9	296,63	0,000	0,000	0,000	0,590	0,410	7,820	0							-7,820
D3	506,95	0,000	0,000	0,000	0,000	1,000	9,000	439,233	0,000	0,000	0,000	0,000	1,000	9,000	0,000
D4	2499,21	0,000	0,000	0,000	0,000	1,000	9,000	0							-9,000
D5	2549,36	0,000	0,000	0,000	0,315	0,685	8,370	0							-8,370
D6	2541,51	0,000	0,000	0,000	0,938	0,062	7,125	0							-7,125
D7	2551,66	0,000	0,000	0,000	0,708	0,292	7,584	424,6276	0,000	0,000	0,000	0,793	0,207	7,414	-0,169
D8	2509,80	0,000	0,000	0,000	0,878	0,122	7,244	1232,641	0,000	0,000	0,000	0,809	0,191	7,383	0,138

Block designa- tion	Blocks throughout the region							Blocks with the presence of an oil and gas production complex							$PSIP_{GW}$
	Areas in blocks	functions of the k-th level of anthropogenic disturbance of the SVL in the region					POF_{GWReg}	Areas of zones with OGPC in blocks	functions of the k-th level of anthropogenic disturbance of the SVL in zones with OGPC					POF_{GWOGP} C	
		F_{GWReg} 1	F_{GWReg2}	F_{GWRe} g3	F_{GWReg} 5	F_{GWReg}			F_{GWOGP} C1	F_{GWOGP} C2	F_{GWOGP} C3	F_{GWOGP} C4	F_{GWOGP} C5		
D9	1249,98	0,000	0,000	0,000	0,719	0,281	7,563	122,8209	0,000	0,000	0,000	1,000	0,000	7,000	-0,563
D10	190,75	0,000	0,000	0,000	1,000	0,000	7,000	85,122	0,000	0,000	0,000	1,000	0,000	7,000	0,000
D11	494,37	0,000	0,000	0,000	1,000	0,000	7,000	0							-7,000
E3	716,61	0,000	0,000	0,000	1,000	0,000	7,000	0							-7,000
E4	2499,16	0,000	0,000	0,000	1,000	0,000	7,000	0							-7,000
E5	2499,36	0,000	0,000	0,000	0,039	0,961	8,921	0							-8,921
E6	2497,51	0,000	0,000	0,000	0,779	0,221	7,442	0							-7,442

Block designa- tion	Blocks throughout the region							Blocks with the presence of an oil and gas production complex							$PSIP_{GW}$
	Areas in blocks	functions of the k-th level of anthropogenic disturbance of the SVL in the region					POF_{GWReg}	Areas of zones with OGPC in blocks	functions of the k-th level of anthropogenic disturbance of the SVL in zones with OGPC					POF_{GWOGP} C	
		F_{GWReg} 1	F_{GWReg} 2	F_{GWRe} g3	F_{GWReg} 4	F_{GWReg} 5			F_{GWOGP} C1	F_{GWOGP} C2	F_{GWOGP} C3	F_{GWOGP} C4	F_{GWOGP} C5		
E7	2499,66	0,000	0,000	0,000	0,605	0,395	7,789	0							-7,789
E8	2507,80	0,000	0,000	0,246	0,150	0,604	7,717	354,699	0,000	0,000	0,000	0,795	0,205	7,409	-0,307
E9	2499,61	0,000	0,000	0,554	0,281	0,165	6,221	0							-6,221
E10	2336,74	0,000	0,000	0,635	0,328	0,037	5,802	184,6095	0,000	0,000	0,000	0,994	0,006	7,011	1,209
E11	670,51	0,000	0,000	0,435	0,565	0,000	6,130	220,9432	0,000	0,000	0,863	0,137	0,000	5,275	-0,855
F2	540,63	0,000	0,000	0,000	0,000	1,000	9,000	0							-9,000
F3	2499,27	0,000	0,000	0,000	0,000	1,000	9,000	140,0546	0,000	0,000	0,000	0,000	1,000	9,000	0,000

Block designa- tion	Blocks throughout the region							Blocks with the presence of an oil and gas production complex							$PSIP_{GW}$
	Areas in blocks	functions of the k-th level of anthropogenic disturbance of the SVL in the region					POF_{GWReg}	Areas of zones with OGPC in blocks	functions of the k-th level of anthropogenic disturbance of the SVL in zones with OGPC					POF_{GWOGP} C	
		F_{GWReg} 1	F_{GWReg2}	F_{GWRe} g3	F_{GWReg} 5	F_{GWReg}			F_{GWOGP} C1	F_{GWOGP} C2	F_{GWOGP} C3	F_{GWOGP} C4	F_{GWOGP} C5		
F4	2499,11	0,000	0,000	0,000	0,052	0,948	8,895	130,4297	0,000	0,000	0,000	0,000	1,000	9,000	0,105
F5	2499,36	0,000	0,000	0,000	0,476	0,524	8,048	0							-8,048
F6	2499,51	0,000	0,000	0,081	0,869	0,051	6,940	0							-6,940
F7	2499,66	0,010	0,000	0,654	0,337	0,000	5,635	0							-5,635
F8	2499,78	0,000	0,000	0,983	0,017	0,000	5,034	0							-5,034
F9	2497,90	0,000	0,000	1,000	0,000	0,000	5,000	0							-5,000
F10	1988,30	0,000	0,000	1,000	0,000	0,000	5,000	0							-5,000

Block design ation	Blocks throughout the region							Blocks with the presence of an oil and gas production complex							$PSIP_{GW}$
	Areas in blocks	functions of the k-th level of anthropogenic disturbance of the SVL in the region					POF_{GWReg}	Areas of zones with OGPC in blocks	functions of the k-th level of anthropogenic disturbance of the SVL in zones with OGPC					POF_{GWOGP} C	
		F_{GWReg} 1	F_{GWReg2}	F_{GWRe} $g3$	F_{GWReg} 5	F_{GWReg}			F_{GWOGP} $C1$	F_{GWOGP} $C2$	F_{GWOGP} $C3$	F_{GWOGP} $C4$	F_{GWOGP} $C5$		
G1	253,35	0,000	0,000	0,000	0,000	1,000	9,000	0							-9,000
G2	2393,41	0,000	0,000	0,000	0,000	1,000	9,000	801,6077	0,000	0,000	0,000	0,000	1,000	9,000	0,000
G3	2499,05	0,000	0,000	0,000	0,000	1,000	9,000	226,4802	0,000	0,000	0,000	0,000	1,000	9,000	0,000
G4	2499,21	0,000	0,000	0,000	0,260	0,740	8,481	58,70816	0,000	0,000	0,000	0,836	0,164	7,328	-1,153
G5	2499,36	0,000	0,000	0,115	0,885	0,000	6,769	231,0258	0,000	0,000	0,000	1,000	0,000	7,000	0,231
G6	2499,51	0,282	0,000	0,631	0,087	0,000	4,046	0							-4,046
G7	2499,65	0,887	0,000	0,113	0,000	0,000	1,452	0							-1,452

Block designa- tion	Blocks throughout the region							Blocks with the presence of an oil and gas production complex							$PSIP_{GW}$
	Areas in blocks	functions of the k-th level of anthropogenic disturbance of the SVL in the region					POF_{GWReg}	Areas of zones with OGPC in blocks	functions of the k-th level of anthropogenic disturbance of the SVL in zones with OGPC					POF_{GWOGP} C	
		F_{GWReg} 1	F_{GWReg2}	F_{GWRe} g3	F_{GWReg} 5	F_{GWReg}			F_{GWOGP} C1	F_{GWOGP} C2	F_{GWOGP} C3	F_{GWOGP} C4	F_{GWOGP} C5		
G8	2499,83	0,141	0,000	0,859	0,000	0,000	4,436	0							-4,436
G9	2499,90	0,008	0,000	0,992	0,000	0,000	4,968	140,0546	0,000	0,000	1,000	0,000	0,000	5,000	0,032
G10	1548,56	0,161	0,078	0,761	0,000	0,000	4,200	0							-4,200
H1	744,07	0,000	0,000	0,000	0,000	1,000	9,000	124,8781	0,000	0,000	0,000	0,000	1,000	9,000	0,000
H2	2499,90	0,000	0,000	0,000	0,000	1,000	9,000	107,0835	0,000	0,000	0,000	0,000	1,000	9,000	0,000
H3	2499,05	0,000	0,000	0,000	0,000	1,000	9,000	0							-9,000
H4	2499,21	0,000	0,000	0,000	0,607	0,393	7,787	0							-7,787

Block designa- tion	Blocks throughout the region							Blocks with the presence of an oil and gas production complex							$PSIP_{GW}$
	Areas in blocks	functions of the k-th level of anthropogenic disturbance of the SVL in the region					POF_{GWReg}	Areas of zones with OGPC in blocks	functions of the k-th level of anthropogenic disturbance of the SVL in zones with OGPC					POF_{GWOGP} C	
		F_{GWReg} 1	F_{GWReg} 2	F_{GWRe} 3	F_{GWReg} 4	F_{GWReg} 5			F_{GWOGP} C1	F_{GWOGP} C2	F_{GWOGP} C3	F_{GWOGP} C4	F_{GWOGP} C5		
H5	2499,36	0,000	0,000	0,388	0,612	0,000	6,225	0							-6,225
H6	2499,51	0,776	0,000	0,224	0,000	0,000	1,895	0							-1,895
H7	2499,65	1,000	0,000	0,000	0,000	0,000	1,000	0							-1,000
H8	2519,77	0,566	0,000	0,434	0,000	0,000	2,737	0							-2,737
H9	2499,94	0,700	0,040	0,260	0,000	0,000	2,120	0							-2,120
H10	2414,34	0,879	0,121	0,000	0,000	0,000	1,242	0							-1,242
H11	473,70	1,000	0,000	0,000	0,000	0,000	1,000	0							-1,000

Block design ation	Blocks throughout the region							Blocks with the presence of an oil and gas production complex							$PSIP_{GW}$
	Areas in blocks	functions of the k-th level of anthropogenic disturbance of the SVL in the region					POF_{GWReg}	Areas of zones with OGPC in blocks	functions of the k-th level of anthropogenic disturbance of the SVL in zones with OGPC					POF_{GWOGP} C	
		F_{GWReg} 1	F_{GWReg2}	F_{GWRe} g^3	F_{GWReg} 5	F_{GWReg}			F_{GWOGP} C1	F_{GWOGP} C2	F_{GWOGP} C3	F_{GWOGP} C4	F_{GWOGP} C5		
I1	1261,51	0,000	0,000	0,575	0,000	0,425	6,700	0							-6,700
I2	2501,88	0,000	0,000	0,727	0,000	0,273	6,093	0							-6,093
I3	2499,08	0,000	0,000	0,507	0,000	0,493	6,973	0							-6,973
I4	2501,18	0,000	0,000	0,617	0,223	0,160	6,086	0							-6,086
I5	2501,37	0,246	0,000	0,750	0,004	0,000	4,024	0							-4,024
I6	2499,51	0,996	0,000	0,004	0,000	0,000	1,014	0							-1,014
I7	2499,66	1,000	0,000	0,000	0,000	0,000	1,000	0							-1,000

Block designa- tion	Blocks throughout the region							Blocks with the presence of an oil and gas production complex							$PSIP_{GW}$
	Areas in blocks	functions of the k-th level of anthropogenic disturbance of the SVL in the region					POF_{GWReg}	Areas of zones with OGPC in blocks	functions of the k-th level of anthropogenic disturbance of the SVL in zones with OGPC					POF_{GWOGP} C	
		F_{GWReg} 1	F_{GWReg} 2	F_{GWRe} 3	F_{GWReg} 4	F_{GWReg} 5			F_{GWOGP} C1	F_{GWOGP} C2	F_{GWOGP} C3	F_{GWOGP} C4	F_{GWOGP} C5		
I8	2499,80	1,000	0,000	0,000	0,000	0,000	1,000	0							-1,000
I9	2479,93	0,992	0,008	0,000	0,000	0,000	1,016	0							-1,016
I10	2499,08	1,000	0,000	0,000	0,000	0,000	1,000	0							-1,000
I11	2459,30	0,990	0,010	0,000	0,000	0,000	1,020	0							-1,020
I12	1285,16	1,000	0,000	0,000	0,000	0,000	1,000	0							-1,000
I13	0,95	1,000	0,000	0,000	0,000	0,000	1,000	0							-1,000
J1	285,59	0,000	0,000	1,000	0,000	0,000	5,000	0							-5,000

Block design ation	Blocks throughout the region							Blocks with the presence of an oil and gas production complex							$PSIP_{GW}$
	Areas in blocks	functions of the k-th level of anthropogenic disturbance of the SVL in the region					POF_{GWReg}	Areas of zones with OGPC in blocks	functions of the k-th level of anthropogenic disturbance of the SVL in zones with OGPC					POF_{GWOGP} C	
		F_{GWReg} 1	F_{GWReg2}	F_{GWRe} g^3	F_{GWReg} 5	F_{GWReg}			F_{GWOGP} C1	F_{GWOGP} C2	F_{GWOGP} C3	F_{GWOGP} C4	F_{GWOGP} C5		
J2	2375,20	0,000	0,000	1,000	0,000	0,000	5,000	0							-5,000
J3	2499,10	0,000	0,000	1,000	0,000	0,000	5,000	0							-5,000
J4	1925,27	0,136	0,204	0,660	0,000	0,000	4,048	0							-4,048
J5	1321,11	0,940	0,000	0,060	0,000	0,000	1,238	0							-1,238
J6	1372,24	1,000	0,000	0,000	0,000	0,000	1,000	0							-1,000
J7	1449,00	1,000	0,000	0,000	0,000	0,000	1,000	0							-1,000
J8	1547,88	1,000	0,000	0,000	0,000	0,000	1,000	0							-1,000

Block designa- tion	Blocks throughout the region							Blocks with the presence of an oil and gas production complex							$PSIP_{GW}$
	Areas in blocks	functions of the k-th level of anthropogenic disturbance of the SVL in the region					POF_{GWReg}	Areas of zones with OGPC in blocks	functions of the k-th level of anthropogenic disturbance of the SVL in zones with OGPC					POF_{GWOGP} C	
		F_{GWReg} 1	F_{GWReg} 2	F_{GWRe} 3	F_{GWReg} 4	F_{GWReg} 5			F_{GWOGP} C1	F_{GWOGP} C2	F_{GWOGP} C3	F_{GWOGP} C4	F_{GWOGP} C5		
J9	1592,61	0,649	0,351	0,000	0,000	0,000	1,702	0							-1,702
J10	1667,55	0,858	0,142	0,000	0,000	0,000	1,283	0							-1,283
J11	1737,94	0,674	0,326	0,000	0,000	0,000	1,652	0							-1,652
J12	1595,06	1,000	0,000	0,000	0,000	0,000	1,000	0							-1,000
K2	734,51	0,000	0,000	1,000	0,000	0,000	5,000	0							-5,000
K3	1288,64	0,000	0,002	0,998	0,000	0,000	4,996	0							-4,996
K4	522,26	0,000	0,689	0,311	0,000	0,000	3,621	0							-3,621

Table A7 – Comparison of Calculation Results for Particular Solutions to the Inverse Problem for the Soil-Vegetation Layer Using Generalized and Differentiated Assessment Methods

Function type and unit of measurement	Generalized assessment method					Average differentiated assessment for all blocks						Relative error , %	
	Degree of anthropogenic transformation					Function value	Degree of anthropogenic transformation						Function value
	insignificant or absent	weak	moderate	significant	strong		insignificant or absent	weak	moderate	significant	strong		
F_{SVLReg} , dimensionless quantity	0,275	0,404	0,251	0,06	0,01		0,284	0,414	0,229	0,062	0,011		
POF_{SVLReg} , point					3,252						3,203	0,494	
$F_{SVL OGPCi}$, dimensionless quantity	0,027	0,183	0,331	0,234	0,224		0,006	0,309	0,418	0,236	0,089		
$POF_{SVLOGPC}$, point						5,889						5,475	4,141
$PSIP_{SVL}$, point						2,64						2,272	3,676

Function type and unit of measurement	Generalized assessment method						Average differentiated assessment for all blocks						Relative error , %
	Degree of anthropogenic transformation					Function value	Degree of anthropogenic transformation					Function value	
	insignificant or absent	weak	moderate	significant	strong		insignificant or absent	weak	moderate	significant	strong		
$PSIP_{SVL}$, %						26,37						22,724	3,676

Table A8 – Comparison of Calculation Results for Particular Solutions to the Inverse Problem for Groundwater Using Generalized and Differentiated Assessment Methods

Function type and unit of measurement	Generalized assessment method						Average differentiated assessment for all blocks						Relative error, %
	Degree of anthropogenic transformation					Function value	Degree of anthropogenic transformation					Function value	
	insignificant or absent	weak	moderate	significant	strong		insignificant or absent	weak	moderate	significant	strong		

$F_{GW\ Reg}$, dimensionless quantity	0,252	0,016	0,239	0,212	0,28 1		0,241	0,022	0,215	0,227	0,29 5		
$POF_{SVL\ Rel}$, point						5,509						5,631	1,216
$F_{GWOGPCi}$, dimensionless quantity	0	0	0,039	0,439	0,52 1		0,000	0,000	0,078	0,464	0,45 8		
POF_{GWOGPC} , point						7,964						7,761	2,033
$PSIP_{GW}$, point						2,46						2,130	3,249
$PSIP_{GW}$, %						24,55						21,301	3,249

Table A9 – Results of Calculations of Integral Functions of Anthropogenic Impact on the Natural Environment of the Mangystau Region and the Inverse Problem of Complex Environmental Assessment (Assessment of the Additional Contribution of the OGPC to the Anthropogenic Transformation of the Natural Environment by Grid Model Blocks)

Block designation	Partial Differentiated Functions									Integral differential		
	Relief			Soil and vegetation layer			Groundwater			functions (for all components of the natural environment)		solution to the inverse problem
	POF_{Rel}	$POF_{RelOGPC}$	$PSIP_{Rel}$	$POF_{SVLRelg}$	$POF_{SVLOGPC}$	$PSIP_{SVL}$	POF_{GWReg}	POF_{GWOGPC}	$PSIP_{RegGW}$	IOF_{Reg}	IOF_{OGPC}	$ISIP$
A-4	1,000	0,000	-1,000	1,000	0,000	-1,000	9,000	0,000	-9,000	3,640	0,000	-3,640
A-5	5,204	0,000	-5,204	3,519	0,000	-3,519	7,650	0,000	-7,650	5,438	0,000	-5,438
A-6	4,949	0,000	-4,949	3,006	0,000	-3,006	8,391	0,000	-8,391	5,424	0,000	-5,424
B-4	7,000	0,000	-7,000	3,000	0,000	-3,000	9,000	0,000	-9,000	6,300	0,000	-6,300
B-5	3,681	5,000	1,319	2,133	2,911	0,778	7,665	7,310	-0,355	4,470	5,052	0,583
B-6	4,817	6,426	1,609	2,807	7,403	4,596	7,475	7,137	-0,338	5,011	6,993	1,982

Block designation	Partial Differentiated Functions									Integral differential		
	Relief			Soil and vegetation layer			Groundwater			functions (for all components of the natural environment)		solution to the inverse problem
	POF_{Rel}	$POF_{RelOGPC}$	$PSIP_{Rel}$	POF_{SVLRel}^g	$POF_{SVLOGPC}$	$PSIP_{SVL}$	$POF_{GWReg}^.$	POF_{GWOGPC}^C	$PSIP_{Reg}^{GW}$	IOF_{Reg}	IOF_{OGPC}	$ISIP$
B-7	8,746	0,000	-8,746	7,124	0,000	-7,124	7,713	0,000	-7,713	7,854	0,000	-7,854
B-8	6,850	0,000	-6,850	5,000	0,000	-5,000	9,000	0,000	-9,000	6,930	0,000	-6,930
C-3	7,000	6,735	-0,265	5,548	8,134	2,587	9,000	9,000	0,000	7,166	7,958	0,792
C-4	5,854	5,867	0,013	5,002	5,592	0,590	9,000	9,000	0,000	6,602	6,808	0,205
C-5	3,454	0,000	-3,454	3,702	0,000	-3,702	8,219	0,000	-8,219	5,111	0,000	-5,111
C-6	4,921	7,494	2,573	1,862	3,000	1,138	7,149	7,000	-0,149	4,616	5,803	1,187
C-7	6,626	8,929	2,302	4,512	7,188	2,676	7,946	8,248	0,302	6,343	8,112	1,769
C-8	5,133	5,330	0,197	3,998	7,052	3,054	8,072	7,742	-0,330	5,717	6,711	0,994
C-9	4,074	0,000	-4,074	5,000	0,000	-5,000	7,820	0,000	-7,820	5,625	0,000	-5,625

Block designation	Partial Differentiated Functions									Integral differential		
	Relief			Soil and vegetation layer			Groundwater			functions (for all components of the natural environment)		solution to the inverse problem
	POF_{Rel}	$POF_{RelOGPC}$	$PSIP_{Rel}$	POF_{SVLRel}^g	$POF_{SVLOGPC}$	$PSIP_{SVL}$	POF_{GWReg}	POF_{GWOGPC}	$PSIP_{Reg}^{GW}$	IOF_{Reg}	IOF_{OGPC}	$ISIP$
D-3	7,000	6,118	-0,882	3,060	4,703	1,643	9,000	9,000	0,000	6,320	6,588	0,268
D-4	4,065	0,000	-4,065	4,396	0,000	-4,396	9,000	0,000	-9,000	5,806	0,000	-5,806
D-5	3,131	0,000	-3,131	3,848	0,000	-3,848	8,370	0,000	-8,370	5,104	0,000	-5,104
D-6	3,064	0,000	-3,064	1,938	0,000	-1,938	7,125	0,000	-7,125	4,021	0,000	-4,021
D-7	4,949	5,412	0,463	4,087	6,213	2,125	7,584	7,414	-0,169	5,525	6,345	0,820
D-8	4,731	8,627	3,897	4,622	5,297	0,675	7,244	7,383	0,138	5,523	7,084	1,561
D-9	3,523	3,973	0,450	3,471	3,096	-0,375	7,563	7,000	-0,563	4,838	4,674	-0,165
D-10	4,227	3,000	-1,227	3,000	7,000	4,000	7,000	7,000	0,000	4,725	5,680	0,955
D-11	3,957	0,000	-3,957	2,326	0,000	-2,326	7,000	0,000	-7,000	4,407	0,000	-4,407

Block designation	Partial Differentiated Functions									Integral differential		
	Relief			Soil and vegetation layer			Groundwater			functions (for all components of the natural environment)		solution to the inverse problem
	POF_{Rel}	$POF_{RelOGPC}$	$PSIP_{Rel}$	POF_{SVLRel}^g	$POF_{SVLOGPC}$	$PSIP_{SVL}$	POF_{GWReg}	POF_{GWOGPC}	$PSIP_{Reg}^{GW}$	IOF_{Reg}	IOF_{OGPC}	$ISIP$
E-3	5,988	0,000	-5,988	2,578	0,000	-2,578	7,000	0,000	-7,000	5,163	0,000	-5,163
E-4	4,706	0,000	-4,706	3,709	0,000	-3,709	7,000	0,000	-7,000	5,124	0,000	-5,124
E-5	3,507	0,000	-3,507	3,090	0,000	-3,090	8,921	0,000	-8,921	5,152	0,000	-5,152
E-6	3,582	0,000	-3,582	1,456	0,000	-1,456	7,442	0,000	-7,442	4,133	0,000	-4,133
E-7	3,923	0,000	-3,923	3,871	0,000	-3,871	7,789	0,000	-7,789	5,181	0,000	-5,181
E-8	4,974	6,550	1,576	5,996	7,478	1,482	7,717	7,409	-0,307	6,227	7,149	0,922
E-9	3,624	0,000	-3,624	3,098	0,000	-3,098	6,221	0,000	-6,221	4,302	0,000	-4,302
E-10	3,113	3,189	0,076	2,328	4,991	2,664	5,802	7,011	1,209	3,733	5,063	1,330
E-11	3,000	3,000	0,000	1,930	3,138	1,208	6,130	5,275	-0,855	3,669	3,798	0,128

Block designation	Partial Differentiated Functions									Integral differential		
	Relief			Soil and vegetation layer			Groundwater			functions (for all components of the natural environment)		solution to the inverse problem
	POF_{Rel}	$POF_{RelOGPC}$	$PSIP_{Rel}$	POF_{SVLRel}^g	$POF_{SVLOGPC}$	$PSIP_{SVL}$	POF_{GWReg}	POF_{GWOGPC}	$PSIP_{Reg}^{GW}$	IOF_{Reg}	IOF_{OGPC}	$ISIP$
F-2	6,264	0,000	-6,264	3,543	0,000	-3,543	9,000	0,000	-9,000	6,242	0,000	-6,242
F-3	6,944	7,000	0,056	3,000	5,000	2,000	9,000	9,000	0,000	6,282	6,980	0,698
F-4	5,064	3,000	-2,064	2,459	5,000	2,541	8,895	9,000	0,105	5,442	5,660	0,218
F-5	3,871	0,000	-3,871	1,923	0,000	-1,923	8,048	0,000	-8,048	4,587	0,000	-4,587
F-6	3,019	0,000	-3,019	3,854	0,000	-3,854	6,940	0,000	-6,940	4,597	0,000	-4,597
F-7	2,217	0,000	-2,217	3,051	0,000	-3,051	5,635	0,000	-5,635	3,629	0,000	-3,629
F-8	2,814	0,000	-2,814	4,033	0,000	-4,033	5,034	0,000	-5,034	3,961	0,000	-3,961
F-9	2,699	0,000	-2,699	2,792	0,000	-2,792	5,000	0,000	-5,000	3,490	0,000	-3,490
F-10	3,000	0,000	-3,000	2,601	0,000	-2,601	5,000	0,000	-5,000	3,524	0,000	-3,524

Block designation	Partial Differentiated Functions									Integral differential		
	Relief			Soil and vegetation layer			Groundwater			functions (for all components of the natural environment)		solution to the inverse problem
	POF_{Rel}	$POF_{RelOGPC}$	$PSIP_{Rel}$	POF_{SVLRel}^g	$POF_{SVLOGPC}$	$PSIP_{SVL}$	POF_{GWReg}	POF_{GWOGPC}	$PSIP_{Reg}^{GW}$	IOF_{Reg}	IOF_{OGPC}	$ISIP$
G-1	5,001	0,000	-5,001	5,563	0,000	-5,563	9,000	0,000	-9,000	6,512	0,000	-6,512
G-2	5,297	7,505	2,208	5,000	6,818	1,818	9,000	9,000	0,000	6,418	7,765	1,347
G-3	5,094	7,000	1,906	2,457	5,040	2,583	9,000	9,000	0,000	5,486	6,994	1,507
G-4	4,413	6,109	1,696	1,644	6,132	4,487	8,481	7,328	-1,153	4,814	6,519	1,705
G-5	3,318	3,224	-0,095	4,950	6,448	1,497	6,769	7,000	0,231	5,012	5,566	0,554
G-6	3,000	0,000	-3,000	5,003	0,000	-5,003	4,046	0,000	-4,046	4,026	0,000	-4,026
G-7	2,779	0,000	-2,779	2,896	0,000	-2,896	1,452	0,000	-1,452	2,381	0,000	-2,381
G-8	1,495	0,000	-1,495	1,724	0,000	-1,724	4,436	0,000	-4,436	2,543	0,000	-2,543
G-9	2,010	8,056	6,046	2,061	2,797	0,736	4,968	5,000	0,032	3,003	5,259	2,256

Block designation	Partial Differentiated Functions									Integral differential		
	Relief			Soil and vegetation layer			Groundwater			functions (for all components of the natural environment)		solution to the inverse problem
	POF_{Rel}	$POF_{RelOGPC}$	$PSIP_{Rel}$	POF_{SVLRel}^g	$POF_{SVLOGPC}$	$PSIP_{SVL}$	POF_{GWReg}	POF_{GWOGPC}	$PSIP_{Reg}^{GW}$	IOF_{Reg}	IOF_{OGPC}	$ISIP$
G-10	2,940	0,000	-2,940	2,757	0,000	-2,757	4,200	0,000	-4,200	3,294	0,000	-3,294
H-1	6,001	7,000	0,999	3,244	5,000	1,756	9,000	9,000	0,000	6,053	6,980	0,927
H-2	5,992	5,497	-0,495	3,893	5,967	2,074	9,000	9,000	0,000	6,271	6,813	0,542
H-3	5,550	0,000	-5,550	3,987	0,000	-3,987	9,000	0,000	-9,000	6,157	0,000	-6,157
H-4	3,764	0,000	-3,764	3,541	0,000	-3,541	7,787	0,000	-7,787	5,016	0,000	-5,016
H-5	3,120	0,000	-3,120	5,228	0,000	-5,228	6,225	0,000	-6,225	4,861	0,000	-4,861
H-6	3,000	0,000	-3,000	4,940	0,000	-4,940	1,895	0,000	-1,895	3,295	0,000	-3,295
H-7	2,940	0,000	-2,940	3,198	0,000	-3,198	1,000	0,000	-1,000	2,387	0,000	-2,387
H-8	2,262	0,000	-2,262	1,675	0,000	-1,675	2,737	0,000	-2,737	2,219	0,000	-2,219

Block designation	Partial Differentiated Functions									Integral differential		
	Relief			Soil and vegetation layer			Groundwater			functions (for all components of the natural environment)		solution to the inverse problem
	POF_{Rel}	$POF_{RelOGPC}$	$PSIP_{Rel}$	POF_{SVLRel}^g	$POF_{SVLOGPC}$	$PSIP_{SVL}$	POF_{GWReg}	POF_{GWOGPC}	$PSIP_{Reg}^{GW}$	IOF_{Reg}	IOF_{OGPC}	$ISIP$
H-9	2,759	0,000	-2,759	2,341	0,000	-2,341	2,120	0,000	-2,120	2,406	0,000	-2,406
H-10	3,000	0,000	-3,000	3,000	0,000	-3,000	1,242	0,000	-1,242	2,420	0,000	-2,420
H-11	3,000	0,000	-3,000	3,000	0,000	-3,000	1,000	0,000	-1,000	2,340	0,000	-2,340
I-1	6,034	0,000	-6,034	2,499	0,000	-2,499	6,700	0,000	-6,700	5,052	0,000	-5,052
I-2	4,077	0,000	-4,077	1,370	0,000	-1,370	6,093	0,000	-6,093	3,822	0,000	-3,822
I-3	4,006	0,000	-4,006	3,987	0,000	-3,987	6,973	0,000	-6,973	4,979	0,000	-4,979
I-4	2,912	0,000	-2,912	5,304	0,000	-5,304	6,086	0,000	-6,086	4,773	0,000	-4,773
I-5	3,541	0,000	-3,541	5,103	0,000	-5,103	4,024	0,000	-4,024	4,231	0,000	-4,231
I-6	3,000	0,000	-3,000	4,996	0,000	-4,996	1,014	0,000	-1,014	3,023	0,000	-3,023

Block designation	Partial Differentiated Functions									Integral differential		
	Relief			Soil and vegetation layer			Groundwater			functions (for all components of the natural environment)		solution to the inverse problem
	POF_{Rel}	$POF_{RelOGPC}$	$PSIP_{Rel}$	POF_{SVLRel}^g	$POF_{SVLOGPC}$	$PSIP_{SVL}$	POF_{GWReg}	POF_{GWOGPC}	$PSIP_{Reg}^{GW}$	IOF_{Reg}	IOF_{OGPC}	$ISIP$
I-7	3,000	0,000	-3,000	4,246	0,000	-4,246	1,000	0,000	-1,000	2,764	0,000	-2,764
I-8	3,000	0,000	-3,000	2,390	0,000	-2,390	1,000	0,000	-1,000	2,133	0,000	-2,133
I-9	3,000	0,000	-3,000	2,179	0,000	-2,179	1,016	0,000	-1,016	2,066	0,000	-2,066
I-10	3,000	0,000	-3,000	1,581	0,000	-1,581	1,000	0,000	-1,000	1,858	0,000	-1,858
I-11	3,000	0,000	-3,000	1,881	0,000	-1,881	1,020	0,000	-1,020	1,966	0,000	-1,966
I-12	3,000	0,000	-3,000	1,024	0,000	-1,024	1,000	0,000	-1,000	1,668	0,000	-1,668
I-13	3,000	0,000	-3,000	1,000	0,000	-1,000	1,000	0,000	-1,000	1,660	0,000	-1,660
J-1	5,455	0,000	-5,455	3,195	0,000	-3,195	5,000	0,000	-5,000	4,536	0,000	-4,536
J-2	3,054	0,000	-3,054	2,562	0,000	-2,562	5,000	0,000	-5,000	3,529	0,000	-3,529

Block designation	Partial Differentiated Functions									Integral differential		
	Relief			Soil and vegetation layer			Groundwater			functions (for all components of the natural environment)		solution to the inverse problem
	POF_{Rel}	$POF_{RelOGPC}$	$PSIP_{Rel}$	POF_{SVLRel}^g	$POF_{SVLOGPC}$	$PSIP_{SVL}$	POF_{GWReg}	POF_{GWOGPC}	$PSIP_{Reg}^{GW}$	IOF_{Reg}	IOF_{OGPC}	$ISIP$
J-3	2,352	0,000	-2,352	3,399	0,000	-3,399	5,000	0,000	-5,000	3,582	0,000	-3,582
J-4	2,651	0,000	-2,651	5,059	0,000	-5,059	4,048	0,000	-4,048	3,931	0,000	-3,931
J-5	2,513	0,000	-2,513	5,628	0,000	-5,628	1,238	0,000	-1,238	3,151	0,000	-3,151
J-6	3,000	0,000	-3,000	3,997	0,000	-3,997	1,000	0,000	-1,000	2,679	0,000	-2,679
J-7	3,000	0,000	-3,000	2,924	0,000	-2,924	1,000	0,000	-1,000	2,314	0,000	-2,314
J-8	3,000	0,000	-3,000	1,002	0,000	-1,002	1,000	0,000	-1,000	1,661	0,000	-1,661
J-9	3,000	0,000	-3,000	1,062	0,000	-1,062	1,702	0,000	-1,702	1,913	0,000	-1,913
J-10	3,000	0,000	-3,000	1,000	0,000	-1,000	1,283	0,000	-1,283	1,753	0,000	-1,753
J-11	3,000	0,000	-3,000	1,000	0,000	-1,000	1,652	0,000	-1,652	1,875	0,000	-1,875

Block designation	Partial Differentiated Functions									Integral differential		
	Relief			Soil and vegetation layer			Groundwater			functions (for all components of the natural environment)		solution to the inverse problem
	POF_{Rel}	$POF_{RelOGPC}$	$PSIP_{Rel}$	POF_{SVLRel}^g	$POF_{SVLOGPC}$	$PSIP_{SVL}$	$POF_{GWReg}^.$	POF_{GWOGPC}^C	$PSIP_{Reg}^{GW}$	IOF_{Reg}	IOF_{OGPC}	$ISIP$
J-12	3,000	0,000	-3,000	1,000	0,000	-1,000	1,000	0,000	-1,000	1,660	0,000	-1,660
K-2	2,181	0,000	-2,181	1,602	0,000	-1,602	5,000	0,000	-5,000	2,914	0,000	-2,914
K-3	2,017	0,000	-2,017	3,286	0,000	-3,286	4,996	0,000	-4,996	3,432	0,000	-3,432
K-4	3,000	0,000	-3,000	1,780	0,000	-1,780	3,621	0,000	-3,621	2,790	0,000	-2,790
Средние	3,910	5,835		3,203	5,475		5,631	7,761		4,237	6,348	

Table A10 – Estimation of the Relative Error in Calculating the Integral Objective Functions for Three Components of the Natural Environment to Assess the Contribution of the OGPC to the Formation of the Ecological Situation in the Mangystau Region Using Generalized and Differentiated Assessment Methods

Function type and unit of measurement	Function value by method		Relative error, %
	generalized assessment*	differentiated assessment	
$IOF_{Reg.}$ – Integral Objective Function of Anthropogenic Disturbance to the Natural Environment of the Mangystau Region, Points	4,28	4,237	0,428
IOF_{OGPC} – integral Objective function of anthropogenic disturbance of the natural environment of the Mangystau region within zones with OGPC, points	6,520	6,348	1,719
$ISIP$ – generalized solution of the inverse problem (additional contribution of the OGPC to anthropogenic disturbance of the natural environment of the Mangystau region), points	2,237	2,111	1,261
$ISIP$ – generalized solution of the inverse problem (additional contribution of the OGPC to the anthropogenic disturbance of the natural environment of the Mangistau region	22,37	21,109	1,261

), %				
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* The values of the functions for the generalized assessment are taken from the variant with three assessment

