позволяют вывести кибербезопасность на новый уровень благодаря быстрой обработке больших объемов данных, выявлению аномалий и проактивному реагированию на атаки. Основная цель статьи - оценить эффективность применения технологий ИИ и предложить пути их интеграции в современные системы кибербезопасности. В ходе исследования использовались алгоритмы машинного обучения и методы обработки данных для анализа точности и скорости обнаружения атак. Результаты показали высокую эффективность ИИ-инструментов по сравнению с традиционными методами. Данная работа вносит вклад в исследования в области кибербезопасности и нацелена на открытие новых возможностей для защиты информационной инфраструктуры. Кроме того, в статье обсуждаются возможные трудности внедрения этих методов и пути их решения.
Ключевые слова: киберугрозы, искусственный интеллект, анализ данных, машинное обучение, выявление аномалий, информационная безопасность.

Using Artificial Intelligence for detecting and preventing cyber threats

[1]D.Nsanbaev, [1]Sh.K.Yelezhanova
[1]Kh.Dosmukhamedov Atyrau University (Atyrau, Kazakhstan)

Abstract
This article explores the use of artificial intelligence (AI) technologies for detecting and preventing cyber threats. With the advancement of the digital age, the number and complexity of cyberattacks are increasing. Traditional methods often fall short in countering these threats, highlighting the need for modern approaches. AI technologies enable cybersecurity to reach a new level by rapidly processing large volumes of data, detecting anomalies, and proactively responding to attacks. The main objective of the article is to evaluate the effectiveness of AI technologies and propose ways to integrate them into modern cybersecurity systems. The study utilized machine learning algorithms and data processing methods to analyze their accuracy and speed in detecting attacks. The findings demonstrated the superior efficiency of AI tools compared to traditional methods. This work contributes to research in the field of cybersecurity and aims to unlock new opportunities for protecting informational infrastructure. Additionally, the article discusses potential challenges in implementing these methods and solutions to address them.
Keywords: cyber threats, artificial intelligence, data analysis, machine learning, anomaly detection, information security.

Поступила в редакцию: 21.01.2025
Одобрена: 19.03.2025
Первая публикация на сайте: 13.08.2025

МРНТИ: 87.13.29 https://doi.org/10.65247/3105-3432-2025-4.04

DYNAMICS OF CHANGES IN THE COASTLINE OF THE NORTHERN CASPIAN SEA FOR THE PERIOD 2016-2024

*[1]S.JARAS, *[1]A.Ye.YEGINBAYEVA*
[1]L.N.Gumilyov Eurasian National University
(Astana, Kazakhstan),
*[1]zsajaly@gmail.com, *[1]yeginbayeva_aye@enu.kz*

Abstract
The article examines the dynamics of coastline changes in the Northern Caspian Sea from 2016 to 2024 based on remote sensing and cartographic data. It identifies key transformation directions, highlighting areas of active erosion and accretion. The study considers natural and anthropogenic factors influencing these changes, including fluctuations in sea level, climatic conditions, and economic activities. The results help assess the environmental and socio-economic consequences of coastal zone transformation. Additionally, the study provides recommendations to mitigate negative impacts on the Northern Caspian Sea ecosystem, aiming to balance environmental sustainability with human activities in the region. The findings contribute to better coastal management and long-term ecological preservation.

Keywords: North Caspian, coastline, dynamics of changes, erosion, accretion, remote sensing, anthropogenic impact, ecosystem, water level change.

Introduction

The western part of the modern Republic of Kazakhstan, known as the Caspian Sea, is located in the Kazakh steppe and covers the territories of Atyrau and Mangystau regions, as well as the northern and middle waters of the Caspian Sea. This region is located within the coordinates 41°20'-49°15' north latitude and 47°05'-56°45' east longitude, referring to the fourth time zone. The land area of the territory is 278.6 thousand km^2, and the water area of the Caspian Sea stretches from west to east for 720 km and from south to north for 880 km. The coastline of Kazakhstan along the Caspian Sea is about 2.3 thousand km long. The geographical appearance of the Caspian region includes steppes, sultry semi-deserts, winding rivers with moderate currents, steep chalk slopes, steep dry channels, arid wastelands, ancient gently sloping mountain ranges and vast plains. In addition, there are low gentle mountains covered with pine forests on its territory. Due to the unique natural conditions of the Caspian region, the Turkic terms «takyr» and «sor» have entered the geographical science, denoting specific types of landscape characteristic of this area [Mamaeva N., 2023: P.64].

Main body

The coast of the Caspian Sea is located in the western part of the country, bordering Atyrau and Mangistau regions. There are several large settlements in the Caspian lowland. In general, on the coast of the Caspian Sea, according to statistics for 2023, the population of the Caspian region of Kazakhstan, including the Mangystau and Atyrau regions, is about 1.1 million people. About 800 thousand people live in the Mangystau region, and about 660 thousand people live in Atyrau region. These regions are actively developing due to the oil and gas industry, attracting labor, contributing to population growth in the cities of Aktau and Atyrau, the main centers of the region. Of particular note are the cities of Aktau, Atyrau, Fort Shevchenko and Kuryk, large settlements. Aktau is a city in the south-west of Kazakhstan, the center of the Mangystau region. Aktau is an important center of the oil and gas industry, a transport hub and port, as well as a popular tourist attraction. Atyrau is another of the major cities located on the coast of the Caspian Sea. Atyrau city is the administrative center of Atyrau region, located in the west of Kazakhstan, along the Zhaiyk River. The city was founded in 1640. Fort Shevchenko is a small town in the north of Aktau with a population of about 6,371 people. Thanks to historical monuments and museums, the city has cultural significance. Kuryk is a village located in the south of Aktau, with a population of about 12,000 people. Kuryk is an important transport point due to the port providing ferry service across the Caspian Sea. These cities play an important role in the region's economy, primarily in the oil and gas industry and marine logistics [Ivkina N. et al., 2023: P.91].

The entire negative relief form of the Caspian territory is occupied by the Caspian lowland, and its surface is covered with sands (Naryn, Mynteke, Taisoygan, Karakum, Sam), valley landscape (Zhaiyk, Oyl, Sagyz, Zhem), salt marshes (Oli, Koltyk, Tentexor, etc.) and numerous takyrs. There are erosive depressions and dry channels between sandy and barren massifs, the Inder Mountains, the Imankara and Koikara ranges stand out. The highest point of the northern coast of the Caspian Sea is Zheltau with a height of 221 m, located in the extreme southeast of Atyrau region. The southern part of the region is characterized by a more elevated relief, where the spurs of the Turanian lowland are located, represented by the Mangystau Mountain Plateau. The terrain of the territory includes a variety of shapes: small hills, gentle mountains of medium height, flat spaces, territorial basins, as well as areas of mantled sands. The highest point of this region is 556 m, and Karakiya (132 m below sea level) is the deepest depression in the country.

The most extensive part of the land is the Tupkaragan Peninsula, which is located in the Caspian Sea with a width of about 40 km and a width of 60 km. The surface of the peninsula is rocky, with an absolute height of 156-203 m. The underwater and water surface of the shores is rocky and steep. In terms of physical and geographical conditions, the Caspian Sea is conditionally divided into three parts: the North Caspian Sea (25% of the sea area), the Middle Caspian Sea (36%), and the South Caspian Sea (39%) (Figure 1) [Kudryavtseva N. et al., 2019: P.230].

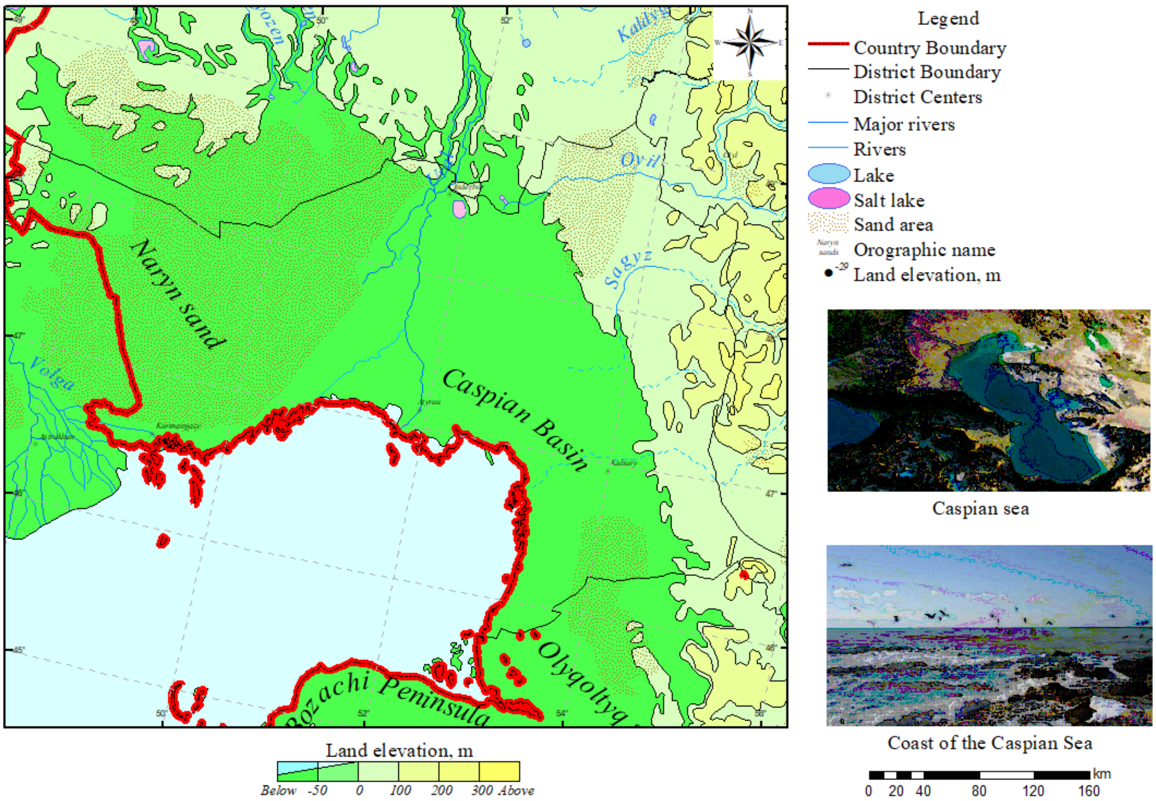


Figure 1. Physical Map of the North Caspian Sea
Note: compiled based on the data [Nacional'nyj atlas RK, 2010]

The terrain is flat, with low hills, the valley is uneven, the plain with sandy and salt lakes. Basically, it is a very flat, sometimes filled space with drainage gullies. Frost, whose temperature changes rapidly, is characterized by windiness, low rainfall and severe continental weather. The maximum air temperature ranges from +36°C to +46°C. The air temperature above +10°C lasts up to 170-180 days. Since the second half of December, the ground has been covered with solid snow. Lasts up to 69-95 days. The average snow thickness does not exceed 10-15 cm. The animal habitat area belongs to a dry and arid area. The annual rainfall reaches 137-200 mm. About 900-1000 mm of water evaporates from the sea surface per year.

It consists of the lower reaches of the Zhaiyk River, the eastern branches of the Yedil delta (in the region of Kazakhstan) and Zhem, Sagyz, Oyil, the bed of which is filled with water only in spring. The Zhaiyk is considered the largest transit and unregulated river in Kazakhstan with reservoirs in the middle and lower reaches of the Caspian basin.

Materials and methods

The exploration of the Caspian Sea began in the last century, but systematic scientific work was initiated by Peter the Great in 1714-1715. The first detailed study of the eastern coast of the Caspian Sea was conducted by an expedition led by A.Bekovich-Cherkassky. In the second half of the 18th century, I.F. Soymonov carried out hydrographic studies of the sea. At the beginning of the 19th century, thanks to the works of A.E.Kolodkin, the coast of the Caspian Sea was mapped for the first time. In the period 1904-1915, large-scale hydrological and hydrobiological expeditions aimed at studying the marine processes of the Caspian Sea were organized under the leadership of N.M.Knipovich. In general, research on the Caspian Sea became widespread after the October Revolution. Since the Caspian Sea connects 5 states, the research in it was not stopped only by scientists-geographers of the USSR. In 1995 a meeting of united representatives of the Caspian littoral states was held in Tehran. The meeting was based on the development of the concept of environmental sustainability of the Caspian region and management of the use of its resources, but in practice any environmental program is complicated by the increasing importance of its importance as a large oil and gas region [Nacional'nyj atlas RK, 2010].

Research at the beginning of the XXI century was directly related to the rapid development of science and technology. At this time, research was carried out that revealed the dynamics of changes in the water level of the Caspian Sea. In 2021 Asakereh H. and Varnaseri N. conducted a comprehensive analysis of precipitation regime patterns on the Iranian coast of the Caspian Sea, identified high annual precipitation with different coefficients of variation and monthly changes in the coastline, and considered the impact on sea level dynamics. Chen J. L., Azizpour J., Ghaffari P., Arpe K., Leroy S. and other researchers have linked the decrease in sea level to the decrease in the flow of the Yedil River in recent years. They examined seasonal and long-term changes in the level of the Caspian Sea. Chen J. in his research, using satellite altimeter data, he noted a downward trend in the level of the Caspian Sea since 2005 and a significant acceleration of this process in these years. Using the altimeter data of the satellite, Lebedev S. later determined the change in sea level in the mid-1970s, and this was influenced by the hydrometeorological process. In most subsequent studies, geographers used space images and remote sensing methods in their research, which made a significant contribution to the accuracy of general information [Alireza A.A., Hashemifaraz A., 2024: P.3230].

To study the dynamics of changes in the coastline of the Northern Caspian Sea in the period 2016-2024, high-resolution Earth remote sensing data obtained from Landsat and Sentinel satellites, as well as topographic and cartographic materials from previous years provided by local and international geographic information services, were used. Additionally, hydrometeorological observations were analyzed, including information on changes in water levels and climatic conditions in the region.

Research methods include: *geoinformation analysis* - processing and interpretation of satellite images using GIS programs (ArcGIS, QGIS); *digital data processing* - identification of shoreline contours using image classification algorithms; *cartographic method* - involves a comparative analysis of changes in the boundaries of the coastline in different time periods; *statistical analysis* is used to study the relationship of shoreline changes with natural factors such as fluctuations in water levels and precipitation, as well as anthropogenic influences; *field observations* - verification of remote sensing data by surveying key areas of the coastal zone. Such an integrated approach allowed not only to establish the nature of the transformation of the coastline, but also to identify the dominant factors determining its dynamics.

Results and discussion

The Kazakh coast of the Caspian Sea is 2,320 km long. The northeastern part of the Caspian Sea plays an important role as a maritime transport route connecting Kazakhstan with foreign countries through shipping routes. Due to the flat terrain of this section of the coast, there is a possibility of flooding up to 35-40 km inland.

In the 1930s, the water level in the Caspian Sea dropped sharply by 1.8 m, and this process continued until 1977, which led to a general decrease in sea level by 3 m. The main reasons for this phenomenon were a decrease in precipitation in the Yedil River basin and the active construction of reservoirs along its course. In the following years, the water level began to rise gradually, and this process continued until 1995. In general, it is assumed that sea level rise during this period is associated with the hydroclimatic effects of El-Nino telecommunications and southern fluctuations. Using satellite altimetry, it is possible to register a decrease in water level by about 7 cm per year between 1996 and 2015, which is about 1.5 m. In recent years, this decline has increased slightly, decreasing by 10 cm per year from 2006 to 2021. The decrease in water levels has led to the drying up of 15,000 km^2 of the marine reservoir, affecting most of the northeastern coastal region, replacing it with a multi-year to seasonal reservoir. Another reason for the decrease in the Caspian Sea level is the intensive evaporation process in the sea as a result of climate change (Figure 2).

Figure 2. Change in the Caspian Sea level based on DAHITI data based on satellite altitude measurements from 1900 to 2024
Note: compiled based on the data [Schwatke C., 2015: P.4360]

Given the significant fluctuations in the Caspian Sea level in the 20th century, it is important to determine the degree of influence of anthropogenic climate change, since climatic factors can cause rises and falls in the water level by 2-3 meters. It should be borne in mind that current trends in sea level change continue and may even intensify under the influence of an increase in greenhouse gas concentrations in the atmosphere. In this context, long-term climate observations and forecasts play a key role in assessing possible changes in the Caspian Sea level in the future [Samant R., 2023: P.357].

Fluctuations in the level of the Caspian Sea are caused by a combination of climatic, tectonic and anthropogenic factors that are in a complex interaction and are constantly changing in time and space. Whereas in the early Neogene the main influence on sea level was exerted by tectonic processes and, to a lesser extent, climatic conditions, at present climatic changes and anthropogenic impact are becoming key factors.

According to modern concepts, the level of the Caspian Sea is determined by its water balance, which is formed due to such processes as climatic conditions, river runoff, precipitation on the surface of the sea, and the water cycle inside its water area. In addition, a number of natural and anthropogenic factors contribute to an increase in the concentration of carbon dioxide and other greenhouse gases in the atmosphere, which leads to climate change in the Caspian Sea region.

In recent years, global warming has continued to reach record levels. According to the World Meteorological Organization, 2020 was one of the three warmest years in the history of observations, with the average global temperature above the level of 1850-1900 by 1.2± 0.1°C. Moreover, the last five years, as well as the previous decade, have been the hottest in the entire period of meteorological measurements. However, the rate of climate change varies from region to region. In Kazakhstan, the Caspian region demonstrates the highest rates of increase in the average annual and seasonal air temperature. In general, warming in the northern latitudes is more important than in the southern latitudes, since in these areas, including the main part of the Yedil River basin, temperature fluctuations exceed global values by 2-3 times. In addition, temperature fluctuations depend on the time of year and vary from month to month. Since air temperature is a key characteristic of climate, changes in its statistical structure cause a restructuring of the processes of heat and moisture transfer in the atmosphere, which, in turn, affects the precipitation regime [Dolgih S.A., 2022: P.43].

One of the main elements of the water balance of the Caspian Sea is the water mass that rivers bring. About 130 rivers flow into the Caspian Sea, but the bulk of the flow into the sea is brought by the Yedil, Zhaiyk, Terek, Sulak, and Kura rivers. According to some reports, the Yedil River accounts for more than 80% of the water entering the Caspian Sea. However, at different stages, this contribution can be quite large. Thus, fluctuations in the Caspian Sea level are largely determined by the variability of the Yedil River. Thus, the study of the hydrological regime of the Yedil River and its influence on fluctuations in the Caspian Sea level is very relevant. In this sense, this study explores the changes taking place in the course of the Yedil River and the factors that influence them, as well as analyzes the relationship between these changes and fluctuations in the Caspian Sea.

The territory on the banks of the Yedil River is characterized by a high level of industrial and agricultural development. However, among the factors influencing the hydrological regime of the Yedil River, there is undoubtedly an advantage of climatic factors. The Yedil is one of the largest rivers in the world and the largest in Europe, with a basin that occupies a third of the European part of Russia. The length of the Yedil River is 3,530 km, and the basin area is 1,360,000 km^2. Currently, about 45% of industry and half of all agriculture in Russia are concentrated in the river basin. The river basin produces more than 20% of all fish for the food industry. The main source of the Yedil River flow is snowmelt and precipitation in its basin. The Yedil River flows into the Caspian Sea, the world's largest inland body of water. Four reservoirs have been built in the upper reaches of the river: Ivankovskoye, Uglichskoye, Rybinsk and Gorkovskoye. All large reservoirs of the Upper Yedil basin are comprehensively used in hydropower, water transport, logging, water supply, fishing, and recreation.

The Yedil River and its tributaries receive the bulk of their water resources from snowmelt, which provides about 60% of the total runoff, while the remaining 40% comes from rainwater. The largest volume of water in the river is observed in spring during floods and in autumn during heavy rains. In winter and summer, the water level decreases significantly. The river freezes in November in the upper and middle reaches, and in the lower reaches the ice cover is formed only in December. In spring, the melting of ice begins in the lower reaches in early March, while in the upper reaches the process of opening the river ends only in April (Figure 3).

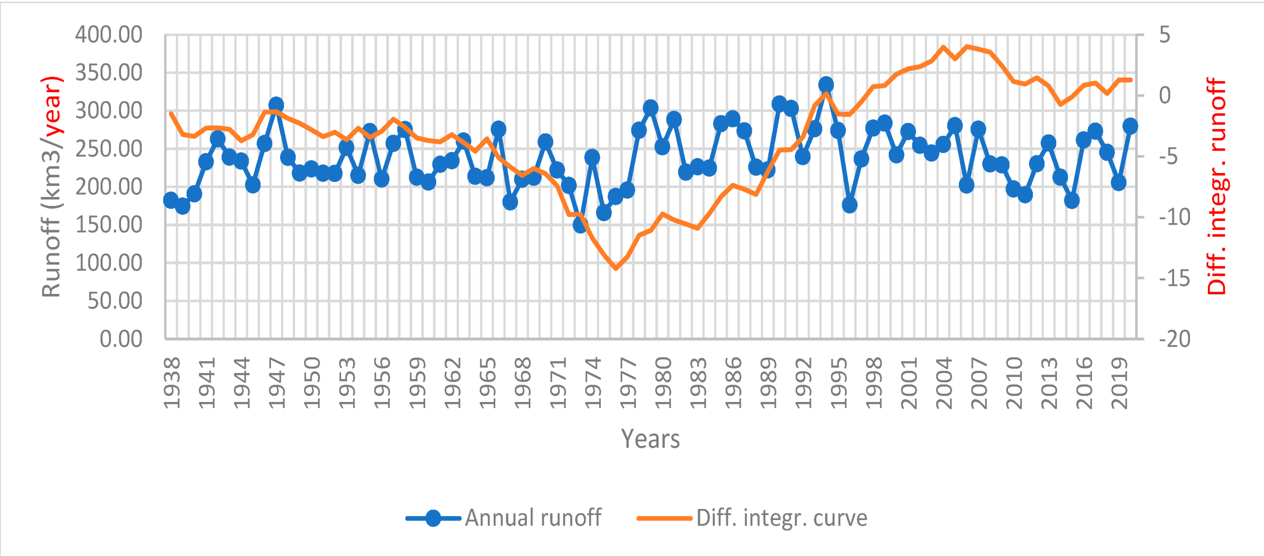


Figure 3. Long-term variability of the annual flow of the Yedil River at the Verkhny Lebyazhy hydrometeorological station in the period from 1938 to 2020 and its integral difference line
Note: compiled based on the data [Chen J.L., 2017: P.6997]

According to the Volgograd Hydrological Station for 1881-2016, the average annual flow of the Yedil River is 253 km^3 per year. The maximum flow was observed in 1926 (389 km^3/year) and 1975 (160 km^3/year). Periods of high runoff of the Yedil River coincide with periods of high precipitation in the basin, while periods of low runoff coincide with periods of less precipitation. The amount of precipitation in the river basin for each period was calculated by multiplying the average annual precipitation per mm by the basin area (Figure 4).

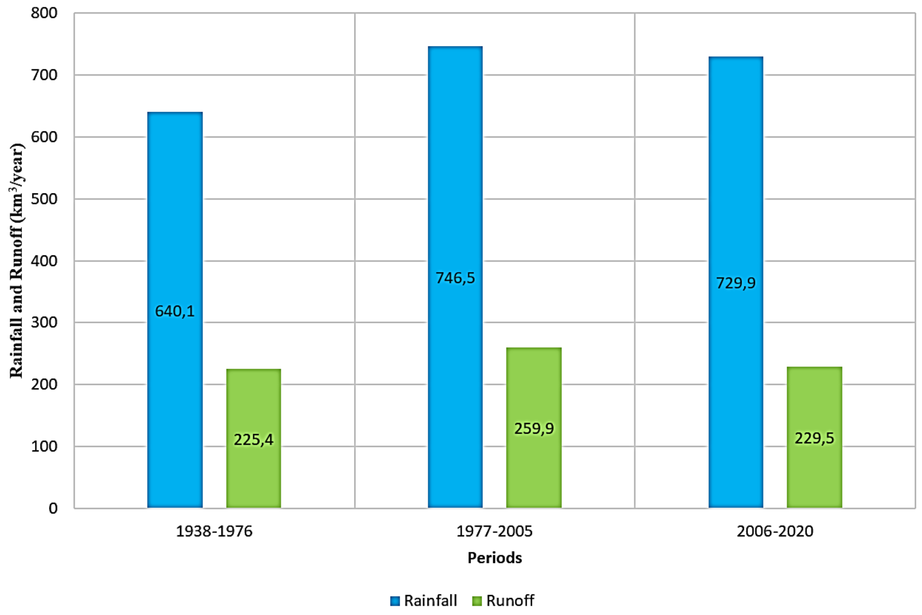


Figure 4. Comparison of precipitation volumes in the Yedil River basin and their runoff at the Verkhny Lebyazhy hydrological post in different time periods
Note: compiled based on the data [Chen J.L., 2017: P. 6997]

If we take into account that the results obtained in this study mainly confirm the forecasts of modern models of the Caspian Sea level, then we can expect that in the future the runoff coefficient and, consequently, the efficiency of converting precipitation into wastewater will decrease. This means that with the current level of precipitation in the Yedil River basin and climate warming, its runoff will decrease. In modern conditions, an annual rainfall of 585.4 mm will be required to ensure the formation of an annual river flow of 250 km. For comparison, in the period from 1938 to 1976, the corresponding value was 522 mm, and in the period from 1977 to 2005 – 528.2 mm.

Of great importance is the study of the relationship of the flow of the Yedil River with the level of the Caspian Sea. According to the data of Makhachkala, upper Lebyazhye point and sea level control, the annual flow of the Yedil River and the total flow of other rivers flowing into the sea (1959-2020) is shown (Figure 5).

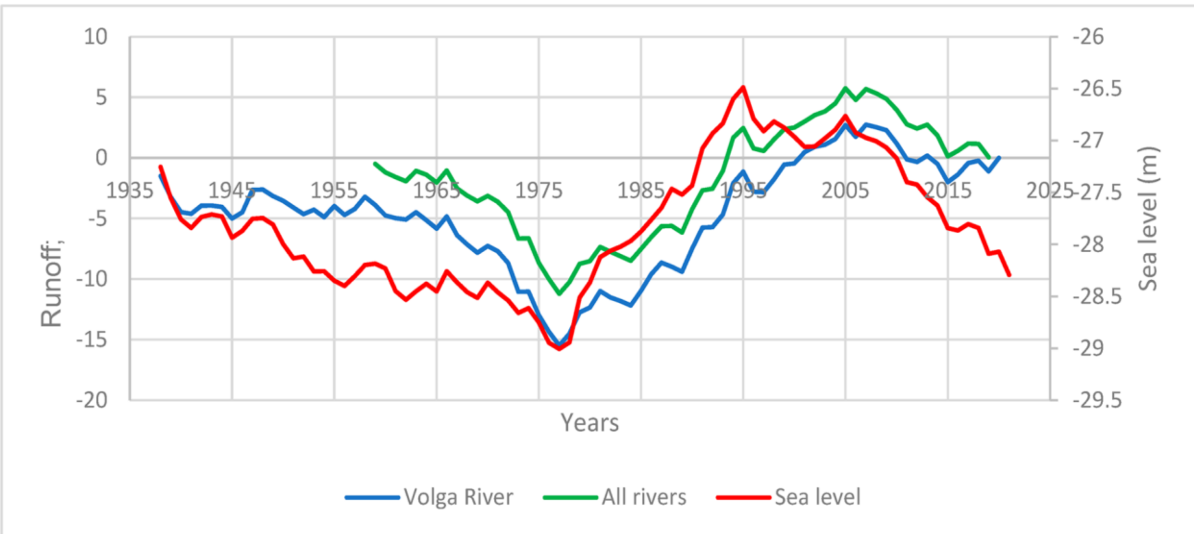


Figure 5. Comparison of the annual flow of the Yedil River (1938-2020) and other rivers flowing into the Caspian Sea (1959-2020) with long-term changes in sea level (1938-2020)
Note: compiled based on the data [Safarov E., 2024: P.1744]

The curves of the total flow of the Yedil River and all rivers flowing into the sea are practically parallel, and the correlation coefficient between them is close to 1 (0.994). This is understandable, since the dynamics of the total flow is largely determined by the dynamics of the flow of the Yedil River, which is 80-90% of the former flow. A comparison of the time curve of the Caspian Sea level with the curve of the differential integral of the annual runoff of the Yedil River mainly showed their similarity, that is, large values of river runoff corresponded to large values of sea level. However, since 2005, the sea level began to decline rapidly, and even with a large annual outflow of water into the sea, the water level continued to decrease. A comparative analysis of this situation with the results of a number of authors shows that a sharp decrease in sea level in recent years has been associated with a sharp increase in evaporation from the sea surface as a result of changes in the wind regime over the Caspian Sea [Yasinskij S.V., 2013: P.95].

Currently, from 2015 to the present, the level of the Caspian Sea tends to decrease. The sea level has already decreased by 1.4 m, and according to some data - by more than 1.5 m. The most severely affected region is the northeastern part of the Caspian Sea, that is, the Kazakh part.

The water balance of the Caspian Sea is formed by several key components:
1. River runoff is the main source of water supply. The main role in maintaining the water balance is played by the Yedil River, which provides 80-85% of the total flow. In addition, Zhaiyk, Kura and Terek have a significant influence. On average, the annual volume of river flow into the sea is about 300 km^3.
2. Precipitation is an additional factor affecting the water balance. Their number depends on climatic conditions and averages 20-30 km^3 per year.
3. Evaporation is one of the most important processes affecting the water level. Water losses due to evaporation can reach 600-800 km^3 per year, which leads to a shortage of water resources and a decrease in sea level.
4. Groundwater is an insignificant but existing source of replenishment of the water balance. Their contribution is significantly lower compared to other components.

These factors are interrelated and determine the water level in the Caspian Sea. Changes in any of them can lead to significant fluctuations in water levels and have an impact on the marine ecosystem.

The oil industry plays a key role in the economy of Kazakhstan, actively developing due to the significant oil reserves in the country. Most of these resources are located in the Caspian Sea, a region of not only strategic economic importance, but also characterized by high environmental vulnerability. The increase in oil production, processing and transportation in the area leads to an increased risk of oil spills. In this regard, the strategic development of oil infrastructure, including coastal, offshore and inland fields, as well as the construction of oil pipelines in resource-rich areas, is of paramount importance. However, the expansion of the industry is accompanied by serious environmental threats, such as the destruction of natural ecosystems and the increased likelihood of oil spills, which can have long-term consequences for the region's biodiversity. Oil transportation by sea requires special attention, since strict environmental safety measures are necessary to prevent accidental spills. In the last ten years, the number of spills has increased due to the growth of international freight traffic caused by the increasing demand for energy resources and industrial goods [Iskakov B., 2024: P.9566].

Oil and gas fields are being actively developed on the territory of the Caspian Sea. The proven oil reserves are estimated at about 10 billion tons, and the total oil and gas condensate resources amount to 18-20 billion tons. Oil production in this region began back in 1820, when the first oil well was drilled on the Absheron shelf near Baku. In the second half of the 19th century, oil production acquired an industrial scale on the Absheron Peninsula, and later spread to other areas.

It is not easy to determine the exact number of industrial enterprises on the Caspian Sea coast, but it is known that Kazakhstan is actively developing its oil and gas infrastructure. For example, Atyrau has about 115 oil and gas enterprises that play an important role in the region's economy.

Up to 70-90 thousand tons of oil hydrocarbons flow into the Caspian Sea annually. Also, about 29 thousand tons of petroleum products come from the coast, including discharges from production facilities and ships. The volume of pollutants entering the Caspian Sea varies significantly depending on the year and the sources of pollution. In 2023, the Caspian Sea received about 70-90 thousand tons of petroleum hydrocarbons annually from river runoff. This pollution occurs both from rivers such as the Yedil and from the coast, where the volume of oil pollutants is about 29 thousand tons per year.

The statistics of pollutants in the Caspian Sea from 2016 to 2024 show that the main sources of pollution are oil and gas operations, wastewater and agriculture. For example, in some areas, the concentration of petroleum products can reach 8000 MPC (maximum permissible concentration) [Erezhep G., 2017].

This study is aimed at analyzing the results of space monitoring of the coastline of the Northern Caspian Sea using data obtained through satellite technologies. The main purpose of monitoring is to assess changes in the state of the coastal zone of the region. Studying the dynamics of the Caspian Sea coastline plays an important role not only for marine tributaries, but also for biological ecosystems located in the area.

The study used GIS technology and obtained several years of space images. With the help of satellite images, it made it possible to track long-term changes in the water level, the area of water bodies and changes in the coastline. This is important for understanding the impact of climate change and anthropogenic activities (Figure 6).

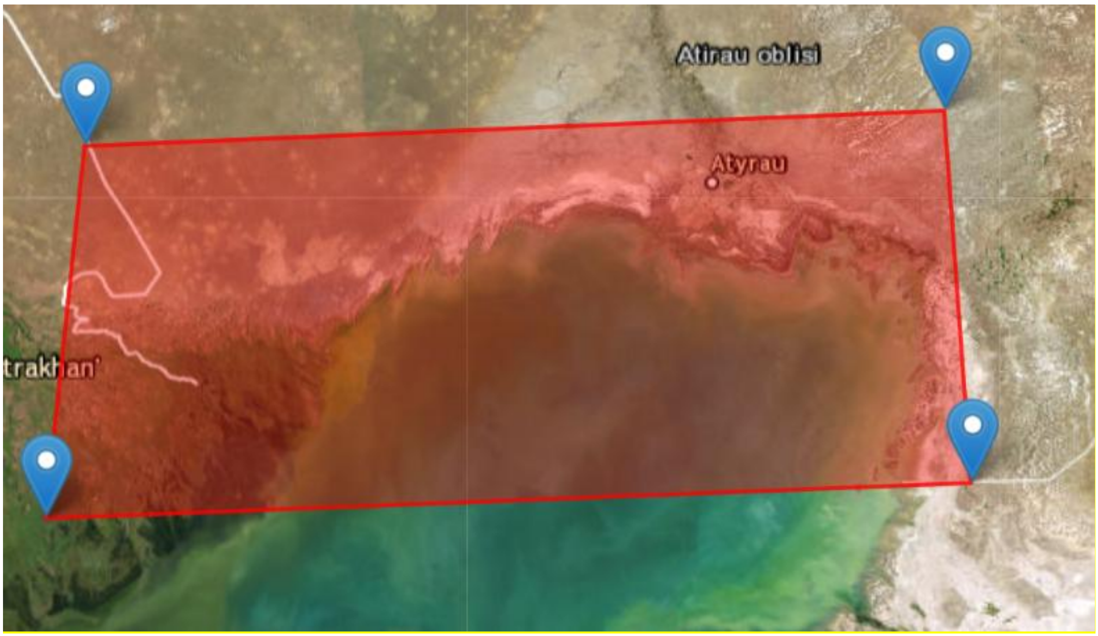


Figure 6. Space image of the Research Area (North Caspian Sea)
Note: compiled based on the data [Ivkina N. et al., 2023: P.70-77]

During the study, combinations 2, 3 and 4 were combined, studying the Landsat 8-9 combination from the space images uploaded. This is because these combinations clearly demonstrate the dynamics of hydrographic analysis and perennial changes in River and lake waters. By combining these combinations, PAN, that is, by combining 8 combinations, it increased the resolution of the cosmic image, giving it high accuracy.

The monitoring was carried out using Landsat 8-9 satellite images. The data was collected over a 9-year period from 2016 to 2024. The research area was located along the coastline of the Caspian Sea, the border of the Atyrau region of the Republic of Kazakhstan (Figure 7) [Ivkina N. et al., 2023: P.70-77].

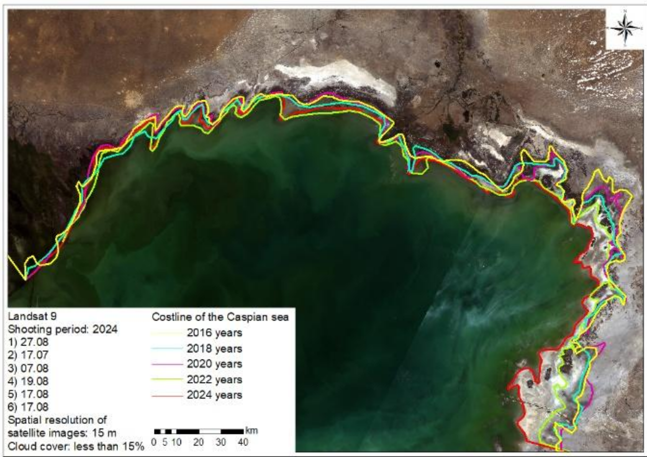


Figure 7. Space picture of the coast of the Northern Caspian Sea from 2016 to 2024
Note: compiled based on the data [Ivkina N. et al., 2023: P.70-77]

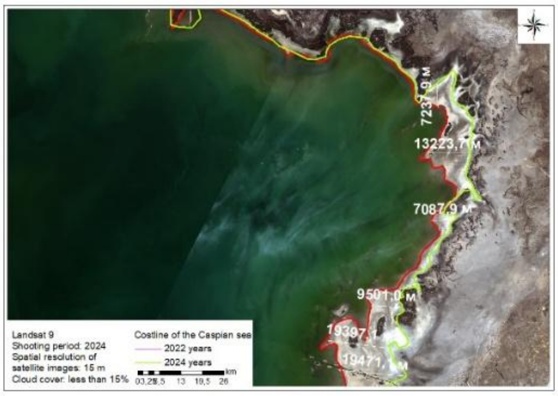
In the Kazakh part near the city of Atyrau, in the delta of the Zhaiyk River, as well as in the northern part of the Mangystau region, the shallowest areas of the sea were observed.

Monitoring results: in the period from 2016 to 2018, an increase in the coastline was observed, by a maximum of 11 km, and the process of extending the northern coastline was also observed (Figure 8).

a) 2016-2018

b) 2018-2020

c) 2020-2022



d) 2022-2024

Figure 8. Dynamics of changes in the eastern coastline on satellite images of the Northern Caspian Sea in the period from 2016 to 2024
Note: compiled based on the data [Ivkina N. et al., 2023: P.70-77]

The largest increase in the coastline in the period 2018-2020 was 7 km, in various areas the shoaling of the eastern part was observed.

In the period 2020-2022, a deviation of the coastline of the Caspian Sea at a distance of 2 km - 16 km was observed in the area near the Atyrau region oil pipeline. The largest deviation of the coastline was observed at 16 km in the eastern part of the sea.

In the period from 2022 to 2024, the water level on the eastern coast of the Caspian Sea varied within 16.6 km, while in the northwestern and western parts of the sea these fluctuations were less pronounced.

In 2023, there was a significant decrease in the water level in the Caspian Sea, which continued the trend observed since 2006. The shallowing of the world's largest enclosed body of water is due to climatic changes, including an increase in air temperature, a decrease in precipitation and a decrease in river flow.

During the monitoring of changes in the coastline of the Northern Caspian Sea, shallow waters were identified within the Atyrau region. In the period 2016-2024, its area was 3,090 km^2 (Figure 9, 10).

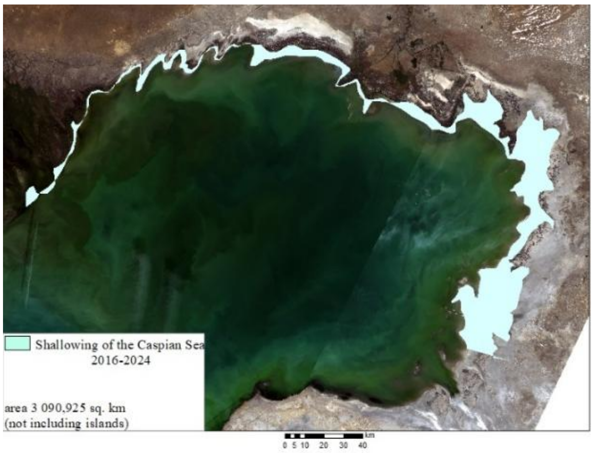


Figure 9. Dynamics of the length of the coastline of the Northern Caspian Sea in 2016-2024
Note: compiled based on the data [Ivkina N. et al., 2023: P.70-77]

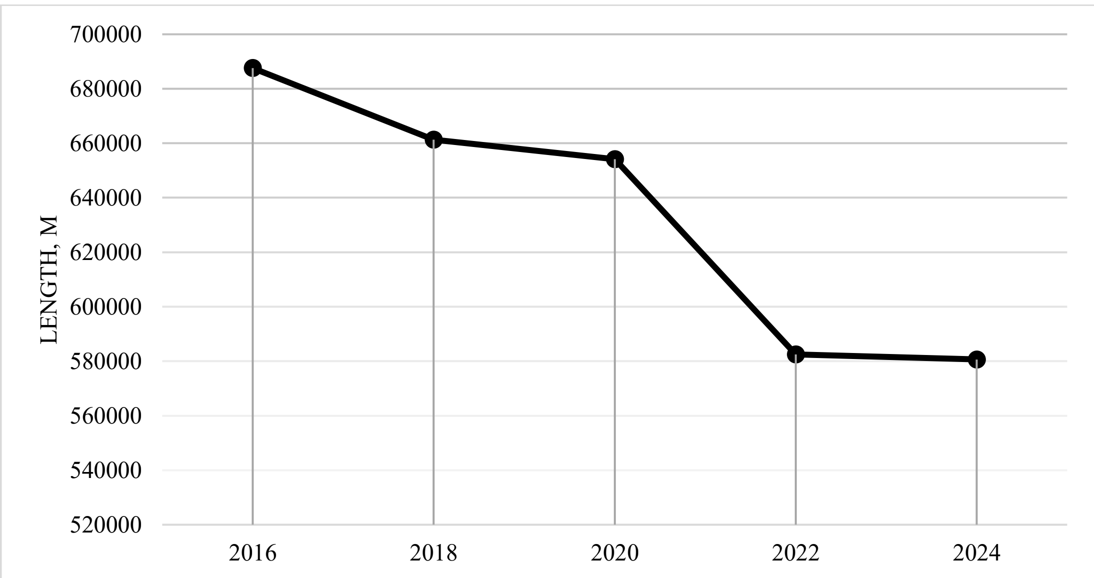


Figure 10. Dynamics of changes in the coastline of the Northern Caspian Sea
Note: compiled based on the data [Ivkina N. et al., 2023: P.70-77]

Shallow waters pose a major threat to the formation of new islands in the northern part of the Caspian Sea. The probability of their formation is highest in this area. Falling water levels have a negative impact on the ecosystem, causing desertification of the soil and a significant reduction in the population of seals, sturgeon and red fish.

Despite the studies conducted aimed at predicting changes in the Caspian Sea level using regional and global climate models, there is still considerable uncertainty in forecasts for the 21st century. After analyzing the trends in water level changes, scientists have drawn the following conclusions: according to the research of N.Elgindi and F.Georgie, by 2100 the level of the Caspian Sea may decrease by 4.5-5 meters. At the same time, other studies suggest that the water level may drop by 9-18 meters, which is associated with an increase in evaporation from the sea surface. In recent scientific papers based on various models, it is predicted that the decrease in sea level will be 8-10 meters within the CMIP5 models under various scenarios of climate change, and according to CMIP6 models, the drop may reach 20-30 meters [Elguindi N., Giorgi F., 2007: P.370].

Conclusion

Thus, the decrease in the water level in the Kazakh part of the Caspian Sea is a serious environmental problem that can have a significant impact on the ecosystem of the region, the population of coastal settlements. As already noted, the main reasons for the decrease in water levels are related to climate change, a decrease in river water supply and anthropogenic activities.

To prevent further reduction of the Caspian Sea coastline within the Atyrau region, the following solutions can be considered:

1. Rational management of water resources of rivers flowing into the sea. The Yedil River is the main source of fresh water flowing into the sea. Therefore, it is necessary to stop excessive water use of the river in agriculture and industry, develop a system for the proper use of water resources and begin work on raising the level of small rivers that provide the sea with water.

2. Reduction of anthropogenic load. This is coastal oil and gas production, which is an urgent problem today. Currently, the sea is becoming unstable and sometimes full depending on the season. At this point, offshore oil pipelines are washed away by water, and such oil spreads over the surface of the water. This has a serious impact not only on sea level, but also on the ecosystem of the sea, where biodiversity lives. To do this, it is necessary to tighten environmental regulations and limit large enterprises.

3. Conducting negotiations within the framework of international cooperation. The Caspian Sea borders not only with Kazakhstan, but also with Russia, Turkmenistan, Iran, and Azerbaijan. Joint programmes for the protection and conservation of water resources should be developed and implemented on the basis of international cooperation. This includes the exchange of information, joint management of water resources and the implementation of environmental initiatives. For example, it is necessary to negotiate with the Russian side and take measures to increase the volume of incoming water.

4. Mitigation of the effects of climate change. The implementation of measures to reduce greenhouse gas emissions from the coastal industry and the fight against global warming can help reduce the change in the hydrological balance of the region. The development of «green» technologies and energy is important to minimize the impact on the climate.

5. Monitoring and forecasting. It is necessary to strengthen monitoring of the Caspian Sea, including monitoring of water levels, water quality, climate change and anthropogenic impact. Modern modeling systems help to predict changes and develop strategies in a timely manner [Sarsenbaev B.S. et al., 2022: P.72].

A comprehensive combination of these measures can contribute to maintaining the water level in the Caspian Sea and ensuring the sustainable development of the region.

References

Mamaeva N. (2023) Vizualizaciya izmenenij beregovoj linii Kaspiijskogo morya. *Gidrometeorologiya i ekologiya,* (3), 63-67. DOI: https://doi.org/10.54668/2789-6323-2021-102-3-63-67 (date of access: 01.10.2024).

Ivkina N., Terekhov A., Naurozbaeva Zh. (2023) Kolebaniya urovnya Kaspijskogo morya i diagnostika sovremennyh izmenenij polozheniya beregovoj linii po sputnikovym dannym LANDSAT perioda 2005…2015 godov. *Gidrometeorologiya i ekologiya,* (2), 89-99 [Electronic resource]: URL: https://journal.kazhydromet.kz/index.php/kazgidro/article/view/259 (date of access: 08.10.2024).

Kudryavtseva N., Kussembayeva K., Rakisheva Z. B., Soomere T. (2019) Spatial variations in the Caspian Sea wave climate in 2002-2013 from satellite altimetry. *Estonian Journal Earth Sciences,* 2019, 68, 4, 225-240. DOI: https://doi.org/10.3176/earth.2019.16 (date of access: 15.10.2024).

NA RK (2010) *Nacional'nyj atlas Respubliki Kazahstan.* Almaty: Vit brand, 1. Prirodnye usloviya i resursy, 150.

Alireza A.A., Hashemifaraz A. (2024) Vyyavlenie zakonomernostej urovnya morya v dannyh al'timetrii Kaspijskogo morya. *Zhurnal vodnyh resursov i izmeneniya klimata*, 15 (7): PP.3222-3235. DOI: https://doi.org/10.2166/wcc.2024.088 (date of access: 22.10.2024).

Schwatke C., Dettmering D., Bosch W., Seitz F. (2015) DAHITI-an innovative approach for estimating water level time series over inland waters using multi-mission satellite altimetry. Hydrol. *Earth Syst. Sci.* 19, 4345-4364. DOI: https://doi.org/10.5194/hess-19-4345-2015 (date of access: 29.10.2024).

Samant R., Prange M. (2023) Climate-driven 21st century Caspian Sea level decline estimated from CMIP6 projections. *Communications Earth & Environment,* 4, 357. DOI: https://doi.org/10.1038/s43247-023-01017-8 (date of access: 05.11.2024).

Dolgih S.A. (2022) Sovremennye izmeneniya klimata na kazahstanskoj territorii Kaspijskogo regiona. Izmenenie klimata v regione Kaspijskogo morya: *Elektronnyj sbornik materialov Mezhdunarodnoj nauchnoj konferencii,* 27-28 oktyabrya 2021, Astrahan': Izdatel' Sorokin R.V., 42-44 [Electronic resource]: URL: https://tehranconvention.org/system/files/web/proceedings_of_the_scientific_conference_on_the_climate_change_in_the_caspian_sea_region_rus.pdf (date of access: 12.11.2024).

Chen J.L., Pekker T., Wilson C.R., Tapley B.D., Kostianoy A.G., Cretaux J.-F., Safarov E.S. (2017) Long-term Caspian Sea level change. Geophys. *Res. Lett.,* 44, 6993-7001. DOI: https://doi.org/10.1002/2017GL073958 (date of access: 19.11.2024).

Safarov E., Safarov S., Bayramov E. (2024) Changes in the Hydrological Regime of the Volga River and Their Influence on Caspian Sea Level Fluctuations. *Water,* 16, 1744. DOI: https://doi.org/10.3390/w16121744 (date of access: 03.12.2024).

Yasinskij S.V. (2013) Vodnyj balans prirodnyh zon bassejna r.Volgi v raznye po vodnosti fazy mnogoletnego perioda. *Izvestiya RAN. Seriya geograficheskaya,* 6, 86-101 [Electronic resource]: URL: https://izvestia.igras.ru/jour/article/viewFile/80/75 (date of access: 26.11.2024).

Iskakov B., Nurakynov S., Dabas J., Zhantayev Z., Balakay L., Dedova T., Yelisseyeva A., Sydyk N. (2024) Enhancing Environmental Sensitivity and Vulnerability Assessments for Oil Spill Responses in the Caspian Sea. *Sustainability,* 16, 9566. DOI: https://doi.org/10.3390/su16219566 (date of access: 10.12.2024).

Erezhep G., Isabekova N.A., Amerbekov E.U., Erimbetova A.A., Karimsakov K.E., Erzhigit A.P., Myrzahmetova A.Zh. (2017) Zagryaznenie Kaspijskogo morya. Studencheskij nauchnyj forum: *Elektronnyj sbornik materialov IX Mezhdunarodnoj studencheskoj nauchnoj konferencii,* 01 iyunya 2017, Moskva [Electronic resource]: URL: https://scienceforum.ru/2017/article/2017038012 (date of access: 17.12.2024).

Elguindi N., Giorgi F. (2007) Simulating future Caspian Sea level changes using regional climate model outputs. *Clim. Dyn.* 28, 365-379. DOI: http:s//doi.org/10.1007/s00382-006-0185-x (date of access: 31.12.2024).

Sarsenbaev B.S., Mankesheva O.T., Zhumadilov K.B., Aralbaeva M.K., Dzhanisenova A.M. (2022) Vliyanie obmeleniya Kaspijskogo morya na gruzopotoki Prikaspijskih gosudarstv: *Elektronnyj sbornik materialov Mezhdunarodnoj nauchno-prakticheskoj konferencii,* 31 marta, Aktau: Esenov universitet, 72 [Electronic resource]: URL: https://casp-geo.ru/wp-content/uploads/2022/05/MNPK-31-03-SBORNIK.pdf (date of access: 07.01.2025)

Conflict of interests:
There are no conflict of interest. All the authors reviewed and approved the final version of the manuscript.

The contribution of the authors:
A.Ye.Yeginbayeva and Jaras Sayaly developed the main concept of the study. A.Ye.Yeginbayeva and Jaras Sayaly designed the methodological approach for the research. A.Ye.Yeginbayeva and Jaras Sayaly verified and confirmed the accuracy of the data and results. A.Ye.Yeginbayeva and Jaras Sayaly conducted the primary stages of the research. A.Ye.Yeginbayeva and Jaras Sayaly drafted and prepared the initial manuscript. A.Ye.Yeginbayeva and Jaras Sayaly were responsible for translating the article into English and editing the review.

Солтүстік Каспий теңізі жағалау сызығының 2016-2024 жылдар аралығындағы өзгеру динамикасы

[1]*С.Жарас,* [1]*А.Е.Егинбаева*
[1]*Л.Н.Гумилев атындағы Еуразия ұлттық университеті (Астана, Қазақстан)*

Аңдатпа
Мақалада қашықтықтан зондтау және картографиялық деректер негізінде 2016-2024 жылдар аралығында Каспийдің солтүстігіндегі жағалау сызығының өзгеру динамикасы қарастырылады. Ол белсенді эрозия мен аккреция аймақтарын бөліп көрсете отырып, трансформацияның негізгі бағыттарын анықтайды. Зерттеу осы өзгерістерге әсер ететін табиғи және антропогендік факторларды, оның ішінде теңіз деңгейінің, климаттық жағдайлардың және шаруашылық қызметтің ауытқуын қарастырады. Нәтижелер жағалау аймағын өзгертудің экологиялық және әлеуметтік-экономикалық салдарын бағалауға көмектеседі. Сонымен қатар, зерттеу экологиялық тұрақтылықты аймақтағы адам әрекетімен теңестіруге бағытталған Солтүстік Каспий теңізінің экожүйесіне теріс әсерді азайту бойынша ұсыныстар береді. Нәтижелер жағалауды басқаруды жақсартуға және қоршаған ортаны ұзақ мерзімді сақтауға ықпал етеді.
Түйін сөздер: Солтүстік Каспий, жағалау сызығы, өзгерістер динамикасы, эрозия, аккреция, қашықтықтан зондылау, антропогендік әсер, экожүйе, су деңгейінің өзгеруі.

Динамика изменений береговой линии Северного Каспия за период 2016-2024 годы

[1]*С.Жарас,* [1]*А.Е.Егинбаева*
[1]*Евразийский национальный университет имени Л.Н.Гумилева (Астана, Казахстан)*

Аннотация
В статье рассматривается динамика изменений береговой линии Северного Каспия с 2016 по 2024 год на основе данных дистанционного зондирования и картографии. В статье определены ключевые направления трансформации, выделены области активной эрозии и аккреции. В исследовании рассматриваются природные и антропогенные факторы, влияющие на эти изменения, включая колебания уровня моря, климатические условия и экономическую деятельность. Результаты помогают оценить экологические и социально-экономические последствия трансформации прибрежной зоны. Кроме того, в исследовании содержатся рекомендации по смягчению негативного воздействия на экосистему Северного Каспия, направленные на обеспечение баланса между экологической устойчивостью и деятельностью человека в регионе. Результаты исследования способствуют

улучшению управления прибрежными районами и сохранению окружающей среды в долгосрочной перспективе.
Ключевые слова: Северный Каспий, береговая линия, динамика изменений, эрозия, аккреция, дистанционное зондирование, антропогенное воздействие, экосистема, изменение уровня воды.

Поступила в редакцию: 26.01.2025
Одобрена: 29.03.2025
Первая публикация на сайте: 13.08.2025

МРНТИ: *06.35.35* https://doi.org/10.65247/3105-3432-2025-4.05

ТҰРАҚТЫ ДАМУ МАҚСАТТАРЫНЫҢ МЕМЛЕКЕТТІК АУДИТІ

*[1] Ә.ЫБРАЙ, [1] Б.А.АЛИБЕКОВА
[1] Л.Н.Гумилев атындағы Еуразия ұлттық университеті
(Астана, Қазақстан)
*assiyaybray@gmail.com, alibekova_ba@enu.kz

Аңдатпа
Бұл мақалада Тұрақты даму мақсаттарын жүзеге асырудағы мемлекеттік аудиттің рөлі қарастырылады. Тұрақты даму мақсаттары – Біріккен Ұлттар Ұйымы қабылдаған әлеуметтік-экономикалық даму мен қоршаған ортаны қорғау арасындағы теңгерімді қамтамасыз ететін бағдарлама. Бұл мақсаттарды орындау – кез келген елдің ұзақ мерзімді дамуының алғышарты. Мемлекеттік аудит – осы мақсаттарға жетудегі маңызды құрал, ол ресурстардың тиімді және ашық пайдаланылуын қадағалап, Тұрақты даму мақсаттарына жетуге бағытталған әрекеттердің нәтижелілігін айқындауға мүмкіндік береді. Мемлекеттік аудит нәтижесінде мемлекеттік жоспарлау жүйесінің құжаттарының тұрақты дамудың күн тәртібін жүзеге асырудағы тиімділігіне баға беруге болады. Мақалада Тұрақты даму мақсаттарының мемлекеттік аудитін қызметіне енгізген Финляндия, Түркия және Ресейдің Жоғары аудит органдарының тәжірибелері талданады. Қазақстанның Тұрақты даму мақсаттарына жету көрсеткіштері талданып, оларды жақсарту жолдары қарастырылады.
Түйін сөздер: Тұрақты даму мақсаттары, Біріккен ұлттар ұйымы, мемлекеттік аудит, халықаралық тәжірибе, есептілік, тиімділік.

Кіріспе

Тұрақты даму мақсаттары (ТДМ) – 2015 жылы Біріккен Ұлттар Ұйымы (БҰҰ) қабылдаған, адамзаттың әлеуметтік-экономикалық дамуы мен қоршаған ортаны қорғау арасындағы тепе-теңдікті сақтауды көздейтін 2030 жылға дейінгі ғаламдық дамудың басымдықтарын айқындайтын бағдарлама [The 17 goals]. Тұрақты даму мақсаттарының мемлекеттік аудиті осы салалардағы мемлекеттік басқару жүйесіндегі кемшіліктерін анықтап, оларды жою бойынша ұсыныстар береді. Аталған мақсаттарды орындау әрбір мемлекеттің мүддесінде, ал оларға жетуде мемлекеттік аудит аса маңызды рөлге ие.

Негізгі бөлім

Қазақстан үшін Тұрақты даму мақсаттары (ТДМ) елдің ұлттық даму саясатының негізгі басымдықтарының бірі болып табылады. Экономиканы әртараптандыру, әлеуметтік әл-ауқатты арттыру және экологиялық тұрақтылықты қамтамасыз ету ТДМ-ның негізгі қағидаттарына толық сәйкес келеді. Бұл мақсаттарға қол жеткізу Қазақстанның халықаралық деңгейдегі беделін арттырумен қатар, ұзақ мерзімді тұрақтылық пен өркендеуді қамтамасыз етеді. Мемлекеттік аудит ТДМ-ға жету жолындағы маңызды құрал ретінде қарастырылады. Ол мемлекеттік және квазимемлекеттік сектор субъектілерінің ұлттық ресурстарды пайдалануының ашықтығы мен есептілігін қамтамасыз етеді. Сондай-ақ «...жаһандық пайымды, елдің орнықты дамуының ұзақ мерзімді бағыттары мен басымдықтарын айқындайтын мақсат қою құжаттарына негізделген» Мемлекеттік жоспарлау жүйесінің