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MONITORING OF LANDSLIDE PROCESSES IN THE ZHETYSU REGION

Purpose. To analyze the development of landslide processes in the village areas, study the causes of the destruction of the coastline of Lake Alakol, and develop recommendations for coastal protection measures. To assess the impact of key geological, hydrological, and climatic factors on the intensity of abrasion processes and the dynamics of the coastline.

Methodology. The methodology includes a comprehensive approach. Monitoring of the shoreline was conducted, covering the measurement of erosion speed and direction, evaluation of sediment volumes, analysis of changes in the coastline and geomorphological features. Computer modeling was used to predict destructive processes, considering multiple factors such as hydrological conditions, lithological composition of rocks, and climatic conditions. Retrospective analysis of long-term observation data and photographs revealed patterns in the development of shoreline changes.

Findings. The changes in the shoreline of Lake Alakol are related to the complex interaction of natural and anthropogenic factors. The main causes of shoreline destruction were identified, including active landslides, wave erosion, and changes in the hydrological regime. Measures for shore strengthening were proposed: installation of breakwaters, slope reinforcements, planting vegetation, creation of artificial beaches, and other engineering measures. A program for predicting coastal destruction using mathematical models has been developed, which allows for effective planning of measures to protect them.

Originality. The scientific novelty of this work lies in the integration of modern monitoring, analysis, and modeling methods to study the dynamics of coastal processes. This approach provides a deeper understanding of the causes of shoreline destruction and contributes to the development of optimal engineering solutions.

Practical value. Recommendations are developed that can be used for strengthening the shores of Lake Alakol, as well as preventing exogenous geological processes (shoreline abrasion, landslides, landslips, collapses, gully formation, etc.) at other water bodies.

Keywords: *abrasion, landslides, shoreline erosion, monitoring, coastline, Lake Alakol*

Introduction. The current length of the lake is 104 km, with a shoreline length of 384 km, a width of 52 km, a maximum depth of 22.1 m, and a catchment area of 68.7 thousand km² [1]. Over the past 50–70 years, this natural water body has been eroding the southeastern coastline, annually “eating” away a strip of land 300 meters wide. The shores of Lake Alakol are flat and composed of loose Quaternary deposits [2]. Only the southern and, to some extent, the eastern shores, washed by the lake, have terraces up to 9 meters above the water level. Long and narrow spits detach from the shores. Thanks to them, the lake was historically named Gunge-Nor, as during lower water levels, some of these spits formed natural “bridges” connecting one shore to another. The formation of the lake’s shores is influenced by rivers and winds. Rivers flowing into the northern part of the lake carry sand and clay, while those entering the southern and partly eastern parts also bring gravel. Winds, causing strong disturbances, erode the shorelines in some areas while building them up in others, forming spits and sandbanks. As a result of the rising water level, the shoreline has retreated by several dozen meters compared to previous years, and in some areas,

even several kilometers (over a 12-year period, the water level rose by 4.25 meters). Both intra-annual and multi-annual fluctuations in the water level of Lake Alakol are observed, as shown in Table [3].

The Alakol Depression is an important object of study from the perspectives of geology, hydrogeology, and hydrology (Fig. 1). The issues related to the hydrogeological conditions of the region and its location within the system of fold structures of the Tien Shan have been extensively discussed in several studies [4].

Stationary hydrological observations in the region began in the mid-20th century, covering water levels, temperature, and precipitation. In the 1960s, comprehensive studies on the water balance, runoff of major rivers, and hydrochemical composition of the waters were carried out [5]. The most significant rivers feeding the region’s lakes are Tentek, Urjar, Emel, and Karakol, which are characterized by bicarbonate-calcium water with low mineralization (up to 0.3 g/L).

Current work includes bathymetric surveys, the study of the morphometry of lakes, bottom sediments, and hydrofauna. The results of the research are summarized in scientific publications, which address the long-term fluctuations in water levels and hydrological features of the Alakol system.

Table

Changes in the Area and Volume of the Water Mass of Lake Alakol with the Decrease in its Water Level

Lowering water levels, m	Water surface area, km ³	Water mass volume, thousand m ³
0	2,650.0	58,560.000
5	2,190.48	46,400.000
10	1,790.52	36,400.000
15	1,437.88	28,400.000
20	1,232.54	21,780.000
25	1,053.23	16,020.000
30	888.27	11,120.000
35	719.71	7,140.000
40	564.94	3,920.000
45	334.06	1,720.000
50	193.6	420.000
54	0	0

The studies conducted allowed for a comprehensive understanding of the main features of the hydrological regime and water balance of the lakes.

The flora of the Alakol Depression has been the subject of study for many specialists throughout the 20th century [6]. These studies laid the foundation for the first comprehensive exploration of the geological-structural framework and hydrogeological features of this area.

Analysis of the research devoted to the Alakol Depression has revealed the variety of approaches, representations, and methods, as well as the differing degrees of study of both qualitative and quantitative aspects of water resources, which are changing under the influence of modern natural and anthropogenic factors and processes [7, 8]. In the context of the intensive socio-economic development of the region, there is a need to develop a sustainable management strategy for the rational use of natural resources. Geographically, this area lies in the foothills of the northeastern slopes of the Dzungarian Alatau and the southwestern part of the Alakol Depression.

In terms of orography, the region represents the southwestern part of the Alakol Depression, bordered to the south and southwest by the northeastern slopes of the Dzungarian Alatau (Fig. 2). The geological structure of the aforementioned geomorphological units includes deposits of varying age and genesis [9]. Along the Dzungarian Fault, the depression connects with the northeastern spurs of the Dzungarian Alatau. The Alakol Depression is composed of a thick cover of loose Cenozoic deposits and is further divided within the studied area into three structural zones of northwest orientation: the central, northeastern, and southwestern zones [10]. The central zone extends as a strip 10–15 km wide from Lake Sasykkol to Lake Kishi-Alakol. The thickness of the loose sediments here ranges from 200 to 300 meters. Their age spans from Miocene to present. Lithologically, in the middle zone, clays and silty clays dominate, with sand and gravel layers playing a subordinate role.

In hydrogeological terms, the described area belongs to the artesian basin of the Balkhash-Alakol depression and its mountain framework. Active erosion of the shoreline has been observed in the last 50 years, while winds have been blowing since the formation of the Alakol depression. The depression began to form in the Mesozoic era and represented a natural aerodynamically dynamic tube. Over such a long period (more than 200 million years), winds would have eroded not only the lake shores but also the ridges surrounding the depression. The engineering-geological conditions are determined by the geological-structural features, geomorphological, and hydrogeological conditions. Engineering-geological properties of the rocks composing the surface are of primary importance for various types of construction. The characteristics of the parameters (composition and properties) of these rocks according to stratigraphic-genetic complexes are provided based on the analysis and generalization of a large amount of factual material obtained from engineering-geological studies conducted in previous years [11].

Literature review. One of the scientific articles related to the study of the Alakol depression suggests conducting bathymetric surveys to evaluate the thickness of underwater beach deposits, determine their area, and analyze their composition [12]. It also recommends establishing the age of beach gravel and loess-like silts covering them. Furthermore, it is important to perform a paleogeographical analysis of the formation and evolution



Fig. 1. Lake Alakol (Google Earth, 2021)

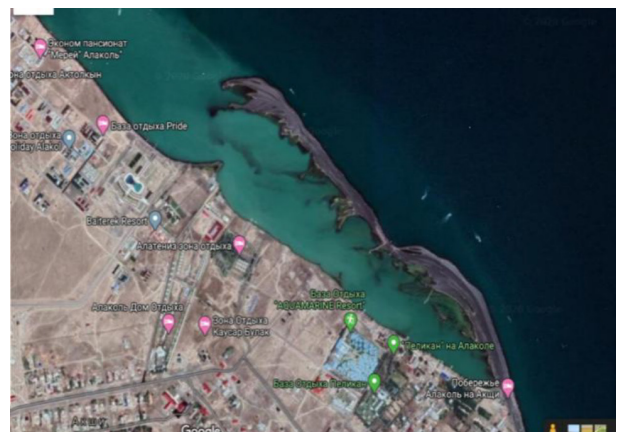


Fig. 2. Southwest part of Lake Alakol (Google Earth, 2019)

of Lake Alakol and its depression to reconstruct the changes in the shoreline over time. According to the renowned Kazakh researcher T. Dzhurkashiev, "It is already necessary to begin replenishing the beaches on the cliffed section of the shore, artificially and systematically increasing the width of the beach, as is done along the southeastern shore of Crimea".

When part of the beach, along with buildings, once again sank into the waves of Alakol, it was decided to take countermeasures against the natural forces in the Urdjar district of East Kazakhstan. The first project involved constructing artificial peninsulas from rocky materials. This approach proved to be the most effective. Mentaschi, et al. [13] studied the issues of controlling and monitoring hazardous processes in the coastal zone, as well as counteracting and managing natural risks. Engineers and researchers such as Umar, et al. [14] explore engineering solutions to the problem of abrasion and the retreat of the coastline. Jonah, et al. [15] conducted a large-scale assessment of the coastal zone in Ghana, utilizing field studies with coastal geomorphology and GIS methods over a 540 km stretch of coastline. The results of the assessment showed significant and widespread coastal erosion, leading to substantial losses.

In an article by Yueyao Zhou, information is provided about the collapse of the banks of the Middle Yangtze River. The collapse of alluvial riverbanks is a typical issue of soil-water interaction, which is linked to various factors, including the direct impact of the flow, changes in river levels, and human activities (e.g., coastal protection) [16].

To improve data accuracy, Telling, et al. proposed an enhanced approach to using terrestrial laser scanning in their work. This method, developed by Jennifer Telling and her colleagues, integrates modern 3D scanning and analysis technologies, providing detailed monitoring of relief changes and improving the reliability of the results [17].

This method is actively used in global coastal terrain studies. In their article, Kuhn, et al. [18] used terrestrial laser scanning data to create highly accurate digital terrain models with geographic references, as well as 2D and 3D visualizations of a marine cliff on the Yasmun Peninsula, located on the southwestern coast of the Baltic Sea. These models are applied to analyze spatial and temporal changes, as well as to evaluate erosion and soilwash processes.

Purpose. The goal of this study is to analyze the development of landslide processes in rural settlements, examine the causes of shoreline destruction at Lake Alakol, and develop recommendations for coastal protection measures. Special attention is given to the primary geological, hydrological, and climatic factors affecting abrasion processes and shoreline dynamics.

The study will involve monitoring and mapping areas of active destruction, analyzing shoreline changes based on satellite images and historical data, as well as assessing the impact of anthropogenic factors. Proposals will be developed for applying environmental and engineering methods to stabilize the shoreline zone, aimed at reducing the rate of erosion and preventing further destruction of coastal areas.

Materials of the research. At present, there is a wide range of landslide types. The most common classifica-

tions are those proposed by F.P. Savarensky and A. P. Emelyanova [19]. The subsystem is designed to identify, assess, and forecast dangerous exogenous geological processes. The primary goal of monitoring is to observe exogenous geological processes and their spread across territories. This includes analyzing both natural and technogenic factors to predict potential threats and develop recommendations for minimizing damage in the event of process activation. Monitoring of dangerous exogenous geological processes is conducted both in natural conditions and in areas affected by technogenic changes, focusing on locations where these processes may impact settlements, infrastructure, and the economy.

Landslides in the Zhetysu region vary significantly in size, types, mechanisms, and movement speeds. Therefore, the methodology and scope of landslide monitoring can vary depending on the level of risk and slope instability.

Regulating coastal processes is an important task that requires a comprehensive approach. One key aspect is monitoring the state of the shores, including regular measurements of erosion speed and direction, assessment of the volumes of displaced sediments, and analysis of shoreline changes and geomorphological features.

Based on monitoring data, coastal protection programs are developed, which may include installation of breakwaters, creation of slope reinforcements, planting vegetation, constructing artificial beaches, and other measures. It is important to consider the interrelationship of various processes, such as hydrological, geological, and biological ones, and their impact on the shores.

The foundational concept for monitoring landslide processes is recommended to use the concept of spatial-hierarchical interrelationship between natural (geological) and technogenic objects in the studied territory. To refine forecasts and monitor the actual state of the coastal zone, regular monitoring is necessary. This includes geodetic and topographic surveys, measuring erosion rates, analyzing vegetation conditions, and other observations. The results of monitoring allow for adjustments to models and forecasts, as well as planning necessary coastal protection measures.

To forecast landslide processes, monitoring must be conducted simultaneously at three different levels: regional, local, and detailed ones. At the regional level, monitoring is typically carried out within the Jetysu and East Kazakhstan regions. The described monitoring provides a general understanding of the area's susceptibility to landslide processes, as well as the dynamics of changes in slope conditions over space and time. Additionally, it evaluates the potential damage that landslides can cause to the environment, transportation infrastructure, industrial facilities, and residential buildings. The area of regional landslide monitoring can cover a territory of over 100 km².

The local monitoring within the region focuses on landslide systems covering large river basins and complex ravine-gully structures, with an area coverage of 10–100 km².

The detailed monitoring is usually carried out for individual specific landslides. The information obtained during detailed monitoring is used for forecasting and timely warning about the risk of landslides. Current geological processes and phenomena in the region are

mainly related to human engineering and economic activities, particularly to reclamation construction. Until the 1960s, the development of certain dangerous geological processes was episodic in nature. Erosion caused by water flow occurred only during spring floods and heavy rainfall, leading to undercutting and collapse of the banks. Deflation manifested itself in the aeolian reworking of alluvial-lake deposits, creating blowout basins, sand dunes, wind ripple marks, and other microrelief forms. Salinization and waterlogging occurred in the form of widespread development of solonchaks, salts, and puffy soils in areas with shallow groundwater levels. Abrasion was particularly intense on the southern and eastern shores of Lake Alakol. The southern shore of the lake (the area around the settlement of Koktumay) has retreated more than 200 meters over 20 years. As a result of undercutting and collapse of the bank, part of the settlement was destroyed. The shoreline of the lake approached the railway track. The intensification of abrasion processes is due to frequently repeated hurricane winds and the expansion of the lake's area. According to measurements from 1862 and 1931, the lake's size increased by 5 km in both length and width. Even more intense growth of the lake's area was recorded in the measurements from 1951. Over 20 years, the length of the lake increased by 15 km, the width by 5 km, and the depth also increased.

The methodology of the research. Current methods and tools for monitoring landslide processes used in landslide monitoring depend on their types and the scale of their distribution. Methods for calculating shoreline erosion are based on mathematical models describing the physical, chemical, and biological processes of shoreline erosion. These allow for accurate calculation of shoreline retreat rates but require large amounts of input data and complex computations. Integrated methods combine elements of statistical, empirical, and analytical approaches. They include both the analysis of accumulated data and physical modeling of shoreline processes. These methods provide high forecasting accuracy with relatively simple calculations.

Research and activities within the framework of landslide process monitoring are carried out using both traditional (field) methods at landslide sites and polygons, as well as those with Earth remote sensing data.

In one scientific paper related to the research on the Alakol depression, it is suggested to conduct bathymetric surveys, assess the thickness of underwater deposits on the beach, determine their area and composition [20]. It is also recommended to establish the age of the beach gravels and the loess-like silty clays covering them. In addition, it is important to perform a paleogeographic analysis of the formation and development of Lake Alakol and its depression in order to reconstruct changes in the shoreline in the past (Figs. 3–6).

The widespread distribution and active manifestation of landslide processes, caused by natural and anthropogenic factors, make it necessary to organize monitoring. This is essential for preventing harmful consequences for the ecosystem, ensuring the safety of residential areas, industrial facilities, transportation networks, and other objects [21].

Among the many dangerous natural processes and phenomena characteristic of the Zhetysay region, special



Fig. 3. Results of shoreline erosion (photo by the author, 2020)



Fig. 4. Results of shoreline erosion at Akshi village (photo by the author, 2019)



Fig. 5. Shoreline abrasion (photo by the author, 2019)



Fig. 6. Shoreline abrasion (photo by the author, 2019)

attention is recommended to be given to landslide processes such as shoreline erosion and abrasion (Figs. 1, 2).

During fieldwork, it was noted that at the observation point, the abrasion coastline is arc-shaped, with active dynamics of shoreline erosion. The recreation bases located near the shoreline are at risk of collapse.

The Alakol Depression, surrounded by mountain ranges on three sides, represents a semi-desert steppe with vast salt depression areas and isolated sand dune masses. To the southeast, it is connected to the Ebi-Nur lake depression through a narrow intermountain pass, while to the northwest, it gradually merges with the Balkhash Depression [22].

Instrumental measurements were conducted at the monitoring site located to the northwest of Akshi (Fig. 7). The distance from 4 reference points (observation points) to the edge of the shoreline cliffs at Lake Alakol was measured (Fig. 4).

1. The dynamics of the retreat of the shoreline cliff edge at reference point I over 10 months (2018–2019) amounted to 6.5 m, at reference point II – 6.3 m over the same period, at reference point III – 6.4 m, and at reference point IV – 6.7 m. The distance from reference point I to the cliff edge is 19.5 m.

2. The width of the beach (from the waterline to the base of the cliff) is 3–3.2 m. The beach is composed of coarse-grained dark-colored sand (almost black) and a gravelly-pebble mixture. Dry soil and fragments of collapsed material from the cliff edge are also found in some areas.

3. The height of the cliff at this monitoring site is approximately 0.7–2 m.

4. Photo documentation of the monitoring site.

During the research, the following areas were identified as being susceptible to natural processes of shoreline erosion due to natural geological and geomorphological factors, as well as active destruction of the coastline resulting from anthropogenic interference (Figs. 7, 8).

Results. In recent years, there has been intensive erosion of the eastern and southeastern shores due to northern winds blowing from the north, particularly affecting the settlements of Akshi and Koktuma, which raises significant concern.

Currently, the lake and its surroundings are used for balneological purposes. A problem has arisen regarding the causes of shoreline destruction. The most common cause of shoreline erosion is associated with the impact of strong northwest winds. The lake receives more than 15 tributaries, among which the main ones are six rivers: the Emel (27.4 %) in the north and northeast, the Yrgayty and the Zhamanty (8.8 %), the Khatinsu (8.8 %), the Zhamanutkol (5 %), and the Urzhar River (providing 50 % of the surface runoff into the lake) [22].

One of the projects is the idea of constructing breakwaters. Between 2007 and 2009, a contracting organization installed a pier and constructed the underwater part of a 168-meter-long reinforced concrete breakwater. The project involved mounting the pier from metal structures that were to be driven into the ground. Stone revetments were planned to be placed on both sides of the pier to reduce water pressure. Tetrapods – heavy concrete forms – were to be placed along the revetment slopes to compress the stone. The recreation centers “Alakol”, “Aigerim”, “Zhagazhaj” and others were at risk. The national program for the development of tourism in the country, in which Lake Alakol in the Urzhar

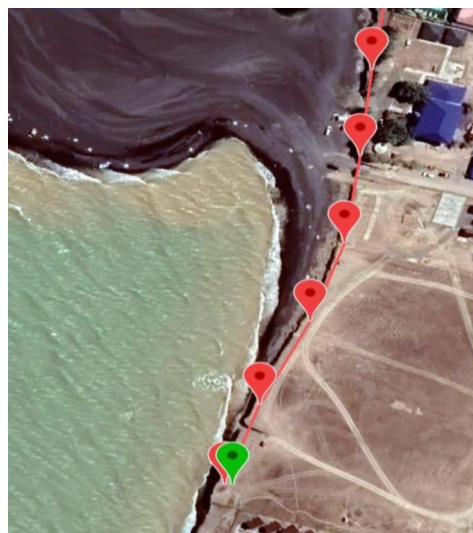


Fig. 7. Changes in the shoreline of Alakol (created by the author using the Planimeter Pro app)



Fig. 8. Results of shoreline erosion at Akshi village (photo by the author, 2024)

district of the East Kazakhstan region was marked as the most promising place for attracting tourists, was also under strain.

The waters of Lake Alakol, gradually rising, have submerged the gravel beaches, leading to the destruction of the shoreline. The underwater beach is shifting along the coast in the southeast direction, creating an accumulating spit. The absence of an underwater beach has gradually led to a critical situation, and currently, there is active abrasion of the southeastern and southwestern shores. The recreational zone of the settlements Akshi and Koktuma is located in the southwestern area of Lake Alakol. The modern landform consists of an alluvial-proluvial sloping, weakly dissected plain, complicated by abrasion cliffs, spits, washout niches, with collapses and landslides. The main hazardous exo-geodynamic processes in the area are abrasion, subsidence, gully erosion, surface wash, swamp formation, and flooding. The shore types are abrasion, abrasion-accumulative, accumulative-phytogenic, and deltaic. The

steep abrasion cliffs have heights ranging from 3 to 9 meters. The shore type was determined based on the predominant engineering-geological process that extends along the entire shoreline.

In conclusion, we have analyzed the scientific foundations for providing ecological and geomorphological assessments of abrasive processes, including methods of evaluation and cartography. Additionally, proposals for monitoring abrasive processes at Lake Alakol were discussed. The results showed the dynamics over a 25-year period along the southeastern and southwestern shorelines, with the shoreline retreating by 60–100 meters. Therefore, we propose reconsidering the issue of shoreline protection.

Unlike our harsh conditions, underwater reefs worldwide are primarily located along coastal marine areas with warm climatic conditions. However, we believe that the proposed method for installing reefs will help address the aforementioned problems at Lake Alakol, as it aims to increase biological productivity by creating favorable ecosystems in the artificial reef, which serves the function of self-purification of the marine water. This will also have a positive impact on slowing down the destruction of the shoreline at Lake Alakol and will serve as the basis for further actions. Shoreline destruction is becoming an increasingly important issue in the context of the intensive settlement and development of coastal areas.

To prevent shoreline destruction and ensure their protection, the construction of specialized structures is required. The main tasks include protecting coastal areas from flooding and inundation, safeguarding the coastline and its buildings from the destructive impact of waves, and improving the coastal zone.

Two types of methods are used in the fight against shoreline destruction: active and passive methods. Passive methods involve the use of structures that absorb wave energy, such as wave-breaking walls, embankments, slopes, and stone revetments. In contrast, active methods focus on using wave energy to strengthen the coastline, including structures like jetties and breakwaters. This division is conditional.

The article by Yueyao Zhou provides information on the collapse of the banks of the Middle Yangtze River. Bank collapses along alluvial rivers are a typical issue related to soil-water interaction, influenced by many factors, including the direct effect of flow, changes in river level, and human activities (such as riverbank reinforcement) [16].

To study the mechanisms of destruction of protected riverbanks and the potential factors affecting their stability, we analyzed data obtained from a typical section of the Middle Yangtze River. Additionally, numerical modeling of seepage and changes in stress within the riverbank was performed. Field observations and modeling results showed that hydraulic erosion by the near-shore flow remains the main factor influencing the erosion of protected riverbanks. However, riverbank reinforcement works effectively limit lateral bank retreat but increase the erosion of the nearby riverbed. The greatest depth of erosion was 10.6 meters from August to November 2020.

The initial damage to protected riverbanks can be caused by local concentrations of tensile stress during

the water level rise, under the combined influence of hydrostatic holding force, pore water pressure, and gravity. This initial damage can evolve into more severe cases of bank failure, especially during floods. After the “Three Gorges” project, the increased rate of river level fluctuations (~1.6–2.5 times) could potentially increase the risk of damage to protected banks of the Middle Yangtze River. Riverbank erosion is an important source of sediment in alluvial rivers but also poses serious challenges in flood management and maintaining navigational channels.

Numerous factors influence bank erosion, including the water level in the riverbed, groundwater flow, riparian vegetation, and the properties of the bank deposits [21]. Moreover, intensive human intervention, such as engineering regulation of rivers, further complicates the erosion processes. For example, riverbank lining works have proven effective in significantly reducing nearshore river erosion and are widely used to increase bank stability. However, the specific mechanism of destruction of protected riverbanks remained unclear. Investigating the response of flow and groundwater stress to fluctuations in river level, and understanding how these factors influence the erosion of protected riverbanks, is of paramount importance. Experimental methods are effective ways of studying hydro-riverbank collapse conditions. Several tests of a trough with built-in sensors were conducted to detect changes in pressure, such as pore pressure, soil load, and water content.

Conclusions. Landslide monitoring is a part of the monitoring system for exogenous geological processes. The study of coastal dynamics and methods of their protection has attracted the attention of many well-known scientists for a long time. The main purpose of this is to collect information on the development of landslides, predict their dynamics and minimize harmful effects on the environment, economic facilities, settlements and road infrastructure.

Coasts are constantly exposed to the sea, with this resulting in the formation of various geomorphological features on the shorelines. The principles of coastal morphostructure formation are of interest to many specialists, but the issue of coastline protection is especially relevant, particularly for shores that are actively used or planned for development, as the effects of the sea do not always yield positive results for humans. The processes of shoreline changes in reservoirs play a key role in maintaining ecological balance and the sustainable use of water resources. In this regard, technologies are being developed, and coastal protection structures are being established, although these are not always fully capable of performing their functions. Various aspects of this issue have been considered, ranging from their significance and methods of processing to the problems and prospects.

The coastal zones represent important ecosystems that support biodiversity and provide a variety of functions, including erosion protection and resource provision for various types of economic activities. However, they also face various challenges such as anthropogenic impact and climate change, which can significantly undermine their stability and functionality.

In conclusion, addressing the issues of lake shoreline management is an integral part of ensuring sustainable

development and the preservation of natural resources for future generations. The systematic and purposeful implementation of measures and policies aimed at protecting and restoring coastal zones is a necessary step toward achieving this goal.

Based on the analysis of all possible factors, it can be concluded that the key factor in the destruction of the shores of Lake Alakol is the latest tectonic processes. The impact of winds and surge waves, as well as delta deposition, are less significant and secondary factors. Currently, both the left and right shores of the village of Akshi, located on a coastal ledge with a height of 5 to 7 meters, are also being actively eroded. Wave action leads to the undercutting of the ground at the base of the ledge, causing its erosion, loss of elasticity, and strength. As a result, the upper part of the ledge collapses onto the beach. The main factor contributing to wave action is the transverse orientation of the coastal ledge relative to the eastern wind. When wind speed reaches 2.5–3.0 m/s, the resulting waves reach the base of the ledge, leading to erosion and soil saturation (wetting). This wind speed is sufficient to initiate active shoreline erosion, and as the wind strength increases, the process may intensify. Based on global practices, a number of recommendations can be made for conducting shoreline protection and environmental conservation measures:

1. It is necessary to conduct a detailed study of the shoreline of the lake.
2. To perform bathymetric measurements, determine the thickness of the sediments of the underwater beach, the area of the underwater zone of the beach and the material composition of the sediments.
3. To determine the age of loose deposits of beach pebbles and loess-like loams overlapping them.
4. To carry out a paleogeographic analysis of the history of the formation and development of the Alakol depression and Lake Alakol in order to establish changes in the position of the coastline in the past.

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Моніторинг зсувних процесів на території Жетисуської області

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Мета. Аналіз розвитку обвальних процесів на території сіл, вивчення причин руйнування берегової лінії озера Алаколь і розробка рекомендацій щодо берегоукріплювальних заходів. Оцінити вплив основних геологічних, гідрологічних і кліматичних факторів на абразію берегової лінії.

Методика. Методика включає комплексний підхід. Проводився моніторинг стану берегів, що охоплює вимірювання швидкості й напрямку розмиву, оцінку обсягів наносів, аналіз змін берегової лінії та геоморфологічних особливостей. Застосовувалося комп'ютерне моделювання для прогнозування руйнівних процесів, що враховує багато факторів, таких як гідрологічний режим, літологічний склад порід і кліматичні умови. Ретроспективний аналіз даних багаторічних спостережень і фотознімків дозволив виявити закономірності розвитку берегових змін.

Результати. Зміна берегової лінії озера Алаколь пов'язана з комплексним впливом природних

і антропогенних факторів. Виявлені основні причини руйнування, зокрема активні обвали, хвильова ерозія й зміни гідрологічного режиму. Запропоновані заходи з укріплення берегів: встановлення хвильових валів, облаштування схилових укріплень, посадка рослинності, створення штучних пляжів й інші інженерні заходи. Розроблена програма прогнозування руйнування берегів із використанням математичних моделей, що дозволяє ефективно планувати заходи щодо їх захисту.

Наукова новизна. Полягає в інтеграції сучасних методів моніторингу, аналізу й моделювання для вивчення динаміки берегових процесів. Такий підхід забезпечує більш глибоке розуміння причин руйнування берегів і сприяє розробці оптимальних інженерних рішень.

Практична значимість. Полягає в розробці рекомендацій, що можуть бути використані для укріплення берегів озера Алаколь, а також для запобігання екзогенним геологічним процесам (руйнування берегів, обвали, осипи, зсуви, яроутворення та ін.) на інших водних об'єктах.

Ключові слова: абразія, обвали, розмив берега, моніторинг, берегова лінія, озеро Алаколь

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