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Geoenvironmental assessment of hydro-mineral recreational resources in the eastern and southeastern parts of the Alakol lakes system

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Abstract: The article discusses the natural and balneological characteristics of the hydromineral resources of the Alakol–Zhalanashkol lake system located in the south-eastern part of the Abai region. The study was conducted in an arid climate, taking into account the spatial variability of the chemical composition of water and mud deposits. Field and laboratory observations conducted in 2024–2025 were aimed at determining the physical and chemical characteristics of mineral waters and therapeutic muds, as well as assessing their potential for recreational and health purposes. Field work covered the eastern, western, northern and south-eastern coastal zones, including areas of active mud accumulation. Analyses performed in the laboratories of the "Shakarim University" NCJSC and the Sanitary and Epidemiological Service of the Zhetysu region showed that concentrations of the main chemical elements and minerals meet acceptable sanitary standard. Variations in water chemistry between the eastern and western sectors were found to depend on hydrological and climatic factors. Sulfates, chlorides, and bischofite ($MgCl_2$) were found to predominate in the composition, imparting pronounced therapeutic properties to the muds. The results confirm the high balneological value and environmental safety of the lakes, supporting their potential use in health tourism, balneotherapy and sustainable regional development.

Keywords: Alakol; Zhalanashkol; hydromineral resources; therapeutic mud; bischofite; recreation; tourism; balneology; chemical composition; sustainable development

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1. Introduction

The southern and south-eastern regions of the Abai region are characterised by high natural resource potential, determined by the unique hydromineral resources of the Alakol Lakes system. These water bodies represent a complex natural and geographical complex, combining a wide variety of landscapes, climatic conditions and recreational opportunities. In recent decades, this territory has been the subject of intensive research by domestic and foreign scientists studying its natural-geographical, hydrochemical and recreational features, as well as the impact of anthropogenic factors on the state of ecosystems.

One of the first comprehensive studies devoted to assessing the

natural resource potential of the Alakol Basin was the work of S. Erdavletov and A. Aktymbaeva (Erdavletov et al., 2012), in which the authors characterised Alakol as a natural resource subsystem of the local tourism and recreation complex. The scientists substantiated the spatial structure of recreational development, identifying key nodes and functional zones of tourist activity. This research was continued in the work of A.S. Aktymbaeva and M.T. Taukebayeva, which provided a geo-ecological description of the region, assessed its tourism and recreation potential, and identified limiting natural factors (Aktymbaeva et al., 2015).

Previously, A.S. Aktymbaeva studied the hydroecological characteristics of the Alakol group of lakes, identifying patterns in the distribution of hydrochemical parameters and their seasonal dynamics (Aktymbaeva, 2006). K.A. Iskakova, A.A. Zhakupova, Sh.T. Abdreeva, and G.R. Aizholova made a significant contribution to understanding the current state of the recreational potential of the Alakol basin by assessing the level of anthropogenic pressure and proposing methods for monitoring the recreational transformation of coastal landscapes (Iskakova et al., 2013).

A geo-ecological assessment of the territorial recreational systems of the Alakol Lake basin was presented by Zh.T. Mukaev, who emphasised the need for spatial analysis of natural resource use and biodiversity conservation (Mukaev, 2017). These provisions were developed in a collective monograph by J.T. Mukaev, K.M. Dzhanaleeva, L.D. David, Zh.O. Ozgeldinova, M.A. Beisembayeva, G.T. Ospan, Z. Kishkenbayeva and E. Sailaubay, which examines in detail the environmental challenges associated with the development of tourism and proposes approaches to the formation of a sustainable model for the recreational use of natural resources (Mukaev et al., 2017). In later works by Z. Kishkenbayeva and E. Sailaubay, the issue of environmental sustainability is considered in the context of integrating environmental protection measures into the region's tourism policy, emphasising the importance of balancing economic development and ecosystem conservation (Kishkenbayeva et al., 2024).

The works of N.A. Amirgaliyev, T.Y. Lopareva, L.A. Gogol, and Sh.Ch. Kanagatova present an analysis of the hydrochemical regime of the lakes, determine the key parameters of their mineral composition, and identify the factors influencing the formation of their balneological properties (Amirgaliev et al., 2003). In her dissertation, N.E. Snegireva was the first to systematise data on the chemical composition of surface waters in the Sasyk-Alakol basin and determine their dependence on climatic and geomorphological conditions (Snegireva, 1970).

Research into hydromineral resources was continued in the works of D.M. Dzhetimov, E.A. Tokpanov, B.K. Asubaev and A.K. Esengabylova (Dzhetimov et al., 2014), who conducted physical, chemical and microbiological analyses of the therapeutic mud deposits at the Kossor site on Lake Alakol. The scientists identified a high concentration of biologically active elements, confirming their potential for medical use and the prospects for the development of balneological tourism. Recent foreign studies (Carbajo et al., 2017; Quattrini et al., 2017) confirm similar patterns in the study of hydrogen sulphide and mineral waters, emphasising their therapeutic and rehabilitative value.

In the context of comparative analysis, Kazakhstani authors (Akimzhanova et al., 2024) studied the chemical composition and physicochemical properties of natural therapeutic muds from the salt lakes of Kazakhstan, including the Alakol system, and identified directions for the rational use of their recreational potential. An important contribution to the understanding of historical and scientific aspects was made by S. Kairgeldina, K. Tekebaev, M. Baurzhan, K. Absattarova, and N. Slivkina made an important contribution to understanding the historical and scientific aspects, tracing the main stages of the development of Kazakh balneology and its connection with geographical research into natural therapeutic factors (Kairgeldina et al., 2024).

The problems of ecosystem degradation under the influence of anthropogenic factors are reflected in the works of T.I. Moiseenko, E.L. Cesonien and co-authors, as well as J.F. Artiola, I.L. Pepper and M.L. Brusseau, which show that the growth of recreational and economic pressure on water bodies requires constant monitoring of water quality (Moiseenko, 2022; Česonienė et al.,

2021; Artiola et al., 2004). Foreign authors A. Durán Sánchez, J. Álvarez-García and M.C. Del Río-Rama note the importance of active tourism and its impact on the sustainable development of regions, while M. Tosic and colleagues propose comprehensive approaches to assessing pollutant loads on coastal areas (Sánchez et al., 2014; Tosic et al., 2018). In turn, S.B. Wassie justifies the need to develop adaptive strategies to prevent the degradation of natural resources, which is in line with the objectives of environmental regulation of tourism activities in the Alacol Basin (Wassie, 2020).

The relevance of this study is determined by several important scientific issues. First, there is a need for a more detailed study of the chemical composition of the waters and therapeutic muds of the Alakol lakes. It is of considerable importance for the development of balneological practices and medical tourism in the region. Secondly, the impact of anthropogenic factors on the ecosystems of this water system remains insufficiently studied, which requires the development of effective methods for monitoring and assessing the sustainability of natural resources.

In addition, the study is of general scientific importance for the geoecology of arid areas, where specific climatic conditions and a high degree of water evaporation determine the formation of unique hydrochemical characteristics of water bodies. The results of the work may be useful for expanding knowledge about geoecological processes in other arid and semi-arid regions, as well as for developing methods for the rational use of natural resources in a changing climate.

Thus, analysis of existing studies shows that the issue of recreational development and rational use of the hydromineral resources of the Alakol lake system is multifaceted. Despite the availability of fundamental works, issues related to the variability of the physical and chemical composition of water and therapeutic muds, as well as the consequences of anthropogenic impact on the region's ecosystems, remain unresolved. This study aims to fill these gaps by conducting a comprehensive study of the hydromineral resources of the eastern and south-eastern parts of the Alakol lake system, assessing their recreational potential and developing recommendations for environmentally safe use.

2. Materials and methods

The Alakol Lakes system is a unique closed natural water body located in the intermountain basin of the same name between the Zhetysu Alatau (4,642 m), Barlyk-Maily (2,242 m) and Tarbagatai (2,992 m) mountain ranges. The main water supply for the reservoir comes from the Tenteq, Zhamanty, Yrgayty, Terekty, Kusak, Emel, Makanchi, Urdzhar and other tributaries. The geographical coordinates of the system range from the northern point (Lake Sasykol) at 46°41′48″ N, 80°44′51″ E to the southern point (Lake Zhalanashkol) at 45°31′56″ N, 82°11′12″ E. The western border is Lake Alakol (46°06′44″ N, 81°20′48″ E), and the eastern border is 46°11′27″ N, 82°03′11″ E.

The total area of the mirror surface of the lakes Sasykkol, Uiyaly (Koshkarkol), Alakol and Zhalanashkol is 3,589.5 km², with a total water volume of 61,58 km³. The average depth of the reservoirs is 22 m, with a maximum depth of 52 m. These physical and geographical characteristics determine the specific hydrochemical regime and the formation of therapeutic mud in the region.

Between May and October 2025, fieldwork was carried out to determine the physical and chemical composition of the water and therapeutic mud. Samples were taken from the northern, southern, western and eastern parts of Lake Alakol and Lake Zhalanashkol, as well as at the mouths of the Tenteq, Zhamanty and Yrgayty rivers. Additional samples were taken from three therapeutic mud deposits located in coastal areas of tourist and recreational activity. A total of 60 water samples and 12 therapeutic mud samples were taken.

Water and sludge sampling and analysis were carried out in accordance with generally accepted methods and current standards (GS 26449.1-85; GS 26449.2-85).

The selected samples were placed in sterile containers, sealed tightly and delivered to the laboratory. Only fresh samples that had not been frozen were used for analysis.

Classic methods were used to process the data obtained: statistical, geoenvironmental and cartographic, as well as systematic analysis to assess the tourist and recreational potential of the region's natural tourist and recreational resources.

The following analytical methods were used to determine the chemical composition of water and mud samples: scanning electron microscopy (SEM) combined with energy dispersive spectroscopy (EDS), X-ray diffraction (XRD), and measurement of physicochemical parameters using pH-metry and portable devices.

A scanning electron microscope (SEM) equipped with an EDS system allowed for qualitative and quantitative analysis of the elemental composition of the samples. During the analysis, X-ray spectra were obtained, including Kα and Lα lines characteristic of each element. Based on the intensity and energy of the spectrum peaks, the mass (%) and atomic (%) fractions of the elements were calculated. ZAF correction was used to process the data, taking into account the atomic number (Z), absorption (A) and fluorescence (F).

Additionally, the surface micro-morphology of the samples was analysed, and particle sizes, porosity and surface texture features were determined. Images obtained at the micron and nanometre scales were subjected to graphic processing.

3. Results

Field expedition studies with water sampling were conducted on the eastern, western, northern and south-eastern shores of Lake Alakol and Lake Zhalanashkol. The samples were analysed in the laboratories of Shakarim University, NCJSC and the sanitary and epidemiological service of the Zhetysu region.

The results of laboratory studies showed that the content of chemical elements and minerals in the water does not exceed the maximum permissible concentrations and is suitable for health and recreation (Table 1).

Table 1. Chemical composition of water in the eastern (Kabanbay village) and western (Akshi) parts of Lake Alakol

Cations	Share, mg/dm^3		Difference, %	Anions	Share, mg/dm^3		Difference, %
	East	West			East	West	
B	9.00	0.55	<8.45	Sulfates	13.2	36.0	>22.8
Ca	165.54	130.28	<78.7	Chlorides	6.3	11.2	>4.9
Si	2.74	1.40	<1.34	HCO_3^-	29.0	23.0	<6
Mg	18.81	0.79	<18.02	CO_3^{-2}	4.0	3.1	<0.9
K	35.51	13.41	<5.4	NH_4^+	0.3	0.4	<0.1
Hg	9.71			Nitrates	2.5	2.7	<0.2
Fe	5.25			Nitrides	1.031	1. 034	<0.003
Sr	0.31	0.34	>0.03				
Li	0.26	0.40	>0.14				
Total mineralization	1920	1450	<4.70	pH	7.9	8.6	>0.7

Field analyses showed the presence of 16 chemical elements in the eastern part of Lake Alakol and 14 in the western part. In the western part, the concentrations of B, Ca, Mg, Si, K, HCO_3^-, and CO_3^{2-} are lower than in the east, but there is an increase in the content of Li, Sr, chlorides, sulphates, nitrates, nitrites, and ammonia (Tokpanov et al., 2021). In the western recreation area of Akshi, Fe and Hg, which are present in the eastern part, have not been detected. The total mineralisation of water in the western part is lower, which is explained by the confluence

of the Zhamanta and Yrgayty rivers with an average annual water flow of more than 7.8 m³/s (Aktymbaeva et al., 2015; Tokpanov, 2016).

The results of the analysis of water samples from Lake Zhalanashkol showed significant differences in the chemical composition of the eastern and western parts (Table 2).

Table 2. Chemical composition of water in the eastern and western parts of Lake Zhalanashkol

Cations	Share, mg/dm³		Difference, %	Anions	Share, mg/dm³		Difference, %
	East	West			East	West	
B	9.00	9.00		Sulfates	13.2	36.0	>22.8
Ca	2.04	23.60	>21.56	Chlorides	6.3	11.2	>4.9
Si	2.74	1.40	<1.34	HCO_3^-	29.0	23.0	<6
Mg	9.08	93.02	<83.22	CO_3^{-2}	4.0	4.6	>0.6
Na+ + K	43.3	43.4	<0.1	Iodides	0.004	0.012	<0.0028
K	3.22	32.84	<29.62	Bromites	0.39	0.49	>0.1
Fe	0.01			Fluorides	0.23	0.21	<0.4
Sr	0.02	0.34	>0.03	NH_4^+	0.28	0.36	>0.1
Li	0.03	0.31	>0.14	Nitrates	2.45	2.6	>0.2
Hg	0.36	0.27	<7.5				
Ammonium	0.01	0.01		Nitrides	1.029	1.031	<0.002
Total mineralization	991	1010	>0.19	pH		7.8	>0.6

The main difference between the water of Zhalanashkol and Alakol is the absence of Hg and the presence of iodides, bromides and fluorides (Tokpanov, 2021; 2016). The concentration of magnesium in Zhalanashkol is relatively high, and the total mineralisation of water is slightly higher in the west.

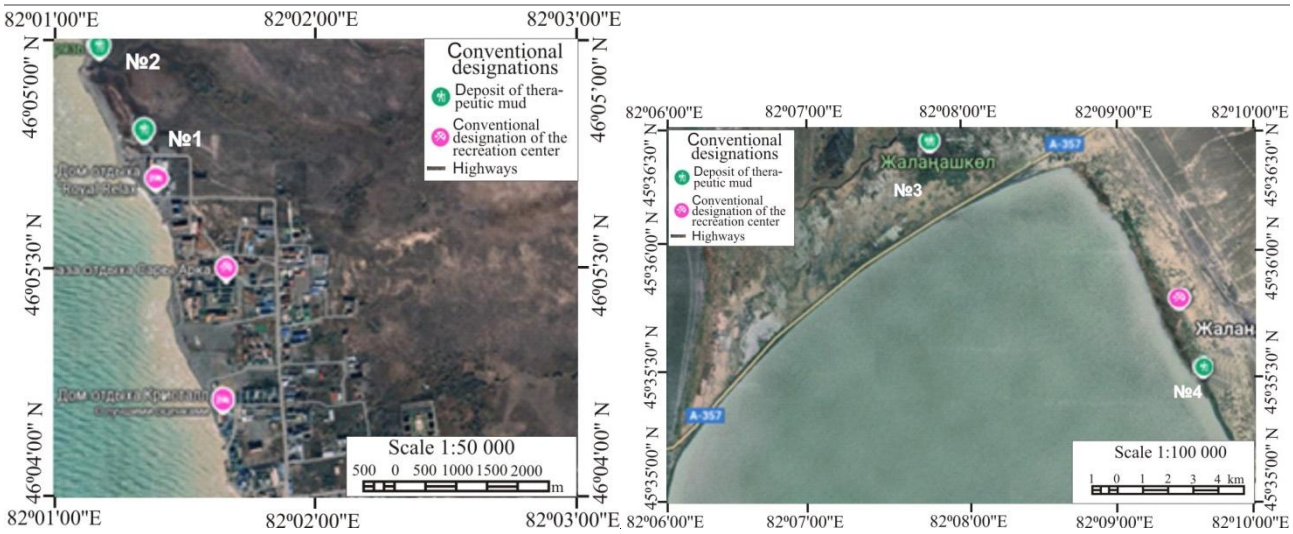
Field and laboratory studies have shown that the water in the eastern part of the lake (pH = 7.8) has a mineralisation of 991 mg/dm³, a dry residue of 3.024 g/l, and a total hardness of 0.4–5.6.

$$M3.0\frac{HCO_3 55.1 SO_4 23.8}{Na 84.0} pH 7.8$$

In the western part (pH = 8.8) - mineralization 1010 mg/dm³, dry residue 3.022 g/l, total hardness 0.39–5.3.

$$M3.0\frac{HCO_3 55.2 SO_4 25.2}{Na 82.4} pH 8.4$$

During field studies (May–October 2025), samples of therapeutic mud were collected from four deposits located in the eastern and south-eastern coastal zone of Lake Alakol. The geographical location of the sampling points was 46º05′24″ N, 82º02′01″ E (Figure 1). Deposits (No. 1 and No. 2) are located on the northern edge of the recreation area of the village of Kabanbay, at a distance of 300–400 m from the shore, in areas with close groundwater deposits. Two additional deposits (No. 3 and No. 4) were identified within 30–40 m of the lake shore, also in areas with shallow groundwater (Figure 1).



(a) (b)

Figure 1. Satellite images of the recreation area of the village of Kabanbay on the eastern shore of Lake Alakol (a) (deposits No. 1 and No. 2) and the therapeutic mud deposits on the northern shore of Lake Zhalanashkol (b) (deposits No. 3 and No. 4) (Source Google maps, resolution 30 cm by 1 pixel)

Spectral and X-ray phase analysis showed that the composition of therapeutic muds No. 1 and No. 2 differs in the amount of chemical elements. Mud No. 2 contains more Ca (27.24 mg/g), Fe (14.34 mg/g), Al (11.44 mg/g), B (0.11 mg/g), Si (0.11 mg/g), Mn (0.52 mg/g), Sr (0.18 mg/g), Li (0.02 mg/g), Cr (0.51 mg/g), K (2.45 mg/g), while sample No. 1 has higher concentrations of P_2O_5 (3.36 g/kg), Mg (1.75 mg/g), Ag (1.03 mg/g). Cr and Si ions were detected only in the second sample (Figures 2, 3).

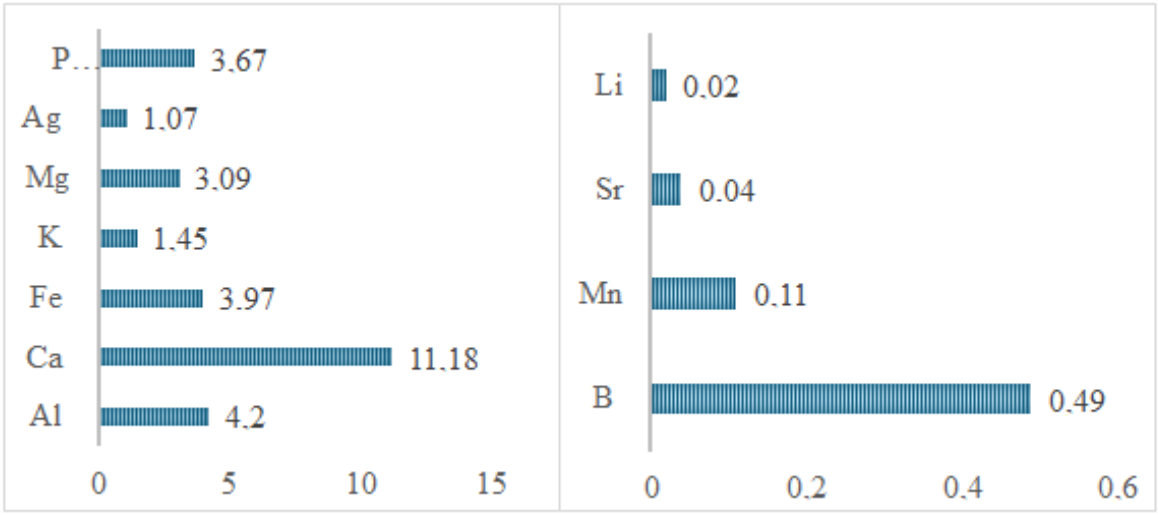


Figure 2. Chemical composition of therapeutic mud from the northern outskirts of the Kabanbay recreation area, mg/g (P_2O_5, g/kg)

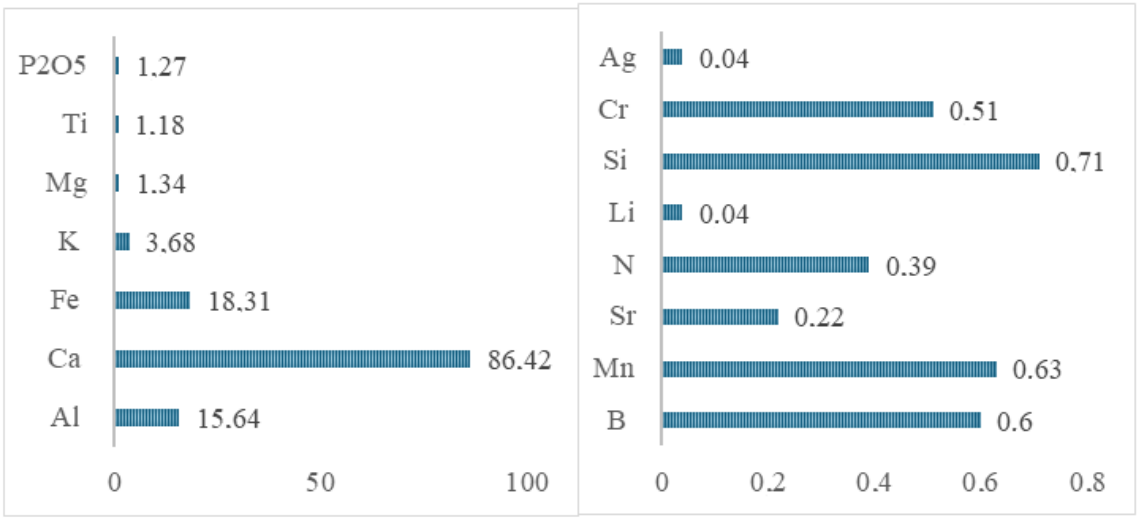


Figure 3. Chemical composition of therapeutic mud 300-400 m north of the Kabanbay recreation area on the eastern shore of Lake Alakol, mg/g (P_2O_5, g/kg)

Deposit No. 3 (east coast) contains more B (0.57 mg/g), Ni (0.34), Ti (1.78), Cr (0.53), Al (14.77), Fe (16.38 mg/g), K (4.28 mg/g), Li (0.01 mg/g), Mg (3.51 mg/g), Sr (0.02 mg/g), P_2O_5 (3.36 g/kg) than deposit No. 4 (north coast), where the concentrations of Ca (21.61 mg/g) and Mn (0.02 mg/g) are higher. Ag ions were recorded only in mud No. 4 (Figures 4, 5).

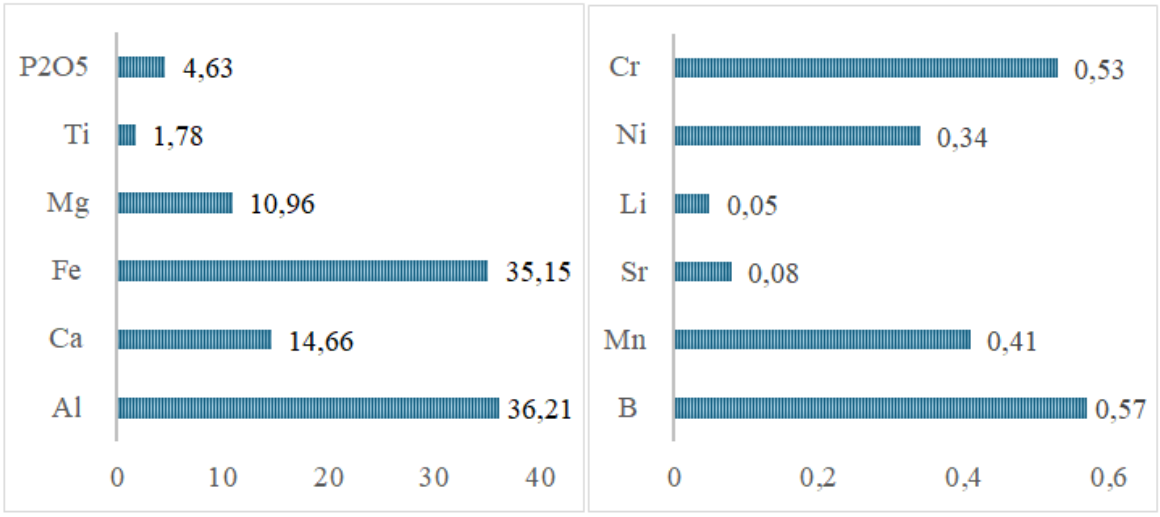


Figure 4. Chemical composition of therapeutic mud from deposit No. 3 in the eastern part of Lake Zhalanashkol, mg/g (P_2O_5, g/kg)

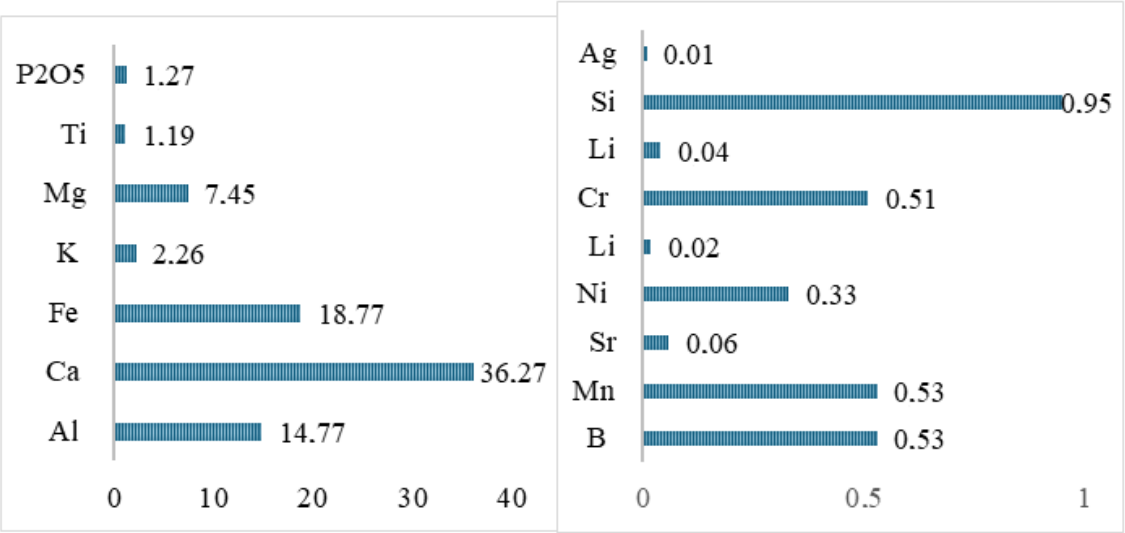


Figure 5. Chemical composition of therapeutic mud from deposit No. 4 in the northern part of Lake Zhalanashkol, mg/g (P_2O_5, g/kg)

The content of all chemical elements in therapeutic mud does not exceed the maximum permissible concentrations.

Field observations have established that in arid climates, lake water evaporation increases in summer, the concentration of dissolved substances rises, and a layer of highly mineralised silt forms at the bottom of water bodies. The mud is a three-component system: a clay solution, a medium-grained skeleton, and a fine-grained colloid.

The crystalline skeleton is composed of calcite, dolomite, heavy metals, organic plant residues, and silicates (up to 56%). Depending on the predominance of components, mud is classified as silicate, carbonate or mixed types.

According to Table 3, the therapeutic mud of Zhalanashkol belongs to the sulphide group.

Table 3. Composition indicators of sulfide therapeutic muds on the coast of Lake Zhalanashkol

№	Indicators	Standards, %	Actual
1.	Consistency, color, odor		The mud is black in color, quickly becomes covered with a gray film, spreads easily, has a dense consistency, smooth structure, and is odorless
2.	180°C humidity, % H_2O	37-70	26.15
3.	Diameter>0.25 mm cavity fill, %	< 3	0.76
4.	Filling types		Mineral crystals, plant remains
5.	Resistance to movement, dynes/cm^3	1500-2000	1260
6.	Loss on heating (900°C), %		12.99
7.	Heat capacity, cal/g, deg	no less 0.400	0.847
8.	Volume mass, g/dm^3	1.2-1.6	1.90
9.	Total mass of CO_2 composition, %		3.62
10.	Saturated thermal index, total, pH		6.91
11.	Total proportion of H_2S, %		0.14

The colloidal fraction accounts for about 7% of the mass and includes organic acids, lipoids, pigments, oxide hydrates and sulphur, which determine the plasticity and therapeutic properties of the mud. The composition includes sulphates (62.38 g/100 g), chlorides (1.90 g/100 g), potassium (0.02 g/100 g), sodium (0.21 g/100 g), $CaSO_4$ (0.62%), $MgSO_4$ (0.83%), NaCl (2.78%), KCl (0.03%), $MgCl_2$ (92.35%).

The mud of the eastern shore is dominated by bischofite ($MgCl_2$), which is used in balneology for diseases of the musculoskeletal system, nervous system and cardiovascular disorders.

4. Discussion

This study is the first comprehensive assessment of the hydromineral resources of the eastern and south-eastern parts of the Alakol lake system. The results expand existing scientific knowledge about the hydrochemical characteristics of the lakes' waters and therapeutic muds, as well as the impact of anthropogenic factors on the region's ecosystems. In particular, a difference in the chemical composition of the waters and muds of the western and eastern parts of the lakes has been established, which can be used to refine approaches to the recreational and medical use of these resources.

In addition, the study proposes new approaches to the ecological assessment of the region's recreational potential and methods for monitoring the impact of tourism on the state of natural ecosystems. Particular attention is paid to the sustainable use of hydromineral resources in the context of growing anthropogenic impact and the need to create environmentally safe conditions for recreational development.

A comparative analysis of the chemical composition of the waters of Lake Alakol and Lake Zhalanashkol showed that both reservoirs are characterised by high mineralisation, which is due to their location in an arid climate zone, where high temperatures and minimal precipitation lead to intense evaporation, increasing the concentration of dissolved substances (Baimyrzayev et al., 2018). These patterns are also observed in other saltwater bodies around the world, such as the Great Salt Lake in the United States (Johnson et al., 2016) and the Dead Sea (Bawab et al., 2018), where high temperatures and a lack of freshwater inflow create similar conditions for mineralisation.

The differences in the chemical composition of the waters of the eastern and western parts of Lake Alakol and Lake Zhalanashkol are explained by hydrological features such as the degree of evaporation and river inflow, as well as the general circulation of water in the lake. Alakol is characterised by the inflow of fresh water from the Zhamantau and Yrgayty rivers, which leads to a decrease in mineralisation and the concentration of a number of chemical elements, such as sodium, calcium and magnesium. In contrast, Lake Zhalanashkol has a lower inflow of fresh water and, as a result, has a higher concentration of iodine, bromides and fluorides, which makes its waters potentially suitable for balneological procedures. This fact is confirmed by studies of the chemical composition of saltwater bodies such as the Dead Sea, where the high content of bromides and iodides is also due to geochemical processes (Bawab et al., 2018).

Statistical methods such as correlation and clustering were used for further analysis, which allowed us to identify the relationship between water mineralisation and temperature regimes. For example, a strong positive correlation was found between water temperature and mineralisation ($r = 0.75$, $p < 0.01$), which is confirmed by similar data for the Great Salt Lake (Johnson et al., 2016), where high water temperatures contribute to significant evaporation and mineral concentration. A negative correlation was also found between the level of freshwater inflow and mineralisation ($r = -0.60$, $p < 0.05$), confirming the influence of freshwater river inflow on the reduction of salt concentration in water, as observed in Lake Alakol.

The results of research into the therapeutic muds of both lakes confirm their unique chemical and mineralogical composition, which makes them suitable for medical use. The content of elements such as Ca, Mg, Fe, Al, Sr and Cr significantly affects the therapeutic properties of mud (Aktymbaeva et al., 2015; Mukaev, 2017; Amirgaliev et al., 2003; Tokpanov, 2016). The

predominance of bischofite ($MgCl_2$) in the muds of Lake Alakol deserves special attention. This mineral has a beneficial effect on diseases of the musculoskeletal system, which is also noted in scientific publications devoted to the medicinal properties of bischofite (Schwalfenberg et al., 2017).

The results of studies of the therapeutic muds of both lakes confirm their unique chemical and mineral composition. Differences in the content of Ca, Mg, Fe, Al, Sr, Cr and other elements determine the difference in therapeutic properties (Aktymbaeva et al., 2015; Mukaev, 2017; Amirgaliev et al., 2003; Tokpanov, 2016). The predominance of bischofite ($MgCl_2$) indicates its potential for widespread use in medical practice, especially for diseases of the musculoskeletal system.

The physicochemical structure of muds - the presence of colloids, clay phase and sulphide compounds - contributes to their high heat capacity, plasticity and ability to retain active substances.

At the same time, the increase in anthropogenic pressure in the recreation area on the eastern coast of Lake Alakol (500–600 thousand tourists per season) requires environmental regulation (Yessengabylova et al., 2025; Berezovikov, 2008). According to laboratory studies, pollution of Lake Alakol by anthropogenic factors such as solid waste and sewage significantly increases microbiological risks and deteriorates water quality. The average values of microbiological contamination of water exceed the maximum permissible concentrations (MPC) for coliphages (2.1×10^6 MPC/100 ml) and total coliform bacteria (1.5×10^6 MPC/100 ml), which exceeds the permissible MPC values by 1.5 times (SanR, 2023). Exceedances are also observed for chemical oxygen demand (COD), which indicates contamination of water with organic substances originating from runoff from coastal areas.

Pollution from solid household waste and sewage increases the risk of coastal ecosystem degradation. To stabilise the situation, it is necessary to introduce public-private partnership mechanisms, build treatment facilities and waste processing plants, and strengthen sanitary and environmental control in accordance with the Law of the Republic of Kazakhstan ‘On Public-Private Partnership’ dated 31 October 2015 No. 379-V RKZ (Law of the Republic of Kazakhstan dated October 2015).

Thus, the results of the studies confirm the high potential of the hydromineral resources of Lake Alakol and Lake Zhalanashkol for the development of medical and health tourism, provided that sustainable environmental management of the territory is ensured.

5. Conclusion

The development of tourism in the Alakol region has significant potential. Given that traditional holiday destinations are often unaffordable for the majority of the population, it is important to identify local and relatively inexpensive tourist and recreational resources. Tourism is a profitable sector of the national economy that contributes to the comprehensive development of the region's social infrastructure, the improvement of territories and the formation of more progressive forms of life and recreation for the population.

According to hydrological and geographical studies, as well as expeditionary and laboratory work carried out in 2024–2025, analysis of the composition of the water and therapeutic mud of Lake Alakol and Lake Zhalanashkol showed that the content of macro- and microelements, sulphates, nitrates, nitrides and carbonates does not exceed the maximum permissible concentrations.

The data obtained indicate that the composition of water and therapeutic mud complies with the sanitary and epidemiological requirements established by Decree No. 104 of the Government of the Republic of Kazakhstan dated 18 January 2012, applicable in sanatoriums and during physiotherapy procedures.

Consequently, for the effective use of therapeutic mud during the bathing season, compliance with sanitary standards and protection of the environment from pollution, it is advisable to open

specialised medical institutions (mud therapy centres) with resort doctors to serve holidaymakers in the recreation area.

Observations and analysis of statistical data have shown that on the eastern and western shores of Lake Alakol in the summer, due to the increase in the number of holidaymakers, the recreational load on the territory increases, which leads to environmental pollution with solid household waste and sewage.

Industry institutions in the Abai and Zhetysu regions, as well as the local authorities of the Makanchinsky and Alakol districts, should pay special attention to finding the best solutions to these issues within the framework of public-private partnerships.

6. Supplementary Materials: No supplementary materials.

7. Author Contributions

Conceptualization, methodology - M.J., Ye.T; software, validation - R.M., A.Ye.; formal analysis, investigation - M.J., Ye.T.; writing, original draft preparation - Ye.T.; writing, review and editing - R.M., visualization - A.Ye.; supervision - M.J. All authors have read and agreed to the published version of the manuscript.

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Алакөл көлдер жүйесінің шығыс және оңтүстік-шығыс бөліктерінің гидроминералдық рекреациялық ресурстарын геоэкологиялық тұрғыдан бағалау

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Аңдатпа. Мақалада Абай облысының оңтүстік-шығыс бөлігінде орналасқан Алакөл-Жаланашкөл көлі жүйесінің гидроминералдық ресурстарының табиғи және бальнеологиялық сипаттамалары қарастырылады. Зерттеу құрғақ климатта судың химиялық құрамы мен балшық шөгінділерінің кеңістіктік өзгергіштігін ескере отырып жүргізілді. 2024-2025 жылдары жүргізілген далалық және зертханалық бақылаулар минералды сулар мен емдік балшықтардың физика-химиялық сипаттамаларын анықтауға, сондай-ақ олардың рекреациялық және сауықтыру мақсаттары үшін әлеуетін бағалауға бағытталған. Далалық жұмыстар шығыс, батыс, солтүстік және оңтүстік-шығыс жағалау аймақтарын, соның ішінде белсенді балшық жиналатын аймақтарды қамтыды. «Шәкәрім университеті» КЕАҚ және Жетісу облысының санитарлық-эпидемиологиялық қызметінің зертханаларында жүргізілген талдаулар негізгі химиялық элементтер мен минералдардың концентрациясы қолайлы санитарлық нормаларға сәйкес келетіндігін көрсетті. Шығыс және Батыс секторлары арасындағы су химиясындағы айырмашылықтар гидрологиялық және климаттық факторларға байланысты екені анықталды. Композицияда сульфаттар, хлоридтер және бишофит ($MgCl_2$) басым, бұл кірге айқын емдік қасиеттер береді. Нәтижелер көлдердің жоғары бальнеологиялық құндылығын және экологиялық қауіпсіздігін растайды, бұл олардың сауықтыру туризмінде, бальнеотерапияда және тұрақты аймақтық дамуда әлеуетті пайдаланылуын негіздейді.

Түйін сөздер: Алакөл; Жаланашкөл; гидроминералдық ресурстар; емдік балшық; бишофит; рекреация; туризм; бальнеология; химиялық құрамы; тұрақты дамуы.

Геоэкологическая оценка гидроминеральных рекреационных ресурсов восточной и юго-восточной части системы Алакольских озер

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Аннотация. В статье рассматриваются природные и бальнеологические характеристики гидроминеральных ресурсов озерной системы Алаколь-Жаланашколь, расположенной в юго-восточной части области Абай. Исследование проводилось в засушливом климате с учетом пространственной изменчивости химического состава воды и грязевых отложений. Полевые и лабораторные наблюдения, проведенные в 2024–2025 годах, были направлены на определение физико-химических характеристик минеральных вод и лечебных грязей, а также на оценку их потенциала для рекреационных и оздоровительных целей. Полевые работы охватывали восточную, западную, северную и юго-восточную прибрежные зоны, включая районы активного накопления грязи. Анализы, выполненные в лабораториях НАО «Шәкәрім университет» и санитарно-эпидемиологической службы области Жетісу, показали, что концентрации основных химических элементов и минералов соответствуют приемлемым санитарным нормам. Было установлено, что различия в химическом составе воды между восточным и западным секторами зависят от гидрологических и климатических факторов. В составе преобладают сульфаты, хлориды и бишофит ($MgCl_2$), что придает грязям выраженные лечебные свойства. Результаты подтверждают высокую бальнеологическую

ценность и экологическую безопасность озер, что обосновывает их потенциальное использование в оздоровительном туризме, бальнеотерапии и устойчивом региональном развитии.

Ключевые слова: Алаколь; Жаланашколь; гидроминеральные ресурсы; лечебная грязь; бишофит; рекреация; туризм; бальнеология; химический состав; устойчивое развитие.