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CURRENT STATE AND ASSESSMENT OF HYDROCHEMICAL AND TOXICOLOGICAL PARAMETERS OF LAKES IMANTAU AND SHALKAR

The aim of this study was to determine the current hydrochemical and toxicological status of two contrasting lakes in the Ayyrtau district of Northern Kazakhstan, Lake Imantau and Lake Shalkar, and to identify potential risks associated with pollution by biogenic substances and heavy metals. Field work, including water sampling and morphometric measurements, was carried out in October 2024; samples were taken in the central part of the water areas at a depth of 0.5 m. pH, temperature and dissolved oxygen were measured with a portable HQ40D device (HACH-LANGE), major ions titrimetrically, biogenic compounds with a DR 3900 spectrophotometer, and heavy metals (Cu, Zn, Pb, Cd, Co, Ni) by atomic absorption spectrometry (AA-7000, Shimadzu), with analytical accuracy verified through the ionic balance. Lake Imantau is characterised by a slightly alkaline reaction, moderate mineralisation (1231 mg/L) and phosphate concentrations exceeding the regulatory standard, whereas Lake Shalkar shows high alkalinity (pH 9.1), considerable mineralisation (17,076 mg/L) and water hardness. Heavy-metal concentrations in both water bodies do not exceed the maximum permissible values; by oxygen regime and biogenic-substance content, both lakes are classified as mesotrophic, while Lake Imantau shows initial signs of a trophic transition. The direct comparison of two hydrochemically contrasting lakes within a single district links differences in water quality to the water-balance features of their basins rather than to recreational load. The results address the data gap on the region's water bodies and provide a basis for further monitoring.

Keywords: water quality, heavy metals, nutrients, mineralisation, contrasting lakes.

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Имантау және Шалқар көлдерінің гидрохимиялық және токсикологиялық параметрлерінің қазіргі жағдайы мен бағалануы

Зерттеудің мақсаты – Солтүстік Қазақстанның Айыртау ауданында орналасқан екі контрасты көлдердің, Имантау мен Шалқардың, қазіргі гидрохимиялық және токсикологиялық жағдайын анықтау және биогенді заттар мен ауыр металдармен ластануға байланысты ықтимал қауіптерді айқындау. Далалық жұмыстар, соның ішінде су сынамаларын іріктеу мен морфометриялық өлшемдер, 2024 жылдың қазан айында жүргізілді; сынамалар акваторияның орталық бөлігінен 0,5 м тереңдіктен алынды. pH, температура және еріген оттегі көрсеткіштері портативті HQ40D (HACH-LANGE) аспабымен өлшенді, негізгі иондар титриметриялық әдіспен, биогенді қосылыстар – DR 3900 спектрофотометрімен, ал ауыр металдар (Cu, Zn, Pb, Cd, Co, Ni) – атомдық-абсорбциялық спектрометрия әдісімен (AA-7000, Shimadzu) анықталды; талдаудың дұрыстығы иондар балансы бойынша бақыланды. Имантау көлі әлсіз сілтілі реакциясымен, орташа минералдануымен (1231 мг/л) және фосфаттар бойынша нормативтің асып кетуімен сипатталатыны, ал Шалқар көлі айқын сілтілі реакциямен (pH 9,1), минералданудың едәуір жоғары деңгейімен (17076 мг/л) және судың қаттылығымен ерекшеленетіні анықталды. Екі су айдынында да ауыр металдардың концентрациясы шекті рұқсат етілген шамалардан аспайды; оттегі режимі мен биогенді заттардың мөлшері бойынша екі көл де мезотрофты типке жатқызылды, бұл ретте Имантауда трофикалық ауысудың бастапқы белгілері байқалды. Бір ауданда орналасқан, гидрохимиялық тұрғыдан ерекшеленетін екі көлді тікелей салыстыру су сапасындағы айырмашылықтарды рекреациялық жүктемемен емес, олардың бассейндерінің су балансы ерекшеліктерімен байланыстыруға мүмкіндік берді. Алынған нәтижелер өңір көлдері бойынша деректердің жетіспеушілігін толықтырып, болашақ мониторинг үшін негіз қалайды.

Түйін сөздер: су сапасы, ауыр металдар, биогенді заттар, минералдану, контрастты көлдер.

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Современное состояние и оценка гидрохимических и токсикологических параметров озер Имантау и Шалкар

Цель исследования – определить современное гидрохимическое и токсикологическое состояние двух контрастных озёр Айыртауского района Северного Казахстана, Имантау и Шалкар, и выявить потенциальные риски, связанные с загрязнением биогенными веществами и тяжёлыми металлами. Полевые работы, включая отбор проб воды и морфометрические измерения, проводились в октябре 2024 года; пробы отбирались в центральной части акваторий с глубины 0,5 м. Показатели pH, температуры и растворённого кислорода измерялись портативным прибором HQ40D (HACH-LANGE), основные ионы определялись титриметрически, биогенные соединения – на спектрофотометре DR 3900, а тяжёлые металлы (Cu, Zn, Pb, Cd, Co, Ni) – методом атомно-абсорбционной спектрометрии (AA-7000, Shimadzu); корректность анализа контролировалась по балансу ионов. Установлено, что озеро Имантау характеризуется слабощелочной реакцией, умеренной минерализацией (1231 мг/л) и превышением норматива по фосфатам, тогда как озеро Шалкар отличается высокой щёлочностью (pH 9,1), значительной минерализацией (17076 мг/л) и жёсткостью воды. Концентрации тяжёлых металлов в обоих водоёмах не превышают предельно допустимых значений; по кислородному режиму и содержанию биогенных веществ оба озера отнесены к мезотрофному типу, при этом в Имантау отмечены начальные признаки трофического перехода. Прямое сравнение двух гидрохимически различающихся озёр одного района позволило связать различия качества воды с особенностями водного баланса их бассейнов, а не с рекреационной нагрузкой. Полученные результаты восполняют дефицит данных по водоёмам региона и формируют основу для дальнейшего мониторинга.

Ключевые слова: качество воды, тяжёлые металлы, биогенные вещества, минерализация, контрастные озёра.

Introduction

Lakes are an important element of the internal water balance, ensuring the stability of ecosystems and water supply in various natural conditions. Within the framework of the limnological approach, they are considered as slowly renewing systems in which interrelated physical, chemical and biological processes take place (Bogoslavsky, 1960). Despite the significant contribution of classical studies (Forel, 1912; Berg, 1945; Welch, 1952) and others, small lakes remain insufficiently covered by systematic monitoring in modern conditions. The relevance of studying such water bodies is increasing in the northern steppe regions of Kazakhstan, where freshwater lakes are particularly vulnerable due to a combination of continental climate, seasonal stratification and characteristic ionic composition (Na^+, SO_4^{2-}). At the same time, about 123,000 km³ of the world's freshwater reserves are concentrated in lake ecosystems, which highlights their importance as natural reservoirs and priority conservation sites (Bogoslavsky & Voskresensky, 1974).

In this context, special attention should be paid to Lake Imantau and Lake Shalkar, located in the Ayyrtau district of Northern Kazakhstan within a rapidly developing resort area. These water bodies are of high environmental and socio-economic importance, but their current hydrochemical and toxicological status remains poorly studied. Given their regional role and growing anthropogenic pressure, the need for a scientific analysis of the aquatic environment is becoming particularly urgent. Assessing the carrying capacity of such nature-based destinations is a recognised tool for balancing tourism development with ecosystem conservation (Aktymbayeva et al., 2023). This study provides an instrumentally based hydrochemical and toxicological comparison of two lakes of contrasting mineralisation within a single landscape-climatic zone of the Ayyrtau district: the fresh, HCO_3-Na Lake Imantau and the hypermineralised, Cl-Na Lake Shalkar.

Freshwater ecosystems under conditions of limited hydrological dynamics serve as indicators of climatic and anthropogenic change. For Lake Imantau, the literature offers only fragmentary data on seasonal fluctuations in pH, ion composition, and signs of local pollution (Zhumay et al., 2021), whereas for Lake Shalkar no systematic hydrochemical or toxicological studies are available in the accessible sources. Neighbouring water bodies of the same landscape-climatic zone have been studied more fully, and their results define the expected background. For Lake Burabay, instrumental monitoring over 2018-2022 recorded a rise in mineralisation from 160 to 321 mg/L, accompanied by a measured contraction in the lake's area and depth that the authors link to evaporation exceeding precipitation (Shulembayeva et al., 2023); the reduction in lake surface area within the Shchuchinsk-Burabay resort zone under recreational pressure has been independently recorded by remote sensing (Ramazanova et al., 2019). For the Esil River basin, to which both studied lakes belong, a semi-arid regime has been established (precipitation 250-450 mm/year) along with heightened vulnerability of surface waters to climatic change, the surveyed lakes including the neighbouring resort-zone water body Burabay (Bahetnur & Lee, 2023). The granulometric and chemical composition of bottom sediments in the water bodies of the North Kazakhstan region has been characterised separately (Yskak et al., 2025). Comprehensive studies of Lakes Imantau and Shalkar themselves, using instrumental methods, quantitative indices, and spatial analysis, are absent.

The international literature emphasises the need for an integrated assessment of water quality that accounts for the spatial and temporal variability of indicators such as pH, dissolved oxygen, electrical conductivity, mineralisation, and the content of biogenic compounds and heavy metals (Daniszewski, 2013; Sharma et al., 2016; Cieśliński & Major, 2012). Such assessment is increasingly supplemented by integrated indices that reduce heterogeneous data to a comparable form: trophic status is characterised by the Carlson index (TSI), whose component indicators frequently diverge and whose phosphorus index tends to overestimate the trophic state of lowland lakes (Karpowicz et al., 2025; Badamian et al., 2025); heavy-metal pollution is assessed by the HPI and HEI indices (Biedunkova & Kuznietsov, 2024), and the combined load by the Nemerow index (Su et al., 2022). The threshold values established by the WHO and USEPA set maximum permissible levels for key parameters: pH 6.5-8.5 (World Health Organization, 2017), dissolved oxygen no less than 5 mg/L (U.S. Environmental Protection Agency, 1986), TDS up to 1000 mg/L (World Health Organization, 2003), and BOD_5 3-5 mg/L (World Health Organization, 2017). Exceedances of these values may result from engineering modifications, wastewater discharge, agricultural diffuse runoff, and tourism activity (Krupa et al., 2016).

The methodology of modern research includes titrimetry (main ions), spectrophotometry (biogenic compounds) and atomic absorption spectroscopy (metals) (Shirokova et al., 2020). Spatial monitoring is supplemented by GIS technologies that allow monitoring the condition of hard-to-reach areas of water bodies (El-Zeiny & El-Kafrawy, 2017; Ramazanova et al., 2019), but for small water bodies, direct field measurements remain more accurate and representative (Ngamile et al., 2025).

Scientific literature pays particular attention to the accumulation of heavy metals (Pb, Cd, As, Ni, Zn) entering water bodies with precipitation, wastewater, and surface runoff. For a number of Kazakhstani water bodies, exceedances of MPCs for individual metals have been recorded, usually linked to specific geological or technogenic sources: copper in the Kolsai Lakes, where it reflects an elevated natural geochemical background rather than pollution (Krupa et al., 2016); lead and cadmium associated with ore-enrichment plant tailings on the shore of Lake Balkhash (Muratkhanov et al., 2024); and lead, cobalt and nickel in Lake Markakol, where concentrations reach up to 16.2, 69.2 and 49.0 µg/L respectively, well above the regional fishery thresholds, owing to the polymetallic deposits of the surrounding catchment (Ismukhanova et al., 2024). This gives grounds to expect that in water bodies without ore or industrial sources the metal load remains at background level. For the natural lakes of the North Kazakhstan region, however, such instrumental assessments are still absent, which constitutes a substantial gap given the growing agricultural and recreational pressure (Su et al., 2022).

Despite the wide variety of available methods of analysis, assessments of the aquatic environment at the level of small and moderately transformed lakes are still characterised by fragmentation and a lack of systematic approaches, especially with regard to natural water bodies in Northern Kazakhstan. At the same time, the influence of seasonal fluctuations, local sources of pollution and the specifics of ion composition remains insufficiently taken into account in the context of both the hydrochemical regime and the toxicological load. The study of Lake Imantau and Lake Shalkar, which differ in morphology, mineralisation and anthropogenic impact, allows us to trace the characteristic patterns of water quality formation within a single landscape-climatic zone. The selection of a comprehensive set of indicators and reliance on instrumental methods of analysis ensure the representativeness of the data obtained and allow for the assessment of the trophic status of water bodies in a comparable format. The results obtained are considered as a basis for updating regional monitoring, developing standards and environmentally sound water use in conditions of growing recreational load.

Materials and methods

This study aims to assess the hydrochemical and toxicological status of two natural lakes, Imantau and Shalkar, located in the Ayyrtau district of North Kazakhstan region. The study was conducted within the framework of applied aquatic geography and ecology using instrumental methods of field sampling, laboratory analysis and normative interpretation in accordance with international and national standards.

The aim of the study was to identify differences in pollution levels and hydrochemical profiles between two lakes subject to varying degrees of natural and anthropogenic stress. The hypothesis was that Lake Shalkar, due to its morphometric characteristics and potential recreational pressure, would demonstrate higher levels of mineralisation and organic pollution compared to Lake Imantau. To achieve this goal, the following tasks were formulated:

(1) to carry out field measurements and laboratory analysis of water samples to determine key physicochemical indicators, ion composition, and the content of biogenic substances and heavy metals;

(2) to conduct a comparative assessment of the data obtained with current standards (MPC) and historical sources to determine the degree of deviation from environmental standards;

(3) determine the typological characteristics of lake waters (hardness, mineralisation, ion composition) and identify inter-lake differences in the context of their natural conditions and anthropogenic load.

The study was carried out in three stages: preparatory (sampling, logging), field (sampling and rapid measurements) and analytical-interpretative (laboratory processing, analysis and comparison of results).

Study Area. The study covered two natural water bodies – Lake Imantau and Lake Shalkar, located in the Ayyrtau district of the North Kazakhstan region. Lake Imantau is a large lake system with an elongated shape along the north-west – south-east axis. It is 13.3 km long, with a maximum width of 4.8 km, a maximum depth of 10.0 m, an average depth of 5.7 m, a coastline length of 35.5 km, and a water level of 323.6 m above sea level. The volume of water at a stable long-term level is estimated at 279 million m³. The coastline stretches for 35.5 km (Figure 1).

Figure 1
Lake Imantau

Note: compiled by the authors

The Lower Burluk River (Kishi Borlyk) flows out of the western part of the lake. A dam has been built at its source, which means that water only leaves the lake in particularly wet years when the level rises above the crest. The southern and eastern parts of the lake are fed by the Zhylandy stream, the Kenesary river, and seven temporary watercourses (logs) that carry water only during the spring snowmelt.

The surface of the lake is mostly open. The south-western shore is rocky and covered with forest (predominantly coniferous), while other areas are characterised by gentle steppe slopes. (Committee for Forestry and Wildlife of the Ministry of Ecology and Natural Resources of the Republic of Kazakhstan, 2023). The fish fauna includes typical eurybionts: perch, pike, chebak, bream, peled, etc.; the presence of crayfish is an indicator of a moderately favourable ecological situation. In terms of its composition, the water is of the hydrocarbonate-sodium type. Lake water is actively used for the water supply needs of the population.

Lake Shalkar is located at an absolute elevation of 309.5 metres above sea level. Its catchment area covers 209 square kilometres, mainly consisting of gently rolling hills with average heights of 30–50 metres. The lake stretches from west to east: its length reaches 12 km, and its width reaches 3.3 km. The water surface covers an area of 35.4 km², with a maximum depth of 15 metres. The average volume of water over many years is estimated at 277 million m³. The length of the coastline is 39.6 km (Figure 2).

Figure 2
Lake Shalkar

Note: compiled by the authors

The surface of the lake is free of aquatic vegetation. The bottom is mostly flat, sandy and rocky, with a gentle slope towards the central part of the basin. Near the shore, it is slightly silted up. The lake is drainless: there is no outflow, and it is fed by temporary streams, five of which flow in from the south-western and south-eastern sides. These watercourses are active only during the spring snowmelt period. Water level fluctuations throughout the year are insignificant and do not exceed 0.6 m, but over a long period of time, fluctuations of up to 3.5-4 m have been observed. In terms of ion composition, the water is of the chloride-sodium type. It is brackish and unsuitable for drinking, but is used for technical needs and sanitary and recreational bathing (Committee for Forestry and Wildlife of the Ministry of Ecology and Natural Resources of the Republic of Kazakhstan, 2023).

In-situ Measurements. Field studies were conducted between 3 and 26 October 2024. During the course of the work, morphometric characteristics were measured and water samples were taken. Samples were taken manually from the central part of each lake at a depth of 0.5 m, i.e. from the surface layer. This was done in accordance with the requirements of the current standard (ST RK GOST R 51592-2003 “Water. General requirements for sampling.” Astana, 2003). Before starting, each sampler and storage container was washed to prevent secondary contamination.

Temperature, pH and dissolved oxygen concentration were measured using a portable two-channel multi-parameter device HACH HQ40D (HACH LANGE, Germany) equipped with IntelliCAL digital sensors. Simultaneous determination of pH, dissolved oxygen (DO) and temperature was carried out. The pH measurement range was 0.00-14.00 with a resolution of up to 0.001 pH; for dissolved oxygen, the range was 0 to 20.00 mg/L with a resolution of 0.01 mg/L, with automatic temperature and barometric compensation. The temperature was measured in the range from 0 to 60 °C with an accuracy of ±0.3 °C. The pH electrodes were calibrated using a 4-point scheme with standard buffers (pH 4.01 and pH 7.00 buffers), and the DO sensor was calibrated using a single-point scheme. The temperature channel did not require calibration.

Hydrochemical parameters were analysed in laboratory conditions in the following areas. The main ions (Ca^{2+}, Mg^{2+}, $Na^{+}+K^{+}$, Cl^{-}, SO_4^{2-}, HCO_3^{-}) were determined by titrimetric method using standard solutions. (according to the methodology (Alekin, 1970; Lurie, 1973; Kishkinova et al., 1977). The content of biogenic substances, including ammonium, nitrite, nitrate nitrogen and phosphates, was determined spectrophotometrically using a DR 3900 (HACH-LANGE) device and appropriate reagents. The device undergoes annual verification at the National Centre for Expertise and Certification, which guarantees the reliability of the values obtained.

Atomic absorption spectroscopy (AAS) was used to assess toxicological characteristics, implemented on a Shimadzu AA-7000 spectrophotometer (Japan). The concentrations of Cu, Zn, Pb, Cd, Co, and Ni were determined. The methodology was consistent with (ST RK ISO 8288-2005 "Water quality. Determination of cobalt, nickel, copper, zinc, cadmium and lead. Flame atomic absorption spectrometric methods" (ISO 8288:1986).

The results were interpreted by comparing the actual concentrations with the maximum permissible values established by Order of the Minister of Health of the Republic of Kazakhstan No. RoK MoH-138 dated 24 November 2022 'On the approval of hygienic standards for the safety of domestic, drinking and cultural water use.' In addition, classical ecological classifications were used (Alekin, 1970; Berg, 1945; Forel, 1912) for contextual interpretation of water types and trophic status. The use of comparative thresholds in historical and modern interpretation allows us to identify not only absolute deviations, but also potential long-term changes in the ecological status of lakes.

Quality control. The reliability of the major-ion determinations was checked by the ionic charge balance, computed as the relative difference between the sums of cations (Ca^{2+}, Mg^{2+}, $Na^{+}+K^{+}$) and anions (Cl^{-}, SO_4^{2-}, HCO_3^{-}) expressed in milliequivalents per litre. The balance error was +0.1% for Lake Imantau and below 0.1% for Lake Shalkar, well within the ±5% range conventionally regarded as acceptable for natural waters; since potassium was determined together with sodium, the combined $Na^{+}+K^{+}$ value was treated as sodium for this calculation. Instrumental accuracy was defined by the manufacturers' specifications: the HACH HQ40D meter measured temperature to ±0.3 °C, pH to a resolution of 0.001 units, and dissolved oxygen to 0.01 mg/L, with automatic temperature and barometric compensation.

Results

Lake Imantau. The surface water temperature is typical for the autumn season and was up to 11.6°C at a depth of 8.0 m with a transparency of 1.2 m (Table 1). The aquatic environment is slightly alkaline with a pH of 8.6. The content of organic substances determined by permanganate oxidizability was 12.8 mg O_2/L, COD – 23.7 mg/L, and classified (Forel, 1912; Berg, 1945) as polluted water. The concentration of suspended solids was 13.0 mg/L, which also indicates moderate anthropogenic impact. These indicators testify to increased trophicity, which may be associated with the inflow of organic matter from coastal areas. The COD indicator is at the upper limit of acceptable values, which requires constant monitoring.

The dissolved oxygen content was 8.7 mg/L with a saturation of 84.2%, which indicates favourable conditions for the life of aquatic organisms. The total oxygen regime meets the criteria for mesotrophic water bodies, with no signs of oxygen deficiency characteristic of stagnant systems.

In terms of overall hardness, lake water is classified (Alekin, 1970) as "very hard" – 7.20 meq/L with mineralisation of 1231 mg/L (Table 2). The mineralisation index is above the limit level (1000 mg/L), which allows the water to be classified as brackish. This indicates a possible increase in evaporation and a limited inflow of fresh water in the autumn period.

The chemical composition of the lake water is determined as hydrocarbonate class, sodium group, type I (C^{Na}_{I}) and belongs to brackish lakes (Forel, 1912; Berg, 1945). The ionic composition of both lakes and the contrast in their mineralization are illustrated by the Stiff diagrams in Figure 3.

Table 1
Hydrochemical Parameters of Lakes

Lake	T, ^{0}C	pH	Permanganate oxidizability, mg O_2/L	COD, mg O_2/L	Suspended solids, mg/L	Dissolved oxygen		Total hardness, meq/L
						mg O_2/L	% saturation	
Imantau	11,6	8,6	12,8	23,7	13,0	8,7	84,2	7,2
Shalkar	10,9	9,1	16,8	31,1	88,0	9,4	88,5	88,0
MAC	-	6-9	5,0	15,0-30,0	< 30 mg/L	4,0	-	7,0

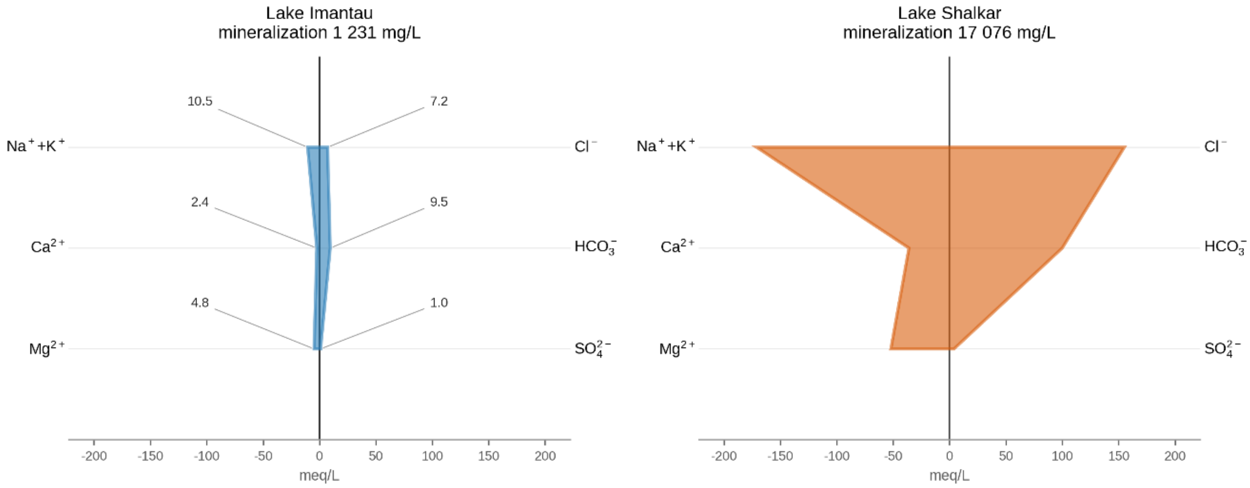
Note – compiled by the authors

Table 2
Ion Composition and Mineralisation of Lake Water

Lake	Ca^{2+}	Mg^{2+}	Na^{+}+K^{+}	Cl^{-}	SO_4^{2-}	HCO_3^{-}	Mineralisation, (mg/L)
	(mg/L)						
Imantau	48,0	58,4	242	255	48,0	580	1231
Shalkar	721	632	3933	5496	192	6102	17076
MAC	-	-	-	350	500	-	1000

Note – compiled by the authors

Figure 3
Stiff Diagrams of the Ionic Composition of Lake Imantau and Lake Shalkar (October 2024)



Note – compiled by the authors.

The content of biogenic substances in the water of Lake Imantau varied within the following limits: NO_2^- – 0.011 mg/L, NO_3^- – 0.40 mg/L, PO_4^{3-} – 0.08 mg/L; ammonium ion absent (Table 3). The phosphate content exceeded the standards by up to 1.6 MPC (Forel, 1912). The recorded exceedance of the MPC for phosphates, despite the absence of ammonium nitrogen, may be a marker of the initial stage of eutrophication.

The concentrations of heavy metals did not exceed the regulatory values (Table 4) (Ryanzhin, 2003, 2005). Only trace levels were recorded: zinc – 2.5 μg/L, lead – 1.0 μg/L, nickel – 6.9 μg/L. Copper, cadmium and cobalt were not detected. This confirms the relative stability of the system with regard to anthropogenic pollution, although retrospective assessments indicate probable fluctuations. The concentrations of all analysed metals relative to the maximum allowable concentrations are summarized in Figure 4, where all values remain below 7% of the MAC for both lakes.

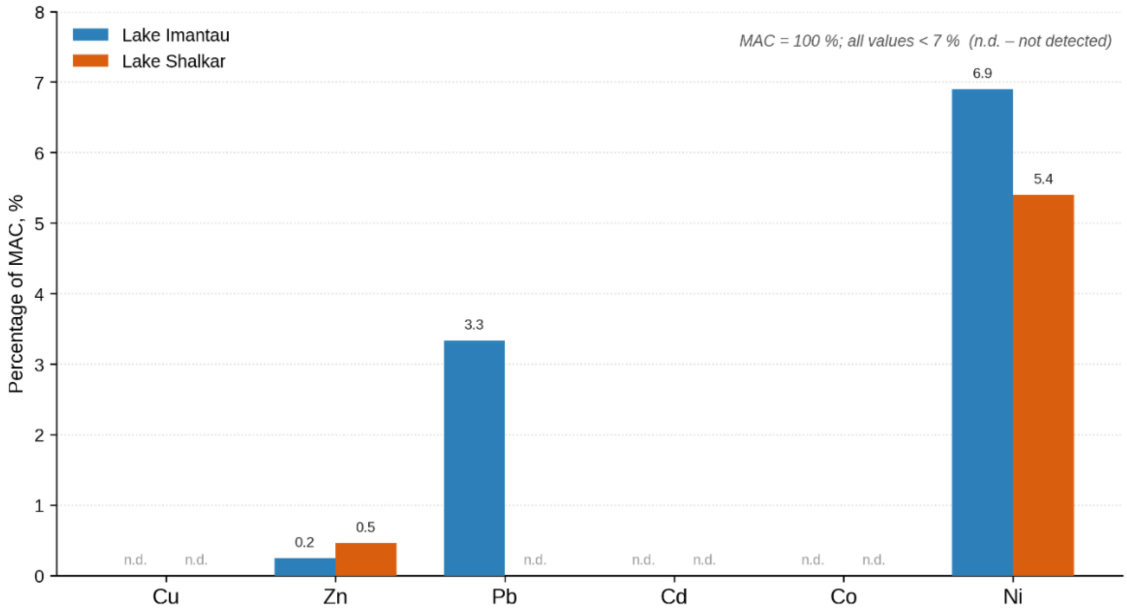
Table 3
Content of Biogenic Substances in Water

Lake	NH_4^+	NO_2^-	NO_3^-	PO_4^{3-}
	mg/L			
Imantau	0,0	0,011	0,4	0,08
Shalkar	0,03	0,009	1,0	0,0
MAC	0,5	40	0,08	0,05
Note – compiled by the authors				

Table 4
Concentration of Heavy Metals in Water

Lake	Cu	Zn	Pb	Cd	Co	Ni
	µg/L					
Imantau	0,0	2,5	1,0	0,0	0,0	6,9
Shalkar	0,0	4,6	0,0	0,0	0,0	5,4
MAC	1000	1000	30	1,0	100	100
Note – compiled by the authors						

Figure 4
Heavy Metal Concentrations as a Percentage of MAC (%)



Note: compiled by the authors

Lake Shalkar. The water temperature warmed up to 10.9 °C at a depth of 2.6 m. The water environment was strongly alkaline, with a pH of 9.1, which may be associated with high photosynthetic activity in shallow water areas (Table 1). This is also confirmed by the low transparency of the water – 0.1 m. The content of organic substances was 16.8 mg O_2/L, suspended solids – 88.0 mg/L. COD reached 31.1 mg/L, which is classified as polluted water (Forel, 1912; Berg, 1945). The oxygen regime is characterised by a concentration of 9.4 mg/L at 88.5% saturation. High COD and suspended solids values may indicate an external inflow of organic matter and the initial stages of biogenic transformation, but the preservation of the oxygen balance indicates self-purification potential.

In terms of its technical properties, the lake water is very hard – 88.0 meq/L. In terms of the amount of salts dissolved in the water, the lake is classified as saline, with a mineralisation of 17,076 mg/L, chloride-sodium composition, type I (ClNaI) (Table 2) (Alekin, 1970; Forel, 1912). Mineralisation exceeds the MPC threshold values by more than 17 times, which may be due to both natural conditions and processes of evaporation and weak water exchange. Under such conditions, the lake's biosystem functions as a hypermineralised environment.

In terms of biogenic substances in lake water, only nitrate levels exceed the standards: 1.0 mg/L, which is equivalent to 0.08 MPC (Table 3) (Ryanzhin, 2005). A stable phosphorus regime (no phosphates detected), combined with a moderate nitrogen load, indicates that the lake is in a stable state in terms of biogenic substances.

Spectrometric analysis showed that heavy metal concentrations in Lake Shalkar water do not exceed maximum permissible concentrations (Ryanzhin, 2003, 2005). According to Table 4, there is no copper, lead, cadmium or cobalt. Small concentrations of zinc (4.6 μg/L) and nickel (5.4 μg/L) were recorded, which is below the MPC (10 μg/L). Thus, Lake Shalkar is characterised by extremely high mineralisation and elevated organic matter and suspended solids of largely natural origin, while its nutrient and heavy-metal load remains stable.

According to research (Goryunova et al., 1978), mineralisation in Lake Imantau fluctuated between 536 and 758 mg/L between 1964 and 1978, and in 1976, 1977 and 2011-2013, it increased to 1256-2010 mg/L. Such fluctuations in the salt regime are probably due to varying volumes of freshwater inflow in the spring, which makes it necessary to continue monitoring seasonal dynamics.

The above-mentioned literature sources contain fairly detailed information on the concentration of biogenic compounds in lake waters. During the growing season, they were recorded within the maximum permissible concentration (MPC) for fish farming reservoirs. Data on heavy metals in lake waters are extremely scarce. In the waters of Lake Imantau in 2015, the concentration was within 2.5-3.0 MPC, with zinc, manganese and nickel recorded at levels below the MPC standards.

When assessing the trophic status of water bodies based on dissolved oxygen concentration and saturation percentage, Lake Imantau and Lake Shalkar are classified as mesotrophic, with trophic type indicators ranging from 50 to 155% (Tsvetkova et al., 2012; Frumin & Huang, 2012). However, based on phosphate concentrations, Lake Imantau is transitioning to an eutrophic state, while Lake Shalkar remains stable. These observations suggest that nutrient input from the shoreline is raising biogenic concentrations in Lake Imantau, which may accelerate overgrowth by higher aquatic vegetation and alter the ecosystem.

Discussion

The two lakes studied here occupy a single landscape-climatic zone of the Ayyrtau district yet diverge sharply in their hydrochemical character. Lake Imantau is a fresh, hydrocarbonate-sodium water body with a mineralisation of 1231 mg/L, whereas Lake Shalkar is a hypermineralised, chloride-sodium system at 17076 mg/L, more than an order of magnitude higher. The Stiff diagrams (Figure 3) make this contrast explicit: Imantau retains a balanced ionic profile dominated by hydrocarbonate, while Shalkar is governed by sodium and chloride. Such a divergence between adjacent lakes of the same region reflects the difference between a through-flow basin with periodic outflow (Imantau) and a closed, drainless basin (Shalkar), where the absence of outflow allows dissolved salts to concentrate over time.

These results confirm the initial hypothesis only in part. Lake Shalkar does show far higher mineralisation than Lake Imantau, but this difference follows from its closed, evaporative basin rather than from recreational pressure. While adaptive monitoring of recreational capacity remains an important management tool for nature-based lake destinations of this type (Tankibayeva et al., 2023), the present data indicate that the anthropogenic signal the hypothesis associated with Shalkar appears instead at

Lake Imantau, where phosphate enrichment points to early eutrophication. The contrast between the two lakes is therefore governed primarily by basin hydrology, with the anthropogenic component concentrated in the through-flow lake rather than the saline one.

This pattern is consistent with the regional hydroclimatic setting. Both lakes belong to the Esil River basin, for which a semi-arid regime with annual precipitation of 250-450 mm and a heightened vulnerability of surface waters to climatic change have been established (Bahetnur & Lee, 2023). Under such conditions, evaporative concentration becomes a leading control on the salt balance of poorly drained lakes. The neighbouring Lake Burabay illustrates the same mechanism within this zone: instrumental monitoring recorded a rise in mineralisation from 160 to 321 mg/L over 2018-2022, attributed to evaporation exceeding precipitation (Shulembayeva et al., 2023), while remote sensing independently documented a contraction in the surface area of the main Shchuchinsk-Burabay lakes under recreational pressure (Ramazanova et al., 2019). The extreme mineralisation of Shalkar is therefore best read as the end-member of a regional gradient driven by aridity, weak water exchange, and a closed basin, rather than as an isolated anomaly. The historical record for Imantau, where mineralisation fluctuated between 536-758 mg/L in 1964-1978 and rose to 1256-2010 mg/L in individual years (Goryunova et al., 1978), confirms that even the fresher of the two lakes is sensitive to these inter-annual swings.

The toxicological picture stands in clear contrast to lakes affected by ore-related sources. In both Imantau and Shalkar, every analysed metal remained below 7% of its maximum allowable concentration (Figure 4), with copper, cadmium and cobalt undetected. This background-level load is what would be expected for water bodies lacking ore or industrial sources nearby. Elsewhere in Kazakhstan, the exceedances noted in the Introduction are each tied to a specific geological or technogenic source: a natural geochemical background in the Kolsai Lakes, ore-enrichment tailings at Lake Balkhash, and polymetallic deposits around Lake Markakol. None of these source types is present in the catchments of Imantau or Shalkar. Against these cases, the trace metal levels in Imantau and Shalkar place both lakes firmly in the natural background range and confirm the absence of a toxicological risk from metals at the time of sampling. At metal levels of a few percent of the MAC, direct comparison with regulatory thresholds characterises the toxicological state more meaningfully than aggregated heavy-metal indices, which converge toward uniformly low values under such conditions (Biedunkova & Kuznietsov, 2024).

The biogenic signal sets the two lakes apart once more. In Shalkar, phosphates were not detected and nitrogen remained moderate, indicating a stable nutrient regime. In Imantau, phosphate reached 1.6 MPC in the absence of ammonium nitrogen, a pattern that may mark the initial stage of eutrophication driven by phosphorus input from the shoreline. This reading is supported by the longer record for Imantau, where a complex pollution index rose markedly between 2014 and 2019 alongside increasing nitrogen forms, in close correlation with the growth of tourist numbers (Zhumay et al., 2021), and by independent measurements in 2022-2023 that recorded rising ammonium and sodium-potassium concentrations in the same lake (Zadagali et al., 2024). The location of Imantau within an active resort zone makes this trajectory plausible, since even the low-level nutrient input characteristic of tourism can trigger a measurable biological response in otherwise clean protected lakes (Cao et al., 2016). The phosphate exceedance recorded in October 2024 thus appears to be one point on a longer eutrophication trend rather than an isolated reading. Accordingly, trophic status here is assessed from dissolved oxygen, nutrients and transparency rather than from a single composite trophic index, an approach better suited to the present dataset and consistent with reported divergences among quality and trophic indices applied to the same water body (Shiretorova et al., 2025).

Limitations

This study is a pilot (case-study) assessment, and several limitations define the scope within which its results should be interpreted.

First, sampling was carried out once, within a single hydrological season (3-26 October 2024). The data reflect the state of the lakes during the autumn period of low biological activity and do not capture seasonal dynamics, including spring snowmelt and meltwater inflow, the summer productivity maximum, and winter under-ice stratification. Given that Lake Imantau has previously shown considerable inter-annual and seasonal fluctuations in mineralisation (536-758 mg/L in 1964–1978, rising to 1256-2010 mg/L in individual years), the present values should be regarded as an instantaneous snapshot rather than an averaged characteristic of the water bodies.

Second, at each lake sampling was performed at a single point, in the central part of the water area, at a depth of 0.5 m. This design ensures comparability between the two lakes but does not allow the spatial heterogeneity to be assessed: the littoral zones, the inflow areas of temporary watercourses, the near-dam section of Lake Imantau, and the silted near-shore zones of Lake Shalkar, where hydrochemical parameters may differ substantially from those at the centre of the basin. Extrapolation of the obtained values to the entire lake area is therefore limited.

Third, the study covers only the surface horizon (0.5 m) and does not include vertical profiling. For Lake Shalkar, with a maximum depth of 15 m, and for Lake Imantau, with a depth of up to 10 m, this means an absence of data on possible vertical stratification in temperature, oxygen, and mineralisation.

These limitations define the status of the results as a reference point for regional monitoring rather than diminishing their value: the work provides an instrumentally confirmed profile hydrochemical and toxicological profile of two contrasting lakes in the Ayyrtau district, against which further changes can be tracked.

Conclusion

Lake Imantau and Lake Shalkar demonstrate differences in hydrochemical composition, reflecting the characteristics of their morphometry, sources of nutrition and anthropogenic load. Lake Imantau is characterised by a slightly alkaline reaction, moderate mineralisation and insignificant levels of organic matter and suspended particles. However, phosphate levels exceed established standards, which may indicate a potential transition to eutrophication. At the same time, Lake Shalkar is characterised by signs of hypermineralised water with extreme total hardness and chloride-sodium type waters. The high alkalinity of the environment and the significant content of organic and suspended substances may be the result of both internal biochemical processes, including photosynthesis, and the external influx of organic matter. Despite this, no exceedances of heavy metal content were recorded in either water body.

Based on the analysis of biogenic compounds and oxygen regime, both lakes can be classified as mesotrophic. However, Lake Imantau shows initial signs of trophic transition, which requires additional attention to coastal loading and nutrient input intensity. Given the identified deviations in certain parameters, there is a need for regular monitoring of water composition, with a focus on phosphorus compounds, organic matter and fluctuations in mineralisation in seasonal dynamics.

The data obtained can serve as a basis for updating environmental regulation – including the application of the unified water-quality classification system for surface water bodies (Ministry of Water Resources and Irrigation of the Republic of Kazakhstan, 2025) – and for protecting water bodies in northern Kazakhstan according to their typological differences. Future work should add seasonal sampling across spring, summer and winter, several sampling points per lake including littoral and inflow zones, vertical profiling in the deeper basins, and measurements of chlorophyll-a and total phosphorus that would allow the Carlson trophic index to be applied to Lake Imantau. These steps would extend the present pilot assessment toward continuous regional monitoring.

Author Contributions

Conceptualization, Y. Nuruly, A.R. Zhumalipov; Methodology, A.R. Zhumalipov and Y. Nuruly; Software, Y. Nuruly, A.M. Serikbol; Validation, A.R. Zhumalipov, Y. Nuruly and A.M.S.; Formal Analysis, A.R. Zhumalipov and A.Z. Shyryntay; Investigation, A.R. Zhumalipov; Resources, A.R. Zhumalipov, A.M. Serikbol; Data Curation, A.Z. Shyryntay, A.M. Serikbol; Writing – Original Draft Preparation, A.R. Zhumalipov; Writing – Review & Editing, Y. Nuruly and A.M. Serikbol; Visualization, A.Z. Shyryntay; Supervision, Y. Nuruly; Project Administration, Y. Nuruly; Funding Acquisition, A.R. Zhumalipov, Y. Nuruly. All authors have read and agreed to the published version of the manuscript.

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Declaration of interest statement

The authors have no conflict of interest to declare.

Declaration on the use of GenAI

During the preparation of this work, the authors used Claude (Anthropic) for editing and language refinement of the English text and for checking the formatting and consistency of the references. After using this tool, the authors reviewed and edited the content as necessary and take full responsibility for the content of the publication.

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