https://doi.org/10.55764/2957-9856/2026-3-118-130.39

IRSTI 87.15.03
UDC 556.531

A. A. Sultanayeva*[1], A. S. Madibekov[2], A. Mussakulkyzy[3], L. T. Ismukhanova[4], N. B. Alekeeva[5], A. O. Zhadi[6]

[1] *Junior researcher, PhD student (JSC Institute of Geography and Water Security, Al-Farabi Kazakh National University, Almaty, Kazakhstan; ***arai1104@mail.ru***)
[2] PhD, associate Professor, Chief researcher (JSC "Institute of Geography and Water Security", Almaty, Kazakhstan; *a.s.madibekov@gmail.com*)
[3] Candidate of Geographical Sciences, Senior researcher (JSC "Institute of Geography and Water Security", Almaty, Kazakhstan; *mus_ain@mail.ru*)
[4] PhD, Senior researcher (JSC "Institute of Geography and Water Security", Al-Farabi Kazakh National University, Almaty, Kazakhstan; *l--aura@bk.ru*)
[5] Researcher (JSC "Institute of Geography and Water Security", Almaty, Kazakhstan; *nazym.alekeeva@bk.ru*)
[6] Researcher (JSC "Institute of Geography and Water Security", Almaty, Kazakhstan; *askhat.zhadi@mail.ru*)

HYDROCHEMISTRY OF THE SHU–TALAS RIVER BASINS UNDER THE INFLUENCE OF NATURAL AND ANTHROPOGENIC FACTORS

Abstract. The research work involves assessing the hydrochemical state of surface waters in the Shu–Talas River basin, determining the spatial characteristics of their main chemical composition, and conducting a comprehensive evaluation of the level of water pollution. The study evaluates water quality based on hydrochemical monitoring data from 2002 to 2025 provided by Kazhydromet RSE, considering mineralisation, pH, dissolved oxygen, total hardness, and the composition of major cations and anions were considered, and the natural waters were classified according to the Alekin classification. The ratio of major ions was analysed using Stiff diagrams, and the Integrated Water Pollution Index (IWPI) was calculated to assess the level of anthropogenic impact. According to the study results, the average mineralisation of the catchment waters was 674 mg/L. Among the heavy metals, the main pollutant affecting water quality was copper, with its concentration exceeding the regulatory limits at certain periods. Furthermore, the long-term dynamics showed a decreasing trend in the concentrations of heavy metals, particularly copper. Although the discharge volumes of organic pollutants decreased in 2023 compared to 2022, petroleum products predominated among them. The research findings can serve as a scientific basis for the long-term assessment of water quality in the Shu-Talas transboundary basin, the identification of pollution sources, and the improvement of an effective water resource management and joint monitoring system.

Keywords: transboundary rivers, hydrochemistry, heavy metals, integrated water pollution index.

Introduction. The effective use and protection of water resources is an important prerequisite for the sustainable development of Kazakhstan, particularly under conditions of increasing water scarcity. Water quality is affected by a number of anthropogenic factors, including agricultural activity, inadequate waste management, industrial development and urbanisation [1, 2]. The combined effect of these pressures makes the provision of safe and sufficient water resources by 2030 a significant challenge [3, 4]. This problem is especially relevant in the southern regions of Kazakhstan, where available water resources are limited while demand from agriculture, the population, industry and municipal services remains high. Changes in hydrological conditions and growing water consumption further increase the importance of regular assessment of river water quality and its suitability for different types of use.

The situation is more complicated in transboundary river basins because both the quantity and quality of water may be affected by activities taking place outside the country. The Shu and Talas Rivers basin is particularly important in this respect. Much of their runoff is generated in the Kyrgyz Republic, whereas substantial water abstraction, including water used for irrigation, occurs on the territory of Kazakhstan. Consequently, the condition of these water resources is closely related to cooperation between the two countries, the regulation of water use and the availability of reliable monitoring data [5, 6].

These circumstances are especially characteristic of the Shu-Talas water-management basin. Around 80% of its surface runoff is formed in Kyrgyzstan, which makes coordination between Kazakhstan and Kyrgyzstan an important condition for the management of the basin [7]. Water distribution between the two countries is based partly on agreements established during the Soviet period, including the 1983 regulations on water allocation. Irrigation is the main type of water use and accounts for approximately 70–80% of the available water resources [8]. In addition to the uneven distribution of water formation and consumption, the basin is vulnerable to the transfer of pollutants between the two countries. Agricultural development, insufficient wastewater treatment and weaknesses in the coordination of monitoring activities can contribute to deterioration of water quality [9].

The hydrological characteristics of the Shu-Talas basin are largely determined by its mountainous setting. River flow is mainly formed by the melting of seasonal snow, high-mountain snow and glaciers. This results in a pronounced increase in discharge during spring and a second rise during the summer period associated with melting in the higher mountain areas. Such a pattern contributes to the formation of the annual runoff regime. However, intensive water abstraction for irrigation changes the natural distribution of river flow. In the Shu River, discharge may decrease substantially during some summer months, while after the end of the irrigation period, autumn and winter discharge may become higher than that observed in summer [10, 11].

The Shu River has considerable environmental and socio-economic importance for the region. Its condition is influenced by both natural hydrological processes and long-term economic activity. For this reason, assessment of anthropogenic pressure on the river requires not only the collection of water-quality data but also an evaluation of changes in the aquatic environment and the factors responsible for them [10]. In the Shu-Talas basin, particular concern is associated with the combination of elevated mineralisation and anthropogenic pollution. These factors can affect the ecological condition of river systems and limit the suitability of water for different uses, highlighting the need for systematic assessment of water quality.

In this context, studying the hydrochemical characteristics of the Shu-Talas basin is relevant from both scientific and practical perspectives. The present study focuses on the major ionic and saline composition of the water, mineralisation, bio-organic compounds and heavy metals, with particular attention to their long-term changes. The Integrated Water Pollution Index (IWPI), calculated from deviations from permissible concentration limits, is applied to assess the degree of pollution and determine its main sources. The results are intended to provide a more detailed assessment of the hydrochemical condition of the basin and to support the improvement of water-resource management and water-quality monitoring in this transboundary region.

Materials and Methods. The Shu-Talas basin is located mainly in the Zhambyl and Turkestan regions (figure 1). The total area of the Shu-Talas and Asa hydrographic basin is 186,790 km², or 6.8% of the republic's territory [12]. Hydrografically, the basin contains 3 major rivers (Shu, Talas and Asa), 242 minor rivers (of which 158 are in the Shu basin, 20 in the Talas basin and 64 in the Asa basin) and 35 lakes [13].

The natural and hydrological conditions of the Shu-Talas basin are characterised by a distinct mountainous-plain topography, seasonal variations in flow, and a high sensitivity of water bodies to external influences. In the upper reaches of the rivers, water quality is largely determined by natural factors influencing runoff, whilst further downstream the role of anthropogenic pressure increases. Changes in the chemical composition of the water are influenced by irrigated agriculture, return flows, domestic and industrial sources of pollution, as well as the characteristics of the water balance and evaporative concentration in an arid climate [14].

One of the most pronounced problems in the basin is the variation in the ionic-saline composition and mineralisation of the water along the course of the rivers. Studies of the long-term dynamics of the Shu River’s water show variations in its ionic-saline composition across different sections of the river [15].

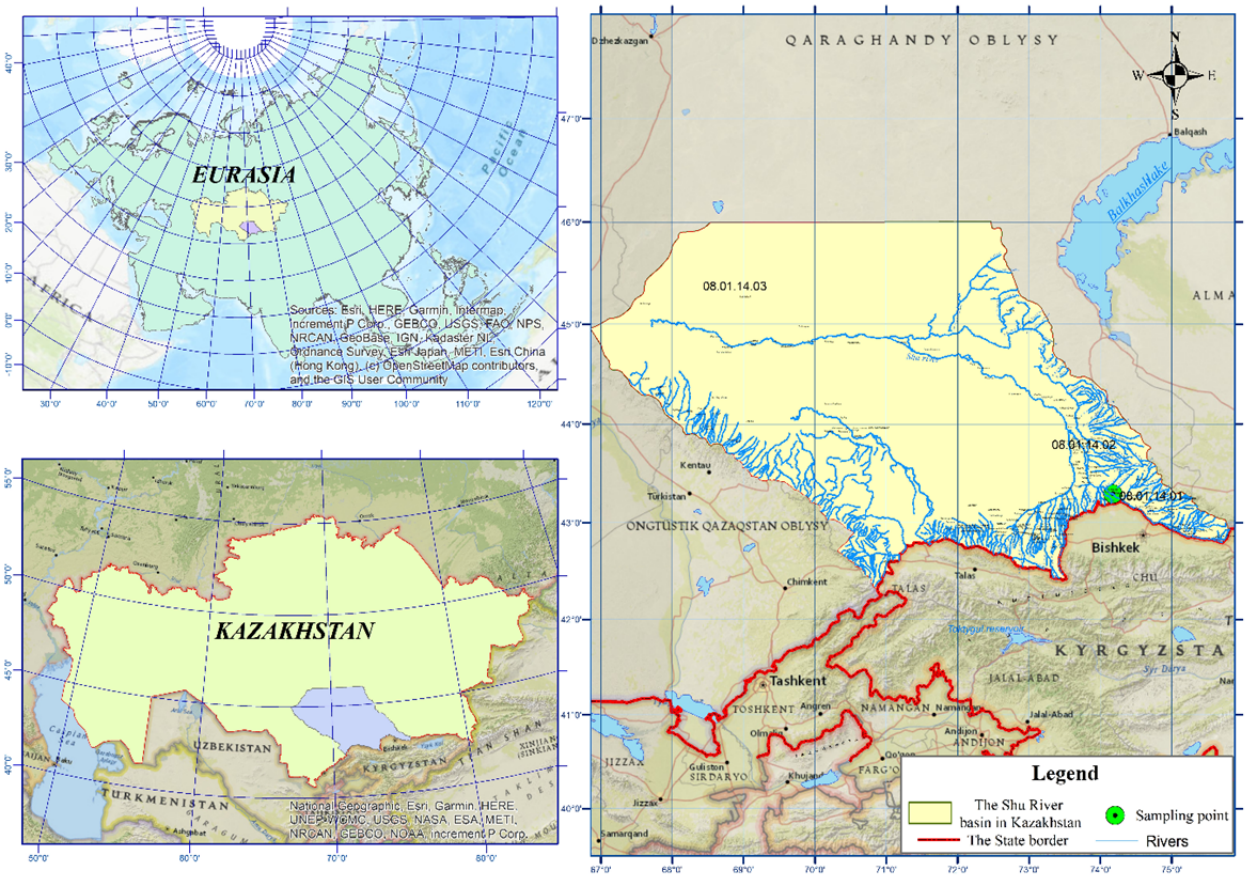


Figure 1 – Map of the Shu-Talas River basin

Alongside changes in the ionic and salt composition of river waters, elevated concentrations of biogenic compounds, petroleum products, phenols, heavy metals and other pollutants have been identified.

The current situation is complicated by the insufficient density and frequency of hydrological and hydrochemical monitoring, as well as the limited availability of data on a number of priority toxicants. This reduces the reliability of assessments of the current state of water bodies and hinders the taking of management decisions aimed at maintaining water quality at the required standard. In this regard, a pressing priority is to carry out comprehensive monitoring that combines hydrochemical, toxicological and geoinformation research methods [12, 14].

The composition and hydrochemical characteristics of natural waters can be described using the classification proposed by O. A. Alekin [16]. This classification is based on pH, mineralisation, water hardness, and the concentrations of major ions. The classification criteria used to determine the hydrochemical type of the studied waters are presented in table 1.

According to Alekin's classification, natural waters are divided into three classes based on the predominant anions: hydrocarbonate (HCO_3^-), sulphate (SO_4^{2-}), and chloride (Cl^-) waters. Each class is further divided into groups according to the predominant cation (Ca^{2+}, Mg^{2+}, or Na^+) and into types based on the relative proportions of the major ions. Each group, in turn, is divided into four types of waters determined by the ratio between ions in equivalents:

I. $HCO_3^- > Ca^{2+} + Mg^{2+}$.

II. $HCO_3^- < Ca^{2+} + Mg^{2+} < HCO_3^- + SO_4^{2-}$.

III. $HCO_3^- + SO_4^{2-} < Ca^{2+} + Mg^{2+}$ or $Cl^- > Na^+$.

IV. $HCO_3^- = 0$.

The Integrated Water Pollution Index was calculated based on the available data on the actual concentrations of hydrochemical and toxicological indicators in the database. The assessment was based on the Methodological Recommendations for the Integrated Assessment of Surface Water Quality Using Hydrochemical Indicators, which provide a differentiated assessment of water pollution by groups of

Table 1 – Classification criteria for the hydrochemical characteristics of natural waters according to O.A. Alekin [16]

Parameter	Classification	Range
pH	Strongly acidic	< 3
	Acidic	3–5
	Slightly acidic	5–6.5
	Neutral	6.5–7.5
	Slightly alkaline	7.5–8.5
	Alkaline	8.5–9.5
	Strongly alkaline	> 9.5
Dissolved oxygen, mg/L	Normatively clean	≥ 4.0
	Moderate pollution	3.1–3.9
	High pollution	1.1–3.0
	Extremely high pollution	≤ 1.0
Mineralisation, mg/L	Freshwater	0–1000
	Brackish water	1000–25,000
	Saline water	25,000–50,000
	Brines	> 50,000
Hardness, mg-eq/L	Very soft	< 1.5
	Soft	1.5–3.0
	Moderately hard	3.0–6.0
	Hard	6.0–9.0
	Very hard	> 9.0

substances. To calculate the IWPI, the measured concentrations of pollutants were compared with the Class 1 water quality standards approved by Order No. 70 [17]. To increase the informativeness of the assessment, the IWPI was calculated separately for each group of indicators. The pollution index for the j-th group was determined based on the exceedance ratio of pollutant concentrations relative to the corresponding maximum permissible concentrations (MPCs). Variants of this approach have been developed under the guidance of M.Zh. Burlibayev [18, 19]:

$$IWPI_j = \frac{\sum_{i=1}^{n} C_i / MPC_i}{n},$$

where $IWPI_j$ – water pollution index for the j-th group; C_j – concentration of the i-th constituent in the j-th group, mg/dm^3; MPC_i – maximum permissible concentration of the i-th constituent corresponding to C_i, mg/L; n – number of constituents exceeding the MPC in the j-th group.

$$IWPI = \sum_{i=1}^{m} IWPI_i / m,$$

where m – number of combined groups of indicators.

Water quality in the Shu–Talas River Basin was assessed based on the values of the IWPI using the following classification (table 2): values below 1 indicate water meeting regulatory quality standards; values ranging from 1 to 3 correspond to a moderate level of pollution; values from 3.1 to 10 indicate a high level of pollution; and values above 10 characterize an extremely high level of pollution.

In accordance with the recommended methods for the IWPI determination and considering the data availability for the study period 2003-2022, it was possible to select pollutant constituents whose concentration exceeds the established maximum permissible concentrations (MPCs) for their own constituents. The list of ingredients that are included in the calculation of the IWPI is divided into the following conventional groups: major ions, nutrients, heavy metals, toxic compounds, organic substances,

and organochlorine pesticides. From these groups of hydrochemical and toxicological indicators, the state monitoring database has long-term information on three groups: major ions, nutrients, and heavy metals.

The overall IWPI is determined solely on the basis of components that exceed their established MPC, while components that do not exceed the MPC are considered non-polluting. The article takes into account the unique soil-climatic, hydrogeological, and other genetic characteristics of the region. Since the concentrations of major ions in natural waters may exceed the established standards due to these specific regional characteristics and the hydrological regime of water bodies, they are excluded from the pollution assessment. Therefore, only heavy metals and biogenic compounds exceeding the established MPC values are considered pollutants.

Results. *Mineralisation.* To assess the long-term dynamics of surface water quality in the Shu-Talas River Basin, hydrochemical monitoring data provided by the RSE "Kazhydromet" for the period 2002-2025 were used. According to the long-term data, the average mineralization of the Shu-Talas River Basin waters was 674 mg/L. The minimum value was recorded in the Berkara River at 315 mg/L, while the maximum values were observed in Lake Bilikol (1357 mg/L) and the Karabalta River (1228 mg/L) (figure 2).

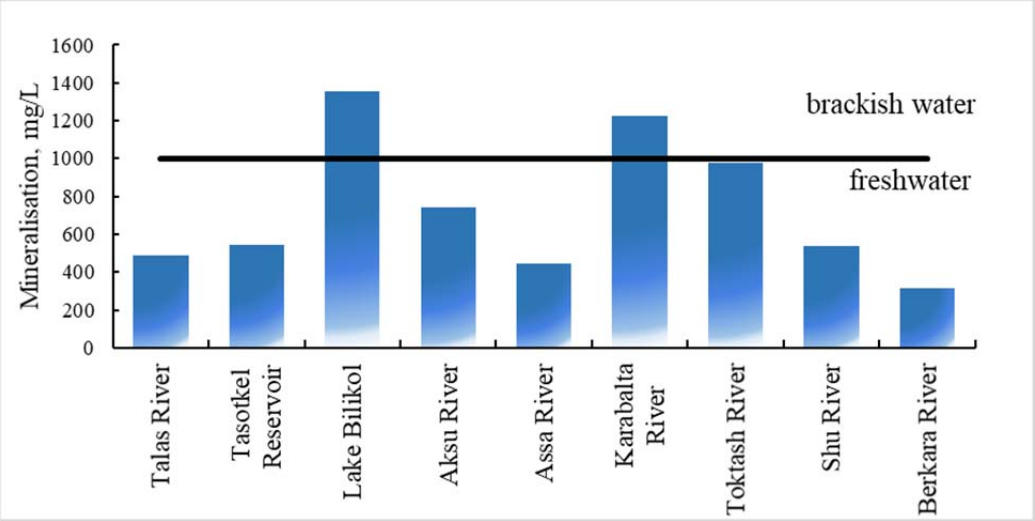


Figure 2 – Mineralisation indicators of the Shu-Talas River basin

According to the document "On the Approval of a Unified System for Classifying Water Quality in Water Bodies", if the mineralisation indicator is below 1000 mg/L, the water quality is classified as Class 1, while higher mineralisation values correspond to higher water quality classes [16]. According to the Alekin classification, the river waters of the basin are classified as fresh water, while the Karabalta River and Lake Bilikol correspond to brackish water.

Classification of the Shu-Talas River basin by chemical composition and dominant ion groups. The long-term average values of pH, dissolved oxygen, total hardness and mineralisation were classified according to the Alekin hydrochemical classification. This approach was used to determine the predominant ionic composition and the main hydrochemical characteristics of the studied water bodies. The names of the hydrochemical groups and the formula used to determine the hydrochemical composition according to the Alekin classification are presented in table 2. The classification is based on the relative predominance of the major anions and cations and allows the studied waters to be assigned to specific hydrochemical classes, groups and types.

According to the results, the pH value at all sites corresponds to a weakly alkaline medium, and the dissolved oxygen level was assessed as meeting the standard for clean water. The majority of the water bodies are classified as freshwater. Only Lake Bilikol and the Karabalta River were found to be brackish.

Differences were identified in terms of total hardness. The Talas, Asa, Shu and Berkara rivers, and the Tasotkel reservoir were found to have moderate hardness. The water of the Aksu river is hard, while the Bilikol lake, Karabalta and Toktash rivers are classified as very hard waters.

Table 2 – Names of classification groups according to the Alekin classification for water bodies

Study object	pH	Dissolved oxygen	Total hardness	Mineralisation	Alekin water composition index
Talas River	Slightly alkaline	Normatively clean	Moderately hard	Fresh	Bicarbonate class, first calcium group
Tasotkel Reservoir			Moderately hard	Fresh	Bicarbonate class, second calcium-sodium group
Bilikol Lake			Very hard	Brackish	Sulfate class, second sodium group
Aksu River			Hard	Fresh	Bicarbonate class, first calcium group
Assa River			Moderately hard	Fresh	Bicarbonate class, first calcium group
Karabalta River			Very hard	Brackish	Sulfate class, first sodium-calcium group
Toktash River			Very hard	Fresh	Sulfate class, first sodium group
Shu River			Moderately hard	Fresh	Bicarbonate class, first calcium group
Berkara River			Moderately hard	Fresh	Bicarbonate class, first calcium group

According to the Alekin classification, the majority of the studied objects belong to the bicarbonate class. Among them, the first type of calcium group predominates. As for Lake Bilikol, The Karabalta and Toktash rivers exhibited characteristics typical of the sulphate class. This variability in water composition is indicative of the natural geochemical conditions of the studied objects and the specific features of their mineral composition.

The Stiff diagrams for the main surface water bodies of the Shu-Talas Rivers basin are presented in figure 3. The diagrams illustrate the equivalent ratio of the principal cations and anions in the water. The

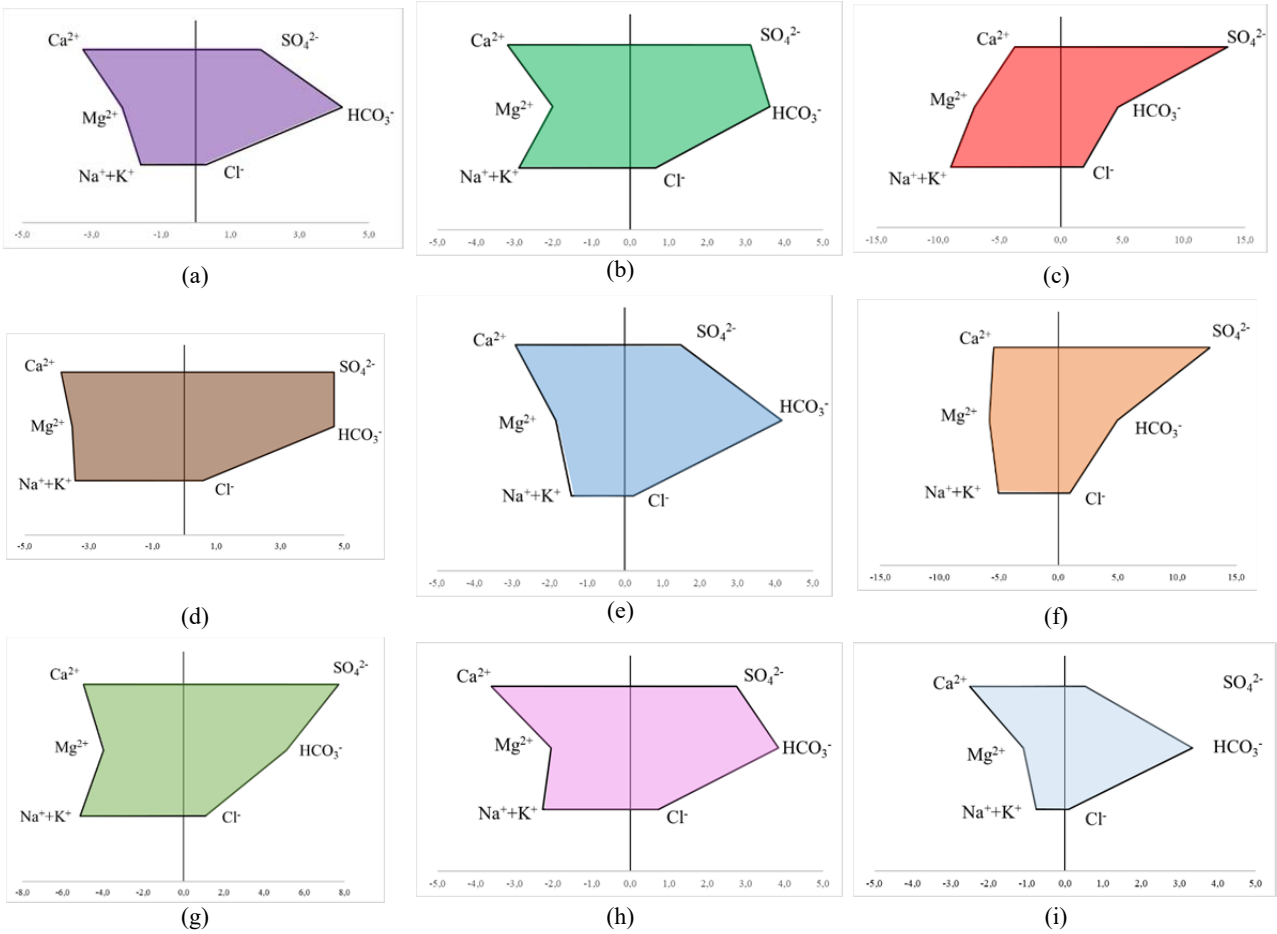


Figure 3 – Stiff diagram, meq/L: a – Talas River; b – Tasotkel Reservoir; c – Lake Bilikol; d – Aksu River; e – Assa River; f – Karabalta River; g – Toktash River; h – Shu River; i – Berkara River

cation side is shown on the left, with Ca^{2+}, Mg^{2+}, $Na^{+} + K^{+}$, and the anion side on the right, with SO_4^{2-}, HCO_3^{-} and Cl^{-} ions.

The anionic composition in the studied water bodies was dominated by bicarbonate and sulphate ions, while the proportion of chloride ions was relatively low. Among the cations, calcium and magnesium ions were significant, with an increase in $Na^{+} + K^{+}$ levels observed at certain points.

The Stiff diagrams for the Talas River sites showed a more pronounced anionic fraction, mainly associated with higher proportions of hydrocarbonate and sulphate ions. A sulphate-bicarbonate composition was also maintained at the Tasotkel Reservoir and Shu River points, although differences in the level of mineralisation and ionic ratios were observed between the water bodies.

The most markedly expanded diagrams were observed for Lake Bilikol, the Aksu River and the Karabalta River, indicating higher concentrations of major ions, particularly SO_4^{2-} and HCO_3^{-}. The diagrams for the Asa, Toktash and Berkara rivers showed a relatively balanced ionic composition, although spatial variations in the cation-to-anion ratios were also observed.

Integrated Water Pollution Index. Based on the data collected for the main hydrochemical indicators for each monitoring point, the values of the IWPI were also calculated (figure 4).

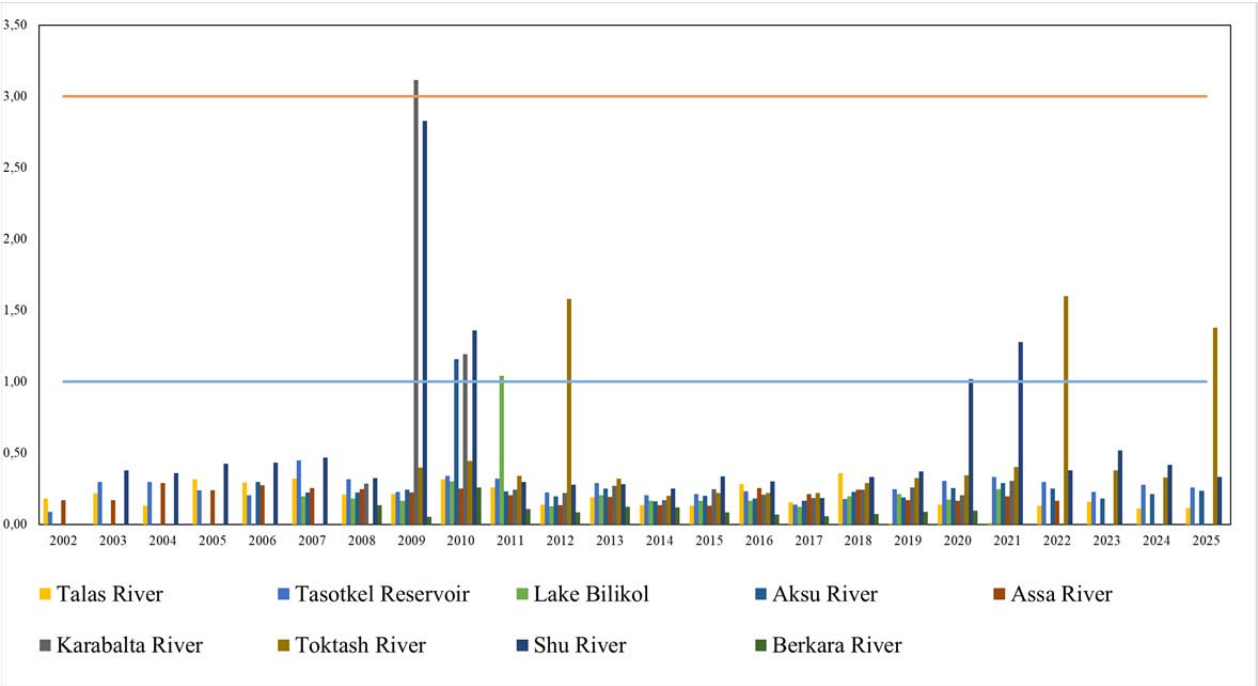


Figure 4 – Integrated Water Pollution Index for Nutrient Compounds in the Shu and Talas River Basins

The IWPI values were below 1 at most monitoring sites and during most years, indicating water quality within the permissible level. Moderate pollution levels (IWPI = 1-3) were recorded occasionally at individual monitoring sites. The most noticeable increases were observed in the Karabalta River, where the IWPI reached 3.12 in 2009 and 1.19 in 2010, and in the Shu River, where values reached 2.83 in 2009 and 1.36 in 2010. In the Toktash River, moderate pollution levels were recorded in 2012 (1.58), 2022 (1.60), and 2025 (1.38). Values slightly above 1 were also observed in Lake Bilikol in 2011 and in the Aksu River in 2010. Overall, most monitoring sites were characterised by IWPI values below 1, while higher values were mainly associated with individual years and specific water bodies.

Heavy metals. A study of the quality parameters of the transboundary flow of the Shu River showed that, amongst heavy metals, copper (Cu) was the most significant pollutant. During the observation period from 2002 to 2008, high levels of exceedance of the maximum permissible concentration (MPC), up to 8.39 times the MPC, were recorded, followed by a steady downward trend in concentrations. In recent years, the values have stabilised at 1.7–2.7 times the MPC. Zinc (Zn) concentrations were generally within permissible limits, with rare instances of minor exceedances. The levels of lead (Pb), nickel (Ni), cobalt (Co) and cadmium (Cd) remained below the MPC in most cases (figure 5).

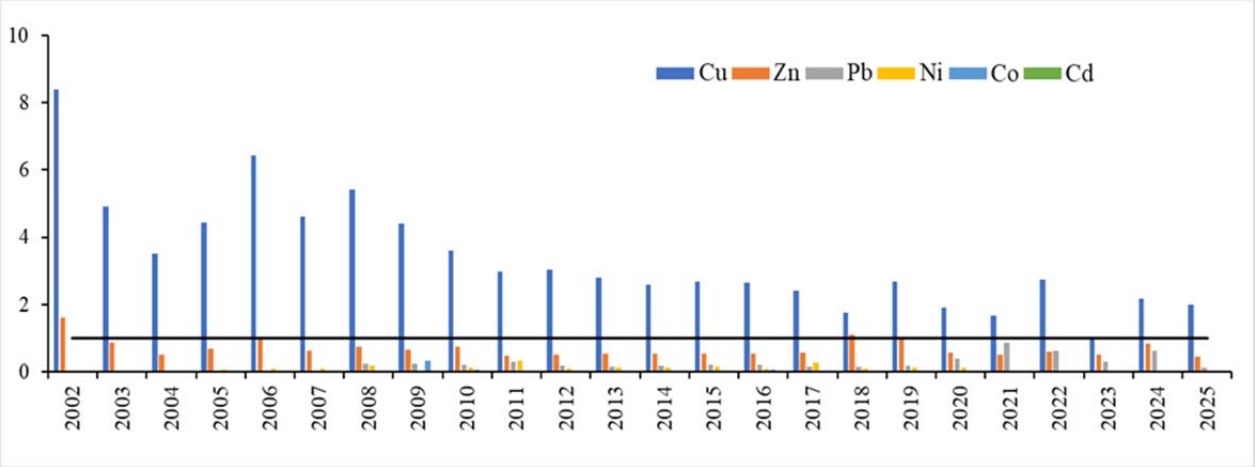


Figure 5 – Exceedance factors for heavy metal MPCs at the transboundary section of the River Shu

An analysis of heavy metal discharge at the transboundary section of the Shu River showed significant interannual variability. The highest discharge values at the start of the period under review were recorded for copper (Cu) and zinc (Zn): in 2002, these stood at 2.16 tonnes and 4.04 tonnes, respectively. In subsequent years, copper values fell to 0.15-0.50 tonnes, whilst zinc values varied over a wider range (0.57-1.60 tonnes), with occasional increases.

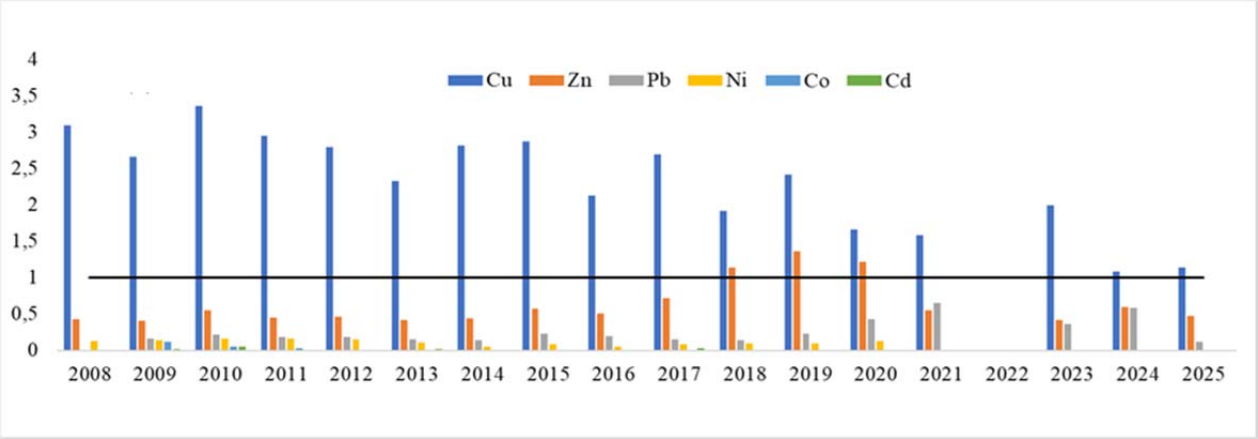


Figure 6 – Multiples of exceedance of the maximum permissible concentrations (MPCs) of heavy metals at the transboundary monitoring station on the Talas River

Lead (Pb) discharge began to be recorded in 2008 and was characterised by moderate levels (0.20-0.48 tonnes). In recent years (2020-2022), an increase to 0.86–0.99 tonnes were observed, followed by a decrease in 2023 to 0.30 tonnes. Nickel (Ni), cobalt (Co) and cadmium (Cd) were characterised by low values and irregular observations.

An analysis of the long-term average heavy metal load at the transboundary section of the Talas River for the period 2008-2021 showed relatively low values and significant interannual variability. The main contributors to heavy metal discharge were zinc (Zn), lead (Pb) and copper (Cu), whilst the concentrations of nickel (Ni), cobalt (Co) and cadmium (Cd) remained negligible and occurred only sporadically.

Organic substances. An analysis of the discharge of specific organic pollutants (surfactants, phenols, petroleum products) at the transboundary section of the Shu River showed that observations for these parameters have only been carried out since 2022. The discharge of these substances was calculated for 2022-2023, as data on water discharge are available up to 2023.

Concentrations of surfactants and phenols did not exceed the maximum permissible concentration (MPC). In 2022, petroleum products exceeded the MPC by 1.17 times (figure 7).

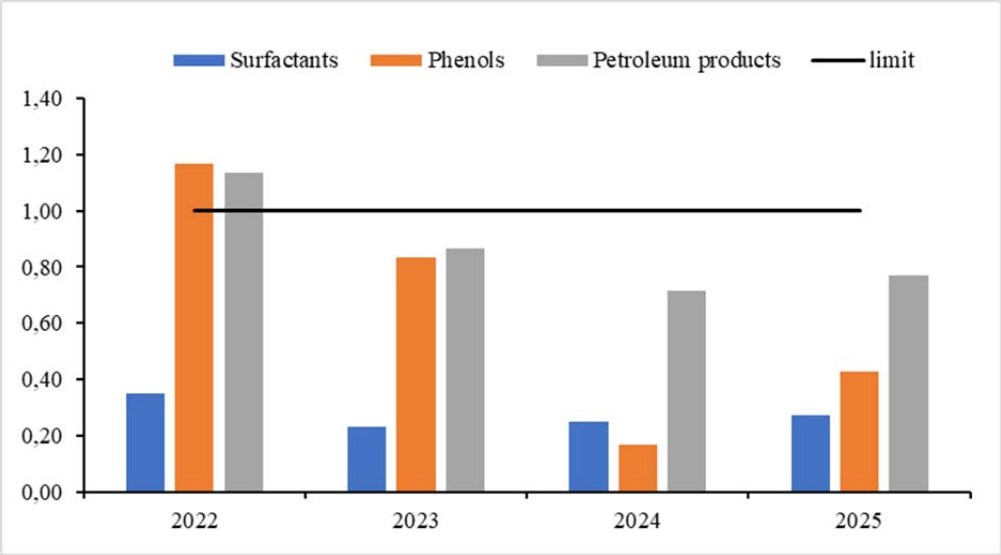


Figure 7 – Multiples of exceedance of the maximum permissible concentrations (MPCs) of specific pollutants at the transboundary monitoring station on the Shu River

Among the substances under consideration, petroleum products make the greatest contribution to pollution. Their average annual discharge amounted to 6.87 tonnes in 2022 and fell to 5.49 tonnes in 2023, whilst the total discharge volume was 82.47 and 65.92 tonnes respectively. Surfactant discharge is also characterised by relatively high values, with average figures of 4.46 tonnes in 2022 and 2.70 tonnes in 2023, and total discharge of 53.48 tonnes and 32.37 tonnes respectively.

Phenols make the smallest contribution to the total pollutant discharge, with average annual values of 0.15 tonnes in 2022 and 0.14 tonnes in 2023, and total volumes of 1.77 tonnes and 1.25 tonnes respectively.

Overall, in 2023, for all indicators under consideration, there is a decrease in both average and total discharge values compared with 2022, which may be due to a reduction in pollutant inflow or a change in hydrological conditions. The composition of the effluent is characterised by a predominance of petroleum products, a significant contribution from surfactants and a minimal role played by phenols.

Therefore, despite the limited number of observations, the data obtained indicate the presence of a sustained anthropogenic impact on the water body, which requires further monitoring and clarification of the identified trends.

Discussion. The mineralisation data show considerable differences between the studied water bodies of the Shu-Talas River Basin. The highest values were recorded in Lake Bilikol and the Karabalta River, whereas the lowest value was observed in the Berkara River. Such differences may be associated with natural hydrogeochemical conditions, flow rate reduction, evaporation intensity and anthropogenic loading.

The classification results also show that mineralisation alone cannot fully characterise the quality of water bodies. The quantities of anion and cation groups, as well as the dominant ions, should also be considered when assessing the hydrochemical state of the basin. The differences in total hardness and water type observed among the monitoring sites reflect the spatial variability of the hydrochemical conditions. The majority of the studied water bodies were freshwater, while Lake Bilikol and the Karabalta River were characterised as brackish. The very high hardness observed in Lake Bilikol, the Karabalta River and the Toktash River also corresponds to differences in their ionic composition.

According to the Alekin classification, the predominance of the bicarbonate class, particularly the first calcium group, is characteristic of most of the studied sites. At the same time, the sulphate character of Lake Bilikol, the Karabalta River and the Toktash River indicates differences in the formation of their chemical composition.

The Stiff diagrams clearly illustrate spatial variations in the ionic composition of the water and the characteristics of the hydrochemical type. Although a sulphate-bicarbonate composition is also maintained at the Tasotkel Reservoir and Shu River points, differences in mineralisation and ionic ratios are observed

between these water bodies. The most markedly expanded diagrams are observed for Lake Bilikol, the Aksu River and the Karabalta River. These sites have higher concentrations of major ions, particularly SO_4^{2-} and HCO_3^-. Such features may be related to natural geochemical factors, evaporation processes, water exchange conditions and potential anthropogenic impacts.

The relatively high SO_4^{2-}/Ca^{2+} ratio could indicate a possible contribution of anthropogenic sources to the hydrogeochemical characteristics of the surface waters in the study area; however, source attribution requires additional hydrochemical, isotopic, and spatial analyses [20, 21].

Overall, the Stiff diagrams show that the hydrochemical composition of the studied water bodies is not uniform. The majority of the basin's waters are close to the sulphate-bicarbonate calcium-magnesium type, while at some sampling points a relative increase in sodium and potassium ions and sulphates is observed. This suggests that the formation of water quality in the Shu-Talas basin is influenced not only by natural lithological conditions but also by local hydrological and anthropogenic factors.

The long-term data for the transboundary section of the Shu River show a clear decrease in copper concentrations compared with the beginning of the observation period. The maximum exceedance, recorded during 2002-2008, reached 8.39 times the MPC. Although the concentrations subsequently decreased, the values of 1.7-2.7 times the MPC observed in recent years still indicate an exceedance of the established standards.

Copper therefore remains the most significant heavy-metal pollutant at the studied transboundary section. Zinc generally remained within permissible limits, while Pb, Ni, Co and Cd had a smaller contribution to the observed pollution because their concentrations remained below the MPC in most cases. The heavy-metal discharge data also show considerable interannual variability. The decrease in copper discharge from 2.16 tonnes in 2002 to 0.15-0.50 tonnes in subsequent years corresponds to the decrease in its concentrations. Zinc showed a less stable pattern, with discharge varying from 0.57 to 1.60 tonnes and occasional increases. The increase in lead discharge during 2020–2022, followed by a decrease in 2023, indicates that individual pollutants may show different temporal patterns within the same transboundary section. The low and irregular discharge values of nickel, cobalt and cadmium indicate their minor role in the total anthropogenic flux. At the transboundary section of the Talas River, zinc, lead and copper were the main contributors to the heavy-metal discharge. The relatively low overall load, together with significant interannual variability, suggests that changes in hydrological conditions and anthropogenic pressure should be considered when interpreting the observed patterns. The assessment of organic pollutants is limited by the relatively short observation period, since monitoring of surfactants, phenols and petroleum products at the transboundary section of the Shu River began only in 2022. Therefore, the available data do not allow a comprehensive multi-year analysis.

The exceedance of the MPC for petroleum products in 2022 indicates a local anthropogenic impact. Among the analysed substances, petroleum products made the greatest contribution to the pollutant discharge, followed by surfactants, while phenols had the smallest contribution.

The decrease in petroleum product discharge from 2022 to 2023, together with the decrease in surfactant and phenol discharge, may be associated with a reduction in pollutant inflow or a change in hydrological conditions. At the same time, the available two-year period is insufficient to establish a stable long-term trend.

Overall, the data indicate the presence of an anthropogenic influence on the transboundary section of the Shu River. The identified differences in pollutant concentrations and discharge, together with the limited observation period for organic substances, support the need for continued monitoring and further clarification of the observed trends.

Conclusion. As a result of the study, a comprehensive assessment of the long-term hydrochemical conditions of the surface waters of the Shu-Talas River Basin was carried out for the period 2002-2025. The average mineralisation across the basin was 674 mg/L, with the majority of the studied water bodies classified as freshwater. Most monitoring sites were characterised by a bicarbonate, predominantly calcium-dominated hydrochemical composition, whereas sulphate character was identified for Lake Bilikol and the Karabalta and Toktash rivers. The highest mineralisation and hardness were observed at Lake Bilikol, the Karabalta River and the Toktash River, indicating pronounced spatial differences in the hydrochemical conditions of the basin.

The assessment of heavy metals showed that copper was the main pollutant at the transboundary section of the Shu River. During 2002–2008, the maximum copper concentration reached 8.39 times the

maximum permissible concentration (MPC). Although copper concentrations subsequently decreased, they remained at 1.7–2.7 MPC in recent years, indicating that copper pollution has not been completely eliminated. In parallel, copper discharge decreased from 2.16 tonnes in 2002 to 0.15–0.50 tonnes in subsequent years. Zinc generally remained within permissible limits, while lead, nickel, cobalt and cadmium remained below the MPC in most monitoring periods. At the Talas River transboundary section, zinc, lead and copper were the main contributors to the heavy-metal discharge, although their contributions varied substantially between years.

The long-term assessment therefore demonstrates a substantial reduction in copper pollution compared with the beginning of the observation period, but the persistence of concentrations above the MPC indicates the need for continued control and monitoring. The observed interannual variability in heavy-metal discharge also indicates that hydrological conditions and changes in anthropogenic pressure should be considered when interpreting long-term pollution dynamics.

The assessment of organic pollutants was limited to 2022–2023, which does not provide a sufficient period for establishing a reliable long-term trend. Nevertheless, pollutant discharge decreased from 2022 to 2023 for petroleum products, surfactants and phenols. Petroleum products made the largest contribution to the discharge, whereas phenols contributed the smallest proportion. The exceedance of the MPC for petroleum products in 2022 confirms the presence of a local anthropogenic impact.

Overall, the results demonstrate pronounced spatial and temporal variability in the hydrochemical and pollution characteristics of the Shu-Talas River Basin. Particular attention should be given to Lake Bilikol and the Karabalta and Toktash rivers, where elevated mineralisation, hardness and sulphate content were identified, as well as to the transboundary sections affected by heavy-metal pollution. Continued monitoring should focus particularly on copper concentrations, seasonal and interannual changes in heavy-metal discharge, and the development of a longer observation series for organic pollutants. The obtained results provide a scientific basis for long-term assessment of water quality in the Shu-Talas transboundary basin, identification of potential pollution sources, and improvement of coordinated water-resource management and monitoring.

Funding. The work is funded by the Scientific and Technical Programme of the Science Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan, under targeted programme financing, contract number BR287006/0225 "Water Security of the Republic of Kazakhstan: Transboundary Shu-Talas Basin under Climate Change and Anthropogenic Activities in the Period up to 2050‘programme, under Sub-programme No. 3 ’River Water Quality in the Transboundary Shu-Talas Basin" project.

REFERENCES

[1] Tong X., Zhang X., Xiao S., Chen J., Zhou C., Zhou J., Zhou X., Zhang Y. (2026). A machine learning-assisted integrated framework for linking water quality and phytoplankton carbon fixation potential in drinking water reservoirs // Water Research, 302, 126104.

[2] Akhtar N., Syakir Ishak M. I., Bhawani S. A., Umar K. (2021). Various Natural and Anthropogenic Factors Responsible for Water Quality Degradation: A Review // Water, 13(19), 2660.

[3] Cai J., Zhao D., Varis O. (2021). Match words with deeds: Curbing water risk with the Sustainable Development Goal 6 index // Journal of Cleaner Production, 318, 128509.

[4] UN-Water et al. (2018). Sustainable Development Goal 6 synthesis report on water and sanitation. New York: United Nations, 10017.

[5] United Nations Development Programme. (2018). Promoting Transboundary Cooperation and Integrated Water Resources Management in the Chu and Talas River Basins [Electronic resource]. URL: https://www.undp.org/ru/kyrgyzstan/projects/sodeystvie-transgranichnomu-sotrudnichestvu-i-integrirovannomu-upravleniyu-vodnymi-resursami-v-basseynakh-rek-chu-i-talas (accessed: 25.08.2026).

[6] Regulations on the Republican State Institution “Shu-Talas Basin Water Inspectorate for the Regulation, Protection and Use of Water Resources of the Committee for Regulation, Protection and Use of Water Resources of the Ministry of Water Resources and Irrigation of the Republic of Kazakhstan” [Electronic resource]. URL: https://cawater-info.net/water_world/pdf/shu-talas-kz.pdf (accessed: 25.08.2026).

[7] Dostai Zh. D., Kulebaev K. M., Kamaliev A. M. (2018). Hydrological Monitoring on the Rivers of the Shu–Talas Basin and Its Development // Hydrometeorology and Ecology, 1, 84-91 (in Russ.).

[8] Alimkulov S. K., Tursunova A. A., Saparova A. A., Zagidullina A. R. (2016). Water Resources of River Runoff in the Southern Regions of Kazakhstan: Retrospective State and Distribution Patterns // Issues of Geography and Geoecology, 3, 26-35 (in Russ.).

[9] Adenova D., Murtazin E., Miroshnichenko O., Sotnikov E., Tazhiev S. (2025). Application of Digital Technologies in Monitoring Transboundary Aquifers of the Shu-Talas Basin // Izdenister, Natigeler – Research, Results, 3(107), 442-454 (in Russ.).

[10] Kaipbaev E., Aldiyarova A., Kalmashova A., Tursynaly D., Muhanbet E. (2024). Methodological Approach to the Formation of a Research Database for Assessing River Basin Activities // Izdenister Natigeler, 3(103), 340-348 (in Russ.).

[11] Alimkulov S. K., Tursunova A. A., Davletgaliev S. K., Saparova A. A. (2018). River Runoff Resources of Kazakhstan // Hydrometeorology and Ecology, 3, 80-94 (in Russ.).

[12] Narbaeva K., Tairov A., Ismailova G., Narbaev M., Muhanbet E. (2025). Assessment of Water Resources of the Shu-Talas Water Management Basin // Hydrometeorology and Ecology, 2, 8-17 (in Kaz.).

[13] Shu-Talasskaya basseynovaya inspektsiya po regulirovaniyu ispol'zovaniya i okhrany vodnykh resursov. (2017). Otchet o deyatel'nosti za 2016 g. Taraz, 151 p. (in Russ.).

[14] Bazhieva A. M. (2023). Sovremennoe sostoyanie kachestva poverkhnostnykh vod reki Shu // Gidrometeorologiya i ekologiya, 1, 75-79 (in Russ.).

[15] Romanova S. M., Serikova A. S., Makhmutova R. E., Krupa E. G. (2025). Izmenenie ionno-solevogo sostava vody reki Shu (kazakhstanskaya chast') v mnogoletnem tsikle // Eurasian Journal of Ecology, 84(3), 4-16 (in Russ.).

[16] Alekin O. A. (1970). Fundamentals of Hydrochemistry. S. V. Bruevich (Ed.). Leningrad: Hydrometeorological Publishing House, 443 p. (in Russ.).

[17] Unified System of Water Quality Classification in Water Bodies, approved by Order No. 70 of the Chairman of the Committee for Water Management of the Ministry of Water Resources and Irrigation of the Republic of Kazakhstan dated 20 March 2024 [Electronic resource]. URL: https://adilet.zan.kz/rus/docs/V1600014513 (accessed: 01.04.2024) (in Russ.).

[18] Burlibayev M. Zh. et al. (2007). Comprehensive Assessment of Surface Water Quality Based on Hydrochemical Parameters. Almaty: Gylym Publishing House, 96 p. (in Russ.).

[19] Mussakulkyzy A., Opp C., Amirgaliev N., Madibekov A., Ismukhanova L., Zhadi A. (2025). Assessment of Anthropogenic Load on the Ile River Ecosystem Considering Regional Peculiarities // Applied Sciences, 15, 8979.

[20] Liu J. T., Lou K. X., Gao Z. J., Wang Y. B., Li Q., Tan M. H. (2024). Comprehending hydrochemical fingerprint, spatial patterns, and driving forces of groundwater in a topical coastal plain of Northern China based on hydrochemical and isotopic evaluations // Journal of Cleaner Production, 461, 142640.

[21] Luo M., Meng Y., Wang X., Xu Y., Wang B., Liu W., Li Z., Zhou K., Zhang L., Tan M., Lou K. (2026). Chemical Characteristics and Suitability Assessment of Surface Water in the Area Surrounding the Nansi Lake // Water, 18(9), 1032.

А. Ә. Сұлтанаева*[1], А. С. Мадибеков[2], А. Мұсақұлқызы[3],
Л. Т. Исмуханова[4], Н. Б. Алекеева[5], А. Ө. Жәди[6]

[1] *Кіші ғылыми қызметкер («География және су қауіпсіздігі» АҚ,
Әл-Фараби атындағы Қазақ ұлттық университеті, Алматы, Қазақстан; ***arai1104@mail.ru***)
[2] PhD, қауымдастырылған профессор, бас ғылыми қызметкер («География және су қауіпсіздігі» АҚ,
Алматы, Қазақстан; a.*s.madibekov@gmail.com*)
[3] Г. ғ. к., аға ғылыми қызметкер («География және су қауіпсіздігі» АҚ, Алматы, Қазақстан; *mus_ain@mail.ru*)
[4] PhD, аға ғылыми қызметкер («География және су қауіпсіздігі» АҚ,
Әл-Фараби атындағы Қазақ ұлттық университеті, Алматы, Қазақстан; *l--aura@bk.ru*)
[5] Ғылыми қызметкер («География және су қауіпсіздігі» АҚ, Алматы, Қазақстан; *nazym.alekeeva@bk.ru*)
[6] Ғылыми қызметкер («География және су қауіпсіздігі» АҚ, Алматы, Қазақстан; *askhat.zhadi@mail.ru*)

ТАБИҒИ-АНТРОПОГЕНДІК ФАКТОРЛАР ӘСЕРІНДЕГІ ШУ–ТАЛАС ӨЗЕНДЕР АЛАБЫНЫҢ ГИДРОХИМИЯСЫ

Аннотация. Зерттеу жұмысы Шу–Талас өзен алабы жерүсті суларының гидрохимиялық жағдайын бағалау, олардың негізгі химиялық құрамының кеңістіктік ерекшеліктерін анықтау және судың ластану деңгейін кешенді бағалауды қамтиды. Зерттеу барысында «Қазгидромет» РМК-ның 2002–2025 жылдар аралығындағы гидрохимиялық бақылау деректері бойынша су сапасын бағалау мақсатында минерализация, pH, суда еріген оттегі, жалпы кермектілік, негізгі катиондар мен аниондардың құрамы қарастырылып, табиғи сулар Алекин классификациясы бойынша жіктелді. Негізгі иондардың арақатынасы Стифф диаграммалары арқылы талданды, ал антропогендік әсер деңгейін бағалау үшін судың ластануының кешенді индексі (СЛКИ) есептелді. Зерттеу нәтижелері бойынша алап суларының орташа минерализациясы 674 мг/дм^3 құрады. Ауыр металдар арасында су сапасына негізгі әсер етуші ластаушы элемент мыс болып, оның концентрациясы жекелеген кезеңдерде нормативтік мәндерден жоғары болды. Сонымен қатар, көпжылдық динамика ауыр металдар концентрациясының, әсіресе мыстың, төмендеу үрдісін көрсетті. 2023 жылы органикалық ластаушылардың шығарынды көлемдері 2022 жылмен салыстырғанда төмендегенімен, олардың құрамында мұнай өнімдері басым болды. Зерттеу нәтижелері Шу-Талас трансшекаралық бассейнінің су сапасын ұзақ мерзімді бағалау, ластану көздерін анықтау және су ресурстарын тиімді басқару мен бірлескен мониторинг жүйесін жетілдіру үшін ғылыми негіз бола алады.

Түйін сөздер: трансшекаралық өзендер, гидрохимия, ауыр металдар, судың ластануының кешенді индексі.

А. Ә. Сұлтанаева*[1], А. С. Мадибеков[2], А. Мұсақұлқызы[3],
Л. Т. Исмуханова[4], Н. Б. Алекеева [5], А. Ө. Жәди [6]

[1] *Младший научный сотрудник (АО «Институт географии и водной безопасности»,
Казахский национальный университет им. аль-Фараби, Алматы, Казахстан; ***arai1104@mail.ru***)
[2] PhD, ассоциированный профессор, главный научный сотрудник
(АО «Институт географии и водной безопасности», Алматы, Казахстан; *a.s.madibekov@gmail.com*)
[3] К.г.н., старший научный сотрудник (АО «Институт географии и водной безопасности»,
Алматы, Казахстан; *mus_ain@mail.ru*)
[4] PhD, старший научный сотрудник (АО «Институт географии и водной безопасности»,
Казахский национальный университет им. аль-Фараби, Алматы, Казахстан; *l--aura@bk.ru*)
[5] Научный сотрудник (АО «Институт географии и водной безопасности»,
Алматы, Казахстан; *nazym.alekeeva@bk.ru*)
[6] Научный сотрудник (АО «Институт географии и водной безопасности»,
Алматы, Казахстан; *askhat.zhadi@mail.ru*)

ГИДРОХИМИЯ БАССЕЙНА РЕК ШУ–ТАЛАС ПОД ВОЗДЕЙСТВИЕМ ПРИРОДНЫХ И АНТРОПОГЕННЫХ ФАКТОРОВ

Аннотация. Исследование включает оценку гидрохимического состояния поверхностных вод Шу-Таласского речного бассейна, выявление пространственных особенностей их основного химического состава и комплексную оценку уровня загрязнения воды. На основе данных гидрохимических наблюдений РГП «Казгидромет» за 2002–2025 гг. для оценки качества воды рассмотрены минерализация, pH, растворенный в воде кислород, общая жесткость, содержание основных катионов и анионов, а природные воды классифицированы по классификации Алекина. Соотношение основных ионов проанализировано с использованием диаграмм Стиффа, а для оценки уровня антропогенного воздействия рассчитан комплексный индекс загрязнения воды (КИЗВ). По результатам исследования средняя минерализация вод бассейна составила 674 мг/дм^3. Среди тяжелых металлов основным загрязняющим элементом, оказывающим влияние на качество воды, являлась медь, концентрация которой в отдельные периоды превышала нормативные значения. Вместе с тем многолетняя динамика показала тенденцию к снижению концентраций тяжелых металлов, особенно меди. В 2023 г. объемы выбросов органических загрязняющих веществ снизились по сравнению с 2022 г., однако в их составе преобладали нефтепродукты. Полученные результаты могут служить научной основой для долгосрочной оценки качества воды трансграничного Шу-Таласского бассейна, выявления источников загрязнения, а также совершенствования эффективного управления водными ресурсами и системы совместного мониторинга.

Ключевые слова: трансграничные реки, гидрохимия, тяжелые металлы, комплексный индекс загрязнения воды.