IRSTI 61.29.01, 87.51.14 **https://doi.org/10.58805/kazutb.v.3.28-1178**

THE HYDROCHEMICAL REGIME AND CURRENT WATER QUALITY OF THE URAL RIVER: IN THE CONTEXT OF RURAL DRINKING WATER SUPPLY

[1]Ye. Kabiyev✉, [2]R. Berndtsson, [3]K. Tussupova

[1]Atyrau University Named After Kh. Dosmukhamedov, Atyrau, Kazakhstan,
[2]Lund University, Lund, Sweden,
[3]Kazakh National University of Water Management and Irrigation, Taraz, Kazakhstan
✉*Correspondent-author: yerlanustaz@gmail.com*

The Ural River is the main source of water supply for Atyrau Region, providing drinking water not only to the city of Atyrau but also to settlements in the Inder, Makhambet, and Makat districts. Therefore, its quality and hydrological regime are of strategic importance. In achieving SDG targets 6.1 and 6.2, related to access to safe drinking water and sanitation in Kazakhstan's rural areas, the hydrochemical regime of the Ural River and the influence of the hydrochemical water regime of the North-Eastern Caspian Sea play a crucial role.

This article presents hydro-physical and hydrochemical indicators obtained during field geo-ecological studies. Based on the chemical analysis of water samples from key sites, the current state and hydrochemical regime of surface waters are described.

Keywords: Ural River, hydrochemical regime, water quality, rural drinking water supply, SDG 6.1, SDG 6.2, safe drinking water access, sanitation, geo-ecological monitoring, hydro-physical indicators, nutrient concentrations.

ЖАЙЫҚ ӨЗЕНІНІҢ ГИДРОХИМИЯЛЫҚ РЕЖИМІ МЕН СУ САПАСЫНЫҢ ҚАЗІРГІ ЖАҒДАЙЫ: АУЫЛДЫҚ АУМАҚТАРДЫ АУЫЗ СУМЕН ҚАМТАМАСЫЗ ЕТУ ТҰРҒЫСЫНАН

[1]Е. Кабиев✉, [2]Р. Берндтссон, [3]К. Тұсупова

[1]Х. Досмұхамедов атындағы Атырау университеті, Атырау, Қазақстан,
[2]Лунд университеті, Лунд, Швеция,
[3]Қазақ ұлттық су шаруашылығы және ирригация университеті, Тараз, Қазақстан,
e-mail: yerlanustaz@gmail.com

Жайық өзені Атырау облысының негізгі су көзі ретінде Атырау қаласымен қоса Индер, Махамбет, Мақат аудандарының елді-мекендерінің халқын ауыз сумен қамтамасыз етеді, сондықтан оның сапасы мен гидрологиялық режимі стратегиялық маңызға ие. Қазақстанның ауылдық аймақтарында қауіпсіз ауыз суға және санитарияға қол жеткізу жолында ТДМ 6.1 және 6.2 мақсаттарына жетуде Жайық өзененің және өзеннің гидрохимиялық режиміне әсер етуші Солтүстік-Шығыс Каспий теңізінің гидрохимиялық су режимі ұлкен маңызға ие.

Бұл мақалада далалық геоэкологиялық зерттеулер жүргізу кезінде алынған гидрофизикалық және гидрохимиялық көрсеткіштер көрсетілген. Негізгі телімдерден сынамаларды химиялық талдау нәтижелері бойынша зерттеу жасалып, беттік сулардың қазіргі жағдайы және гидрохимиялық режимі сипатталған.

Түйін сөздер: Жайық өзені, гидрохимиялық режим, су сапасы, ауылдық аумақтарды ауыз сумен қамтамасыз ету, ТДМ 6.1, ТДМ 6.2, қауіпсіз ауыз суға қолжетімділік, санитария, геоэкологиялық мониторинг, гидрофизикалық көрсеткіштер, қоректік заттар концентрациясы.

ГИДРОХИМИЧЕСКИЙ РЕЖИМ И ТЕКУЩЕЕ СОСТОЯНИЕ КАЧЕСТВА ВОДЫ УРАЛА: В КОНТЕКСТЕ ОБЕСПЕЧЕНИЯ СЕЛЬСКИХ ТЕРРИТОРИЙ ПИТЬЕВОЙ ВОДОЙ

[1]Е. Кабиев✉, [2]Ронни Берндтссон, [3]Камшат Тусупова

[1]*Атырауский университет имени Х. Досмухамедова, Атырау, Казахстан,*
[2]*Лундский университет, Лунд, Швеция,*
[3]*Казахский национальный университет водного хозяйства и ирригации, Тараз, Казахстан,*
e-mail: yerlanustaz@gmail.com

Река Урал, являясь основным источником водоснабжения Атырауской области, обеспечивает питьевой водой население не только города Атырау, но и сельских населённых пунктов Индерского, Махамбетского и Макатского районов. Поэтому её качество и гидрологический режим имеют стратегическое значение. В контексте достижения целей устойчивого развития (ЦУР) 6.1 и 6.2, связанных с обеспечением доступа к безопасной питьевой воде и санитарии в сельских регионах Казахстана, особое значение приобретает гидрохимический режим реки Урал, а также влияние гидрохимического режима Северо-Восточной части Каспийского моря на реку.

В статье представлены гидрофизические и гидрохимические показатели, полученные в ходе полевых геоэкологических исследований. На основе результатов химического анализа проб, отобранных на основных участках, дана характеристика современного состояния поверхностных вод и гидрохимического режима реки.

Ключевые слова: река Урал, гидрохимический режим, качество воды, обеспечение сельских территорий питьевой водой, ЦУР 6.1, ЦУР 6.2, доступ к безопасной питьевой воде, санитария, геоэкологический мониторинг, гидрофизические показатели, концентрация питательных веществ.

Introduction. The hydrochemical regime of the Ural River delta is shaped by interactions with adjacent parts of the North-Eastern Caspian Sea, river discharge, exchange processes between water and bottom sediments, as well as meteorological conditions. During spring and autumn, southerly marine airflows transport polluted air masses to the northern part of the region, where toxic ingredients from the decomposition of atmospheric emissions participate in the overall “mass–energy” exchange of surface waters.

In recent years, the discharge of drainage waters has led to a sharp ecological concern, especially in autumn, with increased concentrations of pesticide and nitrate–nitrite compounds. These and other negative transformations in the geosystem are strongly expressed along the river flow from north to south. The annual runoff layer in the southern part of the region varies from 50 mm to 2 mm, while precipitation decreases from 350 mm to 200 mm in the same direction. Such aridization processes intensify the ecological instability of geosystems.

For this reason, background geo-ecological surveys were conducted in the Atyrau area during summer field expeditions between 2022 and 2024. As a result, hydro-physical and hydrochemical indicators were obtained, and the current state of water quality was comprehensively assessed. Surface water samples were collected at 10 monitoring points and analyzed with the assistance of the Ecosphere organization.

The eastern part of Atyrau represents a semi-enclosed water body, and its hydrological regime largely depends on the Ural River’s discharge. Under arid climatic conditions, water exchange in this area occurs mainly with the western part of the North Caspian. In terms of hydrochemistry, the surface waters of the delta differ from the general regime of the main water body: they are characterized by instability, strong seasonal fluctuations, and a high dependence on soil chemical properties [1].

Furthermore, along with freshwater inflows (snowmelt, the Ural River discharge and its branches), a significant portion of organic matter is transported into the North Caspian. Their concentration reaches maximum levels in the Ural delta. This phenomenon is of particular importance for the highly productive coastal part of the North Caspian, as the river’s discharge forms the ecological and biological raw material base of the marine water body.

Materials and methods. The research was carried out in the main channel of the Ural River,

the Primorsk Canal, and marine monitoring sites.

- Temperature was measured directly at the sampling Temperature was measured directly at the sampling sites using the thermometric method. The range was 12.2-19.1ºC, with an average of 15.65ºC.

- pH was determined using a portable pH meter. Values ranged from 6.20 to 8.80. During the flood period, pH dropped to 6.20-8.20, while the highest values (8.40–8.80) were recorded during the low-flow period.

- Turbidity was measured photometrically in NTU units. Results ranged between 12.0 and 82.3 NTU. The lowest values were recorded at marine sites (12.0-20.2 NTU), while the highest were observed in the Ural River and Primorsk Canal (33.4-58.9 NTU).

- Redox potential (Eh, mV) was measured with platinum electrodes and standard reference electrodes. Values ranged from 34 mV to 280 mV, with an average of 157 mV.

- Mineralization and nutrient concentrations (nitrogen, phosphorus compounds) were determined by photometric and titrimetric methods [2].

Results and Discussion. Nitrogen compounds.

Nitrate nitrogen (NO_3) varied within the range of 0.053 - 0.298 mg/L.

Nitrite nitrogen (NO_2) was recorded at levels of 0.006 - 0.020 mg/L.

Ammonium nitrogen (NH_4) was assessed as an indicator of organic pollution.

Phosphorus compounds were determined in accordance with seasonal changes: concentrations increased during the winter period, while decreasing in summer due to phytoplankton activity. The mineralization of water is known to be closely associated with river discharge [3].

All analyses were performed in accordance with national standards and international methodologies. Samples were processed under laboratory conditions in compliance with preservation requirements.

Dissolved oxygen.

During the spring period, dissolved oxygen ranged from 5.85 to 14.38 mg/L, with an average of 10.1 mg/L. These levels create favorable conditions for the survival of fish and other hydrobionts.

Hydrogen sulfide (H_2S).

Concentrations varied between 0.001 and 0.004 mg/dm³. Exceedances of the Maximum Permissible Concentration (MPC) were observed only in the estuarine section of the river, which is explained by the decomposition of organic matter.

Surface-active substances (SAS).

SAS concentrations ranged from 0.005 to 0.01 mg/dm³, with an average of 0.0075 mg/dm³. No exceedances of MPC were detected. The oil production sector was identified as the main source of SAS.

Organic pollution.

Indicators characterizing water quality included:

- Biochemical Oxygen Demand (BOD_5) - 0.282-0.313 mg/dm³.

- Chemical Oxygen Demand (COD) - 0.852 - 0.948 mg/dm³.

These values indicate that the waters are relatively clean.

Heavy metals.

The concentrations of heavy metals in water samples were recorded within the following ranges:

- Lead (Pb) - 0.02 - 0.070 mg/dm³;

- Zinc (Zn) - 0.001 - 0.154 mg/dm³;

- Iron (Fe) - 0.425 - 7.186 mg/dm³;

- Cadmium (Cd) - below 0.001 mg/dm³;

- Aluminum (Al) - 0.5 - 6.12 mg/dm³.

Elevated levels of iron and aluminum were registered at certain sites.

The increase in lead (Pb) concentrations observed in samples from points 5, 6, 7, and 10 is associated with hydrocarbon extraction activities. Near point 5, a large oil and gas field is located, and the twofold exceedance of the Maximum Permissible Concentration (MPC) for lead is linked to the flaring of associated petroleum gas. At points 6 and 7, the exceedance of MPC is related to hydrocarbon

transportation. Atyrau city, with a population of more than 300,000, represents an urbanized area where, according to [4], each household owns at least one vehicle. Sampling site 7 is located directly in a channel used for waterborne transport, and the exceedance of lead concentrations is directly attributed to these vessels.

Additionally, at points 1, 2, 4, and 5, exceedances of the MPC (1.0 mg/dm³) for iron (Fe) were recorded (Figure 2).

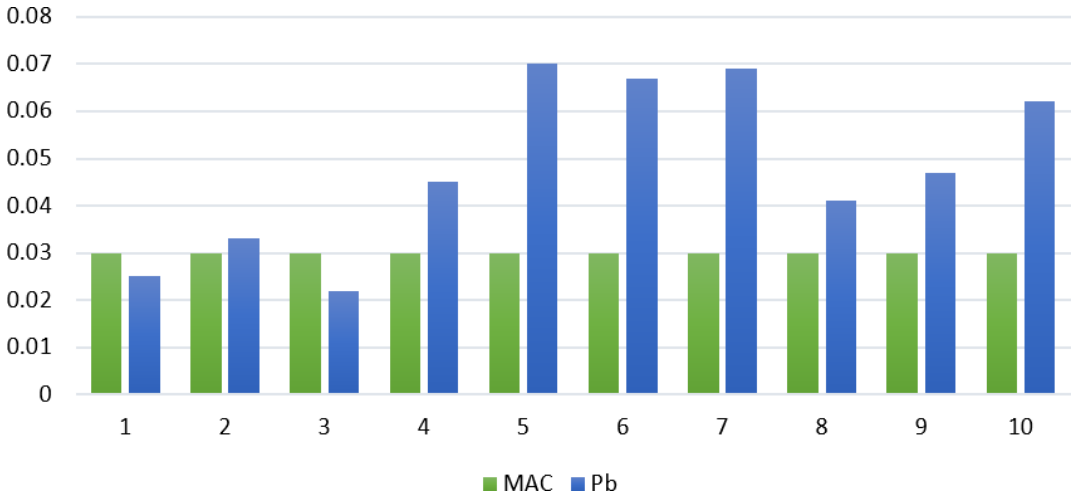


Fig.1 - Lead (Pb) concentrations by sampling points

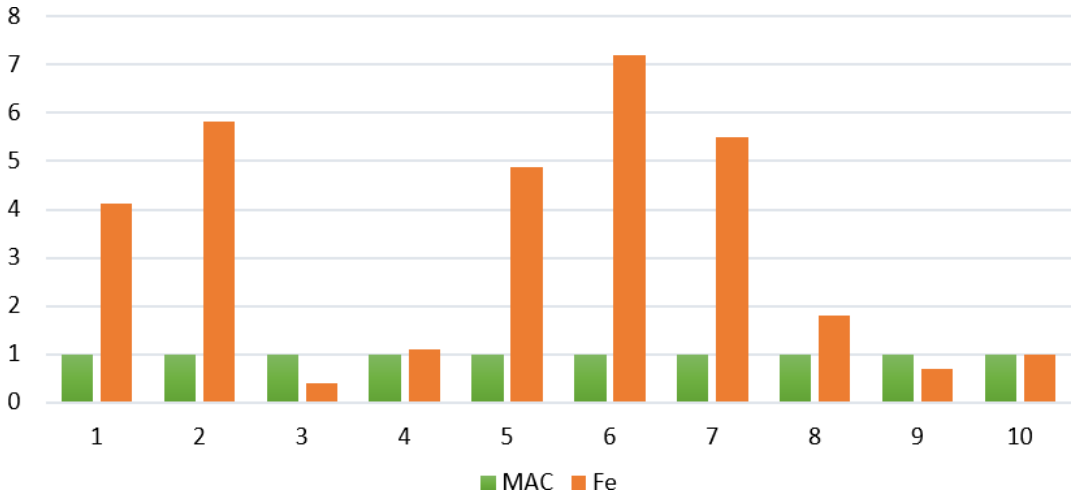


Fig.2 - Iron (Fe) concentrations by sampling points

Wastewaters associated with metallurgical, metal-processing, and paint-and-varnish industries contribute to the observed concentrations. The levels of iron in rivers and lakes depend on the chemical composition of the solution, pH, and to some extent on temperature. The content of suspended forms of iron compounds exceeds 0.45 μg, and these particles primarily consist of mixtures of iron compounds, hydrated iron oxides, and other iron-bearing minerals.

Smaller particles, i.e., colloidal forms of iron, are considered together with dissolved iron compounds. In dissolved form, iron occurs as ions and hydroxo-complexes. In rivers and lakes, the concentration of iron fluctuates at the level of n*0.1 mg/L, but it may rise to several mg/L near marshlands. Iron is an

essential micronutrient linked to various biological processes. It stimulates the intensive development of phytoplankton and influences the quality of microflora in aquatic ecosystems. However, water containing high levels of iron (>1-2 mg/L) is characterized by an unpleasant astringent taste and is unsuitable for industrial purposes. The MPC for iron in water bodies is 0.3 mg/L, while in fishery ponds the fishery-specific MPC is 0.1 mg/L.

In water samples from sites 1 and 2, the exceedance of iron concentrations is associated with “inputs” carried by upstream flows and may be linked to the main industrial activities in the region, such as the production of metal structures and technological equipment (Caspian Contractors Trust Atyrau) in connection with the chemical plant in the southern industrial zone 2 settlement. In addition, a concrete plant is located in this area. Wastewaters from these enterprises may discharge into the Ural River and the Baksy Canal channel [5].

At site 5, the exceedance of the MPC for iron is associated with the location of Kaiman LLP in the village of Akkystau.

In water samples from site 6, an eightfold exceedance of the MPC for iron was recorded, which is linked to the presence of large industrial enterprises in Atyrau city, such as BVB-Alliance Atyrau LLP (Zharbosynov 89) and Rauan Nalco LLP (North Industrial Zone 14). The main activities of these enterprises include ferrous and non-ferrous metallurgy, rolled metal production, and the manufacture of chemical reagents for the oil and gas industry.

At sampling points 5, 6, and 7, exceedances of the MPC for aluminum (Al) (0.5 mg/dm³) were also observed. For other elements, no MPC exceedances were recorded (Figure 3).

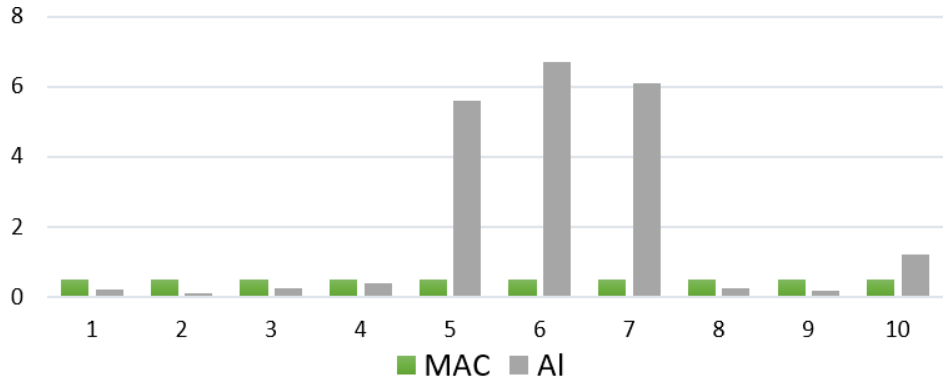


Fig.3 - Aluminum (Al) concentrations by sampling points

Aluminum enters natural waters through natural processes such as the partial dissolution of aluminosilicates and clays, as well as through anthropogenic pathways, including discharges from various industries (aviation, electrical, oil refining, chemical industry, construction, engineering, optics, nuclear and rocket technologies), municipal wastewater, and atmospheric precipitation [6].

Elevated aluminum levels recorded at sampling points 5, 6, and 7 are associated with industrial enterprises, hydrocarbon extraction in settlements (Akkystau village, Atyrau city), and the discharge of sewage into the river system. Aluminum concentrations in water sources typically range between 2.5 and 121 µg/dm³. In surface waters, aluminum levels may vary from a few µg/dm³ to several hundred µg/dm³, depending largely on the degree of soil acidification. According to the analysis results, no cadmium (Cd) pollution was detected in the main sampling sites. The overall concentrations did not exceed the MPC (0.001 mg/L).

Total hydrocarbons.

During spring investigations, the concentrations of petroleum products in water samples ranged from 0.009 to 0.0920 mg/dm³, with an average value of

0.0754 mg/dm³ across all points. No exceedances of the MPC (0.1 mg/dm³ [7]) were observed. The distribution of petroleum hydrocarbons by sampling points is shown in Figure 4.

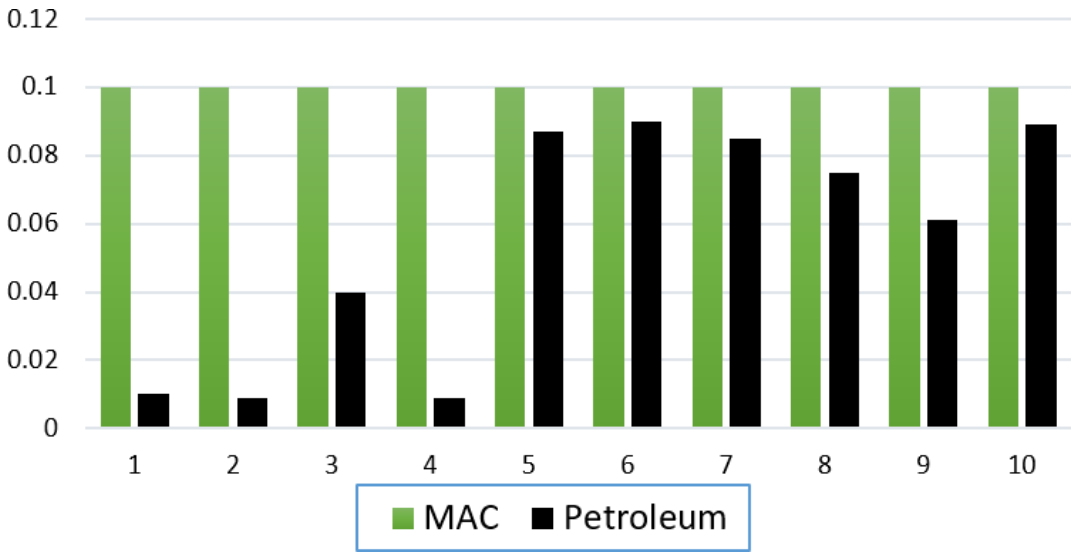


Fig.4 - Petroleum hydrocarbons at sampling points

During field expeditions, phenols were detected at concentrations ranging from below the detection limit (0.0001 mg/dm³) to 0.044811 mg/dm³. Exceedances of the MPC (0.001 mg/dm³) were registered at points 5, 6, 7, and 10. The presence of phenols at different stations is given in Appendix A.

Phenol is a toxic substance with strong irritant and caustic effects. Its maximum permissible concentration in drinking and domestic waters is 0.001 mg/L, and it is classified as a class IV hazardous substance. Phenol pollution in samples from key sites (5, 6, 7, and 10) is associated with industrial discharges from petrochemical and chemical enterprises. Once introduced into water bodies, phenol forms a fluorescent film on the surface, disrupting natural biological processes and ecosystem balance. The presence of phenol sharply slows down biological purification processes. When concentrations exceed 0.001 mg/L, water acquires an unpleasant taste and odor; at 0.01-0.1 mg/L, fish meat develops an undesirable taste and smell; and at higher concentrations, fish become unsuitable for consumption [8].

Polycyclic aromatic hydrocarbons (PAHs).

In water samples, PAH concentrations ranged from 0.00823 to 0.4090 mg/dm³. Relatively high levels were observed for naphthalene (0.0-0.0582 mg/dm³). Acenaphthylene, phenanthrene, anthracene, fluoranthene, and benzo(a)anthracene varied between 0.0 and 0.3193 mg/dm³ across sampling sites. Other analyzed PAHs were found at 0.0 mg/dm³.

Among other chemical elements, boron and fluoride were identified as persistent pollutants of the Ural River. Boron enters the river from upstream areas via the Orenburg and Elek rivers (Alga Chemical Plant) and partially from the Inder district. Fluoride was frequently recorded at concentrations exceeding MPC in the lower reaches of the Ural. Its origin remains uncertain, but it may be linked to the river's geochemical characteristics. Considering the high dispersal ability of fluoride, its source may be located even a thousand kilometers away from the river delta [9].

Hydrochemical structure of the delta (2022-2024).

As a result of field studies conducted between 2022 and 2024, the hydrochemical structure of the delta during different seasons (spring-summer-

autumn) was investigated. A monitoring scheme for key sites was developed. It was established that the waters of the Ural River delta belong to the sodium group (Type II), chloride class; by the degree of mineralization, they are classified as fresh (Ural and its branches) and saline (marine-adjacent). The mineralization of the eastern marine delta (4-4.9) is considerably higher than that of the western delta (2–3.5) [10].

In comparative terms, literature data confirm the relatively high general mineralization of the marine part of the delta and the seasonal variability of the qualitative composition of inflowing river and coastal waters. The study also revealed the composition of biogenic elements, described as the continuation of mineral nitrogen compounds, showing clear seasonal variability.

The Ural River, its branches, floodplain channels, marine delta, Shalyga Islands, and floodplain zones of both banks were examined. In total, 52 water samples were collected from 10 key sites during 2022-2024. Heavily polluted sites included areas affected by flooding and wind-driven phenomena, as well as stagnant river arms - such as Peshnov Bay, Kap-Özek, and stagnant left-bank floodplain channels [11].

These shallow areas warmed rapidly - the average air temperature was 27°C, while water temperature reached 26°C. Laboratory analyses of geo-hydrochemical data indicated that waters of the Ural River delta were polluted with petroleum products, phenols, iron, and showed pH levels exceeding MPC values by more than tenfold.

This pollution can be considered partially natural, as dissolved and undissolved pollutants (plant residues, eroded bank materials, waste, soil leachates, etc.) are carried into water bodies during spring floods. In some areas of the delta with weak currents, stagnant water and shallow depth contribute to chemical reactions in vegetation. As a result, increased COD levels above MPC were recorded in both eastern and western parts of the delta. During summer, algae and aquatic plants proliferated, leading to water discoloration. At this time, physical and chemical water properties sharply deteriorated, and stagnant water phenomena were observed [12].

Conclusion. Analysis of the research results indicates that the waters of the Ural River, its delta, and the Caspian Sea can be classified as moderately polluted, belonging to pollution class III, with the Water Pollution Index (WPI) ranging from 1 to 2. However, heavily polluted areas such as Peshnov Bay, Kap-Özek, and stagnant left-bank channels fall under pollution classes IV-V, with WPI values between 2 and 6.

The data obtained provide a baseline for assessing the ecological state of the ecosystem, the transport of pollutants into the Caspian Sea via river discharge, and the impact of oil production, processing, and transportation on regional pollution. These results should serve as a foundation for establishing a monitoring system in the marine area and the Ural River delta.

Moreover, the findings allow an assessment of the current hydrochemical regime and water quality of the Ural River in the context of rural drinking water supply. The study demonstrated that, overall, river water may be suitable for drinking purposes; however, in some areas (particularly the estuarine and stagnant branches), exceedances of regulatory limits were recorded. This highlights the need for additional treatment, filtration, and sanitary control measures to ensure safe drinking water for rural settlements.

In general, the research results provide an important scientific and practical basis for developing comprehensive measures aimed at the ecological protection of regional water resources and the supply of high-quality drinking water to rural populations.

Funding. *This research was supported by the Science Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan under scientific project AR13068528, conducted at H. Dosmukhamedov Atyrau University. The authors express their gratitude for the support provided.*

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Information about authors

Kabiyev Ye. - Associate Professor, H. Dosmukhamedov Atyrau University, Atyrau, Kazakhstan, e-mail: yerlanustaz@gmail.com;

Ronny Berndtsson - Professor, Division of Water Resources Engineering, Lund University, Sweden, e-mail: ronny.berndtsson@tvrl.lth.se;

Tussupova K. - Professor, Kazakh National University of Water Management and Irrigation, Taraz, Kazakhstan, e-mail: kamshat.tussupova@gmail.com.

Сведения об авторе

Кабиев Е.- доцент, Атырауский университет им. Х. Досмухамедова, Атырау, Казахстан, e-mail: yerlanustaz@gmail.com;

Ронни Берндтссон - профессор, Отделение инженерии водных ресурсов, Лундский университет, Лунд, Швеция; e-mail: ronny.berndtsson@tvrl.lth.se;

Тусупов К. - профессор, Казахский национальный университет водного хозяйства и ирригации, Тараз, Казахстан; e-mail: kamshat.tussupova@gmail.com.