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Article

Hydroecological Assessment of Brackish Groundwater in The Republic of Karakalpakstan

Alim O. Asamatdinov [1,2,*], Daniel D. Snow [3], Djaksimuratov Karamatdin [4], Shuhrat O. Murodov [2], Furkat I. Erkabayev [2], Rajabboy M. Madrimov [2], Mokhira B. Kurambaeva [2] and Asqar Q. Quvatov [5]

[1] Ajiniyaz Nukus State Pedagogical Institute Associate Professor of the Department of Chemistry Uzbekistan, Nukus
[2] Institute of Environmental Protection and Nature Conservation Technologies, 111104, Tashkent, Uzbekistan
[3] Nebraska Water Center, part of the Daugherty Water for Food Global Institute, and School of Natural Resources, University of Nebraska-Lincoln, Lincoln, NE 68583-0844 USA
[4] Karakalpak State University named after Berdakh, Associate Professor of the Department of Hydrogeology and Engineering Geology, Nukus, UZBEKISTAN
[5] Alfraganus university in Tashkent, Uzbekistan, 100190
* Correspondence: asamatdinov1973@gmail.com

Abstract

The Aral Sea crisis has severely impacted water resources in the Republic of Karakalpakstan, making groundwater a critical alternative source for drinking and irrigation. The growing importance of alternative water sources in the Aral Sea region is directly linked to the progressive decline in both the quantity and quality of traditional surface water resources. Over recent decades, reduced inflow from the Amu Darya River, combined with climate aridization, upstream water withdrawals, and inefficient irrigation practices, has significantly limited the availability of reliable freshwater supplies. This study presents a hydroecological assessment of brackish groundwater in the Karauzyak district based on field investigations conducted in 2025. Results showed that groundwater mineralization ranges from 2.1 to 4.8 g/L (predominantly 2.2–3.8 g/L), classifying the water as brackish to highly brackish. The dominant hydrochemical type is sodium-chloride and mixed sodium-sulfate-chloride. Most samples exhibited pH values of 7.1–8.3, moderate to high hardness (6.5–26.5 mg-eq/L), and elevated sulfate and chloride levels. Concentrations of toxic microelements (Pb, Cd, As, Hg, etc.) remained below maximum permissible limits. However, the overall salinity significantly restricts direct use for drinking water supply and limits agricultural application without treatment and proper management. Piper diagram analysis revealed distinct hydrochemical facies, reflecting the influence of natural salinization processes, irrigation seepage, and evaporative concentration under arid conditions. The findings highlight both the potential and limitations of local groundwater resources and underscore the need for desalination technologies, improved drainage, and continuous monitoring to ensure sustainable use in the Aral Sea region.

Keywords: brackish groundwater; hydroecological assessment; karauzyak district; karakalpakstan; mineralization; hydrochemical facies; aral sea region; water quality; sustainable water supply

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1. Introduction

The Aral Sea region remains the most vulnerable and disadvantaged area of Uzbekistan. The drying up of the Aral Sea, once the fourth-largest inland lake in the world but now reduced to 10% of its original size, has caused serious human, environmental, socioeconomic, and demographic problems in the affected areas [1]. Karakalpakstan occupies 37% of Uzbekistan's total territory and accounts for 5.5% of the country's population, but contributes only 2.5% to the country's GDP. The climate is naturally arid, so the local population has long relied on water from the Amu Darya Delta for agricultural irrigation and, in the past, on the Aral Sea for fishing. With the drying up of the Aral Sea and the reduction in water flow to the lower reaches of the river, the livelihoods of the local population are increasingly threatened, and numerous interrelated human security issues have emerged [2].

The growing importance of alternative water sources in the Aral Sea region is directly linked to the progressive decline in both the quantity and quality of traditional surface water resources. Over recent decades, reduced inflow from the Amu Darya River, combined with climate aridization, upstream water withdrawals, and inefficient irrigation practices, has significantly limited the availability of reliable freshwater supplies. At the same time, surface water quality has deteriorated due to salinization, agricultural return flows, and industrial pollution. Under these conditions, groundwater—particularly brackish groundwater—has become a critical supplementary and, in many areas, primary source of water for domestic, agricultural, and industrial use. Although its elevated mineralization restricts direct use, advances in desalination technologies and water management practices have increased its practical value. Therefore, assessing the hydrochemical characteristics, spatial distribution, and usability of brackish groundwater is essential for developing sustainable water supply strategies in Karakalpakstan. This study is motivated by the urgent need to better understand these alternative water resources and their potential role in mitigating water scarcity in one of the most environmentally stressed regions of Central Asia.

From a hydrogeological point of view, the Republic of Uzbekistan is characterized by significant heterogeneity in the distribution of groundwater resources. The largest and strategically important deposits of brackish and slightly mineralized groundwater are concentrated in the northwestern part of the country - within the Republic of Karakalpakstan, the Aral Sea region, and adjacent desert territories [3].

This study presents the concept, development process, and preliminary results of a web-based hydro-environmental atlas designed to improve environmental data management, visualization, and dissemination. The system integrates standardized metadata structures, thematic hydro-environmental layers, and multi-format dissemination tools. The web-based implementation demonstrates the feasibility and usefulness of the atlas in supporting research activities, institutional cooperation, and science-based decision-making. The platform's scalable and modular architecture offers strong potential for future expansion toward a comprehensive environmental data management system [4].

Because few published studies have described the present condition of groundwater quality in the Republic of Karakalpakstan Nothern Uzbekistan, the purpose of this paper is to summarize the quality and availability of groundwater used for municipal drinking water sources in this important region.

Our research objective is to provide a complete assessment of Northern Uzbekistan groundwater quality through the systematic analysis of its chemical composition and to predict sustainable uses for domestic drinking water supply. Our research are to test whether or not there are relationships between current groundwater quality and surface contaminant sources, and between groundwater composition and aquifer composition. This study will help guide future monitoring of these groundwater supplies for the protection of public drinking and irrigation water in Republic of Karakalpakstan. The purpose of this research is to study and assess groundwater in the Republic of Karakalpakstan, drawing conclusions on the region's hydroecological conditions. It is important to note that the study will address key issues related to the shortage of high-quality water resources, progressive salinization, and anthropogenic impacts in the study region. Groundwater quality issues can be divided into two groups, naturally occurring phenomena such as high arsenic levels [5] and degradation of groundwater resources through human action. In terms of human-induced degradation, salinization has been cited as the biggest single threat to aquifer sustainability [6]. One aspect of salinization, already discussed, is salt water intrusion resulting from aquifer drawdown. A more widespread aspect is the human-induced salt accumulation in the upper soil profile known as secondary salinization. It has been estimated that 20% of the world's irrigated areas are affected by secondary salinization in one way or another [7]. India, China, Pakistan, the former Soviet Union, and the United States account for most salinized soils, but the phenomena is also a major national issue in countries with smaller shares of the world's total irrigation, including Argentina, Egypt, and Iran.

Study Location

The Republic of Karakalpakstan is the largest region of Uzbekistan, occupying approximately 38% of the country's total territory. Its population is over 2 million. It is located in the northwest of the Republic of Uzbekistan, in the central part of Central Asia. Territory of the Karauzyak district is 5890 sq. km and the border length is 530.1 km. For agricultural sown areas account for 32,397.0 hectares, including 32,397.0 hectares of irrigated land. Ehe population of the Karauzak district is 52,700 people, of which 15,900 are urban residents and 36,800 are rural residents.

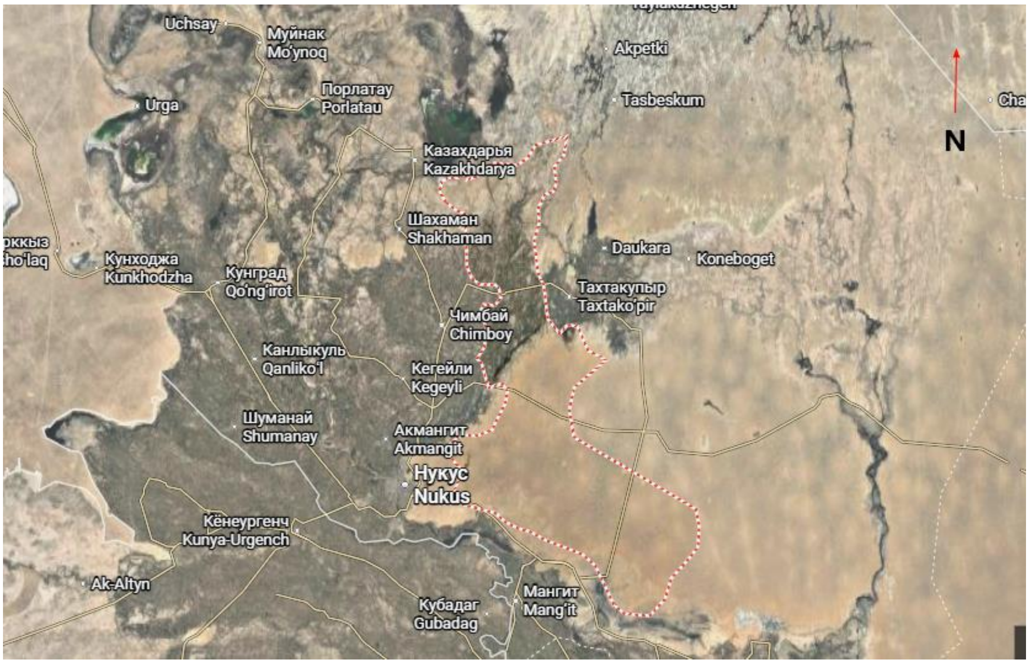

Figure 1. Karauzyak district location, scale 1:500 000 [25].

Geographical location and borders: Karakalpakstan is located in the lower reaches of the Amu Darya River and on the southern coast of the Aral Sea. Land use in Karakalpakstan is characterized by challenging natural conditions and an environmental crisis associated with the drying up of the Aral Sea. The region is adapting to water shortages and soil degradation through the introduction of new agricultural practices and sustainable resource management.

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Figure 2. Geographical map of the Republic of Karakalpakstan, M 1:1000000.

The geopolitical region of Central Asia is characterized by a continental arid and semiarid climate with mean annual precipitation of 600–800 mm in the mountainous areas and 80–150 mm in the desert regions [8]. The specific climatic conditions of Central Asia determine the crucial role that water plays in urbanization, supporting life, and preserving unique natural objects [9]. With the impacts of global warming and the increased demands for food and energy due to rapid population growth throughout Central Asia, the water resources in this region are facing increasing pressure [10]. Therefore, the scarcity of water and the uneven spatial distribution of water resources greatly limit the socio-economic development of the Central Asian region [11]. In addition to the scarcity of water resources, water pollution and corresponding water-related health problems are growing problems throughout Central Asia [12]. Several studies have reported the excessive salinity of the water downstream of the Amu Darya and Syr Darya rivers and described the sources of pollutants discharged into surface water [13–15].

In the areas in which water runoff disperses, which include most of Kazakhstan, Turkmenistan and Uzbekistan, almost all local and foreign scholars have identified two main problems: rising levels of water salinity and desertification coincident with land salinization [16–18]. More- over, the storage of toxic and radioactive substances has become a potential environmental problem associated with water resources in surface runoff catchment areas, mainly in the territories of Kyrgyzstan and Tajikistan, and in the foothills of Kazakhstan and Uzbekistan [19,20].

In addition, the water environment of Central Asia has been greatly impacted by the use of mineral fertilizers and pesticides in agriculture and by the operations of mining, chemical production and other industries related to the utilization and storage of many harmful sub- stances [14,15]. Accordingly, the dilapidation of industrial and urban sewage systems and treatment facilities is a considerable concern in regard to water quality [12]. Furthermore, the distribution of environmental pollution sources has changed; for example, in cities, domestic waste is retained in leaky landfills, the discharge of which has become a major factor in the pollution of brackish groundwater and river ecosystems.

To assess the groundwater and surface water resources of the Karauzyak district, it is necessary to first study the area from the perspective of the hydrogeological development of the region as a whole. This includes the geological structure, hydrogeological conditions, and identification of productive aquifers in the study area.

A total of 20 wells were sampled across various hydrogeological profiles. When studying the chemical composition of groundwater from the wells, we analyzed organoleptic (odor, color), general (pH, hardness, mineralization, oxidizability), and specific parameters (metal ions, nitrates, fluorides,

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microbiology) in accordance with SanPiN standards to assess its safety and suitability for drinking water, often using spectroscopic methods to accurately determine the elemental composition. The characteristics of groundwater in Upper Cretaceous and Neogene-Quaternary deposits of the South Aral artesian basin were studied. Data on groundwater mineralization are presented, and their suitability for various purposes is assessed. The article typically highlights the importance of such analyses, research methods, and interpretation of the results in the context of modern standards. (Table of sample analyses from the Tuyamuyin Vodokanal laboratory) [21].

2. Materials and Methods

2.1. Key Characteristics of Groundwater

The Karauzyak district is located in the northern part of Karakalpakstan (on the right bank of the Amu Darya River) and is considered an irrigated area with typical desert conditions. Key parameters based on long-term observations (including 2025–2026). Groundwater table #**4** (long-term fluctuations, average long-term level, and intra-annual changes). Study of mineralization (salinity) and chemical composition.

Problems and environmental conditions

The rise in groundwater levels is one of the fastest in Karakalpakstan, leading to secondary soil salinization and the formation of solonchaks. High mineralization makes the water unsuitable for drinking without desalination and limits its use in agriculture. Impact of irrigation: Seepage from canals (Tash-Arna, Kok-Ozek, etc.) and poor drainage raise the water level and increase salinity. In rural areas, many residents depend on groundwater (up to 70% in some villages), which creates health risks.

2.2. Water Sampling

Primary Implementers: Aral Sea International Innovation Center for the Aral sea basin (IICAS) of the Republic of Uzbekistan. Sampling and laboratory results are compared with the State Standards of the Water for drinking water [10]. Trends regarding the chemical composition are evaluated in terms of hydrogeology, arid climate, industrial and agricultural land use, and related distribution of contaminant sources.

Monitoring includes: Depth (wells, observation points), sampling for mineralization, chemical composition (dry residue, chlorides, etc.), and frequency (seasonal/monthly at key sites).

In 2025, monitoring wells in the area were monitored for sustainable management.

The objects of study were groundwater from wells in the Karauzyak district. For the study in 2024 and 2025, water samples were collected for chemical composition analysis from 20 wells in the Karauzyak district (Fig. 4) in accordance with established standards [22] in clean, 1000 cm^3 polymer containers. The containers were completely filled with water and sealed with lids to eliminate air. The sample was not preserved and was analyzed as soon as possible after collection, but no later than 24 hours [23].

2.3. Chemical Analysis

The laboratory methods used are listed in Table 2 [11]. General requirements for methods for determining oil products in natural and wastewater are defined according to [2] and details are provided in Supplementary Materials, Section S1. All samples were taken from the water intake nearest the wellhead for general chemical analysis and for the determination of oil products. In the course of early studies at the sites of oil deposits and near oil product plants, traces of oil products were found in groundwater, which indicates that the groundwater is not sufficiently protected during the extraction and processing of oil and gas [1]. This part of the sampling campaign is a follow-up to evaluate whether or not petroleum contamination was still a problem [24].

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Table 1. Laboratory method details used for water testing [27,28].

Parameters	Detection limits (mg/l)	Instruments	Description of methods
Dry residues, total solids		OHAUS Adventurer Balance	Gravimetry (0.00001 g)
pH		Mettler Toledo pH meter	Potentiometry
Ammonia	0.1	KFK-2MP Photocolorimeter	Photometric method for ammonia and ammonium ions (in total) with Nessler reagent calibration from 0.1 to 3.0 mg/L.
Nitrite	0.003	KFK-2MP Photocolorimeter KFK-2	Photometric method for nitrites using sulfanilic acid. Calibration range from 0.003 to 0.3 mg/L.
Nitrate content using sodium salicylic acid	0.1	KFK-2MP Photocolorimeter	Photometric method for determining the nitrate using sodium salicylic acid. Calibration range from 0.1 to 2.0 mg/L.
Ferrum (iron)	0.01-0.03	KFK-2MP Photocolorimeter	Photometric method in an alkaline medium with sulfosalicylic acid to form a yellow-colored complex (400–430 nm). Calibration range is 0.10–2.00 mg/L [11].
Metals: Cd, Co, Mn, Cu, As, Ni, Hg, Pb, Cr, Zn	0.00001	ICPE-9820 Atomic Emission Plasma Spectrophotometer.	ICPE-9820 Atomic Emission Plasma Spectrophotometer. Calibration range is 0.00001–10.0.
Alkalinity CO3, HCO3	10	Automatic titrator	Titration: HCl volume consumption per 100 mL sample using phenolphthalein indicator
Ca, Mg	10	Automatic titrator	Titration: consumption of Triton B per 100 mL sample using an indicator.
Chloride	10	Automatic titrator	Titration: mercurimetry by Hg(NO3)2 per 50 mL sample and indicator.
Sulfate	30	OHAUS Adventurer Balance	Gravimetric method using precipitation of sulfate ions in a hydrochloric acid medium with barium chloride. Range is 30–300 mg/L [12].

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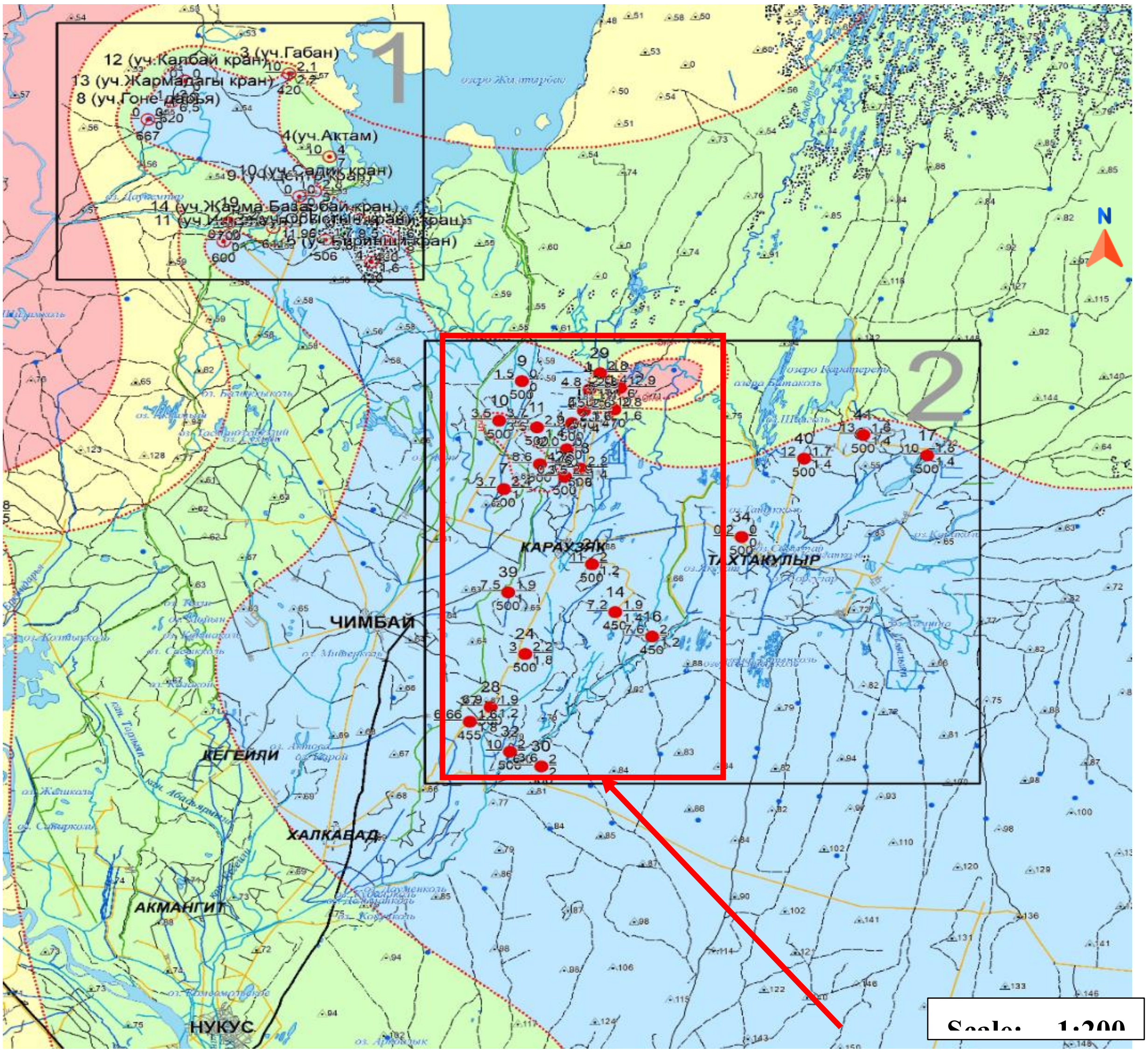

Figure 3. Map of wells in the Karauzyak district.

Quantitative chemical analysis of the collected water samples was carried out in the Central Chemical and Bacteriological Laboratory of JSC “Karakalpak Suv Taminot”.

Chemical and physicochemical analysis of the water samples was conducted immediately after sampling using standard methods. Temperature, transparency, and odor measurements were conducted in accordance with the guidelines [25]. A TM 10-3 thermometer with a measurement range of -5 to +40°C and a measurement error of ±0.2°C was used to measure water and air temperature [26].

To study the chemical composition, water samples were collected monthly from wells in the Karauzyak district throughout 2025. It was found that the groundwater temperature in the studied wells remains virtually constant throughout the year, averaging 4-7°C. Aquifers located deep underground are little affected by seasonal temperature changes. Water and soil analyses were also conducted in the Karauzyak district, where the geological and lithological structure and hydrochemical composition of groundwater in the chalk aquifer complex were clarified, with the aim of identifying areas of low-mineralized groundwater distribution that are of interest for their practical use for the development of livestock farming and small-oasis irrigation of lands [27].

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Figure 4. Water sampling process.

Results and discussions

The lower reaches of the ADR and SDR in the Aral Sea basin, which includes UZ, eastern TM, and southern KZ, face severe surface water and groundwater pollution and land salinization due to agricultural activities [28]. In particular, agricultural irrigation and production processes are the main cause of water pollution in the middle and lower reaches of the ADR and affect the ionic compositions from the upstream to the downstream areas [29]. Overall, the available surface water in the Navoi region (S3) is characterized by significant mineralization. This mineralization occurs because the southern part of this region currently exhibits intensive agricultural irrigation and above-average fertilizer use, which leads to significant soil and groundwater salinization [30]. The upstream region of the Zarafshan River is composed pre-dominantly of calcium bicarbonate, while the downstream region has high levels of SO_4^{2-}, Cl^- and Mg [29].

Currently, the surface water mineralization is approximately 0.9–1.2 g/L in the upper reaches and 1.5–2.0 g/L in the lower reaches of the Syrdarya. These numbers indicate that water mineralization has increased by two to three times compared with the pre-1940 levels. Currently, the ion composition of the river water is dominated by SO_4^{2-}, Na+ and K+, and high concentrations of Cl− have been observed in the lower reaches of the SDR [31].

The Aral Sea basin is a dynamic hydrological system characterized by an arid climate that receives an inflow of river water with high seasonal and interannual variability [32]. In particular, the spatial dynamics of the groundwater levels and salinity in the Khorezm region of Uzbekistan show that the groundwater in the western and southern parts of this region is particularly shallow and saline [33]. In the Amudarya delta there is a distinct contrast in salinity between the low-salinity river water (~1 g/L) and the high-salinity unconfined groundwater (10–95 g/L) [34]. The Aral Sea is currently shrinking, which affects groundwater discharge; this discharge manifest as changes in the groundwater levels and salinization. Thus, shallow groundwater with predominantly moderate salinity is likely to contribute to the increase in soil salinization. Due to the effects of intensive irrigation, the groundwater in the middle and lower reaches of the Zarafshan River is no longer suitable for drinking. The highest mineralization and SO_4^{2-} contents have been recorded in the lower reaches of the Zarafshan River, where the maximum concentrations of SO_4^{2-} reach 6.1–12.0 times the MAC [35]. However, both groundwater and soil salinity have improved slightly in recent years.

Groundwater mineralization within the Karauzyak district ranges from 0.5-2.5 g/L and above. Groundwater mineralization in wells drilled into Upper Cretaceous aquifers (K_2) of the YUPAB, confined to clayey sandstones, ranges from 1.4 to 62.5 g/L. The aquifer penetration depth in the study areas ranges from 300 to 700 meters.

During the research, the groundwater mineralization of the aquifer within the Karauzyaksky district was determined based on the results of analysis of selected samples and ranges from 3.4 g/L to 10.2 g/L. The water is classified as sodium chloride. Its relatively low values are explained by the inconsistency of the impermeable layers separating the Lower and Upper Cretaceous aquifers and the presence of filtration windows in the sedimentary section through which low-mineralized Upper Cretaceous waters mix with the saline waters of the Lower Cretaceous. Based on the ion-chemical composition, the waters studied by the wells belong to the sodium chloride class, classified as brackish and highly saline. The concentration of hydrogen ions (pH) varies from 7.10 to 8.30, and the oxidizability is 2.15-5.85. Total hardness for all wells ranges from 6.5 to 26.5 mg-eq/l.

Piezometric groundwater levels were established at the ground surface or at a depth of 0.5-4.5 m; self-discharge with a flow rate of 6.0 l/s was observed in only one well #46. The well flow rate during pumping was 0.2-13.3 l/s with drawdowns of 10.4-11.8 m, specific flow rates were 0.02-1.13 l/s·m. The filtration coefficient varies from 0.12 to 7.47 m/day, averaging 0.64 m/day, the water yield coefficient - from 15.8 to 156 m2/day, averaging 75 m2/day. Due to high mineralization and low pressure, the tapped aquifers cannot be recommended for irrigation. Other technical uses of this groundwater are possible with further research [36].

The study area is located at the boundary of two large first-order hydrogeological structures: the Ustyurt artesian basin to the west and the Syr-Darya artesian basin to the east. The boundary between them is the Aral-Kyzylkum swell, a powerful linear structure that represents a regional divide between the two basins. The swell itself is the interface between second-order structures—the North Ustyurt and South Aral artesian basins, which comprise the study area. The geological structure of the YUPAB is distinguished by a folded basement composed of highly dislocated and metamorphosed sedimentary and igneous rocks of Paleozoic age and a loose sedimentary cover of Mesozoic-Cenozoic deposits [37].

Currently, four key groundwater deposits are identified in this region, which are of regional importance for water supply, agriculture, and potential industrial development:

1. **Groundwater deposits of Karakalpakstan**. It encompasses the left-bank part of the lower Amu Darya River within the Republic of Karakalpakstan. It is characterized by a complex structure of aquifer systems, including both unconfined alluvial horizons and confined (artesian) horizons of deeper Neogene-Quaternary deposits. A significant portion of the reserves is subject to secondary salinization as a result of rising groundwater levels and capillary rise of salts.
2. **Groundwater deposits of the Lower Amu Darya** Groundwater Deposit is located on the right bank of the lower reaches of the Amu Darya River (primarily within the Khorezm region and southeastern Karakalpakstan). It is composed primarily of highly permeable alluvial aquifers. The deposits are formed through seepage losses from the riverbed and irrigation systems, resulting in a close hydraulic connection with surface water.
3. **Groundwater deposits of the South Aralsea**. Located in the southern Aral Sea region, within the influence zone of the shrinking Aral Sea, the field is characterized by the presence of several pressurized (artesian) complexes in Neogene-Quaternary sediments. Artesian waters exhibit increased mineralization as they approach the former sea basin, but in some areas, horizons of

acceptable quality for domestic and drinking water supply remain. Reserves are formed primarily through lateral filtration from the recharge area in the south and southeast.

4. **Groundwater deposits of the Ustyurt Plateau**. It is located on the Ustyurt Plateau (northern Karakalpakstan). Aquifers are represented primarily by fracture-vein and fracture-pore systems in Paleogene-Neogene carbonate-terrigenous sediments. Brackish and slightly brackish waters occur as localized lenses and zones of active water exchange in the upper part of the section; below, highly mineralized brines predominate. The field is of great importance as a potential source of industrial and drinking water for the development of gas condensate fields and the plateau's infrastructure [37]

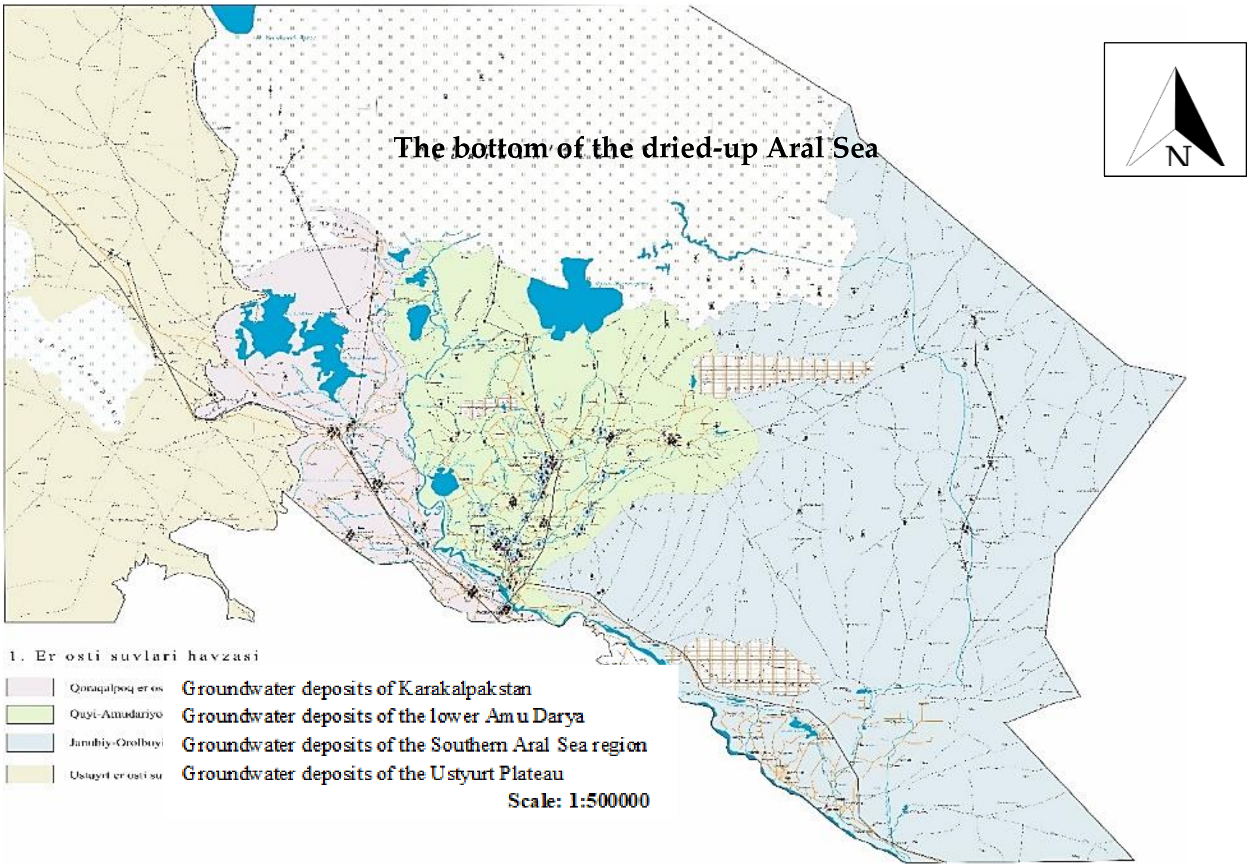

Figure 5. Map of groundwater deposits of the Republic of Karakalpakstan.

These deposits represent the primary source of decentralized water supply in the northwestern region of Uzbekistan, amidst the scarcity of surface water. However, their exploitation is associated with a number of hydrogeological and environmental risks: secondary salinization, reduced pressure in artesian aquifers, contamination by drainage runoff, and a general deterioration in groundwater quality in the Aral Sea region due to climate aridization and anthropogenic pressure.

Further rational use of these deposits requires comprehensive monitoring, modeling of the groundwater regime and the introduction of modern technologies for the protection and artificial replenishment of reserves [3,38].

In the Republic of Karakalpakstan, the hydrogeological conditions of the lower reaches and delta of the Amu Darya River determine the special role of groundwater as an alternative and strategically important water supply source in the face of chronic surface runoff shortages and progressive degradation of river water quality.

Among the currently operating and prospective facilities, two major hydrogeological complexes, located on the right and left banks of the lower Amu Darya valley, are of particular importance:

The Right-Bank Groundwater Field of the Lower Amu Darya is located on the right bank of the river within the administrative boundaries of Karakalpakstan. Its primary source of recharge is seepage from the Amu Darya River bed and major main canals. Hydraulic connection with surface

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waters determines seasonal fluctuations in the groundwater level and chemical composition. Salinity in the active water exchange zone typically ranges from 0.5 to 1.5 g/dm³, classifying these waters as brackish or low-mineralized. The field is actively used for domestic and drinking water supply in populated areas and for industrial and technical needs.

The Left-Bank Groundwater Field of Karakalpakstan encompasses the left-bank part of the Amu Darya delta and lower reaches, including the Khodjeyli, Shumanay, Kungrad, Kanlykul, and parts of the Muynak districts. Aquifers are represented by a multilayered layer of Quaternary alluvial deposits, dominated by sandy and sandy loam fractions, along the riverbed and large canals (Kegeyli, Kuanysh-Zharma, Oktyabr-Arna, etc.). Brackish and slightly brackish lenses form due to infiltration from surface watercourses; the thickness of brackish water lenses reaches 20–40 m and a width of 1–3 km. Artificial replenishment and local desalination are actively used in canal zones. Salinity varies from 0.6–1.2 g/dm³ in zones of intensive recharge to 3–5 g/dm³ and more in peripheral areas affected by collector-drainage runoff and secondary salinization.

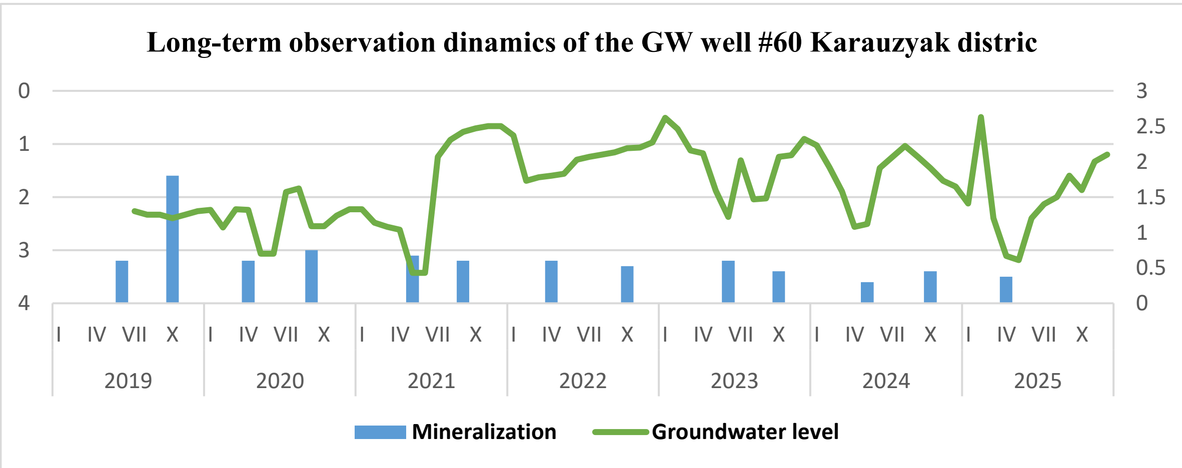
Thus, the right-bank and left-bank groundwater deposits of the lower Amu Darya remain key elements of the decentralized water supply system of the Republic of Karakalpakstan. Their rational use requires comprehensive hydrogeological monitoring, mathematical modeling of the regime, the implementation of artificial replenishment technologies, and strict groundwater quality control under conditions of increasing anthropogenic and climatic stress in the Aral Sea region [39].

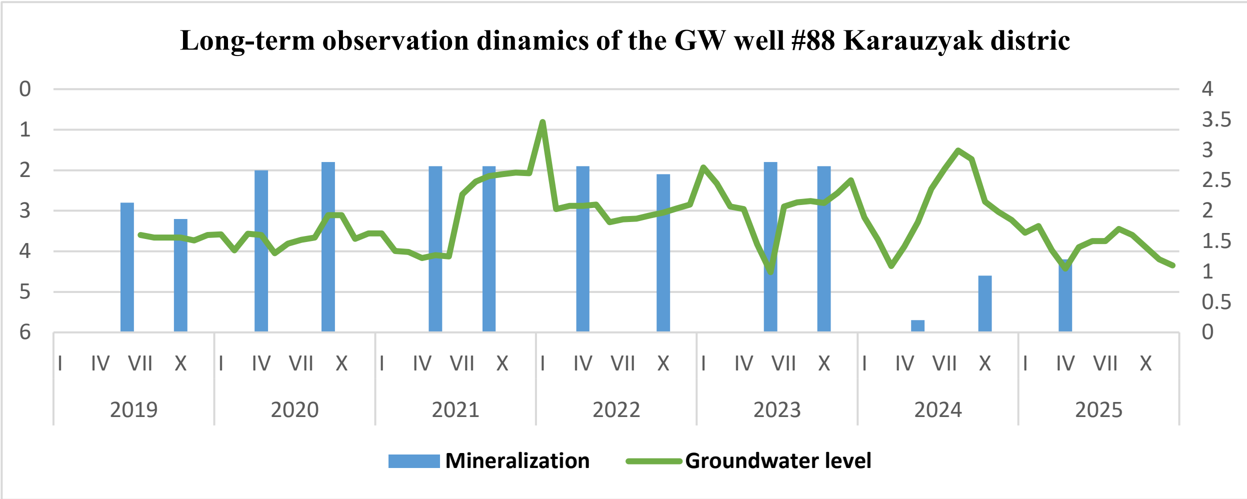
Groundwater in aquifers 10–40 meters thick, primarily associated with Quaternary and Neogene-Quaternary sand and sand-gravel deposits of alluvial and subaerial origin, is considered promising and actively exploited in the Republic of Karakalpakstan. These aquifers form local and extended brackish water and low-mineralized lenses in the valley and delta of the lower Amu Darya, as well as in the canal zones of the main irrigation systems.

Environmental monitoring of groundwater in the Republic of Karakalpakstan is being conducted as part of regional joint research in the Amu Darya Delta, where problems of soil salinization, rising groundwater levels, and land degradation due to intensive irrigation and the consequences of the Aral Sea crisis predominate.

In the Aral Sea region, the environmental situation makes the availability of high-quality drinking water problematic. Therefore, monitoring the qualitative and quantitative state of groundwater in the region is essential. The Karauzyak district, one of the northern regions of the Republic of Karakalpakstan, is one of the most acutely affected by water supply and farm development issues. To study the qualitative and quantitative state of groundwater in the study area, two field expeditions were conducted during the research period, exploring thermal and groundwater sources in the Karauzyak district.

The results of our research group's monitoring of the physical and chemical composition of groundwater in the Karauzyak district are presented in the following graphs.

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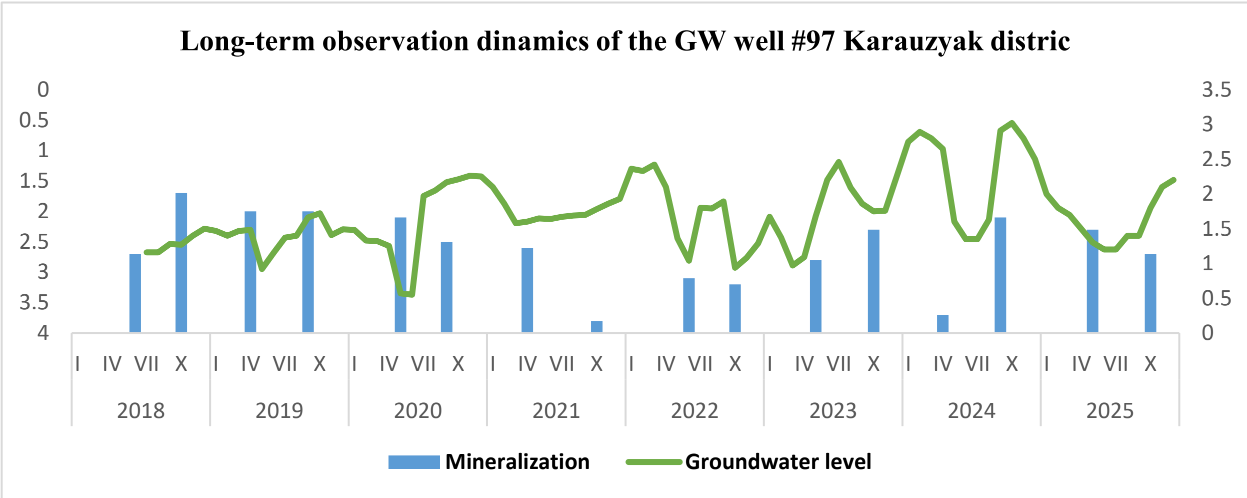
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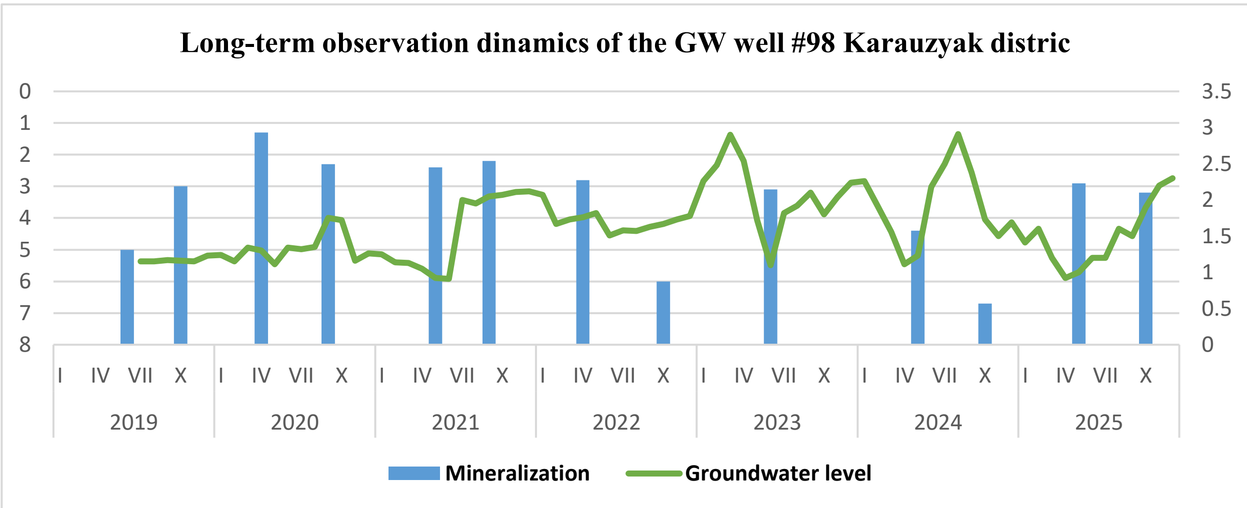
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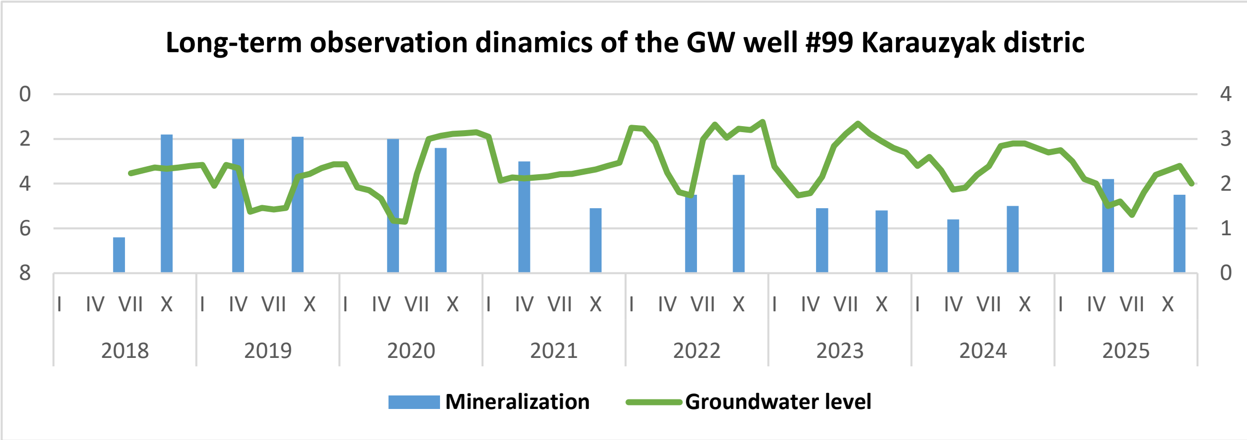

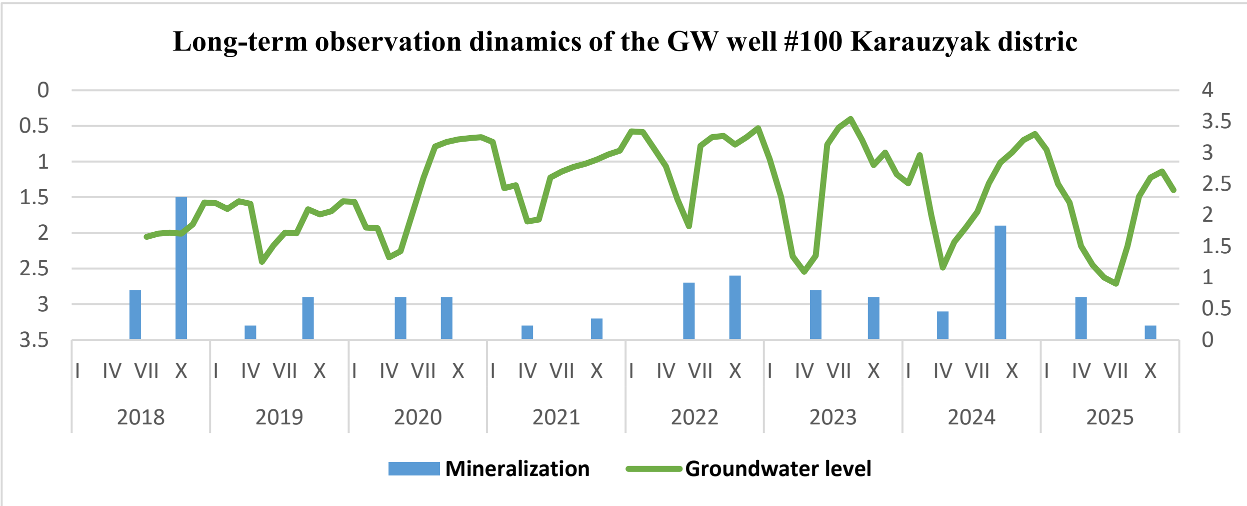

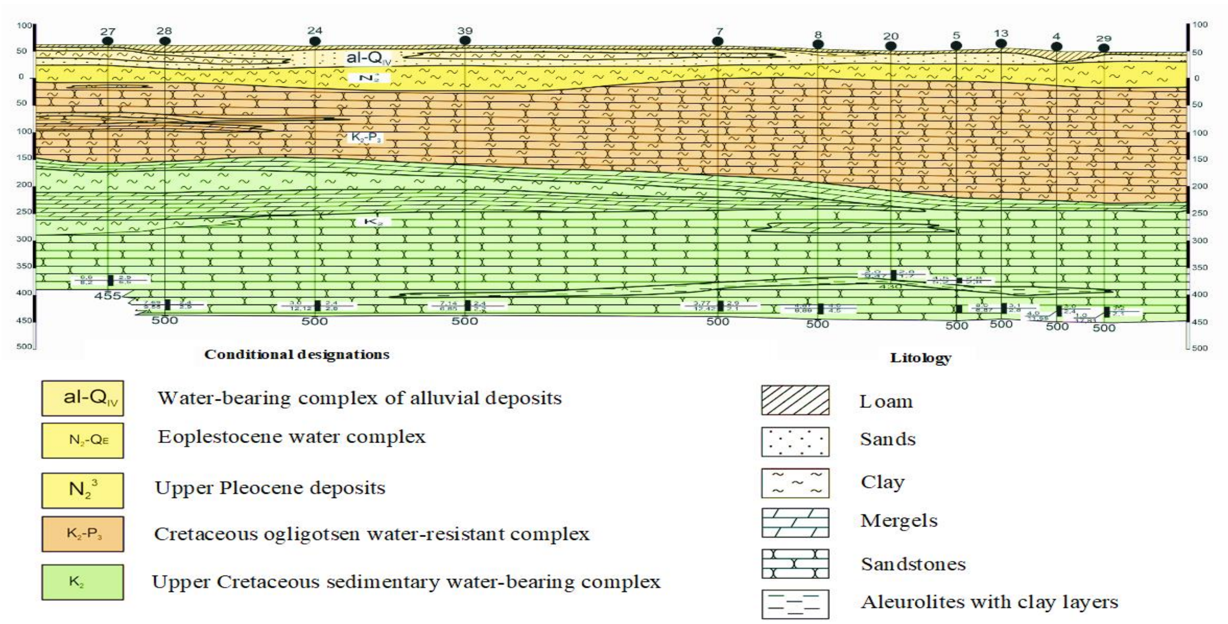

Figure 5. Hydrogeological section of the Karauzyak district.

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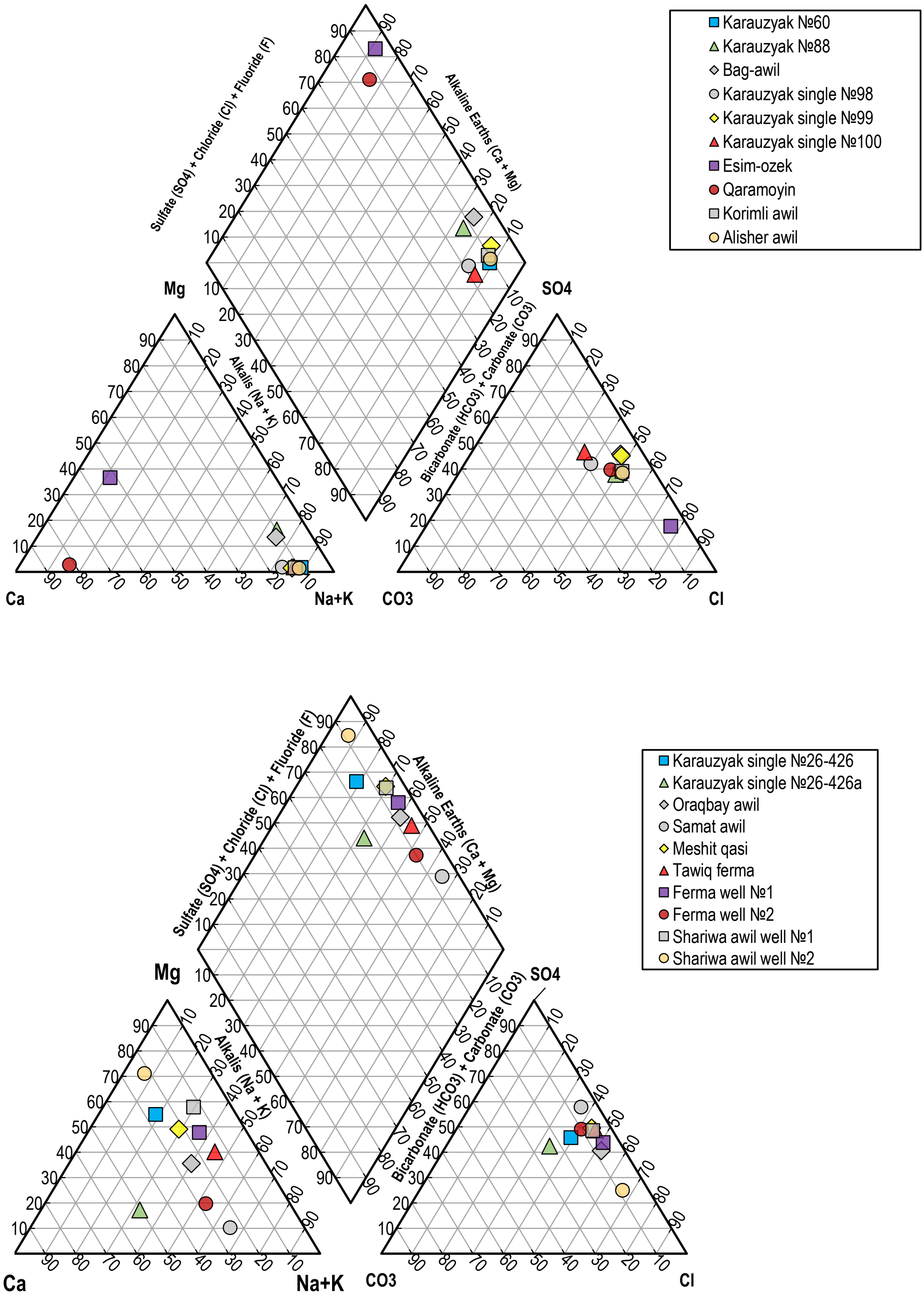

Figure 6. Piper plot of the ground water of Karauzyak district.

Analysis of the plot points

Most samples are located in the lower part of the diamond, closer to the top of Ca (calcium) and HCO_3^-/CO_3^{2-} (bicarbonates/carbonates), with a noticeable contribution of Na+K and Cl in some cases.

Karauyazyak #60 (blue square) closer to the center of the lower part, significant % Ca, but also Na+K and HCO_3, likely a mixed Ca-Na-HCO_3 type. Karauyazyak #88 (green triangle) low Ca, high

Na+K, noticeable SO_4 and HCO_3 closer to the Na-SO_4-HCO_3 or mixed alkaline type. Bag-aul (diamond) very high Ca (~80–90%), low other cations predominantly calcium-bicarbonate type (brackish water). Karauyazyak, isolated, #98 and #99 (circles and diamonds) similar to Bag-aul, strongly shifted toward Ca and HCO_3 calcium-hydrocarbonate waters. Karamoyin (red circle) very low Ca, high Na+K, high Cl chloride-sodium type (brackish/mineralized water). Yesim-ozek (purple square) high Mg and SO_4, low Ca possibly sulfate-magnesium-sodium type. Korimli aul, Alisher aul (rectangles and circles) close to Ca and HCO_3, similar to Bag-aul and isolated Karauyazyak brackish hydrocarbonate-calcium waters.

Many data points (especially Bag-aul, isolated Karauyazyak Nos. 98–100, Korimli and Alisher auls) are clustered in the area of calcium-hydrocarbonate waters this is typical of relatively brackish, good-quality groundwater, often young in age, with low mineralization. Karamoiyn and some Karauyazyak (Nos. 88, 60) show a shift toward sodium-chloride and mixed types more mineralized, possibly influenced by evaporation, soil salinization, or ancient salt horizons. The presence of data points with high SO_4 (Yesim-ozek, some Karauyazyak) may indicate the influence of sulfate rocks or anthropogenic pollution (fertilizers, drainage). Such diagrams are often used in groundwater studies in arid regions (including Karakalpakstan/Aral Sea region in Uzbekistan), where a gradient is observed from brackish water in alluvial fans to more saline water in lower elevations. If this is part of a scientific paper or report, then Karauyazyak and the surrounding points likely represent different horizons or sections of the same aquifer complex with varying degrees of salinity.

The chemical composition of brackish groundwater is spatially variable because it depends in part on local geologic, hydrologic, and climatic conditions. Chemical variations in brackish groundwater are important because they can have implications for the feasibility, treatability, and associated cost of using brackish groundwater [40]. The national brackish groundwater assessment focused on defining the occurrence of brackish groundwater at depths less than 3,000 feet (ft) below land surface because few data were readily available below that depth. Groundwater- chemistry data for about 380,000 groundwater samples were compiled from 33 sources [41] for this assessment. In a preliminary compilation of brackish groundwater data in the United States, five water types accounted for the major-ion composition of 70% of samples. PHREEQC calculations indicate that 57–77% of samples were oversaturated with respect to barite, calcite, or chalcedony. In the study, 5–14% of samples had concentrations of arsenic, fluoride, nitrate, or uranium that exceeded drinking-water standards [42].

Recommendations and Prospects

To improve the ecological situation, the following is required:

- Strengthening drainage and optimizing irrigation.
- Expanding the monitoring network (including automated sensors).
- Using drainage water after desalination.
- Monitoring soil salinity in parallel with groundwater.

Conclusions

Studies conducted in 2025 showed that the mineralization and chemical composition of groundwater in the Karauzyak district's aquifers remained stable. Changes in mineralization over the reporting period amounted to 1.8-2.4 g/L (Senonian aquifer), 3.5-4.0 g/L (Turanian aquifer), and 1.8-2.4 g/L (Cenomanian aquifer). Groundwater in the Albian aquifer is more mineralized and highly thermal. According to chemical analysis, its mineralization ranges from 12.8-16.3 to 24.2-45 g/L. These wells are located within a single depression cone with an absolute elevation of 65-60 m, within which, in some areas, the Senonian and Turanian aquifers no longer discharge.

The well flow rate during self-flowing in the Karauzyak district was 0.2 l/s, the well flow rate during pumping was 0.2-12.5 l/s at drawdowns of 5.2-17.39 m, specific flow rates were 0.08-1.94 l/s. The filtration coefficient varies from 0.10 to 2.4 m/day, up to a maximum of 13.07 m/day, averaging 0.64 m/day, the water recovery coefficient from 5.8 to 405.3 m2/day, averaging 65 m2/day. The dry residue, in general (in 27 wells out of 29), did not exceed 1.6-3.8 g/L, and only in wells 12 and 31 was the mineralization 8.4-9.2 g/L. The chemical composition of the water is sodium sulfate-chloride, mostly slightly brackish. In the areas under consideration, groundwater from the Upper Cretaceous aquifer in the 470-490 m interval may be promising for irrigation; for drinking water supply, it is recommended only under desalination conditions.

In the Karauzyak district, groundwater from the Upper Cretaceous aquifer in the 470-490 m interval may be promising for use for irrigation purposes; for drinking water supply, it is recommended only under desalination conditions. [45]

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BIBLIOGRAPHY

1. Enhancing resilience of the promoting green, inclusive development of the most vulnerable communities in the Aral sea region. UNDP report, 2022, 78 p.
2. Kh. Asilbekova et al. National state of the Environment report: Uzbekistan. Ministry of Ecology, Environmental Protection and Climate Change of the Republic of Uzbekistan. 2023, 136 p.
3. Chembarisov E.I., Khozhamuratova R.T., Sadiyev U.A., Balliyev A.I., Reimova G.B. 2022. Features of hydrological and reclamation monitoring of the irrigated territory of the republic of Karakalpakstan. "Lesson Press" Tashkent, 177 p.
4. Liburius et al. Development of a web-based Hydro-Environmental Atlas For The Republic Of Karakalpakstan, Uzbekistan. (2026), Journal Universum, #3(144), P. 32-37
5. Alaerts G, Khouri N. 2004. Arsenic contamination of groundwater: mitigation strategies and policies. Hydrogeol. J. 12:103–14
6. Morris BL, Lawrence ARL, Chilton PJC, Adams B, Calow RC, Liknck BA. 2003. Groundwater and its susceptibility to degradation: a global assessment of the problem and options for management. Early Warn. Assess. Rep. Ser. RS. 03–3. UN Environ. Program., Nairobi, Kenya
7. Ghassemi F, Jakeman AJ, Nix HA. 1995. Salinization of Land and Water Resources: Human Causes, Extent, Management, and Case Studies. Sydney: Univ. N.S.W. Press
8. Qadir, M., Noble, A.D., Qureshi, A.S., Gupta, R.K., Yuldashev, T., Karimov, A., (2009) Salt- induced land and water degradation in the Aral Sea basin: a challenge to sustainable agriculture in Central Asia. Nat. Resour. Forum 33, 134–149. https://doi.org/10.1111/j.1477-8947.2009.01217.x.
9. Karkra, R., Kumar, P., Bansod, B.K.S., Bagchi, S., Sharma, P., Krishna, C.R., (2017) Classification of heavy metal ions present in multi-frequency multi-electrode potable water data using evolutionary algorithm. Appl. Water Sci. 7, 3679–3689. https://doi.org/10.1007/s13201-016-0514-0
10. Ruan, H.W., Yu, J.J., Wang, P., Wang, T.Y., (2020) Increased crop water requirements have exacerbated water stress in the arid transboundary rivers of Central Asia. Sci. Total Environ. 713, 12. https://doi.org/10.1016/j.scitotenv.2020.136585.
11. Guo, L., Zhou, H., Xia, Z., Huang, F., (2016) Evolution, opportunity and challenges of transboundary water and energy problems in Central Asia. Springer Plus 5. https://doi.org/10.1186/s40064-016-3616-0

 doi:10.20944/preprints202605.0973.v1

12. Bekturganov, Z., Tussupova, K., Berndtsson, R., Sharapatova, N., Aryngazin, K., Zhanasova, M., 2016. Water related health problems in central asia—a review. Water 8, 219. https://doi.org/10.3390/w8060219
13. Ososkova, T., Gorelkin, N., Chub, V., 2000. Water resources of Central Asia and adaptation measures for climate change. Environ. Monit. Assess. 61, 161–166. https://doi.org/10.1023/a:1006394808699
14. Tornqvist, R., Jarsjo, J., Karimov, B., 2011. Health risks from large-scale water pollution: trends in Central Asia. Environ. Int. 37, 435–442. https://doi.org/10.1016/j. envint.2010.11.006.
15. Leng, P., Zhang, Q., Li, F., Kulmatov, R., Wang, G., Qiao, Y., Wang, J., Peng, Y., Tian, C., Zhu, N., Hirwa, H., Khasanov, S., 2021. Agricultural impacts drive longitudinal variations of riverine water quality of the Aral Sea basin (Amu Darya and Syr Darya rivers), central asia. Environmental pollution (Barking, Essex : 1987) 284, 117405. https://doi.org/10.1016/j.envpol.2021.117405.
16. Crosa, G., Froebrich, J., Nikolayenko, V., Stefani, F., Galli, P., Calamari, D., 2006a. Spatial and seasonal variations in the water quality of the Amu Darya river (central asia). Water Res. 40, 2237–2245. https://doi.org/10.1016/j.watres.2006.04.004.
17. Schettler, G., Oberhansli, H., Stulina, G., Mavlonov, A.A., Naumann, R., 2013. Hydrochemical water evolution in the Aral Sea basin. Part I: unconfined groundwater of the Amu Darya delta – interactions with surface waters. J. Hydrol. 495, 267–284. https://doi.org/10.1016/j.jhydrol.2013.03.044.
18. Zhang, Y., Tan, X., Li, D., Ruan, H., Yu, J., Gao, Y., Zhai, X., 2020. Spatial variations of major water quality types and their relationships with land covers in the middle and lower reaches of Aral Sea Basin. Chin. J. Eco-Agric. https://doi.org/10.13930/j.cnki. cjea.200429.
19. Valentini, K.L., Orolbaev, E.E., Abylgazieva, A.K., 2004. Water Problems in Central Asia. Bishkek.
20. Yapiev at al. The hydrochemistry and water quality of glacierized catchments in Central Asia: A review of the current status and anticipated change. (2021) Journal of Hydrology: Regional studies. https://doi.org/10.1016/j.ejrh.2021.100960
21. Environmental problems of water supply in the Republic of Karakalpakstan. Journal of Economy and Society. №6(49). 2018. C.158-161.
22. Dzhaksymuratov K.M. (2021). Use of surface waters in the Aral Sea region. Nukus, 80 p.
23. Ishnyakov A.S., Dustkhodzhaev H.R. Groundwater in the active water exchange zone of the Turan plate. – Tashkent: Fan, 1988
24. Tlueova et al. Relation of hydrogeology and contaminant sources to drinking water quality in Southern Kazakhstan. (2023) Water, 15, 4240, https://doi.org/10.3390/w15244240
25. Interstate standard. Drinking water. Methods for determination of odour, taste, colour and turbidity. Moscow, 1975, 8 p.
26. Asamadinov A.O., Dzhaksymuratov K.M., Seitbekova A.K., Yessenbayev G.R., Zhetpisbayeva A.K. Hydrogeological conditions of the dried-up bottom of the aral sea and adjacent territories of the south aral sea artesian basin Science and Education in Karakalpakstan ISSN 2181-9203, №3/2(51), 2025, C.114-117.
27. Kulikov G.V. Hydrogeological conditions of Karakalpak Ustyurt. – Tashkent: Mingeo RUz, 1971. – 103 p.
28. Hamidov, A., Helming, K., Balla, D., 2016. Impact of agricultural land use in Central Asia: a review. Agron. Sustain. Dev. 36, 23. https://doi.org/10.1007/s13593-015- 0337-7
29. Olsson, O., Gassmann, M., Manig, N., Ikramova, M., Wegerich, K., 2013. Basin efficiency approach and its effect on streamflow quality, Zerafshan River Uzbekistan. J. Hydrol. 476, 128–135. https://doi.org/10.1016/j.jhydrol.2012.10.022.
30. Kulmatov, R., Groll, M., Rasulov, A., Soliev, I., Romic, M., 2018. Status quo and present challenges of the sustainable use and management of water and land resources in Central Asian irrigation zones - the example of the Navoi region (Uzbekistan). Quat. Int. 464, 396–410. https://doi.org/10.1016/j.quaint.2017.11.043.
31. Bissenbayeva, S., Abuduwaili, J., Issanova, G., Samarkhanov, K., 2020. Characteristics and causes of changes in water quality in the Syr Darya river, Kazakhstan. Water Resour. 47, 904–912. https://doi.org/10.1134/s009780782005019x.
32. Crosa, G., Froebrich, J., Nikolayenko, V., Stefani, F., Galli, P., Calamari, D., 2006a. Spatial and seasonal variations in the water quality of the Amu Darya river (central asia). Water Res. 40, 2237–2245. https://doi.org/10.1016/j.watres.2006.04.004.

33. Ibrakhimov, M., Khamzina, A., Forkutsa, I., Paluasheva, G., Lamers, J.P.A., Tischbein, B., Vlek, P.L.G., Martius, C., 2007. Groundwater table and salinity: spatial and temporal distribution and influence on soil salinization in Khorezm region (Uzbekistan, Aral Sea Basin). Irrigat. Drain. Syst. 21, 219–236. https://doi.org/10.1007/s10795-007-9033-3.
34. Schettler, G., Oberhansli, H., Stulina, G., Mavlonov, A.A., Naumann, R., 2013. Hydrochemical water evolution in the Aral Sea basin. Part I: unconfined groundwater of the Amu Darya delta – interactions with surface waters. J. Hydrol. 495, 267–284. https://doi.org/10.1016/j.jhydrol.2013.03.044.
35. Yu Liu, Ping Wang, Boris Gojenko, Jingjie Yu, Lezhang Wei, Dinggui Luo and Tangfu Xiao. 2021. A review of water pollution arising from agriculture and mining activities in Central Asia: facts, causes and effects. J.Env.Pollution, 291, https://doi.org/10.1016/j.envpol.2021.118209
36. Central Asian bureau for analytical reporting. https://cabar.asia/ru/bolshe-treti-uzbekistantsev-ne-imeyut-dostupa-k-chistoj-pitevoj-vode
37. Report of the Karakalpak State Geophysical Service on groundwater monitoring in the Republic of Karakalpakstan for 2022-2025
38. Mirabbos. M. Zakirov, Golib. E. Ochilov, Karamatdin. M. Djaksimuratov, Alim. O. Asamatdinov and Daniel Snow. Key Characteristics of the Ecological and Geodynamic Conditions in Southern Karakalpak Ustyurt of Uzbekistan. (2026) *MDPI Land*, 15(5), 782, https://doi.org/10.3390/land15050782
39. A.Asamatdinov and K.Djaksimuratov. Monitoring the composition and quality of water resources in Karakalpakstan. 2025. Universum Technical sciences 141(12)
40. McMahon, P.B., Böhlke, J.K., Dahm, K.G., Parkhurst, D.L., Anning, D.W., and Stanton, J.S., 2015, Chemical considerations for an updated national assessment of brackish groundwater resources: Groundwater, v. 54, no. 4, p. 464–475, accessed Feb- ruary 3, 2017, at http://dx.doi.org/10.1111/gwat.12367.
41. Qi, S.L., and Harris, A.C., 2017, Geochemical database for the brackish groundwater assessment of the United States: U.S. Geological Survey data release, https://dx.doi.org/10.5066/F72F7KK1
42. P.McMahon et al. 2016. Chemical considerations for an Updated national assessment of brackish groundwater resources. J.Groundwater. V54, #4, pp.464-475
43. https://www.google.com/maps/place
44. Control of water quality in the centralized systems of household and drinking water supply for the population of Uzbekistan. Hygienic criteria #0211-06, 2006, 8 p.
45. Razakov R.M. Aral and the Aral Sea region: problems and solutions. T., 1992. - 210 p.