

Article

Geoinformation and Analytical Support for the Development of Promising Aquifers for Pasture Water Supply in Southern Kazakhstan

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Abstract: Ensuring water resources for livestock production in Kazakhstan presents a multifaceted challenge. Pastoral systems in Southern Kazakhstan are facing a critical groundwater shortage, with 56.5% of pastures currently unused due to limited water access, jeopardizing around 2 million head of livestock and the region's food security. This study presents the first comprehensive groundwater assessment in over 40 years, integrating hydrochemical analysis (55 samples) and field surveys conducted in the Almaty and Zhetysu regions. Key findings include: the total water demand for livestock is estimated at 53,735 thousand m³/year, with approximately 40% of samples exceeding WHO guidelines for total mineralization. It was determined that 45% of exploitable groundwater reserves in the Almaty region and 15–17% in the Zhetysu region are suitable for irrigation. This study also provides updated hydrogeological data, identifying three priority aquifer systems. A novel Groundwater Sustainability Index for pastoral zones of Central Asia is introduced, demonstrating that strategic aquifer development could expand watered pastureland by 30–40%. These findings directly inform Kazakhstan's Agricultural Development Plan through 2030 and provide a replicable framework for sustainable water management in arid regions. With 69,836 rural residents currently lacking access to safe water, our results underscore the urgent need for infrastructure investment to meet SDG 6 targets (ensure availability and sustainable management of water and sanitation for all).



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Keywords: groundwater; artesian well; Almaty region; Zhetysu region; Kazakhstan; Central Asia; health risk; water standards

1. Introduction

Water scarcity is one of the most pressing issues of today, especially in regions with arid and semi-arid conditions, such as Kazakhstan, where livestock farming plays a crucial role in both maintaining the standard of living and ensuring food security [1–4]. Pastoral communities, which largely rely on groundwater for their livestock, are facing increasing pressure due to the consequences of climate change, population growth, and inefficient water extraction methods [5–7]. However, the complexity of groundwater systems, combined with the spatial variability of hydrological and geological factors, requires advanced tools and methodologies for effective resource management.

Thus, the contemporary issues and opportunities related to the development and management of groundwater worldwide are reflected in the UN World Water Development Report for 2022, titled “Groundwater: Making the Invisible Visible” [8]. Groundwater constitutes the majority of the world’s freshwater, and is unevenly distributed across the globe. It holds the potential to provide humanity with significant social, economic, and ecological benefits, including adaptation to climate change [9–13].

Due to the increasing shortage of surface water resources, countries are more actively tapping into groundwater, with global withdrawals rising from 100–150 km³ in the mid-20th century to 950–1000 km³ by the beginning of the current century [14–16]. Eight out of the ten countries with the highest share of groundwater extraction (accounting for 75% of the global volume) are located in Asia (in decreasing order: India, China, Pakistan, Iran, Indonesia, Bangladesh, Saudi Arabia, and Turkey) [17]. Furthermore, 76% of the groundwater withdrawn in Asia is used for agriculture [18]. Practices in Africa, Asia, and Latin America show that groundwater plays an important role in regions where small-scale agriculture and livestock farming provide opportunities to improve livelihoods through the use of shallow aquifers [19–24]. On a global scale, groundwater extraction currently accounts for 25% of the total freshwater withdrawal [25].

For Kazakhstan, pastures are important natural resources [26–29]. In the early period of national history, when grazing areas were abundant, pastures were distributed among clans, and nomadic livestock farming prevailed. However, with the reduction of nomadic routes from the late 18th to early 19th century, the use of pastures began to take on a semi-nomadic character [30]. The administrative method of transitioning the nomadic population to sedentary life in the 1930s led to large areas of pastures allocated to the state fund being left unused. The widespread introduction of livestock in seasonal grazing systems began in 1941–42. The pace of development of new pastures grew rapidly, and by 1947, up to half of the entire public livestock population was transitioned to seasonal grazing [31,32]. As a result, the seasonal grazing system contributed to a significant increase in livestock numbers, which rose nearly five-fold compared to 1934, although it did not reach the 1928 levels. In 1964, the Council of Ministers of the Kazakh SSR (Soviet Socialist Republics) adopted a decree “On the Development of Desert and Semi-Desert Pastures for Sheep Farming”, setting the goal of increasing the number of sheep and goats in the republic to 50 million heads [33].

During this period, the first map of groundwater in the pasture areas of Kazakhstan was created to justify the water supply for grazing centers, livestock watering points, and oasis irrigation. The map most thoroughly represented the shallow aquifers accessible for agricultural water supply. It showed their spatial distribution and groundwater parameters: mineralization (ranging from less than 1 g/L to over 15 g/L); chemical composition by predominant anions; depth of occurrence (from less than 5 m to 100 m); productivity of water points (values of predominant discharge, m³/day, and water level decline, m); and age-lithological complexes of the rocks. The map of groundwater in the pasture areas of Kazakhstan was intended to address the following tasks: scientifically grounded planning and design of water infrastructure in pasture areas for the rational placement of seasonal livestock farming; and design of irrigation facilities and oasis irrigation. By the late 1980s, Kazakhstan had 181.2 million hectares of pastures, including about 164 million hectares designated for agricultural use. The share of pasture feed in the overall feed balance was approximately 45%, and in sheep farming, it accounted for 67%. A feature of natural pastures is their seasonal use. The share of summer pastures was 30%, spring-autumn pastures 43%, winter pastures 12%, and year-round pastures 12%. Of the 164 million hectares of pastures, 123 million hectares were watered, including 91.3 million hectares through artificial structures and 31.7 million hectares through natural water sources. The

most widespread water sources were shaft and pipe wells, which provided water for 32% and 31% of the pastures, respectively; ponds and dug wells for 7.5%; and canals for 2.5%. The effectiveness of using watered pastures largely depends on the technical condition of the irrigation facilities. At that time, it was necessary to restore 40% of the dug wells, 23% of the springs, and 21% of the shaft wells. During the Soviet period, it was planned to complete the watering of all pastures by 1985.

This study aims to address knowledge gaps in pasture water management in Southern Kazakhstan by conducting the first post-Soviet comprehensive assessment of groundwater, moving beyond outdated Soviet-era hydrogeological data dated back to 1985. The objective of this research is to evaluate the current status and potential of groundwater resources for irrigating pasturelands in the administrative regions of Southern Kazakhstan (Almaty and Zhetysu regions), as well as to assess water quality for future use and the sustainability of water supply. This study involves conducting regional field surveys to assess the availability, quality, and suitability of groundwater for agricultural and livestock use. Accordingly, a baseline level of water quality for agricultural use will be established in accordance with WHO/Kazakhstan standards.

2. Materials and Methods

For the analysis of prospective aquifers for water supply to the pastures of Southern Kazakhstan, the following regions were selected (Figure 1): Almaty region (central point at 45° N, 78° E) and Zhetysu region (central point at 45°01' N, 78°22' E).

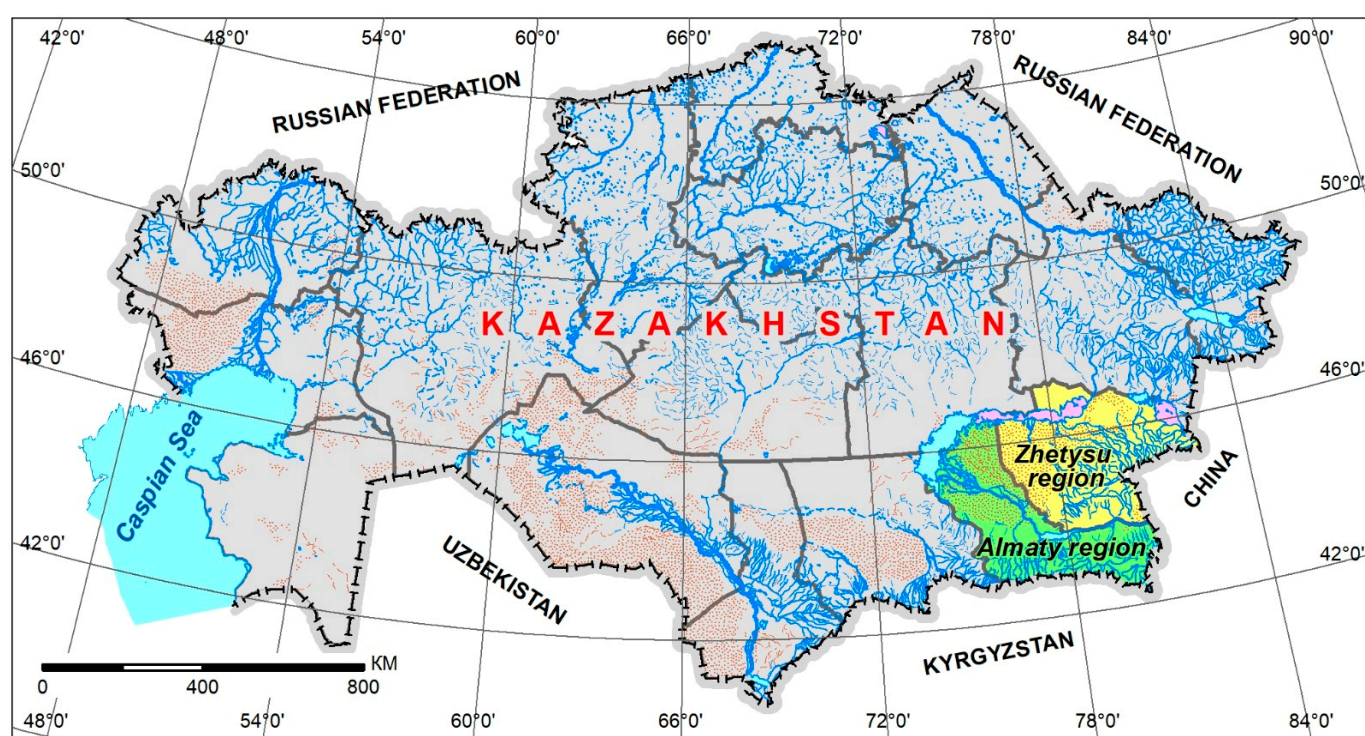


Figure 1. The location of the Almaty region in Kazakhstan is indicated in green, and the location of the Zhetysu region in yellow.

2.1. Almaty Region

The hydrogeological map of Almaty region, depicted in Figure 2, presents a comprehensive overview of the intricate network of hydrogeological features that permeate the region. The following text delves into the intricate details of these divisions.

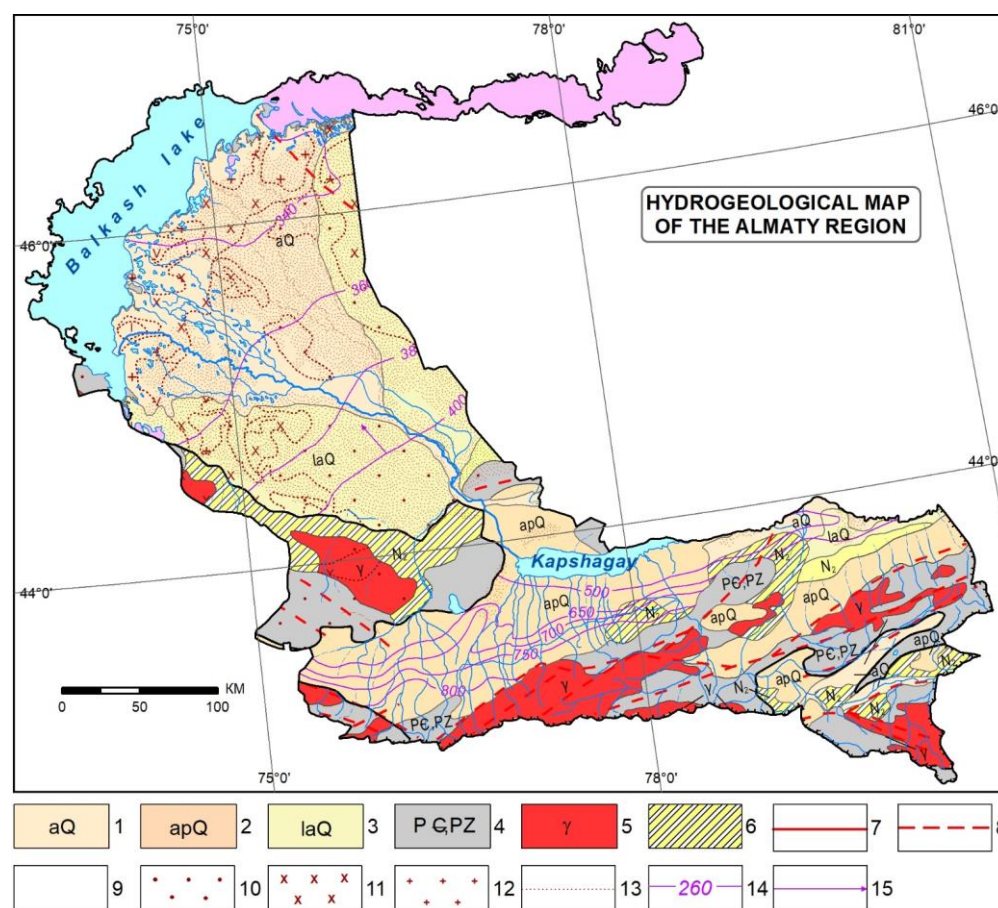


Figure 2. Hydrogeological map of the Almaty region.

Aquifers and complexes, aquifer fracture zones: 1—Quaternary alluvial complex. Sands, sandy loams, loams, pebbles, gravel-pebbles; 2—Quaternary alluvial-proluvial complex. Boulder- and gravel-pebbles, sands, interlayers of loams, sandy loams; 3—Quaternary lacustrine-alluvial complex. Sands, sandy loams, loams, clays; 4—fracturing zone of Precambrian undifferentiated Paleozoic rocks. Shales, quartzites, jaspilites, gneisses; 5—fracturing zone of different-aged, mainly intrusive rocks. Granites, granodiorites. Local aquifers and complexes: 6—Neogene (N_1 , N_2 , N_{1-2}). Interlayers of sand, gravel among clays. Hydrogeological units, distributed linearly. Fault zones: 7—aquifers; 8—hydrogeologically unexplored. Mineralization of groundwater of the first aquifers and complexes from the earth's surface, g/L: 9—<1 g/L; 10—1–3 g/L; 11—3–10 g/L; 12—10–25 g/L; 13—boundary of groundwater areas with different mineralization. Groundwater movement: 14—hydroisohypses with absolute groundwater level mark, m; 15—direction of groundwater flow of the first aquifers and complexes from the earth's surface.

2.2. Zhetysu Region

The hydrogeological map of the Zhetysu region, depicted in Figure 3, presents a comprehensive analysis of the intricate network of hydrogeological characteristics within the region. The subsequent text will provide an in-depth exploration of these characteristics.

Aquifers and complexes, aquiferous fracture zones: 1—Quaternary alluvial complex. Sands, sandy loams, loams, pebbles, gravel-pebbles; 2—Quaternary alluvial-proluvial complex. Boulder- and gravel-pebbles, sands, interlayers of loams, sandy loams; 3—Quaternary lacustrine-alluvial complex. Sands, sandy loams, loams, clays; 4—Pliocene-Quaternary complex. Sands, sandstones, gravelstones with interlayers of silt, sandy loams, loams

and clays; 5—Pliocene complex. Gravel-pebbles, sands with inclusions of pebbles, less often boulder-pebbles, inequigranular sands, sandy loams, loams; 6—complex of mainly Famennian-Lower Carboniferous fractured and karst carbonate rocks. Limestones, dolomites, sandstones on carbonate cement; 7—fracturing zone of Precambrian undifferentiated Paleozoic rocks. Shales, quartzites, jaspilites, gneisses; 8—fracturing zone of different-aged, mainly intrusive rocks. Granites, granodiorites. Local aquifers and complexes: 9—Neogene-Quaternary (N_2-Q). Sand interlayers among clays; 10—Neogene (N_1, N_2, N_{1-2}). Sand and gravel interlayers among clays. Hydrogeological units distributed linearly. Fault zones: 11—aquifers; 12—hydrogeologically unexplored. Mineralization of groundwater of the first aquifers and complexes from the earth's surface, g/L: 13—<1 g/L; 14—1–3 g/L; 15—3–10 g/L; 16—boundary of areas of groundwater with different mineralization. Groundwater movement: 17—hydroisohypses with absolute groundwater level mark, m; 18—direction of groundwater flow of the first aquifers and complexes from the earth's surface.

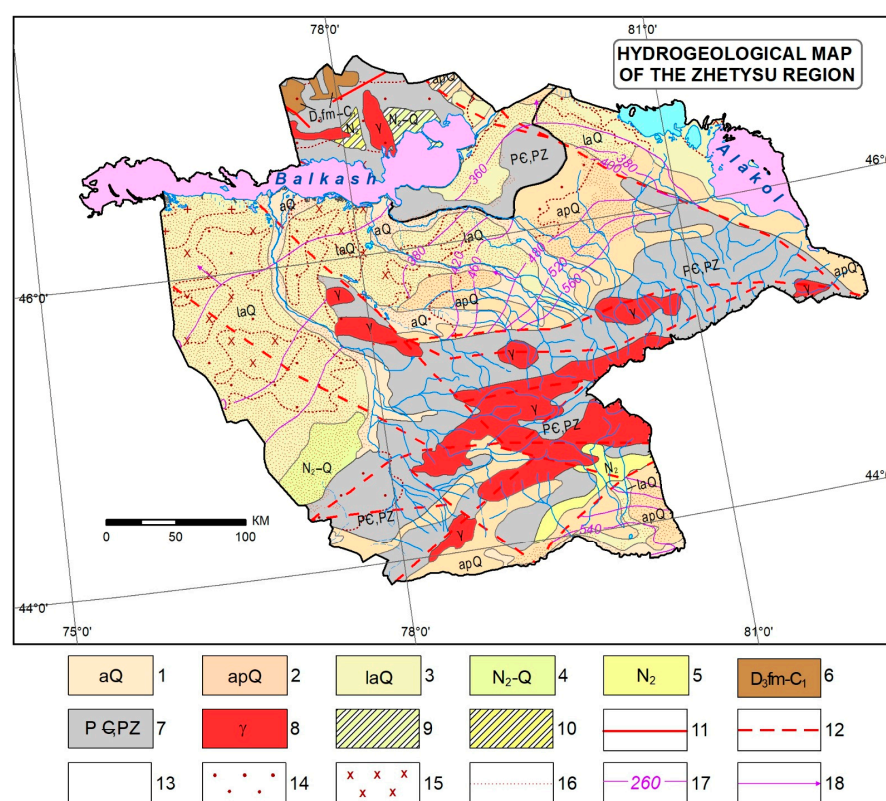


Figure 3. Hydrogeological map of the Zhetysu region.

2.3. Information Gathering

The materials of integrated scientific studies on water supply and assessment of forage reserves in the pasture areas of Southern Kazakhstan were reviewed and analyzed from the archives of the U.M. Akhmedsafin Institute of Hydrogeology and Geoecology, the Institute of Geography and Water Security. Additionally, literature sources from the archives of the National Scientific and Technical Library of Almaty and the library of the Institute of Geological Sciences named after K.I. Satpaev were examined. Data were collected from the Ministry of Ecology and Natural Resources, the Ministry of Water Resources and Irrigation, the Agency of the Republic of Kazakhstan for Statistics, materials from the Institute Kazgiprovodkhoz, as well as information from regional and district akimats of the Southern Kazakhstan regions concerning water supply and the prospective water demand of the rural population.

2.4. Regional Expedition Surveys

Regional expedition hydrogeological studies of the territories of the administrative regions of Almaty and Zhetysu, with groundwater sampling for chemical laboratory analysis, were conducted to assess the current state of pasture land waterlogging.

The sampling was conducted during the pre-field period, as well as based on archival and published data on the distribution of waterlogged pastures, including the number, location, and geographic coordinates of watering points. Catalogs of coordinates for irrigation wells and boreholes were compiled based on the distribution and water withdrawal from water intake structures. Preliminary maps and schematic plans for route surveys were developed within the boundaries of the administrative regions of the area.

Ground expeditionary studies were conducted from September to December 2024 by two field teams within the Almaty and Zhetysu regions of Southern Kazakhstan. During the surveys, existing springs, wells, and boreholes were examined and tested, water samples were collected, and the sanitary and ecological condition of the sites, as well as the technical condition of the watering points, were assessed. The total length of the route surveys in Southern Kazakhstan amounted to up to 4.8 thousand kilometers. A detailed examination was carried out on 28 wells, 26 boreholes, and 1 spring, with 55 water samples collected for chemical laboratory analysis (Table A1).

The map of the actual material from the field expedition surveys is shown in Figure 4.

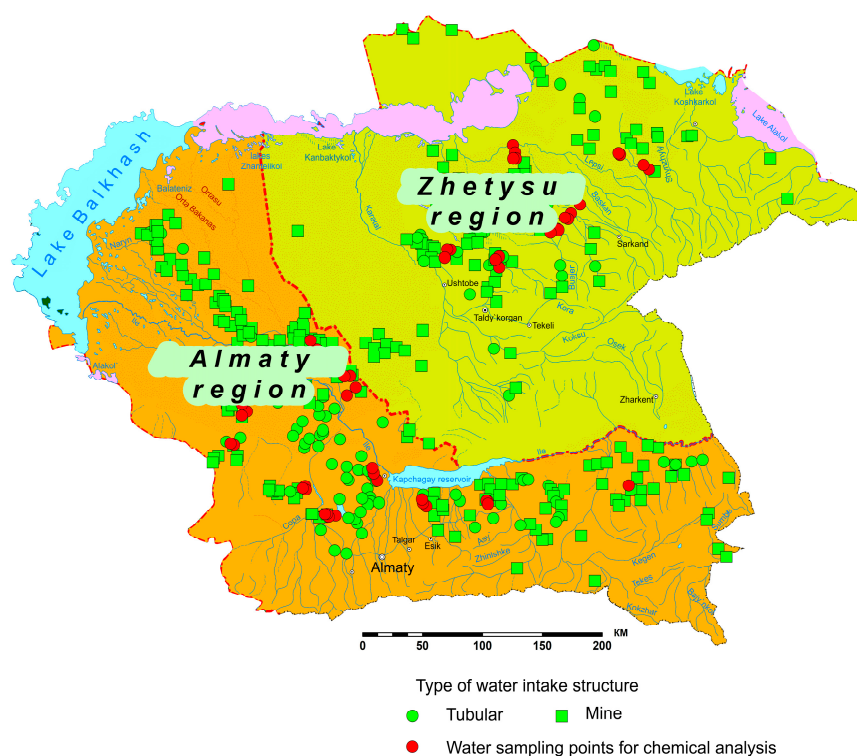


Figure 4. Map-diagram of the materials from the expeditionary surveys in the regions of Southern Kazakhstan (Almaty and Zhetysu regions).

During the route surveys in Almaty region, in the Zhambyl, Ili, Balkhash, Enbekshikazakh, and Uyghur districts, 16 boreholes, 15 wells, and 1 spring were surveyed, located near pastures and used to meet the water needs of livestock. A total of 32 water samples were collected. The total length of the route was 2.3 thousand kilometers.

In the Zhetysu region, during the route field work, 12 boreholes and 11 wells were surveyed in the Karatal, Sarkand, Aksu, and Alakol districts. A total of 23 water samples were collected. The total length of the route was 2.5 thousand kilometers.

In the Karatal district, 1 borehole and 3 wells located near wintering sites north of the city of Ushtobe were surveyed. In the Sarkand district, 4 wells were surveyed east of the Matay–Lepsy highway. In the Aksu district, during the field work, 9 boreholes and 2 wells were surveyed in the territories of wintering sites and agricultural farms (AFs), near the settlements of Kyzylagash, Kopa, Kyzyltu, Onim, Aksu, and Zhanalyk. In the Alakol district, north of the settlement of Kolbay, 2 boreholes and 2 wells were surveyed.

Chemical and analytical studies of groundwater samples collected during regional route surveys of the administrative regions of Southern Kazakhstan were conducted in September–December 2024. The laboratory chemical analytical tests were performed at the U.M. Akhmedsafin Institute of Hydrogeology and Geoecology, an accredited laboratory (Accreditation Certificate No. KZ.T.02.0782, valid until 27.11.2025). The set of components characterizing the quality of groundwater includes: mineralization, pH level, major chemical components of the water, as well as microcomponents (cadmium, lead, copper, zinc) and petroleum products. Exceeding the allowable concentrations of these components indicates contamination.

The methodologies for conducting laboratory tests, methods, and equipment for determining chemical indicators in the collected samples are summarized in Table 1.

Table 1. Methodologies for Conducting Laboratory Tests [34].

Component	Testing Methodologies	Component	Testing Methodologies
Sodium	GOST 26449.1-85, point 17.1 [35]	Carbonates	GOST 26449.1-85, point 7.1
Potassium	GOST 26449.1-85, point 18.1	Bicarbonates	GOST 26449.1-85, point 7.1
Calcium	GOST 26449.1-85, point 11.1	Chlorides	GOST 26449.1-85, point 9
Magnesium	GOST 26449.1-85, point 12	Sulfates	ST RK 1015-2000 [36]
Ammonium	GOST 33045-2014 [37]	Nitrates	GOST 33045-2014
Iron (Fe ²⁺)	ST RK ISO6332-2008 [38]	Nitrites	GOST 33045-2014
Iron (Fe ³⁺)	ST RK ISO6332-2008	Fluorides	ST RK 2727-2015 [39]
pH	ST RK ISO10523-2013 [40]	Total hardness	GOST 26449.1-85, point 10
Dry residue	GOST 26449.1-85	SiO ₂	GOST 26449.1-85, point 22
Boron	Rules for the standardization and documentation of food product quality 14.1:2.4.36-95	Iodides	GOST 23268.16-78 [41]
Cd, Pb, Cu, Zn, Petroleum products	Sanitary standards No 26 from 20.02.2023	Bromides	GOST 23268.15-78

3. Results and Discussion

Animal husbandry in Kazakhstan is an important sector of agricultural production, but the problems of the sector’s development largely depend on the condition of pastures. Currently, out of the 186.4 million hectares of pastureland in the country, more than 56.5% is not used due to the lack of irrigation and related issues with engineering structures for livestock watering, as well as drinking and domestic water supply for servicing personnel. The issue of pasture irrigation and its potential solutions has received considerable attention in the Concept for the Development of the Agro-Industrial Complex of the Republic of Kazakhstan for 2021–2030, developed by the Government of Kazakhstan [42]. Furthermore, ensuring access to drinking water for all population categories, including livestock farmers, is one of the key goals of sustainable development (SDG-6) “Clean Water and Sanitation”.

Currently, due to a sharp reduction in funding, most water supply systems and some of their branches are in unsatisfactory technical condition. Nearly half of the villages in the

northern part of the regions of Southern Kazakhstan have abandoned centralized water supply services due to high water costs, disruptions in water supply due to the emergency condition of water pipelines, and high unpaid debts to energy providers. The most common water supply systems for rural consumers, which cover more than 60% of the population with piped water, are local water supply systems. The technical condition of most of these systems cannot be considered satisfactory either.

Only 50–80% of the population in the villages have access to piped water, and in some cases, this figure drops to as low as 30%. This is due to the insufficient development of intra-village networks and the failure of water extraction wells. Moreover, the capacity of water intake structures does not always meet the full needs of the population, although agricultural water consumption tends to be relatively low. Due to high water tariffs, the population is forced to make wider use of local sources, opting out of piped water. In villages not covered by centralized water supply systems for household and drinking purposes, people collect water from backyard wells, village tube wells, as well as surface water sources, open reservoirs, or by hauling water.

Overall, in Southern Kazakhstan, a survey conducted as part of the state program Auyt–El Besigi on the availability of clean water for the rural population, as of January 2024, showed that 69,836 people in all regions do not have access to clean drinking water. At the same time, the known operational reserves for household and drinking water supply are sufficient to meet the current and future (2030 y.) population needs. As of 2024, there were 27,770 head of cattle, 12,563 sheep and goats, 13,318 horses, and 84 camels grazing in this area (Figure 5).

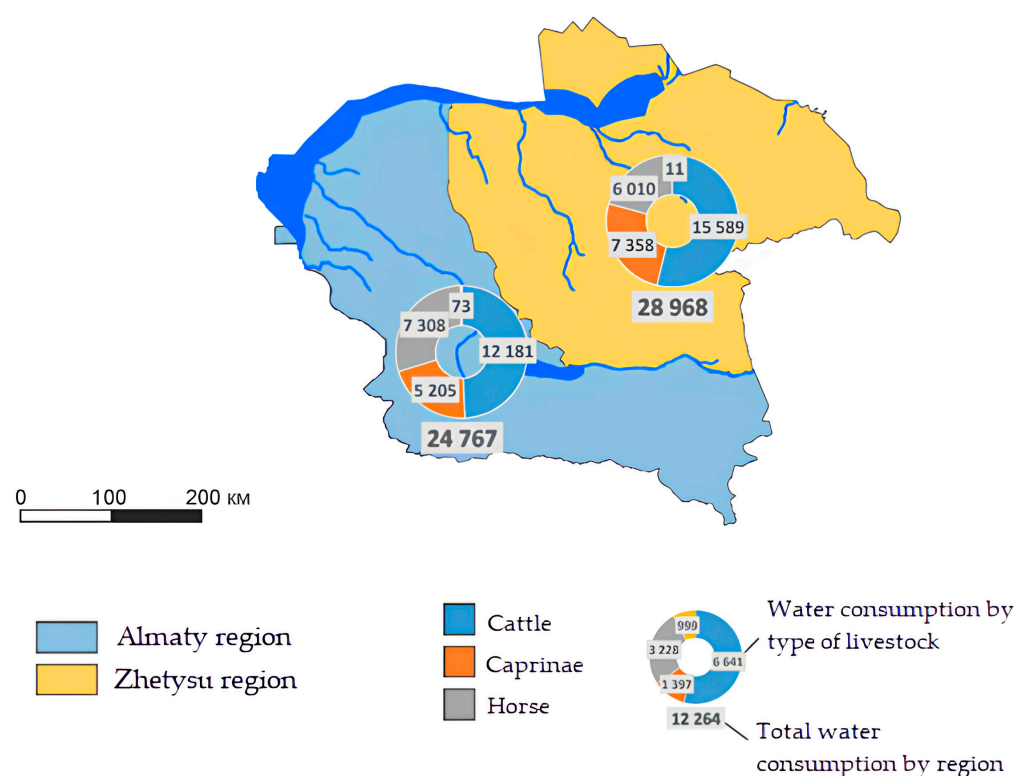


Figure 5. Water consumption by livestock in Almaty and Zhetysay regions.

For clarity, the annex presents the drinking water needs and water availability of the Southern Kazakhstan Agricultural District for 2024 and 2030 and (Table A2) and Water consumption by livestock species in the South Kazakhstan region (Table A3). For the analysis of water availability for livestock, the following scheme is proposed. The calculations of water consumption are based on the average daily water consumption rate

by species of agricultural animals. Water consumption in liters per day (L/day) for the calculations is taken for the maximum consuming individual of the given species, based on the average annual consumption.

As a result, the following initial data on water consumption for the four main types of agricultural animals grazing on pasture lands in the region were chosen: for cattle and horses—40 L/day; for sheep and goats—6 L/day; for camels—35 L/day. The livestock data were collected from the reports of district and regional akimat administrations as of 2023. The processing and analysis of the obtained data allowed for the identification of the total area of pastures, the usable area, and the assessment of the water consumption needs for the entire livestock population by administrative districts across five regions of Southern Kazakhstan. The total water requirement for pasture irrigation for livestock watering amounts to 53,735 thousand m^3 /year.

The results of this study can be used when considering and analyzing the implementation of the points in the Concept for the Development of the Agro-Industrial Complex of the Republic of Kazakhstan for 2021–2030, related to the irrigation of pastures in the Southern Kazakhstan region.

3.1. Hydrogeology of Almaty and Zhetysu Regions

Almaty Region. The territory of Almaty region is predominantly located within the northwestern and southern sectors of the Zhetysu-Alatau-Balkhash first-order hydrogeological district, which forms part of the broader Zhetysu-Alatau-Tian Shan hydrogeological region. Within this district, several major artesian basins are delineated, including the western part of the South Balkhash Basin, the Kopa-Ili Basin, and aquifers in shallow intermontane depressions. Additionally, fractured aquifer systems such as the Kyrgyz-Alatau and Kungey-Alatau basins are present. The southeastern section of the Shu-Ili Basin also extends into the central part of the region.

The principal reserves of fresh and slightly brackish groundwater are associated with aquifers in Quaternary, Neogene, Paleogene, and Cretaceous deposits distributed across the artesian basins. These aquifers play a critical role in supplying potable water, particularly for high-demand consumers. Although fractured aquifer systems typically contain smaller volumes of freshwater, their widespread occurrence across the region renders them practically significant for meeting the water needs of small-scale users.

The most promising aquifers and complexes for exploitation in Almaty region include:

(a) Quaternary alluvial–proluvial boulder-pebble and gravel-pebble aquifers located on the piedmont plains of the Zailiyskiy Alatau. These aquifers are found at depths of 5–200 m with water-bearing formations up to 400–500 m thick. Well yields range from 3–50 to 100–120 L/s. The water is predominantly fresh, with mineralization up to 0.5 g/L, occasionally reaching 1 g/L.

(b) Quaternary aeolian–alluvial and alluvial aquifers within the sandy massifs of Southern Pri-Balkhash and the floodplains of the Ili River and its tributaries. These are found at depths of 5–30 m, locally reaching 100 m. Well yields range from 0.5–3.0 L/s. Water salinity increases toward Lake Balkhash, ranging from fresh and slightly brackish to over 10–20 g/L in proximity to the lake.

(c) Confined aquifers in Neogene, Paleogene, and Cretaceous deposits are encountered in intermontane basins at depths of 150–300 m, and locally beyond 1000 m. These aquifers exhibit significant piezometric pressure and well yields up to 50–60 L/s. In the Almaty Basin, saline thermal waters have been identified at depths exceeding 1000 m.

The estimated exploitable reserves of groundwater with mineralization up to 10 g/L are 21,148.20 thousand m^3 /day, broken down by salinity as follows:

- Up to 1 g/L—17,160.80 thousand m^3 /day

- 1–3 g/L—3073.60 thousand m³/day
- 3–10 g/L—913.8 thousand m³/day

Freshwater reserves (≤ 1 g/L) constitute 81.1% of total estimated resources, while slightly brackish waters (1–3 g/L) account for 14.5%. The average predicted availability per 1 km² is 163.0 m³/day for freshwater and 29.20 m³/day for waters with mineralization between 1–3 g/L.

Natural groundwater resources are estimated at 16,096.43 thousand m³/day, with an average runoff modulus of 152.06 m³/day/km². In the Kopa-Ili Basin, modulus values increase northward from 172.8–432.0 to 432–864, and occasionally 864–1296 m³/day/km². Conversely, in the South Balkhash Basin, these values decrease toward Lake Balkhash from 86.4–172.8 to 43.2–86.4 and 25.92–43.2 m³/day/km², with coastal zones exhibiting values as low as 8.64–17.28 m³/day/km² or less. Exploitable reserves of groundwater total 6758.525 thousand m³/day, of which 6752.794 thousand m³/day is fresh (≤ 1 g/L).

This corresponds to an average of 64.15 m³/day/km² of exploitable reserves of fresh groundwater. The majority of the region is reliably supplied with proven reserves of groundwater suitable for domestic and drinking use. Only areas along the southern shore of Lake Balkhash and the left bank of the Ili River are classified as partially supplied with potable-quality water. Nevertheless, nearly all of the region's population resides within the reliably supplied zones. To date, no measurable impact of climate change on groundwater availability has been detected.

Zhetysu Region. The principal reserves of fresh groundwater in Zhetysu region are associated with aquifers in Quaternary, Neogene, Paleogene, and Cretaceous deposits, predominantly located within intermontane basins. These aquifers play a crucial role in supplying potable water to the population, especially to large-scale consumers. Although fractured aquifer systems contain significantly smaller volumes of fresh groundwater, their widespread occurrence across the region makes them a valuable resource for supplying small-scale water users. The most promising aquifers and hydrogeological complexes for exploitation in Zhetysu region include:

(a) Quaternary alluvial–proluvial boulder-pebble and gravel-pebble aquifers of the piedmont plains along the northern and southern slopes of the Dzungarian Alatau. These aquifers are found at depths ranging from 5 to 200 m, with water-bearing strata 400–500 m thick. Well yields vary from 3–50 to 100–120 L/s. The groundwater is predominantly fresh, with mineralization levels up to 0.5 g/L, occasionally reaching 1 g/L.

(b) Quaternary alluvial–proluvial aquifers of the Aktogay Depression in the Ayagoz River valley (North Balkhash Basin). Well yields may exceed 50 L/s. Groundwater is mostly fresh, with mineralization levels between 0.4 and 1 g/L; in some instances, salinity may range from 1 to 3 g/L.

(c) Quaternary aeolian–alluvial and alluvial aquifers within the sandy massifs of Southern Pri-Balkhash and the valleys of the Karatal, Lepsy, and Aksu rivers. These are found at depths of 5–30 m, locally reaching 100 m. Well yields range from 0.5–10 L/s. Groundwater is fresh to slightly brackish, with salinity increasing toward Lake Balkhash, reaching 3–10 g/L or more.

(d) Confined aquifers in Neogene, Paleogene, and Cretaceous deposits encountered within intermontane basins at depths of 150–300 m and exceeding 1000 m. These aquifers are characterized by high piezometric pressure, with well yields up to 50–60 L/s. In the Zharkent Depression, high-temperature fresh groundwater has been identified at depths of 800–3500 m, associated with Upper Cretaceous and Jurassic formations.

The estimated exploitable groundwater resources with mineralization up to 10 g/L amount to 28,680.1 thousand m³/day, broken down as follows:

- ≤ 1 g/L: 21,963.3 thousand m³/day

- 1–3 g/L: 5330.9 thousand m³/day
- 3–10 g/L: 1393.9 thousand m³/day

Freshwater (≤ 1 g/L) accounts for 76.6% of the total predicted resources, while slightly brackish water (1–3 g/L) comprises 18.6%. The estimated availability per square kilometer is 185.1 m³/day for freshwater and 44.93 m³/day for slightly brackish water.

Natural groundwater resources are estimated at 22,819.26 thousand m³/day, with an average runoff modulus of 195.264 m³/day/km². In the Kopa-Ili Basin, modulus values increase from south to north—from 172.8–432.0 to 432–864 and, occasionally, 864–1296 m³/day/km². In the South Balkhash Basin and the coastal zone of Lake Balkhash, modulus values drop to 8.64–17.28 m³/day/km² or lower. Moving away from the lake toward mountainous terrain, the modulus values gradually increase to 25.92–43.2; 172.8–432.0; 432.0–864.0; and 864.0–1296.0 m³/day/km². Exploitable reserves of groundwater total 10,411.284 thousand m³/day, of which 10,401.436 thousand m³/day is freshwater (≤ 1 g/L). This equates to an average of 87.66 m³/day/km² of exploitable fresh groundwater reserves.

At present, groundwater delivered to consumers meets potable water quality standards. However, the detection of contaminants in zones influenced by active water abstraction necessitates the establishment of permanent monitoring networks at production sites to track groundwater levels and quality. It is worth noting that anthropogenic factors have no significant impact on the volume of fresh and slightly brackish groundwater resources.

3.2. Chemical Analytical Studies of Groundwater Samples

The results of chemical analytical studies of groundwater samples from the Almaty region are presented in Table A4. The pH level of the groundwater was slightly alkaline, with values ranging from 7.1 to 8.1 (average value 7.95). A total of 32 groundwater samples were analyzed. The analysis of groundwater samples collected in the Almaty region revealed the presence of both fresh and saline groundwater. Fresh groundwater is widespread in the foothills of the Ile Alatau and the Ketmen Range. According to the main chemical indicators, they comply with the MAC (Maximum Allowable Concentration) standards for drinking water, except for the content of nitrates, nitrites, and fluoride. Heavy metals and petroleum products were either not detected or present in negligible concentrations (in thousandths). Saline and brackish groundwater were sampled in wells and boreholes near the settlements of Kurty, Kanshengel, Konayev, and the villages in the Balkhash district. Significant concentrations of nitrates and fluoride were found in the groundwater samples.

The results of chemical and analytical studies of groundwater samples from the Zhetysu region are presented in Table A5. In the Zhetysu region, fresh groundwater is predominantly distributed. Slightly saline waters were identified in wells near the city of Usharal. Elevated concentrations of nitrates, nitrites, ammonium nitrogen, and fluoride were found in the groundwater samples. Petroleum products and heavy metals were either absent or found in negligible quantities.

The processing of the above-mentioned laboratory results of groundwater samples from the Almaty and Zhetysu regions was carried out using the AquaChem 11 (S/N: AQCHM-700-444163796-4298) software package, developed by Waterloo Hydrogeologic (Canada), for graphical representation in the form of Piper diagrams. These diagrams depict the main anion-cation composition of groundwater in the Almaty region, as shown in Figure 6.

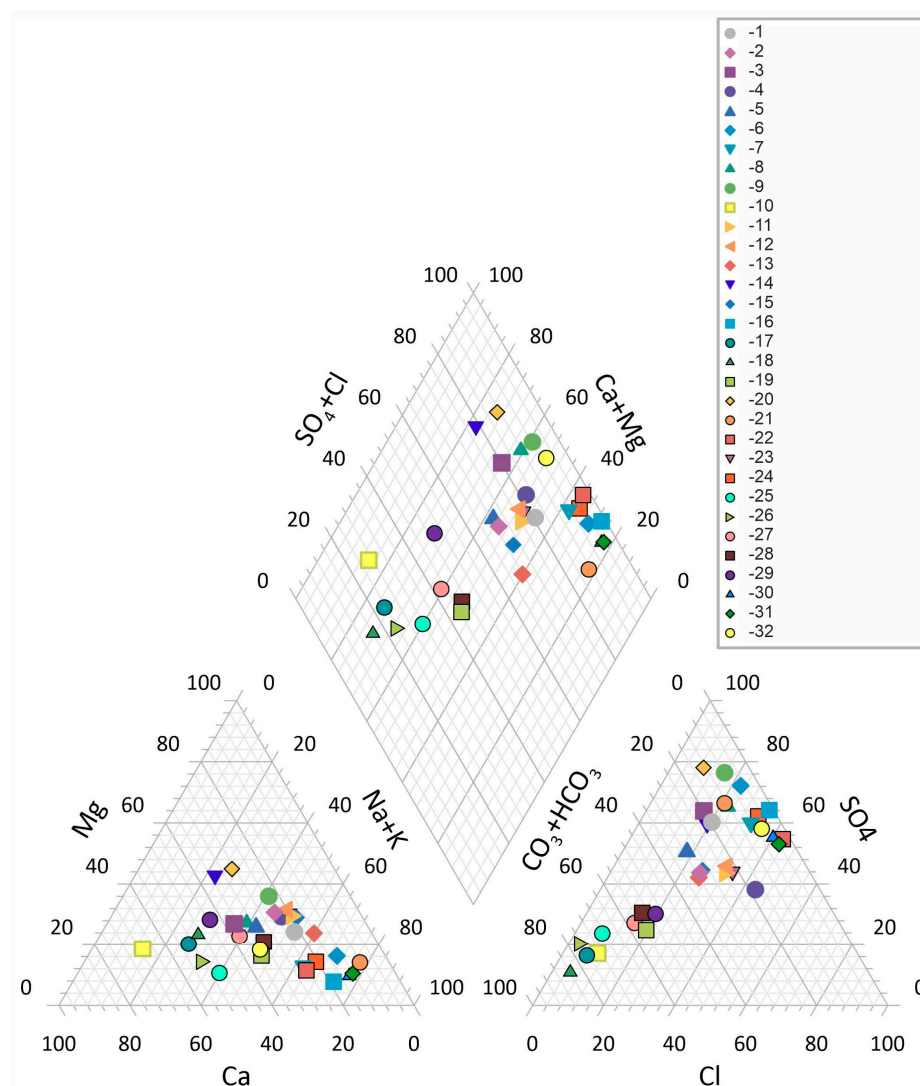


Figure 6. Piper diagram showing the chemical composition of groundwater in the Almaty region: 1—Bakanas 1; 2—Bakanas 2; 3—Birlik 3; 4—Sorbulak 1 (western part); 5—Birlik 2; 6—Kurtov 2; 7—Kurtov 3; 8—Mialy 1; 9—Mialy 2; 10—Chundja 2; 11—East Kanshengel 1; 12—East Kanshengel 2; 13—East Kanshengel 3; 14—Sorbulak lake 3 (western part); 15—Sorbulak lake 4 (western part); 16—Konayev 1 (western part); 17—Kyrbaltabay 1; 18—Kyrbaltabay 2; 19—Kyrbaltabay 3; 20—Birlik 1; 21—Mialy 3; 22—West Kanshengel 1; 23—Sorbulak lake 2; 24—Kurtov 1; 25—Chundja 1; 26—Chundja 3; 27—Shelek 1; 28—Shelek 2; 29—Shelek 3; 30—Western City of Konayev 2 (Shoshkaly); 31—Western City of Konayev 3; 32—West Kanshengel 2.

At Well No. 1 in Chundzha, the maximum permissible concentration (MPC) of silicon dioxide (SiO_2) is exceeded. With an MPC of 10 mg/dm^3 , the result is 12.3 mg/dm^3 . At Well Chundzha No. 3, the MPC for silicon dioxide (SiO_2) is also exceeded. With an MPC of 10 mg/dm^3 , the result is 10.1 mg/dm^3 . At Well No. 1 west of Lake Sorbulak, the MPC is exceeded for nitrates (NO_3), fluorides (F), and total mineralization. With an MPC for NO_3 of 45 mg/dm^3 , the result is 147 mg/dm^3 ; for F, the MPC is 1.5 mg/dm^3 , the result is 5 mg/dm^3 ; for total mineralization, the MPC is 1000 mg/dm^3 , and the result is 1100 mg/dm^3 . At Well No. 2 west of Lake Sorbulak, the MPC is exceeded for nitrates (NO_3) and fluorides (F). For NO_3 (MPC: 45 mg/dm^3), the result is 82 mg/dm^3 ; for F (MPC: 1.5 mg/dm^3), the result is 4.4 mg/dm^3 . At Well No. 3 west of Lake Sorbulak, the MPC is exceeded for fluorides (F) and total mineralization. For F (MPC: 1.5 mg/dm^3), the result is 2 mg/dm^3 ; for mineralization (MPC: 1000 mg/dm^3), the result is 1102 mg/dm^3 . At Well No. 4 west of Lake Sorbulak, the MPC is exceeded for nitrates (NO_3) and fluorides

(F). For NO_3 (MPC: 45 mg/dm³), the result is 50 mg/dm³; for F (MPC: 1.5 mg/dm³), the result is 5 mg/dm³. At Well No. 1 in Kurty, the MPC is exceeded for chlorides (Cl), sulfates (SO_4^{2-}), nitrates (NO_3), fluorides (F), and mineralization. For Cl (MPC: 350 mg/dm³), the result is 574 mg/dm³; SO_4^{2-} (MPC: 500 mg/dm³), the result is 1772 mg/dm³; NO_3 (MPC: 45 mg/dm³), the result is 191 mg/dm³; F (MPC: 1.5 mg/dm³), the result is 2.9 mg/dm³; mineralization (MPC: 1000 mg/dm³), the result is 4062 mg/dm³. At Well No. 2 in Kurty, the MPC is exceeded for Cl, SO_4^{2-} , NO_3 , F, and mineralization. For Cl: 493 mg/dm³; SO_4^{2-} : 3286 mg/dm³; NO_3 : 463 mg/dm³; F: 4.9 mg/dm³; mineralization: 6605 mg/dm³. At Well No. 3 in Kurty, the MPC is exceeded for Cl, SO_4^{2-} , NO_3 , F, and mineralization. For Cl: 352 mg/dm³; SO_4^{2-} : 1115 mg/dm³; NO_3 : 158 mg/dm³; F: 2.7 mg/dm³; mineralization: 2701 mg/dm³. At Well No. 1 west of Kanshengel, the MPC is exceeded for Cl, SO_4^{2-} , NO_3 , F, and mineralization. For Cl: 1007 mg/dm³; SO_4^{2-} : 1823 mg/dm³; NO_3 : 90 mg/dm³; F: 2.5 mg/dm³; mineralization: 4609 mg/dm³. At Well No. 2 west of Kanshengel, the MPC is exceeded for Cl, SO_4^{2-} , NO_3 , F, and mineralization. For Cl: 360 mg/dm³; SO_4^{2-} : 950 mg/dm³; NO_3 : 120 mg/dm³; F: 1.8 mg/dm³; mineralization: 2199 mg/dm³. At Well No. 1 east of Kanshengel, the MPC is exceeded for F and mineralization. For F: 2.8 mg/dm³; mineralization: 1018 mg/dm³. At Well No. 2 east of Kanshengel, the MPC is exceeded for F and mineralization. For F: 3.9 mg/dm³; mineralization: 1138 mg/dm³. At Well No. 3 east of Kanshengel, the MPC is exceeded for F and mineralization. For F: 4 mg/dm³; mineralization: 1090 mg/dm³. At Spring No. 1 west of Konayev, the MPC is exceeded for Cl, SO_4^{2-} , F, and mineralization. For Cl: 1011 mg/dm³; SO_4^{2-} : 2544 mg/dm³; F: 3.4 mg/dm³; mineralization: 5498 mg/dm³. At Well No. 2 west of Konayev (Shoshkaly), the MPC is exceeded for Cl, SO_4^{2-} , NO_3 , F, and mineralization. For Cl: 1510 mg/dm³; SO_4^{2-} : 3580 mg/dm³; NO_3 : 709 mg/dm³; F: 3.6 mg/dm³; mineralization: 9422 mg/dm³. At Well No. 1 in Mialy, the MPC is exceeded for F and mineralization. For F: 1.6 mg/dm³; mineralization: 2210 mg/dm³. At Well No. 2 in Mialy, the MPC is exceeded for SO_4^{2-} and mineralization. For SO_4^{2-} : 1044 mg/dm³; mineralization: 1860 mg/dm³. At Well No. 3 in Mialy, the MPC is exceeded for Cl, SO_4^{2-} , F, and mineralization. For Cl: 366 mg/dm³; SO_4^{2-} : 1580 mg/dm³; F: 3 mg/dm³; mineralization: 3446 mg/dm³. At Well No. 1 in Birlik, the MPC is exceeded for SO_4^{2-} and mineralization. For SO_4^{2-} : 1397 mg/dm³; mineralization: 1000 mg/dm³.

The analysis of groundwater quality conducted in the Almaty region has revealed a widespread contamination issue, with more than 60% of tested wells exceeding safe limits for nitrate, fluoride, and total mineralization, particularly in areas near Lakes Sorbulak, Kurty, and Konayev. The sources of this pollution are likely to be agricultural runoff from fertilizers, natural geological formations rich in fluoride, and legacy industrial waste dating back to the Soviet era, which contains extremely high levels of chlorides and sulfates. Immediate action is required to address this issue, including restrictions on the use of heavily contaminated wells, installation of fluoride filters, and measures to reduce nitrate concentrations. These findings underscore the urgent need for updating water resource management policies and investing in improved pasture water infrastructure in order to ensure food security and protect public health.

These diagrams depict the main anion-cation composition of groundwater in the Zhetysu region, as shown in Figure 7.

At Well 3 in the village of Kyzylagash, the fluoride (F) concentration exceeds the MPC. With an MPC of 1.5 mg/dm³, the result is 2.6 mg/dm³. At Well 1 in Kyzylagash, the fluoride (F) level also exceeds the MPC, with a result of 1.7 mg/dm³. At Well 3 in the city of Usharal, exceedances of the MPC were recorded for sulfates (SO_4^{2-}), fluorides (F), and total mineralization. With an MPC of 500 mg/dm³ for SO_4^{2-} , the result is 829 mg/dm³; for F, with an MPC of 1.5 mg/dm³, the result is 5.7 mg/dm³; and for mineralization, with an

MPC of 1000 mg/dm^3 , the result is 2143 mg/dm^3 . At Well 2 in Usharal, exceedances were also found for SO_4^{2-} (555 mg/dm^3), F (5 mg/dm^3), and mineralization (1490 mg/dm^3). At Well 1 in Usharal, the fluoride (F) level exceeds the MPC, with a result of 2 mg/dm^3 . At Well 1 in the village of Lepsy, the fluoride (F) concentration is 2.6 mg/dm^3 . At Well 2 in Lepsy, fluoride reaches 5.8 mg/dm^3 . At Well 3 in Lepsy, exceedances were recorded for fluoride (4.2 mg/dm^3) and mineralization (1285 mg/dm^3). At Borehole 2 in the village of Kyzyltu, the fluoride (F) concentration exceeds the MPC, with a result of 1.7 mg/dm^3 . At Well 1 in the village of Koilyk, fluoride (F) exceeds the MPC, with a result of 1.6 mg/dm^3 . At Well 2 in Koilyk, exceedances were detected for nitrates (NO_3^-), fluorides (F), and mineralization: for NO_3^- (275 mg/dm^3), for F (2.4 mg/dm^3), and for mineralization (2119 mg/dm^3).

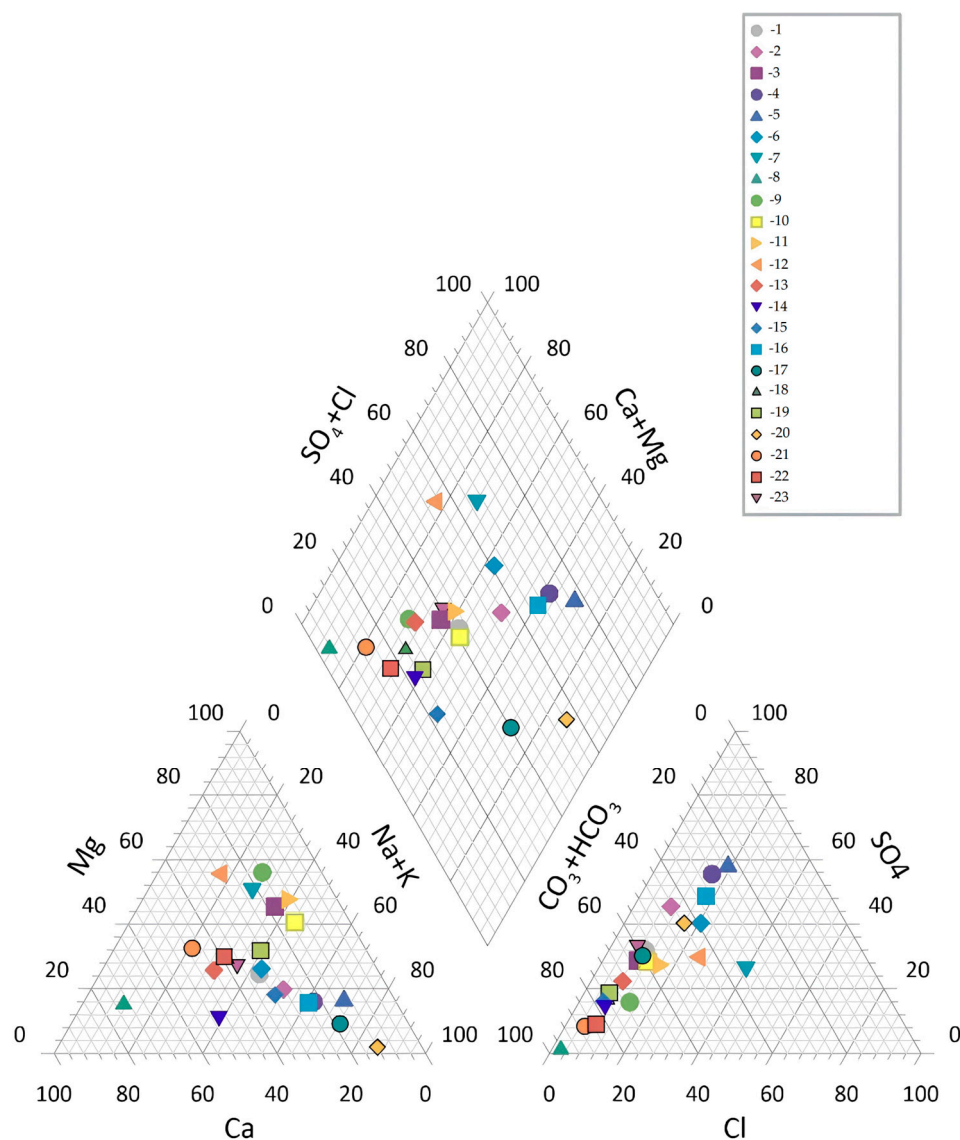


Figure 7. Piper diagram showing the chemical composition of groundwater in the Zhetysu region: 1—Kyzylagash 1; 2—Kyzylagash 3; 3—Lepsy 2; 4—Usharal 2; 5—Usharal 3; 6—Usharal 1; 7—Koilyk 2; 8—Koilyk 1; 9—Lepsy 1; 10—Lepsy 3; 11—Lepsy 4; 12—Usharal 4; 13—Kyzyltu 1; 14—Aksu; 15—Zhanalyk; 16—Koilyk 3; 17—Koilyk 4; 18—Kopa 1; 19—Kopa 2; 20—Kyzyltu 2; 21—Onim 1; 22—Onim 2; 23—Kyzylagash 2.

This study revealed water quality issues in the Zhetysu region, with hazardous levels of fluoride ($1.6\text{--}5.8 \text{ mg/dm}^3$) detected in all surveyed wells, exceeding permissible limits. The most severe contamination was observed in Usharal and Lepsy, where fluoride

concentrations were nearly four times higher than the maximum allowable concentration, accompanied by elevated levels of sulfates and total mineralization in some cases. These issues are likely caused by a combination of natural sources (fluoride-rich geological formations) and anthropogenic activities (industrial waste and runoff). Immediate action is required to provide clean alternative water supplies and to investigate the underlying causes of pollution, followed by long-term measures such as improved water treatment and updated regulations to protect public health and agriculture in the area.

3.3. Justification and Evaluation of Promising Aquifer Horizons for Development in Pasture Areas

Almaty Region. The pasturelands within the region are widely developed and occupy all geomorphological areas. The foothill areas encompass the foothill plains on the northern slopes of the Ile Alatau, Terkey and Kungey Alatau, Ketmen, and small areas of the northeastern part of the Shu-Ili mountains (with the majority of this area belonging to the Zhambyl region). Structurally, this area represents the Kopa-Ile intermountain depression—a typical multi-layered groundwater basin located between the northern slopes of the Tien Shan and the southern slopes of the Zhetysu Alatau. The northern part of the region is dominated by the vast South-Priialkhash Depression, occupied by sandy deserts. The pasturelands in the foothill areas of the Ile Alatau and Ketmen mountain ranges occupy flat plain sections with some uneven terrain, sloping toward the valley of the Ili River. In some areas, they alternate with fields where various agricultural crops are grown, relying on irrigation from surface water sources.

In the Almaty region, both groundwater and artesian waters are widely distributed. Groundwater forms underground flows directed from the mountains towards the valleys of the Ili and Kopa rivers. These waters are mainly located in alluvial and proluvial boulder-gravel deposits of the foothill aprons, as well as in sandy-gravel formations of the foothill plains and gravelly alluvial deposits of river valleys. The thickness of the aquifers varies. In the foothill apron, in the deposits of the alluvial fans, the thickness is maximal—400–500 m, while at the foot of the mountains it ranges from 20–25 m to 50 m (Ile Alatau). Further downstream, in the zone where the groundwater flow of the alluvial fans is disrupted, the thickness of the aquifers becomes small—2–5 m. However, the depth of groundwater here is the shallowest, ranging from several meters to 8–12 m, while near the mountains, in the foothill aprons, it is greatest—100–200 m. Typically, at a distance of 16–20 km from the mountains, due to the lowering of the land surface, the groundwater levels are very close to the surface, often emerging, and creating small watercourses, such as “karasu” or sazy—highly moist land areas distinguished by intense herbaceous vegetation.

The yield of the aquifers varies widely: the maximum discharge of wells in riverine areas and on the periphery of alluvial fans reaches 5–30 L/s, while the minimum yield is found in inter-river and elevated areas, composed of fine soils and clay-rich ground, where it is 3–5 L/s. Groundwater from the alluvial fans, river valleys, and areas of disruption plays a significant role in irrigating pastures and supplying water to settlements. Their exploitation in these areas can be carried out using shaft wells at locations with shallow groundwater levels. These are peripheral areas of alluvial fans, where the depth to water does not exceed 10 m, and if deeper, shallow wells (30–60 m) can be used. The method of capturing descending springs and numerous springs is also very effective, particularly in the valleys of the many small rivers crossing the foothill slope plains, as well as springs along the periphery of alluvial fans. The mineralization of the water ranges from 0.2 to 0.5 g/L, and in areas with shallow groundwater, it increases to 1–2 g/L, with a calcium bicarbonate composition.

The foothill plains on the northeastern slope of the Shu-Ili mountains, in alluvial and deluvial-proluvial deposits, contain high-quality groundwater suitable for pasture

irrigation. Lithologically, the aquifers are represented by loams with a significant amount of rubble, coarse sand, gravel, and pebbles. The thickness of the deposits ranges from 10 to 60 m. The depth of groundwater varies from 1–3 m to 20–50 m. The flow rates of wells range from 0.5 to 10 L/s, with a water level drop of 5–15 m. In terms of water quality, the groundwater is slightly saline, with mineralization ranging from 1 to 3 g/L, and a sulfate-sodium and mixed anion composition.

Artesian waters are widespread in all deposits of the Mesozoic-Cenozoic cover. The most water-rich are the Quaternary, Upper Pliocene, Paleogene, Upper Cretaceous, and Jurassic deposits. In the Kopa-Ile basin, the total thickness of the saturated Quaternary deposits containing artesian waters reaches 400–500 m. The depth of the groundwater ranges from 30–50 m to 300–400 m. The pressure in the aquifers increases with the depth of the aquifer. The waters are fresh (0.2–0.5 g/L), calcium bicarbonate in composition. The discharge rates of wells range from 20 to 50 L/s at artesian flow. In the Eastern Talgar Depression, artesian wells yield between 5 and 25 L/s of freshwater with a calcium bicarbonate composition.

The Karoy Plateau is located between the Shu-Ili Mountains and the western foothills of the Zhetysay Alatau. It is a peneplained plain, with Paleozoic rocks exposed at its center. Groundwater is not widespread across the entire area. In the Quaternary alluvial-deluvial deposits of the Sorbulak Depression, they are accessed by wells at depths ranging from 2 to 30 m. The mineralization of these waters is varied. The predominant waters are weakly mineralized (1–3 g/L) with a sodium sulfate composition. In areas where the groundwater is shallow (less than 3 m deep), the mineralization increases to 48 g/L. The flow rates of the water points range from 0.1 to 0.3 L/s. The groundwater reserves are replenished only during the short period of spring snowmelt.

In the Neogene and Cretaceous deposits, groundwater is found in logs at depths of 5–10 m. The mineralization of these waters is variable, ranging from 0.7 to 6 g/L. Sodium sulfate-chloride waters with a dry residue of 3–5 g/L are predominant. Fracture waters in the effusive-sedimentary Paleozoic deposits are accessed by wells in the Shushkala log and on the southern edge of the plateau. These waters also surface as springs in the Ile River valley and near Lake Sorbulak. The flow rates of the water points reach up to 0.1 L/s. The waters are fresh and slightly saline, with mineralization ranging from 1 to 3 g/L, and a sodium bicarbonate-sulfate composition.

The hilly-ridge plain of Southern Priibalkhashya is the largest desert and semi-desert area in the region, used as excellent pasturelands, especially during the winter months. It includes the sandy massifs of Zhuangkum, Taukum, Sarytau, Saryesik-Atyrau, and several smaller ones, covering a total area of about 4 million hectares. The terrain of this area is characterized by hilly-ridge and large-ridge topography. On the Akdalinsky and Baknassky massifs, the relief is mainly undulating and flat, with only occasional low ridges and mounds.

Groundwater is widely distributed in this area. It is associated with Quaternary alluvial-lake deposits, which have been reworked at the upper levels by aeolian processes and are predominantly represented by fine-grained sands with occasional layers of clay, loams, and silts. To the northwest, the clay content of the strata increases. In the modern alluvial valley of the Ile River (in the southern part, closer to the foothill plains), groundwater lies in poorly sorted sands, sometimes mixed with gravel, with a thickness of up to several tens of meters. The thickness of the aquifers in the southern and central parts of the Saryesik-Atyrau sands, at the latitude of the settlements of Bakanas and Akkum, reaches 200–250 m, gradually decreasing to 50–40 m towards Lake Balkhash.

The depth of the groundwater level varies significantly depending on the relief of the area. In the inter-ridge depressions, it reaches 5 m, while under the mounds and ridges, it

can be 10–15 m. Near Lake Balkhash, in the valley and delta of the Ili River, groundwater is encountered at a depth of no more than 3 m. On the Baknass plain terrace and in the inter-ridge depressions of the Saryesik-Atyrau sands, the depth to the water is somewhat greater, reaching 5–10 m, while under the mounds and ridges, it ranges from 10 to 30 m. In the large-ridge sandy massif of Zhuangkum, which represents a high terrace-like step, even in inter-ridge depressions, the groundwater is found at depths of up to 100–130 m, and on the ridges, this value increases by 1.5 to 2 times. In the inter-ridge depressions of the large-ridge sandy massif of Sarytaukum, the depth to groundwater increases as the distance from the Ili River grows, with wells and dug wells revealing groundwater at depths of 30–50 m in depressions and 30–100 m under ridges and mounds. Within the ancient alluvial plains of Baknass and Akdalinsk, depths of 5–10 m are dominant. On the floodplain terraces of the Ili River, groundwater is typically found at depths of 6–12 m.

The flow rates of the wells range from 1 to 5 L per second, with a drop in water levels of 5 to 20 m. The mineralization of groundwater in the sandy massifs varies widely depending on the sources and recharge conditions. Freshwaters with a mineralization of up to 1 g/l and a calcium bicarbonate composition are common in the southern parts of the Saryesik-Atyrau, Taukum, and Zhuangkum sands, where there is the most intensive infiltration of atmospheric precipitation, as well as in the freshwater zone influenced by the Ili River. As one moves away from the riverbed toward the watersheds of the sandy massifs, mineralization increases to 1–3 g/L, and the composition becomes sodium sulfate. As the flow approaches Lake Balkhash, the salinity of the water increases to 10–20 g/L, and the composition changes to sodium chloride-sulfate. On the shores of Lake Balkhash, the mineralization of groundwater reaches 40–50 g/L, and the composition becomes sodium chloride. In the modern delta of the Ili River, the mineralization and composition of the groundwater are highly varied. On small areas, both fresh calcium bicarbonate waters and salty (up to 50 g/L) sodium chloride waters are found. This is explained by the close occurrence of groundwater (1–3 m), intense evaporation, and continental salinization, alternating with dilution and mixing of salty waters with fresh river waters.

Artesian waters are associated with Jurassic, Upper Cretaceous, Paleogene, and Neogene deposits (lenses and layers of sands and conglomerates) that lie at depths of 200 to 500 m. The artesian waters are pressurized, fresh, and slightly saline, predominantly of sodium sulfate composition. The discharge rates of the wells range from 0.5 to 5.0 L per second, with a drop in the water level of 10 to 25 m.

Zhetysu region. Three major basins are established here—the Southern Pribalhash (eastern part), the Alakol (western part), and the Ili (northern part). The foothill plains of the northern slope of the Zhetysu Alatau cover the foothill fans, where both groundwater and artesian waters are developed. Here, the alluvial fans of large and small rivers and seasonal watercourses stand out, composed of cobble-gravel and gravel-cobble formations, with boulders in the valleys of large rivers, and rubble and scree with clayey fill in the valleys of temporary watercourses.

Groundwater in the foothill fan is found at depths of 60–80 m in the upper part of the alluvial cones, while in the lower part, they emerge to the surface in the form of springs and small rivers, such as “karasu” streams. The water levels experience significant fluctuations, ranging from 6 to 8 m. The highest water levels occur in August and September, while the lowest levels are observed in April. The foothill fan serves as the primary recharge area for groundwater in the Southern Pribalhash Basin. The total volume of groundwater entering the Southern Pribalhash Basin from the foothill fan is 27 cubic meters per second, while in the Alakol Basin, it is 17.8 cubic meters per second.

The well productivity reaches 20 L per second with a water level drop of 2 m and even 42 L per second with a drop of 4 m. The groundwater is generally of good quality, fresh, calcium bicarbonate, with mineralization ranging from 0.2 to 0.5 g/L.

The artesian waters of the foothill fan on the northern slope of the Zhetysu Alatau are associated with alluvial-proluvial lower and middle Quaternary boulder-gravel-cobble deposits, with a thickness ranging from 30 to 150 m, containing layers and lenses of loams, silts, gravel, and scree. Up to four artesian aquifers are encountered in these deposits, with piezometric levels situated 1–15 m above or 5–10 m below the ground surface. The discharge rates of wells can reach 20–50 L per second, and when the water level drops by 20–35 m, production rates range from 30 to 120 L per second. However, the most common discharge rates for wells are between 55 and 100 L per second. The highest water yield from these deposits is observed in the alluvial fans of the Lepsy River. The water is fresh, calcium bicarbonate, with mineralization ranging from 0.2 to 0.5 g/L.

In the Alakol Basin, artesian waters lie at depths of 100–150 m and are associated with gravel layers, 15–20 m thick, located between clay and loam deposits. Toward the center of the basin, the roof of the aquifers drops to depths of 180–540 m. The depth of the artesian water level in the upper parts of the alluvial fans reaches 82–100 m or more. As the underground flow moves towards the Alakol and Sasykkol lakes, the depth gradually decreases to 2–3 m. In the discharge zone near the lakes, the artesian water levels rise above the surface by 5–16 m. The discharge rates of wells vary from 1.5 to 7 L per second in wells to 48 to 79 L per second or more when the water level drops by 10–21 m. The water is fresh, calcium bicarbonate, with mineralization up to 0.5 g/L.

The foothill plains of the southern slope of the Zhetysu Alatau stretch for 45 km and have a width of up to 50–60 km, extending from the foothills of the mountains to the Ili River. The water-bearing deposits are represented by alluvial-proluvial Quaternary gravelly, gravel, and cobble formations with layers and lenses of loess, clay, and gravel. The thickness of the deposits reaches 25–300 m, containing both groundwater and artesian water.

Groundwater is distributed along the southern slopes of the mountains, south of the Chundzha-Dubun fault zone, and in the deltas of rivers. They are found at depths of 50–100 m, and in the peripheral areas of the foothill fans and river valleys, the depth of occurrence does not exceed 3–5 m. The thickness of the aquifer zone ranges from 5 to 20 m, reaching 100 m in the area of the town of Zherkent. The discharge rates of wells vary, with 5–10 L/s predominating at a water level drop of 2–5 m. The water is predominantly fresh (0.5–1.0 g/L), of calcium bicarbonate composition, and only in areas with shallow water levels, in the zones of underground flow dispersion, the mineralization increases to 3–5 g/L, and the composition changes to sodium sulfate.

Artesian waters are widely distributed in the region. The most water-bearing deposits are those of the Upper Pliocene, characterized by coarse-clastic composition. In the foothills of the Zhetysu Alatau, along its southern slopes, wells are known to have discharges up to 25 L/s. The water is fresh, with mineralization ranging from 0.2 to 1.0 g/L, of calcium bicarbonate and sodium composition.

The hummocky-ridged plains in the eastern part of the Southern Pribalhasha region cover the eastern parts of the Juankum and Saryesik-Atirau sands, the Lyukkum, Aralkum, and Karakum sands located east of the Karatal River. These sandy masses have a ridged and hummocky Aeolian relief.

Groundwater is associated with lake and lake-alluvial fine-grained sands with interlayers and lenses of ribbon-shaped clays and loams, which have been reworked by Aeolian processes in the upper part. The thickness of these deposits in the eastern part is 40–50 m, decreasing to 30 m near Lake Balkhash. In the Saryesik-Atirau sands, it ranges from 10–150 m, gradually decreasing to 30 m in the Aralkum sands.

The depth of groundwater occurrence in the inter-ridge depressions of the sands reaches 10–15 m, up to 30 m on the ridges, and in the Juankum sands, it is up to 100 m on the ridges, and 30–80 m in the inter-ridge depressions. Near Lake Balkhash, the depth of groundwater decreases to 5–10 m in inter-ridge depressions and up to 20 m on the ridges. The discharge of wells varies from 0.1 to 0.5 L/s, and of boreholes, from 2 to 3 L/s with a water level drop of 5–20 m.

The mineralization of water in the sandy masses varies widely, from freshwater in the foothills of the Zhetysu Alatau to saline water (30 g/L and more) along the coast of Lake Balkhash. The chemical composition changes from calcium and sodium bicarbonate to sodium chloride. In the western part of the region, in the Saryesik-Atirau sands, there are individual areas where a small amount of atmospheric precipitation falls, and the influence of surface waters is minimal. In these areas, the mineralization of groundwater increases to 3–5 g/L.

In the alluvial deposits of the rivers Karatal, Aksu, and Lepsy, the mineralization of groundwater ranges from 0.3 to 0.95 g/L with a calcium bicarbonate composition. The discharge of wells ranges from 0.1 to 0.5 L/s, and from boreholes, from 2 to 3 L/s with a water level drop of 5–20 m.

Artesian waters in the eastern part of the Southern Pribalhasha region are associated with fractured Paleozoic rocks (porphyries, porphyrites, sandstones, and aleurolites) and lie at depths of 250–800 m. The piezometric levels are established at depths of 0.3–5 m, and less frequently at 2–6 m. The discharge of wells ranges from 0.15 to 3 L/s with a water level drop of 7–45 m. Near the Zhetysu Alatau, the waters are fresh with a mineralization of up to 1 g/L and have a calcium bicarbonate composition. However, at some distance from the mountains, the total salinity increases to 10–15 g/L, and the composition becomes sodium chloride.

Among the Neogene clays, in the sandy lenses and layers with a thickness of 5–10 m, high-pressure, sometimes self-well, slightly brackish and saline waters have been uncovered, with a mineralization of 1 to 5 g/L, and a composition primarily of sodium sulfate, occasionally sodium bicarbonate. The discharge of wells ranges from 1.2 to 5.5 L/s with a water level drop of 37–44 m. In the lower reaches of the Karatal River, the thickness of water-bearing layers increases to 50 m. The depth of artesian waters lies between 200 and 400 m. The discharge rates of wells vary from 0.5 to 5 dm³/s.

Thus, in the Almaty region, for pasture irrigation and related oasis irrigation, it is recommended to use up to 45% of the operational groundwater reserves. In the Zhetysu region, considering the vast reserves of groundwater in the sandy massifs, 15–17% is recommended for pasture irrigation and oasis irrigation.

4. Conclusions

Kazakhstan is facing problems related to surface and groundwater resources for pasture centers' water supply. The risk of water scarcity and inefficient water resource management could become a significant obstacle to the long-term socio-economic progress of Kazakhstan.

Regional expeditionary surveys were conducted to assess the current state of groundwater resource development for pasture irrigation in the administrative regions of Southern Kazakhstan (Almaty and Zhetysu), as well as chemical and analytical studies of groundwater samples collected during the regional surveys.

The field surveys were carried out from September to December 2024 by two field teams within the administrative regions of Southern Kazakhstan (Almaty and Zhetysu). During the surveys, existing springs, wells, and pits were examined and tested, water samples were collected, and the sanitary-ecological condition of the areas and the technical

state of water points were evaluated. The comprehensive survey of the route in the regions of South Kazakhstan amounted to a total length of approximately 4800 km. During this process, 28 springs, 26 wells, and 1 spring were subjected to a thorough examination. Moreover, 55 samples of water were collected for subsequent detailed chemical analysis in laboratories.

Chemical and analytical studies of groundwater samples were conducted from September to December 2024 by the Chemical-Analytical Research Laboratory of the IGG named after U.M. Akhmedsafin. The processing of the laboratory results of groundwater samples was carried out using the AquaChem 11 software suite for graphical representation in the form of Piper diagrams. The summary tables and graphical displays compiled from the chemical analytical study results were used to create geographic information databases.

An assessment of the current and prospective demand for fresh and low-mineralized groundwater for the irrigation of pasture areas in the administrative regions of Southern Kazakhstan (Almaty and Zhetysu) was carried out. The calculation of water consumption was based on the “Average Daily Water Consumption Rate by Types of Agricultural Animals”, with water consumption in liters per day taken for the highest-consuming individual of each species, based on average annual consumption. Data on the number of livestock were collected from the reports of district and regional akimat managements for the year 2024. The processing and analysis of the obtained data allowed for the identification of the total area of pastures, including the used area, and the evaluation of the watering needs for the entire livestock population in the administrative districts of the two regions of Southern Kazakhstan.

An assessment and justification of the prospective aquifers for the development of pasture areas in the arid zone of Southern Kazakhstan, considering climate and anthropogenic changes, have been carried out. The region under consideration has all of the necessary conditions for the intensive development of transhumant animal husbandry, including high-productivity pastures and the required groundwater resources. In the semi-desert and desert pastures, significant reserves of groundwater suitable for agricultural use are concentrated. The resource potential of underground waters allows for the solution of tasks related to the widespread irrigation of pastures and the provision of water for the entire livestock population that can be kept in this area, provided that the necessary water–land infrastructure is established, including the creation of areas for growing and harvesting emergency feed reserves, and the restoration of water infrastructure facilities (watering points). This will significantly improve the efficiency of transhumant animal husbandry. The most promising aquifers for development are reflected on the hydrogeological map of the first aquifers in Southern Kazakhstan, compiled based on updated data obtained in recent years.

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Abbreviations

The following abbreviations are used in this manuscript:

UN United Nations
GIS Geographic Information System
SDG Sustainable Development Goal

Appendix A

Table A1. Field route surveys of pasture lands in Southern Kazakhstan.

“Administrative Region”	“Number of Objects”			“Number of Water Samples Collected”
	Well	Boreholes	Spring	
Almaty	16	15	1	32
Zhetysu	12	11	-	23
TOTAL	28	26	1	55

Table A2. Drinking water demand and water supply of the rural settlements of Southern Kazakhstan for 2024 and 2030.

Region			Almaty Region and Zhetysu Region
Population size	Average annual number by region (base) thousand people	2024 year	4108.0
		2030 year	5045.0
	Change in rural population by 2030, thousand people		720.2
	Rural population share, %	2024 year	38.0
		2030 year	37.0
Need for water	Number of rural population without access to drinking water in 2024 year, people		16,525.0
	Water requirement (standard), m ³ /day	2024 year	1,195,342.0
		2030 year	1,401,550.0
	Changes in rural population needs by 2030, thousand people.		33,768.0
	Deficit of water demand of rural population in 2024, m ³ /day		2644.0
Water supply	Operating reserves for domestic and drinking water supply, m ³ /day		5,828,060.0
	Availability, m ³ /day	2024 year	4,632,718.0
		2030 year	4,426,510.0

Table A3. Water consumption by type of livestock in South Kazakhstan region.

Area		Almaty Region	Zhetysu Region
Total area, ha		7,349,165	5,962,616
Pasture territories, ha		3,091,816	4,920,000
Number of livestock	Cattle	304,517	389,732
	Small cattle	867,467	1,226,267
	Horses	162,398	133,557
	Camel	2096	327
	Total number of livestock	2,592,102	1,749,883
Water consumption by type of livestock, thousand liters/day	Cattle	12,180.68	15,589.28
	Small cattle	5204.80	7357.60
	Horses	7307.91	6010.07
	Camel	73.36	11.45
Total water consumption, thousand m ³ /year		9039.86	10,573.46

Table A4. Results of chemical analytical studies of groundwater samples from Almaty region compared to drinking water standards.

Sampling Location		Well Chundzha 1	Boreholes Chundzha 2	Well Chundzha 3	Well Shelek 1	Well Shelek 2	Well Shelek 3	Well Kyrbaltabay 1
Date of sampling		19.10.2024	19.10.2024	19.10.2024	20.10.2024	20.10.2024	20.10.2024	22.10.2024
The coordinates of sampling points		43°35′30.31″N 79°25′52.32″E	43°31′3.50″N 79°29′46.42″E	43°32′19.19″N 79°34′8.13″E	43°35′1.84″N 78°6′2.11″E	43°35′13.11″N 78°5′19.33″E	43°33′46.66″N 78°5′59.13″E	43°36′38.87″N 77°27′55.83″E
pH		7.1	7.4	7.5	7.5	7.6	7.5	7.9
Dry residue, mg/dm ³		179	260	220	333	321	394	118
Cations, mg/dm ³	Na	29.9	15.8	31.6	60.2	69	50.9	12.7
	K	0.9	3	1.3	1.5	1.8	1.8	1.5
	Ca ²⁺	33	72.1	44	51.1	41	69.1	24
	Mg ²⁺	4.3	12.2	7.3	18.8	16.4	27.4	5.5
	NH ₄ ⁺	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
	Fe _{sum}	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Anions, mg/dm ³	CO ₃ [−]	<8.0	<8.0	<8.0	<8.0	<8.0	<8.0	<8.0
	HCO ₃ [−]	128.1	216.6	195.3	216.6	189.2	219.7	106.8
	Cl [−]	5	10	3	29	28	42	4
	SO ₄ ^{2−}	35	40	41	81	85	104	18
	NO ₃ [−]	6	12	4	7	7	13	3
	NO ₂ [−]	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
F, mg/dm ³		0.2	0.2	0.2	0.7	0.8	0.8	1.1
Mineralization, mg/dm ³		255	390	338	473	445	536	183
Hardness	total	2	4.6	2.8	4.1	3.4	5.7	1.7
	carbonates	2	3.6	2.8	3.6	3.1	3.6	1.7
SiO ₂		12.3	8	10.1	7	7	7.2	
Petroleum products, mg/dm ³		0.006	0.009	0.007	0.006	0.006	-	6.5
Cd, mg/dm ³		0.0005	0.0007	0.0005	0.0008	0.0007	0.0007	0.006
Pb, mg/dm ³		-	-	-	-	-	-	0.0009
Cu, mg/dm ³		0.0015	0.0065	-	0.003	-	0.0044	0.016
Zn, mg/dm ³		0.0017	0.0044	0.0011	0.0022	0.0017	0.0003	0.011
Sampling Location		Well Kyrbaltabay 2	Well Kyrbaltabay 3	Boreholes, Sorbulak 1 (Western Part)	Well, Sorbulak 2 (Western Part)	Boreholes, Sorbulak 3 (Western Part)	Boreholes, Sorbulak 4 (Western Part)	
Date of sampling		22.10.2024	11.10.2024	08.10.2024	08.10.2024	08.10.2024	08.10.2024	
The coordinates of sampling points		43°38′22.61″ N 77°26′7.64″ E	43°39′56.50″ N 77°25′57.80″ E	43°37′48.08″ N 76°31′16.21″ E	43°37′37.65″ N 76°26′53.09″ E	43°39′7.64″ N 76°26′7.08″ E	43°39′5.53″ N 76°24′48.25″ E	

Table A4. Cont.

Sampling Location		Well Chundzha 1	Boreholes Chundzha 2	Well Chundzha 3	Well Shelek 1	Well Shelek 2	Well Shelek 3	Well Kyrbaltabay 1
pH		7.9	8.1	7.4	7.8		7.4	7.9
Dry residue, mg/dm ³		96	121	933	547		913	508
Cations, mg/dm ³	Na	11.5	23.7	189.7	118		92.5	113.1
	K	1.1	0.8	2.1	1.8		1.6	1.5
	Ca ²⁺	19	15	79.1	42		124.1	35
	Mg ²⁺	5.5	4.3	62	37.1		90.6	33.4
	NH ₄ ⁺	<0.05	<0.05	<0.05	<0.05		<0.05	<0.05
	Fe _{sum}	<0.1	<0.1	<0.1	<0.1		<0.1	<0.1
Anions, mg/dm ³	CO ₃ [−]	<8.0	<8.0	<8.0	<8.0		<8.0	<8.0
	HCO ₃ [−]	88.5	76.3	173.9	115.9		207.5	158.6
	Cl [−]	2	14	158	76		111	50
	SO ₄ ^{2−}	9	27	287	179		448	186
	NO ₃ [−]	2	3	147	82		<0.2	50
	NO ₂ [−]	<0.01	<0.01	<0.01	<0.01		17	<0.01
F, mg/dm ³		1.3	1.4	5	4.4		2	5
Mineralization, mg/dm ³		146	172	1110.00	661		1102.00	638
Hardness	total	1.4	1.1	9.1	5.2		13.7	4.5
	carbonates	1.4	1.1	2.9	1.9		3.4	2.6
SiO ₂		6.1	6.5	6.2	5.1		7.3	5.7
Petroleum products, mg/dm ³		0.006	0.007	-	-		-	-
Cd, mg/dm ³		0.0007	0.0008	-	-		-	-
Pb, mg/dm ³		0.01	0.01	-	0.019		0.018	0.018
Cu, mg/dm ³		0.0096	0.0074	0.03	0.013		0.035	0.035
Zn, mg/dm ³		0.0011	0.0006	0.02	0.0034		0.004	0.004
Sampling Location		Well Kurtov 1	Boreholes Kurtov 2	Boreholes Kurtov 3	West Well Kanshengel 1	West Well Kanshengel 2		East Boreholes Kanshengel 1
Date of sampling		08.10.2024	08.10.2024	08.10.2024	09.10.2024	09.10.2024		09.10.2024
The coordinates of sampling points		43°52'47.93" N 76°14'44.71" E	43°51'2.31" N 76°14'48.85" E	43°51'55.75" N 76°13'1.48" E	44°15'6.68" N 75°31'28.62" E	44°15'51.99" N 75°31'28.62" E		44°29'32.81" N 75°43'55.81" E
pH		7.6	7.5	7.6	7.5	7.5		7.6
Dry residue, mg/dm ³		3651.00	5899.00	2428.00	4287.00	1966.00		830

Table A4. Cont.

Sampling Location		Well Chundzha 1	Boreholes Chundzha 2	Well Chundzha 3	Well Shelek 1	Well Shelek 2	Well Shelek 3	Well Kyrbaltabay 1
Cations, mg/dm ³	Na	950.6	1561.00	580.2	1107.00		337.6	182.7
	K	4	25.2	6.8	5.4		5.5	8.4
	Ca ²⁺	260.3	266.3	204.2	370.4		214.2	61.1
	Mg ²⁺	110.7	193.3	59.6	105.8		69.3	57.2
	NH ₄ ⁺	<0.05	<0.05	<0.05	<0.05		0.5	1.3
	Fe _{sum}	<0.1	<0.1	<0.1	<0.1		<0.1	<0.1
Anions, mg/dm ³	CO ₃ [−]	<8.0	<8.0	<8.0	<8.0		<8.0	<8.0
	HCO ₃ [−]	189.2	305.1	213.6	88.5		134.2	207.5
	Cl [−]	574	493	352	1007.00		360	144
	SO ₄ ^{2−}	1772.00	3286.00	1115.00	1823.00		950	303
	NO ₃ [−]	191	463	158	90		120	44
	NO ₂ [−]	<0.01	<0.01	<0.01	<0.01		<0.01	<0.01
F, mg/dm ³		2.9	4.9	2.7	2.5		1.8	2.8
Mineralization, mg/dm ³		4062.00	6605.00	2701.00	4609.00		2199.00	1018.00
Hardness	total	22.1	29.2	15.1	27.2		16.4	7.8
	carbonates	3.1	5	3.5	1.5		2.2	3.4
SiO ²		7.3	7.5	9.1	9.1		5.5	5.9
Petroleum products, mg/dm ³		-	-	-	-		-	-
Cd, mg/dm ³		-	-	-	-		-	-
Pb, mg/dm ³		-	-	-	-		-	-
Cu, mg/dm ³		0.043	0.052	0.035	0.045		0.015	0.021
Zn, mg/dm ³		0.008	0.01	0.0098	0.0097		0.02	0.02
Sampling Location		East Boreholes Kanshengel 2	East Boreholes Kanshengel 3	Spring, Western Part City of Konayev 1	Well, Western Part City of Konayev 2 (Shoshkaly)	West Well, Western Part City of Konayev 3		Boreholes Mialy 1
Date of sampling		09.10.2024	09.10.2024	10.10.2024	10.10.2024	10.10.2024		10.10.2024
The coordinates of sampling points		44°32′59.68″ N 75°41′17.63″ E	44°27′52.15″ N 75°40′26.85″ E	43°51′39.20″ N 77°0′10.92″ E	43°54′36.45″ N 76°58′11.11″ E	43°56′21.35″ N 76°58′16.69″ E		44°31′6.73″ N 76°47′48.60″ E
pH		7.6	7.8	7.6	7.4	7.6		7.4
Dry residue, mg/dm ³		969	873	4983.00	8474.00	4626.00		1923.00

Table A4. Cont.

Sampling Location		Well Chundzha 1	Boreholes Chundzha 2	Well Chundzha 3	Well Shelek 1	Well Shelek 2	Well Shelek 3	Well Kyrbaltabay 1
Cations, mg/dm ³	Na	194.4	223.6	1462.70	2639.00		1438.00	209.6
	K	9.5	10.3	6.8	10.5		6.7	145.8
	Ca ²⁺	75.1	54.1	324.3	400.4		196.2	220.2
	Mg ²⁺	69.9	48.6	82.7	177.5		103.4	109.4
	NH ₄ ⁺	<0.05	0.1	<0.05	<0.05		<0.05	<0.05
	Fe _{sum}	<0.1	<0.1	<0.1	<0.1		<0.1	<0.1
Anions, mg/dm ³	CO ₃ [−]	<8.0	<8.0	<8.0	<8.0		<8.0	<8.0
	HCO ₃ [−]	225.8	292.9	54.9	384.4		183.1	238
	Cl [−]	158	121	1011.00	1510.00		1045.00	253
	SO ₄ ^{2−}	357	303	2544.00	3580.00		1880.00	997
	NO ₃ [−]	38	27	<0.2	709		130	<0.2
	NO ₂ [−]	<0.01	<0.01	<0.01	<0.01		<0.01	29
F, mg/dm ³		3.9	4	3.4	3.6		4.2	1.6
Mineralization, mg/dm ³		1138.00	1090.00	5498.00	9422.00		4992.00	2210.00
Hardness	total	9.5	6.7	23	34.6		18.3	20
	carbonates	3.7	4.8	0.9	6.3		3	3.9
SiO ²		6.5	5.9	8.3	7.8		5.7	6.1
Petroleum products, mg/dm ³		-	-	-	-		0.008	-
Cd, mg/dm ³		-	-	-	-		-	-
Pb, mg/dm ³		-	-	-	-		-	-
Cu, mg/dm ³		0.022	0.018	0.043	0.054		0.039	0.026
Zn, mg/dm ³		0.01	0.0054	0.009	0.02		0.093	0.0098
Sampling Location		Boreholes Mialy 2	Well Mialy 3	Well Birlik 1	Boreholes Birlik 2		Boreholes Birlik 3	
Date of sampling		10.10.2024	10.10.2024	11.10.2024	11.10.2024		11.10.2024	
The coordinates of sampling points		44°34′11.58″ N 76°54′1.38″ E	44°39′41.59″ N 76°51′26.04″ E	44°39′54.76″ N 76°47′45.39″ E	44°49′21.00″ N 76°40′24.65″ E		44°49′56.88″ N 76°37′53.48″ E	
pH		7.8	7.8	7.5	7.7		7.7	
Dry residue, mg/dm ³		1719.00	2951.00	2171.00	529		811	

Table A4. Cont.

Sampling Location		Well Chundzha 1	Boreholes Chundzha 2	Well Chundzha 3	Well Shelek 1	Well Shelek 2	Well Shelek 3	Well Kyrbaltabay 1
Cations, mg/dm ³	Na	259		926.8	226.1	94.6		119.6
	K	5.6		5.1	8.2	3.3		4.2
	Ca ²⁺	128.1		86.1	220.2	62.1		110.1
	Mg ²⁺	121.6		88.8	209.2	32.2		48.6
	NH ₄ ⁺	<0.05		<0.05	<0.05	<0.05		<0.05
	Fe _{sum}	<0.1		<0.1	<0.1	<0.1		<0.1
Anions, mg/dm ³	CO ₃ [−]	<8.0		<8.0	<8.0	<8.0		<8.0
	HCO ₃ [−]	134.2		384.4	289.8	173.9		167.8
	Cl [−]	160		366	107	51		75
	SO ₄ ^{2−}	1044.00		1580.00	1397.00	227		428
	NO ₃ [−]	<0.2		<0.2	24	13		10
	NO ₂ [−]	<0.01		<0.01	<0.01	<0.01		<0.01
F, mg/dm ³		1.5		3	0.5	1.2		0.7
Mineralization, mg/dm ³		1860.00		3446.00	2490.00	666		973
Hardness	total	16.4		11.6	28.2	5.8		9.5
	carbonates	2.2		6.3	4.8	2.9		2.8
SiO ²		5.6		6.3	8	8		9.1
Petroleum products, mg/dm ³		-		-	0.007	-		0.006
Cd, mg/dm ³		-		-	-	-		-
Pb, mg/dm ³		-		-	-	0.018		-
Cu, mg/dm ³		0.032		0.034	0.035	0.015		0.021
Zn, mg/dm ³		0.0063		0.0061	0.01	0.0049		0.0052
Sampling Location		Boreholes Bakanas 1	Boreholes Bakanas 2	Drinking Water Standards				
Date of sampling		11.10.2024	11.10.2024	Kazakhstan		WHO		
The coordinates of sampling points		44°53′45.71″ N 76°32′36.92″ E	44°58′6.10″ N 76°29′26.51″ E	-		-		
pH		7.6	7.6	6.0–9.0		6.2–8.5		
Dry residue, mg/dm ³		1026.00	827	-				

Table A4. Cont.

Sampling Location	Well Chundzha 1	Boreholes Chundzha 2	Well Chundzha 3	Well Shelek 1	Well Shelek 2	Well Shelek 3	Well Kyrbaltabay 1
Cations, mg/dm ³	Na	219.8	154		200		200
	K	8.6	5.6		-		
	Ca ²⁺	78.1	72.1		-		200
	Mg ²⁺	53.5	56.5		-		50
	NH ₄ ⁺	<0.05	<0.05		2.0		0.50
	Fe _{sum}	<0.1	<0.1		0.3		0.3
Anions, mg/dm ³	CO ₃ ⁻	<8.0	<8.0		-		
	HCO ₃ ⁻	207.5	280.7		-		
	Cl ⁻	101	105		350		250
	SO ₄ ²⁻	509	312		500		250
	NO ₃ ⁻	45	50		45		50
	NO ₂ ⁻	<0.01	<0.01		3.0		0.50
F, mg/dm ³		1	1		1.5		1.5
Mineralization, mg/dm ³		1232.00	1044.00		1000.00		
Hardness, moll	total	8.3	8.3		7.0		
	carbonates	3.4	4.6				
SiO ²		8.1	7.4		10		
Petroleum products, mg/dm ³		-	-		0.10		
Cd, mg/dm ³		-	-		0.001		-
Pb, mg/dm ³		-	-		0.03		0.01
Cu, mg/dm ³		0.019	0.02		1.0		1.0
Zn, mg/dm ³		0.008	0.0066		5.0		5.0

Table A5. Results of chemical and analytical studies of groundwater samples from the Zhetysu region in comparison with drinking water standards.

Sampling Location	Boreholes in Kyzylagash 3	Boreholes in Kyzylagash 1	Boreholes in Usharal 3	Boreholes in Usharal 2	Boreholes in Usharal 1	Well in Kyzylagash 2
Date of sampling	12.10.2024	12.10.2024	12.10.2024	12.10.2024	12.10.2024	12.10.2024
The coordinates of sampling points	45°22'58.50'' N 78°33'33.40'' E	45°19'24.86'' N 78°35'29.68'' E	45°27'16.51'' N 78° 1'31.75'' E	45°30'42.53'' N 78° 3'52.30'' E	45°31'56.10'' N 78° 0'30.01'' E	45°24'2.51'' N 78°36'7.19'' E
pH	7.9	7.8	7.7	7.6	7.7	7.8
Dry residue, mg/dm ³	466	513	1790.00	1198.00	496	390

Table A5. *Cont.*[illegible]

Table A5. *Cont.*[illegible]

Table A5. Cont.

Sampling Location		Boreholes in Kyzylagash 3	Boreholes in Kyzylagash 1	Boreholes in Usharal 3	Boreholes in Usharal 2	Boreholes in Usharal 1	Well in Kyzylagash 2
F, mg/dm ³		0.8	0.9	1.4	1.5	1.5	1.6
Mineralization, mg/dm ³		191	206	173	173	163	408
Hardness	total	1.8	1.7	1.1	1.4	1.7	4.1
	carbonates	1.8	1.7	1.1	1.4	1.7	4.1
SiO ²		6	5.8	6.4	5.9	5.6	8.1
Petroleum products, mg/dm ³		0.005	-	-	-	-	0.071
Cd, mg/dm ³		-	0.0009	0.0007	0.0009	0.0008	0.0009
Pb, mg/dm ³		0.014	0.012	0.01	0.012	0.012	0.012
Cu, mg/dm ³		0.0055	0.0008	-	-	0.001	0.0002
Zn, mg/dm ³		0.0023	0.0018	0.0018	0.0019	0.003	0.0014
Sampling Location		Boreholes Koilyk 2	Well Koilyk 3	Well Koilyk 4	Drinking Water Standards		
Date of sampling		16.10.2024	16.10.2024	16.10.2024	Kazakhstan		
The coordinates of sampling points		45° 54' 38.24" N 80° 17' 35.48" E	46° 0' 57.02" N 80° 3' 50.62" E	46° 1' 45.04" N 80° 2' 59.56" E			
pH		7.9	8.1	8.1	6.0–9.0		
Dry residue, mg/dm ³		1666.00	299	395	-		
Cations, mg/dm ³	Na	203.8	69.1	125.6	200		
	K	12.8	2.8	0.6			
	Ca ²⁺	140.1	24	28	200		
	Mg ²⁺	198.2	9.7	8.5	50		
	NH ₄ ⁺	<0.05	<0.05	<0.05	0.50		
	Fe _{sum}	<0.1	<0.1	<0.1	0.3		
Anions, mg/dm ³	CO ₃ ⁻	<8.0	<8.0	<8.0			
	HCO ₃ ⁻	619.3	109.8	256.3			
	Cl ⁻	266	34	19	250		
	SO ₄ ²⁻	374	126	102	250		
	NO ₃ ⁻	275	<0.2	10	50		
	NO ₂ ⁻	22	<0.01	<0.01	0.50		
F, mg/dm ³		2.4	0.5	1.5	1.5		
Mineralization, mg/dm ³		2119.00	379	559	1000.00		

Table A5. Cont.

Sampling Location		Boreholes in Kyzylagash 3	Boreholes in Kyzylagash 1	Boreholes in Usharal 3	Boreholes in Usharal 2	Boreholes in Usharal 1	Well in Kyzylagash 2
Hardness	total	23.3	2		2.1		
	carbonates	10.2	1.8		2.1		
SiO ²		4.9	3.2		7.4	10	
Petroleum products. mg/dm ³		-	0.072		-	0.10	
Cd, mg/dm ³		-	0.0009		0.0009	0.001	-
Pb, mg/dm ³		-	0.013		0.014	0.03	0.01
Cu, mg/dm ³		0.035	0.0032		0.0043	1.0	1.0
Zn, mg/dm ³		0.0085	0.0018		0.0021	5.0	5.0

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