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Case Report

The Study of Groundwater in the Zhambyl Region, Southern Kazakhstan, to Improve Sustainability

Dinara Adenova [1], Dani Sarsekova [2], Malis Absametov [1], Yermek Murtazin [1], Janay Sagin [3,4,*], Ludmila Trushel [1] and Oxana Miroshnichenko [1]

[1] U.M. Ahmedsafin Institute of Hydrogeology and Geoecology, Satbayev University, Almaty 050010, Kazakhstan; d.adenova@satbayev.university (D.A.); m.absametov@satbayev.university (M.A.); ye.murtazin@satbayev.university (Y.M.); l.trushel@satbayev.university (L.T.); o.miroshnichenko@satbayev.university (O.M.)

[2] Departmant of Water, Land and Forest Resources, Kazakh National Agrarian Research University, Almaty 050010, Kazakhstan; sarsekova.dani@kaznaru.edu.kz

[3] School of Information Technology and Engineering, Kazakh-British Technical University, Almaty 050000, Kazakhstan

[4] Departmant of Geological and Environmental Sciences, Western Michigan University, Kalamazoo, MI 49008, USA

* Correspondence: j.sagin@kbtu.kz

Abstract: Water resources are scarce and difficult to manage in Kazakhstan, Central Asia (CA). Anthropic activities largely eliminated the Aral Sea. Afghanistan's large-scale canal construction may eliminate life in the main stream of the Amu Darya River, CA. Kazakhstan's HYRASIA ONE project, with a EUR 50 billion investment to produce green hydrogen, is targeted to withdraw water from the Caspian Sea. Kazakhstan, CA, requires sustainable programs that integrate both decision-makers' and people's behavior. For this paper, the authors investigated groundwater resources for sustainable use, including for consumption, and the potential for natural "white" hydrogen production from underground geological "factories". Kazakhstan is rich in natural resources, such as iron-rich rocks, minerals, and uranium, which are necessary for serpentinization reactions and radiolysis decay in natural hydrogen production from underground water. Investigations of underground geological "factories" require substantial efforts in field data collection. A chemical analysis of 40 groundwater samples from the 97 wells surveyed and investigated in the T. Ryskulov, Zhambyl, Baizak and Zhualy districts of the Zhambyl region in South Kazakhstan in 2021–2022 was carried out. These samples were compared with previously collected water samples from the years 2020–2021. The compositions of groundwater samples were analyzed, revealing various concentrations of different minerals, natural geological rocks, and anthropogenic materials. South Kazakhstan is rich in natural mineral resources. As a result, mining companies extract resources in the Taraz–Zhanatas–Karatau and the Shu–Novotroitsk industrial areas. The most significant levels of minerals found in water samples were found in the territory of the Talas–Assinsky interfluve, where the main industrial mining enterprises are concentrated and the largest groundwater deposits have been explored. Groundwater compositions have direct connections to geological rocks. The geological rocks are confined to sandstones, siltstones, porphyrites, conglomerates, limestones, and metamorphic rocks. In observation wells, a number of components can be found in high concentrations (mg/L): sulfates—602.0 (MPC 500 mg/L); sodium—436.5 (MPC 200 mg/L); chlorine—465.4 (MPC 350 mg/L); lithium—0.18 (MPC 0.03 mg/L); boron—0.74 (MPC 0.5 mg/L); cadmium—0.002 (MPC 0.001 mg/L); strontium—15, 0 (MPC 7.0 mg/L); and TDS—1970 (MPC 1000). The high mineral contents in the water are natural and comprise minerals from geological sources, including iron-rich rocks, to uranium. Proper groundwater classifications for research investigations are required to separate potable groundwater resources, wells, and areas where underground geological "factories" producing natural "white" hydrogen could potentially be located. Our preliminary investigation results are presented with the aim of creating a large-scale targeted program to improve water sustainability in Kazakhstan, CA.

Citation: Adenova, D.; Sarsekova, D.; Absametov, M.; Murtazin, Y.; Sagin, J.; Trushel, L.; Miroshnichenko, O. The Study of Groundwater in the Zhambyl Region, Southern Kazakhstan, to Improve Sustainability. *Sustainability* **2024**, *16*, 4597. https://doi.org/10.3390/su16114597

Academic Editors: Fernando António Leal Pacheco, Pablo A. Garcia-Chevesich, Rodrigo Valdes-Pineda, Daniel G. Neary and Héctor Novoa

Received: 16 March 2024
Revised: 29 April 2024
Accepted: 8 May 2024
Published: 29 May 2024

Keywords: groundwater; water sustainability; white hydrogen; natural hydrogen; Kazakhstan; Central Asia

1. Introduction

Water resource limitations, and particularly water quality issues, are becoming complex worldwide [1–7], including in the Kazakhstan region in Central Asia (CA) [8,9]. Kazakhstan, like many other countries worldwide, is experiencing an increasing threat of water scarcity and requires improvements in water sustainability [10–12]. More than 50% of Kazakhstan's population consumes drinking water of inadequate quality due to a lack of water purification technologies [13]. In many regions, the water is rich in natural mineralization, which can be dangerous for consumption. The intensive extraction of groundwater and minerals has led to many anthropogenic environmental disturbances. Due to the deterioration of surface and groundwater resources, the ecosystem of Kazakhstan is under threat. Inefficient water resource use, poor environmental regulation, and intensive mining and petroleum extraction without proper environmental controls lead to groundwater pollution and groundwater depletion, generating risks to human health [14,15]. The discharge of insufficiently treated wastewater into water bodies directly affects underground water resources in areas with vulnerable groundwater. The pollution of the Caspian and Aral Seas, Lake Balkhash, and smaller bodies of water within these watersheds affects the water throughout these basins [13,16]. This research highlights the issues of groundwater composition analysis, with the estimation status analysis of potential natural and anthropogenic sources of water composition, which could enable future investigations to separate potable groundwater resources and wells from areas where underground geological "factories" producing the natural "white" hydrogen could potentially be located [17]. In the case of underground water use for human consumption, proper standards and classifications of the water's chemical composition, formed under the influence of both natural and anthropogenic factors, are required. The main technogenic impact on the region's environment is exerted by the Taraz–Zhanatas–Karatau and, to a lesser extent, the Shu–Novotroitsk industrial areas, where the developed mining industry covers large areas [18]. The composition of minerals in the water is a result of mining (Karatau) activities and water recharging areas in the plains of the foothills of Kyrgyz Alatau [19]. The highest levels of minerals in the water have been observed in the territory of the Talas–Assinsky interfluve, where the main industrial mining enterprises are concentrated and the largest groundwater deposits are located (i.e., the southern part of Talas–Assinsky and the northern Talas–Assinsky, Zhualinskoye, Prepeskovoe, and Bilikolskoye fields) [20]. The local population of Kazakhstan is accustomed to the uncontrolled use of surface water and groundwater without proper purification [20]. The focus of our research is to sample and assess the state of self-flowing hydrogeological wells using groundwater composition analysis to identify both water safe for human consumption and potential areas where underground geological "factories" produce natural "white" hydrogen. This will aid future large-scale studies. The specific objectives of this study are demonstrated with the following research questions: (1) What is groundwater composition in the southern region? (2) Does the water contain more geologically natural components or does it contain more human-introduced pollution? (3) Would it be reasonable to expand the investigation to identify natural "white" hydrogen? Groundwater resources are used inefficiently in Kazakhstan. Incentives to expand sustainability projects, such as NEXUS (water, food, energy), which aims to efficiently combine water use for consumption and opportunities to increase income through the involvement of natural "white" hydrogen activities, will increase water value and ways to reuse and recycle water with higher profitability. These efforts will aid in the improvement of water sustainability in the region.

Many of the investigated wells are mostly used for livestock and irrigation, though several were reported to be used for drinking purposes.

Research involved field work, water sampling collection, laboratory testing, and additional mapping of these wells using Geographic Information System (GIS) tools [21]. The potential combined effects of the natural geological environment and anthropogenic activities from the mining industry were evaluated based on our research, with the addition of previous investigations, publications, and reports of other researchers in the Zhambyl region. These results will provide a basis for further investigations in water sustainability improvement, water use for consumption or keeping working the underground geological "factories", producing the natural "white" hydrogen. We provided the chemical analysis of 40 groundwater samples from the surveyed 97 wells in the chemical laboratory of the Institute of Hydrogeology and geoecology named after Ahmedsafin, Almaty in 2022 and compared with our previously collected water samples from the years 2020–2021. Water quality is measured by various chemical and physical parameters. These chemical parameters include pH, electrical conductivity, total solids, total dissolved solids (TDS), and hardness. Some of the physical parameters include color, odor, haze, and transparency—organoleptic observations. TDS was measured by two methods: gravimetric and specific conductance.

2. Materials and Methods

2.1. Scope Study Description

The study area includes the Zhambyl region in Southern Kazakhstan, with a central point of 44° N 72° E. The research area is 145,400 km^2, covering ten administrative districts (Figure 1). The region is home to over 1,120,000 people, with 61% living in rural areas.

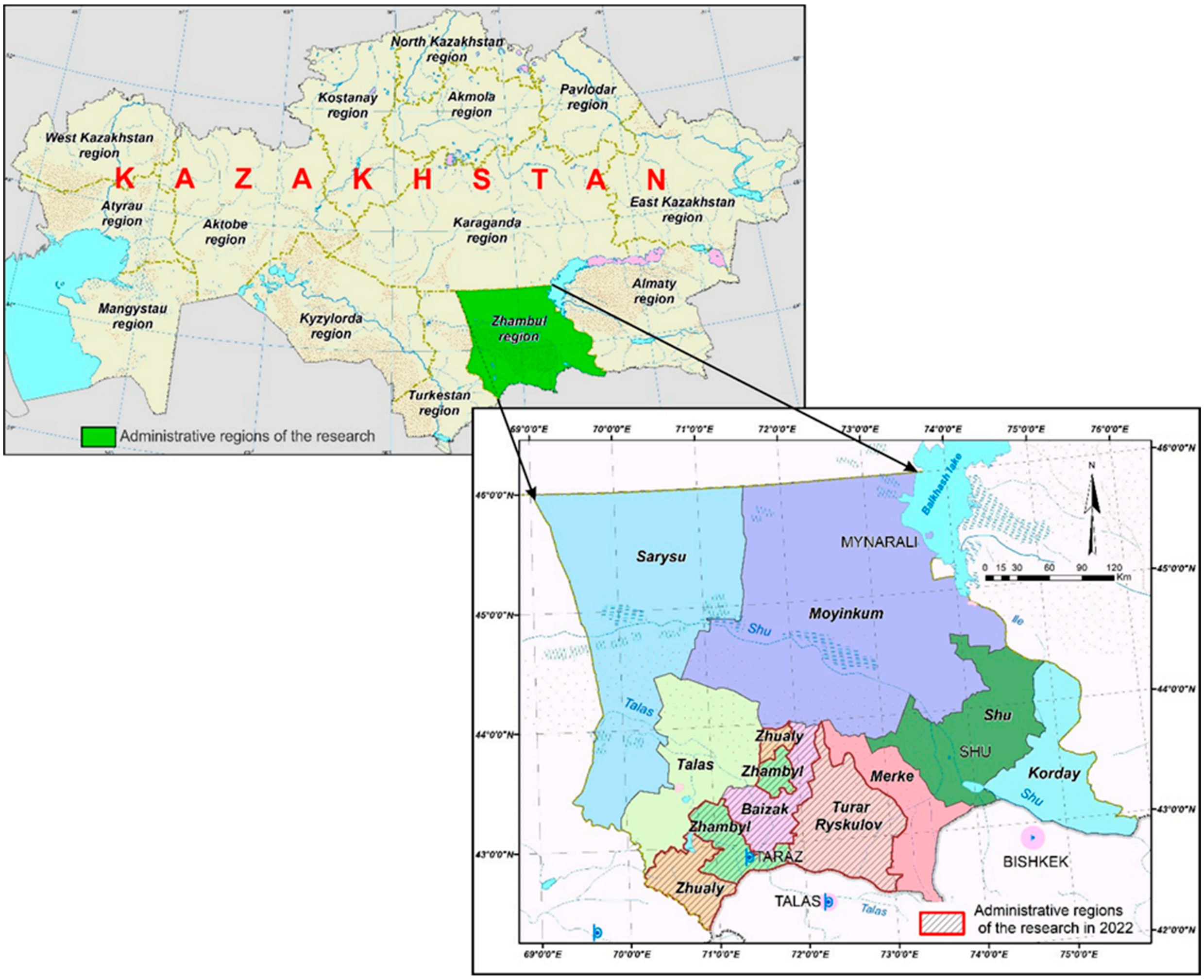

Figure 1. Zhambyl investigation region in Southern Kazakhstan.

The research areas, including field water sampling, chemical laboratory analysis, and experimental results with interpretation, are presented below in the related subheadings.

2.1.1. Orography

The research area in the Zhambyl territory is very diverse (Figures 2 and 3). The central region is occupied by vast alluvial plains of the Shu, Talas, and Asy Rivers, the most elevated areas of which are occupied by hilly ridged sands in the Shu–Talas interfluve. The spurs of the Kyrgyz range and the Talas Alatau rise in the south of the region, the Shu-Ili and Kendyktas mountains in the east, the Karatau ridge in the southwest, and about 1/3 of the area of the region is occupied by the rocky Betpakdala plateau in the north [22].

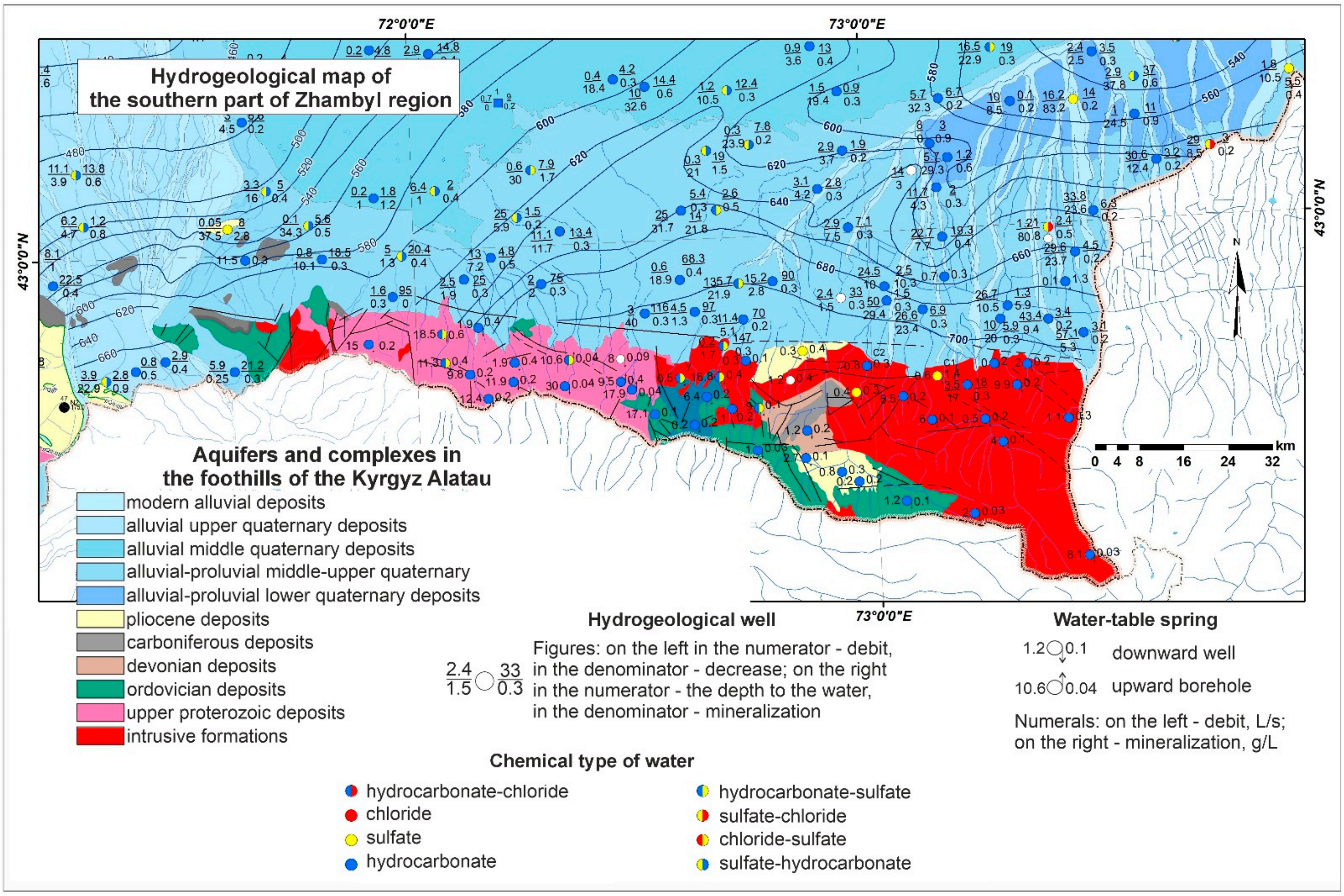

Figure 2. The hydrogeological map of the southern part of Zhambyl region, Kazakhstan.


(**a**) (**b**) (**c**)

Figure 3. Self-flowing artesian wells found in the Ryskulov district, Zhambyl region, in 2022 (**a**–**c**).

2.1.2. Hydrography

Many of the region's rivers are interconnected with local groundwater. The Shu, Talas, and Assa River basins, with numerous small tributaries flowing from the northern slopes of the Kyrgyz Alatau ridge, cover the Zhambyl region [23,24]. The largest of these is the Shu River, which originates in the highlands of the Tien Shan mountain range. Cutting through the spurs of the Kyrgyz Alatau, the Shu River enters the Chui valley and further into the desert spaces on the border of the Muyunkum sandy massif and the Betpakdala plateau. The total length of the Shu River is 1186 km. The Shu River is fed by a mixed glacier–snow melt, and generally, two spring and summer floods are observed annually. The average annual discharge of the river is 59.9 m^3/s. The Talas River originates at the saddle between the Kyrgyz and Talas Alatau. The Talas River receives most of its water from Kyrgyzstan's glacier and snow melts. The melted waters of plain snows, rains, and groundwater seepage in the lower regions provide small co-contributions to Talas River streams. The average annual discharge of the Talas River is 10.5 m^3/s. The Asa River is generated from the confluence of the Ters and Kurkureusu Rivers, originating in the Karatau and Talas Alatau mountains, flowing through Bilikol Lake and then Akkol Lake, becoming lost in the sands. This river also receives snow and glacier meltwater, and the average annual discharge is 11.6 m^3/s. The Kuragaty River is the left tributary of the Shu River and is 181 km long. The average annual consumption is 5.17 m^3/s [25]. Many small rivers are observed on the northern slope of the Kyrgyz Range. Most are lost when leaving the mountains in alluvial fans and on the foothill plain. The largest of them are Merke and Aspara. The average annual discharges of these rivers are 3.4 and 3.2 m^3/s, respectively (Figures 2 and 3). The largest lakes are Bilikol with an area of 87 km^2 and Akkol with an area of 31 km^2. Their sizes vary depending on the water content of the Asa River and climatic factors. Similar lakes include Ashchikol, Tuzkol and other smaller reservoirs. The water in these lakes is generally brackish, though Bilikol Lake has fresh water in its southern part (Figures 2 and 3). In the valley of the Shu River, the largest lakes are Kamkalykol and Karakol with fresh water [26,27].

2.1.3. Climate

The climate of the Zhambyl region is continental and arid. The continentality of the climate is manifested in the harsh temperature contrasts of day and night, winter and summer, and in the rapid transition from winter to summer. In the southern mountainous the continentality is softened, and the winter is milder with higher precipitation levels. The desert plains of the northern and central regions are especially arid. Summer is very hot, with air temperatures sometimes up to 45–47 °C, with harsh winter severity. During severe frosts, the winter temperature drops to −35–46 °C [24]. The Zhambyl region receives less than 250 mm per year of precipitation. Even smaller precipitation of 100–130 mm per year is observed in the northeast of the Zhambyl region near the coast of Balkhash Lake (Figure 2). Rain is rare in summer in the northern and central Zhambyl region. Precipitation in the foothills increases to 300–350 mm, while the Kyrgyz Alatau receives 500–600 mm. Precipitation is distributed extremely unevenly by seasons; most of it falls in the winter–spring period. Snow cover is small and unevenly distributed: in the north of the region, its cover is 10–15 cm, in the southern regions it is 20–25 cm, and in the foothills and mountains it is 20–70 cm. Easterly and northeasterly winds prevail in the Zhambyl region with an average speed of 2.5–3.5 m/s, occasionally exceeding 5–6 m/s [24,25].

2.2. Geological Setting

The water-bearing units within the geological and geographical regions in the Zhambyl region [24,25] are as follows:

1. Big Karatau areas with Precambrian and early Paleozoic formations.
2. Shu–Sarysu depression with Paleozoic outcrops.
3. Eastern Betpak-Dala area with Cambrian and Ordovician sections.

Proterozoic, Paleozoic, Mesozoic and Cenozoic sediments form the geologic strata in the Zhambyl region [24,25].

2.3. Hydrogeological Setting

The hydrogeological conditions of the Zhambyl region territory include mountain structures, foothill plains, hilly ridged sandy plains, southeastern Betpak-Dala plateau, and modern alluvial river valleys [25].

Mountain structures include water-bearing complexes of pre-Paleozoic, Paleozoic, and intrusive rocks. Paleozoic groundwater is confined to sandstones, siltstones, porphyrites, limestones, conglomerates, and tuffs. Aquifer depths range from 15 to 100 m, and typically are calcium bicarbonate type. In the Shu-Ili mountain, groundwater is slightly brackish with salinity from 1 to 3 g/L, in some places up to 6 g/L or more, characterized as sodium sulfate or sodium chloride type. Intrusive rocks consist of granites, granodiorites, syenites, and granite–porphyries. If groundwater is present, it has less dissolved solid content, with mineralization up to 0.6 g/L, generally as calcium-bicarbonate [24,25].

Piedmont plains are common on the northern slopes of the Kyrgyz Alatau, Kendyktas and Shu-Ili mountains. Alluvial benches are composed of coarse-grained material, with a higher water content. Paleogene–Neogene and Quaternary sediments consist of interlayers and lenses of sandstones, gravel–pebbles, conglomerates, and sands occurring in clay strata. Groundwater compositions are dominated by sodium, sulfate, and chloride. Total mineralization varies from 3 to 5 g/L, sometimes reaching up to 10 g/L. Groundwater of Quaternary sediments consists of debris, sand, gravel, and pebbles. The compositions are typically calcium bicarbonate and sodium sulfate.

Hilly ridged sandy plains consist of sands and sandy loams containing separate layers of loams. The composition is calcium bicarbonate, up to 1 g/L.

The southeastern part of the Betpak-Dala Plateau is a plateau rising to the north. The plateau enters the region in the southeastern part, which is adjacent to the valley of the Shu River. In the northeastern and eastern parts, it represents a small hillocky area, where fracture groundwater type is developed. Fracture waters are associated with the weathered zone of granitoids, sandstones, shales, and other metamorphic rocks. The water mineralization varies from 3 to 6 g/L, the composition is sodium sulfate and sodium chloride [24,25].

Modern alluvial river valleys contain water-bearing rocks consisting of boulders–pebbles, gravel, equigranular sand and sandy loams. Aquifers are fed mainly by surface water and atmospheric precipitation. The waters are fresher and dominated by calcium bicarbonate.

The southern part of the Zhambyl region supports several aquifers, among which modern alluvial deposits are most substantial. The depth of groundwater is from 1 to 50 m (Figure 2). Artesian wells in this region, most common in the northwestern portion, are associated with Cretaceous, Paleogene, Neogene, and Quaternary sediments. Mineralization ranges from 1 to 3 g/L, from sodium chloride and sulfate to sodium bicarbonate, and is associated with sand deposited in the clay strata. Artesian wells in the Neogene are also developed in the eastern part of the Muyunkums, in the foothills of the Kyrgyz Alatau and Shu-Ili mountains. Water-bearing sediments are represented by sands, sandstones, and conglomerates. Mineralization is up to 1 g/L, generally as sodium bicarbonate. Springs and artesian wells in Quaternary alluvial–pluvial sediments are found in the foothills of the Kyrgyz and Talas Alatau. Groundwater is predominantly calcium bicarbonate with a mineralization of 0.2–1 g/L [24–27].

2.4. Field Data

For this research, we investigated 97 wells in Ryskulov, Zhambyl, Baizak, and Zhualy districts between 2021 and 2022, utilizing field equipment. Additionally, 40 well samples underwent intensive scrutiny in physico-chemical laboratories (Figures 1–3). The inspection of these 97 groundwater wells is summarized in Table 1. Field chemical analysis of water was performed for all 97 wells. Some wells, being in the immediate vicinity of other wells, share the same aquifer. As a result, we did not give an analysis.

Table 1. Results of the inspection of wells in T. Ryskulov, Zhambyl, Baizak and Zhualy, 2022.

No.	Administrative Districts	Total Inspected	Flowing	Without Flowing	Pumped	Blocked	Liquidated	Well Rate, L/s
1	Zhambyl	10	6	1		2	1	from 0.5 to 5
2	Baizak	16	6	4	3	3		from 0.1 to 5
3	Zhualy	39	25	3		8	3	from 0.2 to 30
4	T. Ryskulov	32	24		2	6		from 0.1 to 10
Total		97	61	8	5	19	4	

This allows us to talk about the identity of the chemical composition of the water and the sufficiency of data on the quality of groundwater. Some wells' water samples have high mineralization compositions, failing to meet international and local standards for salinity, hardness, and chemical parameters, such as Na, Cl, SO_4, Sr, and Li levels for drinking purposes. However, these wells could serve as potential locations for underground geological "factories" producing natural "white" hydrogen. Previously, in 2020–2021, we sampled the groundwater in the Merke, Shu and Korday districts. This survey, conducted on 204 wells between 2020 and 2021, revealed that certain wells exhibit high mineralization compositions, failing to meet international and local standards for salinity, hardness, and chemical parameters, including levels of F, Si, and As for drinking purposes. Further investigations are needed to explore connections to underground geological "factories" producing natural "white" hydrogen. Chemical and analytical studies of the selected water samples were carried out by the Laboratory of Chemical Analytical Research of the U.M. Akhmedsafin Institute of Hydrogeology and Geoecology, Almaty, Kazakhstan (Accreditation Certificate No. KZ.T.02.0782, valid until) 27 November 2025. The laboratory's testing and methods, including equipment for determining chemical indicators, strictly follow Kazakhstan's standards: GOST 26449.1-85 (Na, K, Ca, Mg, Cl, SO_4, HCO_3) [28]; GOST 33045-2014 (NH4) [29]; GOST 33045-2014 (NO_3, NO_2) [29]; ST RK 1015-2000 (H_2 SO_4) [30]; ST RK 2727-2015 (F) [31]; ST RK ISO 17294-2-2006 (Li, Sr, Rb, Cs) [32]; HDPE F 14.1:2:4.36-95 (B) [33]. The following methods and equipment were used to determine chemical indicators of water samples: (1) For the pH index, the potentiometric method and the liquid analyzer "Mettler-Toledo" were used. (2) For Ca, Mg, SO_4, and HCO_3, the titrimetric method was used. (3) For F, Cl, SO_4, NO_3, NO_2, NH_4, K, Na, and Br, the capillary electrophoresis method and capillary electrophoresis system "Kapel-105-M" were used. (4) For spectrometry with inductively coupled plasma for F and Si, the ICPE emission spectrometer "Shimadzu Corporation" was used.

The groundwater wells (Table 1) inspected were classified by the status, working conditions, flowing capacity, not flowing, pumped, blocked with stones and clocking materials, and number abandoned. Groundwater levels were measured at non-flowing wells using a water level tape, and flow rates were estimated at artesian wells using a 10-L bucket and a stopwatch. Temperature was measured with a thermometer and pH was measured with a hand probe. Water samples were collected using 1-L and 5-L plastic bottles. The five-liter water samples were collected for sanitary and epidemiological rules and regulations norm analysis. The one-liter water samples were collected for a reduced chemical analysis. Measurements recorded during inspections include GPS coordinates of wells, latitude, longitude, and depth altitude. Field work was completed within 30 days.

Out of 10 wells in the Zhambyl district (Table 1), 6 wells were flowing at rates of 0.5 to 5 L/s, 1 well had the water at a depth of 2 m below the ground surface, boreholes of 2 wells were blocked with stones and clocking materials, and 1 well was abandoned. Sixteen wells in the Baizak district were inspected (Table 1), from which six were flowing with rates of 0.1 to 5 L/s. Four wells had water tables 2 to 5 m below the surface. Boreholes of 3 wells were blocked with stones and trash materials and 3 wells had a pump installed. Out of

39 hydrogeological wells in the Zhualy region (Table 1), 25 wells were flowing with rates of 0.2 to 30 L/s. Three wells were found with their water table at a depth of ~3 m below the surface. Boreholes of eight wells were blocked with stones and trash materials, and three wells were abandoned. In the Ryskulov district, a total of 32 wells were inspected (Table 1), and it was found that 24 wells were flowing from 0.1 to 10 L/s (Figure 4). Pumps were installed in two wells, while boreholes of six wells were blocked with stones and clocking materials.

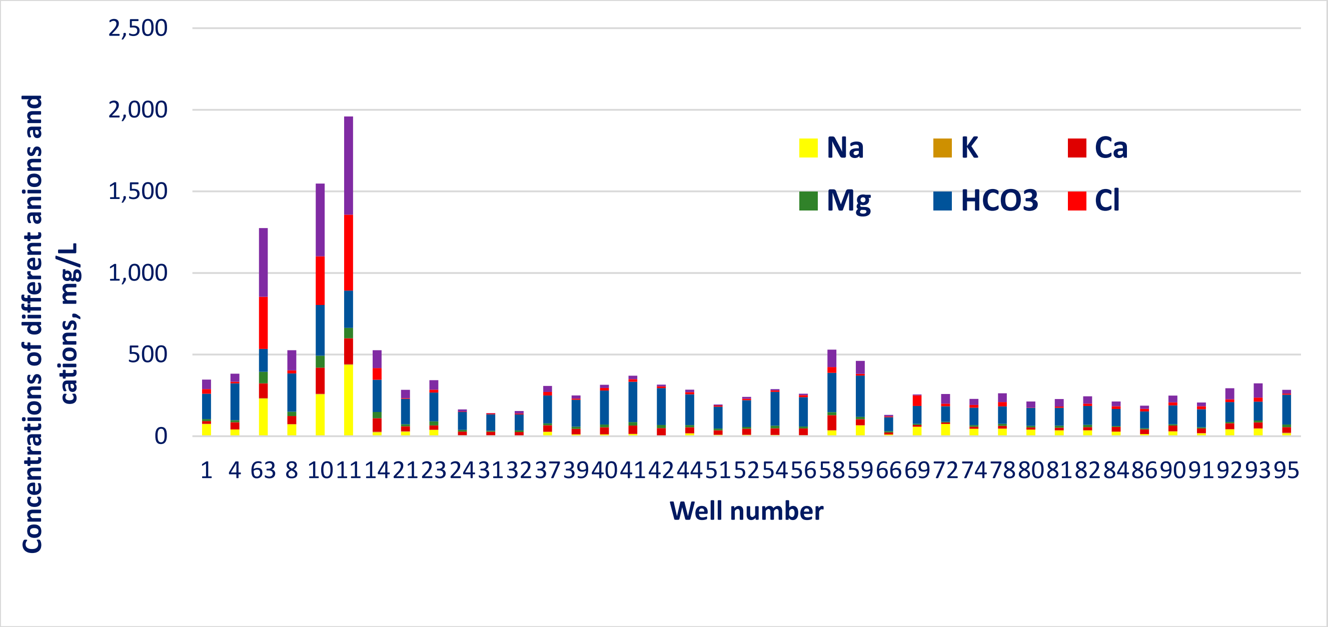

Figure 4. Frequency distribution of chemical components in wells (Colins histogram). Water Chemical samples analysis in Zhambyl, Baizak, T. Ryskulov and Zhualy districts of Zhambyl region, Kazakhstan.

Here are the well inspections from the Zhambyl, Baizak, T. Ryskulov and Zhualy districts. The flow rates of artesian wells varied from 0.1 to 30 L/s. The water levels in the wells were at depths of 0.1 to 10 m. The type of water extraction technologies was examined. Some wells had submersible pumps. Most wells in the Zhambyl, Baizak, T. Ryskulov and Zhualy districts were artesian (Table 1, Figure 3). Submersible pumps were installed in 5% of wells. In total, 20% of wells were blocked with stones. About 70% of artesian wells were located within the Zhualy and T. Ryskulov district areas.

2.5. Sampling and Data Preparation

The subsequent chemical analysis of 40 groundwater samples from the surveyed 97 wells was carried out in the chemical laboratory of the Institute of Hydrogeology and Geo cology named after Ahmedsafin, Almaty in 2022. Water sample compositions were measured by various chemical and physical parameters. These chemical parameters include pH, electrical conductivity, total solids, total dissolved solids (TDS), and hardness. Some of the physical parameters include color, odor, haze, and transparency—organoleptic observations [26]. TDS was measured by two methods: gravimetric and specific conductance.

Orography Laboratory Analysis

Chemical laboratory analysis of the collected field water samples was provided on pH, conductivity, and dry residue by using the Mettler-Toledo liquid analyzer method [27]. Sodium and potassium were measured with a PFP-7 flame photometer. Dissolved calcium, magnesium, nitrite, nitrate, sulfate, chloride, and fluoride components were measured with a Capel 105M capillary electrophoresis device. The KTA-OH, DEA, tartaric acid, hydrochloric acid, and sodium hydroxide reagents were used to prepare electrolytes. Calibration and results are presented in mg/L [34].

Boron (B) and Silicon (Si) were determined with KFK-2 devices [35]. Metals were analyzed with an ICPE-9820 emission spectrometer or Agilent AA 140 atomic absorption spectrophotometer. Samples were then pretreated, treated with nitric acid, and filtered before analysis.

The following methods were used to assess water composition:

(1) Archival data, field work and collection of water samples; (2) laboratory chemical and analytical processing of water samples; (3) "Piper diagram" method of graphical procedure; (4) water sample composition index.

Chemical concentration determinations in water samples from the Zhambyl region were conducted using capillary electrophoresis analysis with the "Kapel-105M" system. Sample preparation is conducted by passing water through a membrane cellulose acetate filter of the "MFAS-B-4" type (diameter 0.2 µm); then, the filtrate was poured into a disposable tube with a capacity of 1.5 cm^3 according to "TU 62-2-300-80". Further measurement of the concentration of chemicals in water samples was conducted using a background electrolyte, in which the following reagents were used: purified water, sodium hydroxide, hydrochloric acid, and tartaric anhydrous. The background electrolyte was also poured into a disposable tube with a capacity of 1.5 cm3. A standard sample of chemicals (1 mg/cm^3) was used to construct the calibration schedule. Before determining the concentration of chemicals in water, the tubes were placed in a laboratory centrifuge (CENTREFUGA-VORTEXSM-70M.09) with a rotation speed of 5000 rpm. After centrifugation, the samples were loaded into an autosampler and then the concentration of chemicals in the water was measured. This method is based on the separation of charged molecules in a liquid medium inside an ultrathin quartz capillary under the influence of an electric current with indirect detection at a wavelength of 267 nm. The lowest detection limits were based on the operating measurement range depending on the matrix and the interference encountered.

For the quality control measures for data to ensure the accuracy and reliability of the results, researchers followed the requirements of the chemical laboratories of the U.M. Akhmedsafin Institute of Hydrogeology and Geoecology (Accreditation Certificate No. KZ.T.02.0782, valid until 27 November 2025). In drinking water and relatively unpolluted water, the detection limit for most elements is between 0.0001 and 0.001 mg/L. Depending on the instruments used, significantly lower limits can be achieved ISO 17294-2:2003, IDT [36].

Kazakhstan's standards for potable water were used for the comparison studies with the collected field water samples:

(NO_3)—not more than 45 mg/L [29];
(NO_2)—not more than 3.0 mg/L [29];
(SO_4)—not more than 500 mg/L [37];
(F)—not more than 1.2 mg/L [31];
(Cl)—not more than 350 mg/L [38];
(Ca), (Mg)—not standardized.

Determination of anion content by chromatography and capillary electrophoresis.

This standard applies to drinking water, including water packaged in containers, and natural (surface and ground) water, including water from sources of drinking water, and establishes the determination of the content of inorganic anions by ion chromatography and capillary electrophoresis in the mass concentration range:

From 0.5 to 50 mg/L—for chloride, sulfate, nitrate, and nitrite ions.
From 0.3 to 20 mg/L for phosphate ions.

The limitations of the study are related to the representativeness of the well's samples:

- The quantity of the well's sampling.
- Consistency of the well's sampling; a permanent well-monitoring system will be reasonable to introduce.

- Quality of the water sample collection and transportation over the long distance from the field to the main chemical laboratory.

Water quality investigations are a complex problem in Kazakhstan, as a proper permanent well-monitoring system is missing. Vandalism is a big obstacle to installing and using a long-term well-monitoring system in Kazakhstan.

3. Results and Discussions

3.1. Groundwater Chemistry

The field samples' chemical analyses are given in Table 2. Groundwater pH was more alkaline, with values from 7.2 to 8.5 (mean value 7.95). The groundwater temperature in wells ranges from 10 to 26 °C.

Table 2. Water sample chemical analysis results of the Zhambyl, Baizak, T. Ryskulov and Zhualy districts, Zhambyl region, Kazakhstan, compared with drinking water standards [27,39], International Standard ISO 17294-2:2003 [36].

Parameter	Unit	Detection Limit, mg/L	Dry Season (Nov. 2020)			Wet Season (May 2022)			Drinking Water Standards	
			Min	Mean	Max	Min	Mean	Max	Kazakhstan	WHO/EU/USA
pH		0–12	6.2	7.9	9.0	7.23	7.9	8.4	6–9	6.2–8.5
Temp.	°C	0–100	11.0	18.4	29.1	10.5	15.5	25.3		
Ca	mg/L	titration method	1.0	20.3	64.0	9.0	40.7	160.3		
Mg	mg/L	titration method	0.3	7.2	29.8	4.9	17.3	73.0		
Na	mg/L	0.1	2.8	38.0	179.0	3.1	50.0	436.5	200	200
K	mg/L	0.05	0.1	0.8	2.2	0.1	1.2	4.2		
CO_3	mg/L	titration method	6.0	3.1	17.0	8.0	8.4	24.0		
HCO_3	mg/L	titration method	12.2	101.7	280.7	85.4	159.3	311.2		
Cl	mg/L	by electrophoresis	3.5	12.2	42.5	2.1	43.1	465.4	350	250
SO_4	mg/L	by electrophoresis	9.9	43.6	198.4	2.5	73.7	602.0	500	250
NO_3	mg/L	by electrophoresis	0.1	3.9	20.9	0.2	5.0	15.4	45.0	50.0
NO_2	mg/L	by electrophoresis	0.01	0.17	0.15	0.01	0.01	0.01	3.0	0.50
NH_4	mg/L	spectrophotometer	0.0	0.0	0.0	0.05	0.05	0.3	0.2	0.50
F	mg/L	electrophoresis method	0.3	1,0	1.5	0.22	0.7	1.2	1.5	1.5
B	mg/L	0.01	0.001	0.005	0.005	0.01	0.01	0.74	0.5	1.0
Cd	mg/L	0.0001	0.0004	0.0005	0.0007	0.0005	0.001	0.002	0.001	
Si	mg/L	spectrophotometer	0.1	0.1	2.2	4.81	0.1	4.81	10.0	
Li	mg/L	0.001	0.01	0.02	0.02	0.1	0.004	0.18	0.03	
Mo	mg/L	0.0005	0.008	0.02	0.1	0.001	0.002	0.005	0.25	
As	mg/L	0.001	0.008	0.008	0.01	0.005	0.005	0.005	0.05	0.01
Pb	mg/L	0.0001	0.003	0.003	0.005	0.002	0.002	0.02	0.03	0.01
Ag	mg/L	0.001	0.0003	0.0003	0.0003	0.0005	0.0002	0.011	0.001	0.001
Sr	mg/L	0.0005	0.1	0.1	0.3	0.8	0.4	15.0	7.0	4.0
Fe_2	mg/L	spectrophotometer	0.0	0.0	0.0	0.05	0.07	0.1	0.3	0.2
Fe_3	mg/L	spectrophotometer	0.05	0.05	0.1	0.05	0.07	0.1	0.3	0.2

Figure 4 shows the concentrations of different anions and cations in the sampled water wells. The concentrations of different anions and cations of the water sampled include HCO_3 bicarbonate, Cl chloride, SO_4 sulfate, calcium Ca, magnesium Mg, sodium Na, and potassium K. The highest concentrations of different anions and cations are found in wells No. 10 and 11, and the lowest concentrations of various anions and cations are found in wells No. 31 and 66. It can be assumed that sulfates, hydrogen carbonates, calcium and magnesium predominate in these wells. This is also confirmed by the Piper diagram.

Mineralization, TDS (total dissolved solids), the ratio of various components by location of hydrogeological wells, and a Piper diagram are given in Figure 5. These graphs show the content of the main macro and micro components of the groundwater composition obtained from the geochemical sampling carried out in 2022. In terms of chemical composition, groundwater has a predominance of sulfates, hydrogen carbonates, calcium, and magnesium.

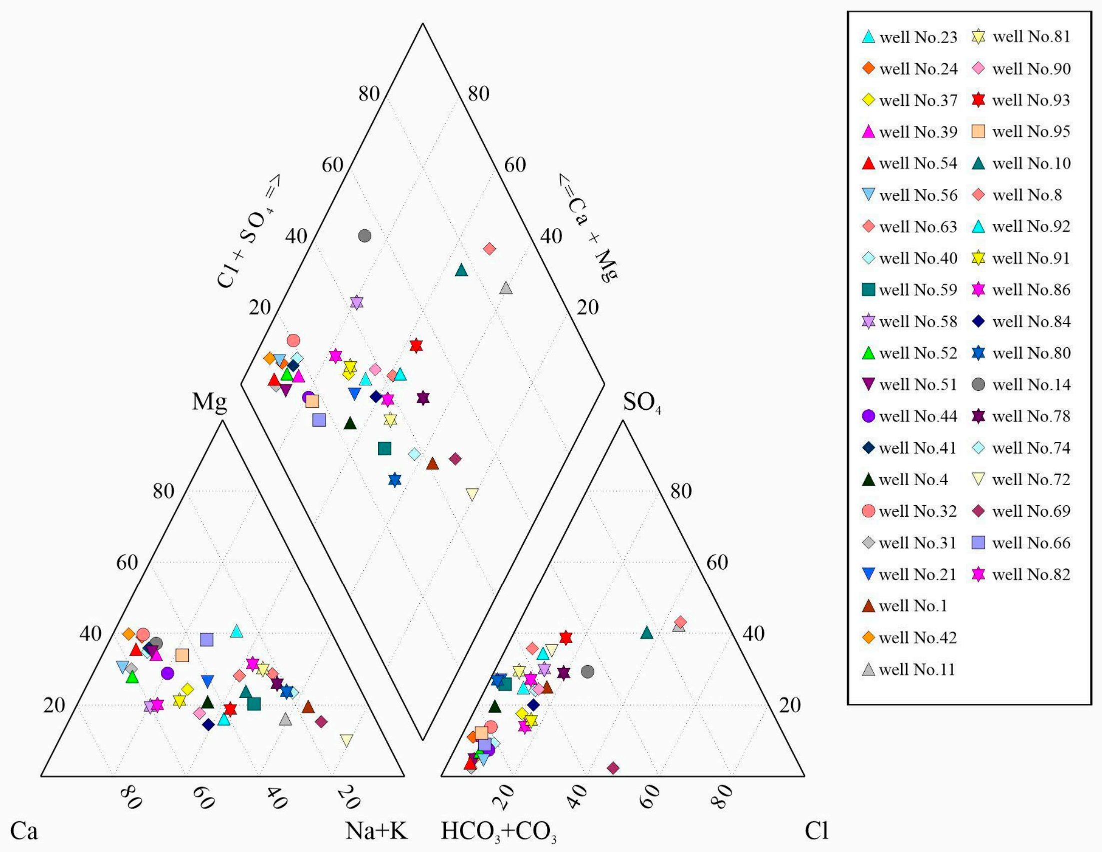

Figure 5. Piper plot depicting the chemical compositions of groundwater from in Zhambyl, Baizak, T. Ryskulov and Zhualy districts.

The TDS-Ca mineralization levels are R2 = 0.8435, TDS-Mg R2 = 0.8629, TDS-Cl R2 = 0.9336, TDS-SO_4 R2 = 0.9686, and TDS-Na R2 = 0.9138 in the Zhambyl, Baizak, T. Ryskulov and Zhualy districts of the Zhambyl region, as shown in Figure 5. Mineralization indicators TDS-HCO3 R2 = 0.2914 are low, which may indicate a decrease in the influence of water–rock interaction processes. Table 3 lists the Water Composition Index (WCI), water type and percentage of different water types in the Zhambyl, Baizak, T. Ryskulov and Zhualy districts of the Zhambyl region. The WCI shows a degree that reflects the combined effect of several water component parameters. WCI is important in determining the suitability of groundwater for drinking purposes. WCI assessment is an effective method for assessing water composition and can be useful for groundwater monitoring. It is also an easy way to present the results of the groundwater composition assessment.

About 89.7% of the wells sampled in the Zhambyl, Baizak, T. Ryskulov and Zhualy districts of the Zhambyl region meet requirements of the sanitary standard for potable use, and 10.3% exceeded the limits of permissible concentrations for drinking. For example, in well No. 10 of the Baizak district, the water mineralization exceeds the limit by one and a half times (1561), while the water mineralization should not exceed 1000 (Figure 6). The dry residue is 1364, which exceeds the permissible norm by almost one and a half times.

Water hardness exceeds the limit twice, which is equal to 14. In well No. 11 in the same area, the water mineralization exceeds the limit twice and is 1970; the dry residue is 1870 and the hardness is almost 14. The same values are found in two other wells (Figure 6).

Table 3. Ranges of correlation coefficients and their interpretation.

Ions	Unit	Min	Mean	Max	Interpretation		R2	WQI	Water Type
HCO_3	mg/L	85.4	159.3	311.2	Weak	from 0.2 to 0.5	0.2914	90–100—very good 70–90—good 50–70—medium 25–50—bad 0–25—very bad	water type: hydro carbonate sulfate, calcium sodium, 84%
Ca	mg/L	9.0	40.7	160.3	Strong	from 0.7 to 0.9	0.8435		
Mg	mg/L	4.9	17.3	73.0			0.8629		
Na	mg/L	3.1	50.0	436.5	Very strong	from 0.9 to 1.0	0.9138		
Cl	mg/L	2.1	43.1	465.4			0.9336		
SO_4	mg/L	2.5	73.7	602.0			0.9686		

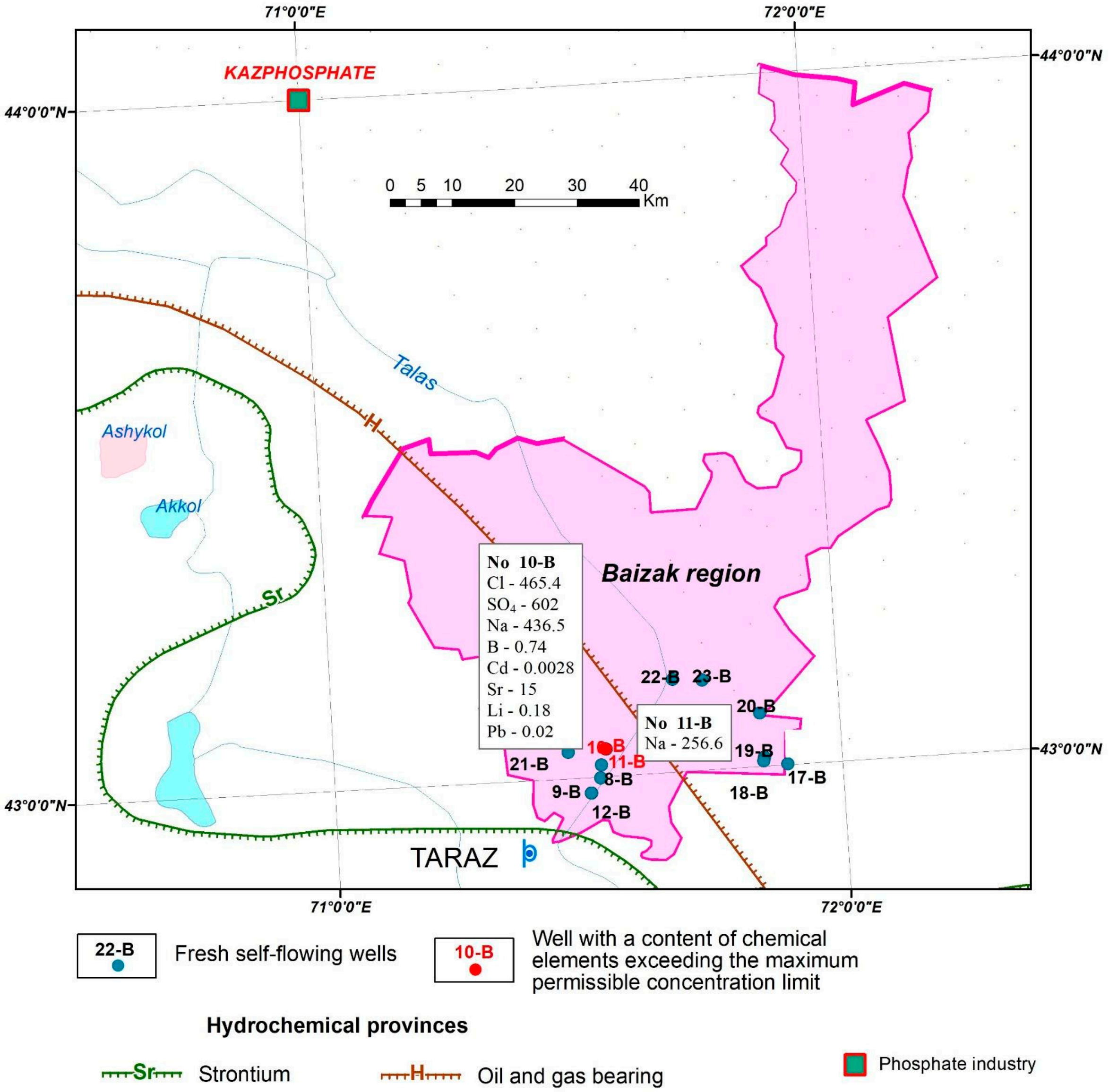

Figure 6. Location of the wells with the exceedance of water quality standards are shown in red, including area with high Sr.

3.2. Potable Water Quality Standard Exceedances

July has the highest average temperature at 26.0 °C, while January is the coldest month of the year, with an average temperature of −3.3 °C.

The least rainfall occurs in August, with an average of 9 mm. In April, precipitation reaches its peak, with an average of 69 mm. The change in precipitation between dry and rainy months is 60 mm.

The lowest relative humidity value was recorded in August (31.31%). Relative humidity is highest in November (71.29%) (Table 4).

Table 4. Climate chart of the study area for 2020–2022.

Months	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*June*	*July*	*Aug*	*Sep*	*Okt*	*Nov*	*Dec*
Average temperature (°C)	*−3.3*	*−1.6*	*5.4*	*11.9*	*18.1*	*23.6*	*26.0*	*24.8*	*18.8*	*10.8*	*2.8*	*−2.8*
Minimum temperature (°C)	*−8.1*	*−7.0*	*−1.1*	*4.4*	*9.8*	*14.7*	*17.5*	*16.4*	*11.2*	*4.1*	*−2.5*	*−7.5*
Maximum temperature (°C)	*2.2*	*4.0*	*11.7*	*18.1*	*24.7*	*30.3*	*32.7*	*31.8*	*25.8*	*17.5*	*8.8*	*2.6*
Precipitation rate (mm)	*40*	*45*	*61*	*69*	*45*	*26*	*15*	*9*	*15*	*36*	*47*	*40*
Humidity (%)	*68*	*70*	*67*	*62*	*51*	*37*	*32*	*31*	*37*	*55*	*71*	*70*

Table 3 and Figure 5 show that some chemical values exceed the permitted drinking water standards (dws). Sodium (Na) enters groundwater through the dissolution of bedrock. The maximum permissible concentration of sodium in drinking water is 200 mg/L. Sodium (Na) values are twice as high as the permitted drinking water standards—436.5 mg/L against the 200 mg/L standard. Continuous exposure to sodium in the body has a detrimental effect on the functioning of the kidneys and cardiovascular system [40,41]. Concentrations of 350 mg/L of chloride (Cl) can be harmful, and the measured concentrations range up to 465.4 mg/L. Daily consumption of water with elevated Cl can lead to heart disease, atherosclerosis, anemia, and increased blood pressure [42].

Sulfate (SO_4) values exceed the permitted limits for the permissible dws by more than two times—602.0 mg/L compared to the WHO/EU standard of 250 mg/L. Consumption of water with excess sulfate (more than 500 mg/L) gives drinking water a bitter taste, and at a concentration of 1–2 g per liter, sulfate water has a laxative effect [43].

The maximum lithium (Li) level was measured at 0.18 mg/L, compared to the allowable 0.03 mg/L for drinking level. This is six times higher than the permissible drinking water standard [44].

Strontium (Sr) is a common metal in the earth's crust; however, it rarely exceeds 1–2 mg/L. However, in its pure form, it rarely comes across, as it is very active and quickly enters various chemical reactions. More than 40 strontium-containing minerals are known, such as celestite and strontian. This element enters natural waters when calcium rocks are washed out, entering their composition as an impurity. Natural strontium is a part of almost all living organisms and is considered a low-toxic substance. However, long-term use of water with an excess content of this substance adversely affects human health. According to the requirements of sanitary and epidemiological rules and regulations, this indicator should not exceed 7 mg/L. In our case, Sr is 15 mg/L. Strontium is very close to calcium in its properties. Long-term high exposure to strontium can gradually displace calcium ions from bone tissues and lead to Urov disease. This is expressed in serious deformities of the musculoskeletal system and can lead to disability. Strontium accumulates especially quickly in a child's body, contributing to growth retardation [45]. Our investigation shows a well with a high strontium content in the Bayzakovsky district—well No. 11-B, which is self-flowing, and the local people consume this water. Well No. 11-B is located at latitude 43°02′25.60″ and longitude 71°32′09.20″ and belongs to the Talas River valley, which begins with mudstones and siltstones. The depth of the well is more than 900 m. The next well with excess Na is located next to well No. 11-B in the same area. Wells where Sr is exceeded are in the Sarykemer rural district, where 15,563 people live. Water containing high levels of strontium should not be used [46–49]. Previous geological studies have also shown that this southern region in Kazakhstan is rich with natural uranium resources [23]. The regions of Well No. 11-B will be reasonable for further investigations into potential underground geological "factories" locations producing natural "white" hydrogen via a serpentinization reaction and radiolysis decays from underground water.

3.3. Comparison of Water Composition Characteristics According to Geology and Land Use

The geological and structural conditions of the regions are very complex. The formation and distribution of groundwater, their migration, discharge, and further transformation are closely related to the geological and structural conditions. The geological formations, consisting of various rocks and loose sedimentary deposits, serve as a water-containing medium. The hydrogeological conditions of the territory under consideration are divided into the following geomorphological regions: mountain structures, foothill plains, hilly ridged sandy plains, the southeastern part of the Betpak-Dala plateau, and modern alluvial river valleys. The southern and northern regions differ in different formation conditions. In the southern part of the regions, underground waters of Paleozoic rocks are confined to sandstones, siltstones, porphyrites, conglomerates, and limestones. The mineralization of groundwater is 0.3 g/L, and the composition is bicarbonate calcium. In the northern part of the districts, groundwater is adjacent to the valley of the Chu River, associated with a weathered zone of effusive rocks, granitoids, sandstones, shales, and other metamorphic rocks. The water quality is low, salinity varies from 3 to 10 g/L, and the composition of the water is sulfate and sodium chloride. Less common with salinity from 10 to 50 g/L, the composition of the water is sodium chloride. The geology of the regions of the southern and northern parts shows that they are separated from each other by different geological characteristics and the composition of groundwater quality [19].

Water compositions are formed from the natural geological minerals combined with human activity [50–54], the chemical composition of groundwater [55–60]. High concentrations of Pb, Sr, Na, Cl, SO_4, B, Li, TDS, and Cd were investigated in the research area.

3.4. Summary of the Areas with the Water Compositions High Levels

The areas with water compositions and high levels of mineralization (Figure 7) exceeding the water drinking quality standards in the study area were summarized.

The wells with the exceedance of water quality standards are shown in red (Figure 7). These exceedances included the following:

- Sodium (Na) with values of 436.5 mg/L (permissible 200 mg/L) leads to hypertension and hypertension, causes dehydration, impaired potassium metabolism, poor digestion, headache and increased blood pressure, and negatively impacts kidneys and cardiovascular system functions [42,43].
- Chloride (Cl) with values of 465.4 mg/L (permissible 250 mg/L) leads to a violation of the digestive system, incidence of cholelithiasis, urolithiasis, cardiovascular system, bladder cancer, stomach cancer, liver cancer, cancer of the rectum and colon, as well as digestive system diseases [42].
- Sulfate (SO_4) with values of 602. mg/L (permissible 250 mg/L) leads to irritated esophagus, affects gastric secretion, disrupts the digestion process, causes intestinal upset, and provokes allergic itching and skin inflammation [43].
- Lithium (Li) with values of 0.18 mg/L (permissible 0.03 mg/L) leads to disruption of the cardiovascular and central nervous system, tremor, ataxia, memory loss, convulsions, and kidney damage [44].
- Strontium (Sr) with values of 15.0 mg/L (permissible 7.0 mg/L) leads to Urov disease, serious deformities of the musculoskeletal system, causing disability, and growth retardation in children [45].

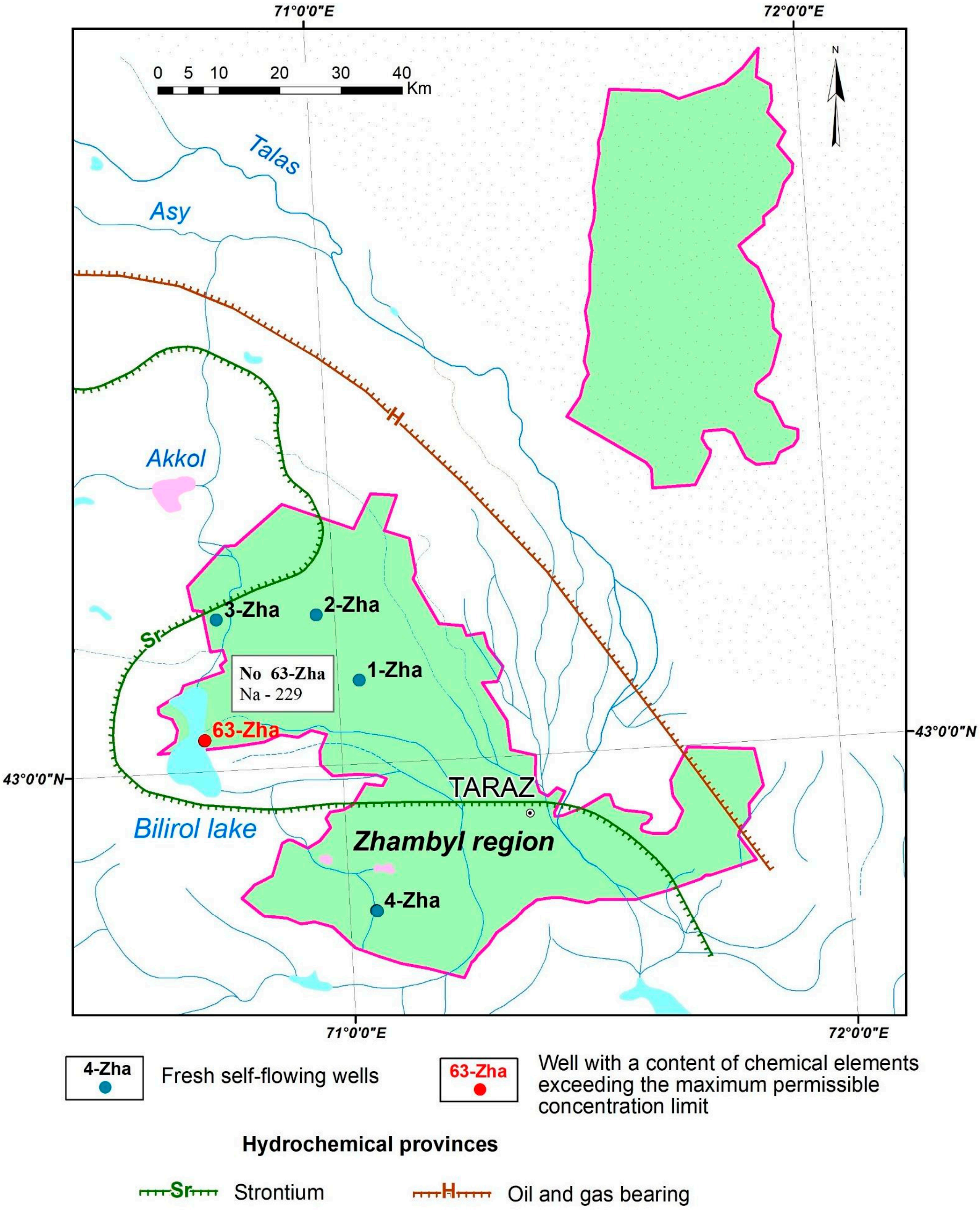

Figure 7. Location of the wells with the exceedance of water quality standards are shown in red.

Chemical hazardous facilities are in many regions [55]. The most common potent toxic substances are chloride (about 30%), hydrogen sulfide, sulfur dioxide (sulfur dioxide), and acrylic acid nitrile [56,57]. Separate dedicated research is needed to determine illnesses, prevention, and treatment of the water composition health issues in the region [58]. Consumption of raw unpurified water causes health problems in Kazakhstan. Stomach cancer is one of the most common cancer diseases in Kazakhstan. Every year, about 2700 new cases of stomach cancer are detected, that is, 14.4 per 100 thousand population, and the mortality rate from this disease is 1700 cases or 9.1 per 100 thousand population. Stomach cancer can develop in any part of the stomach and spread to other organs [59]. Every 22nd resident of the South Kazakhstan region has urolithiasis, compared to other Kazakhstan regions, with an average of 1 in every 16 residents. The genitourinary system illnesses are often caused by environmental, poor water quality issues [58–60].

3.5. Data and Database

The geoinformation database of the flowing wells was generated for the Baizak, Zhambyl, T. Ryskulov and Zhualy districts (Figure 8). Figure 8 represents the preparation for a geodatabase on hydrogeological wells in a more systematic and structured manner for Kazakhstan regions, containing well data such as location, coordinates, chemical composition, temperature, salinity, hardness, and water flow rate in wells. Figure 8 shows the location of the flowing wells, including characteristics such as wells with water on the surface, wells that use a submersible pump for water intake, wells with a borehole blocked with stones, and abandoned wells. With this dataset's information, the next level of water sustainability programs will be developed.

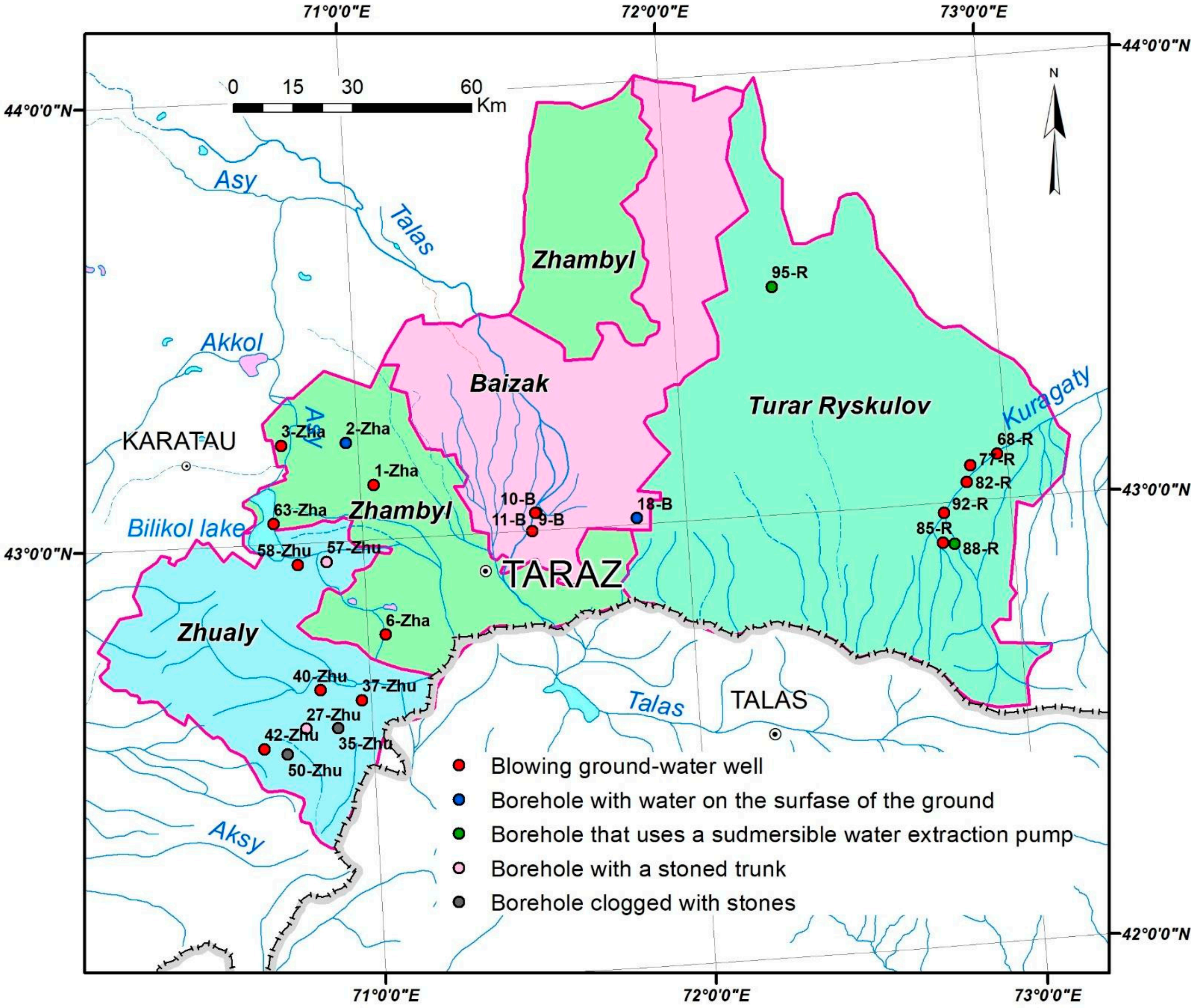

Figure 8. Flowing wells location map in Baizak, Zhambyl, T. Ryskulov and Zhualy districts of Zhambyl region, Kazakhstan, 2022.

This research assessment shows that most flowing wells are in the Zhualy district (Table 5, Figure 8). Additional details are available in the Supplementary Materials. A flowing well with pressure status was developed.

Table 5. Distribution of promising flowing wells in the Zhualy and T. Ryskulov districts.

No.	Quantity of Wells	Location of Wells	Total Flow Rate, L/s
1	11	Zhualy district	147
2	3	T. Ryskulov district	30

A systematic well assessment, including flowing well operation and groundwater pressure, such as wells with capacity above 10 L/s, has been classified (Table 5). The total capacity of 11 flowing wells in the Zhualy district was assessed at 0.147 m^3/s (12,700 m^3/day, 0.004635 $km^2/year$). The total capacity of the flowing wells of the Zhualy district to expand for potable use was assessed at 0.147 m^3/s.

3.6. Further Investigations for the Natural "White" Hydrogen "Factories" Locations

Currently, many countries conduct "white" hydrogen explorations, and treat it as a "gold rush." This includes the region near the Germany–France border, where the world's largest underground reserves of "white" hydrogen have been discovered. On the territory of the transboundary Moselle–Saar River basin, where coal mines abandoned more than 20 years ago are located, large volumes of natural geological "white" hydrogen were discovered with an estimated volume of up to 250 million tons [61]. It is important for underground hydrogen "factories" to replenish water for the physico-chemical oxidative processes of serpentinization and hydrogen production underground [62]. Kazakhstan lacks "white" hydrogen exploration activities and does not have the "gold rush" programs dedicated to underground geological "factories" identification. However, such programs could work for regional sustainability improvement, and it will be reasonable to provide the proper investigations (Figure 9).

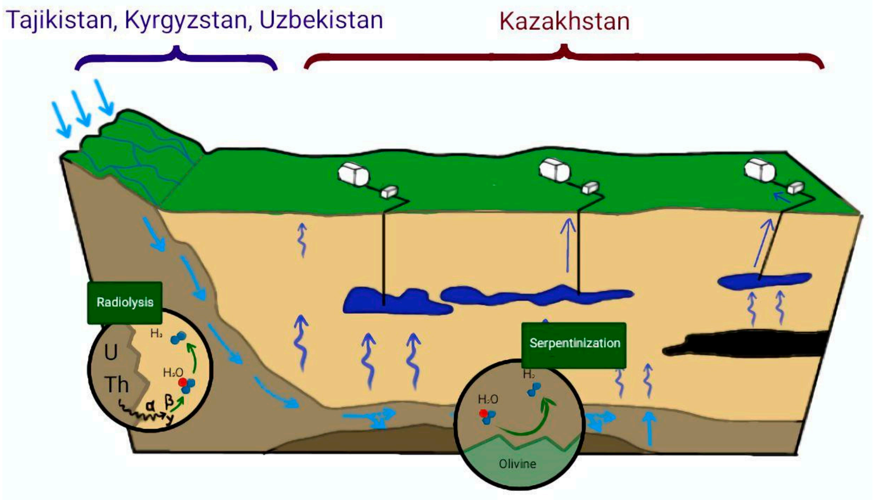

Figure 9. The diagram exhibits the potential of Central Asian countries for cooperation in groundwater resource use to prospect natural geological "white" hydrogen production (adapted from USGS Ellis [63].

3.7. Recommendations, Solutions

Effective water management systems in Kazakhstan are vital for sustainable development. The local people should be involved in solving their problems by providing them with high-quality secondary technical education to work on their water quality issues. Adapting programs like "Know Your Well", which trains high school students to sample and test well water quality, would be appropriate to use in Kazakh regions and villages. Establishing local water treatment facilities in regions and villages, along with support programs based on local technicians' colleges, would be another practical step. In Kazakhstan, if current policies continue, available water resources may be reduced by 30–50% by 2030, which will entail significant restrictions in food production, along with drinking water limitations and ecosystem degradation. A sustainable approach to lifelong blended learning, tailored for ease of use, can effectively disseminate scientific information about water issues. Scaling up such initiatives would greatly enhance awareness among both water users and policy makers. As of now, local people in Kazakhstan are excluded from decision-making activities. Discrepancies in water resource indicators and the lack of objectively reliable information reflecting the surface groundwater resource status create complexities for local people. Groundwater resources are used inefficiently in Kazakhstan. Incentives to expand sustainability project programs, such as NEXUS (water, food, energy), which focus on efficiently combining water used for consumption and opportunities to increase income through the involvement of natural "white" hydrogen activities [64], will increase water value and create ways to reuse and recycle water with higher profitability. One potential opportunity is working with the Canadian natural hydrogen company, Hydroma. Hydroma, while working in Mali [65], involves the local people, something that could be replicated in Kazakhstan. These efforts can improve a region's water sustainability.

4. Conclusions

To improve water sustainability, substantial efforts are required to investigate the water resources on all levels, including groundwater resources. The combination of climate change, human mismanagement, and unsustainable projects threaten Kazakhstan's water. Groundwater studies for water sustainability improvement in Southern Kazakhstan, CA were conducted. Here, the relationship between various hydro-chemical types of groundwater with the physical–geographical, geological–structural, and geochemical features of the area was examined. The groundwater of the Paleozoic, Cretaceous, Neogene and Quaternary consists of alluvial deposits. Geological rocks are confined to sandstones, siltstones, porphyrites, conglomerates, limestones, and metamorphic rocks, which are favorable conditions for the serpentinization reaction for natural hydrogen production from underground water. Further investigations are required for potential underground geological "factories" location identification, which produce the natural "white" hydrogen. Mineralization of underground waters starts at 0.3 g/L in the research area. The calcium bicarbonate composition reaches up to 10 g/L, mostly sulfate and sodium chloride. The sodium chloride composition with mineralization ranges from 10 to 50 g/L in some regions. The water compositions of groundwater vary from 0.8 g/L to 50 g/L for hydro carbonate and sulfate-chloride. The groundwater compositions are directly connected to the geological rocks. Geological rocks are confined to sandstones, siltstones, porphyrites, conglomerates, limestones, and metamorphic rocks. In observation wells, a number of components are contained in high concentrations (mg/L): sulfates—602.0 (MPC 500 mg/L), sodium—436.5 (MPC 200 mg/L), chlorine—465.4 (MPC 350 mg/L), lithium—0.18 (MPC 0.03 mg/L), boron—0.74 (MPC 0.5 mg/L), cadmium—0.002 (MPC 0.001 mg/L), strontium—15, 0 (MPC 7.0 mg/L), and TDS—1970 (MPC 1000). The water compositions are mostly natural and are rich in geological minerals, including uranium deposit areas, which are favorable conditions for radiolysis decays to produce natural hydrogen from underground water. Further studies with classifications, mapping of water sources, groundwater aquifer locations that can be used for consumption, and potential underground geological "factories" locations, producing natural "white" hydrogen, are required to improve the water sustainability in the region.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su16114597/s1, Figure S1: The detailed locations of wells in Baizak, Zhambyl, T. Ryskulov and Zhualy districts.

Author Contributions: All authors have contributed to the concept and design of the study. Preparation of materials, collection and analysis of data has been performed according to D.A., Y.M., J.S. and D.S. The first draft of the manuscript has been written by D.A. and all authors have commented on previous versions of the manuscript. All authors have read and agreed to the published version of the manuscript.

Funding: This work is supported by the Science Committee of the Ministry of Education and Science of the Republic of Kazakhstan, grant No. IRN AP09260877.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The groundwater field data presented in this study were collected with Kazakhstan's local authorities' approvals and are available on request from the corresponding author.

Conflicts of Interest: The authors declare no conflicts of interest.

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