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Hydrogeological characteristics of the Alakol groundwater deposit for resort infrastructure development

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Abstract. The paper presents the results of a comprehensive geological and hydrogeological assessment of the Alakol groundwater deposit in the Alakol Depression, southeastern Kazakhstan. This deposit represents one of the principal groundwater sources for the rapidly developing resort infrastructure on the southern shore of Lake Alakol. It is therefore of considerable socio-economic importance for the region. The study examines the geomorphological setting of the area, the lithological composition and thickness of aquifer-bearing deposits, groundwater occurrence conditions, and the main factors governing groundwater recharge, flow, and discharge. The groundwater regime in both recharge and discharge zones is characterized, and the principal filtration flow directions and hydraulic relationships between groundwater and surface waters are identified. In addition, the paper evaluates the configuration of existing water intake facilities, groundwater abstraction rates, and the influence of pumping on the regional hydrogeological balance. Particular attention is paid to the rational use and protection of groundwater resources under conditions of increasing recreational pressure. The results may serve as a scientific basis for the further development of resort infrastructure and sustainable groundwater management in the southern coastal zone of Lake Alakol.

Keywords: *groundwater; groundwater regime; aquifers; groundwater balance; water intake, deposit.*

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1. Introduction

Ensuring a sustainable water supply in arid regions of Kazakhstan, such as the foothill plains of the Dzungarian Alatau, is a key task of regional development. In conditions of surface water scarcity, the rational use of groundwater becomes particularly important, especially for agricultural and irrigated farming needs. The problem is exacerbated by the fact that most of the land suitable for agricultural use is located above the zone where spring water flows form, where natural moisture is insufficient, and supplying water through traditional irrigation canals is associated with high financial costs. Taking these factors into account, the development of oasis irrigation based on groundwater is becoming a priority. Such work enables effective use of water resources in areas far from swampy or saline areas, creating favorable engineering and geological conditions and minimizing the risk of flooding. Of particular interest is the experience with groundwater from the Alakol deposit, which is considered one of the key sources of water supply and irrigation in the region [1].

This article discusses the characteristics of water intakes, the geological conditions at their locations, and the prospects for using groundwater for sustainable agricultural development in the region. In geological and structural terms, the exploration area lies in the southwestern part of the vast Alakol intermountain basin, which is bounded on the southwest by the Dzungarian Fault. To the northeast, beyond the study area's boundaries, lies the Tarbagatai mountain range. The Alakol Depression is composed of a thick layer of loose Cenozoic sediments and, in turn, within the territory of the Alakol groundwater deposit, is located on a provincial sloping plain formed by sediments from large and small rivers flowing down from the northeastern slopes of the Dzungarian Alatau, and on flat alluvial-lake and partially lake plains formed as a result of periodic transgressions of ancient and modern lake basins. The largest lakes bordering the deposit, Sasykkol and Alakol, are at the same hypsometric level, 347 and 340 m, respectively. Therefore, there is a weak flow from Lake Sasykkol to Lake Alakol through a system of intermediate lakes (Uyaly, Kashkarkol, etc.). The shores of the lakes are mostly low and marshy, only in the south, where Lake Alakol erodes the foothill plain, its shores are steep and precipitous [2]. The depth of hand-dug valleys within the deposit varies from several tens of meters in the upper part of the foothill plain to 5-10 m at its periphery and up to 1-2 m in the deltas. The study area covers the coastal zone of Lake Alakol and adjacent land areas. From the southwest, the boundaries of the area run along the 800 m contour line to the outlet of the Tenteq River alluvial fan.

In the village of Zhaypak, the boundary follows the 380 m contour line, bypassing areas under irrigated agriculture. Near the village of Kainar, it reaches the southern shore of Lake Koshkarkol, crosses the Shubartobek tract, and then

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follows the shoreline of this lake. In the area of the village of Uyal, the border runs along the northern shore of Lake Alakol, including the Urzhar River delta, the Uyal River floodplain, and continues to the village of Koktal, located approximately 8 km from the shoreline [3]. Then the line runs horizontally for 360 m, crossing the Emel River floodplain and the Kossayshagyl tract. The eastern border runs along a 400 m contour line to the southern part of the Yrgayty River delta, then turns southwest and continues until it intersects with the 800 m contour line (Figure 1).

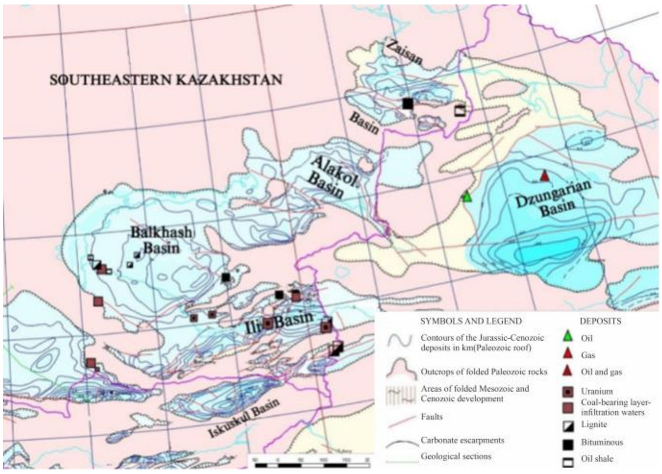

Figure 1. Example map of the Alakol depression

From a structural-tectonic perspective, the Alakol underground water deposit is confined to the southwestern structural zone, which is oriented northwesterly. This zone is a typical foreland depression formed because of prolonged tectonic subsidence. On the northern and northeastern sides, the deposit is bounded by a central tectonic zone that manifests as a mountainous uplift, also elongated in a northwesterly direction.

Based on drilling and geophysical studies of the roof of the Miocene-Pliocene deposits, composed mainly of clayey rocks, at least two additional tectonic uplifts have been identified. These structures are transitional forms between the central and southwestern zones and confirm the complex structure of the aquifer roof [4].

Significant faults, such as the Dzungarian Fault (in the southwest) and the Central Zone Fault (in the northeast), played a key role in shaping the deposit's hydrogeological structure. They caused significant subsidence of the earth's crust, contributed to the accumulation of a thick layer of coarse-grained alluvial deposits, and created favorable conditions for the formation of aquifers. Currently, these tectonic structures serve as natural hydrogeological boundaries of the deposit [5].

From a stratigraphic point of view, the Alakol underground water deposit is confined to a complex of alluvial-proluvial and alluvial-lacustrine deposits of the Quaternary system, which form the upper structural-hydrogeological level in the Alakol artesian basin section. Within the deposit, Quaternary deposits are represented by all stratigraphic subdivisions, from the lower to the modern, but their contributions to groundwater formation and accumulation vary significantly.

Lower Quaternary deposits lie on top of Pliocene and Miocene-Pliocene rocks and comprise two main facies: alluvial-proluvial and lacustrine-alluvial. The thickness of these deposits varies from 70 m on the elevated tectonic blocks in the northern part of the field to 190-200 m in the central, tectonically depressed areas and in the axial zones of the Tente and Zhamantinsky cones [6-7].

Alluvial-proluvial deposits associated with mountain foothills are composed mainly of a homogeneous layer of boulder-pebble material with high filtration capacity. As one moves away from the mountain front, layers of loam with lower permeability appear in the section, contributing to the formation of local areas of groundwater accumulation [8].

Alluvial-lacustrine deposits, along with clayey and gravelly rocks, widely contain sands and sandy loams, which play an essential role in the formation of aquifers. Middle Quaternary deposits are similar to Lower Quaternary deposits in terms of lithological and facies characteristics, but differ in their increased thickness. In the foothill areas, their thickness reaches 300 m, decreasing to 120-150 m in the north. These data are confirmed by the geological section (Figure 2).

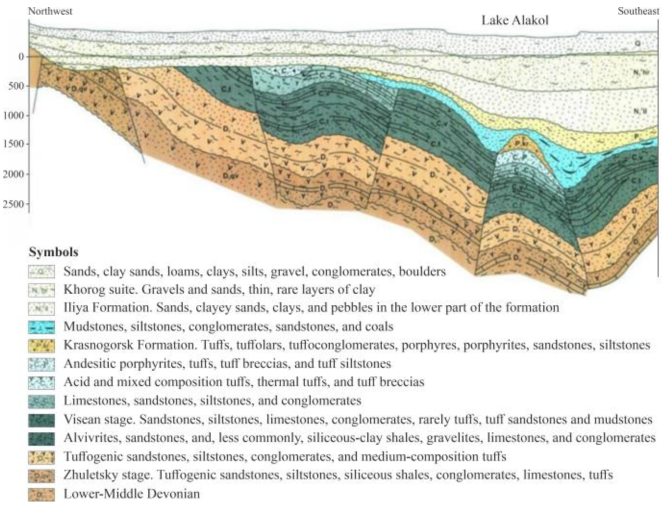

Figure 2. Geological section of the Alakol depression NW-SE

Therefore, this study aims to provide a comprehensive hydrogeological assessment of the Alakol groundwater deposit as a water supply source for the resort infrastructure of the southern Lake Alakol coastal zone. The study examines the geological and hydrogeological setting of the deposit, the structure and hydraulic connectivity of aquifers, groundwater regime features, recharge and discharge components, and the suitability of groundwater for practical use.

2. Materials and methods

The study is based on a comprehensive analysis of geological, hydrogeological, engineering geological, and climatic data obtained from open geoinformation sources, archival materials from hydrogeological surveys, and modern remote and field observations. The following methods were used in the course of the work.

Interpretation of stratigraphic and lithological sections of Quaternary deposits based on archival drilling data.

Classification of groundwater regimes according to D.M. Kats' scheme, adapted to the conditions of the Alakol Depression. Classification of groundwater regimes (according to D.M. Kats' scheme, adapted to the conditions of the Alakol Depression).

The method for classifying groundwater regimes proposed by D.M. Kats is widely used in hydrogeological studies. It is based on an analysis of fluctuations in levels, recharge sources, water yield characteristics, and seasonal dynamics. According to this scheme, the following types of groundwater regimes are distinguished (Table 1).

Table 1. Types and characteristics of groundwater regimes in the Alakol Depression

№	Area / plot	Type of groundwater regime	Mode characteristics
1	Koktuma tract	Free	Groundwater reacts quickly to precipitation and fluctuations in lake level.
2	The area of the village Akshi	Semi-stable	The water level is weakly dependent on precipitation; it feeds from afar
3	The central part of the coast	Mixed	Combined type of nutrition, moderate fluctuations in levels
4	The eastern section of the coast	Free	Intensive nutrition due to infiltration of precipitation and lake water
5	West of the village. Kabanbai	Semi-stable	Low seasonal fluctuations, weak connection with surface waters

Three groundwater regimes have been established in the Alakol Depression, adapted to local natural features. The most stable groundwater regime is observed in the lake-alluvial zone- these areas can be used for the permanent water supply of resort infrastructure facilities.

The most vulnerable areas are dune and coastal zones, where sharp drops in water levels and the risk of pollution are possible. Alluvial fans, despite fluctuations, are highly productive and can be used effectively with the proper water intake and regulation system. Methods used for the hydrogeological assessment of the Alakol groundwater deposit. The research methods included:

1) Conducting preliminary and detailed exploration of the Alakol underground water deposit. During the exploration work, four exploratory and experimental production wells were drilled, experimental work was conducted to assess the water yield and filtration capacity of the aquifers, and groundwater level and quality were monitored.

2) Analysis of groundwater regime. The classification of the groundwater regime of the deposit is based on the scheme developed by D.M. Kats, with modifications tailored to the deposit's specific conditions. This scheme takes into account the interaction of natural and artificial regime-forming factors. The groundwater regime is considered separately for the zone of its formation and discharge.

3) Assessment of groundwater conditions and balance. The groundwater balance equation for the deposit was recorded as follows:

$$q_f + x_i + Q_1 = E + q_{dr} + Q_2, \quad (1)$$

where: q_f is surface water filtration; x_i is atmospheric precipitation infiltration; Q_1 is underground inflow; E is evaporation of groundwater; q_{dr} is groundwater drainage; Q_2 is underground drainage.

To determine surface runoff losses, data from UGMs and temporary hydrometric stations operated by the expedition's hydrological team were used. The station on the Tentek River – the Tunkuruz collective farm, which has been operating since 1932, was taken as the reference point. To align the data from other stations with the long-term series, a 44-year reference period (1932-1977) was selected for the Tente River (Tunkuruz station). These data were used to determine the corrective relationships between the reference and other hydrological stations, regression equations, relationship graphs, tables for calculating the ordinates of the theoretical supply curve, and supply curves for the average annual discharge of rivers and streams.

The source materials for determining evaporation from the groundwater level were lysimeter observations at the Aksu groundwater deposit and a map of groundwater depths based on actual survey and exploration data. Evaporation graphs of groundwater levels for various vegetation types, based on groundwater depth, were used for the Aksu deposit. These data were subsequently used to estimate evaporation from the Alakol groundwater deposit, which has conditions similar to those of the Aksu deposit.

4) Assessment of groundwater quality. To characterize the quality of groundwater at the site and determine its suitability for irrigation, its primary purpose, and possible domestic and drinking water supply, water samples were taken during pumping from wells for general, spectral, and complete chemical analysis. In addition, samples were collected to determine trace element content, and radiological and bacteriological analyses were performed. The sampling methodology, as well as the methods for determining the content of chemical elements and bacteriological indicators, were carried out in accordance with the requirements of GOST 18963-73 and GOST 4979-49 (31.32). According to the requirements for groundwater quality used for irrigation, mineralization should not exceed 2.5 g/L. When the sodium and potassium cation content exceeds 70% of the total cation content, it should not exceed 1.5 g/l. The temperature of groundwater for irrigation should not exceed +350°C, and the irrigation coefficient should not be less than 18. The content of the main components determined in groundwater intended for water supply, as well as the permissible concentrations of several chemical substances entering water sources with domestic, industrial, and agricultural pollution, organoleptic and bacteriological indicators are controlled by GOST 2762-57, 2874-73, and since July 1, 1978, by GOST 17.13.03-77. Engineering-geological assessment of the stability of areas near proposed water intakes, taking into account geomorphological factors (slopes, flooding, erosion, seismic activity).

Hydrogeological zoning – aquifers suitable for exploitation have been identified. Groundwater in the deposit accumulates mainly in Lower and Middle Quaternary sediments. Based on stratigraphic and genetic characteristics, the following aquifers have been identified:

– Lower Quaternary alluvial
– proluvial deposits;
– Lower Quaternary alluvial-lacustrine deposits;
– Middle Quaternary alluvial-proluvial deposits;
– Middle Quaternary alluvial-lacustrine deposits.

In hydrogeological terms, these aquifers form a virtually single entity (aquifer complex). Near the mountains, this is a homogeneous layer of boulder and pebble deposits, in which the groundwater has a common free surface. At some distance from the mountains, the single aquifer is divided into separate aquifers in the form of lenses separated by relatively impermeable interlayers. At the same time, the aquifers are hydraulically connected [9].

3. Results and discussion

The groundwater regime was analyzed based on data from 18 observation and exploration wells drilled in 1976–1978. Four single and seven paired wells are located in the recharge zone, mainly on the alluvial fans of the Tentek and Zhamanta rivers. Wells No. 201 and 202a (310 and 307 m deep) overlap the Lower and Middle Quaternary aquifers. Well No. 208, located in the inter-cone space, is equipped with filters at depths of 156–186 m and reflects the behavior of the Middle Quaternary horizon.

The regime in these wells is characterized by low-amplitude level fluctuations due to the deep location of the filters and by the smoothing effect of infiltration flows from irrigation and rivers. The main rise in groundwater levels is recorded in June–September, coinciding with the irrigation season and the flood period. Minimum levels are observed in winter, which is associated with the cessation of water supply and the winter low water period. In general, stable water yield is recorded, and levels stabilize at the same marks annually, indicating the presence of a single aquifer system in the recharge zone. In the discharge zone, where irrigation is not used, four types of regimes are observed. Hydrological fluctuations in levels are associated with the water level in the Tentek River.

The amplitudes range from 0.5 to 1.6 m. Climatic-seasonal fluctuations are caused by meltwater runoff and spring atmospheric precipitation, and by evaporation in summer. Amplitude is 0.8-1.6 m. Irrigation – sharp rises in levels during the irrigation period (May-September), with an amplitude of 0.7-1.2 m. Characteristic of the isthmus between Lake Koshkarkol and Lake Alakol; levels are stable, depth of occurrence is 4-7 m, replenishment is limited, and outflow is formed by evapotranspiration.

It has also been established that a significant part of the underground flow is lost to evaporation in swampy and saline areas, reducing the total outflow. This confirms that increasing irrigation water withdrawals can improve the reclamation status of adjacent areas. The primary source of groundwater is the filtration of surface runoff in the foothill zone, enhanced by irrigation above the discharge zone [10-11]. According to data from the regional water management authority, water withdrawal for irrigation within the deposit during the growing season averages 39.10 m^3/sec, i.e., the average annual water withdrawal for irrigation was 19.55 m^3/sec. At the same time, irrigation water withdrawal does not depend on the year's water content.

Thus, out of the total amount of 31.25 m^3/sec of total surface runoff losses at 50% reliability and 23.13 m^3/sec of losses at 85% reliability, 19.55 m^3/sec is lost on average in canals and irrigation fields. Water losses directly in river beds due to filtration and evapotranspiration amount to 11.70 m^3/sec at 50% reliability and 3.58 m^3/sec at 85% reliability, respectively, in Table 2.

Table 2. Surface runoff losses

Naming of watercourses	Cost of posts m^3/sec				Loss of surface runoff, m^3/sec	
	Upper gate		Lower gate		Reliability 50%	Reliability 85%
	Reliability 50%	Reliability 85%	Reliability 50%	Reliability 85%		
Tentek River	46.94	34.74	24.39	18.05	22.55	16.69
The river of Zhamanty	5.39	3.99	0	0	5.39	3.99
Total expenses of small rivers and streams	3.31	2.45	0	0	3.31	2.45
Total losses of river flow	–	–	–	–	31.25	23.13

By analogy with other deposits of a similar type (Aksu, Lugovskoye, Merken, Khorgos, etc.), we assume that 80% of the total channel losses are directly replenished to groundwater and 20% are lost to evaporation and soil wetting. Consequently, the amount of water supplied by filtering riverbeds across the entire field will be 9.36 m^3/sec at 50% availability and 2.66 m^3/sec at 85% availability. The flow losses of the Tentech River must be reduced by the flow of the Aksopa MK, which flows from the left bank of the river beyond the boundaries of the field.

According to data from the regional water management agency, the efficiency coefficient of the primary and distribution channels is 76%. The amount of groundwater replenishment due to losses in irrigation fields within the cones of depression varies from 60 to 80% of the water supply to irrigation fields, with an average of 65% (by analogy with the Khorgos field). Consequently, the amount of groundwater recharged from main channels will be 4.70 m^3/sec, and from irrigation fields 9.65 m^3/sec, for a total of 14.35 m^3/sec. Thus, within the cones of groundwater discharge at the Alakol deposit, 23.71 m^3/sec of the total 31.25 m^3/sec of surface runoff losses at 50% reliability and 17.71 m^3/sec out of a total of 23.13 m^3/sec of losses at 85% reliability (Figure 3).

Precipitation infiltration during the winter-spring period occurs in March-April, and during the summer period, it evaporates completely. The replenishment of groundwater through atmospheric precipitation infiltration was determined only in the area of groundwater flow formation, which creates a certain margin of safety in the calculations, since atmospheric precipitation infiltration also occurs in the area of groundwater transit and discharge.

In the area where underground runoff from the Alakol deposit forms, the aeration zone consists of boulders and gravel, with sandy fill and almost no loamy cover. The average adequate precipitation, according to data from the Usharal weather station, was 125.4 mm in a typical year and 89 mm in a dry year, with 85% reliability.

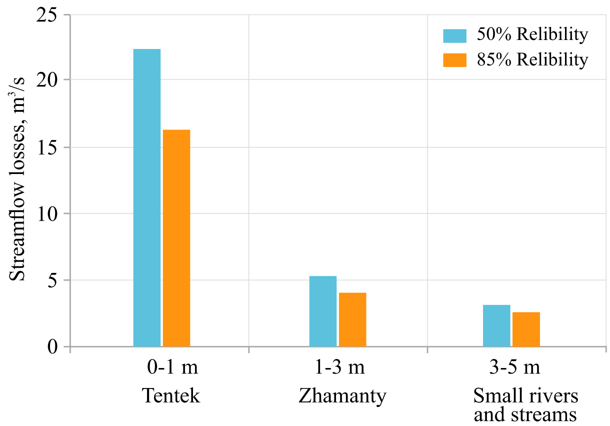

Figure 3. Losses of surface runoff by the watercourse

The area of the foothill plain, which is almost entirely devoid of fine-grained cover deposits, amounts to 815 km^2. The results of the calculations of groundwater recharge due to atmospheric precipitation infiltration are presented in Table 3. Figures 4-6 illustrate the distribution of groundwater recharge parameters by groundwater depth interval, showing variations in total recharge, effective precipitation, and the infiltration coefficient.

Table 3. Groundwater recharge due to atmospheric precipitation infiltration

Groundwater depth intervals	Area, km^2	Effective precipitation, mm	Infiltration coefficient	Infiltration nutrition	
				mm	mln. m^3
0-1	442	125.4	0.60	75.24	33.15
1-3	878	125.4	0.25	43.9	38.54
3-5	60	125.4	0.10	12.54	0.72
Total	–	–	–	131.7	72.4

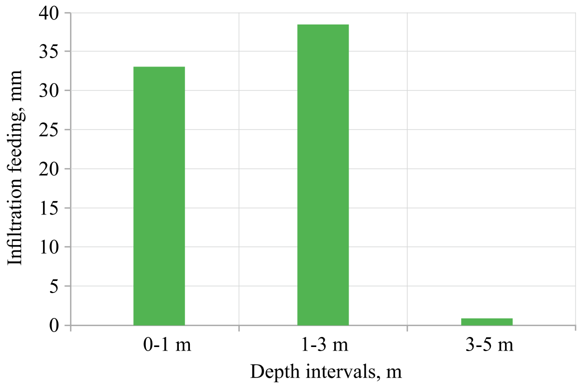

Figure 4. Infiltration of groundwater at different depths

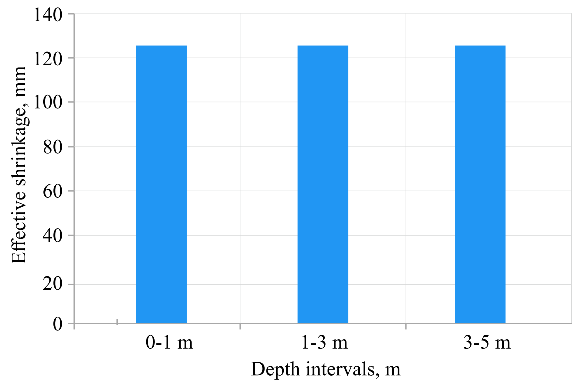

Figure 5. Effective precipitation by groundwater depth interval

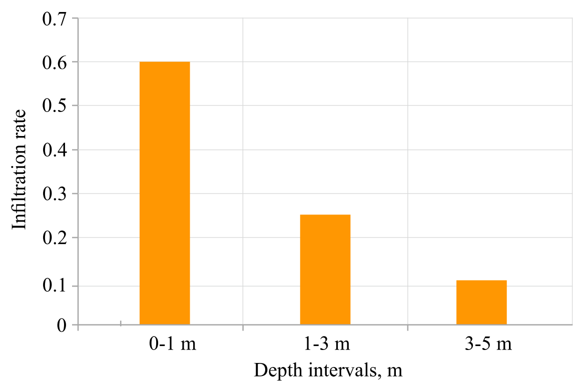

Figure 6. Infiltration coefficient by groundwater depth interval

Adequate precipitation remains constant across all groundwater depth intervals (125.4 mm), whereas the infiltration coefficient decreases with depth, from 0.60 to 0.10.

Infiltration of atmospheric precipitation within this zone is 131.7 mm per year or 30.644 million m^3 (0.97 m^3/sec) in a normal year in terms of water content, and 26.7 mm or 21.761 million m^3 (0.69 m^3/sec) in a dry year with 85% reliability. It's impossible to figure out how much underground water flows from the mountains into the foothill plains. It was assumed that there is no deep underground flow from the mountainous border to the deposit under consideration. This leads to a slight underestimation of natural resources and creates a certain reserve of "engineering" strength.

The expenditure items in the groundwater balance under undisturbed conditions include evaporation (evapotranspiration) and groundwater discharge into rivers and springs. Groundwater evaporation occurs in areas where it lies close to the surface, mainly located below the zone of groundwater formation. Table 4 below shows the results of determining evaporation from the groundwater surface [12].

Table 4. Evaporation from the surface of groundwater

Groundwater depth ranges	Area, km^2	Average evaporation of groundwater, mm.	Total evaporation of groundwater	
			mln. m^3	m^3/sec
0-1	442	800	353.6	11.22
1-3	878	300	263.4	8.35
3-5	60	50	3	0.1
Total	–	–	620.0	19.67

Figure 7 presents total groundwater evaporation and average evaporation by groundwater depth interval. The most significant moisture losses occur where groundwater lies within 1 m of the surface. Evaporation decreases significantly with increasing depth, indicating a strong dependence of evaporation intensity on groundwater level. Despite lower average evaporation in the 1-3 m range, the large area compensates, contributing significantly to the total evaporation volume. At depths greater than 3 m, moisture loss through evaporation is almost negligible. The deeper the water, the less evaporation, as the availability of water for evaporation decreases. The highest average annual evaporation occurs in waters at 0-1 m depth. The closer the water is to the surface, the easier it evaporates. Although evaporation is lower in the 1-3 m interval, due to the large area, it produces almost the same amount of evaporation as the 0-1 m interval. m^3/sec is the conversion of total evaporation into flow over time.

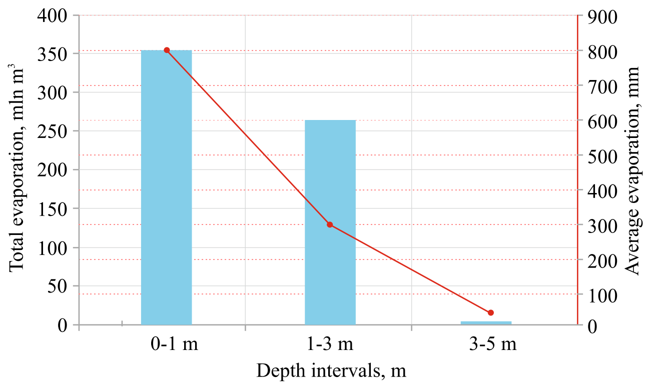

Figure 7. Evaporation from the surface of groundwater at different depths

Total evaporation is 620 million m^3/year or 19.67 m^3/sec and also includes evaporation of atmospheric precipitation that has filtered down to the water table in the shallow groundwater zone [13-14].

Discharge of groundwater into springs, Karasu rivers, and surface water bodies. The spring zone can be traced along the periphery of the Tenteq River's alluvial fan, roughly along a line passing through the settlements of Usharal, Zhagatal, Obukhovka, Chistopolskoye, Socialdy, and Izendy. Merging, the springs form small Karasu rivers, on which temporary hydrometric stations have been installed to record spring discharge. Hypsometrically below the line of springs is an area of surface discharge, which occupies the entire northeastern half of the deposit and is bounded by the lakes Alakol, Uyal, Kashkarkol, and Sasykol. This zone consists of extensive swamps, the most significant of which is located in the form of a strip 3 to 8 km wide and 26 km long, directly adjacent to the spring wedge line.

Groundwater depth varies across the study area. Regular hydrometric measurements of discharge were carried out every ten days using a hydrometric propeller device. The average annual value of the measured spring flow is 12.0 m^3/s. The total length of the spring line is approximately 60 km, corresponding to an average discharge rate of 0.20 m^3/s per kilometer of groundwater emerging as springs and feeding the Karasu River. In the area of the Zhaypak spring, the zone of groundwater discharge approaches the shoreline of Lake Alakol and is further controlled by the coastal line up to the Zhamanty River. These observations indicate a strong hydraulic connection between the aquifer system and surface water bodies, highlighting the importance of springs as a major outlet of the regional groundwater flow. The shore of Lake Alakol in this area is steep, rising 3-5 meters or more. At the base of the cliff, composed of large pebbles, groundwater seepage can be observed everywhere, but it is not possible to take this discharge into account. The erosion zone apparently extends below the lake's waterline, as the slope below it is also composed of large pebbles. Assuming that the intensity of wedging in this zone remains the same, approximately 4.0 m^3/sec of groundwater is discharged along the 20 km of coastline from the Zhaypak spring to the Zhamanty River. Thus, the total spring discharge is 16 m^3/sec. The total amount of groundwater discharge at the deposit will be 18.06 m^3/sec. The groundwater balance of the deposit is presented in Table 5.

Table 5. Groundwater balance of the Alakol groundwater deposit

Name of income and expense items	Groundwater flow rate	
	Reliability 50%	Reliability 85%
Losses of river runoff for filtration	11.08 9560.83	3.58 247.10
Filtration of water from the main channels	4.54 392.26	4.54 392.26
Filtration losses in irrigation fields	9.36 9560.83	9.36 9560.83
Infiltration of atmospheric precipitation	19.67 83.81	0.69 59.62
Total revenue items	44.65 2093.47	17.45 1507.68
Discharge of groundwater into springs, rivers, "Karasu" and surface reservoirs	18.06 1560.4	12.91 1115.42
Evaporation and transpiration	19.67 660.96	8.34 720.58
Total expenditure items	37.73 2222.7	21.25 1836
Balance discrepancy	6.92 127.87	3.80 328.32

Under the 50% reliability scenario, the main components of groundwater inflow are atmospheric precipitation infiltration (19.67 m^3/s) and river runoff losses (11.08 m^3/s). The principal discharge components are evaporation and groundwater discharge into surface water bodies. The calculated balance discrepancy amounts to 6.92 m^3/s (approximately 15.5%), reflecting the difference between total inflow and discharge and likely due to accounting uncertainties or unconsidered subsurface flows.

Under the 85% reliability (dry-year) scenario, precipitation infiltration decreases significantly to 0.69 m^3/s. As a result, the total inflow is reduced by nearly 2.5 times. Although total discharge also decreases, a balance discrepancy of 3.80 m^3/s remains. Thus, under conditions of average water availability (50%), recharge from precipitation plays a substantial role, whereas under dry conditions (85%), the groundwater balance is considerably reduced but remains positive.

The imbalance requires further analysis (possible losses due to deep drainage or underestimation of individual items). The expenditure items for the 85% security balance are approximately determined based on the dependence of total groundwater discharge through springs on aquifer recharge. The imbalance in the balance of 6.92 m^3/sec for normal conditions and 3.80 m^3/sec at 85% security is 6.1% and 21.5%, which is quite acceptable, given the degree of accuracy in determining the expenditure items of the balance [15].

To increase the reliability and accuracy of calculating the total groundwater discharge from springs with 85% confidence, a series of spring discharge observations was conducted over three years (1976-1978) in the area of intensive discharge. The average total discharge was 12 m^3/s. Analyzing data on surface runoff and precipitation in this area, the spring discharge period corresponds to a water content range of 55%-65%. The value of 12 m^3/s was taken as the average annual discharge in the area of intensive spring discharge.

The results determined the structure of aquifers and provided data on water abundance, permeability, and long-term stability of reserves.

Application of the regime classification scheme according to D.M. Kats, taking into account local conditions. Separate consideration of recharge and discharge zones based on the results revealed the characteristics of the interaction between natural and anthropogenic factors. It was established that the groundwater regime is seasonal, with elevated levels in spring and summer.

To assess the recharge and water balance of groundwater at the Alakol deposit, the following balance equation was used:

$$q + \xi_1 + Q_1 = E + q + Q_2, \tag{2}$$

The calculations were based on data from the Hydrometeorological Service and hydrometric observations on the Tentek River (Tunkuruz station) over a 44-year period. It was established that the main recharge of aquifers is provided by infiltration of atmospheric precipitation and filtration of river water, with evaporation and drainage losses accounting for a significant part of the water balance.

Evaporation from the groundwater level was estimated based on lysimeter data from the Aksu deposit and graphs showing the dependence of evaporation on water depth and vegetation cover. It was established that at depths <2 m, evaporation reaches maximum values similar to those in Aksu and significantly reduces available groundwater resources.

The quality of groundwater was determined through a comprehensive analysis of samples collected during pumping, including chemical, spectral, radiological, and bacteriological testing. Compliance was assessed in accordance with GOST standards 18963-73, 4979-49, 2762-57, 2874-73, and others. The results showed that the water mostly meets the requirements for irrigation, with mineralization <2.5 g/l, but for drinking water supply, additional purification is needed to meet specific indicators.

The engineering-geological assessment of the area around the water intakes included an analysis of relief slopes, flooding zones, erosion processes, and seismic activity. Overall, the area is stable, but it is advisable to restrict construction near slopes and to provide erosion control measures.

Hydrogeological zoning of the deposit was performed based on stratigraphic and genetic analyses of sections, identifying the structure and interrelationships among the aquifers. It was established that groundwater is confined to a single aquifer complex formed by alluvial-proluvial and alluvial-lacustrine deposits of the Lower and Middle Quaternary age, with a pronounced hydraulic connection between the layers.

The capacity of water supply points in the Alakol basin ranges from 2.5 to 50 dm^3/s. The flow rates of self-spilling wells reach 50 dm^3/s. The waters are mainly sodium and calcium bicarbonate, with mineralization not exceeding 0.7 g/dm^3. Sediments of stratigraphic-genetic complexes associated with accumulative hummocky-ridge and flat concave plains are linked to groundwater with a level depth (depending on the relief) ranging from 0 to 20 m or more. The mineralization and chemical composition of groundwater are highly diverse. As groundwater flows toward the center of the depressions, water salinity increases, ranging from 1 to 10 g/dm^3. Accordingly, the composition changes from calcium bicarbonate to magnesium-sodium sulfate-chloride.

Groundwater, mostly occurring at shallow depths (1-5m), is associated with alluvial deposits. In floodplains and river deltas, the groundwater level depth is no more than 1 m. The thickness of alluvial aquifers does not exceed 30 m. The water content of rocks varies widely. Flow rates of tenths of a liter per second prevail, and only in the upper reaches of rivers, where the water-bearing rocks are pebbles, do well flow rates reach 3 dm^3/s. The mineralization of the waters reaches 5-10 g/dm^3 and, in some cases, even 50 g/dm^3. The composition of the water is sulfate and sodium chloride [16, 17].

The natural regime of groundwater is characterized by smooth, shallow-amplitude (0.5-1.0 m) fluctuations in levels throughout the year, with weakly expressed spring maxima and summer minima. The central autumn-winter maximum is due to the filtration flow of irrigation and wastewater from irrigated areas. The level rise is 1.8-2.2 m, and in areas of rice crop rotations, it reaches 5 m. An irrigation-type groundwater regime has developed over a large area.

Modern geological processes and phenomena in the region are mainly associated with human engineering and economic activities, particularly land reclamation and construction. Until the 1960s, the development of DGPs was episodic. The erosive activity of water flows was observed only during spring floods and heavy rains, leading to bank erosion and collapse. Deflation was evident in the eolian processing of alluvial-lacustrine sediments, resulting in the formation of blow basins, dunes, wind ripples, and other microrelief forms [18, 19]. Salinization and waterlogging occurred through the extensive development of salt marshes, sores, and puffs in areas with shallow groundwater levels.

Abrasion was intensely observed on the southern and eastern shores of Lake Alakol. The southern shore of the lake (near the village of Koktuma) has moved more than 200 m over 20 years. As a result of the washout and collapse of the coastal ledge, part of the village was destroyed. The shoreline of the lake has advanced very close to the railway track. Abrasion is activated by frequent hurricane winds and an increase in the lake's surface area. According to measurements from 1862 and 1931, the lake's length and width increased by 5 km. Even more intensive growth of the water area was established by the 1951 measurements. Over 20 years, the lake's length increased by 15 km, its width by 5 km, and its depth significantly as well [20].

4. Conclusions

The study established the hydrogeological structure of the Alakol groundwater deposit. It clarified the main characteristics of its aquifer system, including water abundance, permeability, and the long-term stability of groundwater reserves. The results confirmed the existence of a hydraulically connected single aquifer complex formed by Lower and Middle Quaternary alluvial-proluvial and alluvial-lacustrine deposits.

The groundwater regime was found to be predominantly seasonal, with higher groundwater levels during spring and summer. The primary sources of aquifer recharge are infiltration of atmospheric precipitation and filtration of river water, whereas evaporation and drainage constitute major components of groundwater discharge. Evaporation from the groundwater table is especially significant when groundwater occurs at depths of less than 2 m, substantially reducing the volume of available water resources.

The study also demonstrated the critical role of both natural and anthropogenic factors in shaping the groundwater regime and balance. In particular, irrigation-related infiltration contributes noticeably to groundwater recharge, while shallow groundwater occurrence in lowland and swampy areas enhances evaporation losses.

In terms of water-use potential, groundwater in the Alakol deposit generally meets irrigation requirements, with mineralization in most cases remaining below 2.5 g/L. At the same time, its use for drinking water supply may require additional treatment depending on specific chemical indicators. Overall, the obtained results confirm the practical significance of the Alakol groundwater deposit as a promising source of water supply for irrigation development in the region, provided that groundwater abstraction is managed with consideration of recharge conditions, evaporation losses, and local hydrogeological constraints.

Author contributions

Conceptualization: MMA, MRZ; Data curation: MMA, EMK; Formal analysis: MRZ, AZI, EMK; Funding acquisition: MMA, MRZ; Investigation: MMA, EMK; Methodology: MMA, NT; Project administration: MMA, MRZ; Resources: NT, EMK; Software: AZI, EMK; Supervision: MRZ, AZI; Validation: MMA, AZI; Visualization: NT, EMK; Writing – original draft: MMA, MRZ; Writing – review & editing: NT, EMK. All authors have read and agreed to the published version of the manuscript.

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Conflicts of interest

The authors declare no conflict of interest.

Data availability statement

The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding author.

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Курорт инфрақұрылымының қажеттіліктері үшін Алакөл жерасты суы кен орнының гидрогеологиялық сипаттамасы

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Аңдатпа. Мақалада Қазақстанның оңтүстік-шығысындағы Алакөл ойысында орналасқан Алакөл жер асты су кен орнының геологиялық және гидрогеологиялық ерекшеліктеріне кешенді зерттеу жүргізілген. Аталған жер асты су көзі Алакөл көлінің оңтүстік жағалауында қарқынды дамып келе жатқан курорттық инфрақұрылымды сумен қамтамасыз етудің негізгі көздерінің бірі болып табылады және аймақтың әлеуметтік-экономикалық дамуы үшін маңызды рөл атқарады. Зерттеу барысында аумақтың геоморфологиялық ерекшеліктері, су қабаттарының литологиялық құрамы мен қалыңдығы, олардың жату жағдайлары және жер асты суларының түзілуі мен динамикасына әсер ететін факторлар талданды.Жер асты суларының режимі олардың қоректену және ағызылу аймақтары бойынша қарастырылып, сүзгілеу ағынының негізгі бағыттары мен жер асты және жер үсті суларының гидродинамикалық байланысы анықталды. Ерекше назар курорттық аймақтағы құрылыстардың тұрақтылығына әсер ететін инженерлік-геологиялық жағдайларды бағалауға және антропогендік факторлардың әсерінен су балансының өзгеруіне аударылды. Жер асты суларының химиялық құрамы мен физика-химиялық қасиеттеріне талдау жүргізіліп, олардың ауыз су және ауыл шаруашылығы қажеттіліктеріне жарамдылығы анықталды. Нәтижелер бойынша, Алакөл кен орнының суы санитарлық-гигиеналық нормаларға сай келеді, минералдану деңгейі орташа және оны топыраққа зиян келтірмей суару мақсатында пайдалануға болады. Зерттеуде қолданыстағы су тарту құрылыстарының конфигурациясы, жер асты суының өндіру көлемі қарастырылған. Сондай-ақ, жер асты суларын ұтымды және тұрақты пайдалану мәселелеріне, су ресурстарын қорғау шараларын әзірлеуге ерекше назар аударылған. Алынған нәтижелер Алакөл көлінің оңтүстік жағалауының курорттық және аграрлық инфрақұрылымын одан әрі дамытуда пайдаланылуы мүмкін.

Негізгі сөздер: *жер асты сулары; жер асты суларының режимі; сулы қабаттар; жер асты суларының балансы; су алу; кен орны.*

Гидрогеологическая характеристика Алакольского месторождения подземных вод для нужд курортной инфраструктуры

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Аннотация. В статье представлено комплексное исследование геологических и гидрогеологических характеристик подземного водозабора Алаколь, расположенного в пределах Алакольской впадины на юго-востоке Казахстана. Данное месторождение подземных вод служит одним из основных источников водоснабжения быстро развивающейся курортной инфраструктуры на южном берегу озера Алаколь и имеет важное значение для социально-экономического развития региона. В работе проанализированы геоморфологические особенности территории, литологический состав и мощность водоносных горизонтов, условия их залегания, а также факторы, влияющие на формирование и динамику подземных вод. Рассмотрен режим подземных вод в зонах питания и разгрузки, определены основные направления фильтрационного потока и особенности гидродинамической связи между подземными и поверхностными водами. Особое внимание уделено оценке инженерно-геологических условий, влияющих на устойчивость сооружений курортной зоны, а также изменениям водного баланса под воздействием антропогенных факторов. Проведён анализ химического состава и физико-химических свойств подземных вод с целью определения их пригодности для питьевого водоснабжения и сельскохозяйственного использования. Результаты показали, что вода Алакольского месторождения в целом соответствует санитарно-гигиеническим нормам для питьевых целей, имеет умеренную минерализацию и может применяться для орошения сельскохозяйственных угодий без ущерба для почв. Особое внимание уделено вопросам рационального и устойчивого использования подземных вод, а также разработке перспективных мер по охране водных ресурсов. Полученные результаты могут быть использованы при планировании дальнейшего развития курортной и аграрной инфраструктуры южного побережья озера Алаколь.

Ключевые слова: *подземные воды; режим подземных вод; водоносные горизонты; баланс подземных вод; водозабор; месторождение.*

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