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Research Article

ASSESSMENT OF THE HYDROGEOLOGICAL STATE OF GROUNDWATER IN TRANSBORDER AREAS (ON THE EXAMPLE OF THE SOKH AND OSH-ARAVON GROUNDWATER DEPOSITS)

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ABSTRACT
The article analyzes the hydrogeological state of the Sokh and Osh-Aravon groundwater deposits located in transboundary territories, and within the framework of the study, the geological structure of these water deposits, the hydrodynamic properties of the water-bearing layers, the conditions of formation, distribution, and quality of groundwater are assessed. The main goal of the research work is to assess the quantitative and qualitative aspects of groundwater and improve the monitoring system using hydrogeological observations, hydrogeochemical analyses, and GIS technologies.

Keywords: *Transboundary Territory, Groundwater Deposit, Rivers, Hydrogeodynamic and Hydrogeochemical Indicator, Groundwater Monitoring, Mineralization*

INTRODUCTION
The hydrogeological state of groundwater plays an important role in solving problems related to natural resources, especially in regions. Assessment of the hydrogeological situation in the southeastern regions of Uzbekistan, in particular, in the Sokh and Osh-Aravon groundwater deposits, obtaining accurate data on the availability and quality of groundwater is important for economic development, agriculture, and drinking water supply. These territories have specific features in terms of geological structure, climate, and hydrological conditions, which pose specific problems in terms of the quality and quantity of groundwater.

In this article, we will analyze the hydrogeological state of the Sokh and Osh-Aravon groundwater deposits and consider the state of available water resources, their changes, the impact of anthropogenic activity and climate change. It is also planned to develop proposals for the effective management of groundwater and the conservation of its resources. This research serves to make scientifically based decisions, especially in the field of regional hydrogeology.

MATERIALS AND METHODS
The research area is located in the southeastern part of the Fergana Valley. The relevance of studying the issue of technogenic impact on groundwater deposits located in transboundary territories is due to the fact that the resources of many deposits are formed outside the territory of the Republic of Uzbekistan and are subjected to impacts of varying degrees.

The Sokh groundwater field is the largest main field in the Fergana region and is the most unique groundwater field in Uzbekistan. In addition, this groundwater deposit was formed in the transboundary aquifer on the border of the republics of Uzbekistan and Kyrgyzstan.

The Osh-Aravon groundwater deposit is located in the hilly depression of the same name. The boundaries of this groundwater deposit are the Polvontosh-Andijan-Alamushuk range in the west and north, the natural boundary of the Kagart Basin and the Sugandi Range in the northeast, and the Osh hills and the Karachatur Mountains in the south. It borders the Jalal-Abad and Osh regions of the Kyrgyz Republic to the north, south, and east, the Kuva district of the Fergana region to the southwest, and the Andijan and Asaka districts to the west.

Drinking water supply for the population is mainly provided by groundwater, limited by fresh groundwater deposits, in most cases, adjacent to the borders of the republic with Kyrgyzstan. Most of the fresh groundwater deposits are located in high-mountainous areas - outside the borders of Uzbekistan, where weakened geological zones, groundwater flowing through river valleys and streams, enter the Fergana Valley.

One of the peculiarities of the Fergana region is that its territory is not geographically integrated. Part of the Fergana district, Shakhimardan, and Sokh district are enclaves within the territory of Kyrgyzstan. Such a geopolitical situation creates certain difficulties in the development of the service sector, the use of water and land resources, and the management system of the territory as a whole. Studying the technogenic impact on groundwater located in transboundary areas is one of the important issues of today.

The Osh-Aravon Trans-Adir Basin is a small hydrogeological structure, consisting of the Sokh, Tashkent, and Mirzachul Quaternary deposits of the alluvial fans of the Akbura, Aravansay, and Karadarya rivers, with areas of local groundwater recharge, transit, and discharge. This deposit is formed mainly due to the infiltration of surface waters. The deposits consist of rock-gravel and gravel layers, which are distinguished by relatively thin layers of clay and silt (Sultonxodjaev *et al.,* 1972).

RESULTS AND DISCUSSION

Sokh groundwater deposit. In recent years, a very complex ecological situation has developed in some areas of the Fergana Valley. Changes in the ecological and hydrogeological conditions of the transboundary territories of the Fergana Valley are observed. The choice of newly irrigated lands of the Burgandi massif as a typical example of the melioration and technogenic impact depends on many reasons. Land development in the Burgandi massif began to develop rapidly from the mid-70s. Currently, tens of thousands of hectares of winter wheat fields have been developed, and almost 23-30 percent of the Sokh River's flow is used for irrigation. Development of lands of the foothill massif located above the main territory of the Fergana region led to a significant rise in the groundwater level in the Rishtan and Altyaryk districts of the Republic of Uzbekistan. As a result, in the Rishtan district alone, 6,313 hectares of land have become unsuitable for agricultural development (Abdullaev *et al.,* 2021).

The Sokh alluvial fan is located in the southern part of the Fergana Valley and occupies a large area from the foothill zone of the Sokh River to its exit into the Central Fergana Plain. Its width is 70 km, and its length is 50 km.

The Sokh alluvial fan descends from the foothill zone towards the Syr Darya valley. For example, at the outlet of the Sokh River from the foothill zone, the surface of the alluvial fan lies at an altitude of 700 m above sea level, and near the floodplain terrace of the Syr Darya, it decreases to 350 m.

Groundwater saturation, regardless of the region, is closely related to surface water. Basically, this situation plays an incomparable role in the replenishment of groundwater from rivers in mountainous areas.

The Sokh River is a river in Kyrgyzstan (Botkent region) and Uzbekistan (Fergana region) (Figure 1). Length 124 km, water basin 3510 km2. The Sokh River begins near the village of Kurgan, located on the northern slopes of the Alay Range, at an altitude of more than 3 thousand meters, formed by the confluence of the Ak-Terek and Khoja-Achkan rivers, and flows mainly north. In the middle reaches, the enclave of the Republic of Uzbekistan serves as the main source of water supply for the Sokh district.

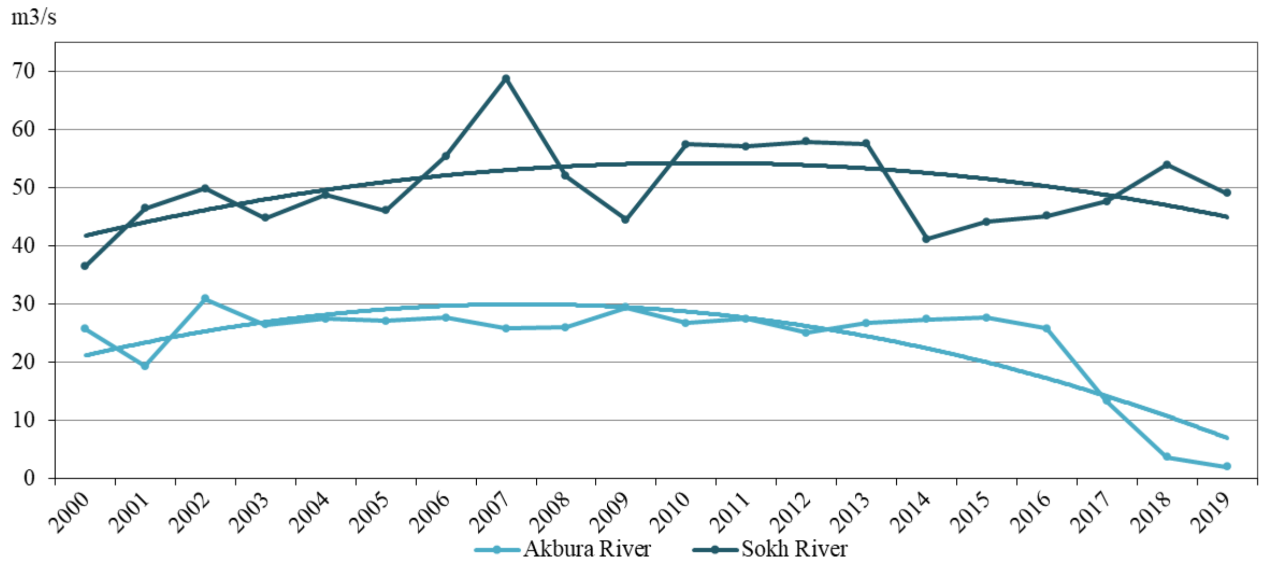

Figure 1. Graph of chronological differences in the average annual flow of the Sokh and Akbura rivers (2000-2019)

The Fergana Valley is one of the main irrigated agricultural regions of Central Asia. The total irrigated area of the Fergana Valley is 1.4 million hectares, of which 2/3 belongs to Uzbekistan, 1⁄4 to Kyrgyzstan, and the rest to Tajikistan.

Natural and technogenic factors of various scales influence the groundwater regime, including climate (atmospheric precipitation, temperature), geological and lithological structure of the territory (water permeability of rocks and porosity and density of rocks), topographical factors (relief shape and height affect groundwater movement), for example, lowlands are a moderate point for water accumulation and concentration, and at sharp elevations, precipitation may be low, hydrogeological in which the depth of groundwater is considered to depend on hydrogeological conditions.

In the upper parts of the alluvial deposits of the Sokh River, the groundwater level is located at a depth of 96.14-96.55 m. The minimum level is observed in June-August at a depth of 97.31-99.82 m. The amplitude of groundwater level fluctuations is 4.64-22.75 m (Abdullaev *et al.,* 2023).

In the peripheral parts of the Sokh groundwater field, the groundwater level is located at a depth of 6.41-8.20 m. The maximum groundwater level is observed in June-July at a depth of 8.81-9.63 m. In December-January, the minimum level is observed at a depth of 4.63-5.63 m. The amplitude of the level oscillation is 3.01-4.22 m.

The Sokh aquifer is part of the quaternary and Pliocene groundwater deposits filling the Fergana valley bottom (Morris, 1995). It consists mostly of the alluvial fan that was formed from deposits of the river Sokh. This fan is visible in Figure 2 as a major water supply canal (the Big Fergana Canal, thick dark blue line, following the topography) has to circle around the base of the fan. Before the conversion of the steppe into agricultural land, the river Sokh used to recharge the river Syr Darya in the north of the irrigated area. Since the 1970ies, the river Sokh does no longer reach the river Syr Darya because all its water is either used for irrigation or infiltrating through the riverbed and recharging groundwater locally (Abdullaev *et al.,* 2021).

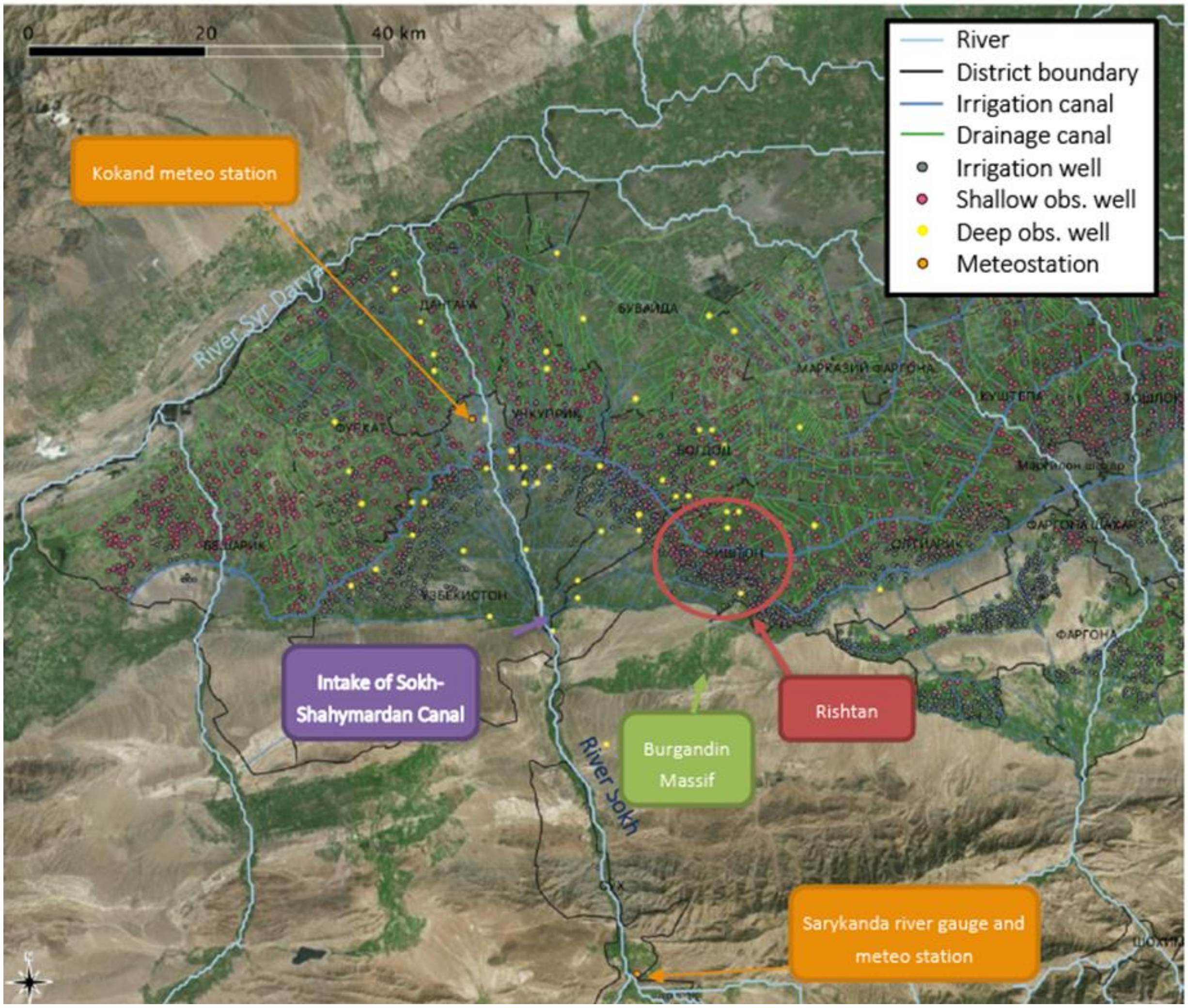

Figure 2. Overview over the western part of the Fergana province. The focus area of the project is indicated with the orange circle. The background image is a publicly available google satellite image composite, the figure has been drawn using the open source software QGIS (QGIS Development Team (2019), 2019). Data source: BISA Fergana.

The main situation in the region is that the source of groundwater saturation is the Sokh River and water seeping in through irrigation from the upper zone, while a sharp rise in the groundwater level is observed in the city of Rishtan, which is a plain in terms of relief on the right side of the deposit. There are several reasons for this: a) rapid melting of glaciers in the mountains and an increase in the flow rate of the Sokh River due to the high global temperature in the last decade; b) due to irrigation and reclamation processes on developed lands in the foothills, it can be observed that not only the quantitative indicator of groundwater, but also the qualitative indicator has changed, that is, the hardness of groundwater has increased due to the introduction of chemicals and salts added to the lands during reclamation measures (Figure 3).

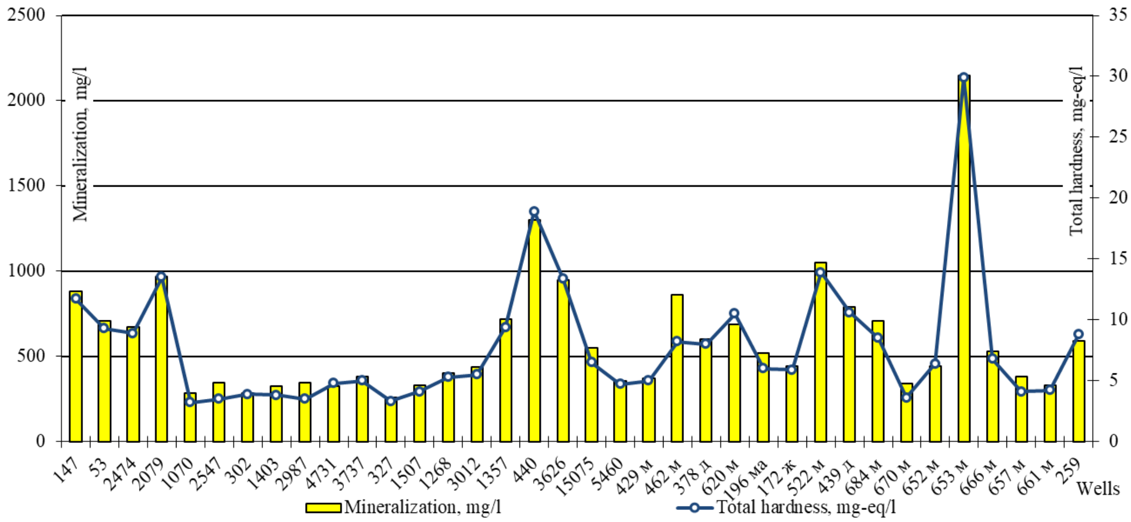

Figure 3. Comparative analysis of the mineralization and total hardness of observation wells based on data from the Sokh groundwater field (2024).

In a hydrogeological sense, the Sokh groundwater deposit is located in the southern, southwestern part of the Fergana artesian basin, bordered by the alluvial cone of the Sokh River and bordered by hilly uplifts to the south, interconical depressions to the east and west; it connects to the alluvial valley of the Syr Darya to the north.

The hydrogeological conditions of the deposit are predetermined by the complexity of the geological structure, hydrogeological and water management conditions, as well as anthropogenic influences.

The total area of the gravel part of the deposit, where groundwater reserves are formed, is 416 km2. Here, the Mirzachul, Tashkent, and Sokh aquifer complexes form a single aquifer. The deepest location of the groundwater level is characteristic of the upper part of the 40-125 m rock-gravel zone, at the northern edge of the rock-gravel field, the groundwater level approaches the surface, and with the onset of the surface, fine soil cover (1.5-2 km to the BFC), gravel deposits are divided by fine soil intermediate layers, and the permeability of the aquifer decreases, part of the groundwater flow seeps out in the form of springs.

At the head of the Sokh alluvial fan, the groundwater level lies at a depth of 90.74-97.06 m. The maximum groundwater level is observed in December-January at a depth of 75.93-78.00 m, the minimum at a depth of 98.51-98.88 m (in July and August). The amplitude of changes in the groundwater level was 4.64-22.75 m.

Osh-Aravon groundwater deposit. The hydrographic network of the Osh-Aravon groundwater field consists of numerous natural and artificial watercourses. The largest natural watercourses are the Karadarya, Akbura, and Aravansay rivers. The most abundant of them is the Karadarya. The flow of the Karadarya is formed by the confluence of the Tar and Karakulja rivers, which collect water from the southwestern slopes of the Fergana Range and partly from the northern slopes of the Alay Range (Ruzimov, 2025).

The Karadarya belongs to the category of rivers fed by hidden glaciation, with its maximum flow in July-August and its minimum flow in November-February. From the confluence of the Tar and Karakulja rivers to the village of Kampirravot, the river flows in a wide terraced valley, where its channel is heavily branched and mainly composed of gravel.

The Akbura River originates from the glaciers of the Lesser Alay Range (Figure 1). Although the area of the river basin is not very large, snow and ice reserves are very rich (Mavlonov *et al.,* 2025). Until it emerges from the Tuleken gorge, the river flows through a narrow valley. After leaving this gorge, the river valley gradually expanded, reaching 600-800 m, and emerged onto the plain from the mountainous terrain 2-3 km north of the city of Osh. With the help of a specially constructed distribution hydraulic structure, the river water is distributed into canals for irrigating the fields below the Tuleken Gorge. The small amount of water passing through the city of Osh is then distributed through separate canals.

During the summer irrigation season, the riverbed completely dries up from the city of Osh to its confluence with the Shahrikhansoy Canal. After joining the Shahrikhan-Sai canal, it flows along a narrow, deeply carved V-shaped valley, known as the last river.

During the period 2000-2019, the average annual maximum consumption was observed in 2002 (30.85 m3/s) and 2009 (29.39 m3/s), and the minimum in 2001 (19.26 m3/s) and 2019 (2.0 m3/s). During this period, the flow rate fluctuates within the range of 2.0-30.85 m3/s.

The maximum flow rate of the river was observed in July 2015 and amounted to 54.6 m3/s, and the minimum flow rate was observed in January 2019 and amounted to 0.7 m3/s. The average long-term average water discharge was 23.5 m3/s.

In the Akbura River, the high-water period of the year is usually June-August (up to 70.3 m3/s), and the low-water period is December-February (up to 0.7 m3/s).

Both groundwater sources serve to provide drinking water to more than 1 million people for various needs of the national economy.

In the main parts of the outlet cones of the Osh-Aravon groundwater field, groundwater is located at a depth of 5-8 m to 48-50 m, while in the main part of the foothill zone, it lies at a depth of 1-3 m. Water-permeable gravel layers settle in the hypsometrically lower peripheral parts, mixing with fine soil and forming layers. As a result, groundwater acquires a pressure character, and its level rises above +10 m. The water discharge of gravity-fed wells can range from 3-5 l/s to 10-20 l/s or even more.

Within the head part of the outlet cone of the Akbura River, in Quaternary deposits with a total hardness of up to 80-150 m, groundwater with a content of more than 10 mg-eq/l is distributed within the foothill alluvial fan with a width of 3000-3500 m. In the north, there are alluvial foothill areas with a width of 750-1000 m, the distribution of groundwater in Quaternary deposits with a total hardness of 8-10 mg is widespread in its northern part in the wastewater of layers with a total hardness of up to 8.0 mg-eq/l.

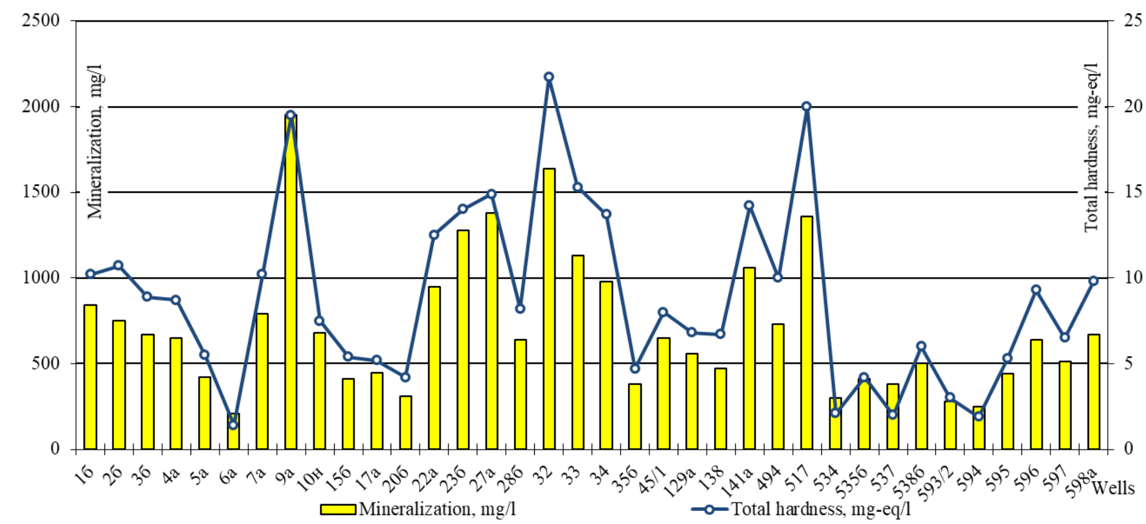

Figure 4. Comparative analysis of the mineralization and total hardness of observation wells based on data from the Osh-Aravon groundwater field. (2024)

Unlike the Sokh groundwater field, in some areas of the Osh-Aravon groundwater field, a decrease in the groundwater level to 5 meters was observed compared to the long-term average groundwater level. As a result, the issuance of a hydrogeological conclusion for irrigation and production purposes in these areas, the drilling of wells for groundwater, and the irrigation of land from existing wells without water-saving technologies have been prohibited. This excludes the drilling of wells up to 25 m deep within the framework of approved state programs and individual withdrawal of groundwater for personal needs in the amount of up to 5 m3 per day (Mavlonov *et al.,* 2025).

One of the main reasons for the decrease in groundwater levels is that the volume of water extracted exceeds the resource by 2.3 times. In turn, the decrease in the groundwater level also affects its quality.

According to the analysis of water samples taken from Andijan HGS observation wells (Figure 4), the mineralization and total hardness of groundwater increased proportionally to each other.

Against the background of a decrease in the groundwater level, an increase in their chemical composition is also observed. From year to year, during the period of rigid water distribution, moving along the flow, the farm is reducing groundwater resources suitable for water supply. In the main part of the groundwater deposit, the mineralization and total hardness of groundwater fluctuate within the range of 300-700 mg/l and 4-6 mg-eq/l, in the head part of the outlet cone and in some places of interconical depressions - within the range of 500-700 g/l and 7.5-10 mg-eq/l. In general, the process of groundwater pollution development is ongoing, which requires further monitoring.

CONCLUSION

The Sokh and Osh-Aravon groundwater deposits are considered a transboundary aquifer, and the main source of groundwater formation in these deposits is groundwater infiltration.

- The main aquifers and complexes used in the territory of the Sokh groundwater deposit correspond to the deposits of the Quaternary and Neogene periods;
- the main factor influencing the formation of groundwater in natural conditions is the hydrometeorological and structural-lithological factor, and the technogenic factor is the melioration factor.
- organization of observations to assess the influence of climate warming on the hydrodynamic and hydrochemical parameters of the groundwater regime.
- ensuring the rational use of groundwater and preventing unscheduled exploitation, developing schemes for the integrated use and protection of water resources of deposits.
- it is necessary to organize observations to assess the possible impact of potential sources located in the neighboring Republic (transboundary territory).

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