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ECOLOGICAL AND HYDROCHEMICAL CHARACTERISTICS OF GROUNDWATER

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Abstract. *Tajikistan possesses abundant drinking water resources, most of which are surface waters. The water resources of the Republic of Tajikistan differ from those of other regions in their high quality, organoleptic properties, and chemical composition. The main advantage of groundwater in Tajikistan lies primarily in its ecological purity and its formation from glacial sources. However, the glaciers of Tajikistan are affected by aerosol and atmospheric pollution as well as other factors that degrade the quality of the water formed from them. To characterize the quality of drinking water in Tajikistan, it is essential to conduct research and study its chemical composition. Therefore, the topic of ecological and physicochemical characterization of the state of water resources in Tajikistan is both important and relevant. Water samples were collected from wells in the jamoats of Tezgaripoyon, Zarnisor, Jangalobod, Choryakkoron, Dekhonobod, and the Elok River. A total of 39 water samples were analyzed for isotopic composition during the research period and it was found that the lowest specific conductivity values were recorded in samples from the Kofarnigan River (249-320 µS/cm), while the highest values were recorded in samples from the Chorakkoron Jamoat (1758-2060 µS/cm). This fact can also be attributed to the high concentration of salts, influenced by anthropogenic factors in the Kofarnigan River basin.*

Keywords: *Kofarnihon River, Water, Ecology, Groundwater*

INTRODUCTION

Given the significance, relevance, and practical value of this topic, we conducted a series of studies (IBROHIMOV ET AL., 2018, 2019, KHOLMIRZOEVA ET ALL., 2008-2022, BOYCHENKO ET AL., 1991). The research was carried out in the upper part of the Kofarnihon River basin, located in the Gissar Valley of Tajikistan. The northern part of the valley is bounded from west to east by the Gissar Range, which consists of karst-fractured rocks, intrusions, and Cretaceous deposits (shale, conglomerates, gypsum, limestone). There are also Neogene formations, including sandstone, conglomerates, and gypsum. The valley floor is filled with a thick layer of Quaternary deposits (gravel-pebble layers, conglomerates, sand, loess, etc.), forming a flat area up to 15 km wide and up to 100 km long. These rocks, filling the trough-shaped valley, serve as a good reservoir for groundwater accumulation.

The Kofarnihon River flows through the valley, originating from two sources on the southern slopes of the Gissar Range. Its main source of replenishment is snowmelt.

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Dushanbe, the capital of Tajikistan, has four water supply sources, two of which are underground: the Kofarnihon Pumping Station (KPS) with a daily capacity of 182,000 m³ and the Southwestern Pumping Station (SWPS) with a daily capacity of 170,000 m³. Dushanbe is located in the widest part of the valley, between the Kofarnihon River and the northern slopes of the Gissar Range. The SWPS (wells 1 and 16, elevation 770 m above sea level) utilizes groundwater from aquifers on the northern bank of the Kofarnihon River. Water is extracted from wells at a depth of 100 m. The Kofarnihon Pumping Station (wells 30 and 44, elevation 775 m above sea level) draws water from a depth of 30 m.

The source of water in the Kofarnihon River basin is precipitation falling on the Gissar Range, which reaches rivers and groundwater through various pathways. In winter, snow accumulates on the Gissar Range and gradually melts in spring and summer. Part of the meltwater flows into rivers, and part infiltrates to recharge groundwater. Additionally, intense spring rainfall leads to rising water levels in rivers. In summer, rivers and aquifers are replenished through the melting of snow and glaciers in the highlands. Moreover, groundwater feeds into riverbeds throughout the year.

MATERIALS AND METHODS

Water samples were collected from wells in the jamoats of Tezgaripoyon (well depth 80 m, elevation 816 m), Zarnisor (depth 100 m, elevation 856 m), Jangalobod (depth 35 m, elevation 809 m), Choryakkoron (depth 160 m, elevation 847 m), Dekhonobod, and the Elok River.

In 2018–2019, fieldwork was conducted to sample groundwater and surface water from the Kofarnihon River basin in Dushanbe and surrounding areas across four seasons (spring, summer, autumn, and winter). In May 2018, 9 samples were collected for hydrogen and oxygen isotope analysis: 8 groundwater samples from the Kofarnihon basin and 1 sample from the Kofarnihon River. In July 2018, 9 samples were collected: 8 groundwater and 1 river sample. In October 2018, 11 samples were taken: 9 groundwater and 2 from the Kafirnigan and Elok rivers. In February 2019, 10 samples were taken: 8 groundwater and 2 from the Kofarnihon and Elok rivers. The sampling locations are shown in Figure 1. A total of 39 water samples were analyzed for isotopic composition during the research period. All isotope data obtained (δ^2H and $\delta^{18}O$) from the Kofarnihon basin are presented in Table 2 and shown in Figure 2 in $\delta^{18}O$ and δ^2H coordinates relative to the global meteoric water line, with the local meteoric water line also plotted.

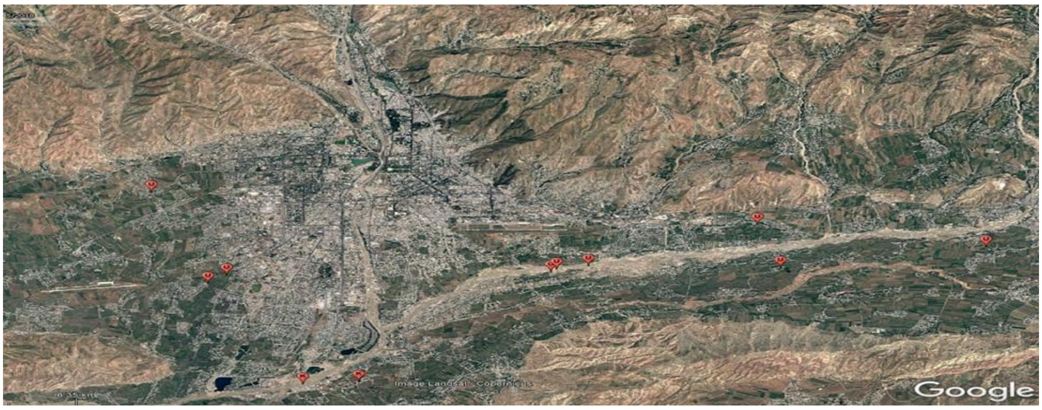

Figure 1. Map of Sampling Locations

The samples were analyzed using a Picarro L2110-i laser isotope analyzer. The isotope data are expressed in relative units:

$$\delta X = (R_{пр}/R_{ст} - 1) \times 1000\%$$

where R is the atomic ratio of hydrogen ($^2H/^1H$) or oxygen ($^{18}O/^{16}O$) isotopes in the sample (s) and in the standard (st), and X is the isotope. The δ value indicates whether the sample is depleted ($\delta < 0$) or enriched ($\delta > 0$) in the heavy isotope relative to the standard ($\delta = 0$). The standard used is Vienna Standard Mean Ocean Water (V-SMOW), for which, by definition, $\delta^2H = 0‰$ and $\delta^{18}O = 0‰$ (‰ — per mil, one-thousandth of a unit).

In June 2018, Tajikistan was connected to the GNIP (Global Network of Isotopes in Precipitation) stations of the IAEA. Precipitation collectors were installed in the courtyard of the Institute of Water Problems, Hydropower and Ecology of the Academy of Sciences of the Republic of Tajikistan. The station ID is 3883600. Precipitation is collected monthly by the institute's staff and sent to Vienna, Austria, to the GNIP IAEA laboratory for the measurement of stable isotopes δ^2H, $\delta^{18}O$, and the radioactive isotope δ^3H. At the same time, we also analyze these precipitation samples for δ^2H and $\delta^{18}O$ isotope composition at the institute.

RESULTS AND DISCUSSINS

The results of the average monthly precipitation collected in October and November 2018 are presented in Table 1. The results of the isotope composition analysis of ^{18}O and ^2H in the studied waters of the Kofarnihon River basin are presented in Table 2 and Figure 2.

Table 1

Average Monthly Precipitation in October and November 2018 in Dushanbe

№	Date	Location	$\delta^{18}O$ (‰)	δ^2H (‰)	d-excess
1	October 2018	(IWPHE AS RT)	-13.51	-90.1	18.0
2	November 2018	(IWPHE AS RT)	-11.45	-70.5	21.1

Table 2

Results of Isotopic Composition Analysis of $\delta^{18}O$ and δ^2H in Water Samples from the Kofarnihon River Basin

№	Date of Analysis	River Basin Location	Water Source Type	N Latitude	E Longitude	$\delta^{18}O$ (‰)	δ^2H (‰)	d-excess
SPRING								
1	02.05.2018	Lower Tezgar	borehole	38°32.976'N	68°54.589'E	-10.45	-66.1	17.5
2	02.05.2018	Zarnisor	well	38°32.248'N	68°59.462'E	-11.04	-68.3	20.0
3	02.05.2018	Jangalabad	well	38°31.586'N	68°55.083'E	-11.07	-68.2	20.4
4	02.05.2018	KNS Well 44	well	38°31.644'N	68°50.981'E	-11.23	-69.3	20.5
5	02.05.2018	KNS Well 30	well	38°31.533'N	68°50.303'E	-11.14	-69.0	20.1
6	02.05.2018	Kofarnihon River	river	38°31.444'N	68°50.180'E	-11.15	-68.6	20.6
7	02.05.2018	YUZV Well 16	borehole	38°31.340'N	68°43.247'E	-10.85	-66.1	20.7
8	02.05.2018	YUZV Well 1	borehole	38°31.074'N	68°42.848'E	-11.09	-68.6	20.1
9	02.05.2018	Choryakkoron	borehole	38°34.011'N	68°41.645'E	-10.77	-67.8	18.4
SUMMER								
10	03.07.2018	Lower Tezgar	borehole	38°32.976'N	68°54.589'E	-10.32	-65.5	17.1
11	03.07.2018	Zarnisor	borehole	38°32.248'N	68°59.462'E	-10.58	-66.7	17.9
12	03.07.2018	Jangalabad	borehole	38°31.586'N	68°55.083'E	-10.74	-67.1	18.8
13	03.07.2018	KNS Well 44	borehole	38°31.644'N	68°50.981'E	-10.85	-67.8	19.0

14	03.07.2018	KNS Well 30	borehole	38°31.533'N	68°50.303'E	-10.91	-68.8	18.5
15	03.07.2018	Kofarnihon River	river	38°31.444'N	68°50.180'E	-11.21	-71.1	18.6
16	03.07.2018	YUZV Well 16	borehole	38°31.340'N	68°43.247'E	-10.49	-65.4	18.5
17	03.07.2018	YUZV Well 1	borehole	38°31.074'N	68°42.848'E	-10.84	-67.8	18.9
18	03.07.2018	Choryakkoron	borehole	38°34.011'N	68°41.645'E	-10.42	-66.5	16.9
AUTUMN								
19	24.10.2018	Lower Tezgar	borehole	38°32.976'N	68°54.589'E	-10.69	-65.1	20.4
20	24.10.2018	Zarnisor	borehole	38°32.248'N	68°59.462'E	-11.11	-67.1	21.8
21	24.10.2018	Jangalabad	borehole	38°31.586'N	68°55.083'E	-11.10	-67.3	21.5
22	24.10.2018	KNS Well 44	borehole	38°31.644'N	68°50.981'E	-11.34	-68.9	21.8
23	24.10.2018	KNS Well 30	borehole	38°31.533'N	68°50.303'E	-11.14	-68.5	20.6
24	24.10.2018	Kofarnihon River	river	38°31.444'N	68°50.180'E	-11.47	-70.4	21.4
25	24.10.2018	YUZV Well 16	borehole	38°31.340'N	68°43.247'E	-11.13	-67.9	21.1
26	24.10.2018	YUZV Well 1	borehole	38°31.074'N	68°42.848'E	-10.86	-65.6	21.3
27	24.10.2018	Choryakkoron	borehole	38°34.011'N	68°41.645'E	-10.86	-66.9	20.0
28	24.10.2018	Dekhonobod	well	38°30.872'N	68°56.363'E	-11.22	-67.5	22.5
29	24.10.2018	Elok River	river	38°31.392'N	68°56.394'E	-11.09	-68.0	20.7
WINTER								

30	13.02.2019	Lower Tezgar	borehole	38°32.976'N	68°54.589'E	-10.64	-64.5	20.6
31	13.02.2019	Jangalabad	borehole	38°31.586'N	68°55.083'E	-11.19	-67.2	22.3
32	13.02.2019	KNS Well 44	borehole	38°31.644'N	68°50.981'E	-11.34	-68.3	22.4
33	13.02.2019	KNS Well 30	borehole	38°31.533'N	68°50.303'E	-11.45	-68.9	22.7
34	13.02.2019	Kofarnihon River	river	38°31.444'N	68°50.180'E	-11.37	-68.8	22.2
35	13.02.2019	YUZV Well 16	borehole	38°31.340'N	68°43.247'E	-10.82	-65.2	21.4
36	13.02.2019	YUZV Well 1	borehole	38°31.074'N	68°42.848'E	-11.20	-67.5	22.1
37	13.02.2019	Choryakkoron	borehole	38°34.011'N	68°41.645'E	-10.84	-66.7	20.0
38	13.02.2019	Dekhonobod	well	38°30.872'N	68°56.363'E	-11.06	-67.2	21.3
39	13.02.2019	Elok River	river	38°31.392'N	68°56.394'E	-10.86	-66.4	20.5

As can be seen from the isotopic composition (Table 2 and Figure 2), the Kafirnigan River has the lightest water in spring due to glacier melt. In summer, as a result of rising temperatures and increased evaporation, the isotopic composition of the river becomes slightly heavier. In autumn and winter, the isotopic values decrease again due to precipitation and a sharp drop in temperature. A comparison of the isotopic composition of the Kafirnigan River with that of the Elok River shows that the Kafirnigan River has lighter water, which indicates that it is fed by higher-altitude water sources compared to the Elok River.

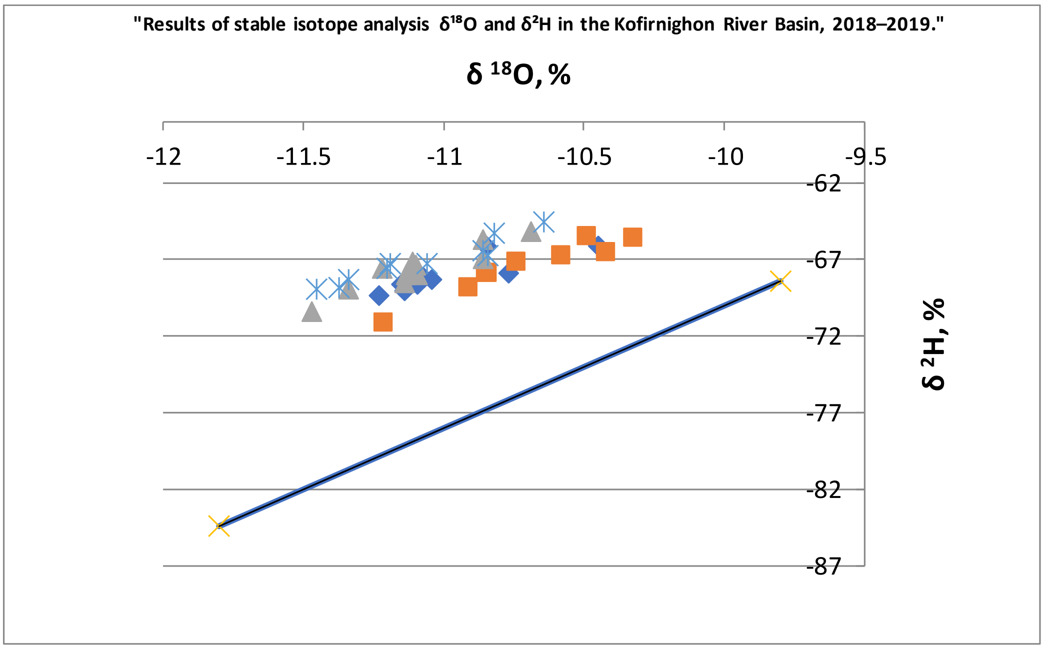

Figure 2. Graph of stable isotope analysis results for $\delta^{18}O$ and $\delta^{2}H$ in the Kofirnihon River basin for 2018-2019.

It was also found that the analyzed samples have a small scatter and, therefore, a related genesis (Fig. 2). All groundwater samples are located slightly above the Global Meteoric Water Line (GMWL), which serves as evidence of their meteoric origin. The recharge of all groundwater samples is derived from local atmospheric precipitation. All groundwater samples are located near the meteorological water line, and their recharge and discharge areas almost coincide, meaning that the groundwater has a local origin.

The graph clearly shows that the water samples from the wells of the Tezgari Poyon, Choryakkorona, and YZN-S areas are enriched with heavy isotopes, unlike the others. The results of the stable isotope analysis indicate that these wells receive slightly evaporated water, which has passed through a long process of infiltration through the aquifer rocks and surface water infiltration. In contrast, other wells exhibit lighter stable isotopes. This is explained by the fact that the wells in the Zarniyor, Jangalobod areas (on the left bank of the Kofirnihon River), and the wells in KNS (on the right bank of the Kofirnihon River) are located near the Kafirnigan River. These wells are mainly replenished by groundwater from the river and have a faster infiltration time through the aquifer layers.

During the summer period, all studied samples show enrichment in stable isotopes. The results of evaporation in comparison with the spring period are presented in Table 3. Variations in the isotopes of natural waters are caused by fractionation (separation) during phase transitions (such as evaporation, condensation, and hydration/dehydration of rocks). In natural conditions, hydrogen isotopes are the most susceptible to fractionation. During the evaporation of water, the isotopes separate (with an increase in the relative content of $\delta^{18}O$ and $\delta^{2}H$ in the liquid phase).

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Table 3

Results of comparative evaporation analysis of water in the summer compared to spring in the Kofirnihon River basin

№	Location	Sample Type	δ18O Enrichment, %	δ18O Enrichment, %	δ2H Enrichment, %	δ2H Enrichment, %
1	Lower Tezgar	Well	-0.13	1.24	-0.6	0.91
2	Zarniyor	Well	-0.46	4.16	-1.6	2.34
3	Jangalabad	Well	-0.33	2.98	-1.1	1.61
4	KNS Well 44	Well	-0.38	3.38	-1.5	2.16
5	KNS Well 30	Well	-0.23	2.06	-0.2	0.29
6	YZV Well 16	Well	-0.36	3.32	-0.7	1.06
7	YZV Well 1	Well	-0.25	2.25	-0.8	1.16
8	Choryakkoron	Well	-0.35	3.25	-1.3	1.92

The well in the Zarniyor community underwent the greatest evaporation. The enrichment of stable isotopes reaches δ18O = -0.46‰ and δ2H = -1.6‰. The minimum enrichment was found in the well of the Tezgarion community, with the isotope composition reaching δ18O = -0.13‰ and δ2H = -0.91‰. This is explained by the fact that the area has a deep aquifer horizon.

According to the isotopic analysis results, almost all samples in the autumn and winter periods have an identical isotope composition and are depleted of heavy isotopes. This is related to the cooling and the large amount of precipitation. From the results in Table 4, it is evident that in October, precipitation with a lighter isotope composition fell, compared to November.

Atmospheric precipitation during the cold months of the year is depleted of heavy oxygen and hydrogen isotopes compared to the warm months. In the autumn-winter and spring periods, atmospheric precipitation has a lighter isotope composition, while in the summer it becomes enriched.

The isotope composition of natural waters in the Kafirnigan River basin suggests that the majority of waters in the basin are fresh and have an infiltration genesis. Groundwater in the Kafirnigan River basin is mainly formed by local atmospheric precipitation. The area is characterized by high water exchange rates in the shallow underground waters.

During the sample collection, we also conducted express analyses using portable devices: a conductivity meter (Cond 3110 SET 1), a pH meter (pH 3110), and an oxygen meter (Oxi 3205) to determine the physicochemical parameters of the studied waters, the results of which are presented in Table 4. The analysis of the physicochemical characteristics of the water showed that the waters in the basin are weakly alkaline. The pH values in the tested waters range from 7.01 to 8.21. The maximum pH value is observed in the Kafirnigan River (pH = 8.21), while the lowest pH value is found in the Tezgarion sample (pH = 7.01).

An important ecological characteristic of water is the concentration of dissolved oxygen. In stagnant waters, oxygen content is greatly reduced, while in mountain rivers, under turbulent flow conditions, oxygen enrichment occurs. In surface waters, the concentration of dissolved oxygen varies from zero to 14 mg/l, with significant seasonal and diurnal fluctuations, mainly depending on the balance between the intensity of consumption and production processes. In static water bodies, as the water depth increases, oxygen content decreases sharply due to reduced photosynthesis. Oxygen concentration decreases due to its consumption for the oxidation of organic substances and by aquatic organisms. On the other hand, in cases of high photosynthesis intensity, the water becomes significantly supersaturated with oxygen, with concentrations potentially reaching over 20 mg/l.

The minimum concentration of dissolved oxygen in waters for the normal development of fish is about 5 mg/l, and its reduction is unfavorable. Excessive supersaturation of water with oxygen is also detrimental to fish development.

The analysis of the physicochemical indicators of the water, as shown in Table 4, revealed that the water in all samples is sufficiently saturated with oxygen. The highest oxygen concentration (8.37 mg/l) is observed in sample 6 from the Kafirnigan River.

Table 4

Hydrochemical and Ecological Characteristics of Groundwater in the Kofarnihon River Basin, Republic of Tajikistan

№	Date	Location	Type	Oxi, mg/l	Oxi, %	Cond., mS/cm	Cond., Sal	pH	-24,4
1	02.05.2018	Lower Tezgar	Well	5.05	53.5	1486	0.7	7.22	-27,7
2	02.05.2018	Zarniyor	Well	6.02	57.7	1101	0.5	7.28	-28,3
3	02.05.2018	Jangalabad	Well	4.58	45	806	0.3	7.29	-52,7
4	02.05.2018	KNS Well 44	Well	6.00	56.8	573	0.2	7.71	-71,0
5	02.05.2018	KNS Well 30	Well	6.75	64.3	416	0.1	8.02	-81,7
6	02.05.2018	Kofarnihon	River	8.37	74.5	315	0.1	8.20	-25,6
7	02.05.2018	YZV Well 16	Well	5.80	57.5	1144	0.5	7.24	-23,9
8	02.05.2018	YZV Well 1	Well	5.97	64.5	1198	0.5	7.21	-48,7
9	02.05.2018	Choryakkoron	Well	6.40	68.6	1758	0.8	7.64	-11,6
10	03.07.2018	Lower Tezgar	Well	3.28	40.0	1468	0.7	7.01	-29,3
11	03.07.2018	Zarniyor	Well	4.76	57.6	1099	0.5	7.31	-32,8
12	03.07.2018	Jangalabad	Well	3.70	43.1	819	0.3	7.37	-41,0
13	03.07.2018	KNS Well 44	Well	4.92	56.5	566	0.2	7.51	-58,3
14	03.07.2018	KNS Well 30	Well	4.75	58.9	423	0.1	7.81	-77,2
15	03.07.2018	Kofarnihon	River	6.05	76.9	249	0.0	8.13	-16,9
16	03.07.2018	YZV Well 16	Well	5.25	78.3	1156	0.5	7.09	-24,0
17	03.07.2018	YZV Well 1	Well	5.96	72.6	1187	0.5	7.22	-40,1

18	03.07.2018	Choryakkoron	Well	5.33	52.1	2060	1.0	7.50	-21.4
30	13.02.2019	Lower Tezgar	Well	4.37	44.7	1458	0.7	7.23	-32.9
31	13.02.2019	Jangalabad	Well	3.62	39.4	847	0.3	7.43	-41.7
32	13.02.2019	KNS Well 44	Well	3.53	35.5	603	0.2	7.59	-61.3
33	13.02.2019	KNS Well 30	Well	4.70	43.4	384	0.1	7.91	-78.4
34	13.02.2019	Kofarnihon	River	6.05	56.4	320	0.1	8.21	-17.3
35	13.02.2019	YZV Well 16	Well	3.64	40.7	1183	0.5	7.16	-20.7
36	13.02.2019	YZV Well 1	Well	4.14	46.8	1198	0.5	7.22	-48.3

Based on the obtained research results, it has been found that the electrical conductivity (Cond) of the analyzed water samples is directly dependent on the concentration of dissolved minerals. The specific electrical conductivity of water depends on temperature, the nature of the ions, and their concentration. Figure 3 presents the results of the specific conductivity for three seasons.

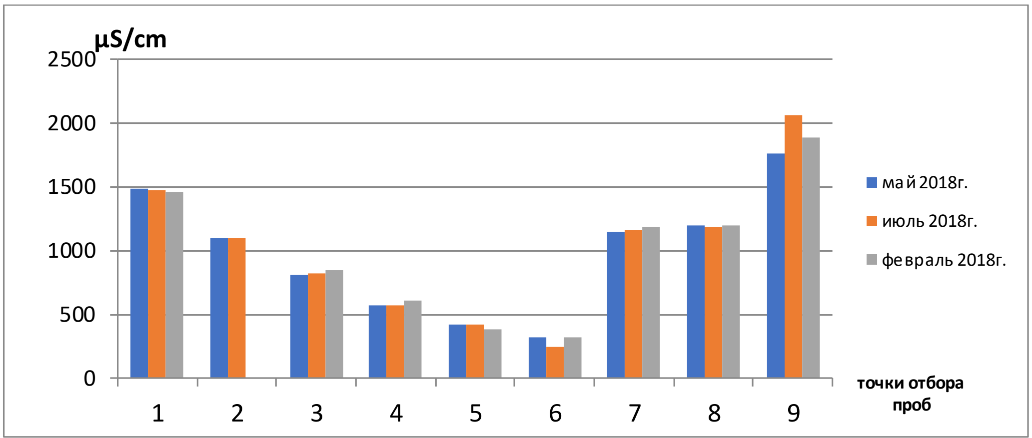

Figure 3. Seasonal variation of specific conductivity in the studied groundwater characteristics of the Kofarnigan River Basin, Republic of Tajikistan

CONCLUSIONS

Based on the results of the study, it was found that the lowest specific conductivity values were recorded in samples 6, 15, and 34 from the Kofarnigan River (249-320 µS/cm), while the highest values were recorded in samples 9, 18, and 37 from the Chorakkoron Jamoat (1758-2060 µS/cm). As seen in the table, nearly all samples exhibit high electrical conductivity. This is due to the high concentration of salts, likely influenced by anthropogenic factors in the Kofarnigan River Basin.

Thus, using hydrochemical and physicochemical methods, the main indicators of stable isotopes and physicochemical parameters were used for ecological characterization, quality assessment, and analysis of the origin, formation, movement, distribution, and residence time in the aquifers of the studied groundwater in the Kofarnigan River Basin, Republic of Tajikistan.

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