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Causes of Changes in Mineralization of Underground Drinking Water in the Shaim Oil and Gas Region of the West Siberian Megabasin

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Abstract: Mineralization of groundwater for drinking purposes is a complex parameter of groundwater chemical composition. In the Shaim oil- and gas-bearing area, as in the whole West Siberian megabasin, the main target horizon for solving the issues of domestic and technical water supply is the Oligocene aquifer. It has significant groundwater reserves to cover the needs of the population and production requirements. However, it also faces a huge anthropogenic load in the form of water withdrawal and possible contamination from the surface with oil products. In Western Siberia, various deviations in the chemical composition of groundwater of the Oligocene horizon are recorded in connection with significant water withdrawal; for example, a sharp increase in chromaticity or total iron concentration, with changes in mineralization acting as a factor necessarily accompanying these deviations. Based on the data obtained in the course of monitoring for the period from 2013 to 2023, the main factors and trends of changes in the components of mineralization of the Oligocene horizon were determined. The lithological and mineralogical peculiarities of the water-bearing rocks of the horizon, the paleogeographic conditions of its formation and their relation to trends in mineralization change were studied. Water withdrawal data were processed for two cluster water withdrawal sites (50 and 5 wells, respectively). Analysis of the results showed that the increase in water withdrawal leads to an increase in infiltration from the overlying Neogene-Quaternary aquifer, which leads to the dilution of groundwater of the Oligocene horizon and a decrease in its mineralization. Here, we show that, during further monitoring, it is necessary to pay attention to the appearance of sites where significant amounts of chloride ions are fixed in the anion composition, which can potentially lead to a sharp deterioration in the quality of drinking groundwater.

Keywords: groundwater mineralization; aquifer; water withdrawal; paleogeography; lithological and mineral composition of rocks; fresh groundwater quality; Shaim oil and gas region

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1. Introduction

The constantly growing need for fresh groundwater, associated with the intensive development of the social economy and population growth in recent years, increases the demand for water resources and causes the relevance of the study of the factors of chemical composition formation for predicting the quality of groundwater [1–3].

Researchers repeatedly emphasize the need for the conscious management and protection of fresh groundwater resources for drinking purposes against the background of their exploitation and increasing use [4–6]. This makes it necessary to increase the detail of the study of the process of human activity's impact on the underground hydrosphere [7,8]. At present, in many regions of the world, there is a need to create tools and services for tracking, assessing, and forecasting water resources indicators, which could provide authorities with access to information in near-real time [9,10]. At the same time, each region has its own specifics, and an individual approach is required, considering the nature of technogenic impact [11,12]. New, useful tools are needed that integrate complex environmental data into a coherent whole, providing an overall picture of water quality and trends [13,14]. The main parameters for assessing the variability of the underground hydrosphere are hydrochemical indicators of groundwater quality, hydrogeological and climatic conditions, sources of groundwater supply, and human economic activity [15–18].

The underground hydrosphere of the West Siberian oil- and gas-bearing region, despite the significant resources of fresh groundwater, is extremely sensitive to anthropogenic impact [19,20]. The equilibrium in the "water–rock" system is easily shifted under intensive water withdrawal [21,22]. A characteristic sign of changes in the general hydrogeochemical state of groundwater is a change in mineralization; in this regard, it is extremely important to understand the factors underlying the formation of this parameter, which is the basis for sustainable water resources management. Effective strategies for long-term groundwater management are needed to develop groundwater monitoring and research initiatives [23], which is only possible based on a full understanding of the hydrogeochemical transformation of chemical composition under the influence of natural and anthropogenic factors. For the study region, the implementation of groundwater management and protection measures requires quantitative assessment of the transformation of aquifer hydrogeochemical conditions based on detailed interdisciplinary studies, which should be supported by reliable data [24,25].

Fresh groundwater used for water supply in the territory of the Shaim oil- and gas-bearing area, as well as in the whole central part of the West Siberian megabasin, is characterized by availability and high coefficients of water conductivity and filtration, but at the same time by instability of chemical composition in time, iron and manganese contents exceeding maximum permissible concentrations, and frequent trapping of hydrocarbons and petroleum products in waters in the territory of oil fields [17–20]. Factors influencing mineralization on the studied territory are of both natural and anthropogenic origin. The anthropogenic, first of all, refers to water withdrawal, which is carried out at cluster water intake sites, amounting to 1.7–5.5 thousand m^3/day and 0.9–2.2 thousand m^3/day.

The purpose of the study was to determine the factors of formation and trends in changes in the mineralization of the Oligocene aquifer under the influence of natural and anthropogenic factors. The study deals with one of the main issues of hydrogeology—the genesis of chemical composition and the mineralization of groundwater.

The following objectives were accomplished during this study:

1. Study of the geological structure and hydrogeological features of the Oligocene aquifer.
2. Systematization and analysis of groundwater condition monitoring materials of the target horizon.

3. Correlation of data on the directions of change in groundwater chemistry at the two research areas with the magnitude of water withdrawal for the period from 2017 to 2023.
4. Study of the lithological and mineral composition of the rocks of the Oligocene horizon and the paleogeographic conditions of its formation in connection with the influence on groundwater mineralization.
5. Analysis of the influence of the water withdrawal value on the mineralization of the Oligocene complex.

1.1. Research Area

The object of this study is the Oligocene aquifer confined to the deposits of stratigraphic analogs—the Kurtamysh and Atlym-Novomikhailov formations in the western part of the Middle Ob hydrogeological basin (Figure 1), in the western part of the West Siberian Plain. The territory belongs to the Shaim oil and gas district.

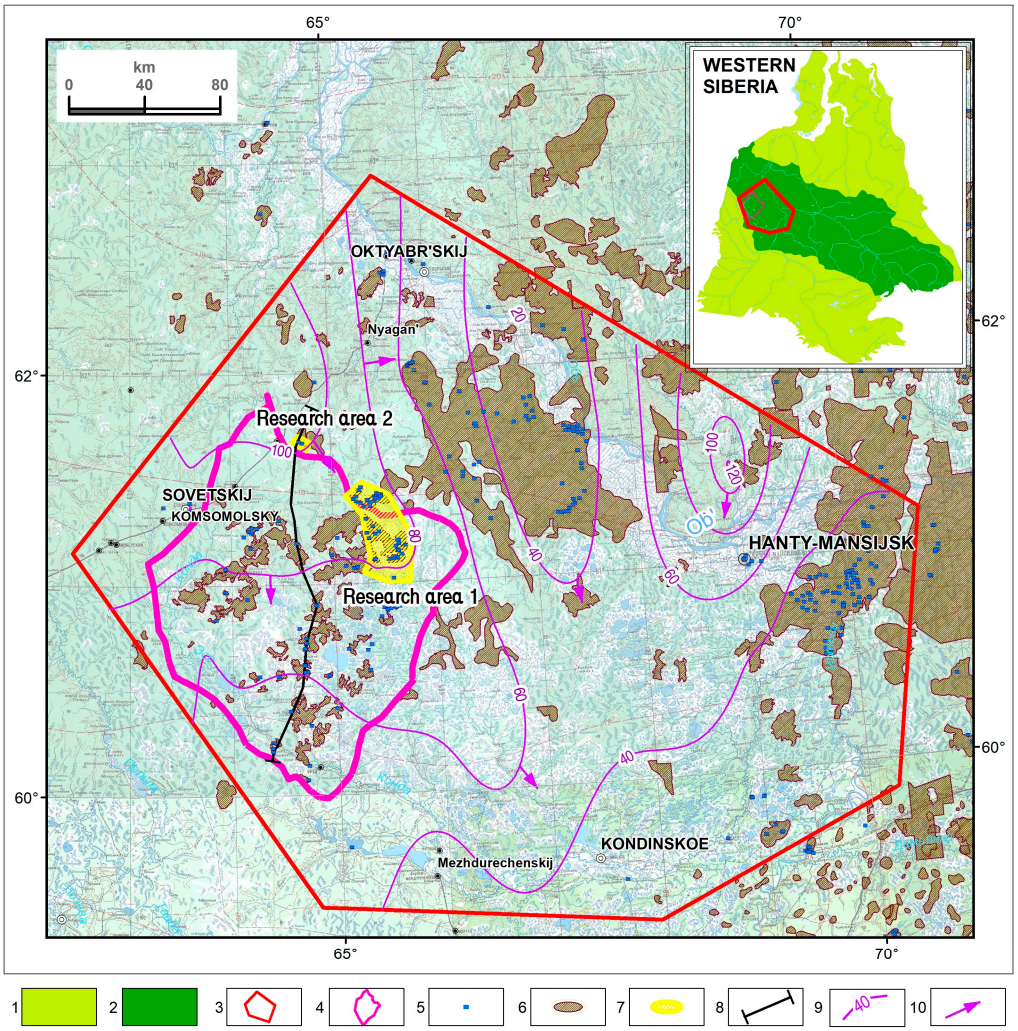


Figure 1. Overview map of the study area: 1—West Siberian megabasin; 2—Middle Ob hydrogeological basin; 3—study area; 4—Shaim oil and gas bearing area; 5—water intake site; 6—hydrocarbon field; 7—technogenic influence observation site; 8—hydrogeological section line; 9—groundwater table, absolute height; 10—main directions of groundwater movement.

The study used data for two groups of water intake clusters—2 m sites (Figure 1). Water withdrawals at the sites of compactly located water intake clusters of 1.08 thousand km^2

and 0.35 thousand km^2 from the Oligocene horizon, depending on demand, are 1.7–5.5 thousand m^3/day and 0.9–2.2 thousand m^3/day, respectively.

The northern part of the territory is located in the Siberian uplands (Severo-Sosvinskaya, Lyulimvor, and Belogorsky mainland) with surface elevations of 101–227 m and a small part in the extreme east in the zone of the Tobolsk mainland with elevations of 82–100 m. The rest of the area belongs to the Kondinskaya and Sredneobskaya lowlands with relief elevations of 22–88 m.

The relief, formed under the influence of Quaternary glaciations, erosion-denudation processes, and waterlogging, is a hillside with erosional dissection and a gentle flat plain, located in the lowlands and heavily waterlogged and silted. In the uplands, soil composition and terrain dissection contribute to better surface and subsurface runoff than in the lowlands.

In general, for the first aquifers, the areas of groundwater flow recharge of the layered water exchange system of runoff basins practically coincide with the area of their distribution; recharge occurs through the upper boundary of the system and vertical water exchange takes place due to dispersed infiltration of meteogenic waters; regionally, the general tendency to lower levels is noted in the direction of the main drain of the area, the Ob River valley (Figure 1), and local gradients create its numerous tributaries [19,26–28].

1.2. Geological Conditions

Tectonically, the study area is located in the western part of the West Siberian plate (geosyncline), in relative proximity to its junction with the Ural orogen.

The Oligocene aquifer under study is a part of the West Siberian megabasin Cenozoic hydrogeological basin, which combines sandy silty and clayey sediments of Oligocene-Quaternary age, hydrodynamically representing a single water-saturated stratum, the ground and interstratum waters of which are closely hydraulically connected. The horizon is a thickness of alternating sands, siltstones, and clays. In general, the upper part is composed of more clayey, weakly permeable sediments, while the middle and lower parts (effective thickness) are composed of fine- and medium-grained clayey sands with interlayers of siltstones and clays. The upper aquifer is formed by essentially clayey sediments of the Turtas Formation, and in places where it is absent, by sediments of Neogene-Quaternary age; the lower regionally sustained aquifer, completing the section of the active water exchange zone, is formed by clays of the Eocene Tavda Formation (Table 1, Figure 2). Groundwater of the horizon is fed by precipitation through downward filtration through the Neogene-Quaternary aquifer. Discharge takes place by upward filtration in places of deep erosion incisions and into ground horizons [28].

In the study area, in accordance with the general submergence of the sedimentary cover of the West Siberian megabasin from west to east, the depth of occurrence of the roof of the regional water-bearing horizon of the Eocene Tavda Formation (the base of the Oligocene aquifer) increases and the thickness of the Oligocene horizon and the depth of occurrence of productive intervals of its section increase.

Table 1. Main characteristics of the Oligocene aquifer.

	Research Area 1	**Research Area 2**
Number of water intake wells	50	5
Depth of roof, m	53	20
Bottom depth, m	150	80
Total thickness, m	98	60
Had above the aquifer roof, m	44	42

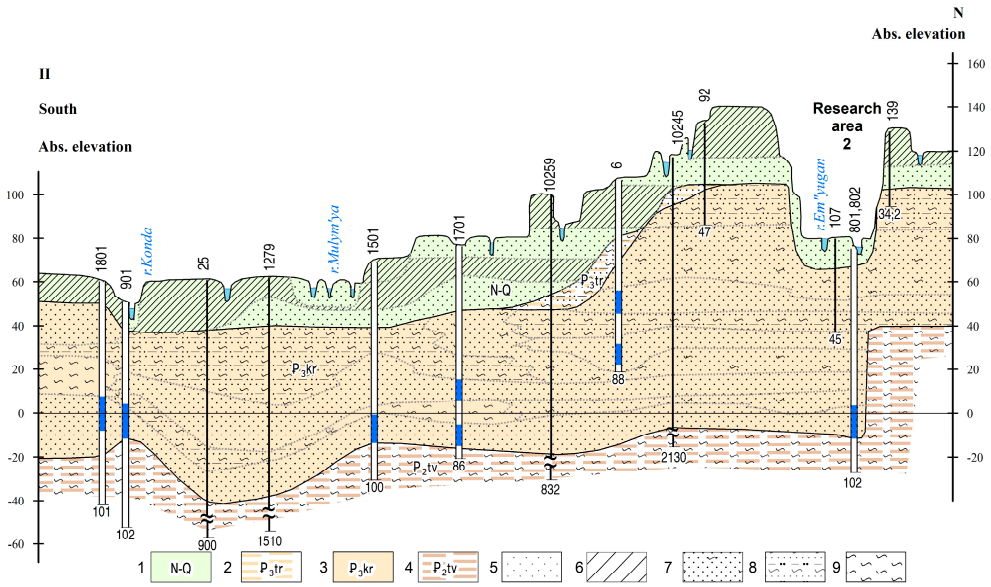


Figure 2. Schematic hydrogeological section of the area: 1—water-bearing Neogene-Quaternary horizon (the section is based on rock descriptions from water well drilling and geophysical logging data from oil wells); 2—water-bearing, locally weak water-bearing Turtassky horizon; 3—water-bearing Kurtamysh (Oligocene) horizon; 4—water-bearing Tavda horizon; 5—sands; 6—loams; 7—clayey sands; 8—interlayering of sands, clays, siltstones; 9—dense clays.

The leading elements of the West Siberian plate neotectonics that formed the systems of the Ob and Irtysh river basins and uplifts in the area of the Siberian Upland Mountains were the basis for the formation of the second-order hydrogeological structure—the Middle Ob groundwater flow basin of the active water exchange zone—and caused the reduction in the Oligocene aquifer's thickness in the area of the Tavda Formation neotectonic uplifts as a result of denudation processes [29] (area of site No. 2, Figure 2).

As noted above, the horizon is characterized by high filtration-capacity properties [30,31]. According to regional estimates [32], the module of predicted exploitable groundwater resources for the first from the surface aquifer for the considered territory is one of the highest on the territory of the Russian Federation—5–10 L/s*km^2.

2. Materials and Methods

2.1. Materials on Chemical Composition and Water Withdrawal from the Oligocene Aquifer

The following quantitative data were used to achieve the objective of this study:

- the results of chemical analyses of groundwater of the Oligocene horizon (1763 analyses of water samples collected within the Shaimskoye oil- and gas-bearing area) obtained in the course of monitoring by various subsoil users for the period 2013–2023.
- the average values of mineral content forming water-bearing sands of Oligocene age (based on geological survey data);
- data on water withdrawal accounting by years for two research areas.

Laboratory studies of the chemical composition of waters of the Oligocene horizon included the determination in various combinations of the following indicators: hydrogen index (pH), total hardness, sum of major ions as a mineralization characteristic, content of the sum of sodium and potassium ions ($Na^+ + K^+$), calcium (Ca^{2+}), magnesium (Mg^{2+}), sulfate (SO_4^{2-}), chloride (Cl^-), hydrocarbonate (HCO_3^-), ammonium (NH_4^+), silicon (Si), total iron (Fe), and manganese (Mn).

Chemical-analytical studies were carried out using an atomic absorption spectrometer with electrothermal atomization with the mercury-hydride attachment MGA-1000 RGP-915,

the liquid ion chromatograph with conductometric detector "Stayer", and the capillary electrophoresis system "Kapel-205".

The systematization of data from laboratory tests of water samples included:

- the rejection of erroneous definitions of indicator values;
- the determination of water mineralization value (M, mg/dm^3) as a sum of main ion content ($Na^+ + K^+$, Ca^{2+}, Mg^{2+}, HCO_3^-, Cl^- and SO_4^{2-}), which is caused by determination of either mineralization or dry residue by different laboratories;
- the calculation of equivalent values (mg-eq, %-eq) of basic ions;
- obtaining the average values of chemical composition indicators for each water intake well;
- the division of all chemical analyses into two groups according to mineralization value: the first group with mineralization values < 1000 mg/dm^3 and the second group with values > 1000 mg/dm^3.
- the generalization of average values for closely located wells into observation sites to construct maps of indicator distribution over the area.

Regularities of changes in chemical composition over time are established by comparing hydrochemical maps of different time periods. All the results of laboratory analyses can be divided into two groups of samples taken in the Shaim oil- and gas-bearing area from the Oligocene aquifer, according to the magnitude of mineralization. The first group includes analyses with mineralization values < 1000 mg/dm^3, typical for fresh waters of the region and limited by sanitary norms for drinking water, the second group with extreme mineralization values >1000 mg/dm^3. The average and extreme values of the indicators are shown in Table 2.

Table 2. Average and extreme values of indicators of chemical composition of the groundwater of the Oligocene horizon.

Indicator	Average Value 39 mg/dm^3—M < 1000 mg/dm^3				Extreme Values 1089 mg/dm^3—M > 1000 mg/dm^3			
	Number of Definitions	Limits of Values	Average Value	Standard Deviation	Number of Definitions	Limits of Values	Average Value	Standard Deviation
pH	1511	5.5–8.8	7.0	0.5	33	5.1–7.2	6.8	0.7
Total hardness, mg-eq/dm^3	1653	0.2–10.2	2.5	1.5		3.6–9.8	5.8	2.0
Mineralization, mg/dm^3	1216	39–924	337	165		1085–3572	1648	682
$Na^+ + K^+$, mg/dm^3	1305	1.4–478.0	45.2	44.7		172.6–1182.2	460.7	257.2
Ca^{2+}, mg/dm^3	1384	1.4–126.6	27.2	19.2		48.1–136.3	83.5	29.2
Mg^{2+}, mg/dm^3	1331	1.1–51.6	13.6	8.2		7.3–36.5	19.8	9.7
SO_4^{2-}, mg/dm^3	801	0.1–87.8	6.1	9.2		1.2–7.2	2.9	1.7
Cl^-, mg/dm^3	1506	0.3–228.4	22.9	38.3		249.9–1801.8	690.4	417.8
HCO_3^-, mg/dm^3	1323	17.7–507.6	222.8	119.8		73.2–634.4	390.9	180.0
NH_4^+, mg/dm^3	945	0.1–7.4	2.6	1.6	Was not determined			
Si, mg/dm^3	547	0.9–28.0	15.1	4.7				
Fe total, mg/dm^3	1059	0.2–19.5	6.1	4.3				
Mn total, mg/dm^3	771	0.01–1.1	0.3	0.2				

Analyses of the first group characterize groundwater as fresh with a mineralization value of 39–924 mg/dm^3; by the reaction of the medium, it ranges from slightly acidic to alkaline (pH 5.5–8.8 units), and by the value of total hardness (0.2–10.2 mg-eq/dm^3), it ranges from very soft to very hard.

The analyses of the second group characterize waters in the places of their sampling as brackish, with mineralization values from 1085–3572 mg/dm^3, from moderately acidic to neutral by the reaction of the environment (5.1–7.2 units), and moderately and very hard by the value of total hardness (3.6–9.8 mg-eq/dm^3). According to the classification of O.A. Alekin, waters are hydrocarbonate and chloride, by predominant cations sodium type I and II.

2.2. Data Characterizing the Lithological and Mineral Composition and Paleogeographic Conditions of Groundwater Formation in the Oligocene Horizon

To characterize the mineral composition of the water-bearing sands of the Oligocene horizon, we analyzed the percentage content of feldspars, magnetite-ilmine minerals, epidote group minerals, leucoxene-titanic minerals, and zircon according to different published sources.

In accordance with the submergence of the Cenozoic hydrogeologic basin, which includes the studied horizon, and the increase in the thickness of Oligocene sediments, the Kurtamysh Formation is replaced by the Atlym Formation in the study area. In the formation of the material composition of the suites, a great role was played by the removal of clastic material from the Urals; therefore, in the direction away from it, there is a change in the relative content of the main components of the mineral composition of the water-bearing sands of the formations over the area, manifested in the increase in the relative content of feldspars due to a decrease in the quartz content in the direction from west to east, as well as a decrease in the content of minerals of the magnetite-ilmenite group from northwest to southeast (Table 3).

Table 3. Average values of material composition of sands of the Kurtamysh and Atlym Formations of the Oligocene (based on geological and survey data) (content, %).

Mineral	Chemical Formula	R-41 [1]		R-42 [1]	O-41 [1]	O-42 [1]	Average Value	
		Kurta-Mysh Suite	Atlym Suite	Atlym Suite	Kurta-Mysh Suite	Atlym Suite	Kurta-Mysh Suite	Atlym Suite
light fraction								
quartz	SiO_2	90.0	82.5	57.5	79.5	55.0	84.8	65.0
feldspar	K, Na, $[AlSi_3O_8]$	7.5	10.0	35.7	17.9	32.0	12.7	25.9
heavy fraction								
magnetite-ilmenite	$FeOFe_2O_3$, $FeTiO_3$	65.0	65.0	66.0	67.2	38.7	66.1	56.6
epidote group	Ca_2 (Al, Fe)$_3$ $[SiO_4]$ $[Si_2O_7]$ O(OH)	n.s.	10.5	11.9	15.9	24.0	15.9	15.5
leucoxene-titanium minerals	Fe_2 Ti_3O_9	7.0	n.s.	n.s.	8.0	18.8	7.5	18.8
zircon	$ZrSiO_4$	8.0	n.s.	n.s.	9.4	5.5	8.7	5.5

[1] Designations R-41, P-42, O-41, and O-42 are given according to the Digital Catalog of State Geological Maps of the Russian Federation (https://karpinskyinstitute.ru/ru/info/pub_ggk1000-3/ accessed on 1 January 2017).

In order to investigate the paleogeographic conditions of groundwater formation in the horizon, the results of published studies on this area were studied. The main theoretical provisions on which further analysis of the formation of mineralization of the Oligocene aquifer was based are given below.

At the turn of the Eocene and Oligocene, the revitalization of tectonic activity led to a vigorous uplift of the West Siberian plate, which caused the Chegan Sea to move beyond its territory, led to the establishment of a stable continental regime, and caused the erosion of weathering crusts in the Urals, to the eastern slope of which iron and manganese ore deposits are confined. The relief of the former seabed contributed to the formation of complex lake-river systems. The alluvial-lake plain in the Atlymian time was dotted with lakes, drainless lacustrine-marshy water bodies, and weakly eroding rivers. In the Novomikhailovo time, waterlogging intensified, the area of shallow lakes increased, and river erosion subsided [33]. Under such conditions, a mass thickness of rocks of the terrigenous lignite-bearing formation was accumulated. The tectonic movements were uneven in time and space, which caused the formation of different genetic types of sediments, along with changes in their thicknesses and lithologic composition [34]. During the whole subsequent period of geologic time, sedimentation took place in the conditions of continental regime, accumulative lacustrine-alluvial plains in the lowlands and denudation plains in the uplands, which determined the proximity of the lithological

and mineral composition of the entire thickness of the Cenozoic sediments. The lithological and mineral composition of water-bearing rocks of the basin is represented mainly by aluminosilicates: quartz sands and, less frequently, feldspar-quartz sands, with inclusions of plant detritus and lignitized plant remains. Siltstones and silty clays are present in interlayers and lenses. The described conditions of water accumulation in the Oligocene horizon gave grounds for elucidating the reasons for the formation of modern values of mineralization of groundwater of the Oligocene complex.

In connection with the purpose of work, consisting in necessity of an estimation of the reasons of fluctuations of value of mineralization of an Oligocene horizon also under the influence of technogenic factors were processed values of water withdrawal on sites of compactly located water intake clusters, Site No. 1 and Site No. 2 (Figure 1); depending on demand, water withdrawal makes accordingly 3192–5207 thousand m^3/day and 904–1114 thousand m^3/day. Average water withdrawal values and corresponding average composition values in mg/d^3 over the observation period for the two sites are given in Tables 4 and 5. rNa/rCl is a genetic coefficient indicating the origin of water. If the rNa/rCl coefficient is higher than 0.87 [19] (as in our case, Table 1), then the waters are either slightly metamorphosed infiltrogenic or sedimentogenic and are from desalinated reservoirs. The coefficient can change when waters of different genesis are pulled from above or below.

Table 4. Average values of water withdrawal and indicators of chemical composition of groundwater of Oligocene horizon (Research area 1).

Average Value of the Indicator	Unit of Measurement	2019	2020	2021	2022	2023
water withdrawal	m^3/day	3591	3192	4194	5160	5207
number of laboratory determinations	items	87	93	175	189	148
Mineralization	mg/dm^3	219	269	205	158	155
$Na^+ + K^+$	mg/dm^3	43.13	59.51	41.79	21.85	25.23
Ca^{2+}		12.15	11.38	10.50	11.76	9.32
Mg^{2+}		6.86	5.27	5.35	7.58	6.90
SO_4^{2-}		6.52	6.26	6.07	8.13	8.57
Cl^-		30.50	34.12	29.27	17.78	21.20
HCO_3^-		120.16	152.37	112.01	91.04	83.39
rNa^+/rCl^-		2.80	4.19	2.80	1.88	2.18

Table 5. Average values of water withdrawal and indicators of chemical composition of groundwater of Oligocene horizon (Research area 2).

Average Value of the Indicator	Unit of Measurement	2017	2018	2019	2020	2021	2022	2023
water withdrawal	m^3/day	904	834	1140	1140	894	1096	1114
number of laboratory determinations	items	10	2	22	6	32	13	14
Mineralization	mg/dm^3	212	181	207	297	174	127	71
$Na^+ + K^+$	mg/dm^3	42.71	40.61	44.23	70.94	34.41	13.88	13.63
Ca^{2+}		10.52	6.71	9.81	10.06	9.49	9.43	6.29
Mg^{2+}		5.25	3.89	6.13	7.58	6.12	8.30	6.06
SO_4^{2-}		6.15	8.23	7.18	21.04	5.76	7.24	6.30
Cl^-		23.13	22.01	40.15	83.19	35.02	13.11	13.34
HCO_3^-		124.07	99.47	99.85	104.55	83.67	75.48	32.83
rNa^+/rCl^-		3.62	2.89	2.58	1.86	2.17	1.73	1.68

This water withdrawal has been approved by the State Commission on Reserves, is indicated in the relevant licenses for subsoil use, and fresh groundwater reserves are secured.

At the same time mineralization at the first site decreased over the period of observations from 230 to 156 mg/d^3, and this trend continues. At the second site, where water

abstraction is significantly lower, variations in salinity corresponded to values ranging from 93 to 297 mg/md^3, with no single trend standing out.

2.3. Research Methods

In a number of studies carried out in different regions of the world, based on detailed analyses of phase changes in the hydrogeochemical system against the background of the main natural and anthropogenic factors that determine the chemical composition of natural waters, it was established that the leading parameter of water diversity on a regional scale is the rate of water exchange (the model parameter is the mass ratio of rock/water), with the mineral composition of water-bearing rocks serving as a base. [35–39]. This was the concept we adhered to in the study of the factors of mineralization formation in the Oligocene aquifer of the Shaim oil- and gas-bearing area. The rate of water exchange is controlled by both natural and anthropogenic factors.

In the course of this research, the character of mineralization variation along the lateral was analyzed to identify trends of similarity in the fluctuations of the lithological and mineralogical composition of water-bearing rocks.

To construct a map of changes in mineralization and lithological and mineralogical composition indicators, the GST software package, version 7.2.4. [40,41], which implements the method of generalized spline approximation, was used. To account for rock anisotropy, the geometry of the top (and bottom) of the aquifer was taken into account during construction. Accounting for anisotropy based on modeling the deformation of the original isotropic medium of the aquifer is quite simple in its formulation and agrees well with the nature of geological processes, leading to the spatial heterogeneity of many properties of geological objects [42].

Additionally, a graph of mineralization distribution by depth was plotted based on systematized data, which revealed the main direction of the parameter change. A correlation coefficient was obtained between the depth of water sampling from the Oligocene aquifer and mineralization.

Additionally, using the GST software package, maps of the relative content of feldspars in the material composition of the sands of the Kurtamysh and Atlym formations, silicon content in the groundwater of the Oligocene aquifer, and total iron content in the groundwater of the Oligocene aquifer were constructed. Trends in the relationship between changes in these parameters and the mineralization of the Oligocene aquifer are shown.

The main type of anthropogenic impact on the groundwater of the horizon in the area under consideration is water withdrawal. The operation of water wells leads to changes in groundwater dynamics, indirectly affecting the groundwater's chemical composition. As a result of water withdrawal in the exploited reservoir, the filtration flow velocity increases and conditions for overflow are created; at the same time, depending on the lithological composition of the overlying and underlying rocks, this process may occur both "from above" and "below".

To analyze the effect of water withdrawal, the nature of the relationship between water withdrawal and salinity was determined. Histograms of distribution in time of the course of changes in mineralization and the main components of water composition at the first and second sites depending on the water withdrawal value were constructed. Special attention was paid to the sodium–chlorine genetic coefficient characterizing the degree of metamorphization of rNa/rCl waters [43,44]. Component values are used in the form of mg-eq/dm^3, which is indicated by the letter "r". This form is obtained by dividing the values in mg/dm^3 by the corresponding molecular weight of the ions.

The paleogeographic conditions of formation of the Oligocene horizon of the underlying sediments were analyzed, which provided a basis for the formation of ideas about

further variants of changes in mineralization of the Oligocene horizon under the influence of water withdrawal.

3. Results and Discussion

3.1. Analysis of Natural Conditions of Groundwater Mineralization Quality Formation in the Oligocene Aquifer

The confinement of the Cenozoic hydrogeologic basin to hydrogeologic structures determines its groundwater dynamics. The areas of feeding of groundwater flows of the layered water exchange system of flow basins practically coincide with the area of their distribution; feeding occurs through the upper boundary of the system and vertical water exchange due to dispersed infiltration of meteogenic waters; regionally, the general tendency to lower levels is noted towards the main drain of the area, the Ob River valley, and local gradients create its numerous tributaries. In accordance with the general submergence of the sedimentary cover from west to east, the increasing thickness and depth of occurrence of productive intervals of the Oligocene aquifer, the intensity of water exchange decreases and the time of contact of water with the mineral part of rocks increases, which causes an increase in the mineralization of groundwater (Figures 3 and 4).

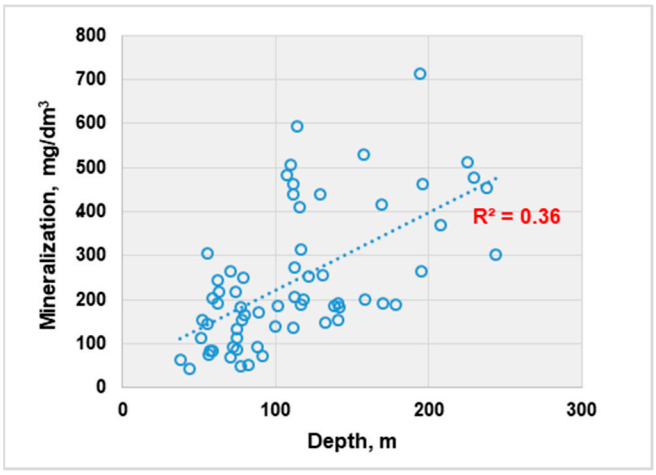


Figure 3. Dependence of groundwater salinity on the depth of the sampled interval.

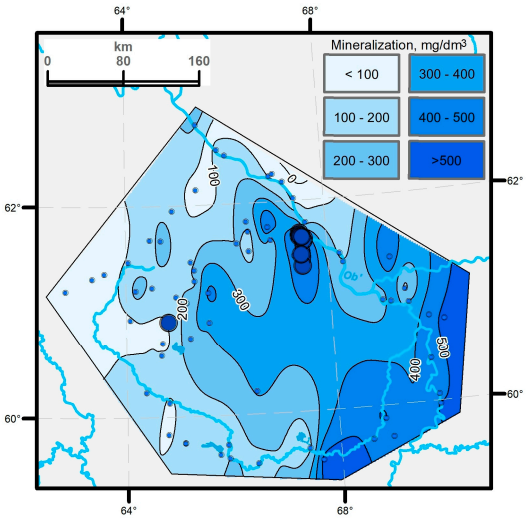


Figure 4. Map of changes in groundwater mineralization of the Oligocene horizon. The blue lines indicate the river network of the study area.

The influence of the lithological and mineral composition of rocks is observed in the pattern of increase from west to east of silicon content in the groundwater of the Oligocene horizon (Figure 5a) and the relative content of feldspars in water-bearing sands (Figure 5b), directly corresponding to the trend of increase in the same direction as mineralization value (Figure 4). Due to a lack of data, it is not possible to trace the regularity of manganese content change in Oligocene rocks, but the observed tendency of its content decrease in groundwater from north-west to south-east is similar to the tendency of total iron content decrease in this direction (Figure 5c). Due to the proximity of the hydrochemistry processes of iron and manganese [45], the fixed trend of concentration decrease is inversely dependent on the remoteness from the Ural deposits of iron and manganese ores.

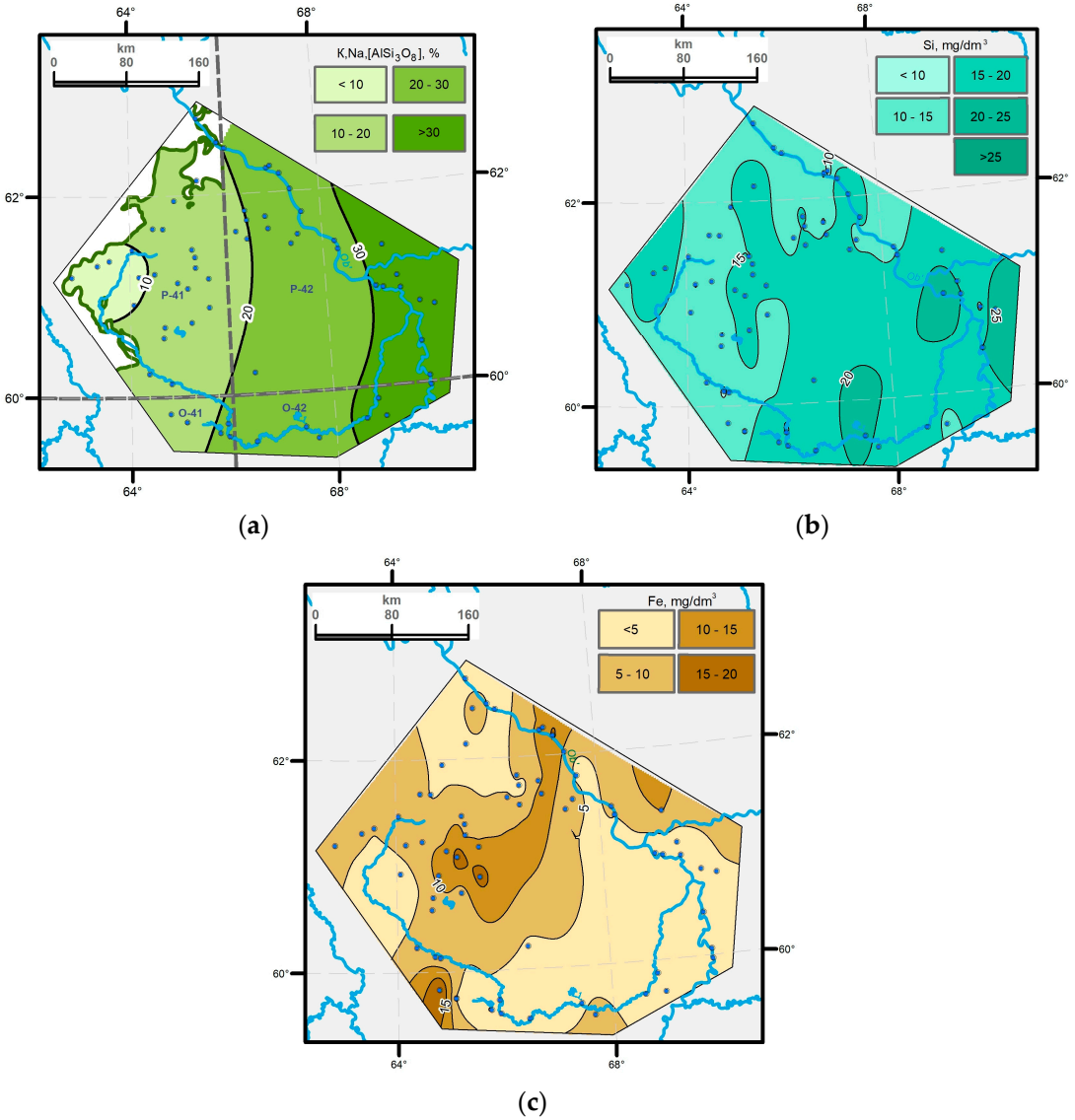


Figure 5. Schematic maps: (**a**) relative content of feldspars in the material composition of sands of the Kurtamysh and Atlym Formations; (**b**) silicon content in groundwater of the Oligocene aquifer, mg/dm^3; (**c**) total iron content in groundwater of the Oligocene aquifer, mg/dm^3.

Thus, the described lithological and mineralogical conditions (remoteness from the feeding province of the Uralic frame, the ratio of rock-forming minerals in the composition of the Oligocene aquifer) have a direct impact on the character of mineralization changes in the study area, both at depth and laterally. The constructed maps demonstrate the general growth tendencies of the values of the studied parameters from west to east.

The chemical composition of geologic materials affects the hydrochemistry of groundwater during circulation [46,47]. At the same time, the ion exchange between rock and water and the constant shift in equilibrium in the water–rock system changes the degree of geologic heterogeneity at the microlevel.

In sedimentary aquifers, water is enriched with ions directly through the leaching of soluble minerals in the rocks. In fine-grained, colloidal environments, the formation of water chemistry is complicated by cation exchange, diagenesis, and other related phenomena [48].

In terms of hydrochemical facies, the considered waters are characterized by a very heterogeneous composition: in terms of anions, classes of hydrocarbonate and chloride waters are distinguished; in terms of predominant cations, groups of sodium, calcium, and magnesium waters of types I, II, and III are distinguished [49].

Waters of the first type are characterized by the ratio $rHCO_3^- > rCa^{2+} + rMg^{2+}$ and can be formed by an exchange of Ca^{2+} for Na^+ contained in soils or rocks (e.g., glauconites, alkaline clays). Waters of the second type are characterized by the ratio $rHCO_3^- < rCa^{2+} + rMg^{2+}$. Genetically, waters of this type are associated with various sedimentary rocks and weathering products of bedrock, being predominantly mixed waters. Most rivers, lakes, and groundwater of low and moderate mineralization belong to this type. The third type is characterized by the ratio $r\,rHCO_3^- + rSO_4^{2-} < rCa^{2+} + rMg^{2+}$, or the same $rCl^- > rNa^+$. Genetically, these waters are mixed and have undergone significant changes as a result of cation exchange. Waters including strongly mineralized ground waters belong to this type [49,50]. The character of anion and cation distribution in the composition of the investigated waters is presented in Figure 6.

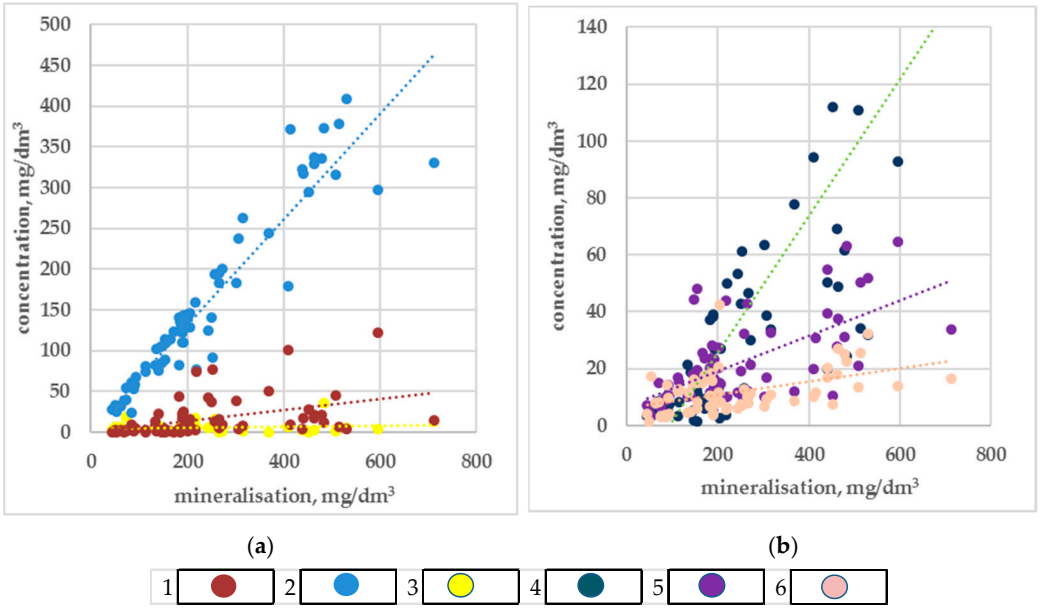


Figure 6. Distribution of main components of groundwater ion-salt composition: (**a**) anions; (**b**) cations. 1—Cl^-; 2—HCO_3^-; 3—SO_4^{2-}; 4—$Na^+ + K^+$; 5—Ca^{2+}; 6—Mg^{2+}.

The leading role of the material composition of rocks in the formation of the chemical composition of groundwater, especially in the upper hydrogeochemical zone, is emphasized by numerous researchers. In aquifers enclosed in sedimentary strata, water is enriched with ions directly due to the leaching of soluble minerals found in rocks. In a fine-grained environment containing colloids, the formation of the chemical composition of water is complicated by cation exchange, diagenesis, and other accompanying phenomena. Sodium is a part of many silicates, mainly sodium feldspars; potassium enters groundwater during

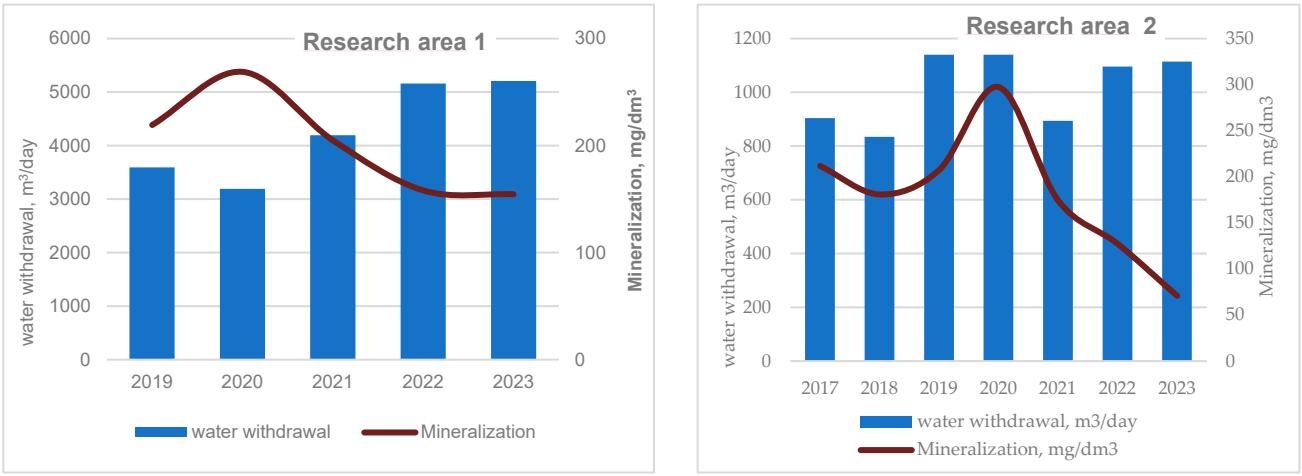
interactions with potassium-containing minerals such as orthoclase, microcline, phlogopite, muscovite and hydromicas. In sedimentary rocks, the most important source of calcium and magnesium is calcite—the main mineral of limestones, marls, and chalk—as well as dolomite and magnesite. The sources of chlorine are sedimentary rocks and sedimentary solutions. The main source of carbon dioxide entering underground waters is atmospheric CO_2, in the formation of which transformations in soil horizons are of great importance. As a result of its interaction with water, a hydrocarbonate ion and a free hydrogen ion are formed. In sedimentary rocks, the sources of sulfates are sulfate minerals—gypsum and anhydrite. The sources of silicon in underground waters are numerous silicate minerals; when they interact with water, significant amounts of silicon pass into the liquid phase in the form of silicic acid. The main sources of iron in underground waters are aluminosilicate minerals containing its oxides, as well as bottom sediments of swamps and reservoirs, converting it into a solution in the form of complex organic acids. In the process of decomposition of organic substances containing protein, ammonifying bacteria produce and enrich underground waters with ammonium. Sandy-clayey, siliceous, and concretion-clayey sedimentary deposits containing minerals of Ural manganese ores, such as manganocalcite, calcium rhodochrosite, pyrolusite, psilomelane, and manganite, contribute to the accumulation of manganese in groundwater. The above characteristics of groundwater give grounds to assert that the chemical composition of groundwater is complex, because it is a sum of elements borrowed from the atmosphere, lithosphere, and even hydrosphere [50]. The qualitative composition of lithogenic elements is only indirectly related to the composition of water-bearing deposits, since within the same rocks, the composition is different. This is due to the different directions of weathering of carbonates and aluminosilicates and the nature of the geochemical environment, which is a derivative of a number of factors, including, in addition to those considered in this study, the nature of water movement, the permeability of the rock, its composition, the duration of interaction, its forms, and others.

3.2. Analyzing the Impact of Water Withdrawal on Fresh Groundwater Quality

The study area is an area of intensive oil production with the use of a reservoir pressure maintenance system. Due to the fact that the waters of the Oligocene horizon are also used for water flooding purposes, water withdrawal is rather high and reaches 5.5 thousand m^3/day at the first site and 2.2 thousand m^3/day at the second site. The value of water withdrawal at the first site is significantly higher than at the second site; however, the specific water withdrawal per well at the second site is on average twice as much as at the first site.

Direct dependences on "mineralization-water withdrawal" in various geological conditions are described in many sources [51–53]. Moreover, large-scale withdrawals even change the geologic formation of the aquifer [54].

This study produced mineralization-water withdrawal correlation coefficients for both sites. For the first site, due to the initially high water withdrawal, a single dependence was formed for the entire observation period from 2019 to 2023 (Figure 7a); for the second site, two time periods are conditionally distinguished on the graphs from 2017 to 2020 and from 2021 to 2023 (Figure 7b) with inverse dependencies in terms of "mineralization-water withdrawal" (Table 6).



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

Figure 7. The character of "mineralization-water withdrawal" dependence: (**a**) at research area 1; (**b**) at research area 2.

Table 6. Characteristics of the dependence "sampling-mineralization".

Research Area	Observation Period	Correlation Coefficient R	Dependency Equation
1	2019–2023	0.97	y = −0.05x + 418.02
2	2017–2020	0.67	y = 0.21x + 9.26
2	2021–2023	0.88	y = −0.37x + 509.39

At research area 1, we observed an inverse relationship in terms of "mineralization-water withdrawal" with a correlation coefficient of 0.97 throughout the observation period. The average water withdrawal for the period under consideration amounted to 4268.8 m^3/day. The average water withdrawal for the 2017–2020 observation period at the second site was 1004.5 m^3/d, and for the 2021–2023 observation period it was 1034.7 m^3/d. Close correlation coefficients are observed for the whole period for the first research area 1 and the second observation period for the research area 2.

Figure 7 shows the character of the course of changes in the ratio of anions and cations in %-eq over the entire observation period for the research areas. All descriptions are based on the average concentrations of the components. The number of samples analyzed for research area 1 is 692 and for research area 2 is 99 (including for the period 2017–2020—40, 2021–2023—59) (Table 1). The influence of water withdrawal is noted at both sites, but water withdrawal at Site 1 is initially higher (in 2019–3591 m^3/day) than at Site 2 (in 2019–1140 m^3/day). The course of change in the relative and absolute content of major ions and mineralization at Site 1 has the following trend: with increasing water withdrawal, there is a decrease in mineralization, relative and absolute concentrations of sodium and potassium ions, hydrogen carbonate ions, and an increase in magnesium and sulfate. At research area 2, the trend has a multidirectional character in the periods 2017–2020 and 2021–2023: in the I period of observations for 4 years with an increase in water withdrawal by 236 m^3/day there is an increase in the average mineralization by 86 mg/dm^3 and a slight increase in the relative and absolute content of magnesium and chlorine ions. Thus, in the I period of operation (2017–2020), at the second site, there are trends different from the trends in chemical composition changes at the first site. At the same time, when considering the II period of operation of water intakes of the second site, trends close to the operation of the first site are already recorded: a decrease in the value of mineralization and hydrocarbonates and an increase in the relative and absolute content of sulfates

(Figure 8). Different tendencies of chemical composition change under the influence of water withdrawal at the second site can be explained by small water withdrawal in comparison with the first site and the possible influence of other factors requiring additional study. The maximum water mineralization was detected at both research areas in 2020, which is probably due to the fact that, in 2020, the amount of precipitation was 4–7% less (according to the two nearest weather stations) than the average precipitation for the period 2017–2023.

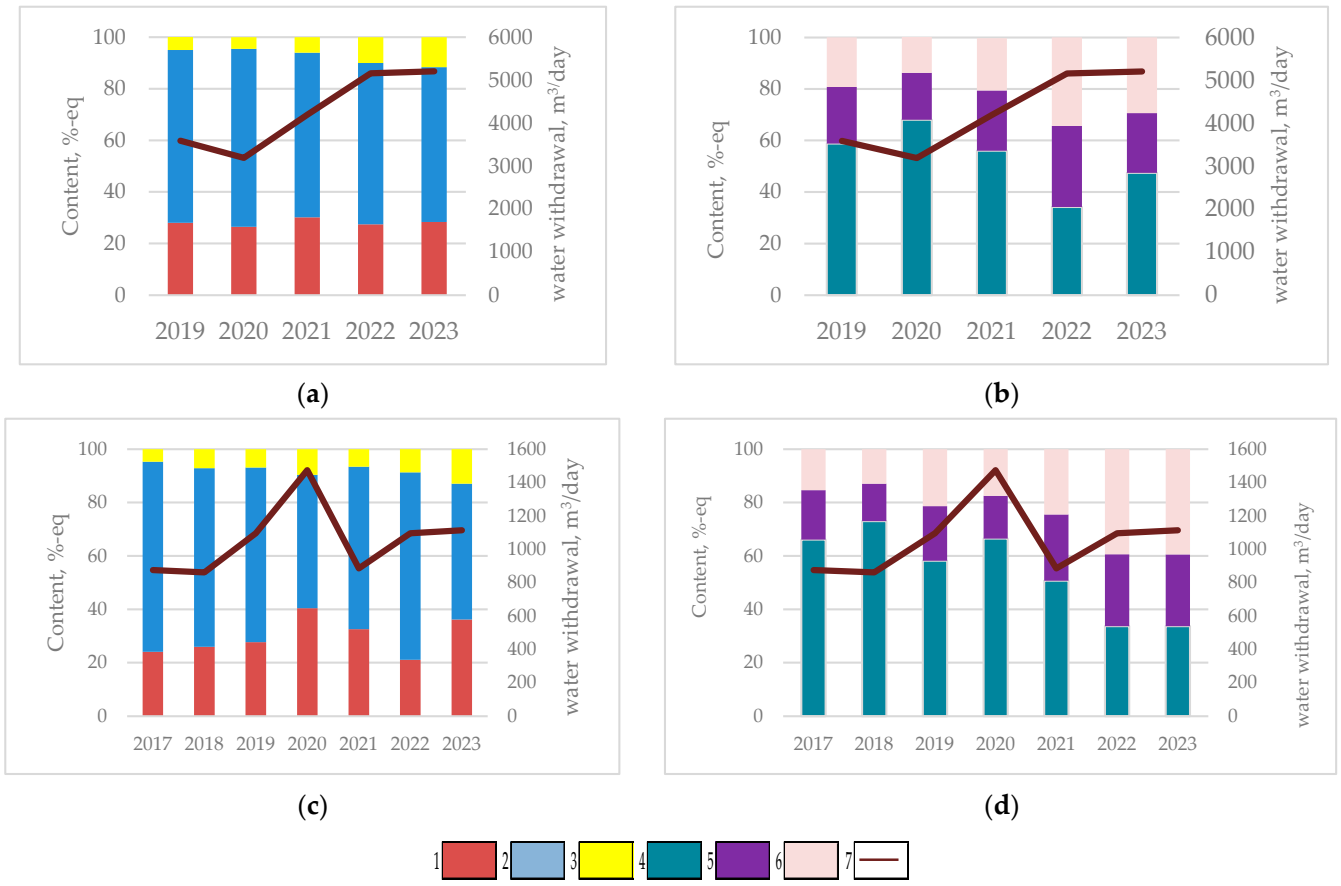


Figure 8. Changes in the anion–cation ratio as a function of water withdrawal: (**a**,**b**) at the first site; (**c**,**d**) at the second site. 1—Cl^-, 2—$HCO_3{}^-$, 3—$SO_4{}^{2-}$, 4—$Na^+ + K^+$, 5—Ca^{2+}, 6—Mg^{2+}, 7—water withdrawal, m^3/day.

Of interest is the behavior of the genetic sodium-chloride coefficient (Figure 9), which characterizes the degree of metamorphization of waters and, consequently, the interaction time in the water–rock system. At the first site, there is a decrease in this coefficient as water withdrawal increases (Figure 9a) (R = 0.81); during the I observation period (2017–2020) at the second site, the trend is similar, but the dependence of the sodium-chlorine coefficient on water withdrawal is weaker (R = 0.54) (Figure 9b). There is a similarity in the considered trend recorded at the first site and in the II period of observations at the second site (R = 1) (Figure 9c).

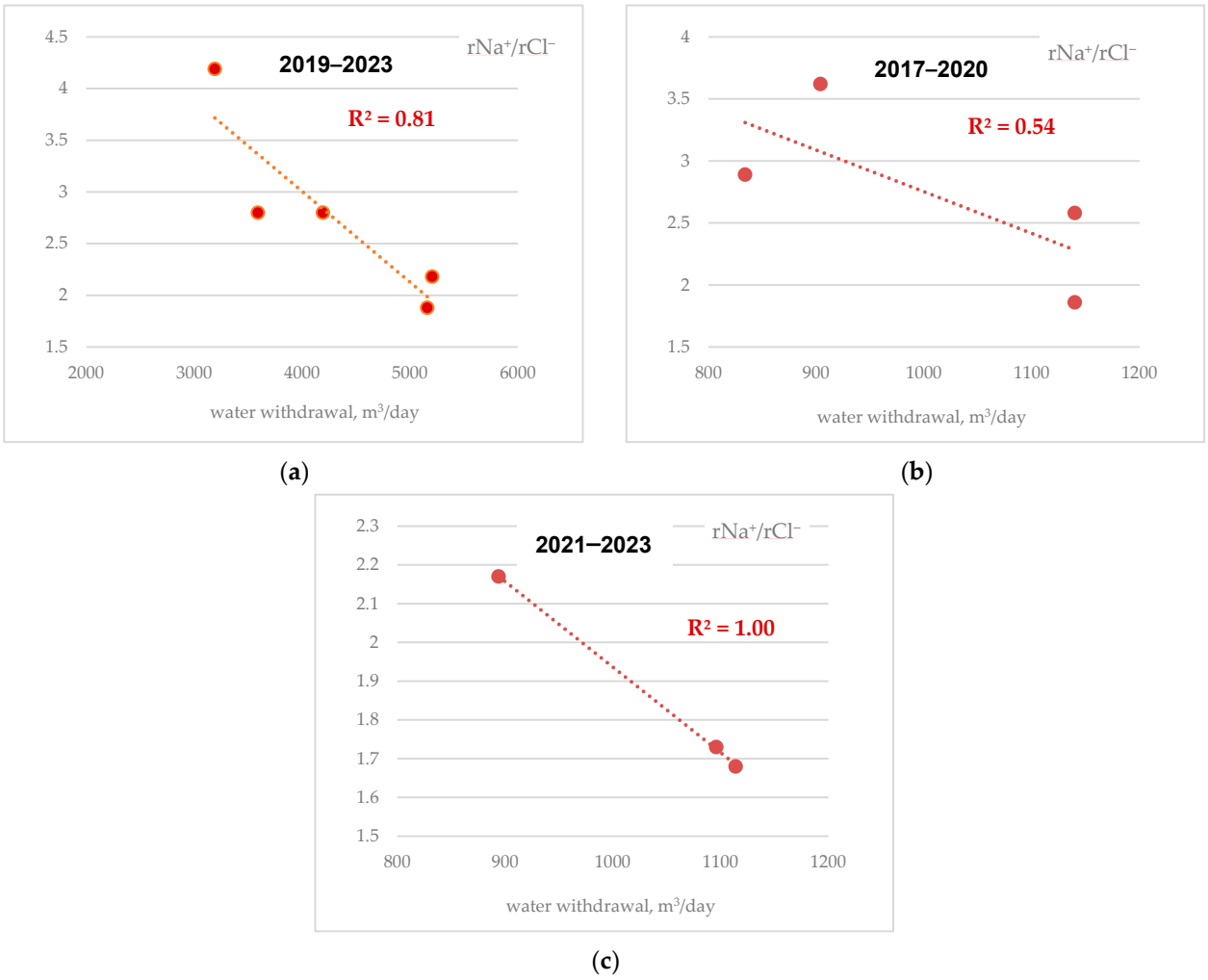


Figure 9. The character of "rNa^+/rCl^-—water withdrawal" dependence: (**a**) on the first site; (**b**,**c**) on the second site.

The operation of site water wells undoubtedly leads to changes in groundwater dynamics, indirectly affecting its chemical composition. As a result of water withdrawal in the exploited reservoir, the filtration flow velocity increases and the conditions for overflow are created [4]. Taking into account the lithological structure of the sites (Figure 2), summarized in Figure 10, which is characterized by predominantly sandy composition of sediments overlying the target horizon, the increase in water withdrawal results in the pulling of ultrapreserved water from the overlying horizons, leading to a decrease in water mineralization and mixing of Neogene-Quaternary and Oligocene sediments. The averaged geological and technical column of the study area was constructed by us based on the results of averaging the data from reports on the calculation of fresh groundwater reserves in this territory. The mentioned process leads to "rejuvenation" of waters due to mixing and, as a consequence, to decrease of sodium-chlorine coefficient. As indicated above, the module of predicted exploitable groundwater resources for the first from the surface aquifer for the territory under consideration is one of the highest on the territory of the Russian Federation—5–10 L/s*km^2, which along with the sandy composition of the Neogene-Quaternary aquifer creates favorable conditions for overflow and decrease in salinity as water withdrawal increases. Due to the fact that during the I period of observations at the second site water withdrawal was much less, there is an increase in mineralization due to the development of elastic reserves of the Oligocene aquifer, and further in the II period (as water withdrawal increases)—the processes of overflow from

the overlying horizon more fresh water have already begun. Calculation of the overflow coefficient is planned during further studies and experimental infiltration works.

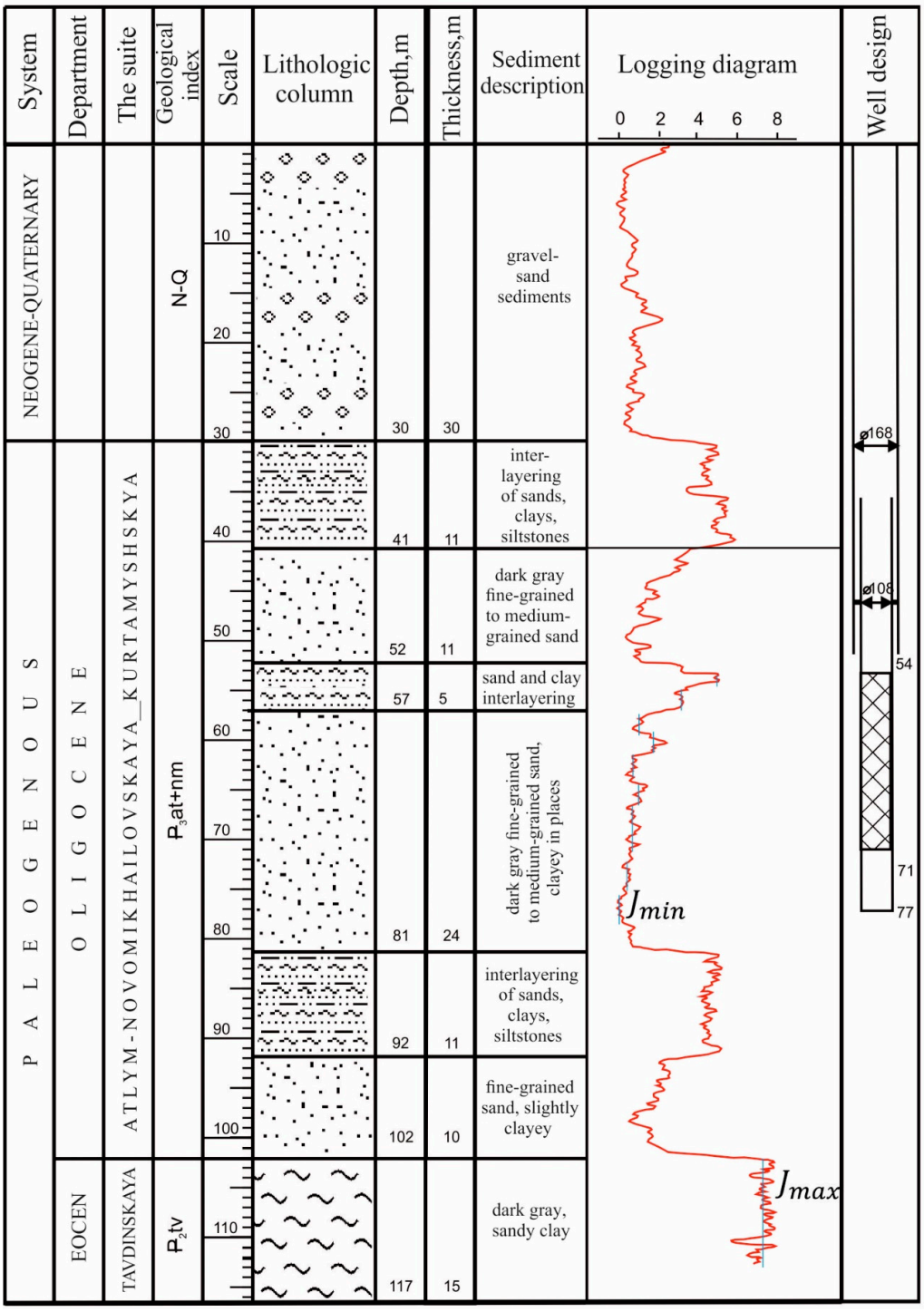


Figure 10. Averaged geological and technical column of the study area.

At the moment, there is no negative impact on water quality from increased water withdrawal. However, it is necessary to control water composition and risks of groundwater contamination of the feeding Neogene-Quaternary horizon. Since the contamination of waters of the Neogene-Quaternary horizon, taking into account the existence of a single hydraulic system, the "Neogene-Quaternary aquifer—Oligocene aquifer" can negatively affect the water quality of the target horizon.

3.3. Stability of Hydrogeochemical Conditions

Figure 11 shows the map of hydrogeochemical types of groundwater of Oligocene horizon from west to east of the study area there is a change in basic water composition from calcium hydrocarbonate to sodium hydrocarbonate type.

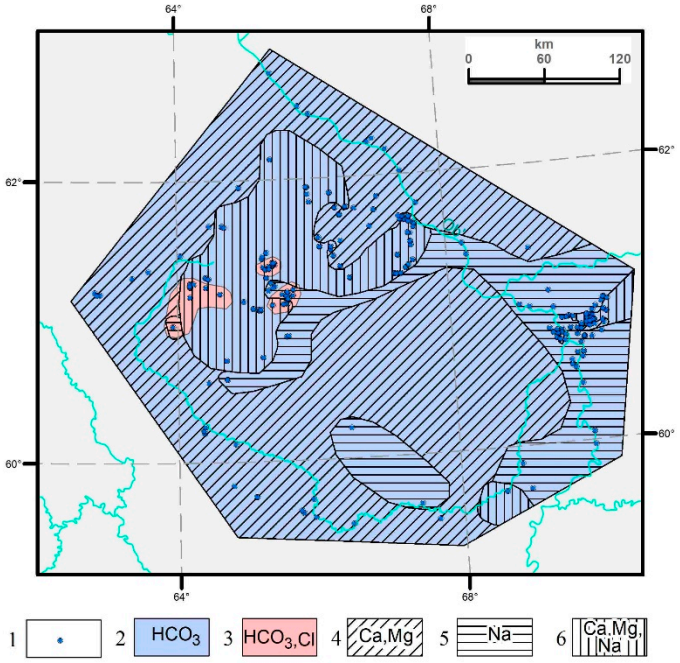


Figure 11. Hydrogeochemical maps of the Oligocene aquifer by state: 1—hydrogeochemical water type assessment area; 2—hydrocarbonate water type; 3—anion-mixed water type; 4—calcium- and magnesium-dominated waters in cation composition; 5—sodium-dominated waters in cation composition; 6—cation-mixed water type.

At the same time, there are areas of mixed anion water type, characterized by the presence of significant amounts of hydrocarbonate-ion and chlorine-ion, which may also be associated with an increase in water withdrawal and pulling up of waters with increased salinity "from below" in places of sandstone underlying the Tavda horizon. Due to the fact that the underlying sediments of the Oligocene aquifer were formed in marine conditions (Figure 12), in the regional plan in the Tavda horizon there are water types of sodium chloride–hydrocarbonate water with mineralization 0.8–1.2 g/dm^3, sodium chloride water with mineralization 1–1.5 g/dm^3, characterized by increased sodium-chlorine genetic coefficient.

Thus, intensification of water withdrawal can lead to potential pulling of water of increased mineralization from the Tavda horizon. The danger of their occurrence in the Oligocene horizon under study is associated with the possible interaction of lignified water-bearing rocks of the horizon of continental genesis with waters of increased mineralization, which was discussed above in the description of paleogeographic conditions, which in turn may cause an increase in mineralization and deterioration of such indicators of fresh groundwater quality as, for example, color. Similar cases of extreme color increase (up to 300 degrees and more) of groundwater of the Oligocene horizon for the described reasons have already been recorded in the central part of Western Siberia [4,12,18,21,31]. The single detection of groundwater samples with extreme mineralization attracts attention (Table 1), which possibly indicates the existence of the described processes in the study area.

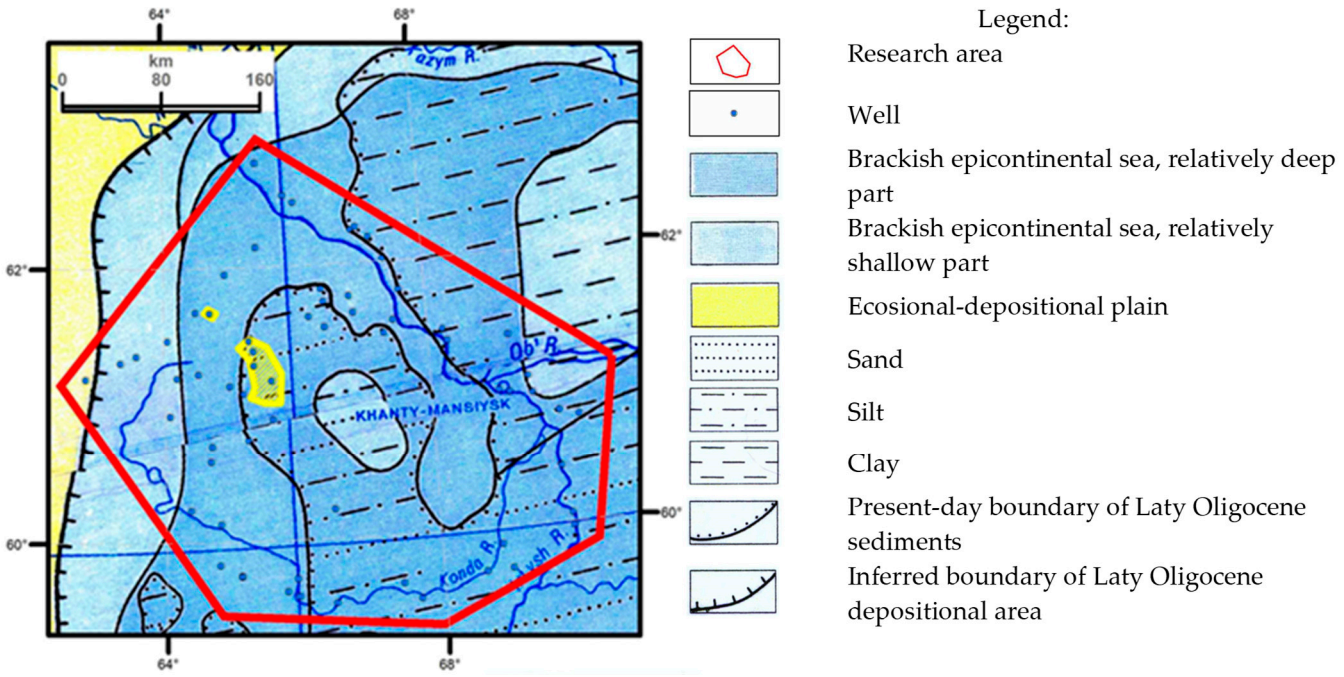


Figure 12. Paleogeographic map of the formation of the underlying sediments of the Oligocene aquifer complex [55].

In this territory, the issues of monitoring, taking into account the complex condition of groundwater for drinking purposes, accurate forecasting of its changes and maintenance of stability are of great importance [56].

4. Conclusions

Data on chemical groundwater of drinking water from the Oligocene aquifer in Shaimsky district allowed to identify 2 groups of samples: fresh with mineralization value of 39–924 mg/dm^3 (1216 samples) and brackish with mineralization value of 1085–3572 mg/dm^3 (33 samples), which are classified as extreme values requiring increased attention of subsoil users.

The analysis of geological structure, relative content of feldspars in the material composition of sands of the Oligocene horizon, silicon concentration in groundwater of the Oligocene aquifer and total iron in groundwater corresponds to the growth of mineralization from west to east, in the direction of general dipping of the sedimentary cover and the corresponding increase in the contact of water with the mineral part of rocks. The described conditions correspond to the general regional regularities of the Oligocene aquifer of the West Siberian megabasin.

Studies of the influence of water withdrawal on the mineralization of the Oligocene horizon carried out at two cluster water intake sites showed the influence of the recharge process from the overlying Neogene-Quaternary horizon with increasing water withdrawal. Taking into account that, at the first site, water withdrawal is rather high initially (up to 5.5 thousand m^3/day), and at the second site it is lower (up to 2.2 thousand m^3/day), at the second site there are two periods of mineralization parameter change—firstly, growth due to the Oligocene aquifer elastic reserves depletion, and further—in the II period (as water withdrawal grows)—decrease due to mixing of more fresh waters of the Oligocene-Quaternary complex coming from above. At the first site, the process of water pulling up goes on during the whole observation period.

The presence of recorded areas of mixed anionic composition (chloride and hydrocarbonate) in the Oligocene aquifer indicates the need for careful monitoring of groundwater

due to the danger of more mineralized water inflow from the underlying Tavda horizon and possible subsequent deterioration of drinking groundwater quality due to interaction with lignified water-bearing rocks of the studied horizon of continental genesis. This possibility is underlined by the detection of samples with extreme values of mineralization 1085–3572 mg/dm^3.

Based on the knowledge gained from this study, it is recommended to study the equilibrium conditions in the water–rock system and factor statistical analysis of the formation of groundwater chemical composition. This study represents the initial stage of consideration of factors influencing the chemical composition of groundwater and sets the direction for further detailed consideration of hydrogeochemical processes in the water–rock system under technogenic influence. For a more accurate understanding of the genesis of individual groups of groundwater, a detailed analysis of the ratios of the main ions, calculation of the equilibrium of groundwater with carbonates and aluminosilicates, factor statistical analysis and a more detailed study of the effect of the technogenic factor on the chemical composition are planned.

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

References

1. Wu, Y.Z.; Pan, C.F.; Lin, Y.; Cao, F.L.; Wang, Z.J. Hydrogeochemical characteristics and controlling factors of main water filled aquifers in the typical North China coalfield. *Bull. Geol. Sci. Technol.* **2018**, *37*, 191–199. [CrossRef]
2. Zektser, I.S. *Groundwater Flow and Fresh Groundwater Resources*; Scientific World: Moscow, Russia, 2012.
3. Shiklomanov, I.A.; Babkin, V.I.; Nikiforova, I.A. *Water Resources of Russia and Their Use*; Shiklomanov, I.A., Ed.; State Hydrological Institute: St. Petersburg, Russia, 2008.
4. Vashurina, M.V.; Rusakova, Y.O.; Khramtsova, A.L. Chemical composition of fresh groundwater in natural and disturbed states in the central part of the Vartovsky oil and gas region. *Geol. Geophys. Devel. Oil Gas Fields* **2020**, *4*, 58–64. [CrossRef]
5. Yuan, H.; Yang, S.; Wang, B. Hydrochemistry characteristics of groundwater with the influence of spatial variability and water flow in Hetao Irrigation District, China. *Environ. Sci. Pollut. Res.* **2022**, *29*, 71150–71164. [CrossRef]
6. Fekete, A. Natural Hazards and Climate Change Impacts on Food Security and Rural—Urban Livelihoods in Mozambique—A Bibliometric Analysis and Framework. *Earth* **2024**, *5*, 761–783. [CrossRef]
7. Xiao, J.; Lv, G.; Chai, N.; Hu, J.; Jin, Z. Hydrochemistry and source apportionment of boron, sulfate, and nitrate in the Fen River, a typical loess covered area in the eastern Chinese Loess Plateau. *Environ. Res.* **2022**, *206*, 112570. [CrossRef]
8. Ebrahim, G.Y.; Taye, M.T.; Seid, A.; Tekleab, S. Enhancing smallholder agricultural production through sustainable use of shallow groundwater in the Borkena catchment, Awash River Basin, Ethiopia. *Hydrol. Res.* **2024**, *55*, 1014–1029. [CrossRef]
9. Saravani, M.J.; Saadatpour, M.; Shahvaran, A.R. A web GIS based integrated water resources assessment tool for Javeh Reservoir. *Expert Syst. Appl.* **2024**, *252*, 124198. [CrossRef]
10. Darwish, M.H.; Megahed, H.A.; Sayed, A.G.; Abdalla, O.; Scopa, A.; Hassan, S.H.A. Hydro-Geochemistry and Water Quality Index Assessment in the Dakhla Oasis, Egypt. *Hydrology* **2024**, *11*, 160. [CrossRef]

11. He, C.; Harden, C.P.; Liu, Y. Comparison of water resources management between China and the United States. *Geogr. Sustain.* **2020**, *1*, 98–108. [CrossRef]
12. Vashurina, M.V.; Rusakova, Y.O.; Khramtsova, A.L.; Timshanov, R.I. Study of the patterns of formation of the chemical composition of groundwater in the Atlym-Novomikhailovsky aquifer in the conditions of development of the central part of the Samotlor oil field using the principal component method. *Geol. Geophys. Devel. Oil Gas Fields* **2022**, *3*, 66–72. [CrossRef]
13. Singh, G.; Singh, J.; Wani, O.A.; Egbueri, J.C.; Agbasi, J.C. Assessment of groundwater suitability for sustainable irrigation: A comprehensive study using indexical, statistical, and machine learning approaches. *Groundw. Sustain. Devel.* **2024**, *24*, 101059. [CrossRef]
14. Petio, P.; Liso, I.S.; Pastore, N.; Pagliarulo, P.; Refice, A.; Parise, M.; Mastronuzzi, G.; Caldara, M.A.; Capolongo, D. Application of Hydrological and Hydrogeological Models for Evaluating Groundwater Budget in a Shallow Aquifer in a Semi-Arid Region Under Three Pumping Rate Scenarios (Tavoliere di Puglia, Italy). *Water* **2024**, *16*, 3253. [CrossRef]
15. Rodriguez, M.; Ohlanders, N.; Pellicciotti, F.; Williams, M.W.; McPhee, J. Estimating runoff from a glacierized catchment using natural tracers in the semi-arid Andes cordillera. *Hydrol. Processes* **2016**, *30*, 3609–3626. [CrossRef]
16. Tran, D.A.; Tsujimura, M.; Vo, L.P.; Nguyen, V.T.; Nguyen, L.D.; Dang, T.D. Stable isotope characteristics of water resources in the coastal area of the Vietnamese Mekong Delta. *Isot. Environ. Health Stud.* **2019**, *55*, 566–587. [CrossRef]
17. Beshentsev, V.A.; Ponomarev, A.A. Formation of technogenic hydrogeological systems on the territory of the Yamalo-Nenets Autonomous Okrug. *Geoecol. Eng. Geol. Hydrogeol. Geocryol.* **2009**, *2*, 123–135.
18. Vashurina, M.V.; Rusakova, Y.O.; Khramtsova, A.A. Chemical composition of fresh groundwater in natural and disturbed states in the southwestern part of Khanty-Mansi Autonomous Okrug-Yugra. *Geol. Geophys. Devel. Oil Gas Fields* **2018**, *7*, 44–51.
19. Matusevich, V.M.; Rylkov, A.M.; Rylkov, A.V.; Ushatinskiy, I.N. *Geofluidal Systems and Problems of Oil and Gas Bearing Capacity of West Siberian Megabasin*; Tyumen Industrial University Press: Tyumen, Russia, 2005.
20. Gulyaeva, Y.V.; Koviatkina, L.A.; Kurchikov, A.R.; Trofimova, N.S. Ecological and hydrogeological problems of the Oligocene-Quaternary complex of the West Siberian mega-basin. In Proceedings of the XXIII All-Russian Conference on Groundwater in the East of Russia with International Participation. Irkutsk, Underground Hydrosphere, Irkutsk, Russia, 20–26 June 2021; pp. 458–462. [CrossRef]
21. Bespalova, Y.V.; Matusevich, V.M.; Popov, V.K.; Kuzevanov, K.I. Assessment of fresh groundwater vulnerability to contamination caused by production operations in oil and gas fields of Nizhnevartovsk Region (Western Siberia). *IOP Conf. Ser. Earth Environ. Sci.* **2016**, *43*, 012033. [CrossRef]
22. Vashurina, M.V.; Rusakova, Y.O.; Khramtsova, A.L. Study of the state of fresh groundwater in the conditions of development of oil fields in the southwestern part of the Tomsk region. *Geol. Geophys. Devel. Oil Gas Fields* **2020**, *8*, 64–73. [CrossRef]
23. Lin, M.; Biswas, A.; Bennett, E.M. Spatio-temporal dynamics of groundwater storage changes in the Yellow River Basin. *J. Environ. Manag.* **2019**, *235*, 84–95. [CrossRef]
24. Custodio, E. Custodio. Aquifer overexploitation: What does it mean? *Hydrogeol. J.* **2002**, *10*, 254–277. [CrossRef]
25. Monir, M.M.; Sarker, S.C.; Islam, A.R.M.T. A critical review on groundwater level depletion monitoring based on GIS and data-driven models: Global perspectives and future challenges. *HydroResearch* **2024**, *7*, 285–300. [CrossRef]
26. Shvartsev, S.L. Geochemistry of fresh groundwater in the main landscape zones of the Earth. *Geochem. Int.* **2008**, *46*, 1285–1398. [CrossRef]
27. Smolentsev, Y.K. Composition of drinking groundwater of the West Siberian megabasin as a biohydrogeochemical factor of endemic diseases of the population. In *Hydrogeological and Engineering-Geological Conditions for the Development of Western Siberia: Interuniversity Collection of Scientific Papers*; TyumII: Tyumen, Russia, 1991; pp. 63–75.
28. Nudner, V.A. *Hydrogeology of the USSR Volume XVI West Siberian Plain*; Nedra: Moscow, Russia, 1970.
29. Salnikova, Y.I.; Abdrashitova, R.N.; Semenova, T.V. *Plaeohydrogeology*; Industrial University of Tyumen: Tyumen, Russia, 2022.
30. Kurchikov, A.R.; Vashurina, M.V. Aspects of environmental safety during the operation of fresh groundwater intakes in oil fields of Western Siberia. *News High. Educ. Inst. Oil Gas* **2016**, *1*, 21–27.
31. Vashurina, M.V.; Rusakova, Y.O.; Khramtsova, A.L. Study of the state of fresh groundwater under conditions of intensive development of the Krasnoleninskoye field. *Geol. Geophys. Devel. Oil Gas Fields* **2019**, *11*, 51–59.
32. Borevsky, B.V.; Garayeva, T.V.; Zubanova, T.N.; Kurenoy, V.V.; Oliferova, O.A.; Palkin, S.S.; Palkin, S.V.; Prosekov, A.M.; Seleznev, V.S.; Skvortsova, G.A.; et al. Map Resource Capacity of Russia's Resources. Available online: https://www.hydrogeoecology.ru/index.php/biblioteka-gidek/karta-resursnogo-potentsiala-presnykh-podzemnykh-vod-rossii (accessed on 10 November 2024).
33. Maloletko, A.M. *Evolution of River Systems of Western Siberia in the Mesozoic and Cenozoic*; Tomsk State University: Tomsk, Russia, 2008.
34. Ananyev, S.A.; Noskov, I.V.; Noskov, K.I. Development of the territory of the central part of the West Siberian Plain in Oligocene-Quaternary time. *Bull. Euras. Sci.* **2021**, *13*, 1.
35. Kayukova, E.P.; Baraboshkina, T.A.; Filimonova, E.A. The Hydrogeochemical Features of Groundwater of the Bodrak River Basin, Kacha Uplift of Mountainous Crimea. *Moscow Univ. Geol. Bull.* **2020**, *75*, 506–514. [CrossRef]
36. Limantseva, O.A.; Ryzhenko, B.N.; Shvarov, Y.V. Influence of Water Exchange on the Equilibrium Composition of Aqueous Phase and Mineral Association. In *Advances in Geochemistry, Analytical Chemistry, and Planetary Sciences*; Springer: Cham, Switzerland, 2023; pp. 187–192. [CrossRef]

37. Musin, R.K.; Kalkamanova, Z.G. The formation of the underground water in the upper part of hydrolithosphere in the Vostochno-Zakamsky region of Tatarstan (Russian). *Oil Ind. J.* **2016**, *2*, 18–22.
38. Swain, S.; Sahoo, S.; Taloor, A.K. Groundwater quality assessment using geospatial and statistical approaches over Faridabad and Gurgaon districts of National Capital Region, India. *Appl. Water Sci.* **2022**, *12*, 75. [CrossRef]
39. Sidhu, B.S.; Sharda, R.; Singh, S. Spatio-temporal assessment of groundwater depletion in Punjab, India. *Groundw. Sustain. Dev.* **2021**, *12*, 100498. [CrossRef]
40. Kurchikov, A.R.; Plavnik, A.G.; Itskovich, M.V. Quasi-three-dimensional modelling of the Jurassic-Cretaceous sediments hydrogeochemical conditions in the central part of the West Siberian megabasin. *Appl. Geochem.* **2019**, *110*, 104433. [CrossRef]
41. Plavnik, A.G.; Sidorov, A.A. Construction of compositional geological and structural models within the framework of the variational grid method of geomapping and the object-hierarchical approach. *Bull. Tyumen State Univ. Phys. Math. Model. Oil Gas Energy* **2024**, *10*, 88–103. [CrossRef]
42. Shpilman, A.V. *Atlas of Geology and Oil-and-Gas Bearing Capacity of Khanty-Mansiysk Autonomous District*; Shpilman National Research Centre: Khanty-Mansiysk, Russia, 2004.
43. Fetter, C.W. *Applied Hydrogeology: University Textbook*; Macmillian College Publishing: London, UK, 2001.
44. McMahon, P.B.; Galloway, J.M.; Hunt, A.G.; Belitz, K.; Jurgens, B.C.; Johnson, T.D. Geochemistry and age of groundwater in the Williston Basin, USA: Assessing potential effects of shale-oil production on groundwater quality. *Appl. Geochem.* **2021**, *125*, 104833. [CrossRef]
45. Kraynov, S.R.; Ryzhenko, B.N.; Shvets, V.M. *Geochemistry of Groundwater*; Theoretical, Applied and Ecological Aspects; CentreLit-NefteGas: Moscow, Russia, 2012.
46. Rajmohan, N.; Elango, L. Identification and evolution of hydrogeochemical processes in the groundwater environment in an area of the Palar and Cheyyar River Basins, Southern India. *Environ. Geol.* **2004**, *46*, 47–61. [CrossRef]
47. Bodrud-Doza, M.; Bhuiyan, M.A.H.; Didar-Ul Islam, S.M.; Safiur Rahman, M.; Haque, M.; Konica, J.F.; Nasir, A.; Rakib, M.A.; Rahman, A. Hydrogeochemical investigation of groundwater in Dhaka City of Bangladesh using GIS and multivariate statistical techniques. *Groundw. Sustain. Devel.* **2019**, *8*, 226–244. [CrossRef]
48. Eaton, T.T. On the importance of geological heterogeneity for flow simulation. *Sedim. Geol.* **2006**, *184*, 187–201. [CrossRef]
49. Alekin, A.O. *Fundamentals of Hydrochemistry*; Hydrometeorological Publishing House: Leningrad, Russia, 1970.
50. Shvartsev, S.L. *Hydrogeochemistry of the Hypergenesis Zone*; Nedra: Moscow, Russia, 1998.
51. Hoque, M.A.; Hoque, M.M.; Ahmed, K.M. Declining groundwater level and aquifer dewatering in Dhaka metropolitan area, Bangladesh: Causes and quantification. *Hydrogeol. J.* **2007**, *15*, 1523–1534. [CrossRef]
52. Knappett, P.S.K.; Li, Y.; Hernandez, H.; Rodriguez, R.; Aviles, M.; Deng, C.; Piña, V.; Giardino, J.R.; Mahlknecht, J.; Datta, S. Changing recharge pathways within an intensively pumped aquifer with high fluoride concentrations in Central Mexico. *Sci. Total Environ.* **2018**, *622*, 1029–1045. [CrossRef]
53. Akhter, S.; Hossain, M.S. Groundwater modelling of Dhaka City and surrounding areas and evaluation of the effect of artificial recharge to aquifers. *World J. Res. Rev.* **2017**, *5*, 54–60.
54. Stenvik, L.A.; Hilmo, B.O.; Frengstad, B.S. Elevated manganese concentrations in groundwater wells after longtime abstraction with bank filtration: Developing and testing of a sorption model for Ringerike waterworks, Norway. *Hydrogeol. J.* **2022**, *30*, 2059–2071. [CrossRef]
55. Babushkin, A.E.; Devyatov, V.P.; Grigor'yev, N.V.; Gurari, F.G.; Kazakov, A.M.; Shatskiy, S.B.; Smirnov, L.V.; Surkov, V.S. *Atlas of Paleotectonic and Paleogeologicial-Landscape Maps of Hydrocarbon Provinces of Siberia: West Siberia in Late Oligocene*; SNIIG-GIMS: Novosibirsk, Russia, 1995.
56. Al-Ruwaih, F.M.; Qabazard, H.A. Aquifer characteristics and water quality of Miocene—Pleistocene sediments, Kuwait. *Bull. Eng. Geol. Environ.* **2005**, *64*, 175–191. [CrossRef]

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