Assessment of the State of the Hydrosphere in the Zone of Development of Oil Fields of the Western Orenburg Region

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Abstract The Orenburg region occupies one of the first places in the Russian Federation in terms of natural resources. More than 180 deposits of a wide variety of ores, oil, gas, and mineral raw materials have been explored on its territory. Strengthening in recent years of mining and processing of minerals, lead to an increase in the anthropogenic load on the underground hydrosphere and its main component–groundwater. Technogenic impact causes a change in the quality of groundwater and the depletion of their reserves. The purpose of this study is to assess the state of groundwater in the area of intensive development of the Kurmanaevskoye and Shulaevskoye oil fields, based on the study of the results of regime observations on observational networks of these fields. It was revealed that there are excesses of such indicators of the chemical composition of groundwater as: iron, manganese, oil products and chlorides. It is recommended to expand the groundwater monitoring network, modernize production with its transfer to low-waste technologies, conduct territorial planning when placing productive forces and production facilities.

Keywords Hydrosphere · Groundwater · Mineralization · Oil fields

1 Introduction

Oil production is accompanied by a complex and negative impact on the ecosystem as a whole and on its individual components, since there are no such technologies for prospecting, exploration and production of hydrocarbon raw materials at the present stage of development of science and technology that would not have a negative impact on the geosphere (Kudelina 2019a; Leontieva 2018).

The negative technogenic impact on the environment depends on the following factors: features of the geological structure, development method, qualitative composition of oil and gas, equipment of oilfield equipment, its condition, intensity of

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production of formation fluids, associated changes in formation pressure, volumes of pollutant emissions, degree of stability components of the natural environment, etc. (Kudelina 2019b; Kudelina 2021).

The volumes of production and processing of oil and gas have been increasing in recent years, which leads to an increase in the technogenic load on the hydrosphere and its main component–groundwater. These impacts cause changes in the quality of groundwater, including pollution and depletion of their reserves (Khusainova and Leontieva 2020; Ecological state of the hydrosphere of the Buzuluk pine forest 2022).

Given the critical role of groundwater, primarily for domestic drinking water supply of the population, their close relationship with other components of the natural environment, it is necessary to study the state of groundwater, their qualitative and quantitative characteristics on the basis of a single State concept, which provides for mandatory pairing with the monitoring system of other components of the natural environment (Kudelina 2021; Klimenko 2019).

The purpose of this study is to assess the state of groundwater in the area of intensive development of the Kurmanaevsky and Shulaevsky oil fields in the Western Orenburg region, based on the study of the results of regime observations on the observation networks of these fields.

2 Results and Discussions

The most environmentally significant impact during mining is the pollution of environmental components with oil, oil products and highly mineralized waters. According to expert estimates, up to 0.5% of all produced crude oil is lost in the oil fields.

The exploitation of deposits leads to the formation of the following main types of waste: reservoir wastewater; associated petroleum gas; oily sludge from tank cleaning; domestic waste water; surface sewage; construction waste (Khusainova and Leontieva 2020; Klimenko 2019; Sanitary rules and regulations 2001).

Measures to protect the geological environment are to preserve the natural regime of ground and groundwater, reduce pollution of rocks in the aeration zone. Groundwater is the most mobile component of the subsoil and is the first to respond to technogenic changes. The creation and maintenance of local monitoring of groundwater and surface water at the Kurmanaevskoye and Shulaevskoye oil fields is the receipt of prompt and timely information about negative trends and changes.

3 Kurmanaevskoye Oil Field

In the area of the Kurmanaevskoye oil field, the aeration zone is subject to pollution, represented by an anhydrous permeable Quaternary alluvial-deluvial horizon (adQ), the first Upper Pleistocene-Holocene alluvial horizon from the surface (aQIII-H) and the main aquiferous Lower Triassic complex (T1), which is widespread and mainly economically–drinking value. Observations are organized for these aquifers and complexes (Analysis of the development of the Kurmanaevsky oil field in the Orenburg region 2005; Report on the results of work on the creation of a regime network of observation wells on the territory of the Shulaevskoye oil field 2003; Gatskov 1999).

Anhydrous permeable Quaternary alluvial-deluvial horizon (adQ)

Five observation wells have been equipped for this horizon. According to the chemical composition, groundwater is mixed with a mineralization of 1.7 mg/dm^3. Of the microcomponents, a significant excess of the norm was observed for iron − 1.95 mg/dm^3 (at MPC-0.3 mg/dm^3) and bromine −1.20 mg/dm^3 (at MPC-0.2 mg/dm^3), oil products were found in insignificant quantity −0.37 mg/dm^3 (at MPC-0.1 mg/dm^3).

In all observation wells, an excess of dry residue from 1.2 MPC to 3 MPC (from 1213 mg/dm^3 to 3014 mg/dm^3) was found at MPC-1000 mg/dm^3. The chemical composition of water is bicarbonate-calcium, and in a separate well, where an increased mineralization (from 1299 to 1622 g/dm^3) is noted, underground water is hydrocarbonate-chloride magnesium-calcium. With an increase in mineralization, the content of calcium and magnesium increases, respectively, the hardness of the underground water of the considered aquifer increases. This well is located in a zone of increased man-made load, downstream from the central pumping station and the commodity park, and, apparently, the recorded pollution is associated with this.

In some wells, the excess of manganese content can be traced from 0.22 to 1.46 mg/dm3 (at MPC 0.1).

In all wells, the content of turbidity and color is recorded from 3.4 to 57.0 mg/l (at MPC 1.5), which may either be the result of poor pumping before sampling, which cannot be done due to the small water column in shallow wells, or is the result of the oxidation of ferrous iron, the content of which exceeds the MPC. The latter may be due to the natural background.

Exceeding the MPC for salinity and water hardness by 1.5–2.3 times may be the result of anthropogenic impact. The increase in hardness is observed mainly due to an increase in the calcium content in underground water, respectively, the removable hardness increases. In accordance with the general requirements for the composition and properties of water in water bodies, the pH value should not go beyond the range of 6.5–8.5. The pH value in the water of the evaluated wells varies from 7.2 to 8.14. The waters are neutral.

Aquifer Upper Neopleistocene-Holocene alluvial horizon (aQIII -H) is distributed mainly in the valley of the Buzuluk river within the low, high floodplain and in the valley of the Tarpanovka river (right tributary of the Buzuluk river), as well as in the mouths of numerous ravines and dens, in a ravine-beam network.

Monitoring wells of the regime network are also equipped for this aquifer. Water-bearing rocks are fine-grained, fractional sands, with the inclusion of gravel-pebble and sand-gravel deposits. The thickness of the water-bearing rocks is 10.0–15.0 m. The waters are free-flowing.

According to the chemical composition, underground waters are variegated, along with hydrocarbonate waters, there were hydrocarbonate-sulfate, hydrocarbonate-chloride and mixed waters. Of the cations, sodium and calcium ions predominate. Mineralization of underground waters is 0.3–0.8 g/dm^3 and in isolated cases exceeds 1.0 g/dm^3. In the observation well, located downstream from the booster pumping station (BPS), the water salinity was 1.2 g/dm^3. In terms of water hardness, they are mostly moderately hard, and in the well near the CPS, the water is very hard–14.8 mmol/dm^3 (at MPC–7 mmol/dm^3). Of the microcomponents, the excess of the norm is recorded for iron from 1.92 to 6.50 mg/dm^3 (at MPC–0.3 mg/dm^3), manganese from 0.43 to 1.11 mg/dm^3) and bromine from 0.21 to 1.0 mg/dm^3 (with MPC–0.2 mg/dm^3), the total hardness varies from 2.36 to 14.8 mmol/dm^3, most often it was 3.0–4.0 mmol/dm^3.

Exceeding the MPC for salinity and hardness of underground water by 1.5–2.3 times in some wells may be a consequence of anthropogenic impact. These wells are located in the zone of increased technogenic load, downstream from the booster pumping station (BPS) and, probably, the pollution of the observed aquifer is associated with this. So the content of oil products in almost all samples in these wells is above the permissible limits of MPC, from 0.15 to 0.36 mg/dm^3. The content of iron and manganese in underground water varies from 1.5 to 12.8 MPC, which may be the result of poor pumping before sampling or is a natural background.

The excess in turbidity and color is recorded for all wells of the monitoring network of observation wells of the Kurmanaevskoye oil field, which may be the result of poor pumping before sampling.

The aquiferous Lower Triassic complex (T1) is ubiquitous in the area of the described deposit. Depending on the depth of immersion, it is the second or third aquifer from the surface.

The water-bearing complex was tested by monitoring wells of the regime network. The depth of the wells is 85.0 m.

In groundwater, there is an increased content of oil products in individual wells from 0.16 to 0.5 mg/dm^3 at MPC 0.1 mg/dm^3, an increased content of iron from 0.59 to 1.37 mg/dm^3 at MPC-0.3 mg/dm^3, increased content of dry residue 2839 mg/dm^3 at MPC 1000 mg/dm^3. With increased mineralization, the chemical composition of underground water is hydrocarbonate-chloride magnesium-calcium. With an increase in mineralization, the content of calcium and magnesium increases and, accordingly, the hardness of the water increases, which is 33.5 mg-eq /dm^3 and the water is characterized as very hard. Exceeding the MPC for salinity and water hardness by 1.5–2.3 times may be the result of anthropogenic impact, and it is in those observation wells where the development of neighboring oil fields affects. These observation wells were drilled by the project as background wells to control the qualitative composition of groundwater from the possible impact of the development of the Bobrovsky and Shulayevsky oil fields.

The described water-bearing complex is the most promising for the organization of both household and drinking and technical water supply of the field. In erosion incisions, that is, where the complex occurs close to the day surface, it can be used for drinking water supply in its upper and middle parts. In the lower parts of the water-bearing complex, where the salinity increases above 1.0 g/dm^3, it is recommended for use for technical water supply.

In the process of further activities, it is necessary to control the limit of the use of drinking water and technical quality and forecast the development of possible pollution and depletion of groundwater.

An analysis of the quality of drinking water in rural settlements of the Kurmanaevsky district revealed an excess of the standards for such indicators as total hardness, iron, oil products, ammonia, and copper.

So, in s. Romashkino exceeded the standards for total hardness (1.56–8 MPC,), in the village of Kurmanaevka for ammonia nitrogen (2.1 MPC) and oil products (5.1 MPC). Exceeding the MPC standards for domestic and drinking water supply in terms of total hardness is noted in the villages of Semenovka (1.1–1.3 MPC), Petrovka- (1.1–1.2 MPC), Danilovka - (1.4 MPC) and Volzhsky (1.0–1,3 MPC).

Exceeding the standards for iron was noted in the villages of Petrovka (3.4–6.1 MPC) and Kandaurovka (1.4–3.3 MPC), for copper–in the village. Volzhsky (3.5 MPC), total mineralization–in the village. Danilovka (1.3 MPC). All excess components can be influenced not only by the Kurmanaevskoye field, but also by other nearby oil fields.

To assess the current state of surface waters, the results of departmental monitoring in the area of the Kurmanaevskoye field on the Buzuluk River (2 sampling points: before the field and after the field) and Tarpanovka (1 point within the field) were used. Water samples were taken monthly and examined for a number of indicators standardized by SanPiN 2.1.5.980–00 “Hygienic requirements for the protection of surface waters”. The quality of water bodies was assessed by general chemical analysis and oil products.

According to the results of the analyzes, the chemical composition of the water in the river. Buzuluk hydrocarbonate magnesium-calcium, calcium-magnesium. Fresh water–dry residue is 586–917 mg/dm^3. In terms of total hardness, which varies within the range of 5.1–8.24 mg-eq/dm^3, water is moderately hard and hard. The active reaction of the medium is slightly alkaline (pH 7.7–8.43). The content of oil products is mainly contained within the MPC for fishery rivers (0.5 mg/dm^3) or not found in water samples, in isolated cases the excess of oil products is 1.6–2.8 MPC.

According to the results of analyzes, the water in the Tarpanovka River is fresh with water salinity from 596–831 to 1004–1286 mg/dm^3. According to the chemical composition, the water is sulfate-hydrocarbonate chloride-hydrocarbonate, according to cations, mainly calcium-magnesium. The pH value in the water is within the normal range. The waters can be classified as neutral and slightly alkaline (pH 6.94–8.36). The total hardness of water varies within 4.1–12.0 mg-eq/dm^3–water from moderately hard to very hard. The content of oil products is within the MPC or not detected. As a result of consideration and analysis of the content of chemicals in the surface waters of rivers, according to monitoring studies, it can be concluded that the composition of water in the rivers of the Kurmanaevskoye field corresponds to the original natural composition.

Water pollution in reservoirs in the Kurmanaevsky district is mainly due to runoff from agricultural fields and discharges from livestock farms. These pollutions are seasonal and occur mainly during the warm season.

The results of laboratory monitoring of water in reservoirs on the territory of the Kurmanaevskoye oil field indicate the absence of samples exceeding sanitary standards, both in terms of bacteriological and chemical indicators, it does not exceed the MPC.

Shulaevskoye oil field. The object of observation in the analysis of the qualitative composition of groundwater is the Lower Triassic aquifer complex, the first from the surface (Report on the results of work on the creation of a regime network of observation wells on the territory of the Shulaevskoye oil field 2003). Within the field there is an observation network of 10 wells for the aquiferous Lower Triassic complex. Well depth–from 50.0 to 202.9 m.

The upper interval of the Lower Triassic aquifer is exposed and observed by wells with a depth of 50.0–60.0 m. The chemical composition of groundwater is varied–from sulfate-hydrocarbonate and mixed with a mineralization of 0.6 g/dm 0.3 to 1.6 g/dm^3. By cations, the water is mixed and calcium-magnesium. Exceedances of MPC were noted for dry residue and total stiffness in a well located near an oil well, for oil products and oxidizability in a well located in the BPS area.

The quality of groundwater in the upper part of the complex does not meet the requirements of SanPiN 2.1.4.1074–01 "Drinking water ...." in all wells, perhaps this is due to the anthropogenic factor in the formation of the chemical composition (Sanitary rules and regulations 2001; Koronkevich 2022). Dry residue, chlorides, hardness in individual observation wells. Also, excesses were noted for color, turbidity and iron in observation wells.

The color of groundwater refers to normalized physical properties, the definition of which is required by regulatory documents. Color is a secondary organoleptic indicator of groundwater quality and cannot be formed without certain geochemical processes. The formation of increased color of groundwater is possible when they are contaminated with micro-amounts of specific organic compounds (Maskooni et al. 2020; Ushakova et al. 2021). An increased color of groundwater is also possible with an increased concentration of ferrous iron.

The turbidity index also refers to the normalized physical properties of groundwater. The turbidity of groundwater is formed in the same way as the color in cases where they contain suspended, colloidal particles. The amount of turbidity depends on the amount of suspended particles, a large content of which is in the water of an insufficiently pumped well. Therefore, before sampling water from observation wells, it is necessary to carry out pumping according to the existing method (Yu et al. 2021; Zakir et al. 2020).

At the Shulaevskoye field, there were no excesses for oil products in the upper aquifer at a depth of 50.0–60.0 m. Only in one observation well, at the date of drilling, the content of oil products was recorded–0.21 mg/dm^3 (at 0.1 MPC).

In the groundwater of the upper aquifer in an observation well with a depth of 50.0 m, the highest content of manganese was found; at MPC 0.1, the concentration of manganese was 1.29 mg/dm^3. Perhaps this is due to surface contamination and spillage of oily waters.

The presence of ammonium ions in amounts above the MPC was recorded in one sample in the interval of the observed aquifer at the date of drilling. Basically, in the groundwater of the interval under consideration, the ammonium content is below the MPC.

The average interval of the Lower Triassic aquifer was opened at a depth of 115.0 m. mixed calcium-magnesium with a mineralization of 0.6–0.9 g/dm^3. Exceeding the MPC of normalized components in terms of dry residue, chloride content, hardness in samples taken in the observed interval was not recorded.

The content of oil products above the MPC and ammonium in this water-bearing interval was observed in individual wells.

In the observed interval of the aquifer, as in all observation intervals, an increased content of color, turbidity, iron, and manganese was recorded.

An increased content of ammonium ions was recorded in observation wells, but in subsequent years, a decrease in the content of this component is observed in the interval of the observed aquifer.

The lower interval of the Lower Triassic aquifer was opened at a depth of 200.9 and 202.9 m, respectively. Underground waters are bicarbonate-chloride with a mineralization of 0.6–0.7 g/dm^3. No excesses of the MPC of normalized components were noted. The nature of the change in the content of iron, color, turbidity, manganese, hardness, oil products, ammonium in the observation well is almost identical to the content of these components of the second observation interval, and only by the content of chlorides and color are opposite.

In addition, observations of the quality of groundwater in the Lower Triassic aquifer complex are carried out at a spring located in the upper part of the Guryev ravine (near the uninhabited village of Shulaevka). According to the results of observations, the chemical composition of the water in the spring is hydrocarbonate calcium and chloride-hydrocarbonate calcium. The water is fresh with a mineralization value of 0.5–0.6 g/dm^3, very hard, the reaction of the aquatic environment is neutral (pH 6.47–7.21). Exceedances of MPC are noted in terms of color by 2.1 times, once the content of oil products exceeded the norm by 2 times. The data of the subsequent selection of excesses for oil products did not show.

4 Conclusions

Analyzing all the data of chemical analyzes, it can be noted that the water in most observation wells is fresh. The chemical composition of water in the wells is hydrocarbonate, hydrocarbonate-sulfate, chloride-hydrocarbonate, sodium predominates in the cationic composition. The water is soft to moderately hard. The reaction of the environment is most often neutral and slightly alkaline, less often alkaline. Exceedings of MPCs for oil products, ammonium nitrogen, and manganese were noted periodically.

Practically in all water samples from observation wells there is an increased content of iron, color and turbidity. Exceeding the MPC for color and turbidity is most likely due to insufficient well pumping before water sampling.

In observation wells located in the area of oil wells, an increase in dry residue is noted. According to the chemical composition, the water is bicarbonate-chloride and mixed with a predominance of chlorides, brackish, very hard.

In conclusion, we can say that objective information has been obtained on the impact of the economic activities of the oil production at the Kurmanaevsky and Shulayevsky oil fields on the environment. As a result of regime observations, the situation with the state of groundwater at these fields was revealed, priority indicators of pollution were reflected. A stable source of pollution in the groundwater of the main aquifer used for domestic and drinking water supply is temporary and is associated with oil production facilities.

Based on the analysis carried out, for further monitoring work, it is recommended to carry out repair work on all observation wells to continue local monitoring. It is necessary to expand the groundwater monitoring network, modernize oil production with its transfer to low-waste technologies, conduct territorial planning when placing productive forces and production facilities.

References

Analysis of the development of the Kurmanaevsky oil field in the Orenburg region (2005) CJSC Izhevsk Oil Research Center, Izhevsk, p 360

Ecological state of the hydrosphere of the Buzuluk pine forest; Kudelina IV, Leontieva TV, Fatyunina MV, Khusainova MF (2022) Problems of regional ecology, no 6, pp 55–59

Gatskov VG (1999) Assessment of the state of the natural environment on the territory of the enterprises of JSC "Orenburgneft"; Gatskov VG, Lukinykh EN (1999) Orenburg, p 267

Khusainova LF, Leontieva TV (2020) Prospecting and exploration for oil and gas; University complex as a regional center of education, science and culture: materials of All-Russia. Scientific method conference (with international participation), 23–25 Jan 2020, Orenburg, pp 940–943

Klimenko AV (2019) Associated petroleum gas and methods of its processing; Klimenko AV, Leonteva TV (2019) New directions of work on oil and gas, innovative technologies for the development of their deposits, prospects for the production of unconventional hydrocarbon raw materials: materials of Vseros. Scientific-practical conference; resp. Kolomoets AV (ed). Press Agency, Electron. Dan. - Orenburg, pp 40–42

Koronkevich NI (2022) Assessment of the impact of urbanization on the annual runoff and water quality in the world and on the continents; Koronkevich NI, Baranova EA, Zaitseva IS et al (2022) Izvestia of the Russian academy of sciences. Geogr Ser 86(3):470–480

Kudelina IV (2019) Influence of oil field development on the underground hydrosphere of the Orenburg region. Regional problems of geology, geography, technospheric and environmental safety: collection of articles. Proceedings of the scientific-practical conference, 18–20 Nov 2019, Orenburg; Ministry, pp 19–23

Kudelina IV (2019) To the methodology of hydrogeological research in the Southern Urals; Kudelina IV (2019) New directions of work on oil and gas, innovative technologies for the development of their fields, prospects for the extraction of non-traditional carbon raw materials: materials of Vseros. Scientific-practical conference; otv. Kolomoets AV (ed). Electron. Dan. Press Agency, Orenburg, pp 57–59

Kudelina IV (2021) Impact of the development of the Vakhitovskoye oil field on the underground hydrosphere. Int Res J 7(109):150–153. Part 1

Leontieva TV (2018) Issues of methods of hydrogeological research and substantiation of the possibility of replenishing groundwater reserves, no 2. Izvestia of universities in Kyrgyzstan, pp 14–17

Maskooni EK, Naseri-Rad M, Berndtsson R, Nakagawa K (2020) Use of heavy metal content and modified water quality index to assess groundwater quality in a semiarid area. Water 12:1115

Report on the results of work on the creation of a regime network of observation wells on the territory of the Shulaevskoye oil field (2003) Monitoring Regulations for 2004–2007 Rep. Use Levanina SS, Chechetkin TV. CJSC "Vostochnaya GRE". Orsk, p 236

Sanitary rules and regulations (2001) Drinking water. Hygienic requirements for water quality of centralized drinking water supply systems. Quality control" SanPiN 2.1.4.1074–01. Goskomsanepidnadzor of Russia, M, p 103

Ushakova E, Menshikova E, Karavaeva T, Puzik A (2021) Trace element distribution in the snow cover of different functional zones in Berezniki-Solikamskindustrial hub. Russia. J Ecol Eng T. 22(10):28–39

Yu L, Zhang F, Zang K, He L, Wan F, Liu H, Zhang X, Shi Z (2021) Potential ecological risk assessment of heavy metals in cultivated land basedon soil geochemical zoning: Yishui County, North China Case Study. Water 13:3322

Zakir HM, Sharmin S, Akter A, Rahman MS (2020) Assessment of health risk of heavy metals and water quality indices for irrigation and drinking suitability of waters: a case study of Jamalpur Sadar area, Bangladesh. Environ Adv 2:10000