Formation of the hydrochemical regime of Lake Zuratkul

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Abstract. The changes in the hydrochemical state of the water masses of the lake-reservoir Zuratkul for the period 1966 - 2018 are considered. on the concentration of the main water ions, nitrogen and phosphorus compounds, oxidability, some hydrophysical parameters (transparency, chromaticity). Conclusions about cyclical and evolutionary change of individual parameters and characteristics of water masses are made. Defined modern water quality in the reservoir.

1. Introduction
The highest mountain lake in the European part of the Russian Federation, Lake Zuratkul, is blocked by a dam and is a lake-type reservoir in the water regime. Human intervention in the water regime led to a restructuring of the morphometric and hydrochemical parameters of the reservoir, changes in water quality. The study of perennial changes in the main hydrochemical parameters of water masses made it possible to identify the directional and cyclical features of the formation of hydrochemical mode and quality of water. Research materials are of practical importance for monitoring and protection of the reservoir.

2. Materials and methods
Based on our own materials received in 2006–2007, 2013–2014, and 2018 and also with the involvement of materials from other researchers (data from the 1960s and 1990), fluctuations in the concentrations of various hydrochemical parameters of Lake Zuratkul for the period 1966 - 2018 were considered. (basic ions, trace elements, nutrients, organic matter). Sampling and observations were carried out using standard hydrological equipment in different seasons of the year, in two points of the water area: in the central zone (including the deep vertical) and near the dam. In 2014 and 2018, samples were taken from a nameless temporary watercourse flowing from the recreationally developed territory of Zuratkul village. Analysis of the taken samples was carried out in the laboratory of surface waters of the Chelyabinsk TsGMS - a branch of the Federal State Budgetary Institution “Ural UGMS” according to the certified procedures of the RD package.

3. Results and discussion
Lake Zuratkul reservoir is located in the national park "Zuratkul" in the southern part of the Satka municipal district of the Chelyabinsk region. The Bolshoi and Maly Kyl, Cherni Kyl, Ninny Kyl rivers (up to 20 small rivers and streams) flow into Lake Zuratkul, the Bolshaya Satka river flows out (tributary of the Ay river; the Kama river basin).

The coordinates of the central zone of the lake: 54°54′38″N, 59°12′40″E.
This was originally a small mountain lake (the highest in the European part of Russia; the absolute elevation above sea level 723.5 - 724.2 m) at the end of the 19th century was regulated by a dam, which was subsequently increased several times (1923-24 for the needs of timber rafting; 1942-49 - for the needs of hydropower). The lake turned into a reservoir (after 1978, with an unregulated spillway) (table 1). According to the morphogenetic classification, this reservoir belongs to the class of hollow, a subclass of lake-hollow lakes, morphologically simple [2].

**Table 1. Morphometric parameters of Lake Zyuratkul in different years.**

| Type of water object | Mirror area, km$^2$ | Volume of water mass, mln. m$^3$ | Depth maximum | Depth average |
|----------------------|--------------------|---------------------------------|---------------|--------------|
| Lake water reservoir [1] | 13.2               | 32.8                           | 4.2           | 2.5          |
| Lake water reservoir [5] | 13.2               | 80.0                           | 9.8           | 6.0          |
| Lake water reservoir [9] | 13.5               | 79.9                           | 12            | 5.9          |
| Lake [9] | about 6 | 7.2 | 1.7 | 1.2 |

The total lake catchment area is 178 km$^2$ [1]. According to the Google-Earth satellite image from 16.05. In 2016, the water surface area is 13.9 km$^2$, the coastline is 28.7 km. There are no islands. During our research 2013-2014 no depths greater than 10 m were found.

The lake is characterized by high intensity of water exchange, Kv, c = 1.0 – 1.5 [1]; The lake’s water mass can be renewed in 8 – 12 months. The inflow from the catchment is 76% of the input part of the water balance [8]. According to the classification by B. B. Bogoslovsky, the lake belongs to the low-flow (accumulative-transit, A-T2) reservoirs [7]. Lake Zyuratkul characterized by ultrafresh waters with a low (5.6 - 6.9) pH value, a high content of organic matter and total iron (table 2).

**Table 2. Average water mass of Lake Zyuratkul (1990 - 2018).**

| № | Indicator | Range | Value (av. value ± st.deviation) | Number of samples |
|---|-----------|-------|---------------------------------|-------------------|
| 1 | pH (surface waters) | 5.61 – 6.94 | 6.5±0.46                        | 9                |
| 2 | pH (bottom waters) | 5.66 – 6.0 | 6.05±0.46                       | 4                |
| 3 | Mineralization, mg/dm$^3$ | 31.2 – 56.5 | 43.0±0.9                         | 8                |
| 4 | Chromaticity, ° | 30 – 121 | 79.5±34.1                       | 8                |
| 5 | Total Iron, mg/dm$^3$ | 0.15 – 0.88 | 0.476±0.267                    | 8                |
| 6 | Total Phosphorus. mg/dm$^3$ | 0.02 – 0.04 | 0.03±0.0077                   | 8                |

In the 1960s various authors [1, 8] note bicarbonate-calcium waters with a total mineralization of 53.7 - 55.2 mg / dm$^3$, as well as the “dark brown” colour of water and its weak humification. In 1990 waters of the hydrocarbonate class are also observed in the lake, but there is a change of hydrochemical type: from sodium sulphate (II) to chlorine-magnesium (IIIa). Also, since 1990, in the cation group, along with calcium, magnesium begins to steadily dominate.

For the first time in the summer of 2006, we observed a change in the hydrocarbonate class to the sulphate class in the surface layers [2]. Bicarbonate class persistently maintained only in the bottom horizons. From 2007 to 2014 in the lake, a pronounced sulphate hydrochemical class was observed, which led to the thought of the identified evolutionary (directed) development of water masses. But in 2018, the recovery of a hydrocarbonate class of waters by 2018 was detected (similar to the period of 1960s) (table 3).
Table 3. Dynamics of mineralization and hydrochemical class of water (lake center, surface).

|                  | Aug. 1966 | Aug. 1990 | Aug. 2006 | Jan. 2007 | July 2013 | July 2014 | March 2014 | July 2014 | October 2018 |
|------------------|-----------|-----------|-----------|-----------|-----------|-----------|------------|-----------|-------------|
| Mineralization, mg/dm³ | 53,7      | 31,2      | 33,7      | 43,8      | 46,0      | 56,5      | 37,0       | 42,7      |
| rSO₄/rHCO₃       | 0,75      | 0,25      | 1,77*     | 1,53      | 2,3       | 2,7**     | 1,17       | 0,8       |
| Class            | C         | C         | S         | S         | S         | S         | S          | C         |

* -- bottom waters – 0,55; ** -- bottom waters – 1,56

In the years of increased water content, an increase in the chromaticity values and increased iron concentrations is observed, which is associated with the flow of organic matter from the catchment area and, probably, with the erosion of the coastal zone.

The water quality of Lake Zyuratkul is low, but it should be noted that this is mainly the result of natural processes. A certain negative role was played by the decomposition of organic matter, which appeared in the aquatic ecosystem from the areas of flooded soil and vegetation cover during the regulation of the water body.

The transparency of the water on the white disc is insignificant (about 0.8 - 1 m in summer, and 1.3 - 1.6 m in winter).

Part of the north and east coast is used for recreational purposes. Anthropogenic impact on P total is very likely (beach-bathing rest and uncomfortable places of rest). It should be noted that in the water of the tributaries the concentration P total in the summertime is 0.017–0.02 mg / l; in the flow from a recreationally developed territory, it can increase 4 times (Table 4).

Table 4. Nutrients in the waters of a nameless stream near the dam.

|                  | pH    | N-NH₄  | N-NO₂  | N-NO₃  | P total | Fe total |
|------------------|-------|--------|--------|--------|---------|----------|
| July 2014, full flowing | 6,35  | 0,68   | 0,017  | 0,28   | 0,079   | 0,72     |
| October 2018 light water | 8,6   | 0,57   | 0,008  | 0,21   | 0,02    | 0,18     |

The TSI index averaged over phosphorus and transparency is 55, which corresponds to a reservoir of mesotrophic-eutrophic type.

The main group of substances that have a significant negative impact on the formation of water quality is total iron (up to 8–9 MAC) and organic matter.

Water Pollution Index (WPI) in 2006–2018 - fluctuations in the range from 2.0 (summer) to 4.1 (winter) are noted, correspond to the waters of the III-IV quality class (moderately polluted - polluted).

The reservoir belongs to the second group of recreational lakes of the Chelyabinsk region (picturesque and curative, relatively little altered by human activity of the lake, but somewhat remote from the main highways and significant settlements [3]). Conditions for beach-bathing holidays here are not quite favorable - (short duration of the swimming season, cold waters, lack of comfortable beaches and difficult approaches to bathing places); However, the popularity of the lake is growing from year to year. In summer, on the lake Zyuratkul in 2013-2014 there was a “bloom” of waters, a phenomenon not previously characteristic of the lake. This phenomenon is alarming, since the recreational load intensifies the general process of eutrophication of the world's lakes associated with global warming: this may result in the restructuring of the lake phytoplankton community, irreversibly worsening both the habitat of the fish fauna and the quality of the water as a whole [11, 12].
Currently, water quality is formed by drain from the catchment area. The smallest anthropogenic transformation of the catchment (especially in the areas of the active catchment - the area adjacent to tributaries and near-lake areas) can fundamentally disrupt the existing hydrochemical regime of the lake. The unique ultra-fresh waters of Lake Zyuratkul need increased protection measures (improvement of parking areas and the beach, regulation of the recreational load on the coast and water area).

4. Conclusion
1. Transition of the flow lake to the reservoir mode; the flooding of the surrounding forests and the destruction of the clayey sections of the coast contributed not only to changes in the water regime, but also changes in the qualitative composition of lake waters.

2. In the waters of the lake, there is a cyclic Change in the hydrochemical class of water. In the period from 1966 - 1990 lake waters had a hydrocarbon class; in the period 2006 - 2014 - sulfate; in 2018 - hydrocarbonate.

3. The influence of runoff from the recreational-developed part of the coast on the enhancement of the processes of total phosphorus intake and the associated “water bloom” flashes has been revealed.

4. Currently, the reservoir has water characteristic of both the dystrophic and mesotrophic-eutrophic type with TSI = 55. The water pollution index during the year varies from 2.0 to 4.1 (water of the III-IV quality class).

5. To improve water quality, it is necessary to improve parking and the beach, to regulate the recreational load on the coast and water area.

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