Assessment of the Volga river state as a source of drinking water supply

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Abstract. The monitoring results of the Saratov reservoir water quality for the period 2000-2018 are presented. The observations were carried out monthly at a stationary point located in the downstream of the Zhiguli hydroelectric station. It is established that the water quality in the water supply source is characterized by a significant seasonal variability. During the period of algal nuisance, the reservoir organic pollution increases, and the concentration of nutrients decreases. Excessive content of organic substances in the summer low water period complicates the technological processes of water purification. Phosphates, which concentration drops to almost zero at the peak of water "bloom" are the limiting indicator inhibiting the algal nuisance.

Introduction

With the growth of nutrient load and global warming, the water quality problem of surface water sources under anthropogenic eutrophication becomes increasingly important [1-3].

The reservoirs ecological state of the Volga-Kama cascade, which are the only alternative sources of water supply in large cities, worsens during the summer low water period. This problem is particularly acute in the Lower Volga reservoirs (Kuibyshev, Saratov and Volgograd); where during the summer low water period there is an algal nuisance or water "bloom". Sharp algae increase in the number and biomass causes water deterioration in reservoirs in a number of indicators: the number and biomass of phytoplankton; smell; chromaticity; organic and toxic substances, dissolved oxygen; pH; oxidation-reduction potential Eh [4, 5].

Water deterioration in the water supply source creates significant difficulties in water purification in water purification plants. At the same time, water treatment technologies applied in the Volga cities do not allow bringing the water supplied to the population to the standard quality.

When using the reservoir as a source of drinking water supply, it is important to know the peculiarities of the water "bloom" process in it, as well as those quantitative indicators of water quality that can significantly reduce its consumer properties and make it difficult to clean.

The goal of research is to assess the seasonal changes in the Volga water quality by organic indicators and nutrients in the anthropogenic eutrophication conditions of the surface source of drinking water supply. Saratov reservoir was chosen as an object. Saratov reservoir was chosen as an object.
Results and its discussion

The water quality of the Saratov reservoir mainly formed in the Kuibyshev, which is located upstream in the Volga-Kama cascade. The average annual water consumption entering the Saratov reservoir through the dam of the Zhiguli hydroelectric station is 5500 m$^3$/s, and the lateral inflow consumption is 203-230 m$^3$/s (4%).

In the Kuibyshev reservoir, annually during the summer low water period there is an algal nuisance (water «bloom»). Its intensity and duration depend on nutrient load, regulation of water flow regime and hydro meteorological conditions of a particular year.

The water «bloom» process is characterized by significant spatial heterogeneity. In the inundable parts of the reservoir, gulls, in backflow zones of the inflowing streams, where there is little depth and flow is practically absent, the water «bloom» is more active than in the course. The process develops most intensively in the largest and shallowest Cheremshansky gulf, as well as in the near-dam deeps, where extensive “bloom” zones are formed (the thickness of the algae layer on the reservoir surface reaches several centimeters).

Phytoplankton composition analysis of reservoirs showed that the predominant ones are blue-green, diatom, green [12]. At the same time, blue - green algae cause water to bloom in summer. Blue-green algae species such as Microcystis, Anabaena and Aphanizomenon are capable to produce toxins (microcystins). Currently, more than 70 structural variants of microcystins are known, microcystin-LR is the most toxic. According to the recommendations of the World Health Organization, its permissible concentration in water is 1 µg/dm$^3$.

With the algal biomass increase in the reservoir, chlorophyll-a concentration increases, as well as pH (up to 9–9.5), color of water (up to 40–50 degrees), odor (up to 3-4 points) and Eh decreases (up to 230–250 mV). Excess of oxygen (200–300%) is observed in the reservoir surface layer, and its deficit is in the bottom layer. The content of suspended and dissolved organic substances in water increases, while the concentration of NO$_3^-$ and PO$_4^{3-}$ decreases. The PO$_4^{3-}$ content may fall to zero, and then the algae development temporarily stops [13, 14].

Of particular concern is organic water pollution in terms of integral indicators - BOD, permanganate oxidation and COD during the summer low water period. Concentration increase of permanganate oxidation in summer is associated with an amount increase of autochthonous organic matter due to the phytoplankton intensive development. Even in the Zhiguli HPP site, where there is a good mixing and aeration, the Volga water does not meet the regulatory requirements for permanganate oxidation and COD throughout the year and for BOD during the water “bloom” [15, 16]. Data on the organic substances content for 2000–2018 are given in table 1.

| Index | Month |
|-------|-------|
|       | 1     | 2     | 3     | 4     | 5     | 6     | 7     | 8     | 9     | 10    | 11    | 12    |
| PO, [mgO/dm$^3$] |       |       |       |       |       |       |       |       |       |       |       |       |
| $C_{av}$ | 7.5   | 7.1   | 7.8   | 7.5   | 7.5   | 7.8   | 8.6   | 7.9   | 7.4   | 7.1   | 7.0   | 7.0   |
| $\sigma$ | 1.4   | 1.4   | 1.3   | 1.1   | 1.2   | 1.0   | 1.5   | 1.3   | 1.0   | 1.1   | 0.8   | 0.9   |
| $C_{max}$ | 9.8   | 13.8  | 10.7  | 10.5  | 9.4   | 10    | 12.1  | 9.8   | 9.7   | 9.8   | 8.6   | 8.6   |
| $C_{min}$ | 5.5   | 4.1   | 5.2   | 5.4   | 5.8   | 5.5   | 7.1   | 6.5   | 6.2   | 5.9   | 6.0   | 5.3   |
| COD, [mgO/dm$^3$] |       |       |       |       |       |       |       |       |       |       |       |       |
| $C_{av}$ | 23    | 24    | 25    | 25    | 24    | 27    | 27    | 27    | 27    | 27    | 26    | 25    |
| $\sigma$ | 7     | 7     | 6     | 6     | 8     | 6     | 5     | 5     | 5     | 4     | 5     |       |
| $C_{max}$ | 39    | 36    | 35    | 33    | 31    | 35    | 36    | 35    | 34    | 32    | 29    | 33    |
| $C_{min}$ | 12    | 13    | 15    | 14    | 10    | 15    | 17    | 14    | 16    | 15    | 17    | 13    |

The average annual value of permanganate oxidation in the Saratov reservoir water is 7.4 mgO/dm$^3$. Average monthly values (C$_{av}$) vary within 7.0–8.6 mg/dm3, maximum (C$_{max}$) - 8.6–13.8 mg/dm3, minimum (C$_{min}$) - 4.1–7.1 mg/dm$^3$. The highest average monthly values (C$_{av}$) are observed
during the summer low water period (July), at the peak of water «bloom», and the lowest - during the winter low water period. Due to the water «bloom» permanganate oxidation increases by 10–15% (refer with Figure 1).

**Figure 1.** Permanganate oxidation change in water of the Saratov reservoir

The average annual COD value is 25.3 mg/dm³. Average monthly values (Cav) vary within 22.9–27.3 mg/dm³, maximum - 28.9–38.7 mg/dm³, minimum-9.5–16.9 mg/dm³. The highest average monthly values are observed in the summer low water period (July), at the peak of water “bloom”, the lowest - in the winter low water period. Due to the water “bloom”, the COD increases by 6–8% (refer with Figure 2).

**Figure 2.** COD change in water of the Saratov reservoir

Serious consequences of the organic matter concentration increase in the water source of water supply associated with the formation of toxic organic pollutants in the drinking water preparation. The
increased content of organic substances can significantly complicate the technological processes of water purification, in particular the flocculation process. The water «bloom» process has a strong effect on the seasonal nutrients content, while phosphates and nitrates are of particular interest (from the point of view of combating the water «bloom» process). For the period 2000-2018 the average annual nitrates concentration was 0.75 mg/dm³. Average monthly values (Cₘ) vary within 0.41–1.26 mg/dm³, maximum (Cₘₐₓ) - 1.13–2.37 mg/dm³, minimum (Cₘᵢₙ) - 0.2–0.52 mg/dm³ (refer with table 2).

Table 2. Concentration statistical characteristics of NO₃⁻ and PO₄³⁻ for long-term series

| Index   | Months | Nitrates, [mgN/dm³] | Phosphates, [mgR/dm³] |
|---------|--------|---------------------|-----------------------|
|         | 1      | 2                   | 3                     | 4                     | 5       | 6       | 7       | 8       | 9       | 10      | 11      | 12      |
|         | Cₘ     | σ                  | Cₘₐₓ                  | Cₘᵢₙ                  | 1       | 0.80    | 1.00    | 1.21    | 1.26    | 1.10    | 0.72    | 0.54    | 0.58    | 0.44    | 0.47    | 0.41    | 0.51    |
|         | Cₘᵢₙ   | σ                  | Cₘₐₓ                  | Cₘᵢₙ                  | 1       | 1.37    | 1.89    | 2.37    | 2.35    | 1.96    | 1.33    | 1.24    | 1.92    | 1.46    | 1.28    | 1.13    | 1.28    |
|         | Cₘᵢₙ   | σ                  | Cₘₐₓ                  | Cₘᵢₙ                  | 1       | 0.42    | 0.42    | 0.52    | 0.42    | 0.47    | 0.21    | 0.11    | 0.14    | 0.12    | 0.12    | 0.20    | 0.26    |

The highest nitrates concentrations are observed before the spring young flood. During the flood period, the nitrates concentration decreases, reaching minimum values in July, in the summer-autumn low water period (June – September) - is stable, and then begins to slowly increase during the winter low water period. The average annual phosphate concentration is 0.065 mg/dm³. During the year, the average monthly values (Cₘ) vary within 0.029–0.095 mg/dm³, the maximum - 0.052–0.149 mg/dm³, and the minimum - 0.01–0.058 mg/dm³. The highest phosphates concentration is observed in the autumn low flow period, the lowest - in the summer low water period, during the algal nuisance period.

The observations show that as a result of phytoplankton nitrate and phosphate being actively consumed by the phytoplankton, the concentration of these substances in the water of the reservoir decreases sharply in the summer period. At the same time, the phosphate content is reduced to a minimum, while the nitrates concentration remains quite high. In the inaudible parts of the reservoir, where the number and biomass of phytoplankton at the peak of water «bloom» is much higher than in the course, the phosphates concentration is practically zero. Consequently, the phosphates presence in the reservoir water is a deterrent of the phytoplankton development in the summer period. To reduce the phosphorus load, restore the ecological state of the reservoir and improve water quality, it is necessary to develop and introduce regional quality standards that would take into account the natural features of the reservoir regarding the natural content of nutrients in the water.

One of the main reasons for the water «bloom» quality and the water quality deterioration is an excessive nutrient load, which has become possible due to the imperfection of the rationing system. The criteria for water quality rationing of water bodies are the maximum permissible concentrations that are the same for the whole territory of the Russian Federation and depend only on the type of water use without taking into account the natural features of water ecosystems. As a result, erroneous priorities are established for managing the anthropogenic load on water bodies that are sources of the drinking water supply. To reduce the nutrient load on the reservoir, it is necessary to start the development and implementation of regional water quality standards that take into account the natural features of water bodies [17, 18].

Summary
1. The water quality in the Saratov reservoir by organic indicators (PO, COD) and nutrients (nitrates, phosphates) is characterized by significant seasonal variability. In summer, the organic matter content increases, while the nutrients concentration decreases. The amplitude of seasonal changes in PO is 7.1–13.8 mgO/dm³ and does not meet the regulatory requirements for drinking water sources.

2. The excessive content of organic matter during the summer in the Saratov reservoir water is due to the algal nuisance. Due to the water «bloom”, permanganate oxidation during the water «bloom” increases by 10–15%.

3. The Saratov reservoir, as a surface source of water supply, belongs to the second class. However, the proposed purification technology for this class does not allow to bring the water quality in centralized drinking water supply systems to the standard quality.

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