Sustainable water use of the Kuibyshev reservoir as an hydropower facility

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Abstract. Sustainable water use in a broad sense is a combination of all forms and uses of water resources that directly and indirectly affect the formation of the water fund. When operating hydropower facilities, it is necessary to comply with the requirements for the rational use and protection of water bodies. The article presents the results of the assessment of the specificity of water consumption and water disposal in the Kuibyshev reservoir within the Republic of Tajikistan, as well as the calculation and assessment of the main trends in water reservoir quality dynamics. Calculation of the index of the combinatory water pollution index during the period 2009-2017 yrs allowed to reveal a moderate tendency of its decrease within the limits of the 4th class of quality from the upper reaches to the dam of the Kuibyshev reservoir.

Introduction

In Russia, the concept of sustainable water use began to form in 1997. In accordance with the Concept of the transition of the Russian Federation to sustainable development, legally fixed by the Presidential Decree of 1.01.1996. № 440. During these years the scientific literature actively discusses the issues of sustainable water use, the draft Concept of the State Policy of Sustainable Water Use in the Russian Federation (RF). Ensuring sustainable water use is the highest priority in the field of environmental protection and rational nature management, as reflected in the Law of the RF On Environmental Protection (2002), the Water Code of the RF (2006), and the Environmental Doctrine of the RF. The Russian Government adopted the Water Strategy of the Russian Federation for the period up to 2020 adopted by the Government of the RF dated August 27, 2009 N 1235-r. Within the framework of this program, work is also being done to improve the regulatory legal regulation of rational use of water resources, reduce the discharge of contaminants in sewage, economic mechanisms.

In general, the structure of water consumption in the Russian Federation is as follows: production needs are 58%, domestic and drinking needs 20%, irrigation 14%, agricultural water supply 2%, other needs 6%. Thus, industry is the main water consumer. Within this sector, the main water-consuming industry is energy (75% of total industrial water consumption), followed by ferrous and non-ferrous metallurgy (6%, pulp and paper industry (5%), chemical and food industries (5%), engineering (3%) [1].
On the territory of the RF, about 3% of water reserves, or approximately 90 km³, are annually used for water abstraction, extraction and transportation to places of use. However, for individual basins, the ratio of the fence to the reserves is significantly differentiated. A third of all water abstraction and more than 40% of the total wastewater discharge in the RF is carried out in the basin of the river Volga. Virtually all the watercourses of the basin of the river Volga is subject to anthropogenic impact, the average annual concentrations of many pollutants exceed the maximum permissible levels, and the water quality of most of them does not meet regulatory requirements. In addition, the contribution of the anthropogenic load to the formation of the quality of the water resources is already commensurate with the natural factors [2].

The Kuibyshev Reservoir is the largest in Eurasia and the third largest in the world after the African Lake Volta (Ghana) and the North American Reservoir Smallwood (Canada), was established in 1955-1957 yrs dam of the Zhiguli hydroelectric power station (HPP) and is part of the Unified Energy System of the European part of the Russian Federation. The idea of energy use of the Volga on the site of the Samara Luke proposed by G.M. Krzhizhanovskiy and developed by engineer K.V. Bogoyavlensky and Professor A.V. Chaplygin.

The Kuibyshev reservoir is a seasonal regulation water basin and is used in the interests of industry, energy, drinking and domestic water supply, health, agriculture and forestry, mining, transport, recreation, construction, fire safety, etc. [3].

The main contribution to the pollution of the waters of the Kuibyshev reservoir is made by the transit transfer of pollutants from the upper regions of the RF, which is mainly carried out along its bed part. A significant contribution to the pollution of the Kuibyshev reservoir waters is caused by discharges of insufficiently treated sewage from industrial and communal enterprises adjacent to the water area of the reservoir [4, 5] and diffuse runoff. In addition, a significant contribution to the pollution of water bodies is made by the geological environment and aerotechnogenic pollution. And this is far from a complete list of the most significant factors that cause the pollution of the water resources of the Kuibyshev reservoir and its tributaries. Studies conducted by the Institute of Ecology of the Volga Basin of the Russian Academy of Sciences in 1997-2010. on the Middle and Lower Volga [6], showed that, despite the decrease in anthropogenic pressure over the past decade, the quality of the Volga water remains unsatisfactory. For a number of hydrochemical indicators, the water of the Kuibyshev reservoir does not meet the regulatory requirements for fishery water reservoirs.

In connection with the foregoing, the purpose of this work was to assess the specificity of water consumption and wastewater in the Kuibyshev reservoir within the Republic of Tatarstan (RT), as well as the calculation and assessment of dynamics of water quality in the reservoir.

Materials and Methods

The work uses data from observations of the quality of the waters of the Kuibyshev Reservoir, carried out by FGBU "Sredvolgavodkhoz" since 2009. The work on the sampling of water and hydrochemical analysis is carried out by the hydrochemical laboratory of the Svervolgavodkhoz FGBU in the main phases of the water regime: winter low water, high water and recession), summer low water, in the autumn before freezing, as well as during the passage of rainwater. In 2009, sampling was carried out at 8 points of observation, and the analysis of the selected samples was performed on 25 ingredients and water quality indicators. Starting in 2015, sampling was conducted at 12 points of observation, and the analysis of samples taken was performed on 45 ingredients and water quality indicators.

Calculation of the combinatory water pollution index (CWPI) was carried out to assess the quality of surface waters of the Kuibyshev Reservoir for the period from 2009 to 2017.

Indicators of water consumption and sanitation in the Republic of Tatarstan (RT) in the retrospect of years 1998 - 2014, performed according to the materials of state statistical reporting with the purpose of assessing the impact of indicators on the level of water pollution.
In order to obtain comparable information, the data processing of water pollution observations of the Kuibyshev reservoir was carried out using physical and statistical methods of analysis.

**Results and Discussion**
The dynamics of consumption of water from natural sources in RT is shown in Fig. 1. Analysis of Fig. 1. shows that the amount of water consumption from natural water bodies for the considered period decreased by 202,47 million m\(^3\) or by 18.7%. During the period 1998-2009 yrs the decrease in water consumption from natural water bodies has been registered, and since 2010 there has been an increase. The maximum water consumption from natural water bodies was 1081.88 million m\(^3\) in 1998 and the minimum in 2009 was 736.74 million m\(^3\). On the one hand, the decrease in water withdrawal from natural water bodies was caused by a decrease in production volumes, and on the other hand introduction of technologies aimed at reducing water consumption at economic facilities.

![Fig. 1. Water consumption from natural water bodies, million m\(^3\)](image1)

**Discharge of contaminated sewage into surface water bodies of the RT, million m\(^3\)**

![Fig. 2. Discharge of contaminated sewage into surface water bodies of the RT, million m\(^3\)](image2)
The dynamics of discharge of contaminated sewage into surface water bodies of RT is shown in Fig. 2. Analysis of Fig. 2 shows that the discharge of contaminated sewage into surface water bodies of the RT for the considered period decreased by 54,131 million m$^3$ or by 7.3%. In the period 2000 - 2009 yrs there is a decrease in discharges of polluted sewage into surface water bodies, and from 2010-2014 yrs there is an increase. Maximum discharges of contaminated sewage into surface water bodies were registered in 2000 and amounted to 768,262 million m$^3$, while the minimum in 2009 was 548,16 million m$^3$.

We obtained the regression equations between a water intake from natural water objects and dumping of the polluted sewage in superficial water objects of RT describe by the equation:

$$V_i = 0.57 \cdot V_d + 154.28,$$

where – $V_i$ water intake from natural water bodies, $V_d$ - discharge of contaminated sewage into surface water bodies of RT.

In the regression equation, the correlation coefficient between the values of $V_i$ and $V_d$ is $r = 0.93$. The correlation coefficient is significant at the level $\alpha = 0.05$. The factor $V_i$ determines 87% of the variance $V_d$. For the analyzed case $R^2 > 0.7$, which indicates a high binding strength between the values of $V_i$ and $V_d$.

Values of actual ($V_a$) and calculated ($V_c$) values of discharges of contaminated sewage into surface water bodies of RT using the regression equation (1) are shown in Fig. 3. As the analysis of Fig. 3, the actual and calculated values of discharges of contaminated sewage into the surface water bodies of the RT are well connected.

Fig. 3. Variability of actual ($V_a$) and calculated ($V_c$) values of discharges of contaminated sewage into surface water bodies of RT

The resulting regression equation can be used to predict the discharge of contaminated sewage into surface water bodies of RT.

Assessment of the quality of surface waters of the Kuibyshev Reservoir for the period from 2009 to 2017 yrs. is performed using the CWPI [7, 8]. It was revealed that the period under consideration of
the value of the CWPI varied within the limits from 3.9 to 5.5 (Fig. 4). The maximum value CWPI of the – 5.5 was observed in 2010, and the minimum value – 3.9 in 2011. Analysis of Fig. 4 shows that in the period 2012-2017 yrs. there was a weak tendency to reduce the CWPI within one quality class. Substantial improvement (deterioration) in the quality of the waters of the Kuibyshev reservoir during the considered period was not revealed.

![Figure 4](image1.png)

**Fig. 4. Annual average dynamics and trend of surface water quality in the Kuibyshev reservoir (2009 – 2017 yrs)**

![Figure 5](image2.png)

**Fig. 5. Dynamics and trend of CWPI of waters along the water area of the Kuibyshev reservoir**
Dynamics and trend of changes in the quality of surface waters over the water area of the Kuibyshev Reservoir for the period from 2012 to 2017 yrs. are shown in Fig. 5.

The analysis of Fig. 5 shows that in the period 2009-2017 yrs. there was a moderate decline in the CWPI within the 4th grade class from the upper reaches to the dam of the Kuibyshev Reservoir. During the period under review, the values of the CWPI varied between 4.4 and 5.2. The maximum value of the CWPI equal to 5.2 was observed on the left bank of the Kuibyshev reservoir below the settlement Borovoye Matyushino RT. The minimum value of the CWPI equal to 4.4 is registered on the left bank of the Kuibyshev reservoir below the city of Naberezhie Chelny.

Conclusions
The analysis of the received materials shows that there has been no significant improvement (deterioration) in the quality of the waters of the Kuibyshev Reservoir during the period under review. All changes in water quality, both in time and in the water area of the reservoir, were observed within the limits of grade 4, and the waters were still characterized as "dirty".

In order to improve the quality of water in the Kuibyshev reservoir and its tributaries, it is necessary to reduce the diffuse discharge through the purification of sewage and meltwater from the territory of large industrial complexes located in the catchment area, as well as the conduction and reforestation of water protection zones. In addition, it is necessary to continue work on further improvement of wastewater treatment of industrial and municipal enterprises that discharge to the Kuibyshev Reservoir and its tributaries.

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