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Assessment of an ecological state of the Kuibyshev reservoir based on zoobenthos indicators

T A Kondrateva[1], N Yu Stepanova[2]

[1]Federal State Budget Institution «Management of Hydrometeorology and Environmental monitoring of the Republic of Tatarstan, Zavodskaja str., 3, Kazan city, 420021, Russia

[2]Institute of Environmental Sciences, Kazan Federal University, Kremlevskay str., 18, 420008, Russia

tatjana_kondrate@mail.ru

Abstract. On the basis of the analysis of long-term data of chemical and biological monitoring, the ecological state of the Kuibyshev reservoir (the Republic of Tatarstan, Russia) was defined. There were used the dissolved oxygen, BOD, ammonium content and pollutants with excess of maximum allowable concentration (15 ingredients in total) as markers of chemical pollution. Total number of a zoobenthos and relative number of oligochaetes were chosen as biological indicators. Based on chemical and biological indicators it was noted that the lower sites of the Kuibyshev reservoir are less polluted in comparison with top sites which ecosystem now is in transition state from equilibrium to crisis.

Introduction

By the end of the 20th century more than 45 000 large dams were constructed in more than 140 countries. It is expected that the construction of reservoirs will be a continuous increase in the future. These artificial reservoirs meet needs of the human for providing with drinking water, electricity generation, agricultural irrigation, industry, fishing trade and a recreation [2]. All this belongs also to the Kuibyshev reservoir which is located in the central part of the Middle Volga area.

The enterprises of housing and communal services, the power and petrochemical industry, agriculture make negative impact on a water quality of the Kuibyshev reservoir. The largest volumes of the polluted waste waters come to the reservoir from the enterprises of the cities of Kazan and Naberezhnye Chelny. Poor quality of water is the result of such influence. In the same time the quality of the water is the prime factor which defines the existence and a possibility of water biological resources using [3].

Significance/Relevance of the study

Two main approaches, chemical and biological, are used in surface waters monitoring system. The first one is based on the determination of pollutants content and their comparison with the maximum permissible concentrations (MPC), calculation of water pollution indexes. Despite the fact that this system does not take into account the state of the biotic component of the ecosystem, at the same time, formalized indicators, for example, the specific combinatory water pollution index are very useful and informative for characterizing the dynamics of the anthropogenic component of the chemical pollution of the hydrosphere. As an alternative to MPC, recently it has been proposed to use the so-called ecologically permissible levels, developed by mathematical modeling methods for individual regions with taking into account the biotic component by in situ methods [4, 5]. In this case the limits of the environmental factors (chemical substances content) are introduced as levels that do not violate the norm of the ecological state, established by biological indicators.

The second approach takes into account the state of the biotic component of the ecosystem. To implement the biotic approach, a set of methods is necessary for obtaining assessments of the state of biotic communities, with the help of which it would be possible to distinguish an ecologically safe ecosystem from an ecosystem in which there were significant changes caused by external (mainly anthropogenic) impacts [6]. The most common methods of indication are based on expert estimates for specific groups of hydrobionts. Most scientists agree that the most objective assessment of the quality of the aquatic environment by the biotic component can be obtained by using zoobenthos organisms as bioindicators [7, 8, 9, etc.].

The objective of the study

The objective of this study is the determination of the ecological state of the Kuibyshev reservoir based on characteristics of abiotic and biotic components.

Materials and methods

Sampling zoobenthos and water for the chemical analysis was performed at the following locations: the Zelenodolsk and Kazan cities, the settlement Tenishevo, the settlement Zaovrazhnye Karatai, the Laishevo town, the Tetyushi town. Collection and processing of hydrobiological and hydrochemical samples was carried out according to standard methods [10].

Water quality by chemical indicators was evaluated using a specific combinatorial index [11].

To assess the state of ecosystems according to the abiotic component, statistical analysis of long-term information on the variation in the concentration of dissolved oxygen, easily oxidized organic substances according to BOD (Biological Oxygen Demand), ammonium nitrogen, and modal intervals MI (intervals including the most frequent values in this variation series) was carried out. In addition, calculated indicators, such as the proportion and degree of anthropogenic impact, were used. The share of anthropogenic impact (S) was calculated by the formula 1:

$$S = N_1/N*100 \quad (1),$$

where N_1 – the number of ingredients exceeding the MPC;
N – total number of rated priority pollutants.

The degree of anthropogenic impact was calculated by the formula (2):

$$C = N_2/N_1*100 \quad (2),$$

where N_2 – the number of ingredients in excess of 10 MPC.

In total, 15 ingredients were used for calculations: oxygen dissolved, BOD, COD (Chemical Oxygen Demand), nitrates, nitrites, ammonium, chlorides, sulfates, total iron, phenols, total petroleum hydrocarbons (TPH), Cu^{2+}, Zn^{2+}, Cr total, Mn^{2+}.

The following indicators were used to assess the status of ecosystems using the biotic component:

- the total number of zoobenthos, N_{zb}, mill ind.M^{-2};
- the relative abundance of oligochaetes in zoobenthos, N_{ol},%.
- Woodiwiss biotic index.

Based on the results an invariant condition of an ecosystem was defined according to a procedure of ecological modifications [12, 13].

Result and Discussion

Generalization and analysis of long-term information of hydrochemical and hydrobiological indicators allowed to determine the ecological status of the Kuibyshev reservoir.

Assessment of the abiotic component

Analysis of hydrochemical information showed that the exceed of MPC was for 12 ingredients. The main contribution to the pollution of surface waters of the Kuibyshev reservoir introduced nitrogen nitrite, nitrogen ammonium, TPH, copper compounds, BOD, COD and water quality was characterized as “characteristic”. At the same time the oxygen regime was satisfactory in all investigation points. Water quality on the upper parts of the reservoir was characterized as “dirty”, the other as “very polluted”.

Table 1. The state of the Kuibyshev reservoir based on abiotic parameters

№[a] Water quality	MI[b] BOD_5 mgO_2/L (moda)	MI NH_4^-, mg/L (moda)	The share of anthropogenic impact	
			range values, %	state of the ecosystem
1) dirty	1.54–3.25 (2.29) crisis	0-0.38 (0.21) equilibrium	0-80[c] 6.7-53.3[d] (33.3)[e]	transition from equilibrium to crisis
2) dirty	0.84–2.89 (1.96) transition from equilibrium to crisis	0-0.62 (0.32) transition from equilibrium to crisis	0–80 6.7-66.7 (33.3)	transition from equilibrium to crisis
3) very polluted	1.02-1.67 (1.59) equilibrium	0.14-0.25 (0.17) equilibrium	0-40 20-27 (20)	equilibrium
4) very polluted	1.04-1.82 (1.38) equilibrium	0-0.19 (0.1) equilibrium	0-33 20-30 (20)	equilibrium
5) very polluted	0.98-1.45 (1.33) equilibrium	0-0.09 (0.06) equilibrium	0-33.3 13.3-20 (11.7)	natural
6) very polluted	0.71-2.45 (1.64) transition from equilibrium to crisis	0-0.22 (0.12) equilibrium	0–80 6.7–46.7 (26.7)	equilibrium

a – points of investigation: 1) the Zelenodolsk city. 2) the Kazan city, 3) the settlement Tenishevo, 4) the Laishevo city, 5) the settlement Zaovrazhnye Karatay, 6) the Tetyushi city;
b – modal interval; c – total range; d – MI; e - long-term value.

According the share of anthropogenic loading the state of the water ecosystems on the upper sites of the reservoir was assessed as transitional from equilibrium to crisis, the lower sites as equilibrium, and near the Kama Mouth as natural. Based on the extent of anthropogenic influence the state of the ecosystem of the Kuibyshev reservoir was characterized as equilibrium (cases of excess of MPC more than 10 times were not fixed). Such differences in ecological state assessment of the top and lower sites of the reservoir are caused, first of all, by impact of large industrial centers like Zelenodolsk and Kazan cities.

Assessment of the biotic component.

Typical groups of zoobenthos for reservoirs were marked out. These are, in general, Mollusca, Olygochaeta, Chironomidae, Gammaridae (Crustacea). There were also Hirudinea, Hydracarina, Polychaeta, Cumacea (Crustacea), Misidacea (Crustacea), Nematoda. There were fewer larvae Trichoptera, Ephemeroptera and others. The greatest group and specific variety of a zoobenthos was observed on the lower sites (3-14 taxons by a rank higher than a genus), the smallest on the top (1-10 taxons by a rank higher than a genus). The number of a zoobenthos varied from 0.02 to 9.48 mill ind.M^{-2} (Table.2).

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Table.2. Statistic characteristics of a zoobenthos

№, Water quality	BI[a] Min-max M±Δ	N_{zb}, (mill ind.M^{-2}) Min-max *M*±Δ	MI (w, %)	N_{ol}, % Min-max *M*±Δ	MI (w, %)	Invariant state
1) polluted	1.0-6.0 3.6±0.1	0.1–8.32 0.96±0.14	0.1–1.22 (77)	0–100 50.8±3.8	31–87 (55)	Elements of ecological regress
2) polluted	2.0-6.0 3.4±0.1	0.04–22.4 2.67±0.32	0.04-3.88 (83)	0–93 33.6±2.3	27-93 (52)	Elements of ecological regress
3) polluted	2.0-8.0 3.9±0.2	0.28-4.16 1.86±0.13	0.28-1.28 (55)	1.3–80.6 25.9±2.2	6-51 (61)	Anthropogenic stress with elements of ecological regress
4) polluted	2.0-7.0 4.3±0.2	0.18-1.68 3.26±0.4	0.18-5.16 (81)	1.2-92.9 23.4±2.1	30-82 (60)	Elements of ecological regress
5) poorly polluted	4.0-5.0 4.6±0.1	0.02-9.08 1.7±0.3	0.04-1.64 (74)	2-100 19.6±2.1	1-25 (61)	Background
6) poorly polluted	4.0-6.0 4.6±0.1	0.34-9.48 5.0±0.9	0.34-4.64 (68)	0.9-66.7 22.8±2.4	1-17 (64)	Background

a – Woodiwiss biotic index

The largest average values of the number are recorded in the lower parts, the smallest in the upper and middle one. Mollusca (Dreissena spp.), Olygochaeta, Chironomidae dominated in the benthic community. The total number of zoobenthos remained at the same level during last two decades (Figure 1), while slight increase of the number of Mollusca was noted (Figure 2).

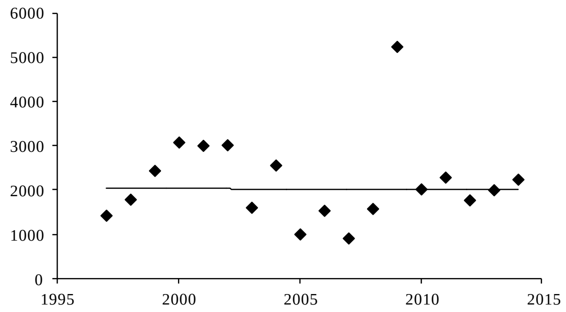

Fig. 1. Dynamics of the total number of zoobenthos, ind.M^{-2}

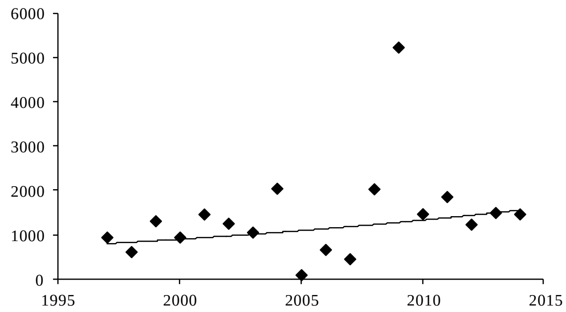

Fig. 2. Dynamics of the number of Mollusca,ind.M^{-2}

The relative number of oligochaetes changed from 0 to 100%. The greatest average values were noted also on the top sites of the reservoir, the smallest on the lower. The analysis of long-term data of the number of oligochaetes revealed a tendency of it decrease (Figure 3). This fact was already noted earlier [14, 15]. At the same time small, but steady increase of the number of polychaetes - the main competitors of oligochaetes were observed since 2005 (Figure 4).

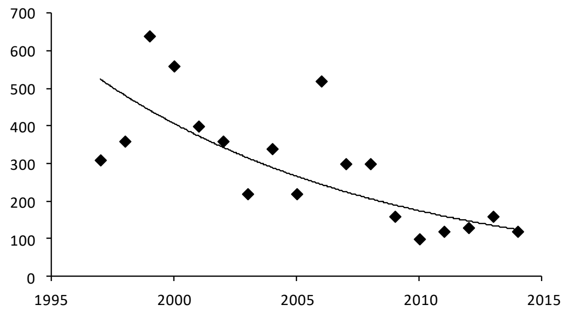

Fig. 3. Dynamics of number of Olygochaeta, ind.M^{-2}

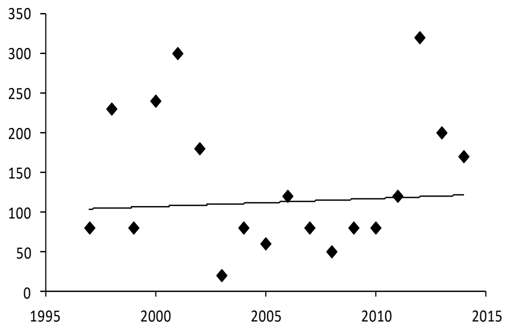

Fig. 4. Dynamics of number of Polychaeta, ind.M^{-2}

The quality of benthonic water determined by the biotic Woodiwiss index was characterized as polluted on the majority of investigated sites of the reservoir and only in area of the settlement Zaovrazhnye Karatay and the Tetyusha city as poorly polluted. The obtained in this study water quality assessment for the upper sites of the reservoir agree with the previously reported [16, 17].

The invariant condition of ground ecosystems on the majority of sites of the reservoir was characterized by elements of ecological regress. And only the lower sites of the Kuibyshev reservoir can be characterized as background (natural) on which ecological modulations are observed.

In case of increased level pollution, when the ecosystem moves from an equilibrium state to a crisis, the benthic communities simplify their structure by reducing the species diversity with a simultaneous increase in abundance with dominating of 1-2 species.

Conclusion

Based on results of chemical analysis the Kuibyshev reservoir in investigated area was characterized as dirty and very polluted. The reservoir ecosystem on a share of anthropogenic influence an ecosystem on the majority of sites was in an equilibrium state and only in a zone of influence of Zelenodolsk and Kazan cities – in transitional of equilibrium in crisis. The quality of benthonic water based on zoobenthos indicators on the same sites was estimated as polluted with elements of ecological regress. Other sites were characterized as poorly polluted in which anthropogenic tension with elements of ecological regress was observed.

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