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Risk Assessment of Anthropogenic Impact on Water Ecosystems Based on Chemical and Biological Monitoring Data

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Abstract. Based on long-term data of chemical and biological monitoring, the risk of anthropogenic impact on urban water bodies was estimated (Kazan, Republic of Tatarstan, Russia). These chemical parameters were used as pollution markers: dissolved oxygen, BOD, ammonium compounds, as well as pollutants, which exceeded MAC (15 ingredients in total). The main biological indicators were the total number of phytoplankton, the relative number of oligochaetes in the composition of zoobenthos and the relative number of rotifers in the zooplankton. It is shown that urban aquatic ecosystems are in transition from equilibrium to critical state according to the degree of risk of anthropogenic impact.

1. Introduction

Most of the water bodies, including the ones in urban centres, experience significant anthropogenic impacts. The main load on them is water intake and water disposal. The reservoirs of Kazan are no exception. The main water bodies in the city of Kazan are Kazanka River, the Lake Sredene Kaban, and Kuibyshev Reservoir. Each of them experiences anthropogenic pressure: industrial, domestic, recreational, etc. The result of such an impact is a low quality of water. At the same time, water reservoirs of the city are used for excellent sports competitions. So, in 2013 and 2015, the XXVII World Summer Universiade and World FINA Games were held respectively in Kazan. At the same time, part of the competition was held directly on the open water areas of the Kazanka River and the lake Sredene Kaban. In 2018, it is planned to hold qualifying matches for the 2018 FIFA World Cup. Therefore, the condition of water bodies, their ecological and aesthetic significance, is becoming a very pressing problem for the city and the republic as a whole.

2. Significance/Relevance of the study

Urban water bodies are multifunctional in their role. At the same time, they experience multiple effects of a variety of factors [1]. However, their aesthetic and ecological value depends on the state of the aquatic ecosystem [2]. At the same time, the quality of most urban water bodies in many cities and countries leaves much to be desired [3, 4, 5] and need constant monitoring of their condition. The



quality of the aquatic environment is the primary factor determining the existence and possibility of exploitation of aquatic biological resources [6]

Two main approaches are used to monitor surface water pollution: chemical and biological. The first is based on the determination of the concentrations of pollutants and their comparison with the allowable maximum concentrations allowable (MAC), the calculation on their basis of the water pollution index (WPI). The second approach takes into account the state of the biotic component of the ecosystem. These are different indices, which in turn are expert assessments of water quality for individual groups of organisms [7].

These approaches are most often used in combination with more adequate assessment [8]. Recently, instead of the MAC system, it is proposed to use environmentally acceptable levels (EDL), developed on the basis of the biotic concept of environmental regulation [9, 10]. At the same time, the boundaries of the norms of environmental factors are introduced at levels that do not violate the norm of the ecological state established by biological indicators.

At the same time, the anthropogenic load on freshwater ecosystems, long-term and high in level, increases the probability of critical situations [11]. The recurrence of such situations is now due not so much to the hydrological characteristics of the object and the nature of the long-term anthropogenic impact, as to the decrease in the stability of the ecosystem during its transition to a new trophic state with the strengthening of eutrophication and environmental regression [12, 13, 14]. In this case, there is a risk of transition of the ecosystem from one ecological status to another, the rank below.

The study of the global experiences in the field of risk analysis has shown the formation of three main directions for solving this problem [15]: the degree of risk of emergencies, environmental technology, and environmental impact. The concept of assessing the risk of anthropogenic impact on freshwater ecosystems is based on the analysis of risk factors, in particular, the impact of pollutants, in conjunction with the system-forming hydrobiological parameters of the state of aquatic ecosystems. [16].

3. The objective of the study

The purpose of the work is to determine the ecological status of the water bodies of Kazan by abiotic and biotic components, to assess the risk of anthropogenic impact on aquatic ecosystems.

4. Theoretical/Methodical Framework

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 in water, BOD, COD (Chemical Oxygen Demand), nitrates nitrites, ammonium nitrogen, 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:

- M_{ta} - modal interval mode of total phytoplankton abundance

- M_{da} - mode of the modal interval of the relative abundance of the dominant species;
- M_{ns} - modal interval mode of the total number of species;
- f_0 - the density of the various series ($f_0 = w/k$, where w – the frequency or proportion of a range in the sum of all frequencies, %; k - the value of the interval);
- α_1 – detection frequency of high values of the abundance of phytoplankton species ($\alpha_1 = n_j/n_j^* \cdot 100$, n_j – the number of analysis results in which the values of the defined indicator are higher than the most common range of oscillations, n_j^* – total number of values);
- β – the multiplicity of the excess of the total number over the average for the most frequently encountered values ($\beta = \text{high value} / Mta$)
- the relative number of rotifers in zooplankton, N_{rot} , %;
- the total number of zoobenthos, N_{zb} , mill ind. M^{-2} ;
- the relative abundance of oligochaetes in zoobenthos, N_{ol} , %.

5. Result and Discussion

Generalization and analysis of long-term information on hydrochemical and hydrobiological indicators allowed assessing the risk of anthropogenic impact on water bodies in Kazan.

5.1. Assessment of the abiotic component

Analysis of hydrochemical information showed that the main contribution to the pollution of surface waters of the Lake Sredene Kaban introduced nitrogen nitrite, TPH, sulfates, copper compounds and organic compounds (BOD). The ecological state of the lake is characterized by a high degree of eutrophication, as well as high pollution by oil products and heavy metals. The surface water of the Lake Sredene Kaban was classified as "dirty" by the degree of contamination. A high level of pollution of the lake was registered earlier, which caused a certain tension and the need for taking measures for its rehabilitation [17].

In the Kazanka river for 6 pollutants for 10 years, water pollution was defined as "characteristic" (sulfates, chemical consumption of oxygen, BOD, copper compounds, ammonium nitrogen and TPH). The largest share in the overall assessment of the degree of contamination of the water introduced sulfates and copper compounds. Sulphates are critical indicators of water pollution. The surface waters of the river are characterized as "dirty". In the Kuibyshev reservoir, excess MPC was observed for 12 ingredients. Copper, COD, BOD, ammonium nitrogen, nitrate nitrogen and TPH, which were defined as "typical", made the largest share in the overall assessment of the degree of water pollution. The surface waters of the Kuibyshev reservoir near Kazan were characterized as "dirty".

The results of an assessment of the degree of risk of anthropogenic impact on the abiotic component are given in Table 1.

Table 1. The state of ecosystems in the parameters of the abiotic components.

N_0^a	MI^b BOD5, mgO ₂ L ⁻¹ (Mode)	MI NH ₄ ⁻ , mg.L ⁻¹ (Mode)	NI ^c	The share of anthropogenic impact		
				range values, %	state of the ecosystem	
1)	0,84–2,89 transition from equilibrium to crisis	(1,96)	n.d. ^d –0,6 (0,32) the transition from equilibrium to crisis	15	<u>0–80</u> 6,7–66,7 (33,3)	the transition from equilibrium to crisis
2)	1,4 –5,91 crisis	(3.1)	0–1,06 (0.36) equilibrium	14	<u>0 – 71,4</u> 0-57,1 (50)	the transition from equilibrium to crisis
3)	1,0–3,66 crisis	(2.42)	0–0,89 (0.47) transition from equilibrium to crisis	15	<u>0 – 80</u> 0–64,2 (64,2)	the transition from equilibrium to crisis

N_0^a - water resources:

1) Kuibyshev Reservoir, Kazan

2) Lake Sredene Kaban, Kazan

3) Kazanka River, Kazan.

MI^b - modal interval

NI^c - number of ingredients

n.d.^d – not detected

The state of the investigated aquatic ecosystems is estimated by the share of the anthropogenic load on all water bodies as a transition from equilibrium to crisis. According to the degree of anthropogenic impact-as an equilibrium (cases of exceeding the maximum permissible concentration by more than 10 times).

5.2. Assessment of the biotic component

The main statistical characteristics of phytoplankton development are given in Table 2, 3.

The most intensive development of phytoplankton is observed in the Kazanka River and the Lake Sredene Kaban, with the highest values being recorded in the Lake Sredene Kaban.

Table 2. Statistical parameters of phytoplankton development.

№, n ^a	Q ^b (min-max)	Nph ^c , (min-max)	M _{ta} /M _{ts}
	M±m	mill cell.ml ⁻¹ M±m	
1) n=140	<u>1,0-31,0</u> 11,9±0,6	<u>0,02-29,14</u> 3,80±0,53	<u>0,02-1,99</u> 8,0-21,0
2) n=62	<u>5,0-32,0</u> 16,3±1,3	<u>3,21-1759,16</u> 220,52±68,47	<u>34,03-925,11</u> 10,0-18,0
3) n=114	<u>4,0-34,0</u> 19,8±0,8	<u>0,28-300,69</u> 41,19±6,92	<u>31,42-300,69</u> 11,0-17,0

n^a– number of observations

Q^b– number of species

N_{ph}^c – total number of phytoplankton

Table 3. Level of anthropogenic eutrophication and environmental regression.

№	Statistical characteristics of phytoplankton development						Degree of contamination	The effect of anthropogenic impact
	M _{ta}	M _{ts}	M _{da}	α ₁	β	f ₀		
1)	0,47	11	26	62	45	27	Medium toxic	Elements of ecological regress
2)	99,64	15	67	50	17,7	0,04	Highly eutrophic	Anthropogenic eutrophication
3)	51,88	17	36	50	5,8	0,16	High eutrophic	Anthropogenic eutrophication

Very high values of phytoplankton abundance lead to an increase in the value of the modal interval of Mode (Mo) and a sharp decrease in the density of the various series of f₀, which indicates an increase in the processes of anthropogenic eutrophication. The latter is the cause of such a phenomenon as "flowering" of water, which is regularly observed in the city's waters [18], which significantly worsens the quality of water bodies, reduces their recreational and fishing potential [19]. At the same time, the decrease in M_{ta} and increase in the values of α₁ and β indicate the presence of toxic pollution in the Kuibyshev reservoir.

Zooplankton of the investigated water bodies differed in the level of quantitative development (table. 4). The maximum values were noted in the Lake Sredene Kaban and Kazanka River, minimum- in the Kuibyshev reservoir.

Table 4. Statistical characteristics of zooplankton.

№, n	N _{zp} , mill ind.M ⁻³ (min-max) M±Δ	N _{rot} , %		The effect of anthropogenic impact
		Min-max	MI	
		M±Δ	(w, %)	
1) n=168	<u>0,05-406,60</u> 38,05±4,84	<u>0,0-93,98</u> 37,91±2,05	10,0-57,0 (72,3)	Anthropogenic stress with elements of ecological regress
2) n=62	<u>1,29-2888,00</u> 270,12±75,39	<u>3,09-97,14</u> 50,52±3,72	58-97 (51)	Anthropogenic stress with elements of ecological regress
3) n=111	<u>1,41-2069,25</u> 294,82±36,81	<u>18,75-100,0</u> 85,57±1,68	89,5-100,0 (59,2)	Elements of ecological regress

The share of rotifers is high in all water bodies, which is an indicator of their eutrophication. The largest relative number of rotifers recorded in the Kazanka River. By the level of their development in water bodies, we can say that in the Kuibyshev reservoir and the lake Sredene Kaban anthropogenic strain with elements of ecological regress is traced, whereas in the Kazanka River there are only elements of ecological regress.

The number of zoobenthos, as well as the relative proportion of oligochaetes in it, varied in different water bodies (Table 5).

Table 5. The statistical characteristics of the zoobenthos.

№, n	N _{zb} , mill ind.M ⁻²		N _{ol} , %		The effect of anthropogenic impact
	Min-max	MI	Min-max	MI	
	M±Δ	(w, %)	M±Δ	(w, %)	
1) n=150	<u>0,04-22,44</u> 2,67±0,31	0,04-3,88 (83)	<u>0-93</u> 33,6±2,3	27-93 (52)	Elements of ecological regress
2) n=62	<u>0,0-4,0</u> 0,88±0,12	0,02-0,88 (64,8)	<u>0,0-96,2</u> 28,0±3,8	1,4-29,3 (59,6)	Ecological regression against the background of increased anthropogenic eutrophication
3) n=111	<u>0,04-26,72</u> 1,93±0,28	0,04-2,77 (80,2)	<u>0,0-100,0</u> 37,8±3,0	10,1-63,5 (70,8)	Anthropogenic stress with elements of ecological regress

The maximum values of the number are typical for the Kazanka River; the minimum is for Lake Sredene Kaban. Low development of zoobenthos in Lake Sredene Kaban, the result of long-term pollution of the lake, which led to the strengthening of its eutrophication processes [20] and thus ecological regression of bottom biocenoses.

6. Conclusion

The water bodies of Kazan experience a different anthropogenic impact, the result of which is the low quality of water. An analysis was made of the risk of anthropogenic impact on water bodies in the city of Kazan: the Kuibyshev Reservoir, the Lake Sredene Kaban, Kazanka River. Based on the analysis of long-term information hydrochemical and hydrobiological components, it was found that all water bodies by abiotic components are classified as dirty on the biotic component of ecosystems are at different stages of environmental recourse against the background of anthropogenic eutrophication and

toxic effects. In terms of the degree of risk of anthropogenic impact, urban aquatic ecosystems are in a transitional state from the equilibrium to the critical.

7. References

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