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INTEGRATED ASSESSMENT OF THE ECOLOGICAL STATE OF A WATER BODY UNDER CLIMATE CHANGE CONDITIONS

Research article

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Abstract

The aim of the study was to compare different testing methods and apply an integrated approach to diagnostics of the ecological state of water bodies, including chemical control, water biotesting, biondication of pollution by the characteristics of aquatic communities and biomarkers on the example of the cut-off Lake Ivanovskoye (Russia, Kirov region), that receives wastewater from a combined heat and power plant, and simultaneously communicates with the Vyatka River – a source of drinking water supply. Wastewater and natural water analysews included: pH, hardness, total biological oxygen demand (BOD), mass concentration of dry residue, content of chloride ions, ammonium ions, sulfate ions, calcium, dissolved oxygen, aluminum, fluoride ions, and total iron. Concentration of Cu, Ni, Cd, Pb, Zn, Mo, Fe, Cr, Mn were defined in water samples, silt sediments and organs of indicator plant species. Consideration of indicator species of coastal-aquatic vegetation showed that Lake Ivanovskoe is a water body, which trophicity changes from otrophic to eutrophic and depends on meteorological parameters of the vegetation period, primarily on the average monthly temperature and the amount of precipitation, have a significant impact on the indicators of bioindication, complicates the use of macrophytes in bioindication. Chemical analysis of wastewater from the CHPP entering the lake defined ammonia nitrogen and organic matter (by total BOD) as priority pollutants. The results allow to assume further strengthening of pollution and eutrophication of water bodies within anthropogenic ecosystems.

Keywords: pollution of aquatic environment, biotesting, bioindication, ammonium ions, heavy metals, coastal aquatic vegetation.

КОМПЛЕКСНАЯ ОЦЕНКА ЭКОЛОГИЧЕСКОГО СОСТОЯНИЯ ВОДОЕМА В УСЛОВИЯХ ИЗМЕНЕНИЯ КЛИМАТА

Научная статья

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Аннотация

В работе приведены результаты комплексного подхода к диагностике экологического состояния водных объектов, включающего химический контроль, проведение биотестирования воды, биондикацию загрязнения по характеристикам водных сообществ и биомаркеров на примере озера Ивановское старичного типа (Россия, Кировская область), принимающего сточные воды от теплоэлектростанции и одновременно сообщающегося с рекой Вятка – источником питьевого водоснабжения. Установлены приоритетные загрязняющие веществами: ионы аммония, органические вещества (по биохимическому потреблению кислорода за 20 суток) и тяжелые металлы. Учет индикаторных видов прибрежно-водной растительности показал, что трофность озера Ивановское изменяется от мезотрофного до эвтрофного и зависит от метеопараметров вегетационного периода, прежде всего, от среднемесячной температуры и суммы выпавших осадков, которые оказывают значительное влияние на показатели биоиндикации и затрудняют использование макрофитов в биоиндикации. Результаты исследования позволяют предположить дальнейшее усиление степени загрязнения и эвтрофикации водоемов антропогенных экосистем.

Ключевые слова: загрязнение водной среды, биотестирование, биоиндикация, химический анализ, ионы аммония, тяжелые металлы, прибрежно-водная растительность.

Introduction

State environmental monitoring of water bodies in Russia is carried out by Roshydromet under the programs including hydrochemical, hydrological and hydrobiological indicators, which differ in the coverage of work at observation points of different categories [9], [16], [18]. In the European Union, there is also an important legislative opportunity to promote and implement an integrated approach to the conditions diagnostics and further protection of water bodies [17]. Thus, simultaneous use of methods of chemical analysis, bioindication and biotesting in order to objectively describe the ecological state of water bodies is universally recognized, declared by the scientific community and supported by legislation [16], [17], [18].

The results of integrated screening of water bodies state the importance and informative value of bioindication and biotesting methods, but raise questions concerning bioavailability of pollutants [4], [11].

Works assessing the informative value of biotests [13], as well as proposing biological early-warning systems [14], are aimed at obtaining objective results of biodiagnostics.

Thus, the issue of interpreting the results of comprehensive studies of water quality of surface water bodies remains relevant.

The aim of this work is to compare the results of chemical analysis, biotesting and bioindication on the example of a floodplain cut-off lake, which receives wastewater from one of the most common enterprises of urban systems - combined heat and power plant (CHPP) [3].

Research methods and principles

The object of the study was the cut-off lake – Ivanovskoye, located in the floodplain of the Vyatka River. The main characteristics of the water body are presented in Table 1.

Table 1 - Morphometric and hydrological characteristics of Lake Ivanovskoye

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Indicators	Value
Lake volume	21.8 thousand m³
Water table area	5.74 ha
Lake length	3.8 km
Average depth	4 m
Water level fluctuations	less than 1 m
Water exchange intensity coefficient	more than 50 Intensive

Wastewater from Kirovo-Chepetsk CHPP-3 is discharged into Lake Ivanovskoye through two outlets. Outlet No. 1 discharges untreated wastewater after cooling of units, industrial storm water from the territory of CHPP-3, chemical water treatment of make-up water. Outlet No. 2 is organized for blow-off water of the hydraulic ash removal system, which is discharged without clarification. Water from the lake flows into the Vyatka River through an artificially created Ivanovskaya duct. During spring flooding, the lake can connect with the river.

In accordance with the purpose of the study, we set several objectives, which included: chemical analyses of wastewater and natural water; analyses of HMs content in water and sediments; peculiarities of HM accumulation by indicator species; biotesting of water toxicityl; and comparison of the results of implemented study methods.

Quantitative chemical analysis of wastewater entering Lake Ivanovskoye and water in the channel connecting the lake with the Vyatka River (Ivanovskaya duct) is performed monthly by the accredited laboratory of CHPP-3. Water samples for HMs were taken annually, in the first decade of August, and analyzed in the Institute's laboratory. The data from 2007-2017 were analyzed. Wastewater and natural water were analyzed for the following indicators: pH, hardness, total biological oxygen demand (BOD), mass concentration of dry residue, content of chloride ions, ammonium ions, sulfate ions, calcium, dissolved oxygen, aluminum, fluoride ions, and total iron. Additionally, in the last decade of July 2007, 2010, 2017, 2022 samples were taken from the middle part of the lake to determine the concentration of Cu, Ni, Cd, Pb, Zn, Mo, Fe, Cr, Mn. Concentrations of these HMs were also measured in silt sediments and organs of indicator plant species.

In 2017, water samples were subjected to biotesting. We used certified methods for recording the mortality of daphnia *Daphnia magna* Straus (1820) [6], the biomass growth of *Scenedesmus quadricauda* (Turp.) Breb. by direct counting method in Goryaev chamber [7], by change of chemotaxis of *Paramecium caudatum* Ehrenberg (1838) [5] and by bioluminescence of bacterial preparation "Ecolum" based on conditionally non-pathogenic strain of *Escherichia coli* Migula (1895) [15].

Bioindication of anthropogenic impact on the water body by indicator species of coastal-aquatic vegetation was carried out in 2007, 2010, 2017 and 2022.

Main results

3.1. Chemical analysis

The results of chemical analysis of wastewater and natural waters for the ten-year period showed that of the list of analyzed components, the main pollutant, which annually exceeds the maximum permissible concentrations (MPC), is ammonium ion. The range of its concentrations in the Ivanovskaya duct varied from 0.79 to 3.17 mg/dm3, which is 1.6-6.3 times higher than the norm.

Insignificant exceedances of total biological oxygen demand, up to 1.4 MPC, were regularly observed. A single case of exceeding the content of oil and petroleum products in outlet No. 2 by 1.24 times was detected. Thus, based on the detected high levels of ammonium nitrogen and elevated BOD, Lake Ivanovskoye is characterized by pollution with rapidly and slowly mineralizing organic substances, which brings it closer to a water body of eutrophic type.

The concentration of Fe and Mn in all years of the study also exceeded MPC (Table 2). A significant increase in the concentration of all types of pollutants was noted in 2010, characterized by an increased average monthly temperature (deviation from the monthly average + 4.8°C) and low precipitation (9% of the monthly average) in July.

Table 2 - Concentration of HMs in water samples from the middle part of Lake Ivanovskoe

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Object	Cu, mg/l	Ni, mg/l	Cd, mg/l	Pb, mg/l	Zn, mg/l	Fe, mg/l	Cr, mg/l	Mn,

								mg/l
2007	0.062	0.047	0.005	0.056	0.057	0.156	0.038	0.120
2010	0.093	0.066	0.011	0.082	0.067	0.123	0.042	0.241
2017	0.056	0.044	0.006	0.053	0.051	0.118	0.030	0.098
2020	0.051	0.038	0.008	0.051	0.051	0.148	0.037	0.102
MPC for drinking water*	1.0	0.1	0	-	-	0.3	-	0,1
MPC for fish farms**	0	0	0.01	0.1	0	0.1	-	-

*Note: *MPC for drinking water and domestic water use (GN 2.1.5.689-98; GN 2.1.5.690-98) [10]; **List of MPC for fishery basins [8].*

3.2. Biotesting

When conducting biotesting, the principle of "battery of biotests" was realized, i.e. we did not limit ourselves to the minimum of two necessary methods, but applied 4 different ways of defining toxicity of samples. The results are presented in Table 3.

Table 3 - Biotesting of CHPP-3 wastewater and natural waters of Lake Ivanovskoe

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Water sampling location	Biotesting result by the reaction of different test organisms			
	Mortality of *D. magna*, %	Biomass growth of *S. quadricauda*, % to the control	Toxicity index by *P. caudatum*, c.u.	“Ecolum” toxicity index, c.u.
Wastewater, Outlet №1	0	7±0.7	0.15±0.08	12.5±1.6
Wastewater, Outlet №2	0	8±1.1	0.36±0.06	26.6±5.1
Natural surface water, 500 m from outlet	0	21±1.9	-0.18±0.06	-40.5±11.6
Natural surface water, 3000 m from outlet	0	15±0.9	-0.22±0.9	-36.7±9.5
Ivanovskaya duct	0	14±0.9	-0.25±0.07	-15.4±5.4

The results of biotesting are consistent with the chemical analysis and show that the maximum toxicity levels were found in the samples from outlet 2. According to the test system "Ecolum" toxicity index corresponds with the 2nd toxicity group out of three possible (average toxicity), the toxicity index in the biotest for *P. caudatum* is also close to the 2nd group. At the same time, *S. quadridaudida* and *D. magna* showed no reaction to the pollution.

The rest of the samples should be considered safe according to the used biotesting methods. Low informative value of biotests based on mortality of organisms is quite explainable and understandable from the toxicological point of view. We can agree with the methodological approach proposed in a research paper [8], where daphnia tests are not criticized, but a list of test functions is proposed, thanks to which it is possible to detect low doses of contaminants.

The biomass growth of protococcal algae is slightly higher in natural waters compared to the values obtained for wastewater. We attribute this fact to the presence of a spectrum of biogenic elements necessary for autotrophs for their growth and reproduction in natural waters. Probably, the same reason led to negative toxicity indices (stimulation) in experiments with *P. caudatum* and bacterial preparation based on *E. coli*. It is known that the phenomenon of hormesis, stimulation of vital functions, can also be considered a toxic effect. In our case, the stimulation of test-organisms is probably related to the intake of organic substances into the lake, as evidenced by the regular approach of the BOD indicator to the established standard according to the data of the CCHP-3 laboratory and the defined 3-fold exceeding of the MPC for this indicator (see above).

Thus, when comparing the results of chemical analysis and biotesting, no strict correlation was established, but a number of logical regularities were traced: the pollution level does not reach lethal, but stimulation effects are observed as the first manifestations of toxic stress.

3.3. Bioindication

The results of determining the trophicity of the reservoir by indicator species of coastal aquatic vegetation allowed to attribute the reservoir to the mesotrophic type; in the warmer but damp year of 2007, the trophicity of the reservoir was slightly higher. In dry and hot 2010, when the July temperature exceeded the mean annual norm by 4.8°C and the sum of precipitation reached only 9% of the mean annual values, there was a sharp increase in the frequency of occurrence of dominant indicator species of macrophytes (*Comarum palustre*, *Carex vesicaria*, *Alisma plantago-aquatica*, *Nuphar lutea*).

Assessment of Lake Ivanovskoe pollution level by frequency of occurrence of indicator species of floating and submerged-water macrophytes, such as *Potamogeton perfoliatus*, *Ceratophyllum demersum*, conducted in 2007, 2010, 2017 and 2022 in accordance with the methodology showed that the level of pollution in different parts of the reservoir in all years of the study (except 2022) ranged from weak to borderline between strong and moderate. In the dry and hot year of 2010, the pollution level of the whole water body was strong.

Thus, eutrophication of the water body could be predicted based on the main chemical impact on the water body. The results of bioindication confirmed the hypothesis. Moderate pollution of the lake was detected; the ecological type of the water body was mesotrophic in cool and wet years. In hot and dry year 2010, severe pollution of the lake was documented. Its ecological type changed to eutrophic. In the same year, a significant increase in the concentration of some pollutants such as Cu, Ni, Cd, Cd, Pb, Zn, Mo, Fe, Cr, Mn was observed. There is evidence in the literature that the characteristics of coastal plant communities are highly informative as aquatic environmental indicators of dissolved oxygen, water temperature, turbidity, total suspended sediment, nitrate and orthophosphate [1], [2]. However, as shown in the study, the meteorological characteristics of the vegetation period, primarily average monthly temperature and precipitation, have a significant impact on bioindication indicators, which makes it difficult to use macrophytes in bioindication [3].

Conclusion

The results of chemical analysis of wastewater from the CHPP entering the lake defined ammonia nitrogen and organic matter (by total BOD) as priority pollutants. This type of pollution usually leads to eutrophication processes to a varying extent. This was confirmed by assessing indicator macrophytes, some of which showed a moderate to strong change in the level of pollution of the water body depending on the meteorological parameters of the year. The selected "battery of biotests" confirmed the increased hazard of wastewaters compared to surface waters of Lake Ivanovskoye. However, the moderate level of pollution of the lake, revealed by bioindication, was not established. Consequently, bioindicator organisms, being a part of the ecosystem and continuously experiencing pollution, turned out to be more sensitive than test organisms used in biotesting. Dependence of the results of biotesting and concentration of some pollutants on meteorological parameters of the summer period suggests further strengthening of pollution degree and eutrophication of water bodies of anthropogenic ecosystems under climate change conditions.

Конфликт интересов

Не указан.

Рецензия

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Conflict of Interest

None declared.

Review

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