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Article

Water quality assessment in the Gorky Reservoir (Volga River, Russia) based on biotesting and chemical analysis

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Abstract. In 2010–2022, the toxicological characteristics of the Gorky Reservoir waters were studied using the biotesting method with the cladoceran *Ceriodaphnia dubia* Richard, 1894. A statistically significant decline in the fecundity of crustaceans in the lake section (regardless of the year of observation), compared to the river part of the reservoir, was recorded. The chemical composition of the surface waters of the Gorky Reservoir in September 2015 was distinguished by the excess of the maximum permissible concentration established for fishery (MPC_{fish}), i.e. for Cu (16.8–38.3) and Zn (1.1–3.4). Their peak concentrations (38.3 and 3.4, respectively) were detected at the Sezema River station. Downstream, a gradual increase (by1.1–3.5 times) in concentrations of Sr, Mo, Si, As and V occurred, being maximum at the dam section. During the observation period, a tendency towards a decrease in the average toxicity index was noted for the reservoir as a whole. Unlike other sites, the lake section of the reservoir (regardless of the year of observation) demonstrated a statistically significant reduction in the crustacean fecundity. This was due to water contamination, as evidenced by the results of correlation analysis and the presence of higher concentrations of the studied chemicals in sampling stations located within this section.

Keywords: toxicity, *Ceriodaphnia dubia*, pollution

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Научная статья

Оценка качества воды Горьковского водохранилища (р. Волга, Россия) по данным биотестирования и химического анализа

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Аннотация. Исследованы токсикологические характеристики воды Горьковского водохранилища методом биотестирования с использованием ветвистоусого рачка *Ceriodaphnia dubia* Richard, 1894 за период 2010–2022 гг. Для озерного участка водохранилища (без учета года наблюдения) зарегистрировано статистически значимое снижение плодовитости рачков по сравнению с речным участком. Химический состав поверхностных вод Горьковского водохранилища в сентябре 2015 г. отличался превышением предельно допустимой концентрации для водных объектов рыбохозяйственного значения ($ПДК_{р/х}$) по Cu (16.8–38.3 $ПДК_{р/х}$) и Zn (1.1–3.4 $ПДК_{р/х}$). Максимальные концентрации этих элементов отмечены на станции речного участка р. Сезема (38.3 и 3.4 $ПДК_{р/х}$ соответственно). Для Sr, Mo, Si, As и V наблюдали постепенное увеличение их концентрации вниз по течению с максимальными значениями в приплотинном участке. Увеличение составило 1.1–3.5 раз. В целом для водохранилища за период наблюдений отмечена тенденция к снижению средних значений индекса токсичности. Для озерного участка водохранилища без учета года наблюдения отмечено статистически значимое снижение плодовитости рачков по сравнению с другими участками. Это связано с загрязнением воды, о чем свидетельствуют данные корреляционного анализа и более высокие концентрации исследованных химических элементов на станциях, расположенных на этом участке.

Ключевые слова: токсичность, Ceriodaphnia dubia, загрязнение

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Introduction

The large industrial and agricultural potential of the Volga-Caspian basin, as well as natural-climatic factors greatly contribute to the changes in the chemical and toxicological characteristics of the aquatic environment and, as a consequence, to the transformation of the habitat of aquatic organisms (Rylina et al., 2013). The Gorky Reservoir was created in 1955–1957 at the Volga River section between the cities of Rybinsk and Gorodets during the Gorky Hydroelectric Power Plant construction. The great length of the reservoir in the Volga cascade determines its importance in water supply, shipping and recreation. Geographically, the Gorky Reservoir is situated within the densely populated industrial regions of European Russia (Yaroslavl, Kostroma, Ivanovo and Nizhny Novgorod oblasts) and undergoes significant anthropogenic pressure. The characteristics of its water (especially in the upper part) largely depend on the waters of the Rybinsk Reservoir. The low sections consist of the water masses of the Gorky Reservoir itself (Frolova et al., 2020).

The annual inflow of polluted water to the reservoir reaches 6 km^3. In the past few years, the waters of the Gorky Reservoir are considered to be "very polluted" (class 3, category B) and "dirty" (class 4, category A) according to the Upper Volga Department for Hydrometeorology and Environmental Monitoring[1]. The composition of key pollutants of the reservoir remains constant in recent years. These are copper, zinc, manganese, iron, difficult-to-oxidize organic matter (by COD), easily oxidizable organic matter (by BOD_5), ammonium nitrogen, oil products, phenols, nitrites, formaldehydes, and synthetic surfactants (Frolova et al., 2020; Igonina et al., 2016; Kochetkova, 2010).

Nowadays, biotesting is a technique capable to improve the system of assessment and the quality control of environmental objects. Not replacing a quantitative chemical analysis, biotesting precedes and complements it owing to promptness, ease of implementation and low costs of analysis (Bakaeva et al., 2020). Biotesting methods allow assessing the impact of a range of contaminants on living organisms of different systematic affiliation both in the controlled laboratory experiments and in the natural environments with unspecified toxicity factors. In biotesting, cladocerans are among the organisms most commonly used for assessing the quality of natural waters (Zhmur, 2018). Previously, water toxicity was evaluated in some sections of the Gorky Reservoir and its tributaries (Kovaleva, 2003; Krylova and Tomilina, 2000; Marchenko, 2016; Tyukanova et al., 2019). These one-time studies were conducted on the reservoir tributaries and at the stations located near large cities of Yaroslavl and Rybinsk. Note that they do not reflect the interannual trends in toxicity dynamics and do not cover the entire water area of the Gorky Reservoir.

The aim of the work is to estimate the integrated toxicity of the Gorky Reservoir waters using biotesting methods, as well as to establish the cause-and-effect relationships between the level of pollutant concentrations and the response of test organisms.

[1] State report “State of the environment and natural resources of the Nizhny Novgorod region in 2019”, 2020. Ministry of Ecology and Natural Resources of the Nizhny Novgorod Region.

Materials and methods

In 2010–2022, water samples were collected at 33 stations during the complex expeditions aboard the "Akademik Topchiev" vessel of IBIW RAS. Sampling stations were located in the flooded bed of the Volga River, at the mouths of rivers flowing into the reservoir and in the populated areas. In terms of sedimentation conditions, the reservoir was divided into 3 sections according to V.V. Zakonnov (2015): river (upper), lake (lower), and the Kostroma Reach (Fig. 1).

Integral water samples (139 samples) were collected with the Elgmork bathometer (Korneva, 2015) sequentially from each 1-meter layer from surface to bottom. Water was filtered through ash-free "white ribbon" filters. To determine metal concentrations, 50 ml of filtered water was placed in Falcon centrifuge tubes and acidified to 0.1 N with nitric acid. For biotesting, filtered water was poured into food grade plastic bottles (0.5 l) with tightly screwed caps to exclude oxygen ingress. Prior to biotesting, the samples were stored in a refrigerator at a temperature of +2...+4 °C for 14 days.

To measure the concentrations of chemical elements we used an ICP MS ELAN DRC-e inductively coupled plasma mass spectrometer (Perkin Elmer, USA) and the Total Quant Analysis method. For the instrument calibration, multi-element standards for Perkin Elmer (USA) were applied; In was employed as an internal standard (Taylor, 2001).

Biotesting of water samples was carried out with the use of the laboratory culture of planktonic cladocerans *Ceriodaphnia dubia* Richard, 1894 in accordance with the standard method (Mount and Norberg, 1984). In the course of the experiment, every two days during the medium change, the animals were fed with green algae *Chlorella vulgaris* Beijerinck, 1890 in concentrations of 250–300 thous. cells/ml[2]. The death of at least 50% of crustaceans within 48 hours in the test water served as the criterion of acute toxicity, provided that their death in the control did not exceed 10%. The death of 20% or more of the test organisms and a significant deviation in their fecundity during the experiment, compared to the control, were the criteria of chronic toxicity[2]. An increase in the crustacean fecundity more than 30% was also considered as a manifestation of chronic toxic effect (CTE) (Aleksandrova, 2009; Olkova and Dabakh, 2014; Zhmur, 2018).

In the experiments, the following optimal environmental conditions were maintained: water temperature of 21 ± 3 °C, pH 7.5–8.0, dissolved oxygen at the saturation level. Light regime (light: 16 hours, darkness: 8 hours) was provided with white light lamps. The control group of test organisms was kept under similar conditions in the settled artesian water.

To obtain the comparable results of biotesting, the toxicity index (TI) was calculated from the formula:

$$TI = TP/TPc,$$

where TP is the value of the test parameter in the experiment and TPc in the control.

The average toxicity index was estimated for each site and the reservoir as its annual mean. The proportion of CTE stations from their total number was calculated.

The data are presented as mean values and their errors (x ± SE). The significance of differences was estimated from the analysis of variance (ANOVA, LSD test) at a significance level $p = 0.05$ (Sokal and Rohlf, 1995). The studied parameters characterized by asymmetric distribution (the Shapiro–Wilk test) were analyzed using the Spearman correlation coefficient (r_s, $p < 0.05$).

Results

According to the results of ceriodaphnia-based biotesting, the absence of acute toxic effects was reported for all samples studied in 2010–2022. For 10 days of exposure, the mortality of crustaceans (MPC_{fish} excess of 20%) and, consequently, CTE were recorded in the samples from the stations at Rybinsk city (below the treatment facilities, Kopaevo microdistrict), Tunoshna and Krasny Profintern settlements, the Sezema River, the Kostroma Reach, below Kostroma city, Volgorechensk and Ples towns, downstream Kineshma town, Puchezh town, mouths of Unzha and Kotorosl rivers.

The average number of juveniles per 1 female in the reservoir sections was usually lower than in the control (Fig 2), except for the river (2010) and lake (2010, 2015, 2016) parts, where the fecundity

[2] FR.1.39.2007.03221. Methodology for determining the toxicity of water and water extracts from soils, sewage sludge, waste by mortality and changes in the fertility of ceriodaphnia.

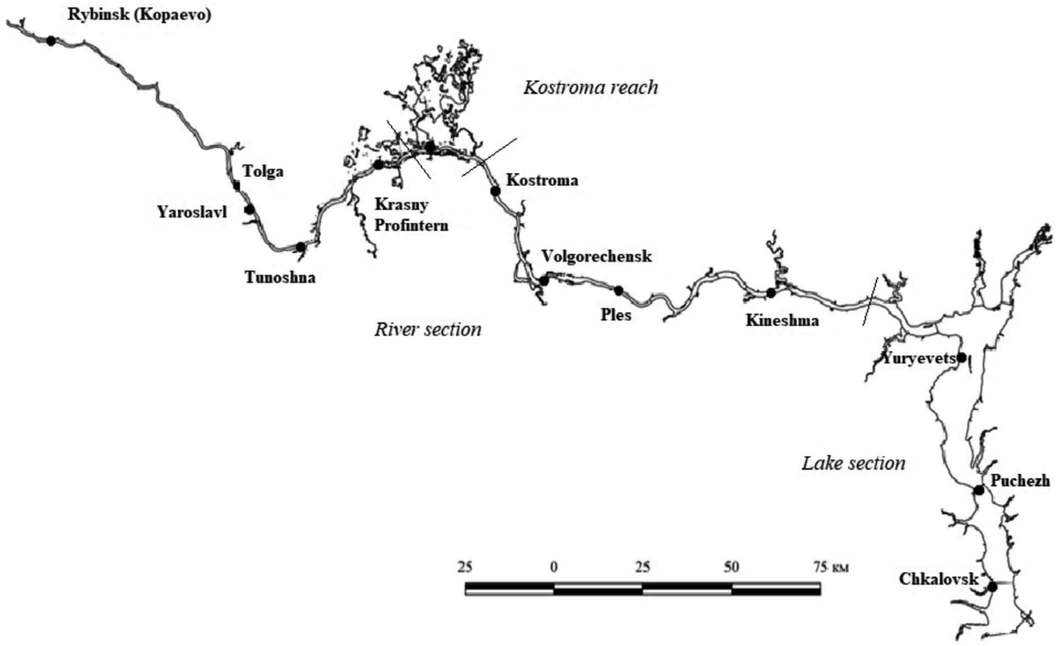

Fig. 1. Schematic map of water sampling in the Gorky reservoir.

was significantly higher than in the control. Since 2017, a tendency towards a decrease in the average crustacean fecundity by 30–50%, compared to the control, has been noted in all sections of the reservoir.

For the observation dates, there were no significant differences in IT dynamics by the crustacean fecundity between the sections (Table 1). The exception was the year 2017, when IT statistically significantly decreased (water toxicity increased) downstream. Its minimum was recorded in the lake section of the reservoir (0.24) and maximum in the river site (0.55). The least average value of IT (regardless of the year of observation) was noted for the Kostroma Reach (0.75). Over the entire observation period, the highest (0.24) and lowest (1.44) average values of IT were recorded for the lake section in 2017 and 2010, respectively. In general, a downward trend in the average (IT) was observed in the reservoir during the study period (Fig. 3).

In 2012, water samples from all investigated stations were not classified as toxic (Fig. 4), whereas in 2013, they, on the contrary had a chronic toxic effect. The maximum average number of CTE stations was registered in the river section of the reservoir: 44.7% of the total number of stations. At the same time, the proportion of stations where reproductive parameters of crustaceans declined by more than 50% (compared to the control) made up 21.9 and 15.5% for the lake and river sections, respectively.

To identify possible causes of water toxicity, one should know the level of its contamination. Unfortunately, no regular measurements of harmful substances in the Gorky Reservoir waters were made. There are only our own data (2015) on water pollution with some chemical elements (Table 2). In most cases, the content of heavy metals in water was lower or corresponded to the previously recorded average concentrations in the upper and lower reaches of the Volga River (Moiseenko et al., 2006; Tatarnikov and Gavrilova, 2019). The exceptions were such elements as Cr, Cu and Zn. Higher concentrations of Cr were detected at the sampling sites of the river section, i.e. at Tolga and Tunoshna settlements, the Sezema River and below Kineshma city. Compared to the average concentrations for the Volga River, the increased content of Cu and Zn was noted in all studied stations of the reservoir, showing the 7 and 5-fold excess on average. In all sampling stations, Cu and Zn concentrations exceeded MPC_{fish} (Table 2). For Cu, this indicator was 16.8–38.3. Its concentrations above 30 μg/l were found for the stations of Tunoshna settlement, the Sezema River mouth, and Puchezh town. For Zn, the MPC_{fish} excess made up 1.1–3.4. High concentrations (over 6.5 μg/l) of Zn were at the stations of Tunoshna settlement, the Sezema River mouth, towns Yuryevets and Puchezh. Maximum concentrations of Cu and Zn (38.3 and 3.4 MPC_{fish}, respectively) were recorded for the station at the Sezema River connecting the Kostroma Reach with the Gorky Reservoir. Cr, Ni, Cu, and Zn were unevenly distributed in the reservoir waters. A growing (by 1.1–3.5 times) concentrations of Sr, Mo, Si, As and V downstream, with peak values in the dam section, were observed (Table 2).

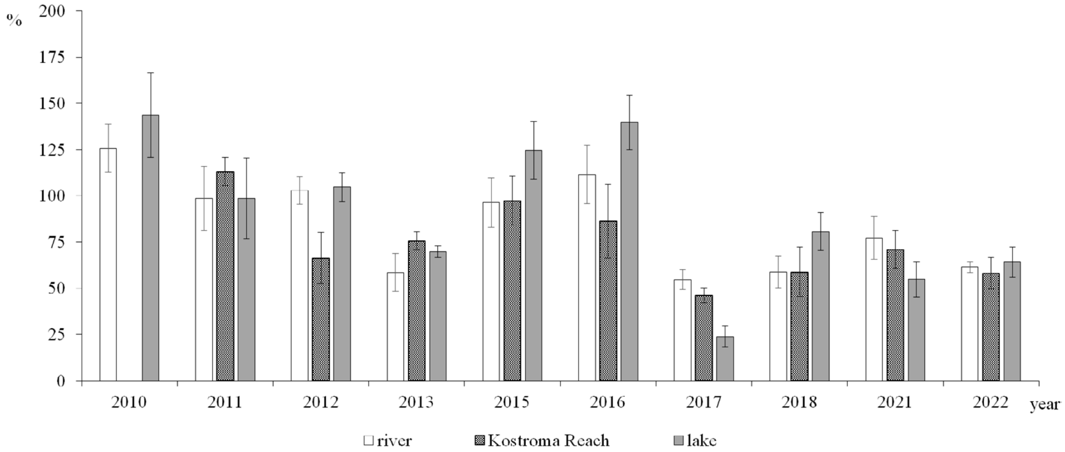

Fig. 2. Dynamics of chronic toxicity of water in various sections of the Gorky reservoir according to the indicator of fertility of *Ceriodaphnia dubia* (average number of juveniles per 1 female for 7 days, % of control). Direct line – control (100%).

Table 1. The average toxicity index of water in various sections of the Gorky Reservoir based on the average number of juveniles per 1 female *C. dubia*. $^{a, b, c}$ – the indices of statistically significant differences; the number of samples is given in brackets; "–" no data available**.**

Year	Section			Reservoir
	river	Kostroma Reach	lake	
2010	1.26 ± 0.13 (9)	–	1.44 ± 0.23 (4)	1.31 ± 0.11 (13)^{de}
2011	0.98 ± 0.17 (6)	1.13 (1)	0.99 ± 0.22 (4)	1.00 ± 0.12 (11)^{c}
2012	1.03 ± 0.07 (5)	0.66 (1)	1.05 ± 0.08 (5)	1.00 ± 0.06 (11)^{c}
2013	0.59 ± 0.10 (3)	0.76 (1)	0.70 ± 0.03 (7)	0.67 ± 0.03 (11)^{ab}
2015	0.96 ± 0.13 (10)	0.97 (1)	1.25 ± 0.16 (3)	1.03 ± 0.10 (13)^{c}
2016	1.12 ± 0.16 (9)	0.86 (1)	1.40 ± 0.15 (3)	1.16 ± 0.12 (13)^{cd}
2017	0.55 ± 0.05 (9)^{b}	0.46 (1)^{ab}	0.24 ± 0.06 (3)^{a}	0.47 ± 0.05 (13)^{a}
2018	0.59 ± 0.09 (9)	0.59 (1)	0.81 ± 0.10 (5)	0.66 ± 0.07 (15)^{ab}
2021	0.77 ± 0.12 (18)	0.71 (1)	0.55 ± 0.09 (7)	0.71 ± 0.09 (26)^{b}
2022	0.61 ± 0.03 (10)	0.58 (1)	0.64 ± 0.08 (2)	0.62 ± 0.03 (13)^{ab}
Average	**0.84 ± 0.04 (87)**	**0.75 ± 0.07 (9)**	**0.87 ± 0.06 (43)**	**0.84 ± 0.03 (139)**

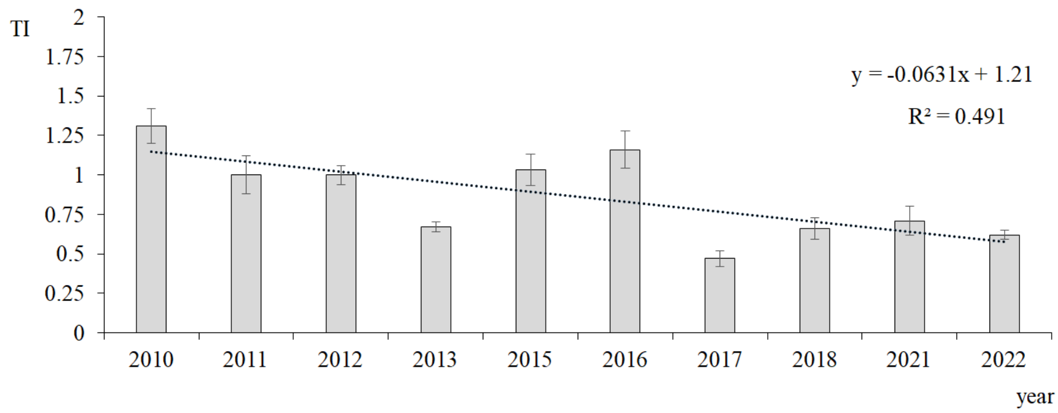

Fig. 3. The toxicity index of the Gorky reservoir water (% of the total number of stations)

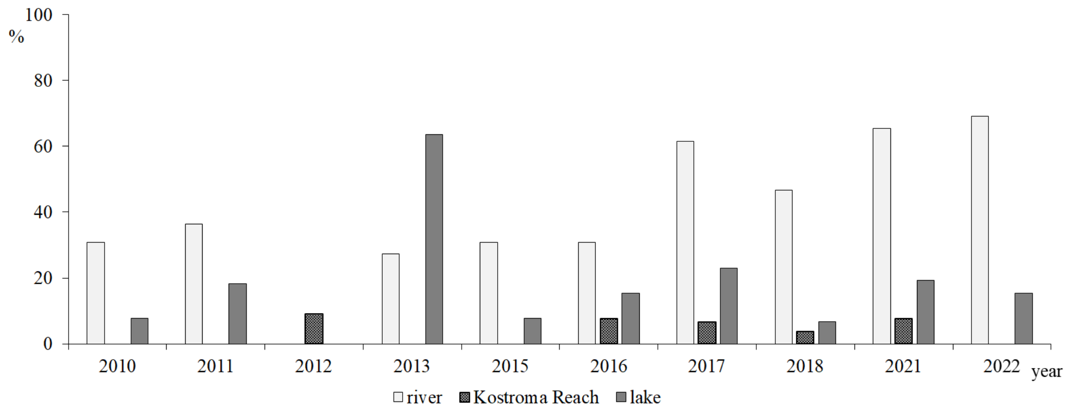

Fig. 4. The share of stations (% of the total number of stations) in various sections of the Gorky reservoir with chronic toxic effects of water for the period 2010–2022.

To establish the relationship between the content of toxic substances and water suitability for aquatic organisms, we performed the correlation analysis and established the Cu dependence (r_s = −0.57, p = 0.05) of ceriodaphnia mortality (Table 3). Despite meaningful correlations between the content of Cu and crustacean mortality, the regression model turned out to be insignificant (R2 = 0.293). Reproductive indicators depended on the concentrations of such elements as Li, Na, V, As, Sr and Mo. The regression models for the average number of juveniles per female and concentrations of Li, V, As appeared to be unreliable. The strongest dependencies (r_s = 0.77–0.81, p = 0.001–0.002) were established between the content of Li, V, As, Sr and the average number of litters per female (Table 3).

Discussion of results

In the course of biotesting, the absence of acute toxicity of the water from the Gorky Reservoir and low mortality of crustaceans during the exposure period were evidence of survival of most test specimens. Other authors also stated about the absence of acute toxicity in the water area under study. Biotesting of waters from the Volga River tributaries (Sunzha, Kazokha, Kineshemka, Mera) revealed acute toxicity for the crustacean *Daphnia magna* Straus, 1820 (Marchenko et al., 2016). K.A. Tyukanova et al. (2019) made the same conclusions about water toxicity for these watercourses based on biotesting with the use of *Ch. vulgaris* Beijerinck, 1890 and *D. magna.*

Table 2. The content of some chemical elements (μg/l) in the Gorky Reservoir water (September 2015). "–" no data available; MPC_{fish} excess is indicated in bold.

Station	Si	V	Cr	Ni	Cu	Zn	As	Sr	Mo
River section									
Rybinsk city (Kopaevo microdistrict)	289.2	0.2	0.0	0.0	**23.6**	**19.4**	0.5	125.4	0.2
Tolga settl.	370.7	0.3	1.8	0.0	**16.8**	**11.2**	0.7	136.6	0.3
Tunoshna settl.	325.3	0.3	1.4	0.0	**36.5**	**27.5**	0.7	137.5	0.3
Krasny Profintern settl.	379.1	0.3	0.0	0.0	**19.9**	**14.4**	0.8	130.4	0.3
Sezema River	404.7	0.3	1.7	0.3	**38.3**	**34.2**	0.8	136.5	0.4
below Kostroma city	359.4	0.4	0.0	0.0	**22.3**	**13.2**	0.9	137.2	0.4
Volgorechensk town	245.8	0.4	0.0	0.3	**29.6**	**15.6**	0.9	140.8	0.4
below Ples town	256.4	0.5	0.0	0.0	**29.7**	**11.8**	0.9	141.8	0.4
below Kineshma town	370.2	0.6	1.4	0.0	**19.1**	**20.2**	1.1	143.0	0.4
Kostroma Reach									
Kostroma Reach	356.9	0.4	0.0	0.2	**25.9**	**20.8**	0.8	135.1	0.4
Lake section									
Yuryevets town	502.5	0.7	0.0	0.3	**25.2**	**23.8**	1.3	141.9	0.5
Puchezh town	477.4	0.7	0.0	0.4	**31.5**	**24.2**	1.3	148.8	0.5
Chkalovsk city	756.4	0.7	0.0	0.2	**23.4**	**10.6**	1.5	143.1	0.4
Average content in waters of Volga River (upper and middle reaches) (Moiseenko et al., 2006)	860	1.1	0.7	2.1	3.7	4.0	1.6	169	0.5
MPC_{fish} [3]	–	1	70	10	1	10	50	400	1

[3] Order of the Ministry of Agriculture of Russia dated December 13, 2016 No. 552 "On approval of water quality standards for water bodies of fishery importance. including standards for maximum permissible concentrations of harmful substances in the waters of water bodies of fishery importance" (Registered with the Ministry of Justice of the Russian Federation on January 13, 2017 N 45203).

Table 3. The relationship between the chemicals content and analyzed indicators of *C. dubia* during biotesting of the Gorky Reservoir water (2015).

Parameter	Spearman correlation coefficient, p ≤ 0.5	Regression equation	R^2
Death, 10 days	Cu (−0.570)	9.706−0.311×Cu, r=−0.54, p=0.056	0.293
Average number of litters	Li (0.766)	−8.794+5.872×Li, r = 0.781, p = 0.002	0.610
	Na (0.697)	−2.637+0.002×Na, r = 0.703, p = 0.007	0.494
	V (0.752)	1.890+2.952×V, r = 0.806, p = 0.001	0.650
	As (0.750)	1.688+1.619×As, r = 0.727, p = 0.005	0.528
	Rb (−0.636)	6.485−3.388×Rb, r = −0.541, p = 0.057	0.292
	Sr (0.769)	−7.807+0.080×Sr, r = 0.771, p = 0.002	0.595
	Mo (0.758)	1.125+5.583×Mo, r = 0.661, p = 0.014	0.436
Average number of juveniles per 1 female	Li (064)	104.251+63.037×Li, r = 0.615, p = 0.025	0.378
	Na (0.624)	−59.495+0.030×Na, r = 0.742, p = 0.004	0.551
	V (0.591)	−11.121+30.174×V, r = 0.604, p = 0.029	0.366
	As (0.586)	9.556+16.018×As, r = 0.527, p = 0.064	0.278
	Sr (0.663)	−117.741+1.029×Sr, r = 0.731, p = 0.005	0.535

During the observation period, there was a tendency towards a decrease in the average IT. For instance, an increase in the integral toxicity of water was recorded for the crustacean fecundity (Fig. 2), rates of which were statistically significantly lower for the lake section (regardless of the year of observation) than in other reservoir sites. This phenomenon was associated with water pollution, as evidenced by the results of correlation analysis (Table 3) and higher concentrations of As and Sr in waters of the lake section (Table 2).

Experiments for establishing CTE, during which such parameters as changes in motor and feeding activity, reproduction rate, etc. are measured, more adequately reflect the pollution of natural waters. Reproductive indicators are among the most sensitive (Olkova and Makhanova, 2018). In our study, the average rates of the ceriodaphnia fecundity in the sections did not reach the control values (Fig. 2), except for the river (2010) and lake (2010, 2015, 2016) parts where this indicator was significantly higher than in the controls. This may be due to the increased average temperature of water during this period. In years with normal temperatures, the average monthly temperature of the surface water layer fluctuated within 18.4–23.0 °C, with the average long-term of 20 °C. In 2015–2016, the warming of the water surface most often exceeded the norm by 1.5–6 °C, being especially strong in the summer of 2016 (Gerasimov et al., 2017). However, the previous studies did not contain the information about an extremely strong water warming (27.6 °C) in the summer of 2010, covering a large area of the Gorky Reservoir (Kopylov et al., 2013). It is well-known that rise in water temperature prolongs the growing season, increases the availability of nutrients, reduces the number of predators and leads to the uncontrolled development of algae (Cazzolla Gatti, 2016), often used as extra food for crustaceans in laboratory testing conditions. Increased concentrations of chlorophyll *a* in the shallow Kostroma Reach of the Gorky Reservoir and throughout (below the sites of tributaries inflow) indicate the growing phytoplankton production in 2015–2020 (Mineeva et al., 2022).

The chemical composition of the surface waters of the Gorky Reservoir in September 2015 was distinguished by the increased MPC_{fish} for Cu[4] (16.8–38.3) and Zn (1.1–3.4) (Table 3). The MPC_{fish} excess for Zn (1.3) and Cu (7.7) was also reported in other studies[5]. The average annual inflow of waters to the Gorky Reservoir made up 55.4 km^3, which by 70–90% was formed of the Volga waters coming from the Rybinsk Reservoir located upstream (Mineeva et al., 2022). Previously, the Rybinsk Reservoir was characterized by high concentrations of Cu and Zn caused, among other things, by natural geochemical features of this region (Gapeeva, 2019; Tomilina et al., 2018). In addition, the concentrations of Fe (on average 3.2), Mn (5.8) and COD (2.7) also exceeded MPC_{fish}. The average concentration of components such as sulfates, BOD_5, oil products, ammonium nitrogen, chlorides, nitrites, nitrates, phenols, dissolved oxygen and Ni ions were within MPC_{fish} throughout the observation period. The reservoirs of the Volga cascade, including the Gorky Reservoir, showed the increased content of biogenic substances because of high anthropogenic loads on the ecosystems in the densely populated industrial regions of European Russia (Rivers..., 2021).

The assessment of the surface water quality depends on objectives, approaches and methods of study. To obtain the data on chemical contamination of a waterbody, it is sufficient to evaluate its water quality using the pollution indices. The average value of the specific combinatorial index of water pollution for the study period in the Gorky Reservoir is 2.77 that corresponds to quality class 3A, "polluted". The quality of water in the upper reaches (from Rybinsk to Yuryevets) mainly depends on the waters coming from the Rybinsk Reservoir, as well as on the water content, amounts of industrial and domestic discharges, including concentrations of hazardous substances (Kochetkova, 2010).

One of the problems of biotesting methodology is the interpretation of data on natural water toxicity caused by anthropogenic factors, as well as the establishment of the relationships between the pollutant content and the detected total toxicity (Olkova and Dabakh, 2014). Correlation analysis reveals strong significant dependences between the content of some chemical elements and biological parameters of the cladoceran *C. dubia* (Table 3). Metals are always present in nature in various concentrations. Microconcentrations of many metals play an important role in the metabolic processes of living organisms and participate in biological functions (e.g. oxygen transport, free radical binding). They are a part of macromolecules, enzymes, hormones ensuring normal vital activity. However, in high concentrations, they can have a toxic effect on aquatic organisms. The strongest dependences have been found between the content of Li, V, As, Sr and the average number of litters per female (Table 3). Some authors (Byeon et al., 2021, Zhang et al., 2022) consider As to be a vital microelement classifying as an ultramicroelement. Microelements, e.g. Se, V, Cr and Ni, are necessary for the organism in trace amounts. In high concentrations, As and V compounds are toxic to living organisms (Meina, 2020; Sharma and Sohn, 2009).

To have a comprehensive notion about the ecological and toxicological situation in the reservoir, it is important to make evaluations based both on physicochemical and biological methods of analysis. It is worth noting that the results obtained by different methods for water quality control do not always coincide. According to the hydrochemical indicators, the water of the Gorky Reservoir and its tributaries refers to "polluted" and "dirty", whereas by the hydrobiological ones it is "weakly polluted". Active movement of mobile aquatic organisms induced by water masses and the delayed effect on indicator species of phyto- and zooplankton are responsible for the differences in evaluations. Biotesting methods usually assess water quality as toxic and/or non-toxic. Thus, biotesting results provide an integral assessment of water quality, taking into account the impact of all chemical compounds. Bioindication, to a greater extent, relies on the trophic factor (eutrophication) and ensures assessing the quality of water with different level of pollution (Bakaeva et al., 2022). At the same time, the structure and functioning of aquatic communities are influenced not only by chemical parameters, but also physical and geographical features of the reservoir.

Conclusion

During the observation period (2010–2022), the average toxicity index of the Gorky Reservoir waters decreased by 2.2 times. For the lake section of the reservoir (regardless of the year of observation), lower rates of the crustacean fecundity, compared to its other sections, were recorded. This is due

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[4] Order of the Ministry of Agriculture of Russia dated December 13, 2016 No. 552 “On approval of water quality standards for water bodies of fishery importance. including standards for maximum permissible concentrations of harmful substances in the waters of water bodies of fishery importance" (Registered with the Ministry of Justice of the Russian Federation on January 13, 2017 N 45203).

[5] Report on the state of water quality in the Gorky, Cheboksary and Kuibyshev reservoirs in the area of responsibility of the Institution in the first half of 2016, 2016. Federal Agency of Water Resources State Federal Institution of Engineering Protection of the Cheboksary Reservoir in the Nizhny Novgorod Region.

to water pollution, as evidenced by the results of correlation analysis and higher concentrations of chemical elements at stations located in the lake section of the reservoir.

In September 2015, the MPC_{fish} excess for Cu and Zn in the surface waters of the Gorky Reservoir was recorded. The maximum content of these elements we detected at the Sezema River station. A gradual increase in concentrations of Sr, Mo, Si, As, V was observed downstream, with the highest values present in the dam section.

The maximum average number of stations with CTE on *C. dubia* falls on the river section of the reservoir.

In chemical and hydrobiological studies, water biotesting can serve as an additional source of information and an effective tool for assessing possible biological consequences of pollution.

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