Current aspects of freshwater quality protection in the Arctic zone of the Russian Federation

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Abstract. The state of freshwater reservoirs is a component of the complex conceptual space of the Arctic zone. On the example of the largest reservoir of the Arctic zone of the Russian Federation Lake Imandra, the article describes the current trends in water quality changes due to the massive development of potentially toxic cyanobacteria, which is not typical of high latitudes. "Blooming" of waters deteriorates water quality, causes deaths of valuable fish species, deteriorates the recreational attractiveness of water bodies. As a result of complex long-term observations, the main reasons for these phenomena were established. These are a change in the hydrochemical parameters of water along with the Arctic climate system. A decrease in the intake of toxic heavy metals and a high level of biogenic elements have created favorable conditions for the development of phytoplankton, including cyanoprokaryotes. To prevent the environmental risks of water quality deterioration and justify the adoption of strategic decisions for drinking and fishery water bodies in the urbanized regions of the Arctic, it is recommended to control the concentration of nutrients and the ratio of ammonium nitrogen to nitrate nitrogen.

1. Introduction

The preservation of the natural system of the Arctic while enhancing the use of the resource and transport potential of the Arctic zone of the Earth requires a systematic analysis of the features of this territory. Is necessary to develop methods for monitoring, analyzing and forecasting the natural and anthropogenic processes. The solutions should provide a comprehensive account of factors, be based on an interdisciplinary approach and allow the sharing of knowledge and data obtained in various areas. The development of new solutions based on the interdisciplinary approach can be facilitated by the use of information resources that combine structured information about various studies conducted in the Arctic zone [1].

One of the "tools" for obtaining solutions with these properties is the use of a generalized interdisciplinary conceptual space based on the dimensions of quality [2]. Conceptual space (CP) allows you to characterize complex objects from the perspective of various subject areas.

The method for creating an interdisciplinary CP based on a limited set of tasks from several subject areas that play an important role for situational control of spatial systems of the Arctic zone of the
Russian Federation (AZRF) is developed within the RFBR project No. 18-29-03093-mk. The project is aimed at creating a prototype of a CP on the example of a generalized space of situational modeling [3] of industrial-natural systems and freshwater ecosystems of the Russian Arctic, taking into account their mutual influence and risks of non-standard situations caused by large-scale atmospheric phenomena.

The long-term anthropogenic load in the industrially developed regions of the Arctic has caused the degradation of aquatic ecosystems and decreased the resource potential of fresh waters, as well as caused significant rearrangements in the communities of aquatic organisms. The processes of degradation of inland water bodies in Murmansk region as a result of long-term exploitation of natural resources have led to a shortage of high-quality fresh water and valuable hydrobiological resources, which can become one of the main factors of socio-economic and political instability [4]. Thus, the phenomena of mass development of algae and cyanoprokaryotes, previously characteristic of temperate and southern latitudes, are regularly manifested in the Arctic water bodies subject to the anthropogenic eutrophication. For the largest Arctic Lake Imandra, located in Murmansk region, water bloom has been regularly recorded since the beginning of the XXI century [5].

Research on causes and consequences of water blooming during the mass development of cyanoprokaryotes is one of the most urgent scientific directions. World experience [6, 7] shows that modern climate warming is one of the key factors in regulating the development of cyanobacteria, and to predict blooming processes, it is necessary to know the species composition and identify the threshold values of regulatory factors, including hydrological and geochemical conditions of water quality. For the reservoirs of the Arctic zone, information on the development of these processes has been insufficiently studied, which complicates the assessment of the environmental risks and adequate protection of fresh waters in the Arctic zone of the Russian Federation (AZRF).

The aim of this article is to analyze reasons for the massive development of cyanoprokaryotes in the Arctic water bodies. The analysis was based on the long-term comprehensive monitoring observations. The analysis specified indicators which should be taken into account when assessing situational awareness of water quality and developing measures for the protection of water resources, taking into account the specifics of the Russian Arctic.

2. Materials and methods
The material for the study was results of the long-term (1992–2019) complex ecological observations of water quality in Lake Imandra. This is one of the largest reservoirs in the Euro-Arctic region, experiencing powerful anthropogenic impacts. On its shores, there are ferrous and non-ferrous metallurgy and apatite production enterprises and one nuclear power plant (Fig. 1). The powerful anthropogenic load associated with the influx of industrial and household wastewater has changed the quality of water and restructured the structural and functional characteristics of the ecosystem [8]. Since the beginning of the 21st century, the climatic factor and the input of nutrients caused the eutrophication of the reservoir [9] and adaptation of communities of aquatic organisms to new conditions, which also created opportunities for the mass development of cyanoprokaryotes [10].

The selection and analysis of water samples were carried out using the unified recommended standard methods adopted in the world and domestic practice described in [8, 11]. All analytical procedures were carried out on the basis of the IPPES Collective Use Center of the KSC RAS. The selection and analysis of phytoplankton samples were carried out according to the methods generally accepted in the world and domestic practice [12], according to the scheme described in [13]. The taxonomic names of cyanoprokaryotes have been brought in line with the international algological database [14].
Figure 1. (a) – lake Imandra in Murmansk region, (b) – the industrial enterprises on the shores of the reservoir (1 – ferrous metallurgy; 2 – nonferrous metallurgy; 3 – apatite industry; 4 – Kola nuclear power plant) and the integrated environmental monitoring station (5)

3. Results and discussion

The observation of phytoplankton of Lake Imandra identified 41 taxa of cyanobacteria wi from 19 genera. Among them, the species that are characterized by the greatest environmental hazard due to the ability to produce cyanotoxins were identified (hepatotoxins, neurotoxins, microcystins, etc.): Microcystis aeruginosa (Kütz.) Kütz.; Aphanizomenon flosaquae Ralfs ex Bornet & Flahault; Dolichospermum lemmermannii (Ricter) Wacklin, Hoffmann и Komár.; D. spiroides (Kleb.) Wacklin, Hoffmann & Komár.; D. planctonicum (Brunnth.) Wacklin, Hoffmann & Komár.; Dolichospermum flosaquae (Bréb. ex Bornet & Flahault) Wacklin, Hoffmann & Komár.; Planktothrix agardhii (Gomont) Anag. & Komár. (Fig. 2).

Figure 2. Some potentially toxic representatives of cyanobacteria from Lake Imandra. (a) – Dolichospermum lemmermannii, (b) – D. spiroides, (c),(d) – D. planctonicum, (e) – D. flosaquae
Blooming waters of Lake Imandra cause massive development of *D. lemmermannii*. Blossoming zones are localized in the water area of the reservoir in the form of separate spots localized in eutrophied areas. The biomass of *D. lemmermannii* can reach 84.40 mg/l within the blooming zone. The blooming period varies from several hours to several days, depending on the meteorological conditions. It was found that the formation of a film from *D. lemmermannii* colonies and blooming development can be interrupted by increased wind and intense surf activities. In blooming spots, mass deaths of juvenile fish, mainly whitefish, were observed [5]. During the blooming period, single adult whitefish died in open areas of the water area, which indicates an increase in the toxicity of the environment. The deaths of fish, in addition to cyanotoxins, can be caused by a lack of oxygen during the mass development and destruction of cyanoprokaryotic colonies, as well as by mechanical actions on the gills.

**Figure 3.** Average (median) indicators of water quality in Lake Imandra in different periods of research (years): 1 – 1992–1998; 2 – 2006–2010; 3 – 2011–2015; 4 – 2016–2019. (a) – Chl a content (mg/l m3), (b) – phytoplankton biomass (g/m3), (c) – the number of recorded water bloom phenomena (number of cases), (d) – total phosphorus content (μgP/L), (e) – total nitrogen content (μgN/L), (f) – ratio of nitrate nitrogen (NO$_3^-$, μgN/L) to ammonium nitrogen (NH$_4^+$, μgN/L), (g) – nickel content (μg/L), (h) – copper content (μg/L), (i) – cadmium content (μg/L)
On the basis of long-term data on the dynamics of the chemical composition of waters, 4 periods were identified in the development of the ecosystem of the lake. They differ in median values of the main factors determining the development of phytoplankton: 1 – 1992–1998; 2 – 2006–2010; 3 – 2011–2015; 4 – 2016–2019. It was found that the concentration of toxic heavy metals (Cu, Ni, Cd) has been decreasing since the beginning of the 21st century, as a result of a decline in the production rates in the 1990s and an increase in the efficiency of wastewater treatment systems (Fig. 3, g, h, i).

In comparison with the 1990s, currently, the average (median) content of nickel has decreased more than three times, copper – almost twice, and cadmium – 30 times, which indicates a significant decrease in the toxicity of the aquatic environment. Along with this, the content of biogenic elements, primarily nitrogen and phosphorus compounds, does not show steady downward trends (Fig. 3, d, f). Reducing the toxic load and maintaining the same rates of development of the processes of eutrophication of lake waters led to a natural increase in the average phytoplankton biomass (Fig. 3, b). An increase in the productivity of lake waters also confirms an increase in the average content of chlorophyll "a" (Fig. 3, a). Thus, there are favorable conditions for the development of plankton and cyanoprokaryotic algae, realized in episodic local phenomena of water blooming – the number of reported cases also increased (Fig 3, c). Another important hydrochemical factor stimulating the mass development of cyanoprokaryotes was a decrease in the average value of the ratio of nitrate nitrogen to ammonium (Fig 3, f). It was shown [15] that for the mass development of cyanoprokaryotes, it is important to have a sufficient total content of nutrients and reduce the ratio of NO₃⁻:NH₄⁺.

During the period under study, significant changes in the key hydrochemical parameters that determine the development of phytoplankton occurred. They created favorable conditions for the development of cyanoprokaryotic water bloom processes. High rates of observed changes are due to the warming of the Arctic climate system: positive temperature anomalies are a key factor triggering water blooming. Local blooming spots were observed in shallow bays, which warm in calm conditions. Higher water temperatures at the surface inhibit mixing, allowing cyanoprokaryotes to rapidly build up biomass, which absorbs sunlight, making the water even warmer and increasing the blooming rate.

4. Conclusion

In recent decades, a phenomenon not typical of these latitudes has been observed in Arctic freshwater reservoirs – water blooming resulted from the massive development of cyanoprokaryotes. On the example of Lake Imandra used as a source of drinking water, causes of blooming have been found. These are D. lemmermannii which are potentially toxic. In addition, other potentially toxic species of cyanoprokaryotes have been identified in the phytoplankton composition. This requires special attention to the quality control of waters used for drinking and fishery needs. Determination of the key factors governing the processes of cyanoprokaryotic water blooming is a difficult task, since this phenomenon is difficult, unpredictable, irregular and (or) short-lived.

The specific contribution of each factor depends on the region where the reservoir is located. According to the results of long-term observations, it was found that the occurrence of blooming was facilitated by the processes of reducing the toxicity of the environment – a decrease in anthropogenic pollution of waters with heavy metals, along with the preservation of a high content of nutrients for phytoplankton. This is reflected in positive trends in the average phytoplankton biomass and chlorophyll “a” content. In the Arctic, temperature is one of the key parameters triggering blooming. The data obtained are necessary for the development of a methodology for regional forecasting of changes in water quality and making decisions to prevent and minimize possible negative consequences.

The influence of industrial enterprises on the cyanoprokaryotic water blooming confirms that for an adequate assessment and forecast of changes in freshwater reservoirs in the Arctic, ecological data and data on industrial facilities and meteorological parameters are required. Socio-economic factors are also significant. They influence intensity and ways of using water resources. Consequently, it is
advisable to develop systemic solutions for managing the rational "non-destructive" use of freshwater systems in the Russian Arctic on the basis of an integrated conceptual space, where the "ecological" component itself is one of the components.

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