Sanitary and ecological assessment of fishery water-use objects in the Arctic

M. Litvinova*, *E.* Makarevich, *E.* Alekseevskaya, *A.* Garbul, and *E.* Kozhukhova

Microbiology and Biochemistry Department, Murmansk State Technical University, 13, Sportivnaya Str., Murmansk 183010, Russian Federation

Abstract. This work is devoted to the study of sanitary and hygienic monitoring of fishery water use objects in Murmansk region. The paper presents assessment of the ecological and sanitary conditions of fishery reservoirs in the Arctic region of the Kola and Tuloma rivers for the period 2016-2018 based on the use of microbiological, hydrochemical and parasitological indicators, as well as the integral index of surface water pollution. Hydrochemical studies consisted of determining the biochemical oxygen consumption, the mass content of NH4+, NO2-, NO3-, iron, and dissolved O2. The assessment of the river waters sanitary state was carried out by means of microbiological and parasitological methods. The microbiological parameters were used to determine the number of common and thermotolerant coliform bacteria, coliphages, and the presence of intestinal infections pathogens. The water of rivers does not meet the hygienic standards in terms of hydrochemical indicators in seventeen percent and in terms of microbiological indicators in five percent of cases. According to parasitological indicators, hygienic standards meet the requirements. In five points of water sampling, the water of the Tuloma and Kola rivers was evaluated as pure according to the integral hydrochemical index value and belongs to the second category of quality. In general, the high-water quality of Murmansk region rivers was noted. In conclusion, it should be emphasized that systematic monitoring of water supply sources is necessary to obtain an idea of the indicators' variability and to assess the rivers pollution degree.

1 Introduction

One of the most important and relevant environmental issues nowadays is the assessment of the water resources state. More than 15 thousand large and small rivers flow on the Kola Peninsula. Many of these reservoirs are of commercial importance and are included in the fisheries fund.

Natural sources of fresh water experience a constant anthropogenic load, for this reason, it is important to monitor the water quality. Pollution of water bodies occurs directly as a result of the runoff water discharge and indirectly through runoff from the catchment area and groundwater. Hydrochemical and sanitary-microbiological observations are part of monitoring studies of aquatic ecosystems, as they allow us to assess the state of the aquatic environment and its ability to naturally purify itself from most pollutants, including those of anthropogenic origin. All these types of pollution affect the quality of hydrobionts bred and extracted in the reservoir.

The purpose of this work was to assess the ecological and sanitary state of the Tuloma and Kola rivers by means of hydrochemical and microbiological indicators for 2016–2018. When assessing the ecological state of the reservoir, both basic (the content of nitrites, nitrates, biochemical oxygen consumption (BOC_5), the number of common and thermotolerant bacteria, coliphages) and integral (water pollution index) indicators of water quality were used.

Main research objectives:

– to study the spatial and temporal variability and water quality by hydrochemical, microbiological and parasitological indicators of river water masses, as well as to assess the correlation of these indicators;
– to evaluate the ecological state of rivers based on the water pollution index (WPI).

2 Materials and methods

The objects of the study are two rivers of the Kola Peninsula – Kola and Tuloma, as they are located in its densely populated region.

The Tuloma River is one of the major rivers of the Kola Peninsula. The river is 64 km long. The source of the river is located at the outlet of Notozero Lake, it flows into the Kola Bay. There are five villages and two hydroelectric power stations located on the Tuloma; they form reservoirs. Fishing is well developed.

The Kola River (the name originates from the Finno-Ugric word "fish river") is 83 km. The source of the river starts at the Kolozero Lake and flows into the Kola

* Corresponding author: mlit1@rambler.ru

Bay. The largest settlement on the river is the city of Kola [1].

Water sampling was carried out at several points (stations) on both rivers. Sampling points on the Kola River are: station 1 (st. 1) - Molochniy urban-type settlement; station 2 (st. 2) Shonguy settlement; station 3 (st. 3) Magnetity settlement; station 4 (st. 4) Loparskaya station. Sampling points on the Tuloma River: station 5 (st. 5) Tuloma village and station 6 (st.6) the territory of the agricultural enterprise "Tuloma". The sampling points are shown in the diagram (Figure 1).

Fig. 1. Sampling scheme on the Tuloma and Kola rivers.

According to microbiological indicators, water samples were taken monthly, according to hydrochemical and parasitological indicators, samples were taken once a quarter from January 2016 to December 2018. From microbiological indicators, river water was evaluated by the number of common, thermotolerant coliform bacteria (CCB and TCB), coliphages, as well as the presence of intestinal infections pathogens (salmonella). Microbiological and parasitological studies were carried out according to the guidelines 4.2.1884-04 [2].

The dissolved O_2, the biochemical oxygen consumption (BOC_5), the amount of nitrites, nitrates, ammonium nitrogen and iron were determined by means of the hygienic standards for chemical parameters.

The results obtained were compared with the standards defined in the sanitary rules and norms 2.1.5.980-00. Statistical data processing was performed using the Statistica 12.0 program. In the correlation analysis, the Spearman rank correlation coefficient was used.

Among other things, the hydrochemical index of water pollution (IWP) was determined in the work. It is the average fraction of the excess of the maximum permissible concentration (MPC) for a strictly limited number of individual components; it is calculated by the formula (1):

$$IWP = \frac{1}{n} \cdot \sum_{i=1}^{n} \frac{C_i}{MPC_i} = \frac{1}{6} \cdot \sum_{i=1}^{6} \frac{C_i}{MPC_{e_i}} \quad (1)$$

where n – is the number of indicators used to calculate the index; Ci – is the chemical concentration in water, mg/l; ПДКi (MPC) – maximum permissible concentration of the substance in water, mg/l.

To calculate this index, it is mandatory to use such indicators as dissolved oxygen and BOC5, as well as four other indicators. Such indicators for the Kola and Tuloma rivers were: iron (total), nitrites, nitrates, and ammonium ion [3].

3 Results and discussion

According to the regulatory documentation for open water bodies, parasitic organisms are not allowed in 25 liters. In the period from 2016 to 2018, no helminth eggs, no teniid oncospheres or viable cysts of pathogenic intestinal protozoa were found in any of the selected samples, in addition, the water does not contain intestinal infections pathogens.

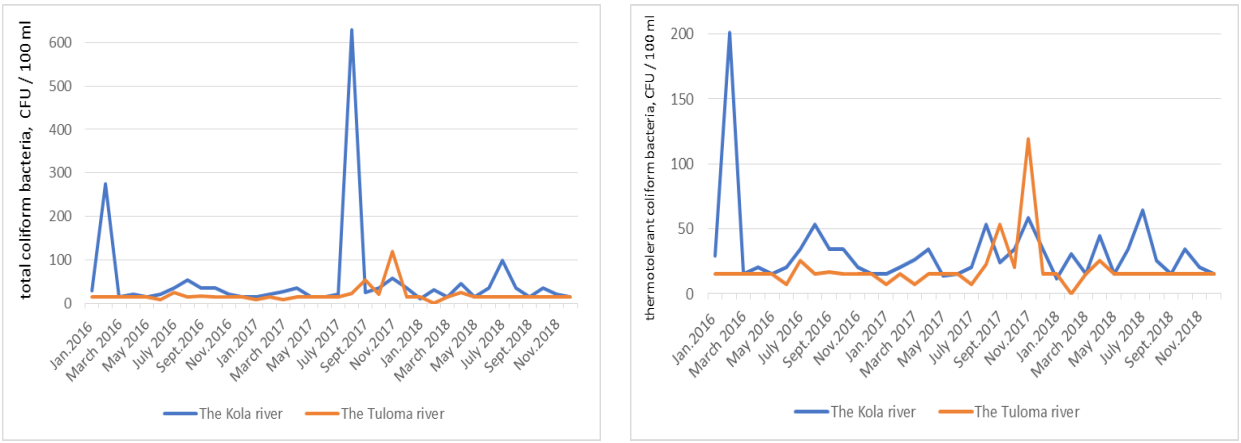
Water samples for coliphages determination were carried out monthly. Coliphages are bacterial viruses capable of lysing *E. coli* and forming lysis zones (plaques) on agar [4]. Their amount should not exceed 10 PFU/100 ml. During the period under review, no coliphages were found in the Kola River. In the Tuloma River, coliphages were found at the water intake point near the village of Tuloma in April 2018, their number was 1 PFU in 100 ml. At the water intake point of the agricultural enterprise "Tuloma", coliphages were found in January 2017 (3 PFU in 100 ml) and in August 2018 (4 PFU in 100 ml). This indicator in the fisheries water is within the normal range.

Table 1. Results of microbiological and hydrochemical parameters measurements in water samples of the Kola and Tuloma rivers from 2016 to 2018 (average values).

Sampling station number	Microbiological indicators			Hydrochemical parameters					
	CCB, CFU/100 ml	TCB CFU/100 ml	Coliphages PFU/100 ml	Iron, mg/l	Ammonium nitrogen, mg/l	Nitrates, mg/l	Nitrites, mg/l	Dissolved oxygen, mg/l	BOD_5 mg\l
The Kola River									
st. 1	80.0± 3.2	68 ± 2.7	0	1.63± 0.06	0.25± 0.009	0.51±0.03	0.01± 0.0004	8.32±0.33	1.9±0.076
st. 2	87.2± 3.3	22.1 ±0.8	0	0.19± 0.007	0.24± 0.009	0.78±0.01	0.01± 0.0004	8.77±0.31	1.8±0.070
st. 3	17.6± 0.67	17.6 ±0.79	0	0.17± 0.006	0.19± 0.007	2.06±0.07	0.02± 0.0008	9.11±0.34	1.3±0.06
st. 4	21.5± 0.73	21.5 ±0.67	0	0.37± 0.012	0.20± 0.007	1.79±0.061	0.01± 0.0002	8.68±0.29	1.4±0.05
The Tuloma river									
st. 5	15.6± 0.59	15.6 ±0.47	0.02± 0.001	0.16± 0.006	0.21± 0.008	0.80±0.03	0.01± 0.0001	7.1±0.27	1.6±0.07
st. 6	22.1± 0.82	21.7± 0.803	0.19± 0.007	0.07± 0.002	0.18± 0.006	0.29±0.11	0.01± 0.0003	7.4±0.27	1.4±0.07

CCB is an integral indicator of the fecal contamination degree; it acts as a reservoirs water quality assessment indicator and has indicator properties in relation to intestinal infections caused by pathogens [5]. According to the norms established by Sanpin (Sanitary Consumer Supervision) 2.1.5.980-00, the amount of CCB should not exceed 1000 CFU/100 ml. The results obtained from the study of samples from the Kola and Tuloma Rivers are shown in Figure 2a. In February 2017, in Molochniy village, a violation of the norms for this indicator was recorded, the number of CCB was 1058 CFU/100 ml. Also, the excess of permissible norms was noted in August 2018 in the village of Shongui – 2400 CFU/100 ml. In the Tuloma River, the excess of the norm in the number of CCB was not observed.

It is recommended to determine the TCB at the same time as the CCB to confirm the fecal origin of the contamination [5]. The standard for the amount of TCB is not more than 100 CFU/100 ml. According to the data presented in Figure 2b, in Molochniy village, excess of the norm for this indicator was noted three times: in February 2016 -– 758 CFU/100 ml, in April 2018 – 133 CFU/100 ml, in July 2019 – 190 CFU/100 ml. In November 2018, there was an excess of the indicator at the Loparskaya station -– 188 CFU/100 ml.

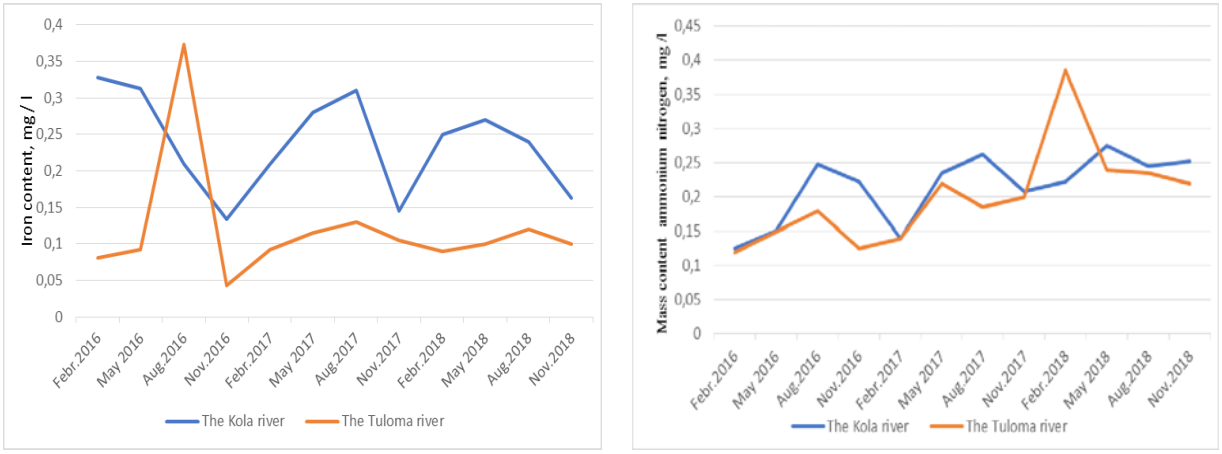


(a) (b)

Fig. 2. Changes in the quantitative content of total coliform bacteria (a) and thermotolerant coliform bacteria (b) in the water of the Kola and Tuloma rivers from year 2016 to 2018 (average values).

According to the standards established in Hygiene standards 2.1.5.1315-03, the iron content should not exceed 0.3 mg/l. It is believed that when this concentration is exceeded, the water gets a glandular taste, and serious health problems begin when the indicator exceeds 2 mg/l. Violation of the MPC of iron in the Kola River was noted at the Loparskaya station in 2016 in the first quarter — 1 mg/l and in the second quarter – 0.6 mg/l. In the first quarter of 2019, the iron content at the Loparskaya station was 0.4 mg/l. In Molochniy village, the maximum permissible concentration of iron was exceeded in 2019: in the second quarter – 0.35 mg/l and in the third – 0.34 mg/l. In Magnetity village, a violation of the norms was recorded in the second quarter of year 2018 – 0.4 mg/l. During the period under review, a violation of the iron MPC was recorded on the Tuloma River in the 3rd quarter of year 2016 with the water intake in Tuloma village – 0.65 mg/l. The soil and rocks of Murmansk region are rich in iron compounds. Therefore, the norms of this indicator are often exceeded.

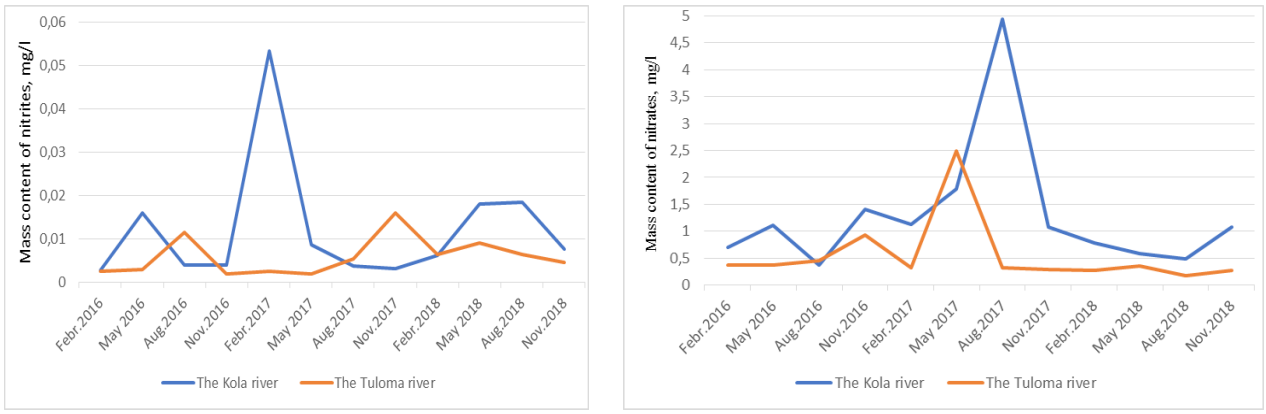
The presence of ammonium ions in surface waters is mainly associated with the biochemical decomposition of protein substances, urea and amino acids deamination processes. Due to the process of anaerobic regain of nitrates and nitrites, ammonium ions can be formed, in addition, hydrobionts release ammonia in the process of vital activity. During the study period, there were no violations of the ammonium nitrogen content in the Kola and Tuloma rivers.



(a) (b)

Fig. 3. Changes in the mass content of iron (a) and ammonium nitrogen (b) in the water of the Kola and Tuloma rivers from 2016 to 2018 (average values).

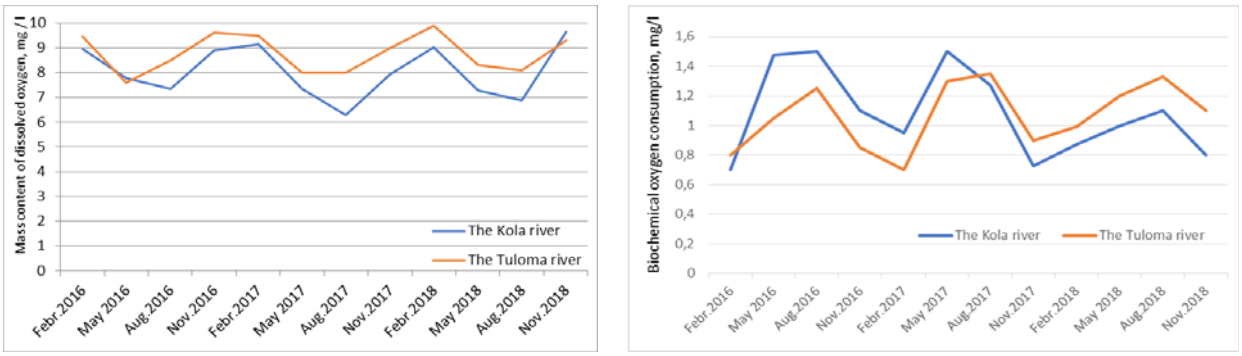
According to the standards established in Hygiene standards 2.1.5.1315-03, the content of nitrates should not exceed 40 mg/l, and of nitrites should not exceed 3.3 mg/l. The concentrations of these indicators in the water corresponded to the hygienic standards and the water was possible to be used in households and for drinking, according to these indicators.



(a) (b)

Figure 4. Changes in the mass content of nitrites (a) and nitrates (b) in the water of the Kola and Tuloma rivers from year 2016 to 2018 (average values).

The oxygen regime determines the chemical and biological state of the water body and affects the vital activity of the reservoir. Oxygen for surface waters is absorbed from the atmosphere, produced as a result of aquatic organisms' photosynthetic activity, as well as obtained with rain and snow waters. The loss of oxygen in the reservoir is determined by the processes of substances oxidation, and hydrobionts respiration. Biochemical oxygen consumption (BOC_5) – the amount of oxygen consumed for aerobic biochemical oxidation influenced by microorganisms and decomposition of unstable organic compounds contained in the tested water. BOC is an important criterion used to determine the level to which the reservoir is polluted with organic substances. It determines the amount of easily oxidizing organic pollutants in the water [6]. The results obtained in terms of dissolved oxygen and BOC_5 meet the requirements set out in the regulatory document Hygiene standards 2.1.5.1315-03 [7].



(a) (b)

Fig. 5. Changes in the mass content of dissolved oxygen (a) and BOC_5 (b) in the water of the Kola and Tuloma rivers from years 2016 to 2018 (average values).

The results of studies of the water quality of the Kola and Tuloma rivers on microbiological, hydrochemical and parasitological indicators are presented in Table 2.

Table 2. Comparative analysis of the results obtained.

Name	Number of samples	Number of research	The number of results					
			Microbiological		Hydrochemical		Parasitological	
			Abs.	%	Abs.	%	Abs.	%
The Kola river	144	768	6	4,17	6	12,5	–	–
The Tuloma river	72	384	1	1,39	1	4,17	–	–
Note: the "–" symbol means the absence of results that do not correspond to the regulatory and technical documentation								

It's a common knowledge, the Spearman rank correlation method allows to determine the closeness and direction of the correlation between two features [8]. Let's check the tightness of the data connection in pairs between the available features (BOC_5, concentration of oxygen, iron, nitrites, nitrates, ammonium nitrogen, CCB and TCB). Spearman's rank correlation coefficient conditionally evaluates the closeness of the correlation between the features (Table 3). The correlation analysis of the links between the values of hydrochemical and microbiological parameters in river water showed that a significant direct correlation occurs between the parameters of the CCB and TCB (Table 3). The calculated value of the correlation coefficient turned out to be 0.94 – this conditionally indicates a direct and strong dependence on CCB and TCB content. There is a moderate correlation between the values of dissolved oxygen and ammonium nitrogen, BOC_5, and oxygen concentration. The calculated values of the correlation coefficient were –0.66 and –0.69, respectively. They indicate an inverse and moderate correlation. The feedback is the opposite correlation between the two variables, i.e., as the BOC_5 increases, the amount of dissolved oxygen in the river water decreases.

No significant correlations were found between the remaining concentrations of hydrochemical and microbiological parameters.

The Water Pollution Index indicator is useful for monitoring the dynamics of water quality pollution changes and determining its quality class (Table 4). The calculation Water Pollution Index was carried out according to the formula 1.

Table 3. Values of correlation coefficients between microbiological and hydrochemical parameters in lake waters.

Indicator	Nitrites, mg/l	Nitrates, mg/l	Ammo-nium nitrogen, mg/l	Dissolved oxygen, mg/l	$BOC_{5,}$ mg/l	Iron, mg/l	CCB, KOE/100 ml
	n = 48	n = 48	n = 48	n = 48	n = 48	n = 48	n = 48
Nitrites, mg/l	–	–0.18	0.22	–0.11	0.36	0.34	–0.02
Nitrates, mg/l	–0.18	–	–0.24	0.14	–0.11	–0.19	0.17
Ammonium nitrogen, mg/l	0.22	–0.37	–	**–0.66**	0.23	0.28	0.33
Dissolved oxygen, mg/l	–0.11	0.14	–0.36	–	**–0.69**	–0.28	0.07
BOC_5, mg/l	0.19	–0.11	0.23	**–0.69**	–	0.38	0.17
Iron, mg/l	0.24	–0.19	0.29	–0.28	0.31	–	0.0004
CCB,	–0.03	0.17	0.48	0.07	0.17	0.0004	–
CFU/100 ml	0.17	–0.01	0.22	0.08	0.17	0.0006	**0.94**

Table 4. Calculated values of WPI of the Kola and Tuloma rivers' waters.

Sampling points	WPI calculated values	Water quality status	Water quality class
Molochniy village	1.12	Moderately polluted	3
Shonguy village	0.32	Pure	2
Magnetity village	0.31	Pure	2
Loparskaya station	0.41	Pure	2
Tuloma village	0.36	Pure	2
'Tuloma' Agricultural enterprise	0.30	Pure	2

4 Conclusion

Thus, as a result of the conducted studies on microbiological indicators for the period (2016-2018) in the Kola River, 4.17 % of the samples taken do not meet the standards. In the Tuloma River, the number of violations is 1.39 %. According to hydrochemical indicators for the period under review, 12.5% of water samples taken in the Kola River do not meet the established standards. In the Tuloma River, the proportion of violations is 4.17% out of the number of samples taken. According to parasitological indicators, the quality of the Kola and Tuloma rivers met the sanitary and epidemiological requirements. The water of the Kola and Tuloma rivers for the three-year period from 2016 to 2018 is characterized by the hydrochemical index of water pollution as clean at the points of water intake near the settlements of Shonguy, Magnetity, Tuloma, Loparskaya station and as moderately polluted at the point of water intake near Molochniy village and belongs to the 2 and 3 classes of water quality, respectively.

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