Chemical composition and water quality of the Baikal ecosystem in 2018

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Abstract. Analysis of the ion composition in the water of the Baikal ecosystem (Lake Baikal, the Angara River estuary and 35 tributaries) in the spring and autumn of 2018 has shown that the water from Baikal and the Angara estuary maintains low mineralization (94-98 mg/l) and corresponds to the calcium bicarbonate composition. The average chemical composition of the water from the Angara estuary is within the range of minimum-maximum values of the Baikal water. In the water from some tributaries, mineralization is two-three times higher compared to Baikal and the estuary. The average ion composition of the Baikal water intermediates in the range of minimum-maximum values of the studied tributaries. Microbiological studies have shown that the average number of hygiene indicator microorganisms in the water from the tributaries is much higher than in Baikal and the Angara estuary. Unlike the tributaries, the water from Baikal and the Angara estuary contain less number of organotrophic microorganisms. The most extensive Baikal tributaries, which drain the significant and status diverse (anthropogenic and natural) areas around Lake Baikal, definitely have a negative impact on the lake. However, many smaller rivers and streams flowing into Baikal, as well as horizontal and cyclonic currents existing in Baikal, preserve its status as the site with pure drinking water, but only in the pelagic zone of the lake.

1. Introduction
In the 21st century, many countries of the world (Africa, South Asia, the Middle East, etc.) are experiencing a shortage of drinking water. Such a situation evokes thoughts about the preservation of the available water reserves and the development of effective methods for the treatment of the used domestic water. Freshwater bodies occupy only 3% on Earth. In addition to the shortage of freshwater, its quality and compliance with sanitary and epidemiological standards are important. Lake Baikal contains 20% of the world’s pure drinking water. No wonder that UNESCO stated Baikal the World Heritage site. Scientists from many countries monitor and examine its state.

More than 360 rivers flow into Lake Baikal. The Angara River is the only surface runoff of the lake. Baikal, the Angara estuary and numerous tributaries are located in the Baikal Rift Zone, in which shifts and earthquakes constantly occur [1]. In geological terms, rocks of different ages (the Archean-Cenozoic) and composition (from basic to acidic) represent Baikal surroundings [2].

In river valleys draining rocks, there are different types of waters, depending on their predominant feed, as well as different types of subsurface waters or their combinations: pore, stratal,
fissure waters, etc. Moreover, the composition of precipitation influences the feed and composition of the tributaries. Previously, researchers already stated the presence of hydrothermal provinces with different composition around Baikal [3, 4].

The water composition of Baikal, the Angara estuary and numerous tributaries draining various rocks also differs in different seasons. Moreover, it is necessary to consider the anthropogenic impact on the Baikal ecosystem (diversified industries, fires, intensive tourism, etc.). The largest tributaries (the Selenga, the Upper Angara, the Barguzin, the Bolshaya Goloustnaya, the Buguldeika, etc.) form large deltas or macrobarriers at the confluence, where the introduced substances deposit in a significant amount [3].

Figure 1. The scheme of the geological structure of Baikal and its environment (according to O A Sklyarova et al., 2017).
2. Models and Methods

The aim of the study is a comparative analysis of the macroscale component and microbiological composition of the main elements of the Baikal aquatic ecosystem: Lake Baikal, the Angara estuary and some tributaries (Figure 1).

The water from Baikal, the Angara estuary and the Baikal tributaries were sampled into clean 1 liter polyethylene bottles. Baikal was tested from the surface in its central (pelagic) part (1 liter) as well as in two deep sections (1200 and 1642 m) in 2011-2018. The analysis was performed in 36 samples. The water from the Angara estuary was sampled each month at a distance of 1.5-2 m from the coast at a depth of 0.4-0.5 m. The analysis was performed in 70 samples.

Chemical analysis of water was carried out using the equipment of Isotope-Geochemical Research Center at Vinogradov Institute of Geochemistry SB RAS. SO$_4^{2-}$, Cl$^-$, HCO$_3^-$, NO$_2^-$, NO$_3^-$, F$^-$, NH$_4^+$, etc. were determined according to the generally accepted methods (titrimetry, potentiometry, turbidimetry, etc.). The results were confirmed by the analysis of standard samples of the Baikal water composition [5].

Microbiological analysis of water was performed at Limnological Institute SB RAS. The assessment of the and microbiological quality of the surface waters in the Russian Federation is regulated by the mandatory characteristics according to the standard SanPIN 2.1.5.980-00: coliform bacteria (CB, less than 500 CFU/100 ml) – indicator of the water quality; thermotolerant coliform bacteria (TCB, less than 100 CFU/100 ml) and coliphages (CPh, less than 10 PFU/100 ml) – indices of the degree of faecal contamination, as well as by recommended characteristics according to the instructions MUK 4.2.1884-04: enterococci (Ent, less than 50 CFU/100 ml) and self-cleaning coefficient (SCC, more than 4). The number of enterococci above the standard indicates fresh faecal contamination and a potential epidemiological hazard. SCC less than 4 indicates a low self-cleaning ability of the water body and pollution from domestic wastewater. In cases of non-compliance of the sample with at least one characteristic, it is considered non-standard.

3. Results and Discussion

According to all researchers, the water from Baikal and the Angara estuary is low-mineralized and calcium bicarbonate one [6, 7]. Total dissolved solids (TDS) in Baikal are 93.6 mg/l (2011-2018). In the Angara estuary for the previously studied period of 1997-2013, it was 95.6 (90–112) mg/l; in 2017 – 94.6 mg/l; and in 2018 – 95.6 mg/l. The obtained long-term data on the macroscale component composition showed the presence of the geochemical cycles (variations) of three-seven years in the distribution of elements in the water from the Angara estuary [8]. Seasonal changes in the macroscale compositions occur with cyclic changes mainly caused by the change in the bicarbonate ion concentration. There is a strong correlation between the bicarbonate ion concentration and mineralization (0.8-0.9).

The ion composition of the water from tributaries reflects the composition of the drained rocks in the main systems of mountains surrounding Lake Baikal, i.e. the Baikal, the Primorsky, the Khamar-Daban, the Ulan-Burgas, and the Barguzin ranges.

The chemical compositions of the water from Baikal, the Angara estuary and numerous tributaries show both close concentrations of macroscale components and significant differences (Figure 2). The content of most compared elements, but not all of them, in the water from Baikal and its estuary can be significantly lower than in numerous tributaries.

However, there are also the elements, which contents in the water from the Baikal tributaries, Baikal itself and the Angara estuary are close or less than two-three times different. These can be, for example, mineralization, HCO$_3^-$, F$^-$, Ca$^{2+}$, Mg$^{2+}$, K$^+$, as well as some other elements. Some components in the water from Baikal and its estuary have significantly lower values than in the tributaries. These are mainly nitrogenous compounds.

The pH value of the Baikal water in the spring is slightly higher in the south (8.4) than in the north (7.2). In the Angara estuary, pH is 7.8 in the spring and 8.4 in the autumn. In the tributaries, pH
changes from 6.7 to 8.2 in the spring and autumn. Minimum pH values in the tributaries (6.7-7.2) are characteristic of the water from the south-eastern Baikal hydromineral province. In addition to the relatively low pH value, these tributaries (the Utulik, the Solzan, the Snezhnaya, the Pereyomnaya, etc.) have the lowest TDS (< 50 mg/l), HCO$_3^-$ and SO$_4^{2-}$, which is likely due to the difficultly soluble composition of the drained rocks, i.e. gneisses and crystalline schists of the Khamar-Daban terrane.

The major anions in the water from Baikal, the Angara estuary and the tributaries are HCO$_3^-$ and SO$_4^{2-}$. These components have high values in the Baikal water; they form and maintain water mineralization: TDS – 94-110 mg/l. The tributaries of the Primorsky (the Kuchelga and the Buguldeika) and the Barguzin (the Selenga, the Kika and the Bezmyannaya) ranges have high anion content, where they are 1.5-2 times higher than in other tributaries and almost comparable to the water from Baikal and the Angara estuary.

Figure 2. Water mineralization (TDS) in Baikal, the source of the Angara and its tributaries.
The surface Baikal water moves counterclockwise along the coastline [9]. Moreover, there is circular (cyclonic) movement of the surface water in the northern, central and southern basins of Lake Baikal. The total mineralization of the Baikal water and, then, the Angara estuary is likely to equalize, and it becomes equal to 94-100 mg/l despite the influence of tributaries.

Ca²⁺ and Mg²⁺ are the major cations in the Baikal ecosystem; K⁺ and Na⁺ are present in lower concentrations. Carbonate rocks prevail among the bedrocks surrounding Baikal. High concentrations of calcium of up to 16.3 mg/l and magnesium of up to 3 mg/l in the surface Baikal water are due to drainage of carbonate rocks by the tributaries. At the same time, in the western tributaries the cation content can be significantly higher, up to 55 mg/l of Ca²⁺ and 20 mg/l of Mg²⁺ (the Buguldeika and its tributary Kurtun). In the Angara estuary, the Ca²⁺ and Mg²⁺ contents are comparable to the Baikal water, 15-16 mg/l and 2.5-3.0 mg/l, respectively. The Rel River, which drains rhyolites and dacites of the Baikal range, has low contents of these elements.

There are high contents of K⁺ (up to 2 mg/l) and Na⁺ (up to 7 mg/l) in the tributaries that drain granites of the Primorsky (the Anga and the Buguldeika) and the Barguzin (the Barguzin, the Turk and the Maximikha) complexes. In the water from Baikal and the Angara estuary, their concentrations are close, up to 1 mg/l of K⁺ and up to 3.6 mg/l of Na⁺.

The deficit of F⁻ in the surface waters is characteristic of the Baikal region [3]. This is also characteristic of the Baikal ecosystem. In the water from Baikal, the Angara estuary and most tributaries, the content of F-ion varies within a small range of 0.15-0.25 mg/l. Only the Rel and Anga rivers, which drain acid rocks, have a high content of fluoride, 0.6 mg/l and up to 0.5 mg/l, respectively. In the tributaries draining the Angaro-Vitim batholith (The Barguzin granitoid complex), the F⁻ ion content in water is 0.3-0.35 mg/l. In the tributaries of the southeastern Baikal (The Khamar-Daban), the F⁻ content is very low, < 0.1 mg/l.

The Cl⁻ contents in the water from Baikal and the Angara estuary are close and equal to 0.6-0.8 mg/l. In the spring and autumn, there are relatively high Cl⁻ contents in the water from the Selenga, Buguldeika and Anga rivers (up to 1.87 mg/l). The water of all southeastern Baikal tributaries had low Cl⁻ contents of 0.2 mg/l in the spring, but in the autumn Cl⁻ contents increase two- or threefold.

Nitrogenous compounds, NO₂⁻, NO₃⁻ and NH₄⁺, in the water from Baikal and the Angara estuary are significantly lower compared to the tributaries. In the spring, there is a high content of NO₃⁻, and in the autumn – NO₂⁻ (the Solzan and the Manturikha). On the western Baikal coast, there are high concentrations of NH₄⁺ in the Buguldeika, Anga, Shida, and Sarma rivers, where they reach 0.12-0.18 mg/l. Only the Selenga River have the maximum NH₄⁺ value of 0.26 mg/l. In other tributaries, the ammonium ion values range within 0.006-0.06 mg/l. On the eastern coast, the water from the mouth of the Solzan River, where the pulp and paper mill closed in 2013 is located, and the Manturikha River had the high NO₃⁻ content of 2 mg/l. In the mouth of the Upper Angara and the Tyya, as well as in the water from the northern part of Baikal, nitrite ion content is relatively high (0.006 mg/l). There are lower values (0.002 mg/l) further to the south in Baikal and the Angara estuary. Most tributaries also contained NO₂⁻ of 0.002 mg/l or less. The NO₃⁻ content in the water from Baikal and the Angara estuary is 3-5 times less than in the tributaries.

Microbiological studies have shown that the water from the pelagic zone of Lake Baikal and the estuary of the Angara River compiled with the standards for the surface waters according to the standard SanPiN 2.1.5.980-00 and instructions MUK 4.2.1884-04. The occurrence of hygiene indicator microorganisms in the spring of 2018 was higher than in 2016 and 2017. Thus, in May-June of 2016 and 2017 they were detected at 30% of stations, whereas in 2018 – at 80% of stations. During the autumn expeditions of 2017 and 2018, the occurrence was equal at 26% of stations. River samples (four) were non-standard; the Turka River in May (Ent. 70 CFU/100 ml), and the Goloustnaya (TCB 136 CFU/100 ml and Ent. 86 CFU/100 ml), Anga (Ent. 78 CFU/100 ml) and Barguzin (CB 594 CFU/100 ml) rivers in September, which confirms the data on the ion composition.
4. Conclusion
The results of the analysis of the ion distribution in the Baikal aquatic ecosystem in 2018 (spring and autumn) indicate the following characteristics:
- the water from Baikal and the Angara estuary maintains low mineralization (94-98 mg/l) and correspond to the calcium bicarbonate composition. Macroscale composition of the water does not actually change over the past 70 years. The contents of all anions and cations do not exceed the maximum permissible concentrations for drinking water;
- the average chemical composition of the water from the Angara estuary is within the range of minimum-maximum values of the Baikal water (Figure 3);
- the water from some tributaries has two-three times higher mineralization compared to Baikal and the estuary: on the western Baikal coast (the Kuchelga, the Buguldeika and the Anga) – due to a significant increase in Ca$^{2+}$, Mg$^{2+}$, HCO$_3^-$ and SO$_4^{2-}$ ions, especially, in the autumn; on the eastern Baikal coast (the Selenga, the Barguzin and the Maksimikha) – mainly due to Ca$^{2+}$ and Na$^+$, as well as HCO$_3^-$;
- the average ion composition of the Baikal water (trend) intermediates in the range of minimum-maximum values of the studied Baikal tributaries (Figure 4);
- in the Rel and Anga rivers, F$^-$ ion concentrations of up to 0.6 mg/l in the water are high for the Baikal ecosystem, and they are very low in the south-eastern tributaries (0.03-0.06 mg/l);
- there is a two- or threefold increase in chlorine ion content in the Selenga, Anga and Buguldeika rivers compared to the water from Baikal and the estuary;
- in the water of the Solzanka River, NO$_2^-$ is more than 100 times higher, as well as in the Selenga River NH$_4^+$ and NO$_2^-$ are high, in comparison with the water from Baikal, the estuary and other tributaries. Values of these ions sometimes reach the maximum permissible concentrations for drinking water, but the Baikal water dilute them, and they hardly disrupt the biochemical processes in Baikal;
- the average number of hygiene indicator microorganisms in river samples of the tributaries is significantly higher than in the lake water and water from the Angara estuary. The number of coliform
bacteria in the pelagic zone and the estuary is 4.3 CFU/100 ml, and in river samples – 62.9 CFU/100 ml; enterococci – 1.3 CFU/100 ml and 18.8 CFU/100 ml, respectively;

- unlike the tributaries, the water from Baikal and the Angara estuary contain less number of organotrophic microorganisms. In rivers, there are from 1.5 to 6 times more organotrophs; thus, in the spring of 2018 the average number was 206 CFU/ml in the pelagic samples, 1251 CFU/ml – in river samples, whereas in the autumn – 385 and 558 CFU/ml, respectively.

Figure 4. Macro-component composition of the water of the tributaries of Baikal (minimum-maximum) in 2018 (shaded) and the trend (blue line) of the composition of water of Baikal in 2011-2018.

The obtained results indicate that the most extensive tributaries of Lake Baikal, which drain the significant and status diverse (anthropogenic and natural) areas around Baikal (the Selenga, the Tunka, the Barguzin, the Buguldeika, the Bolshaya Goloustnaya, and the Anga), definitely have a negative impact on the lake. However, many small rivers and streams flowing into Lake Baikal, as well as the horizontal and cyclonic currents and eddies existing in Baikal, preserve its status as a natural site with pure drinking water, but only in the pelagic zone of the lake. We cannot exclude the known ability of the Baikal water to self-purification and the additional inflow of deep (juvenile) waters with shifts and earthquakes in the rift zone, as well as the renewal of the Baikal water. Nevertheless, the pollution of Baikal continues due to the increasing anthropogenic impact (enterprises, boiler facilities, fires, wastewater of numerous tourist sites, intensively developing tourism, etc.).

The existing anthropogenic load on the Baikal ecosystem indicates the necessity to continue geochemical and sanitary microbiological research in the monitoring regime.

State bodies conduct regular observations in the Baikal region in order to preserve the Baikal aquatic ecosystem.

Acknowledgments
The study was supported by the grant RFBRofi-m No. 17-29-05022, the research project (0350-2016-0027) and the Russian Government represented by the Ministry of Science and Higher Education within the state task No. 0345-2019-0008.
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