Geoecological assessment of the water quality and bottom deposits of middle lake Baikal

M S Yanchuk, I B Vorobyeva and N V Vlasova
Sochava Institute of Geography SB RAS, Russia, Irkutsk

E-mail: m_s_yanchuk@mail.ru, irine@irigs.irk.ru, vlasova@irigs.irk.ru

Abstract. The article describes the western coast of Lake Baikal from the mouth of the Kuchelga River to the Maloe More strait. It also presents the data of the comprehensive assessment of the quality of the surface water and bottom deposits of the water area and western shore of Baikal which was conducted in the summer of 2016-2017. The study of the hydrochemical composition of the Baikal water has been conducted in the course of the research as well as of the following Tazheran lakes: Tyzgyi-Nur, Kholbo-Nur, Shadaran, Tsagan-Tyrym. It has been established that, based on the content of microcomponents, the still and weakly alkaline waters of Lake Baikal meet the standards of the maximum allowable concentrations (MAC) established for water bodies used for fishing and household purposes. The waters of the lakes refer to the hydrocarbonate type, calcium group. Based on their sum of ion, the lakes of Tyzgyi-Nur, Kholbo-Nur, Shadaran-Nur and Tsagan-Tyrym refer to the brackish type, the waters of these lakes mostly have the hydrocarbonate and magnesium content with a predominance of sulfate ion. The levels of the content of heavy metals (V, Cr, Mn, Co, Ni, Cu) in the water and bottom deposits have also been identified.

1. Introduction
Lake Baikal is a unique natural object of tectonic origin located nearly at the center of the Asian continent. Baikal holds over 80% of Russia’s fresh water and approximately 20% of the world’s fresh water supply [1]. Thanks to the unique ecological system, the lake and its nearby territories were included in the UNESCO World Heritage List in 1996, and in 1999, the Government of the Russian Federation adopted the law “On the Protection of Lake Baikal”.

Since recently, Lake Baikal and its nearby areas including the western shore of Middle Lake Baikal have become an extremely popular tourist destination. As a result, the anthropogenic load on all of the natural components has increased rapidly. The most popular tourist destinations are the Tazheran steppes located in the western shore of Lake Baikal. They extend for 50 km in length and are famous for their brackish lakes, or, as they are also called, the Tazheran Lakes.

A great number of scientific papers are devoted to the analysis and assessment of the composition and geoeocological state of the Baikal water [2-4]. The brackish lakes of the Pribaikalsky (Near-Baikal) steppe have also been examined in numerous research [5, 6].

One of the biggest geoeocological problems of the researched area is the pollution of Lake Baikal’s water. The main sources of the anthropogenic impact on the lake’s ecosystem and its shoreline areas are: river transport, motor vehicles, and domestic wastewater from the nearby localities and camping sites. The pollutants penetrate the lake’s area through the atmosphere emissions coming from the industrial hubs of the Irkutsk Region and local heating plants.
The study of the hydrochemical conditions and re-distribution of chemical elements in the water-bottom deposits system is an important task when giving a proper geoenvironmental assessment of a water body. Most of the organic and non-organic material which has been penetrating the water body for a long period of time is concentrated in the bottom deposits. These bottom deposits can both play an active role in the process of the self-purification of a water body and serve as a source of its secondary pollution.

The goal of the research is the assessment of the geoenvironmental state of the waters of Middle Lake Baikal and the brackish lakes located in the western shore of the lake, relying on the hydrochemical data and identifying the pollution level of the bottom deposits with heavy metals.

2. Models and methods
The research was carried out in the western shore of Lake Baikal, in the area of the lake’s middle basin, from the mouth of the Kuchelga River to the Maloe More strait. From the north-west, the researched lake basin is characterized by the substantial bottom accretion extending linearly from Olkhon Island to the Ushkan Islands. A large number of tourist recreational objects affecting the entire ecosystem of the lake are located in the western shore of Baikal (figure 1).

![Figure 1. A schematic map of the sampling.](image)

Water and bottom deposits samples from 11 different points were taken in June-July 2016-2017 to analyze the geochemical state of the water body. Points 1-6 and 11 refer to the water surface of Lake Baikal, 7-10 to the brackish lakes (figure 1). The lakes researched in the paper are: Tyzgyi-Nur (p. 7), Kholbo-Nur (p. 8), Shadar-Nur (p. 9), Tsagan-Tyrym (p. 10). The lakes are located 15 km far from the Tazheran steppe, north-east of the mouth of the Buguldeika River and are drawn to the shoreline of Baikal [5].

The sampling of the surface waters and bottom deposits was carried out according to GOST 17.1.5.01-80 and GOST 51592-2000.

The chemical analysis of the samples was carried out according to the standards of the GOST methods [7]. The surface water samples were used to determine the pH level, basic mineralization ions, and the presence of heavy metals (V, Cr, Mn, Co, Ni, Cu).

Atomic emission spectrometer Optima-2000 was used to determine the concentrations of heavy metals in the bottom deposits.

3. Results and discussion
Hydrogen index. According to GN (Hygienic Standards) 2.1.5 1315-03, the pH value in water bodies
used for fishing and household purposes varies between 6 and 9. The pH level in Baikal conforms to the permissible values and varies from 6.9 to 8.0. The waters of the lake refer to the slightly alkaline and neutral class. The water reaction in the brackish lakes is 8.7-9.2 and refers to the slightly alkaline and alkaline class.

Macrocomponents. According to its mineralization degree, the water of Lake Baikal refers to the class of still waters with the content of dissolved salt varying from 0 to 1.0 g/dm$^3$. The obtained data showed that the total content of ions in the lake’s water varies between 0.08 and 0.137 g/dm$^3$.

According to the classification by O.A. Alyokin [8], the waters of the lake refer to the hydrocarbonate class, calcium group. Chloride ions are also slightly present in the water in the equivalent of 0.10-0.18%.

The main factors determining the chemical properties of the brackish lakes’ water are the ground waters nourishing the lakes, the processes of summer evaporization and winter cryogenesis. According to the sum of ions (from 1 to 8.4 g/l), the researched lakes refer to the brackish class. The waters of Tzygyi-Nur and Kholbo-Nur refer to the hydrocarbonate and magnesian type, the content of sulphate ions is almost equal to that of hydrocarbonates; the dominant cation is Mg. Sulphate ion prevails in the water of Shadar-Nur in the equivalent of 89%. According to the classification [8], it refers to the group of sulphate-sodium lakes. The level of chloride ion in the brackish lakes is rather low and does not exceed the equivalent of 2.6%.

The content of macrocomponents in Baikal does not exceed the MAC for water bodies used for fishing and household purposes. The water of the brackish lakes is unfit for household use in terms of the content of sulphates, magnesium, sodium and potassium.

Heavy metals. In the analyzed samples of the water of Lake Baikal, the content of Cr, Mn, Co, Ni does not exceed the MAC for surface waters. However, we have discovered the exceedance of V for the MAC established for water bodies used for fishing. In the water sample taken in p. 11, in the mouth of the Buguldeika River, we have also detected the exceedance of nickel (figure 2) for the MAC established for water bodies used for fishing (0.01 mg/l).

![Figure 2](image_url)

**Figure 2.** Content of heavy metals in the water of: a) Lake Baikal; b) the brackish lakes, mg/dm$^3$.

The concentrations of most of the identified heavy metals conform to the MAC established for water bodies used for household purposes. In terms of the MAC established for fishing purposes, we have detected the exceedance of V by a factor of 60 and the exceedance of Cu by a factor of 9.

According to the geophysical research, a thick layer of deposits has been accumulated within the water area of Lake Baikal. In the middle part of the lake, where the research was conducted, the thickness of deposits reaches 7.5-8.0 km [9]. The water deposits in the examined area have a nonhomogeneous structure and are presented in the form of various clastic formations and clayed silt. The thickness of deposits varies between 1 and 8 cm.

Unlike organic substances, heavy metals are not degradable. It is for this reason that they migrate and accumulate in various components of the natural ecosystem.
In Russia, there are no maximum allowable concentrations of heavy metals established for bottom deposits, therefore the MAC of the content of pollutants in soil mantle were used for the assessment of the pollution level of the water bodies. We have also conducted the comparative study with the background regional values for bottom deposits [10].

The analysis showed that the concentrations of heavy metals in bottom deposits are several times higher than in the surface waters.

The exceedance of the MAC of nickel for soil and background [10] has been detected in the sample taken from Tsagan Tyrym Lake (p. 10) (table 1). The content of manganese in Tyzgyi-Nur Lake exceeds the MAC for soil (1962.26 mg/kg). All of the examined samples show the exceedance of the MAC of cobalt, the exceedance of background level for this metal has only been detected in points 1, 2 and 6. The lowest content of heavy metals has been detected in sample 11.

**Table 1.** Content of heavy metals in bottom deposits, mg/dm$^3$.

| Sample | V  | Cr  | Mn  | Co  | Ni  | Cu  |
|--------|----|-----|-----|-----|-----|-----|
| 1      | 55.85 | 60.71 | 432.59 | 18.90 | 36.54 | 37.58 |
| 2      | 38.95 | 55.62 | 520.42 | 14.36 | 33.02 | 22.98 |
| 3      | 35.03 | 37.08 | 383.38 | 9.16  | 21.38 | 25.25 |
| 4      | 53.47 | 60.13 | 856.74 | 20.33 | 40.08 | 23.80 |
| 5      | 47.56 | 72.11 | 489.74 | 10.89 | 37.09 | 19.07 |
| 6      | 34.74 | 46.82 | 484.37 | 5.76  | 18.04 | 14.18 |
| 7      | 79.11 | 67.80 | 1962.96 | 22.73 | 31.55 | 28.60 |
| 8      | 48.44 | 56.40 | 525.78 | 10.45 | 32.69 | 27.20 |
| 9      | 42.52 | 53.32 | 545.99 | 13.88 | 34.78 | 22.70 |
| 10     | 45.89 | 72.34 | 502.58 | 14.23 | 55.53 | 21.54 |
| 11     | 27.54 | 36.96 | 577.65 | 3.74  | 9.97  | 15.80 |
| MAC$^a$| 150.00 | 6.00 | 1500.00 | 5.00  | 4.00  | 32.00 |
| BACKGROUND$^b$ | 109.00 | 111.00 | 945.00 | 18.00 | 44.00 | 41.00 |

$^a$ Note – according to the MAC of chemical substances in soil, Hygienic Standards GN 2.1.7.2041-06

$^b$ Note – according to Grebenshikova et al.

Pollution coefficient ($C_i$) has been calculated to assess the pollution level of the surface waters in the researched area:

$$C_i = \frac{C_i}{C_\alpha}$$

where $C_i$ is the content of an examined substance; $C_\alpha$ is an average background value for bottom deposits.

Pollution coefficient has been calculated for K Cr, Mn, Co, Ni, and Cu. According to the coefficient’s value, the pollution levels for the water bodies are as follows: $C_f<3$ – low; $1\leq C_f<3$ – medium; $3\leq C_f<6$ – significant; $C_f\geq6$ – high. The calculation results are presented in table 2.

The medium pollution level for the content of cobalt is identified in points 1 and 4, for the content of nickel – in point 10. The samples of bottom deposits taken in point 7 show the medium pollution level for manganese and cobalt. The pollution coefficient for chrome and copper is identified as low in all of the examined samples, therefore the pollution level for these elements is low.

4. **Conclusion**

The research conducted in the summer of 2016 and 2017 in the water area of Lake Baikal and the brackish lakes located in its shore showed that, in general, the water quality in the examined objects conforms to the established sanitary standards. In terms of the concentrations of some anions and cations the water of the brackish lakes is unfit for household use. The exceedance of the MAC of V for fishing purposes has been detected in the waters of Lake Baikal. The water samples taken in the mouth of the Kuchelga River showed the exceedance of the MAC of Ni for fishing purposes. In the waters of
the brackish lakes the concentrations of vanadium and copper exceed the MAC for fishing purposes by a factor of 60 and 9 respectively.

**Table 2. Values of Cf pollution coefficient in bottom deposits.**

| Sample | Cr  | Mn  | Co  | Ni  | Cu  |
|-------|-----|-----|-----|-----|-----|
| Lake Baikal |     |     |     |     |     |
| 1     | 0.55| 0.46| 1.05| 0.83| 0.92|
| 2     | 0.50| 0.55| 0.80| 0.75| 0.56|
| 3     | 0.33| 0.41| 0.51| 0.49| 0.62|
| 4     | 0.55| 0.91| 1.13| 0.91| 0.58|
| 5     | 0.65| 0.52| 0.61| 0.84| 0.47|
| 6     | 0.42| 0.51| 0.32| 0.41| 0.35|
| 11    | 0.33| 0.61| 0.21| 0.23| 0.39|
| Brackish Lakes |     |     |     |     |     |
| 7     | 0.61| 2.08| 1.26| 0.72| 0.70|
| 8     | 0.51| 0.56| 0.58| 0.74| 0.66|
| 9     | 0.48| 0.58| 0.77| 0.79| 0.55|
| 10    | 0.65| 0.53| 0.79| 1.26| 0.53|

The analysis of the water-bottom deposits system showed that the content of heavy metals in the bottom sediments is several times higher than in the water. The exceedance of the MAC and regional background for nickel has been detected in the water samples taken in the mouth of the Kuchelga River. High concentrations of manganese exceeding the allowable limits for soil have been discovered in one of the brackish lakes. All of the examined samples of bottom deposits showed that the concentrations of Co exceed the MAC established for soil mantle. The identified level of Co in points 1, 2 and 6 exceeds the regional background values. The level of manganese pollution in the researched objects is identified as low.

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