Hydrochemical and hydrobiological characteristics of the Torey Plain lakes during the period of the lowest territory moisture

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Abstract. The largest salt lakes on the territory of Southeastern Transbaikalia and Northeastern Mongolia have been studied. It is shown that all lakes differ in hydrochemical and hydrobiological characteristics. According to the chemical composition of water, they belong to the soda type and sodium, carbonate, bicarbonate and chloride ions are predominant. Sulfates are in a subordinate meaning. The established relationship between abiotic and biotic parameters indicates the conjugation of biogeochemical processes involved in the formation of the soda type of lakes through the carbon cycle.

1. Introduction

The geographic features of the modern distribution and state of the lakes in Southeastern Transbaikalia and the territory of Northeastern Mongolia are of exceptional interest, since they provide a basis for understanding the evolutionary processes of geobiosystems development in Central Asia. Under conditions of insufficient moisture in the territory, an important task is to understand the natural laws and trends in the development of lakes for the purpose of scientifically grounded rational use of their water, mineral and biological resources, which are of great value, require protection and rational use.

The considered steppe region is characterized by the predominance of small salty lakes. In high-water years, there are several thousand natural lake reservoirs on this territory, of which 72\% falls on the Onon, Uldza and Khalkhin river basins. The overwhelming majority of them (85\%) are among the so-called smallest lakes with an area of less than 1.0 km\(^2\). Lakes with a surface area of more than 1.0 km\(^2\) are relatively few in number (15\%), but their total area is relatively large and amounts to 82.9\% of the total water area of all lakes in this region. The water balance, thermal and level regimes, hydrochemical and hydrobiological parameters of water bodies in this region are largely determined by regional climatic features. Thus, when surveyed in July 2008, about half of the small lakes in the steppe region turned out to be dry. The remaining lakes showed morphological signs of a higher standing of lake waters in the form of distinct littoral zones, as well as coastal accumulative and abrasive microforms of the landscape. At present, lakes hydrochemical regime of the territory is assessed as close to the period of the driest climate for the last 50-60 years \cite{1}. In this regard, the main task of our study was to identify patterns between the abiotic and biotic parameters of salt lakes during the period of area lowest moisture under consideration.
2. Materials and methods

Lakes are very common in the territory of Transbaikalia and Mongolia. All of them are confined to the steppe landscape climatic zones and located in the Uldza-Torey plains (the latter is the northern part of the larger morphostructure – the Dalainor Plain), which are cut by shallow creek valleys extending for several kilometers. The climate of the region is sharply continental and semi-arid. A thin snow cover is formed in early November, which thaws at the end of April before the ice melts, so there is essentially no water supply from the thawed snow to the reservoirs. Most precipitation falls in summer.

Water samples were taken from 9 lakes from 6 to 12 July 2008 (table 1). Sampling was carried out using standard hydrobiological methods and instruments (Molchanov's bathometer) along the horizons (surface and bottom layers, transparency zone) in the central deep-water part of the lakes and in the coastal area. The water transparency of the lakes was determined using the Secchi disk.

Rapidly changing parameters (pH, O₂, temperature and TDS) were determined using the AMTASTAMT 03 (USA) directly at the sampling site. General chemical analysis was carried out by standard methods. The concentrations of Ca and Mg were determined by the method of atomic absorption in a nitrous acetylene flame using a SOLAAR 6M spectrophotometer. The determination of Na and K was based on the flame-emission method F and Cl were determined potentiometrically with the use of ion-selective electrodes. Titration was used to determine the content of CO₃²⁻ and HCO₃⁻. The SO₄²⁻ was analyzed by the turbidimetric method, in the form of BaSO₄.

### Table 1. Hydrological parameters of Northeastern Mongolia and Southeastern Transbaikalia lakes.

| Lake (location)                        | Sampling point     | Coordinates          |
|---------------------------------------|--------------------|----------------------|
| Shogoy Tsagan Nuur (Northeastern Mongolia) | Geometric center  | N 49°31.368'E 114°39.221' h 661.6 |
| Baga Dalay Nuur (Northeastern Mongolia)    |foreshore          | N 49°57.529'E 114°22.376' h 710 |
| Baga Dalay Nuur (Northeastern Mongolia)    |bay                | N 49°58.589'E 114°23.488' h 710 |
| Khaichiin Tsagan Nuur (Northeastern Mongolia) | Hypogene center   | N 49°41.333'E 114°40.293' h 657.9 |
| Khorin Tsagan Nuur (Northeastern Mongolia)    |Geometric center   | N 49°39.491'E 114°37.313' h 658.2 |
| Khukh Nuur (Northeastern Mongolia)          |foreshore          | N 49°32.592'E 115°34.125' h 569 |
| Khukh Nuur (Northeastern Mongolia)          |bay                | N 49°29.368'E 115°36.165' h 560.9 |
| Ikh Dalay Nuur (Northeastern Mongolia)       |Hypogene center    | N 49°55.263'E 114°22.363' h 713 |
| Ikh Dalay Nuur (Northeastern Mongolia)       |foreshore          | N 49°55.441'E 114°22.204' h 713 |
| Delger Nuur (Northeastern Mongolia)          |Geometric center   | N 49°43.061'E 114°33.481' h 650 |
| Davsan Tsagan Nuur Baga (Northeastern Mongolia) | bay              | N 49°38.384'E 114°41.051'h 656.1 |
| Zun-Torey (Southeastern Transbaikalia)        |southwestern foreshore| N 50°01.193'E 115°41.593' h 596.5 |
| Zun-Torey (Southeastern Transbaikalia)        |western foreshore  | N 50°06.251'E 115°41.363' h 593.1 |
| Zun-Torey (Southeastern Transbaikalia)        |northern foreshore | N 50°09.522'E 115°47.072' h 591.1 |

For microscopic analysis in the field, aliquots of 10 ml of water were filtered through a nitrocellulose filter with a pore diameter of 0.22 μm. Microscopic analysis of water samples was carried out according to the standard method [2].

3. Results

The lakes studied by us are characterized by a variety of chemical composition and a significant range of water salinity (table 2). Analysis of lake waters chemical composition showed that the main components of water mineralization are sodium, carbonate and bicarbonate and chloride ions. Sulfate ions with a content of more than 20% eq. were recorded in two cases (Lake Baga Dalay Nuur and Khaichiin Tsagan Nuur). All lakes are represented by the soda type with transitional subtypes [3]. In the composition of cations, up to a salinity of 4 g/l, magnesium is the second most important (after sodium) (Lake Shogoy Tsagan Nuur, Ikh Dalay Nuur, Baga Dalay Nuur, Khorin Tsagan Nuur, and Davsan Tsagan Nuur Baga). Along with the main ions in lake waters, with an increase in water salinity, such micro- and biogenic components as fluorine, phosphorus, strontium, arsenic, and nitrogen accumulate. At the time of the study, among the largest interconnecting lakes Barun- and Zun-Torey, having a total area of the water surface of up to 850 km² in high-water periods, the presence of water was noted only in the lake Zun-Torey (Lake Barun-Torey turned out to be dry, with the exception of a small puddle at the place of brook exit). The chemical composition of lake water is...
dominated by sodium, carbonate-hydrocarbonate and chloride ions. Sulfates are contained in a relatively low concentration (13% eq.).

**Table 2. Basic physical and chemical parameters of lake waters.**

| Lakes          | Khukh Nuur | Khukh Nuur | Khukh Nuur | Khukh Nuur | Khukh Nuur | Shagoy Tsaagan Nuur | Ikh Dalay Nuur | Ikh Dalay Nuur | Ikh Dalay Nuur | Bagu Dalay Nuur | Bagu Dalay Nuur | Delger Nuur | Khachin Tsaagan Nuur | Khorin Tsaagan Nuur | Davan Nuur | Tsagan Nuur Baga Torey | Zun-Torey |
|----------------|------------|------------|------------|------------|------------|---------------------|----------------|----------------|----------------|----------------|----------------|------------|------------------------------|----------------------|-----------|----------------------------|-----------|
| Sampling depth | m          |            |            |            |            |                     |                |                |                |                |                |            |                              |                       |           |                             |           |
| pH             |            |            |            |            |            |                     |                |                |                |                |                |            |                              |                       |           |                             |           |
| CO₂            |            |            |            |            |            |                     |                |                |                |                |                |            |                              |                       |           |                             |           |
| NO₂            |            |            |            |            |            |                     |                |                |                |                |                |            |                              |                       |           |                             |           |
| NO₃            |            |            |            |            |            |                     |                |                |                |                |                |            |                              |                       |           |                             |           |
| Cl             |            |            |            |            |            |                     |                |                |                |                |                |            |                              |                       |           |                             |           |
| F              |            |            |            |            |            |                     |                |                |                |                |                |            |                              |                       |           |                             |           |
| Ca²⁺          |            |            |            |            |            |                     |                |                |                |                |                |            |                              |                       |           |                             |           |
| Mg²⁺          |            |            |            |            |            |                     |                |                |                |                |                |            |                              |                       |           |                             |           |
| Na⁺           |            |            |            |            |            |                     |                |                |                |                |                |            |                              |                       |           |                             |           |
| K⁺            |            |            |            |            |            |                     |                |                |                |                |                |            |                              |                       |           |                             |           |
| Sr             |            |            |            |            |            |                     |                |                |                |                |                |            |                              |                       |           |                             |           |
| NO₃⁻          |            |            |            |            |            |                     |                |                |                |                |                |            |                              |                       |           |                             |           |
| SO₄²⁻         |            |            |            |            |            |                     |                |                |                |                |                |            |                              |                       |           |                             |           |
| Fe             |            |            |            |            |            |                     |                |                |                |                |                |            |                              |                       |           |                             |           |
| Pb             |            |            |            |            |            |                     |                |                |                |                |                |            |                              |                       |           |                             |           |
| Ni             |            |            |            |            |            |                     |                |                |                |                |                |            |                              |                       |           |                             |           |
| Cd             |            |            |            |            |            |                     |                |                |                |                |                |            |                              |                       |           |                             |           |
| Zn             | µg/L       |            |            |            |            |                     |                |                |                |                |                |            |                              |                       |           |                             |           |
| Cu             |            |            |            |            |            |                     |                |                |                |                |                |            |                              |                       |           |                             |           |
| Cr             |            |            |            |            |            |                     |                |                |                |                |                |            |                              |                       |           |                             |           |
| Mn             |            |            |            |            |            |                     |                |                |                |                |                |            |                              |                       |           |                             |           |
| As             |            |            |            |            |            |                     |                |                |                |                |                |            |                              |                       |           |                             |           |
| Al             |            |            |            |            |            |                     |                |                |                |                |                |            |                              |                       |           |                             |           |

- water sample taken at another point of the lake, M - water salinity.

The second largest lake among the studied by us is the closed-drainage lake Khukh Nuur with an area of about 55 km², which lies at an absolute height of 560 m (the lowest point of the territory). It has a rounded shape with increasing depth towards the center. The transparency of the water is relatively high. The content of dissolved oxygen is on average 5.6 mg/l, with a slight decrease in its amount towards the bottom. On the contrary, the concentration of macromolecules gradually increases with depth; accordingly, the mineralization of water increases, but the pH value decreases. A
similar situation, but with a lower water transparency, large gradients of the concentration of macrocomponents and salinity, is observed in the shallower lake Ikh Dalay Nuur.

The total number of microorganisms in the lakes ranged from 0.53 to 4.47 × 10^6 cells / ml (table 3). Its maximum values were revealed in the lake, stratified by physicochemical parameters Khukh Nuur at the horizon 4.6 m (transparency zone), the minimum - in the surface layer of the lake Delger Nuur. The density of bacteria in the surface and near-bottom layers of water did not differ significantly in lakes, the depth of which did not exceed 2-2.5 m during the study period Shogoy Tsagan Nuur, Baga Dalay Nuur, Delger Nuur, Khaiichii Tsagan Nuur (table 3).

**Table 3.** Some hydrological and microbiological parameters of lakes in Northeastern Mongolia and Southeastern Transbaikalia of different trophic status, July 2008.

| Lake (sampling point) | Depth (m) | TW (m) | Horizon (m) | T° (°C) | N° (×10^6 cells/mL) | V° (mkm³) | B° (mg/L) |
|-----------------------|-----------|--------|-------------|---------|---------------------|-----------|-----------|
| Mesotrophic           |           |        |             |         |                     |           |           |
| Shogoy Tsagan Nuur (GCL) | 1.0       | 1.0    | surface layer | 26.0    | 1.55                | 0.81      | 1.26      |
| Shogoy Tsagan Nuur (GCL) | 1.1       | 0.5    | bottom layer (1.0) | 25.8    | 1.55                | 0.64      | 0.99      |
| Baga Dalay Nuur (CL)  | 1.6       | 1.0    | surface layer | 21.9    | 1.20                | 1.39      | 1.67      |
| Baga Dalay Nuur (CL)  | 1.6       | 0.5    | bottom layer (1.6) | 21.9    | 0.63                | 0.59      | 0.37      |
| Baga Dalay Nuur (LB)  | 0.5       | 0.5    | surface layer | 21.6    | 0.66                | 1.42      | 0.94      |
| Khaiichii Tsagan Nuur (DCL) | 0.5     | 0.5    | surface layer | 23.3    | 1.55                | 0.76      | 1.17      |
| Khorin Tsagan Nuur (GCL) | 0.5      | 0.5    | surface layer | 20.0    | 1.12                | 1.35      | 1.50      |
| Mesotrophic           |           |        |             |         |                     |           |           |
| Khuk Nuur (DCL)       | 11.5      | 4.6    | surface layer | 21.1    | 0.60                | 0.25      | 0.15      |
| Khuk Nuur (DCL)       | 4.6       | 4.6    | bottom layer | 20.3    | 4.47                | 0.83      | 3.86      |
| Khuk Nuur (DCL)       | 9.2       | 9.2    | surface layer | 19.7    | 0.77                | 0.69      | 0.54      |
| Khuk Nuur (DCL)       | 11.5      | 11.5   | bottom layer | 19.0    | 0.83                | 0.53      | 0.44      |
| Khuk Nuur (CL)        | 4.8       | 4.8    | surface layer | 23.7    | 0.86                | 0.43      | 0.06      |
| Khuk Nuur (CL)        | 4.8       | 4.8    | bottom layer (4.8) | 20.8    | 1.09                | 0.53      | 0.57      |
| Ikh Dalay Nuur (DCL)  | 3.1       | 3.1    | surface layer | 22.0    | 1.63                | 0.89      | 1.45      |
| Ikh Dalay Nuur (DCL)  | 0.7       | 0.7    | surface layer | 22.1    | 1.90                | 2.55      | 4.84      |
| Ikh Dalay Nuur (DCL)  | 2.1       | 2.1    | bottom layer (3.1) | 21.4    | 2.33                | 1.34      | 3.13      |
| Ikh Dalay Nuur (CL)   | 1.4       | 1.4    | surface layer | 21.7    | 1.62                | 2.39      | 2.79      |
| Delger Nuur (GCL)     |           |        |             |         |                     |           |           |
| Davsan Tsagan Nuur Baga (LB) | 0.5 | 0.5    | surface layer | 18.7    | 2.48                | 0.71      | 1.76      |
| Zun-Torey (southwestern CL) | 0.5 | 0.5    | surface layer | 24.7    | 0.62                | 1.04      | 0.06      |
| Zun-Torey (western CL) | 0.5       | 0.5    | surface layer | 24.7    | 0.97                | 1.94      | 1.88      |
| Zun-Torey (northern CL) | 0.5      | 0.5    | surface layer | 24.7    | 1.71                | 2.18      | 3.73      |

TW – transparency of water.  
T° – water temperature (°C).  
N° – total bacteria number (×10^6 cells/mL).  
V° – average volume of bacterial bodies (mkm³).  
B° – biomass of bacteria (mg/L).

The waters of Lake Khukh Nuur and Ikh Dalay Nuur were characterized by a vertical stratified distribution of microorganisms. The maximum indicators of the average volumes of bacterial bodies and biomass - 2.5 μm³ and 4.84 mg / L, respectively, were established for the lake Ikh Dalay Nuur, minimum - 0.25 μm³ and 0.15 mg / L for the surface water horizon of lake Khukh Nuur.

4. Discussions

Analysis of the factual material showed that the distribution of chemical components in the waters of the studied lakes differs from the indicated schemes of metamorphization [4]. Only in the lake Ikh Dalay Nuur, the anionic composition of water was actually hydrocarbonate; in other lakes, the chlorine ion was predominant or second in importance. In a number of lakes, chlorine was the main anion already in the early stages of water concentration. The outstripping growth of the chloride ion content in lake waters corresponds to the ratio of the main anions in the groundwater of the continental
salinization zone [5], which provide the bulk of the salt supply of the lakes. Its equivalent concentration is on average higher than that of sulfate. Therefore, in the general case, the sulfate ion cannot be the main anion of lake waters. Hence, the formation of sulphate lakes proper is possible if there are additional sources of sulphate entering the lakes. In fact, in the waters of the studied lakes, not only does the accumulation of sulfates proportional to chlorides occur, but they lag behind in the rate of accumulation, and the contents of bicarbonate and carbonate, in comparison with them, in most cases grow more intensively. Let us take a closer look at the current situation.

As our studies have shown, the absolute range of fluctuations in the number of bacterioplankton in the studied lakes (extreme values of all random changes in space and time) is not so large - 8 times: from 0.53 to \(4.46 \times 10^6\) cells / ml. It is known that the spatial distribution of lake bacteria is determined by the diversity of lake biotopes and their variability over time. No regular changes in the size of the bacterial population in space have been established. The density of bacteria in the surface and bottom layers of water in shallow lakes did not differ significantly. The even distribution of bacteria along the vertical is explained by the good mixing of the entire water mass of the lakes by the wind (the average depth of these lakes is 1 m). The population density of planktonic bacteria in the studied lakes with a depth of more than 3.0 m in deep-water areas and in the shallow waters of their coastal areas also did not differ significantly. Sometimes it was higher in shallow waters, sometimes in the pelagic zone, but in most cases the distribution of bacterioplankton was relatively uniform. For example, the spatial distribution of TMN in lakes Khukh Nuur and Ikh Dalay Nuur (table 3).

The maximum average sizes of bacterial bodies and biomass are established for zones of the water column of lakes, where the vertical gradients of characteristics (temperature, salinity, density, etc.) increase sharply in comparison with the vertical gradients in the upper and lower layers. The total number of bacteria can, to some extent, be judged on the intensity of microbiological processes and on the trophicity of the reservoir. According to the data obtained on the total number of microorganisms, the studied lakes were classified as mesotrophic and mesoeutrophic (table 2).

In general, the lakes show consistency in the distribution of the carbonic acid derivative and bacterial biomass with a reliable approximation value \(R^2 = 0.54\) (figure 1). This consistency is due to the conjugation of geo- and biochemical processes occurring in lakes through the carbon cycle.

![Figure 1](image.png)

In salt lakes, the input items of the hydrochemical balance of carbon, in addition to the input with the underground and surface runoff, are also formed due to the mineralization of organic substances dissolved and accumulating in bottom sediments. One of the sources of organic matter is detritus that undergoes bacterial destruction, which comes from catchments and is produced in the water bodies themselves by communities of microorganisms and algae. Research has confirmed that organic carbon generation from bacterial photosynthesis is equally important, if not essential. In the surface horizons of saline lakes of the considered territory, the total production of organic matter by bacteria and algae in summer is estimated at 0.23–33.6 mg C / (m² × day) [6].
The lag in the accumulation of sulfate ions in lake waters is also associated with microbiological processes [7]. This happens exclusively due to the processes of sulfate reduction, since, as thermodynamic calculations show, the water of the lakes is not saturated with gypsum [8]. The recovery of sulfates is actively proceeding both in bottom sediments and in the water column of lakes. In the lake Zun-Torey, the content of hydrogen sulfide in the bottom layers at certain times was fixed up to 80 mg / l [8]. Its formation is reliably established in the water column. In the considered lakes, sulfate reduction, judging by the strong smell of H₂S and the presence of black silty mud deposits, is most pronounced in Lake Khukh Nuur. Of those studied microbiologically in the lake, Barun-Torey, the rate of sulfate reduction reached 12.0 mg S / dm³ day [9]. In this case, the electron donor is the carbon of organic matter, which as a result is converted into CO₂ and enters the water column, and at a relatively high pH value is transformed into HCO₃⁻ and CO₃²⁻.

5. Conclusions

During the study period, water bodies represent the greatest variability of conditions for organisms living in them both in space (biotopes with terrestrial, lacustrine and transitional regimes) and in time. As a result of changes in hydrology, morphology and hydrochemistry during the period of water level decline, the entire ecosystem as a whole is constantly changing. In this connection, for bacterioplankton communities of mesotrophic and mesoeutrophic lakes under the studied conditions, no significant changes in the population size in space have been established. Meanwhile, there is a clear relationship between the biomass of bacterioplankton and the content of hydrocarbonate ions. It follows from this that the microbiological processes occurring in the lakes affect the content of carbonates and sulfates in the water, although the scales of this influence are different and depend on the functioning of the microbial community in a particular water body. The production of organic matter and the microbiological reduction of sulfates vary considerably and may not always be the factors that determine the ratio of anions in the waters of salt lakes. In such cases, the main role in their hydrochemical regime may be played by the processes of evaporation – dilution of water against the background of changes in climatic parameters.

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