Changing parameters of waters chemical composition in the Lake Arakhley water column (Eastern Transbaikalia)

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Abstract. The need to preserve the quality of water resources under conditions of anthropogenic impact is one of the most urgent problems of our time. The purpose of this work was to study the features of the distribution of the parameters of the chemical composition of the waters of Lake Arakhley in a vertical section. The investigated waters are characterised by a constancy of mineralisation and chemical composition, both within the water area and in the vertical section. The waters are ultra-fresh (salinity less than 200 mg/L), neutral and slightly alkaline (average pH 7.9), HCO3 Mg-Ca chemical composition. The carbon dioxide content in the water column has a significant impact on the concentration of hydrogen ions, as evidenced by the inverse relationship between pH and CO2 content. The observed increase in the nitrogen form and CO2 contents in the bottom part of the lake is most likely related to the life processes of organisms and vegetation. The recorded excess concentrations of Mn, Cu, Ni, and Al over maximum permissible concentrations indicate the need for additional studies to identify their sources.

1. Introduction
The study of lakes aimed at their use in human economic activities is relevant all over the world. The growing population, urbanisation, and the use of land resources in lakeside areas create problems of waste disposal and pollution of surface waters, including lake waters. The deterioration of their ecological state as a result of the use of fertilisers contributes to their pollution with heavy metals and leads, ultimately, to the loss of biodiversity within lake ecosystems [1–2].

The Ivano-Arakhley system of lakes, located in the Trans-Baikal Territory, consists of six large lakes with a water surface of more than 10 km² (Arakhley, Shakshinskoye, Irgen, Ivan, Tasey, Bolshoi Undugun) and about 20 small lakes with an area of less than 1 km². At present, the Ivano-Arakhley lakes are actively used by the local population for water supply and fishing, and also have a high recreational value for the inhabitants of the regional centre of the Trans-Baikal Territory [3].

An active study of the regularities of the formation of the hydrochemical regime, chemical composition, and biodiversity of the waters of the Ivano-Arakhley system of lakes was started in the 60–70s by B A Shishkin and AV Ivanov [4–6] and was then continued by their students and colleagues [7]. The Ivano-Arakhley system of lakes are mainly fresh water bodies. Only two of them, Bolshoye Guzhirnoe and Maloye Guzhirnoe, are brackish. Depending on the flow rate and chemical composition of the waters, four groups have been identified among the lakes of the Ivano-Arakhley system [8], the first of which includes the largest Lake Arakhley. This work is a continuation of many years of research carried out at the Laboratory of Geoecology and Hydrogeochemistry INREC SB
RAS. The purpose of the work is to study the distribution of the physicochemical parameters of waters in a vertical section of Lake Arakhley.

2. Objects and methods
Lake Arakhley is located in the southeast of the Vitim plateau, 70 km from the city of Chita; it has an area of 58.5 km², an average depth of 10.4 m, and a maximum depth of 17.0 m. The hydrochemical state of the lake is determined by the chemical composition of the waters being supplied to it, which are represented by atmospheric precipitation, groundwater, and surface waters. The streams and rivers flowing into the lake are slightly mineralised (69.9–127.9 mg / L), the chemical composition of the waters is HCO₃ Ca. In 2012, a threefold (March, June, August) sampling of the waters of Lake Arakhley was carried out. Chemical and analytical studies were carried out using conventional methods (turbiditymetry, potentiometry, and colourimetry) in the laboratory of the Institute of Natural Resources, Ecology, and Cryology of the SB RAS (Chita). The main cations and metals were determined with the atomic adsorption method on a SOLAAR M6 spectrophotometer.

3. Results
The studies carried out indicate the constancy of the ionic composition and mineralisation of the waters of Lake Arakhley, both in different parts of the reservoir (centre of the lake, coastal zone) and at depth. A slight decrease in the value of mineralisation was noted during the period from March to August, which is associated with heavy precipitation at this time. Its average values were (mg / L): in March – 170.3; in June – 162.8; and in August – 158.5 (table 1).

| №  | Date   | pH | PO₄⁺ | CO₂ | HCO₃⁻ | SO₄²⁻ | Cl⁻ | F⁻ | Ca²⁺ | Mg²⁺ | Na⁺ | K⁺ | Σ ions | NO₃⁻ | NO₂⁻ | NH₄⁺ |
|----|--------|----|------|-----|-------|-------|-----|----|------|------|-----|----|--------|------|------|------|
| C-1 | 03.2012 | 8.1 | 4.6  | 2.6 | 122   | 1.92  | 4.5 | 0.7 | 16.4 | 8.41 | 15.1 | 1.60 | 169.9  | 0.008 | 0.10 |
| C-2 | 03.2012 | 8.1 | 4.5  | 1.8 | 122   | 1.88  | 4.4 | 0.4 | 15.6 | 8.43 | 15.0 | 1.52 | 168.8  | 0.007 | 0.12 |
| C-3 | 03.2012 | 8.1 | 4.7  | 2.2 | 121   | 1.90  | 4.5 | 0.4 | 15.3 | 8.24 | 15.0 | 1.46 | 167.4  | 0.007 | 0.07 |
| C-4 | 03.2012 | 8.1 | 4.6  | 2.2 | 127   | 1.92  | 4.4 | 0.4 | 15.0 | 8.27 | 15.6 | 1.44 | 173.6  | 0.010 | 0.07 |
| C-5 | 03.2012 | 7.9 | 4.5  | 3.9 | 122   | 1.90  | 4.4 | 0.4 | 15.7 | 8.36 | 15.4 | 1.48 | 169.2  | 0.007 | 0.07 |
| C-6 | 03.2012 | 7.8 | 4.6  | 4.8 | 126   | 1.88  | 4.4 | 0.4 | 15.4 | 8.24 | 15.7 | 1.57 | 173.2  | 0.68  | 0.24 | 0.58 |
| CZ-0 |        | 7.9 | 5.0  | 2.6 | 121   | 2.85  | 2.8 | 0.3 | 17.9 | 6.66 | 12.3 | 1.15 | 164.6  | 0.009 | 0.08 |
| CZ-7 |        | 7.6 | 5.2  | 2.6 | 118   | 2.90  | 2.5 | 0.3 | 16.5 | 6.45 | 12.0 | 1.15 | 159.5  | 0.008 | 0.09 |
| C-0 | 06.2012 | 7.8 | 4.9  | 2.6 | 118   | 2.85  | 2.4 | 0.3 | 16.7 | 6.12 | 12.1 | 1.15 | 159.3  | 0.009 | 0.10 |
| C-2 | 06.2012 | 7.9 | 5.0  | 2.6 | 120   | 2.90  | 2.5 | 0.3 | 17.5 | 6.56 | 12.5 | 1.16 | 163.1  | 0.008 | 0.08 |
| C-4 | 06.2012 | 7.8 | 5.1  | 1.8 | 120   | 2.92  | 2.4 | 0.3 | 17.5 | 6.56 | 12.5 | 1.16 | 163.0  | 0.009 | 0.09 |
| C-6 | 06.2012 | 7.8 | 4.8  | 1.8 | 122   | 2.84  | 2.4 | 0.4 | 17.5 | 6.59 | 12.5 | 1.16 | 164.9  | 0.008 | 0.10 |
| C-8 |        | 7.7 | 4.8  | 1.8 | 124   | 2.90  | 2.5 | 0.3 | 17.7 | 6.60 | 12.8 | 1.16 | 167.6  | 0.007 | 0.12 |
| C-10 |       | 7.7 | 5.2  | 2.6 | 120   | 2.92  | 2.5 | 0.3 | 17.5 | 6.56 | 12.5 | 1.15 | 163.1  | 0.008 | 0.09 |
| C-13,3 |      | 7.7 | 5.1  | 2.6 | 122   | 2.85  | 2.4 | 0.3 | 17.6 | 6.60 | 12.6 | 1.16 | 165.2  | 0.009 | 0.12 |
| C-0 | 08.2012 | 8.1 | –    | 2.6 | 120   | 1.95  | 2.9 | 0.3 | 16.8 | 7.29 | 11.3 | 1.23 | 161.4  | 0.008 | 0.10 |
| C-2 | 08.2012 | 8.1 | –    | 0.9 | 117   | 1.80  | 2.9 | 0.4 | 16.8 | 7.30 | 11.3 | 1.20 | 158.3  | 0.09  | 0.05 |
| C-4 | 08.2012 | 8.0 | –    | 1.8 | 115   | 1.83  | 2.8 | 0.4 | 16.8 | 7.29 | 11.4 | 1.23 | 156.3  | 0.04  | 0.09 |
| C-6 | 08.2012 | 8.1 | –    | 1.8 | 113   | 1.78  | 2.8 | 0.3 | 16.7 | 7.41 | 11.2 | 1.23 | 154.1  | 0.86  | 0.09 |
| C-8 | 08.2012 | 8.1 | –    | 0.9 | 117   | 1.75  | 2.7 | 0.4 | 16.8 | 7.72 | 11.5 | 1.23 | 158.7  | 0.78  | 0.09 |
| C-10 |       | 7.6 | –    | 2.6 | 117   | 1.75  | 2.7 | 0.4 | 16.9 | 7.89 | 11.5 | 1.22 | 158.9  | 0.72  | 0.06 |
| C-13,3 |      | 7.3 | –    | 3.5 | 117   | 1.75  | 2.8 | 0.4 | 17.2 | 7.95 | 11.6 | 1.23 | 159.5  | 0.94  | 0.11 | 0.09 |
| CZ-0 |       | 8.2 | –    | 1.8 | 117   | 2.00  | 3.2 | 0.3 | 16.7 | 7.56 | 11.2 | 1.29 | 158.9  | 0.90  | 0.09 | 0.10 |
| CZ-1,7 |       | 8.1 | –    | 1.8 | 118   | 2.05  | 3.2 | 0.3 | 16.7 | 7.68 | 11.5 | 1.32 | 160.5  | 0.94  | 0.08 | 0.05 |

*a* Permanganate oxidation (mg O₂ / L).

*b* In the sample number: C – the central part of the lake, CZ – coastal zone, the numbers – water sampling depth (m).
In general, during the period under consideration, mineralisation varied within 154.1–173.6 (average value – 163.1 mg / L). In terms of pH, the water was classified as neutral and slightly alkaline (average pH is 7.9). The predominant chemical type of the lake waters was HCO$_3$ Na-Mg-Ca, and less often HCO$_3$ Mg-Na-Ca, which is in good agreement with [4–9].

Changes in the main indicators of the chemical composition of waters in the water area were insignificant. Indeed, there was a slight increase in the pH value from the centre of the lake to the coast, the content of free CO$_2$ was mostly constant, a slight decrease from the centre to the coastal zone of the lake was recorded only in August, and changes in mineralisation were multidirectional (table 1).

Layer-by-layer sampling of the central part of the lake showed a tendency, common for all three sampling periods, toward a certain decrease in pH values from the surface to the bottom layer, both in winter (table 1, figure 1 a) and summer (table 1, figure 1 b, c) time. The concentration of dissolved CO$_2$, on the contrary, increased in March and August, and in June decreased at a depth of 4-8 m, before increasing again to the values of the surface layer (table 1, figure 1 a, b, c).

**Figure 1.** Changes in pH and CO$_2$ values in the central part of Lake Arakhley at depth: a – March, b – June, c – August.

During the winter period (March), a significant increase in the concentration of nitrogen forms was recorded at a depth interval of 5–6 m (table 1, figure 2 a). In June, at a depth of 6–8 m, against the background of decreasing concentrations of the nitrite form, a significant increase in the contents of NO$_3^-$ was noted. In the bottom layer (8-13.3 m), on the contrary, an increase in the concentrations of nitrite and a decrease in nitrate forms was recorded, while changes in the amount of NH$_4^+$ were insignificant (table 1, figure 2 b). In August, there was an increase in depth in the contents of the nitrite and nitrate forms, and in parallel, the concentrations of the ammonium form of nitrogen decreased (table 1, figure 2). The increase in the concentrations of nitrogen forms and CO$_2$ at the bottom of the lake is most likely associated with the oxidation of organic matter.

The study of the microcomponent composition of lake waters allows the determination of the concentrations of Al, Sr, Mn, Fe, Cu, Zn, Pb, Cd, As, Ag, Hg, Cr, Ni, and Co. The contents of Cd, Pb, As, Hg, and Ag during the study period were mainly below the detection limits. On the contrary, the contents of Mn, Cu, Ni, and Al often exceeded the Maximum Permissible Concentrations (MPC) for fishery water bodies [10] (table 2). The presence of these metals entering the surface waters can be due to natural causes (leaching from underlying rocks, input from ground and surface waters, decomposition of aquatic animals and plant organisms) and anthropogenic factors (agricultural activities, fuel combustion, traffic, etc.).
Figure 2. The vertical distribution of the nitrogen form contents in the water column in the central part of Lake Arakhley: a – March, b – June, c – August (the value of NO$_3^-$ in March and June is equal to half the sensitivity of the method).

Table 2. Metal concentrations in the Lake Arakhley waters (µg / L).

| No  | Sr  | Mn | Fe | Zn | Cu | Ni | Co | Al | Cr |
|-----|-----|----|----|----|----|----|----|----|----|
| C-1 | 30.0| 2.5| 17.0| 2.3| 1.50| 0.81| – | 48.7| – |
| C-2 | 30.0| 1.4| 19.3| 2.4| 0.55| 0.73| – | 33.2| – |
| C-3 | 30.0| 2.7| 19.5| 2.4| 0.95| 5.50| 1.25| 29.0| – |
| C-4 | 30.0| 3.1| 18.3| 1.7| 0.18| – | – | 25.6| – |
| C-5 | 30.0| 2.6| 18.0| 1.5| 0.25| – | – | 25.5| – |
| C-6 | 30.0| 39.5| 18.3| 1.1| 0.64| 1.54| – | 25.4| – |
| CZ-0 | – | 6.97| 21.0| 0.47| 2.50| 4.14| 2.51| 47.7| – |
| CZ-1.7 | – | 6.97| 20.3| 0.29| 1.24| 3.75| 1.59| 51.2| – |
| C-0 | – | 7.00| 21.1| 0.27| 0.48| 3.96| 0.91| 43.2| – |
| C-2 | – | 7.27| 20.1| 0.10| 0.64| 3.74| 1.20| 35.7| – |
| C-4 | – | 7.23| 19.8| 0.33| 1.48| 3.14| 1.08| 50.4| – |
| C-6 | – | 6.78| 19.9| 0.12| 1.16| 3.03| 0.74| 44.5| – |
| C-8 | – | 6.54| 21.0| 0.15| 1.22| 2.78| 0.64| 36.1| – |
| C-10 | – | 6.70| 21.0| 0.28| 2.23| 2.40| 0.29| 19.9| – |
| C-13.3 | – | 6.77| 20.3| 0.21| 2.29| 2.93| 1.38| 14.1| – |
| C-0 | 26.0| 6.95| 63.4| 2.94| 1.41| 2.41| – | 31.9| 0.35 |
| C-2 | 26.0| 6.95| 56.2| 2.95| 1.41| 2.49| – | 43.4| 0.35 |
| C-4 | 27.0| 6.93| 58.0| 2.95| 1.45| 2.41| – | 30.9| 0.35 |
| C-6 | 27.0| 6.86| 63.0| 2.94| 1.46| 2.43| – | 45.9| 0.35 |
| C-8 | 27.0| 6.86| 63.2| 2.94| 1.42| 2.41| – | 47.5| 0.36 |
| C-10 | 28.0| 6.96| 63.2| 2.94| 1.56| 2.43| – | 48.4| 0.45 |
| C-13.3 | 29.0| 6.96| 72.4| 3.05| 1.61| 2.88| – | 48.4| 0.53 |
| CZ-0 | 28.0| 6.92| 52.9| 2.98| 1.72| 1.08| – | 48.5| 0.43 |
| CZ-1.7 | 28.0| 6.59| 62.5| 2.96| 1.78| 10.3| – | 48.5| 0.43 |
| MPC a | 400 | 10.0| 100| 1.00| 1.00| 10.0| 10.0| 40.0| 50.0 |

a – MPC for waters of fishery value (Order of the Ministry of agriculture of the Russian Federation No. 552 from January 13, 2016).

The changes in metal concentrations vertically along the water column were, in general, multidirectional. The most significant changes in concentrations recorded in the central part of Lake Arakhley are characteristic of Cu, Co, Al, and Fe (table 2).
4. Conclusions
The composition of the waters of Lake Arakhley was dominated by HCO$_3$ Mg-Ca, the value of mineralisation during the study period varied within 154–174 mg / L, and the average pH value was 7.9. The studies carried out indicate the constancy of the ionic composition and mineralisation of the waters of Lake Arakhley, both within the water area and in the vertical section.

The concentration of hydrogen ions in the water column of the lake is significantly influenced by the content of dissolved CO$_2$, with an increase in the value of which, a decrease in pH was noted and vice versa. The increase in the nitrogen form and CO$_2$ contents in the bottom part of the lake is associated with the processes of vital activity of organisms and vegetation.

The recorded excess of the concentrations of metals, especially Cu and Al, in the water column of the lake indicates the pollution of its waters and the need for additional research to identify their sources.

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