

Transformation of the chemical composition of waters from the Barguzin River in the Barguzin Bay (Lake Baikal)

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ABSTRACT. We have studied the changes in the chemical composition of the Barguzin River waters that inflow to Lake Baikal under the different water level. We have shown that river and lake waters that involved in the mixing differ in the ion composition and temperature. Despite this, the mixing in the Barguzin Bay under the influence of circulation currents and thermal barrier occurs in a comparatively narrow coastline, which is usually less than four kilometres. Mixed waters distribute north- and northwestward and reach the southern end of the Svyatoy Nos Peninsula. In summer, the distribution scale of river waters in the bay becomes greater but is mainly limited to the surface layer. In the central part of the bay, within one-two kilometres from the river estuary, a lens of lake waters can form. Not only the change in the chemical composition and temperature of the water but also its colour indicate the influx of these waters. The change in the concentrations of individual ions at a distance from the estuary of the Barguzin River occurs linearly, which indicates ordinary dynamic mixing of river and lake water masses.

Keywords: Barguzin Bay, chemical composition of waters, river runoff, thermal bar, dynamic mixing

1. Introduction

The Barguzin Bay is the largest on Lake Baikal. Its area is 725 km², average depth is approximately 200 m, and the maximum depth reaches 1284 m. The Barguzin River (the third largest Baikal tributary), as well as several small watercourses, flow into the bay. The bay warms up well under the influence of the Barguzin River and owing to the extended coastal shallow water. The hydrochemical regime of the bay results from the mixing of river and lake waters and shows high variability in time and space. The active economic development of the Barguzin River basin between the 1950s and 1980s (logging, ploughing, increasing the area of an irrigated land, influx of drainage water enriched with various chemical components to the channel network, etc.) accompanied by a decrease in quality of river water and, consequently, an increase in the emissions of chemical components to the bay (Obozhin et al., 1984; Bogdanov, 1986; Drucker et al., 1997; Urbazaeva et al., 2016).

We aimed to study the transformation of the chemical composition of the Barguzin River water that inflows to Lake Baikal, seasonal and spatial dynamics of concentrations of major ions in the Barguzin Bay as well as their variability in long-term aspect.

2. Materials and methods

We analysed the results of hydrochemical investigations that were conducted in 2004, 2007, 2011, and 2016 at the estuary of the Barguzin River and in the water area of the Barguzin Bay. Sampling was carried out in different seasons, considering the shift of the main inflow of the Barguzin water along the constant northeast coast of the bay (Verbolov, 1996). Water was sampled from three transects: southern, central and northern (Fig. 1). From each transect, the samples were taken with a Niskin bathometer at four-eight stations from depths of 0, 5, 10, and 25 m as well as at the bottom. Temperature and electroconductivity were measured with an SBE 19 plus CTD-probe (Sea-Bird Electronics).

The cations were determined by atomic absorption and flame emission methods; anions – by HPLC (Baram et al., 1999; Guidelines..., 2009). The reliability of the obtained results was controlled by ion balance error and through comparison of the calculated and measured specific electroconductivity (Technical Documents ..., 2000).

The degree of transformation of river water masses into lake ones was estimated (Sinyukovich et al., 2008) through the share of lake water (K_{lake}) at a certain

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site of the bay, depending on the measured concentration (C_{bay}) of the indicator substance as well as its initial value in river (C_{river}) and lake (C_{lake}) water:

$$K_{lake} = (C_{river} - C_{bay}) / (C_{river} - C_{lake}) * 100 \%$$

The concentrations of major ions (Na^+ , K^+ , Ca^{2+} , Mg^{2+} , SO_4^{2-} , Cl^- , and HCO_3^-) and their total concentration (Σi) were used as indicators of lake and river waters.

3. Results and discussion

Analysis of concentrations dynamics of components in the river runoff to the Barguzin Bay reveals their substantial spatial and vertical heterogeneity, which is due to a complex of hydrometeorological factors, in particular, the volume of the river runoff and the temperature of the mixed waters (Sorokovikova et al., 2010). A substantial variability throughout the year as well as in long-term aspect distinguishes the influence of each factor, which determines a complex nature in the formation of the mixing zone of river and lake waters and their transformation in the water area of the bay. The waters of the Barguzin River enter the bay in a single flow and, being carried away with a stream of the Baikal current, distribute along the northeast and north coasts of the bay, reaching Nizhneye Izgolovye Cape (Verbolov, 1996), and inflow to Lake Baikal (Ivanov, Sherstyankin, 2015).

In the closed Barguzin Bay, the mixing of river and lake waters is much lower than at open near-delta sites, such as the Selenga shallow waters (Tomberg, 2008). There is also a lower influence of the wind mixing since 75 % are southeast- and eastward winds, which, in the absence of a thermal bar, can extend the mixing zone but do not detach it from the northeast coast of the bay.

Seasonal changes in water temperature and hydrophysical conditions also predetermine the distribution and transformation features of river waters in the water area of the bay (Fig. 1, Fig. 2).

In spring, after the river ice breakup, the temperature of river waters rapidly increases, and in mid-May and early June, it reaches 13-15 °C. At this time, the temperature in Baikal is approximately 3-5 °C. The different temperature of the Barguzin and Baikal waters leads to the formation on a thermal bar in the water area of the bay at a distance of one-three kilometres from the site of the river inflow (see Fig. 1b). The front of the thermal bar serves as a natural barrier that prevents a free entry of river waters to the lake, and they mainly distribute from the river estuary along the coast of the bay. Consequently, the chemical composition

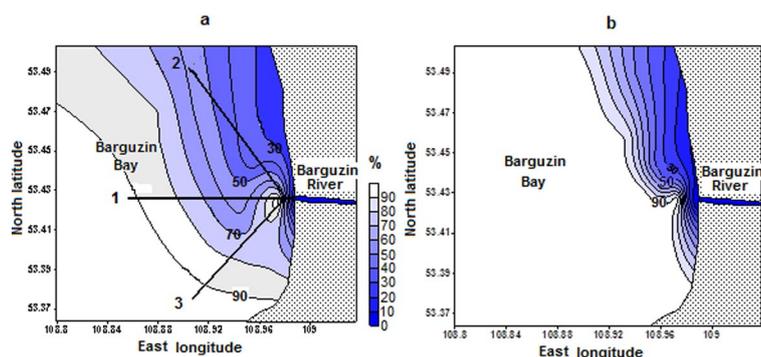


Fig.1. Distribution of mixed (%) river and lake waters in the water area of the Barguzin Bay in July 2004 (a) and June 2007 (b). Straight lines (a) are transects: 1 – central, 2 – northern and 3 – southern

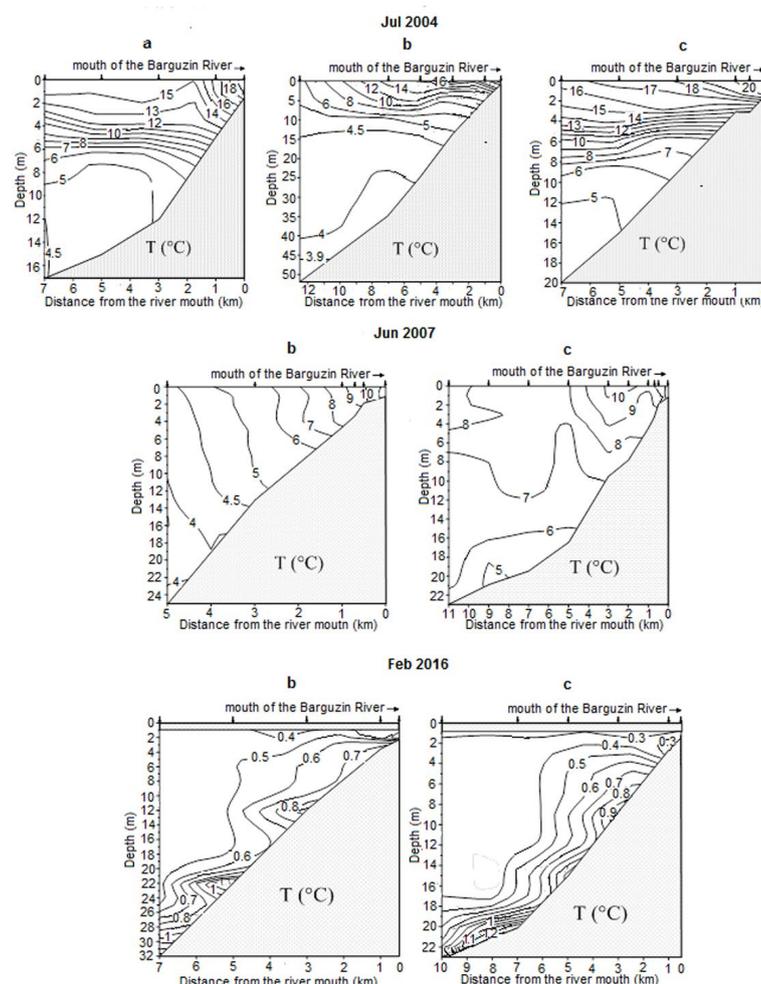


Fig.2. Water temperature distribution in the Barguzin Bay in different periods along the southern (a), central (b) and northern (c) transects

throughout the entire water column from the water edge to the thermal bar remains typical of the river waters, and beyond the thermal bar, it corresponds to the Baikal water.

Subsequently, when the water temperature in the bay rises higher than 4 °C, convection ceases, and a direct temperature stratification sets in with the maximum warm-up of the river and coastal waters of up to 18-20 °C, as it was on 1st July 2004 (Fig. 2). At the same time, the near-bottom temperature in the bay does not exceed 5.5 °C.

In summer, there is a seasonal increase in the Baikal water level, and a significant volume of lake water enters the Barguzin Bay, which additionally impedes the distribution of river water masses deep into the water area of the bay. In June-August, an increase in water level averages 0.5-0.7, which corresponds to the influx of the Baikal waters to the bay in the amount of up to 0.5 km³. Under these conditions, the warmer Barguzin waters distribute in the surface layer of 5-10 m (Fig. 1, Fig. 2). At a distance of 1.5-3 km, water masses actively transform, and at the station of 4 km from the estuary, the concentration of major ions is mainly close to the composition in waters of open Baikal. In summer, warm river waters can distribute in the water area of the bay for a considerable distance, but their share in the surface layer does not exceed 3-5% (Fig. 1).

Considering insignificant amount of the river waters influx in comparison with the total amount of water in the bay (approximately 150 km³), there may be a local influence of the Barguzin River on the chemical composition of water in the bay, i.e. limited mixing zone, which is confined to the northeastern coast of the bay.

As mentioned above, the features of the currents in the Barguzin Bay cause the transfer of the Barguzin River waters from the estuary mainly along the northeast and north coasts, explaining the heterogeneity in the distribution of mixed waters and differences in the chemical composition of water in the bay. Thus, along the central and southern transects, we recorded the total number of ions typical of the Baikal water at a closer distance from the river estuary than along the northern transect (Fig. 3). Moreover, along the central transect, in one-two kilometres from the river estuary, the influx and formation of a lens of lake waters can

influence the chemical composition of water (see Fig. 1a). Not only the change in the chemical composition but also water temperature (see Fig. 2) and the colour of water indicate this. Further deep into the lake, during all seasons, there is a gradual decrease in the concentration of the components that were brought by river waters (see Fig. 3).

There is a special situation in the mixing zone during floods when the river runoff forms mainly due to low-mineralized snow waters, and low-mineralized waters enter the bay. In 2007, along with the influx of river waters to the bay and their mixing with the Baikal waters, the concentration of most components in the salt composition and their total number increased (Fig. 4). Sulfates and chlorids, whose concentrations were higher in river water than in lake water, were the exception.

In winter, the main changes in the water mineralization were at a distance of 3 km, and deeper into the bay, they gradually faded. Other researchers also showed a similar distribution pattern of hydrochemical indicators in the bay in winter (Vorobyevskaya et al., 2016).

The obtained results have shown that despite the different hydrological conditions in the bay during our investigations, the nature of changes in the water composition in the estuarine area remains rather close. Indeed, thermal conditions in the bay significantly differed (2004: straight thermal stratification; 2007: thermal bar; 2016: inverse thermal stratification), and the river runoff was in different phases of water regime (2004: summer low water; 2007: flood; 2016: winter low water). All this was accompanied by significant differences in concentrations of major ions and their total number both in the river and the bay. Nevertheless, the maximum gradients of the total number of ions along the central and southern transects, regardless of the water-level conditions and temperature, were at a distance of up to one kilometre from the river estuary (Fig. 5). The gradient values and their vertical arrangement remained sufficiently similar.

Along the northern transect, the maximum changes in ion concentrations were also within the first kilometre from the estuary. However, in the surface layer, they were much lower than in the near-bottom area, and their significant values were at a

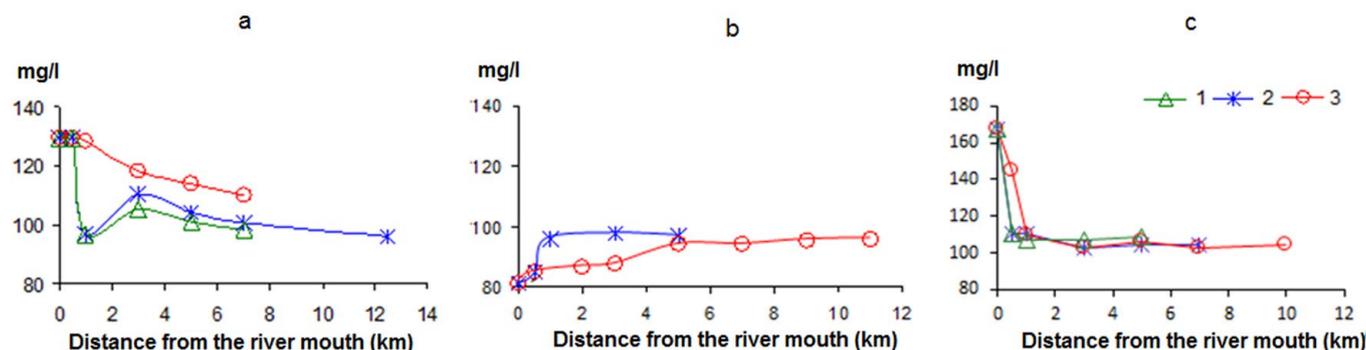


Fig.3. Distribution of the total number of ions in the surface water layer of the Barguzin Bay: a – July 2004; b – June 2007; c – March 2016. Transects: 1 – southern; 2 – central; 3 – northern

great distance, which indicates a lesser dilution of river waters and their more active distribution over the water area of the bay.

Analysis of the obtained results has shown that with the increased share of the Baikal water in samples from the estuarine area of the Barguzin Bay, the concentrations of some ions in the salt composition change linearly (Fig. 6). Linearity remains regardless of the greater or smaller concentration of the element in the water and its increased or decreased content in the mixing zone. This enables to conclude that during the mixing of river waters with lake waters, the change in the ion concentrations of the salt composition in the zone where river and lake waters interact results from ordinary dynamic mixing. This conservative behaviour is typical of both individual ions and their total number, and this does not change within the year.

Long-term investigations of the hydrochemical regime in the Barguzin Bay reveal the chemical composition features of its waters over the past 60 years. In 1950-60s, the chemical composition of water in the bay formed under the influence of natural factors, and the Baikal waters as well as those of the rivers that inflow to the bay, mainly the Barguzin River, determined seasonal and interannual changes in the concentrations of components (Votintsev, 1961). During the regulation of Baikal and rise of its water level, lake waters flowed to the bay, increasing the

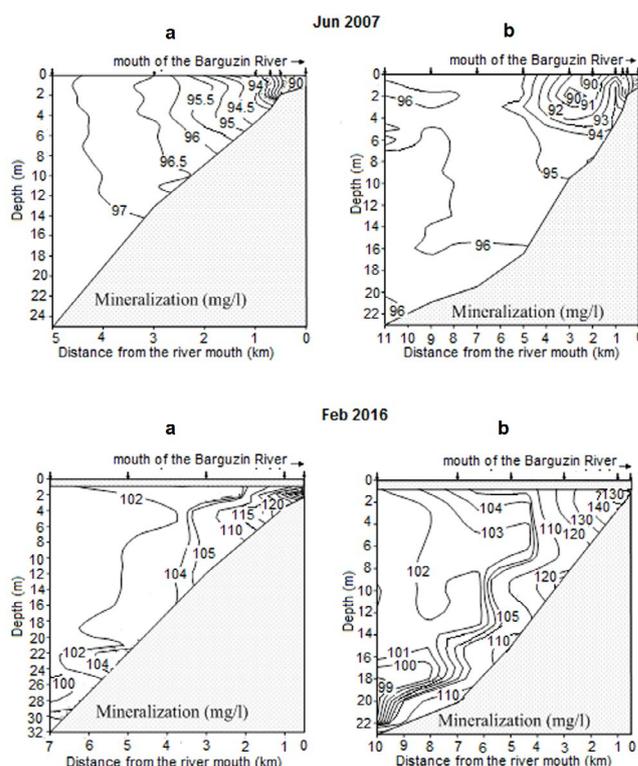


Fig.4. Change in the water mineralization in the Barguzine Bay in spring and winter along the central (a) and northern (b) transects

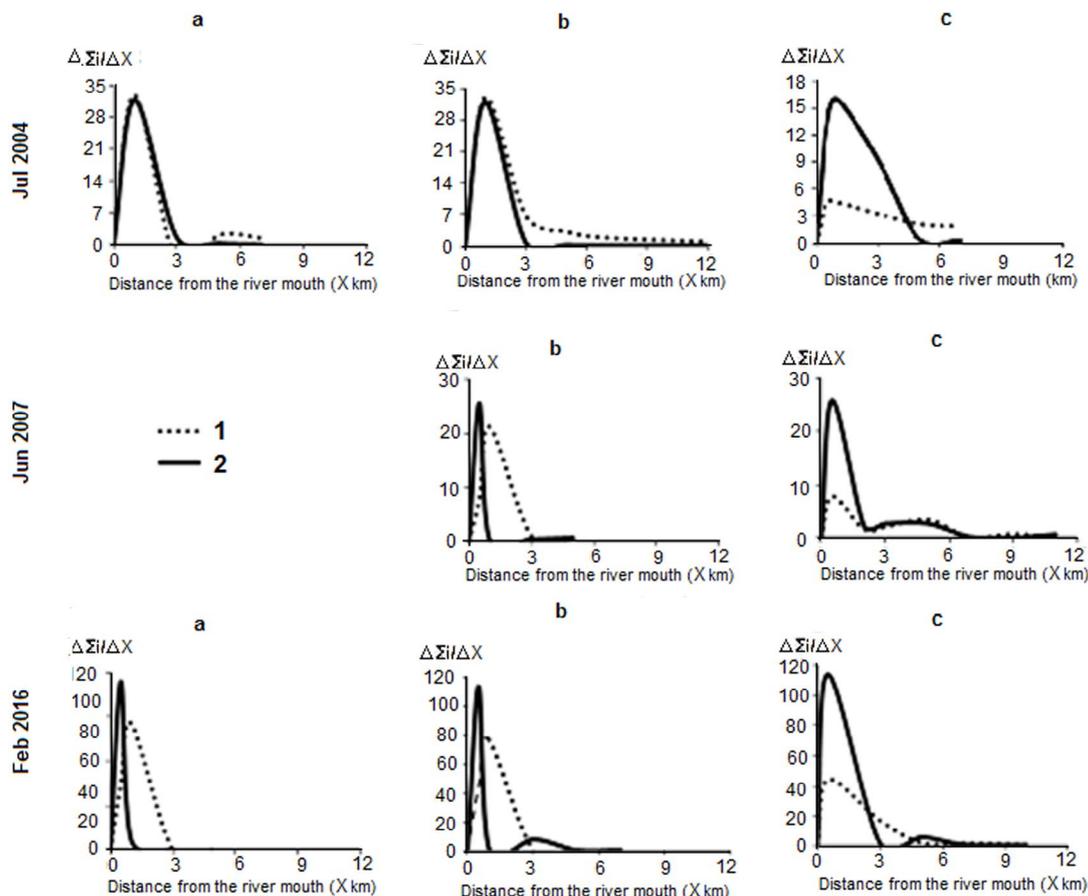


Fig.5. Horizontal gradients of the total number of ions in the salt composition ($\Delta\Sigma_i$) of the surface layer (1) and near the bottom (2) along the three transects from the estuary of the Barguzin River. Transects: a – southern; b – central; c – northern

concentrations and the total number of ions (Table) there. At the same time, the water composition did not change and still corresponded to bicarbonate class and calcium group (Mescheryakova and Verbolova, 1977).

Subsequent investigations, which were conducted in 2000, indicated an increase in the concentration of major ions and their total number in the water of the bay compared to the 1970s (Table). This can be due to an increase in the flow of ions with the waters of the Barguzin River, resulting from the economic activity in its watershed and influx of sewage and drainage waters to the river channel and then the bay (Drucker et al., 1997). Furthermore, during the past two decades, there was a low water level in the Baikal basin, including the basin of the Barguzin River (Sutyryna, 2019), which could also contribute to the increase in the water mineralization in the bay.

Despite the change in absolute concentrations of ions, their relative concentration remains unchangeable, and the water in the bay still corresponds to bicarbonate class and calcium group.

4. Conclusions

The conducted hydrophysical and hydrochemical investigations of the Barguzin Bay have shown that formation of the chemical composition and its waters, water-level conditions on the Barguzin River as well as water temperature differences determine seasonal changes in the concentration of major ions and their spatial distribution. Moreover, the system of currents in the bay predetermines the main transfer of the Barguzin River waters from the estuary along the northeast coast of the bay, which explains the heterogeneity in the distribution of the component concentrations of the ion composition in the water area of the bay. Along the central and southern transects, the concentrations of major ions and their total number, which are typical of the Baikal water, are recorded at a closer distance from the estuary than those along the northern transect. At the same time, the nature of changes in the chemical composition of water, which take place in the mixing zone of river and lake waters, is rather similar along all transects. The maximum gradients of the total number of ions are located at a distance of less than

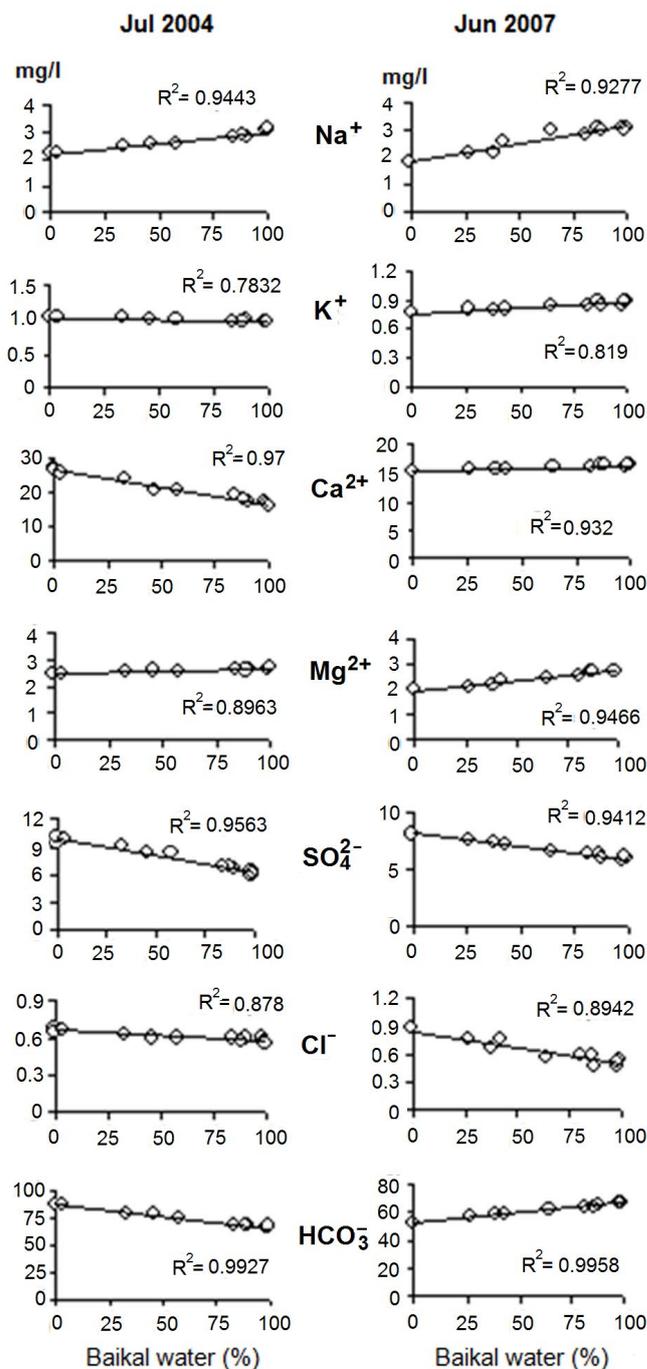


Fig.6. Change in the concentrations of major ions in the mixing zone "the Barguzin River – Lake Baikal"

Table. Concentrations of major ions at the central station of the Barguzin Bay in different periods, mg/l

Year/month	HCO ₃ ⁻	SO ₄ ²⁻	Cl ⁻	Ca ²⁺	Mg ²⁺	ΣNa ⁺ + K ⁺	Σi
1955*	66.8	5.3	0.56	17.1	3.1	3.4	96.4
1974**	56.7	5.5	0.17	15.5	3.0	3.4	87.9
2004/July	67.1	6.5	0.61	19.8	2.8	2.8+1.0	100.5
2007/June	66.4	6.5	0.8	16.3	2.8	3.1+0.8	96.7
2011/February	70.8	6.8	0.46	16.1	3.3	3.5+1.1	102.0
2016/March	71.4	6.8	0.51	17.4	3.4	3.8+1.1	104.4
2016/August	62.4	6.4	0.49	16.1	3.1	3.5+1.0	93.4

*Votintsev, 1961; ** Mescheryakova and Verbolova, 1977

one kilometre from the river estuary.

In spring, the thermal bar influences the distribution of river waters in the bay. The front of the thermal bar serves as a natural barrier that prevents the free entry of the Barguzin waters into the lake. Consequently, the chemical composition throughout the water column from the water edge to the thermal bar corresponds to river waters, and beyond thermal bar – lake waters. In different phases of the water regime, when water mineralization in the river can be both higher and lower than in the bay, the change in the ion concentrations of the salt composition in the mixing zone results from ordinary dynamic mixing of river and lake waters.

In the long-term aspect, the chemical composition of the water from the Barguzin Bay remains stable, corresponding to bicarbonate class and calcium group. The increase in the Baikal water level led to an insignificant decrease in the concentrations of major ions under the influence of lake waters. However, there is currently an increase in the concentrations of major ions under the influence of the economic activity in the watershed of the Barguzin River and, probably, a decrease in the runoff of the Barguzin River in conditions of the continuous low-water level.

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