The current ecological status of snow and ice on the west coast of Lake Baikal (on the example of the Goloustnaye settlements)

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Abstract. During the winter period from 2015 to 2019, in the third decade of February and the first decade of March, snow and ice samples were taken from the area of the Goloustnaye municipal settlements located on the west coast of Lake Baikal, as well as from the adjacent water area of the lake (at a distance not exceeding 1000 m from the coast) and the Goloustnaya River. The sampling was carried out to give a modern ecological assessment of the state of the considered natural components and determine the relationship between the presence of pollutants and the level of human impact. Based on the data obtained, we constructed a map of the distribution of suspended solids, sulfates and heavy metals, such as manganese, copper, zinc, and lead, in the study area. The highest content of pollutants was determined in the samples of snow taken near settlements: the village of Bolshoye Goloustnaye and the village of Maloye Goloustnaye. Additionally, increased concentrations of suspended solids, sulfates, nitrites, ammonium, and manganese were found in the coastal area of Lake Baikal. At the same sampling sites, the pH values of meltwater corresponded to alkaline waters, which indicates anthropogenic pollution.

1. Introduction
At present, the processes of urbanization and other types of anthropogenic impact are intensifying on the shores of Lake Baikal. For this reason, the ecological assessment of the unique natural complexes of Lake Baikal is of particular importance. Snow and ice can be environmental indicators of the ecological state and the level of anthropogenic load in the investigated areas, acting as an adsorbent of pollutants coming from the atmospheric air.

Environmental monitoring of snow is one of the most effective methods for assessing the state of natural complexes during the cold season. This type of research allows us to assess the level of anthropogenic impact on the environment in settlements and the health of the population living in them. Man-made anomalies in snow are more contrasting; a significant amount of pollutants accumulate in it and then enter the soil and other natural environments.

The aim of the study was to assess the current ecological state of snow and ice on the west coast of Lake Baikal, within the Goloustnaye settlements.

2. Model and methods
The study object was samples of snow and ice taken on the west coast of Lake Baikal, in the area of the Goloustnaye settlements (figure 1). Bolshoye Goloustnaye is located on the shore of the lake; Lake Baikal is shallow near the settlement, and the shores of the Goloustnaya River delta are very swampy. The village of Nizhniy Kochergat and the village of Maloye Goloustnaye are located in the valley of
the Goloustnaya River and its tributaries. The study area is included in the central ecological zone of the Baikal Natural Territory, where economic activity is regulated to protect natural components, including groundwater and surface waters [1].

Now, there is an active development of the area in the tourist and recreational spheres; construction of various tourist facilities in the coastal part of the lake is taking place, due to which the anthropogenic load on the components of the natural environment increases. There are no industrial enterprises in the settlements located on the southwest coast of Lake Baikal, but stove heating of the dwellings is widely used. With this type of heating, various substances can enter the atmospheric air: soot, ash, sulfates, etc. Pollutants also enter this territory along with atmospheric emissions from the Irkutsk-Cheremkhovo and Southern Baikal industrial centers and local heating installations. Emissions from motor vehicles also contribute to air pollution.

The climate on the west coast of Lake Baikal is extreme continental; the winter period lasts more than 145 days (from the first decade of November to the last decade of March) [2]. During the cold season, approximately 14 mm of precipitation falls in the area; the atmospheric circulation and the structure of the lake basin affect their distribution [3]. The average temperature in the winter months is -9.1°C. In the municipality of Bolshoe Goloustnoye and near the Goloustnaya river valley, the absolute minimum air temperature reaches 45°C in January. The formation of a stable snow cover occurs in the first ten days of December. During the cold season, from November to March, approximately 14-16 mm of snowfalls in the study area, which is 5% of the annual precipitation.

During the study years, the snow height in remote areas far from settlements varied within 23-38 cm, whereas near them and in the water area of the Goloustnaya River, it did not exceed 20 cm. Snow sampling in the lake water has proven difficult: due to strong winds blowing from land to the water area, the snow was blown out.

In the study area, Lake Baikal freezes from late December to mid-January. The duration of the ice is more than 100 days. The ice thickness can vary from 8 to 95 cm.

The formation of the ice on the Goloustnaya River occurs in late October. In the third decade of October, the water temperature drops to 0.2°C. Due to the low water content of the river and the harsh climatic conditions in winter, the river is frozen and the water flow stops. The thickness of the ice is 1-1.5 meters. The average duration of ice on the river is 183 days.

![Figure 1. Schematic map of the study area](image-url)
The study area is located on the Primorsky Ridge, which is a distinct mountain structure, narrow in the south and gradually expanding in the north [4]. The relief in the study area varies: there are mountains, basins, deeps and flat watersheds. In the nature of the terrain, the area of the village of Bolshoe Goloustnoe belongs to the category of fold-blocky low mountains with erosive dismemberment. At a distance from Lake Baikal, the terrain is smoothed: there is a decrease in watershed ridges and elevations.

The Goloustnaya River is one of the most significant tributaries of Lake Baikal. It originates on the northern slopes of the Primorsky Ridge and flows through a valley running between the Onotsky and Primorsky ridges parallel to the shore of Lake Baikal, then, turning to the southeast, the river cuts through the Primorsky Ridge and goes to the west coast of the lake. The Goloustnaya is formed among Precambrian rocks with developed deposits of dolomites and limestones.

In the estuarine part, the Goloustnaya River forms a wide, sometimes swampy delta, extending along the coast up to 6 km. Prior to the organization of the river chopping wood, the Goloustnaya flowed into Lake Baikal in three channels; at present, its waters are directed in one channel. The length of the river reaches 100 km; the basin area is 2300 km², and the average annual water flow is 0.3 km³. The river valley has less than 10 tributaries flowing from the Onot and the coastal ranges. The total salinity of the river varies between 0.13 and 0.25 g/l, which corresponds to fresh water. The waters of the Goloustnaya River have a high degree of oxygen saturation, and the temperature in the river is within the natural values corresponding to the seasonal course.

The sampling of snow and ice was carried out from 2015 to 2019 in late February and early March, before the beginning of snowmelt, taking into account the dominant wind directions and according to the established sanitary standards GOST 17.1.5.05-85.

The snow was sampled using a VS-43 snow gauge according to the methodology for the sites not subject to visible anthropogenic impact.

Ice samples were taken with a drill on the coastal part of the lake, which experiences the greatest load associated with human activities in winter.

The collected samples of snow and ice were melted and filtered in the laboratory. The quality of snow and ice was assessed according to a wide range of criteria: pH, suspended solids, sulfates, nitrogen-containing substances, and some metals. These parameters were determined based on hosted methods [5].

The results obtained were compared with the established maximum permissible concentrations (MPC) of harmful substances for surface waters for fishery purposes (ORDER of April 28, 1999, No 96). Additionally, the data obtained in the course of the study were compared with regional background values for surface waters [7].

3. Results and discussion

The pH values in the samples taken near settlements varied within 6.1-7.8 pH units in all study years; in snow samples from the lake coast, the values reached 6.5-7.9, whereas in ice the values were lower: 6.3-6.8. In the samples taken at a distance from the settlements, the pH values were determined in the range from 6 to 6.9 pH units. According to [8], in the natural state, the reaction of meltwater is slightly acidic, not exceeding 5.8 units; alkalization of snow and ice occurs as a result of particles of soot, ash and other emissions from industrial enterprises and vehicles settling on the underlying surface. The pH values obtained during the analysis of snow and ice sampled in the study area indicate that the pH value is higher than in natural conditions, but, at the same time, it is within the sanitary standards established for water bodies (6.5-8.5 units) (ORDER of April 28, 1999, No 96).

Based on the results of the analysis of the data obtained from 2015 to 2019, we constructed a map of the spatial distribution of suspended solids, sulfates and some heavy metals (figure 2).

Suspended solids are dust, ash, soot, and other solids. The sources of their supply are the combustion processes of various types of fuel used in winter during the heating season. During this period, the emissions of potentially toxic substances from coal combustion are significantly higher than in seasons when heating is not used [9]. The concentration of suspended solids in the study area
varies from 0.02 to 0.12 g/dm$^3$. The highest concentrations are observed near settlements (Bolshoye Goloustnoye and Maloye Goloustnoye) (figure 2) as well as in the coastal part of the lake. According to the results obtained, there is an increase in the concentration of suspended solids from year to year, as the highest values were determined in snow and ice samples in 2019.

Sulfates are widely used both in industry and everyday life. They are present in the form of aerosols and result from the combustion of fossil fuels. Sulfates are supplied to the coast together with atmospheric transport from industrial enterprises of the Irkutsk Region [10], thermal power plants and local boiler houses. Concentrations of sulfate ions in the snow samples taken in the coastal part of the lake, as well as in its water area, varied within 9.1-11.7 mg/dm$^3$, whereas in the samples of the Baikal ice the, the values were lower: 1.6-3.2 mg/dm$^3$. Near settlements, SO$_4$ concentrations were 1-4 mg/dm$^3$; the lowest values of sulfates (0.65-0.95 mg/dm$^3$) were recorded in snow sampled in an area located at a distance from the anthropogenic impact of settlements (figure 2). The background concentration of sulfates for the study area is 5.5 mg/dm$^3$ [11]; therefore, in the coastal part of the lake and its water area, the background value was several times higher. According to SanPiN 2.1.4.1074-01, the maximum permissible concentration for sulfates in fish farm waters is 100 mg/dm$^3$.

Suspended solids are dust, ash, soot, and other solids. The sources of their supply are the combustion of heavy metals. Metals are widespread in nature and of both natural and anthropogenic origin. In the latter case, most often, their sources are various industries (chemical, non-ferrous metallurgy and others), road transport, etc. To assess the current geoecological state of snow and ice in the study area, we determined the concentrations of manganese, zinc, nickel, cobalt, strontium copper, and lead in the selected samples.

**Figure 2.** Schematic map of the distribution of suspended solids, sulfates (a), manganese (b), copper (c), lead (d) and zinc (e) in snow and ice in the water area of Lake Baikal and the Goloustnaya River, as well as the territory of the Goloustnoye settlements.

Manganese is one of the most widespread heavy metals; it belongs to the fourth hazard class, and its maximum permissible concentration for water bodies of fishery purposes is 0.01 mg/dm$^3$ [6]. Manganese can be leached from ferromanganese ores and other Mn-containing minerals as well as from wastewater of metallurgical plants and emissions from ferrous metallurgy factories. A high Mn concentration with an excess of sanitary standards was recorded in 2018-2019 in the snow, the water
area of the lake and the water area of the Goloustnaya River, near the village of Maloye Goloustnoye: their concentrations ranged from 0.04 to 0.07 mg/dm³, whereas the background is 0.024 mg/dm³ [7]. In other snow and ice samples, the manganese concentration ranged from 0.001 to 0.008 mg/dm³, which corresponds to sanitary standards.

Copper belongs to metals of the third hazard class with MPC not exceeding 0.001 mg/dm³ for fishery water bodies [6]. Sources of copper entering the environment are emissions from non-ferrous metallurgy enterprises, and copper can be washed out from the rocks containing this metal. In the observed area, copper concentrations ranged from 0.001 to 0.004 mg/dm³, which exceeds the MPC, but is within the regional background values (0.019 mg/dm³) [7].

Lead is one of the most toxic metals and belongs to the second hazard class. Sanitary standards of Pb for fishery water bodies are set within 0.006 mg/dm³ [6]. The concentration of lead in the analyzed samples of snow and ice, which were taken both in the water area of the lake and near settlements was determined at a level from 0.002 mg/dm³ to 0.03 mg/dm³. The highest concentrations were found at sites located in the vicinity of settlements and in the coastal part of the water area of Lake Baikal; lower values were found at sites far from anthropogenic sources.

Zinc, like copper, belongs to the third hazard class [6]. Its concentration in the water bodies of fishery use should not exceed 0.01 mg/dm³, and the regional background for the study area is 0.02 mg/dm³ [7]. The main sources of zinc in the ambient air are industrial emissions and coal combustion. The Zn concentration in the snow samples for the selected study period ranged from 0.002 to 0.018 mg/dm³, whereas in the ice sampled from the water area of Lake Baikal and the Goloustnaya River, the values were lower, 0.001-0.01 mg/dm³. The determined Zn values in the ice samples corresponded to the maximum permissible concentration for fish farms; in the snow, the excess was determined at the sites located near settlements and on the coast of the lake. Regional background values for zinc concentration were not exceeded.

Concentrations of metals, such as strontium, nickel and cobalt, are set within acceptable sanitary standards.

Nitrogen-containing substances. In the warm season of the year, the presence of nitrogen-containing compounds is largely due to the activity of bacteria. In winter, the concentration of nitrates, nitrites and ammonium ions in snowmelt water is associated with anthropogenic sources, for example, these substances come from emissions from industrial enterprises and vehicles.

The concentrations of nitrates in all considered samples of snow and ice for the study period of 2015-2019 were determined at a low level (0.05-3.95 mg/dm³), not exceeding the sanitary standards for fishery water bodies (40 mg/dm³).

The excess of the MPC for fishery water bodies in terms of nitrite concentration (0.08 mg/dm³) was detected in snow and ice samples from the coastal part of the water area of Lake Baikal. The concentrations ranged from 0.14 to 0.19 mg/dm³.

In most of the analyzed samples of snow and ice, ammonium did not exceed the sanitary standards (0.5 mg/dm³) and ranged from 0.003 to 0.18 mg/dm³. The excess of the MPC was identified in the snow samples taken in 2015 from the water area of the Goloustnaya River near the Maloye Goloustnoye village.

4. Conclusion

Monitoring the state of snow and ice in the area of Goloustnoye settlements, the water area of Lake Baikal and the Goloustnaya River in the winter from 2015 to 2019 revealed that the investigated samples, in general, correspond to the level of maximum permissible concentrations for fishery water bodies. However, there is a tendency of an increase in pH of meltwater, as well as the concentrations of suspended solids, sulfates, manganese, and zinc, which indicates the anthropogenic component of the pollution in the study area.

The highest concentrations of suspended solids, sulfate ions, heavy metals, as well as the pH value indicating the alkalization of snow and ice, were recorded in the snow samples taken near settlements (Bolshoye and Maloye Goloustnoye). Since there are no industrial enterprises in the study area, it is
likely that pollutants come along with atmospheric transport from the industrial centers of the Irkutsk Region. The main source of pollutants is stove heating that is widely used in these settlements.

There are increased concentrations of suspended solids, sulfates, nitrogen-containing substances, and manganese in comparison with areas remote from settlements in the coastal part of the water area of Lake Baikal, where a focus of anthropogenic pollution is formed.

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