

Current State of Water Resources of Gusinoe Lake (Western Transbaikalia)

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Abstract—Seasonal and spatial dynamics of the concentrations of major ions, biogenic elements, organic matter, and microelements in Gusinoe Lake water are studied. The economic activity on lake coast has caused an increase in the concentrations of sulfate, sodium, and biogenic and organic matter in areas subject to direct technogenic impact. Lake areas subject to different technogenic impacts were found to differ in water mineralization and pH and the concentrations of microelements. The concentrations of Mo and Sr in lake water are 12–14 and 2–4 times greater than Russian MACs for water bodies used for fishery, respectively.

Keywords: lake water chemistry, sulfates, N compounds, microelements

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INTRODUCTION

Gusinoe Lake is largest in Transbaikalia in terms of its water volume and most important for water supply and fishery. In recent decades, after the commissioning of the Gusinozerskaya SDPP, the industrial and household use of Gusinoe Lake water increased abruptly. The lake is used by the SDPP as a cooling reservoir. Mine waters of the Gusinozerskoe Coal Deposit, developed by underground mining, have been discharged into the lake for more than 40 years. The lake receives the quarry water of the Khol'bodzhinskii Coal Strip Mine, and washout from industrial sites and rock dumps. Gusinozersk T. discharges into the lake poorly treated household sewage.

The lake is located in Gusinozerskaya Depression of graben-synclinal type between two crystalline uplifts—the Khambinskii and Monostoiskii ridges. From northeast, the depression is bounded by Zagustaisko-Ubukunskaya interbasin ridge. The southwestern part of Gusinozerskaya Depression is Tamchinskaya Plain, overlain by the deposits of Temnik R. delta. The lake is located among the formations of Permian, Paleozoic age, carbonate metamorphic rocks of Later Paleozoic. The lake is surrounded by granites and granosyenites of Early Paleozoic in its northwestern part; porphyrites, andesites, and basaltoids of Jurassic in Southwestern part, and metamorphized tuffs of Carboniferous and Permian in the eastern and southeastern parts. The main elements of the mesozoic structure are two large carbon-bearing synclinal folds: the southern—Gusinozerskaya, and the northern—Zagustaiskaya, separated by an anticline protrusion [4].

The morphometric characteristics of Lake Gusinoe are as follows: the length is 25 km, the maximal width and depth are 8.5 km and 25–30 m, respectively, water area is 164 km², water volume is 2.4 km³, and the total drainage area is 924 km². The hydrographic network contains 72 watercourses with a total length of 312 km. The largest tributary is the Zagustai R. (with a length of 44 km and a drainage area of 382 km²), which flows into the lake in its northern part, cutting the Khambinskii Ridge. The second tributary in terms of runoff and length (25 km) is the Tsagan-gol R., which flows from the Temnik R. and empties into the lake in its southwestern part. The Bain-gol is the single river flowing out of the lake (from its southeastern part). Lake water balance was calculated for 1991 (Table 1) [3]. Water withdrawal from the lake for technical and drinking needs is 655 million m³ water (1/4 of its volume). The water surface area of the coastal part of the lake (shallows with depths up to 2 m) accounts for as little as 6.3% of the total lake area. The major portion of shallows lie in the northern and southwestern parts of the lake.

The underwater part of the lake consists of two parts, separated by an underwater ridge, extending from the Kholbol'dzhinskii section to Gusinoe Lake St.; it hampers rapid mixing of the entire water mass of the lake [5]. Water chemical composition in the northern part of Lake Gusinoe varies because of municipal wastewater inflow from Gusinozersk T. and aerotechnogenic pollution of the drainage basin by coal combustion products at the SDPP. Wastewaters create areas of lake water pollution near their discharge sites, and they are carried by flows over lake

Table 1. Water balance of Lake Gusinoe over 1991 [3]

| Balance element | Water volume, million m ³ /year |
|---|--|
| Water input | |
| Total river runoff | 116.34 |
| Precipitation onto lake water area | 32.64 |
| Industrial and municipal water discharge | 635.9 |
| Groundwater inflow | 34.9 |
| Total | 819.77 |
| Water-resources output | |
| Surface runoff of the Bain-Gol R. | 30.12 |
| Evaporation from water surface | 134.12 |
| Water intake for industrial and municipal needs | 655.11 |
| Groundwater outflow | 0.41 |
| Total | 819.79 |

water area. The eastern part of the lake receives mine waters from abandoned Gusinoozerskoe deposit and polluted subsoil waters from the Khol'bodzhinskii Coal Strip Mine. Gusinoe ozero railway station is situated in the southern part of the lake. Seasonal variations of water mineralization and ion composition in the southern part of the lake are largely determined by natural processes. Overall, water chemistry is different in different parts of the lake because of varying natural–anthropogenic impacts.

The objective of this study is to identify the changes in water chemistry of Lake Gusinoe that have taken place recently under the effect of technogenic processes.

METHODS OF STUDY

Samples for water chemistry analyses were taken 5–6 times per year in different parts of the lake to reveal seasonal variations. The layout of water sampling sites is given in Fig. 1. Water samples were taken from the depth of 2 m in the following areas: in the SDPP discharge canal (stations 1–4); in the coastal part of the lake (stations 5, 7–11), as well as in the central part of the lake (station 6). The data collected at the sampling sites in the coastal part of the lake are used to assess the effect of pollution sources: st. 5 is in the zone of influence of water discharge from Baraty railway station; st. 7 is in the zone of influence of the Tel'ya R., the basin of which contains SDPP industrial site (coal store, garages, and repair base); st. 8 is in the zone of influence of the Zagustai R., into which municipal wastewater from Gusinoozersk T. are discharged; and st. 9 is in the discharge area of mine water from the Khol'bodzhinskii Coal Strip Mine. The effect of natural sources is characterized by data collected at st. 10 (Tsagan-gol R. mouth) and st. 11 (the zone near the source of the Bayan-gol R.).

Water temperature T_w and pH were measured in situ. The samples were filtered through a membrane filter with a pore diameter of 0.45 μm . The obtained filtrates were acidified by HNO_3 (to pH 2) to determine later the concentrations of dissolved metal forms.

Water chemistry was analyzed by methods commonly used in freshwater hydrochemistry [1, 2, 7, 9]. In the 1960s–1970s, the components were determined by titrimetric methods. To compare the results of observations of the 1950s–1970s with current data, the macrocomponent composition of samples was analyzed by titrimetric methods.

The concentrations of biogenic substances were determined by colorimetric method with a relative error of 1.5 for phosphates, 4–5 for ammonium N, 3–5 for nitrite N, and 4% for nitrate N. Dissolved O_2 was determined by Winkler method (with an error of 0.3%), organic matter (OM) concentration was calculated by bichromate oxidability (with an error of 8%) [2, 7, 9].

The concentrations of dissolved microelements were determined by mass-spectrometry with inductively coupled plasma (ICP-MS) with the device ELEMENT XR. Water samples were filtered through membrane filters (0.45 μm) not later than 8 h after sampling. The filtrates were stored in a refrigerator until analyzed. The samples for elemental analysis were fixed by double-distilled 70% HNO_3 solution.

DISCUSSION OF RESULTS

The effect of water discharged from the Gusinoozersk SDPP on the thermal regime of Lake Gusinoe was studied by regular measurements of T_w on the watershed, in the water discharge canal near the SDPP, and at the mouth. The depth of the discharge canal nowhere exceeds 4 m, and its length is 700 m.

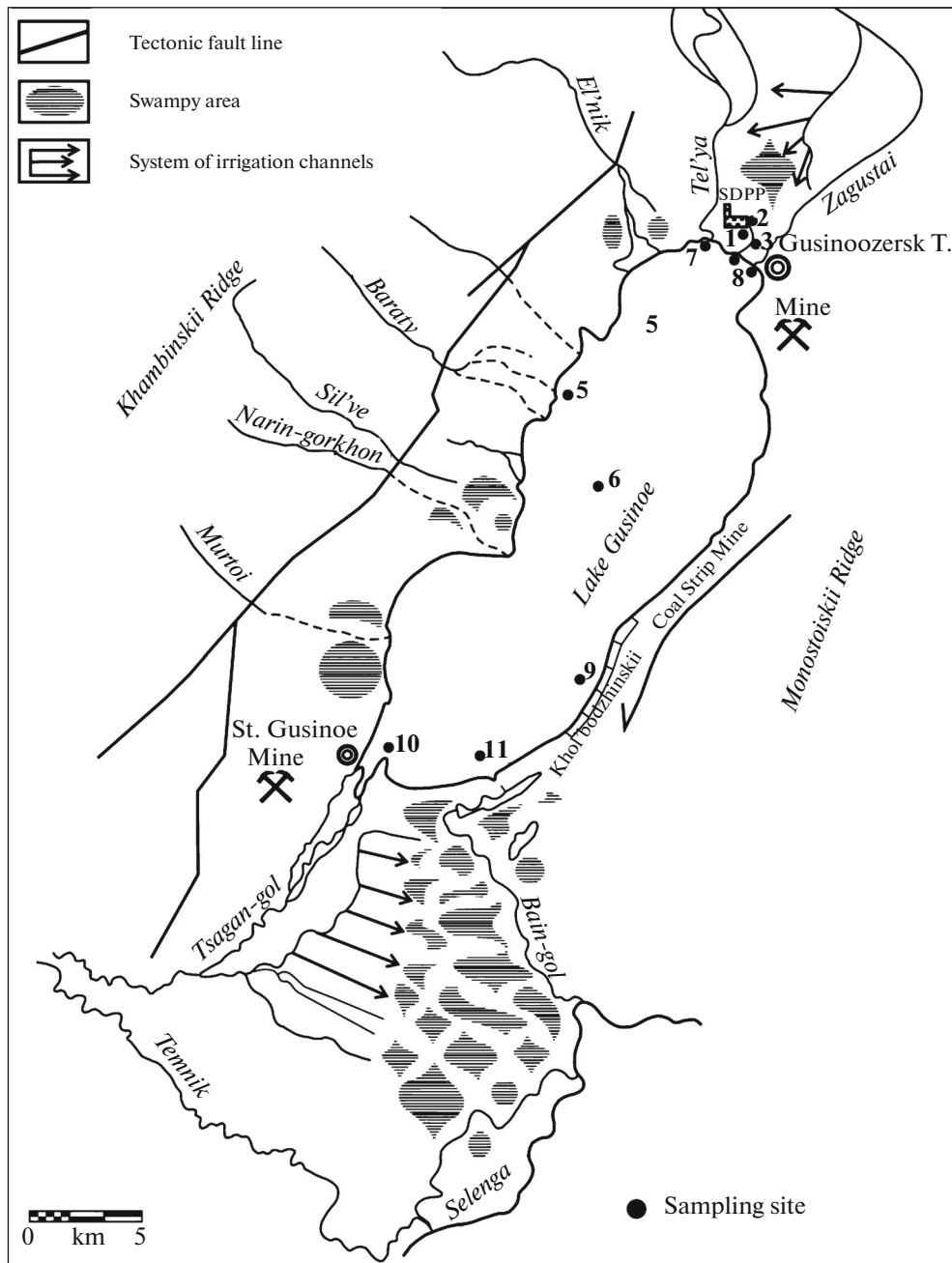


Fig. 1. Layout of water sampling sites in Lake Gusinoe.

The difference between water temperatures in the discharge canal near SDPP and at the mouth reaches 11.2–12.8 in winter, 6–7 in spring, and 1.8–2.5°C. The values of T_w at the canal mouth are close to those in the coastal lake zone. The vertical gradient of T_w in lake water mass depends on the season. While in winter and spring, the gradient T_w never exceeds 0.2–0.6°C, its value in summer is 1.6–2.8°C, which is close to the natural variations in lake water. Therefore, the effect of discharged SDPP water on the thermal

regime of water masses in Lake Gusinoe is insignificant.

By its chemistry, water in Lake Gusinoe can be referred to hydrocarbonate–calcium–sodium type. In the study period, the values of Σ_{ion} in different sections differed significantly. The maximal value of $\Sigma_{ion} = 365$ mg/L was recorded in May at station 9 (the zone of influence of melt-water from the coal strip mine), while at other observation stations, the values of Σ_{ion} varied within 217–278 mg/L. Water pH at st. 10 was 7.4–8.1, while at other stations, it varied within 8.2–

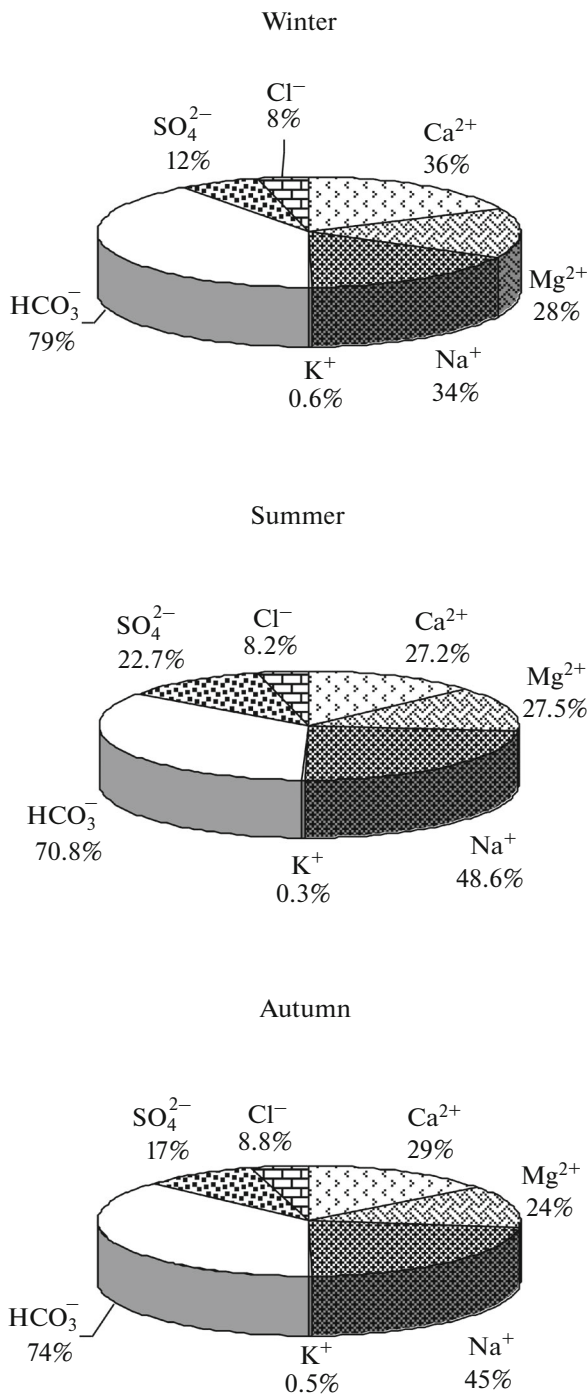


Fig. 2. Seasonal variations of relative ion composition of water at stations in the northeastern part of Lake Gusinoe.

8.8 with an appreciable decrease in autumn (down to 7.6–8.2). The concentration of dissolved O₂ varied within 7.4–12.4 mg O₂/L, decreasing to 7.2–8.6 mg O₂/L during summer dry season.

Hydrocarbonate ions (HCO₃⁻) dominated in water chemical composition in the coastal part of the lake.

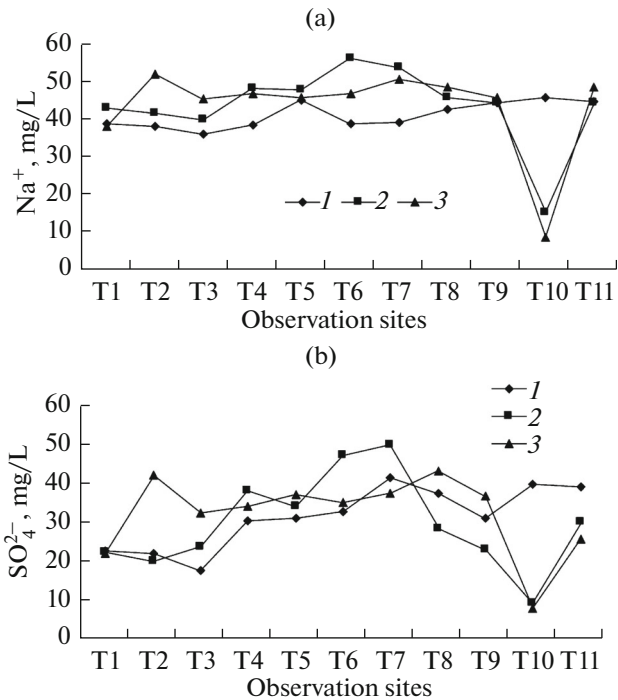


Fig. 3. Spatial and seasonal distribution of (a) Na⁺ and (b) SO₄²⁻ in Lake Gusinoe water: (1) spring, (2) summer, (3) autumn.

During a year, their concentration in water at north-eastern sites varied from 176.8 to 213.5 mg/L with minimal values in May and maximal, in February. The concentration of sulfate ions (SO₄²⁻) varied from 22.0 to 51.8 mg/L, and that of chlorine ions (Cl⁻) varied from 12.4 to 14.8 mg/L. In open-water period, Na⁺ dominated among cations in lake water: its concentrations (39.7–56.9 mg/L) were 1.1–1.4 and 3 times the concentrations of Ca²⁺ (26.1–32.1 mg/L) and Mg²⁺ (14.0–17.6 mg/L), respectively. Water chemistry at st. 10 was specific because of water inflow from the Tsagan-gol R. The values of \sum_{ion} varied from 63 to 86 mg/L. The concentration of HCO₃⁻ varied from 48 to 52 mg/L; SO₄²⁻, within 6.4–9.1; Cl⁻, 5.1–7.2; Ca²⁺, 11.2–14.5; Mg²⁺, 1.5–1.8; and Na⁺, 12.3–15.4 mg/L. The shares of cations Ca²⁺ and Na⁺ within a year were similar (44–46%).

The relative ionic composition of water at north-eastern sites varied depending on the season (Fig. 2). In winter, the relative concentrations of Ca²⁺ and Na⁺ were nearly the same; however, in open-water period, the share of Na⁺ increases 1.3 times. Similar changes take place in the relative composition of anions. For example, the share of SO₄²⁻ increases 1.4 times.

The annual dynamics of the concentrations of Na⁺ and SO₄²⁻ ions show their increase during open-water

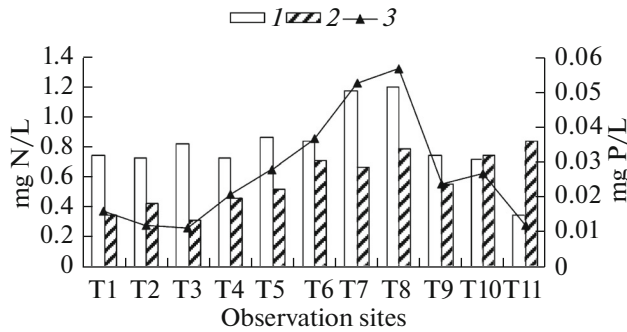


Fig. 4. Spatial distribution of nitrate and ammonium N in autumn and mineral P in spring in Lake Gusinoe water: (1) nitrate, (2) ammonium nitrogen, (3) mineral phosphorus.

period in the central and northeastern parts of the lake (at stations 6–9), caused by the inflow of surface waters subject to anthropogenic impact and the effect of mine water discharge (Fig. 3). Na^+ and SO_4^{2-} concentrations increased by 20% at stations 6 and 7 and by 8–10% at st. 8; SO_4^{2-} concentration increased by 15% at st. 9.

The dynamics of biogenic substance concentrations in lake water is of seasonal character. The concentration of nitrate N varied from 0.05 to 1.21 mg N/L; that of ammonium N, from 0.01 to 0.83 mg N/L; and that of mineral P, from 0.005 to 0.057 mg P/L. Maximal concentrations of nitrate N were recorded in winter and autumn in the northern part of the lake (stations 7 and 8); that of ammonium N, in autumn in the southern part (st. 11); and that of mineral P, during spring flood in the northern part of the lake (stations 7 and 8). Analysis of samples for ammonium N in water in spring showed its concentrations to be in excess of the MAC for water bodies used for fishery (MAC_{fish}), equal to 0.39 mg/L, in 62.5% of examined samples from stations 7 and 8 (Fig. 4). The identified increase in the concentrations of N compounds is due to water pollution by discharges from SDPP and Gusinoozersk T. In June–July, the concentrations of biogenic substances in water decrease to minimal values and their spatial distribution becomes more uniform because of the intense consumption of these substances by higher aquatic plants and plankton during vegetation period.

OM concentration in water was evaluated by the following characteristics: permanganate oxidability PO, biological oxygen demand over five days (BOD_5), and chemical oxygen demand (COD). Seasonal variations of these characteristics lied within the intervals of 3.2–4.4 for PO, 1.3–4.4 for BOD_5 , and 12.5–54.7 mg O/L for COD. Maximal values of COD were recorded in summer at stations 6–8 and 10 near the wastewater discharge site from Gusinoozersk T.; and maximums of BOD_5 , in summer and autumn, at stations 8, 10, 11 (Fig. 5). The ratio PO/COD varies from 0.21 (in win-

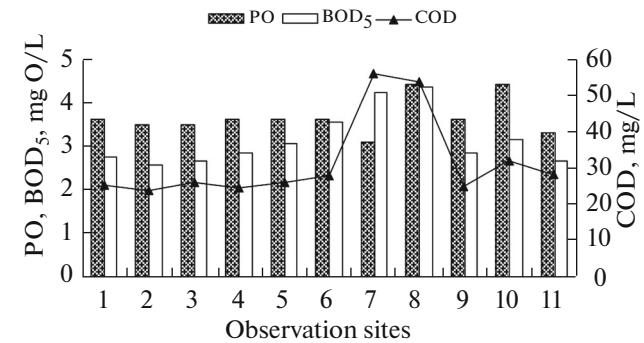


Fig. 5. OM spatial distribution in summer in Lake Gusinoe water.

ter) to 0.06 (in summer), suggesting the presence of hardly mineralizable OM.

The comparison of data on the macrocomponent composition of water from Lake Gusinoe, obtained in this study, with data over 1960–1970 [2, 8] and 1990–1992 [3] is given in Table 2. Compared with data of 1960–1970, the concentrations of SO_4^{2-} and Cl^- increased 1.6–1.7 times, and those of Na^+ cations, 1.3 times.

The distribution of microelement concentrations is different in different parts of the lake. In the southern part of the lake (at the inflow of the Tsagan-gol R., st. 10), we recorded higher concentrations of elements-hydrolyzates, which form, predominantly, hydroxyl complexes (Al, Ti, Zr, Th, and Hf), elements of iron group (Fe, Mn, Cr, Sc, and Sn), as well as rare earth elements (REE) (except for Eu). In this part of the lake, in addition to a decrease in the values of Σ_{ion} , a considerable decrease was recorded in the concentrations of cationogenic microelements-lithophyls (Li, Cs, Sr, and Ba), anionogenic elements-lithophyls with variable valence (V, Nb, Mo, W, and U), metals and nonmetals-sulfophyls (Cu, Cd, Pb, Bi, As, and Sb), and REE Eu (Fig. 6a). These elements are cations with low polarization capacity and weak complex-formers in freshwater [10, 11].

In the northern part of the lake (stations 7 and 8), an increase in the concentrations of principal ions and an increase in Σ_{ion} are accompanied by an appreciable increase in heavy metal concentrations (Mn, Fe, Cu, and Zn) against the background of insignificant changes in the concentrations of all other microelements (Fig. 6b).

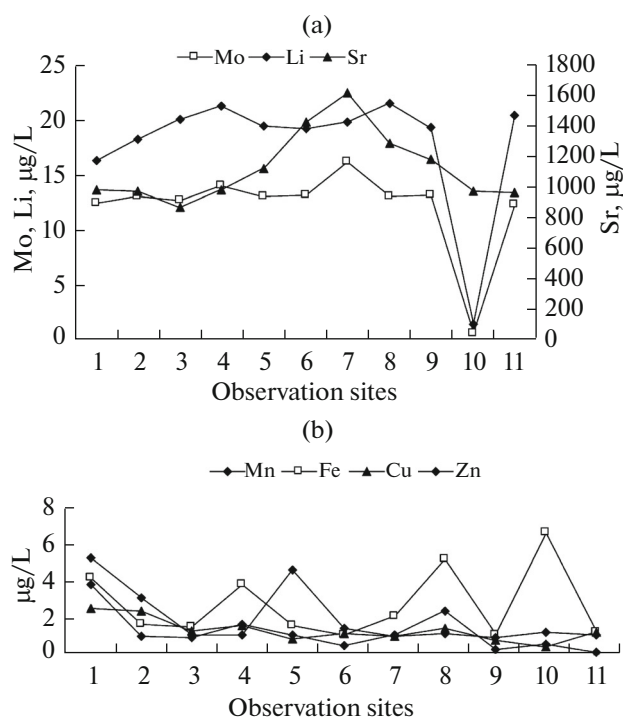
The concentrations of Mo and Sr in lake water are in excess of Russian MAC_{fish} [6] by factors of 12–14 and 2–4, respectively.

CONCLUSIONS

The effect of SDPP and Gusinoozersk T. on water in the northeastern part of Lake Gusinoe manifested

Table 2. Data of water chemical analyses in Lake Gusinoe, mg/L

| Characteristic | Data of [8], 1965–1967 | Data of [2], 1974 | Data of [3], 1990–1992 | Data of this study, 2013 |
|----------------------------------|------------------------|-------------------|------------------------|--------------------------|
| HCO ₃ ⁻ | 155.5–167.1 | 114.1–183 | 158–213 | 176.8–213.2 |
| SO ₄ ²⁻ | 15.2–21.2 | 8.2–22.1 | 18–53 | 22.0–51.8 |
| Cl ⁻ | 3.6–4.1 | 1.6–8.1 | 8–12 | 12.9–14.9 |
| Ca ²⁺ | 20.4–23.9 | 21.5–35.7 | 24–32 | 26.1–32.1 |
| Mg ²⁺ | 7.8–11.3 | 2.9–11.7 | 4–14 | 14.0–17.8 |
| Na ⁺ + K ⁺ | 25.3–37.1 | Up to 30.4 | 36–43 | 39.1–56.9 |
| Σ _{ion} | 232.7–256.7 | 175–280 | 232–338 | 118–343 |
| P–PO ₄ ³⁻ | 0.003–0.015 | – | 0.02–0.08 | 0.005–0.057 |
| N–NO ₃ ⁻ | 0.009–0.035 | – | 0.1–0.9 | 0.02–1.21 |
| N–NO ₂ ⁻ | – | – | – | 0.001–0.004 |
| N–NH ₄ ⁺ | – | – | – | 0.01–0.83 |
| P _{tot} | – | – | – | 0.005–0.083 |
| PO–COD _{Mn} | – | – | – | 3.3–4.3 |
| BOD ₅ | – | – | – | 1.3–4.4 |
| COD | 10.3–12.9 | 5.1–20.3 | 10.8–51.7 | 12.5–54.7 |

**Fig. 6.** Spatial distribution of observed element concentrations in water of Lake Gusinoe: (a) autumn, (b) summer.

itself in seasonal variations of the concentration of Na⁺ and SO₄²⁻ in water. In winter, the relative concentrations of Ca²⁺ and Na⁺ are almost the same, while during open-water period, the shares of Na⁺ and SO₄²⁻ increase 1.3–1.4 times. In these parts of the lake, maximal concentrations of biogenic elements were recorded in winter; and those of OM, in summer.

The analysis of samples for the concentration of ammonium N in lake water in the spring showed it to be in excess of MAC_{fish} (0.39 mg/L) in 62.5% of the examined samples from the northeastern part of the lake because of the wastewater discharges from SDPP and Gusinozerks T. The maximal concentration of ammonium N (0.83 mg N/L) in lake water was recorded in autumn in the southern part of the lake.

The difference between pH and Σ_{ion} values in the northern and southern parts of the lake resulted in the difference of the spatial distribution of microelements. The concentrations of Mo and Sr in lake water are in excess of Russian MAC_{fish} by factors of 12–14 and 2–4, respectively.

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