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Zonal Features of Bog and Lake Water Chemistry Along a Transect from Boreal to Arid Landscapes in The South of Western Siberia, Russia

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Abstract. Western Siberia is a unique territory where more than 12000 water reservoirs are located. The region is characterized by high bogginess up to 90% in the north. Bog and lake systems are able to accumulate natural and technogenic resources, including trace elements and organic matter. The article presents the results of a surface water chemical composition along a 5-year monitoring. The obtained data allow concluding that dynamics of water chemistry is predetermined by their location in various landscape zones and subordinated to zonal distribution of such major landscape elements as moistening, evaporation, rate of groundwater flow, etc.

1. Introduction

The characterized territory has the highest ratio of lake surface to drainage area in Russia. On its plains, Vasyugan, Barabinsk and Kulunda, the latitudinal zoning is very clearly expressed which is reflected in the course of the basic hydrothermal elements, character of soil and vegetable cover. The processes caused by action of zone regularities along with local factors (changes in a relief, differences of hypsometric levels, geological structure), cause a variety of landscapes. Within the region three landscape zones (forest, forest-steppe and steppe) are allocated (Figure 1).

Every bog and lake system is an accumulative complex where wide range of elements is concentrated. The ratio of these elements is various in polytypic objects as well as in different landscapes. It is widely believed that a dominant chemical type of water depends on climatic and geomorphological factors (precipitation, evaporation, water exchange), humidity and temperature conditions, hydrochemical features and biological productivity of reservoirs [1, 2, 3, 4].

In this respect, the main aim of this report is to reveal zonal features of chemical composition of bog and lake water in the south of Western Siberia during the transition of landscape areas: forest - forest-steppe - steppe.

2. Climatic features of the study area

The forest (south taiga) zone (Figure 1) covers an area of approximately 1000 km^2, occupying about 62% of the territory of Western Siberia. It belongs to one of the most humidified spaces on a terrestrial surface.

The forest-steppe zone is characterized by the presence of forest and steppe vegetable communities as well as bogs, saline soils and meadows. A characteristic feature of the forest-steppe of Western Siberia is abundance of saline closed lakes. The steppe zone covers the southern part of the Omsk region, the southwest part of the Novosibirsk region, and the western part of Altai Krai, including Kulunda, Aleysk and Biysk steppes. The most precipitation in Western Siberia falls in the summer and is brought by air masses coming from the west (from the Atlantic). From May to October Western Siberia receives up to 70-80% of annual precipitation. The territory is characterized by large fluctuations in rainfall in different years.

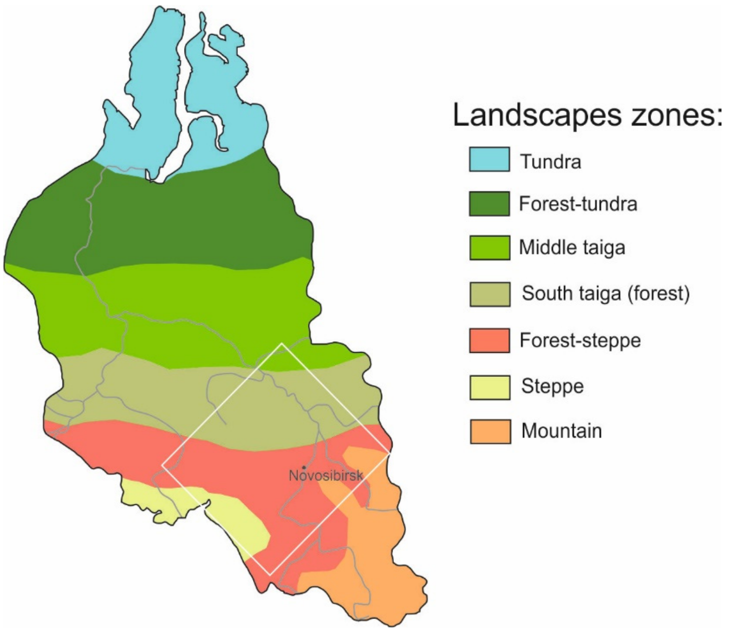

Figure 1. Landscapes map of Western Siberia showing the location of the study area (white contour)

Even in the forest, where these changes are less than in other areas, precipitation ranges from 339 mm in a dry year to 769 mm in a wet one (Tomsk region). Particularly large differences in the steppe zone are observed, where in wet years falls up to 550-600 mm/year and only 170-180 mm/year in dry.

There are significant zonal differences in evaporation, which depend on the amount of precipitation, air temperature and evaporative properties of the underlying surface. The forest-steppe zone is characterized by the highest evaporation (350-400 mm/year). In the north, where in summer humidity is relatively large, the evaporation does not exceed 150-200 mm/year. Evaporation is about the same in the south of the steppe zone (200-250 mm) that is explained by small precipitation. However, the volatility reaches here 650-700 mm; therefore, in some months (especially in May) the amount of the evaporating moisture can exceed the rainfall sum by 2-3 times. The lack of precipitation is compensated in this case by soil moisture reserves accumulated by autumn rains and melting snow.

3. Methods

Investigation of bog and lake water was performed during the fieldwork in warm period (May-September) 2014-2015. The applied methods are described in detail in previous studies [5; 6]. The classification of chemical type of water is provided from the highest to the lowest concentration of major ions.

4. Chemical composition of bog-lake systems

4.1 Forest (south taiga)

As a specific feature of the territory is its considerable bogginess, the chemical composition of bog water is of special interest here [7]. The ionic composition of upland bogs water is HCO_3 or HCO_3-SO_4, Ca and Ca-Mg. Bog water is ultrafresh and fresh (TDS fluctuates from 3 to 214 mg/L), acid and slightly acid, rarely neutral (pH 3.1-7.5) (Table 1). The main reason for water acidification of these systems in the boreal landscapes is organic anion dominance [8]. The content of dissolved organic matter (in terms of TOC) ranges from 8-108 in the lowland bogs to 20-286 mg/L in the upland bogs. The more water enriched with organic matter, the more acid it is. The higher content of TOC is connected with the sites of the most stagnancy [6].

Despite very low values of TDS in bog water, high concentration of trace elements is determined, in particular: Zn, Pb, Cu, As, Sr, Mn and Al, which form the stable complexes with the humic acid [9] and thus concentrate in such waters. For the same reason, the considerable concentration of Fe is founded (85 mg/L).

In floodplain lakes of the territory the concentration of mineral substances, except for trace elements, is higher than in bog water. Nevertheless, small lakes of the southern taiga are ultrafresh, the TDS level doesn't reach 0.1 g/L (Table 1). It is explained by a larger share of low-mineralized and more acid atmospheric precipitation in total volume of lake water that defines reduction of elements concentration and pH values (5.9-7.0).

4.2 Forest steppe

In contrast to the bog water of the forest zone, forest-steppe bogs significantly differ in higher values of TDS (0.4 g/L) and pH (7.7). Thus, the share of mineral components in comparison with the organic considerably increases in the general chemical composition of water. It is connected primarily with increasing of saltier groundwater flow in recharge of bogs, in degree of an evaporability and reduction of an amount of precipitation. The rising of TDS occurs due to the alkalinity (252 mg/L), Cl (13 mg/L), Mg (105 mg/L) and Na (120 mg/L). The maximum values are found in the south of the zone, consentaneously) at TDS values up to 1 g/L. Although the amount of organic carbon in bogs of the forest-steppe decreases, its values are significantly higher than in lakes of the zone (the amount of TOC is up to 70 and 40 mg/L, consentaneously). In bog systems, despite changes of climatic conditions, there is a local microclimate, which is reflected from a significant amount of decaying organic matter.

For the very reason the water of forest steppe lakes is fundamentally different from that of the forest zone. The pH values of the lakes averaged 7.9, the TDS is up to 1 g/L, which is higher than in water from forest area by two orders of magnitude. The most abundant anions remain to be HCO and CO_3 (6.7 g/L), while cations are strongly dominated by Na (156 mg/L).

A sharp change in the soil type, geologic conditions and hydroclimatic parameters is reflected in the trace element composition of lake water. The results of chemical analyses revealed distinct enrichments in elements accumulated in carbonate rocks, Pb, Zn, and Sr. In contrast, the concentration of Fe, which is immobile under highly aerated conditions, decreases.

4.3 Steppe

The predominant anion in most lakes is Cl, its content ranges from 0.2 to 190 g/L. Then there is SO4 (0.1 to 96 g/L). The content of CO3 can vary from 0.05 to 0.7, HCO3 from 0.1 to 3.5 g/L. CO_3 dominates in low mineralized lake waters (TDS is not higher than 40 g/L and pH value > 9.0). The pH values, which are depending of the TDS and the amount of CO_3 and CO_2, are directly opposite [5].

Table 1. Minimal, maximal and average values of chemical composition of bog and lake water from various natural zones in Western Siberia

	pH	TDS	CO_2	Alk.	SO_4^{2-}	Cl^-	Ca^{2+}	Mg^{2+}	Na^+	K^+	TOC	Si	Sr	Al	Mn	Fe (tot)	As	Zn	Pb	Cu
		g/L	mg/L														μg/L			
Forest (56 bog and lakes)																				
Upland bogs in forest zone																				
Min	3.1	0.003	3.0	3.0	2.0	0.5	1.0	1.0	1.0	1.0	19.9	1.0	0.003	0.04	0.010	1.00	0.30	8.0	0.2	0.7
Max	6.0	0.07	141.0	43.0	16.5	5.8	13.8	8.4	11.5	4.0	286	11.6	0.100	1.20	0.70	23.0	5.00	250.0	265.0	25.0
Av.	4.4	0.02	72.1	5.0	4.3	2.0	4.3	1.0	1.4	1.0	79.6	4.2	0.010	0.20	0.03	7.00	1.80	49.5	1.8	2.5
Lowland bogs in forest zone																				
Min	4.0	0.01	3.5	3.0	2.0	0.8	1.6	1.0	1.0	1.0	7.50	1.0	0.001	0.30	0.01	1.00	5.00	0.5	0.6	0.6
Max	7.6	0.21	154.0	159.0	11.3	20.6	46.0	8.5	8.5	5.2	113	10.2	0.020	0.80	5.90	85.0	54.0	267.0	19.0	706.0
Av.	5.5	0.04	57.2	17.9	2.5	3.4	6.4	3.0	2.5	2.1	46.9	5.0	0.001	0.50	0.20	16.0	5.70	24.4	2.1	3.6
Small lakes in forest zone																				
Min	5.9	0.02	3.5	11.2	2.0	0.8	4.0	1.2	0.5	1.5	7.0	0.8	0.0002	n/d*	n/d	0.36	5.00	7.7	0.3	0.9
Max	7.0	0.07	13.2	48.8	6.0	1.4	10.0	2.4	0.8	4.4	21.6	1.5	0.041	0.60	4.30	1.42	5.30	19.0	2.9	3.0
Av.	6.5	0.05	7.7	33.3	4.8	1.1	7.5	1.5	0.7	2.8	13.8	1.3	0.001	0.20	1.90	0.80	11.0	10.6	1.1	2.3
Forest-steppe (23 lakes and bogs)																				
Lowland bogs in forest-steppe zone																				
Min	6.2	0.12	27.3	89.1	0.1	3.0	11.0	6.4	1.5	2.1	21.6	1.7	0.050	0.006	0.002	0.07	0.61	2.2	0.8	3.2
Max	7.7	1.04	133.0	558.0	170.0	45.5	44.0	105.0	120.0	15.5	69.8	12.4	1.600	0.72	0.070	47.60	3.45	217.0	4.3	20.0
Av.	6.8	0.40	65.7	252.4	104.0	13.0	26.3	30.7	38.8	5.5	43.5	7.3	0.320	0.23	0.017	8.36	1.58	40.3	0.9	6.9
*Small lakes in forest-steppe zone****																				
Min	7.5	0.10	n/a	5787	0.6	22.5	27.3	8.4	12.7	4.1	19.0	0.3	0.270	0.03	0.001	0.01	0.002	10.6	0.3	2.1
Max	8.8	1.04	n/a	12304	325.0	910.0	80.8	75.3	221.0	30.0	39.4	8.5	0.700	0.09	0.020	0.23	0.01	30.7	0.9	5.3
Av.	7.9	0.25	n/a	6731	9.5	174.0	33.1	35.4	156.0	14.0	26.5	2.6	0.370	0.04	0.005	0.06	0.003	18.6	0.5	4.5
Steppe (12 lakes)																				
Lakes with TDS up to 3 g/L in steppe zone																				
Min	8.8	1.06	n/d	463.0	87.8	188.0	16.0	32.9	250.0	11.0	n/a	0.2	0.420	0.01	0.003	0.05	0.01	2.0	0.4	1.0
Max	9.6	3.30	4.0	1217	591.0	600.0	32.1	171.0	775.0	23.0	n/a	4.1	2.300	0.05	0.015	0.42	0.07	1000	4.2	40.0
Av.	9.1	1.95	1.2	733.0	285.0	401.0	25.4	87.7	460.0	18.0	n/a	3.0	0.970	0.04	0.010	0.20	0.03	291.0	1.7	11.0
Lakes with TDS 10-100 g/L in steppe zone																				
Min	8.5	14.0	0.4	241.0	1728	3674	n/a	43.7	4670	42.0	114.0	0.001	0.460	0.002	0.002	0.03	0.03	54.0	3.3	220.0
Max	9.9	94.0	8.8	58920	17784	43500	32.7	4982	27260	294.0	477.0	42.0	11.000	1.30	0.050	20.00	1.10	350.0	610.0	1000
Av.	9.4	48.0	3.5	13729	8125	15243	13.9	1277	14515	145.0	296.0	15.6	2.990	0.29	0.020	6.29	0.32	137.0	130.0	408.0
Lakes with TDS more than 100 g/L in steppe zone																				
Min	7.2	101.0	n/d	488.0	5208	21950	6.9	30.6	33000	20.0	76.0	0.2	0.830	n/d	0.001	0.05	0.02	9.0	0.4	22.0
Max	9.8	369.0	255.2	39240	97224	190400	993.0	38796	116500	561.0	599.0	54.0	20.900	2.30	1.000	79.00	1.30	1400	870.0	1200
Av.	8.1	254.0	70.4	5410	39178	118927	220.0	12044	76144	257.0	307.0	18.5	6.880	0.40	0.260	15.90	0.45	556.0	141.0	375.0

*n/a – not available; **n/d – not detected; *** - data according to [3]

The growth of Cl content significantly ahead of the growth of SO_4, the content of which in different lakes range from 0.1 to 65 g/L.

The dominant part of the cations is Na; its average concentration is 60 g/L. The second part is Mg with concentration from 30 mg/L to 38.8 g/L. The K content is in the range from 11 to 700 mg/L. Ca has a significant share only in saline lakes. The lagging in accumulation of Ca and CO_3 in waters is explained by precipitation of calcite at the early stage of chemical evolution of water [5].

These lakes have high concentrations of K, Si (up to 21 mg/L), Al (330 mg/L), Mn (up to 423 mg/L), Sr (up to 21 mg/L).

5. Results and discussion

The comparative analysis of water composition in bog and lake systems of various landscape zones reveals their geochemical specifics consisting first of all in various degree of their mineralization, different composition, the complexes formation of chemical elements and the environment. Chemical composition of the systems is a result of direct reflection of intensity and direction of inner evolution not only in various landscapes zones, but also in local area. There are three main sources of chemical and organic matter that can be highlighted to illustrate the different stage of the evolution of chemical composition in such systems: atmosphere (amount and chemical composition of precipitation, evaporation, water exchange), biosphere (biological productivity of landscapes) and lithosphere (structure of catchment area, geological conditions). The ratio of these sources, as it is presented in Figure 2, can be different in various landscape zones. Firstly, chemical composition is formed due to climatic conditions of the area and depends on the amount of precipitation and its chemical compound as well as the evaporation process which can lead to elements concentration in arid area. Moreover, the higher the humidity of a territory, the intensively a leaching of elements from the soil and larger an input of elements (Na, Cl, Mg) are. Secondly, the formation of various complexes with organic matter (HA, FA, living organisms) and trace elements (Fe, Mn, Ca, As) provide its accumulation in water [10; 11]. These processes are more intensive in forest and forest-steppe landscapes in comparison with steppe zone where secondary mineral formation is the main factor controlling rejection of elements (Ca, HCO_3, SO_4, Ba, As) from water to sediments [12]. As a result, great diversity in sedimentation can be pointed out in different landscapes: peat, slime and mineral formation.

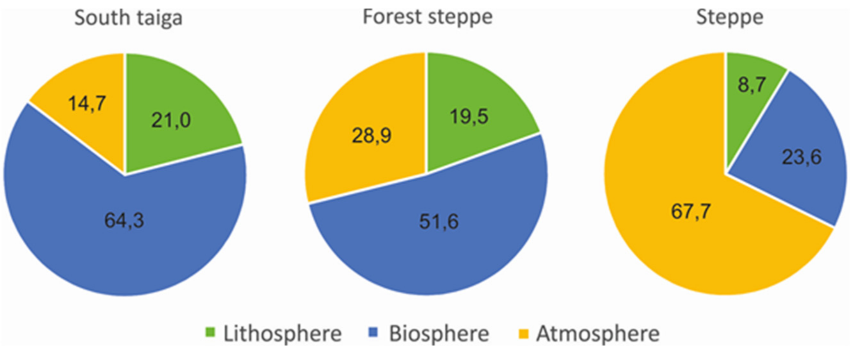

Figure 2. Three main sources of chemical and organic matter (%) in different landscapes according to Shvartsev [13]

6. Conclusions

All of the aforesaid allow us to make a few important conclusions: 1) there is a geochemical complex of elements in aqueous solution of bog and lake water that forms a very stable system, which is reflected by the climatic and geomorphological factors; 2) individual hydrogeochemical system forms in every type of landscapes with a considerable degree of freedom that allows its individual parameters to vary slightly but only in strictly defined limits and which can be estimated by average parameters; 3) identity and stability of hydrogeochemical system is ensured by the presence of its deep linkage with all components of the landscape (rocks, soil, vegetation, topography, secondary mineral products, organic matter), as well as the components of the environment (temperature, precipitation and its quantity, etc.).

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