Spatio - temporal analysis of the lakes of the Kamyshlovsky Log of the Omsk region and their impact on the soil cover

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Abstract. The article presents data on changes in the state of the lakes of the Kamyshlovsky Log of the Omsk region based on spatio-temporal data of satellite images and analysis of the chemical composition of water. It is shown that the sodium sulfate type of water in the lakes of the region is formed in the foci of continental salinization – in the Kamyshlovsky Log. It is shown that the decisive role in the formation of lakes is played by their feeding with groundwater enriched with sodium chlorides. The data of the spatial-temporal analysis of the lakes of the Kamyshlovsky Log indicate the course of the process of salinization in the period from 2016 to 2020. Chlorides are of decisive importance in terms of chemical composition in lakes, the type of salinity in all lakes is sulfate-chloride. The exception is Kamyshnoye Lake – according to 2016 data, the type of salinity in the lake is sulphate, which by 2018-2020 was replaced by sulphate-chloride. The soil cover is mainly represented by soils of the saline range, mainly salt marshes, near Lake Piketnoe – solonets, near Kamyshlov – lugovo-chernozem saline saline soil. The type of salinization in the presented soils is sulphate.

Keywords: Kamyshlovsky Log, mineralized lakes, soil cover, spatio-temporal data analysis.

1 Introduction

Salt lakes are found throughout Russia. They are mostly drainless, which means that minerals and salts are not washed out of them. Over time, the concentration of substances in lakes can change under the influence of various factors. According to the degree of mineralization, lakes are divided into fresh, containing up to 1 g / l of dissolved solids; brackish, containing 1-10 g / l of salts; salty (10-50 g / l); brines (over 50 g / l).

Salt lakes are formed in different ways, so some in the past were bays of the seas. This way of formation of mineralized lakes is typical for the territory of Western Siberia. The glacier coming from the north has created backwater of the rivers of the Ob-Irtysh basin. This formed a giant fresh sea. As a result of evaporation, the sea broke up into a number of large lakes. Later, large lakes partially dried up, partially broke up into small ones, with varying degrees of mineralization [1].

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Kamyshlovsky Log is a chain of salt and fresh lakes formed on the site of the once flowing relict river Kamyshlovka (Figure 1). Its length is about 570 km with a width of 15-20 km in its western part and 30 km in the east. The lakes of the Kamyshlovsky Log are located on the territory of the North Kazakhstan region of the Republic of Kazakhstan and the Omsk region of the Russian Federation. At the same time, the southwestern part of the ravine has predominantly fresh lakes, whereas the lakes of the Omsk region are salty and bitterly salty. The largest lakes of the Kamyshlovsky Log are: Reinfeld, Pokrovskoe, Kamyshnoye, Polovinnoye, Krugloye, Solenoye, Krivoe. This is a protected area, because in the spring many waterfowl come here, including rare and endangered ones listed in the Red Book of the Omsk region.

The groundwater in the studied area is mineralized, but the degree of the mineralization and the nature of salinization are very heterogeneous, and depend on the salt composition of the lakes. Soil–forming rocks are clayey, carbonate and saline, of alluvial and lacustrine-boggy origin [2, 3, 5, 5].

Information on the assessment of the properties and distribution of saline soils mainly refers to the period of the middle and end of the twentieth century. Undoubtedly, these data require updating based on modern methods and approaches [6, 7, 8].

2 Materials and Method

Water samples were taken in July 2016, 2018 and 2020 from the following lakes:

- Piketnoye, Reinfeld (Maryanovsky district);
- Kamyshnoye, Kamyshlovskoye and Kamyshlovo (Moskalensky district).

The studied areas are located in the southern part of the West Siberian Plain in the southwest of the Omsk region and are part of the Ishim plain of the Irtysh interfluve. According to the relief, it is a gently undulating plain with sparse ridges, with a pronounced microrelief in the form of saucer–shaped lows and shallow holes; shallow and deeper depressions occupied by swamps and lakes.

In order to study the soil cover, sections were laid in the territories adjacent to the lakes. Soil samples were taken from the section from each horizon in its middle part. The soil cover is represented by: arable soils (meadow – chernozem soils), soils of pastures and hayfields (meadow soils and solonetzes), and soils of the reclamation fund (solonchaks). At the Department of Agrochemistry and Soil Science of the Omsk State Agrarian University, total alkalinity, chloride ions, sulfate ions, calcium and magnesium in the studied water and soils were determined by titration, the amount of sodium and potassium were calculated, dry residue was determined by evaporation, and the reaction of the environment at the pH-meter.

Kamyshlovsky Log passes through the southern part of the forest-steppe zone, characterized by insufficient moisture and moisture deficiency. The landscape of this territory in the north is characterized by the presence of forests, and in the south there are fewer of them. The climate on the territory of the studied areas is typically continental.

The air temperature in 2018 during the entire growing season was lower than during the same period in 2016 and compared with the average long-term observations (Figure 2). Whereas the amount of precipitation in 2018 was greater than in 2016 and compared with the average annual observations from April to June and in August (Figure 3). The year 2018 in the area of the lakes of the Kamyshlovsky Log lakes was characterized by a low temperature with a large amount of precipitation, which contributed to a change in the salt composition of the lakes and adjacent territories. In 2020, almost the entire spring-summer period was hot, humid weather, with temperature and precipitation above the long-time annual average norm.

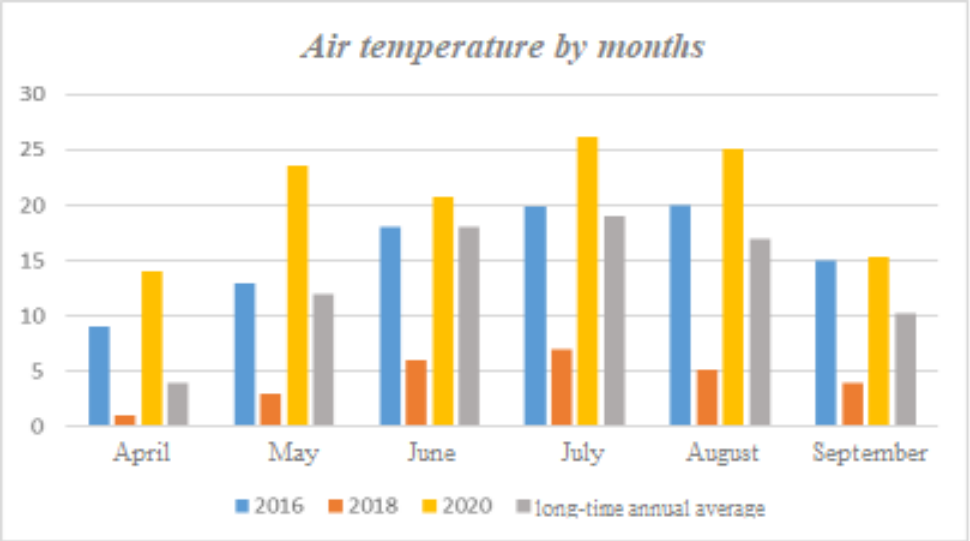

Fig. 1 Average monthly temperature for the growing season.
Source: "Compiled by the authors"

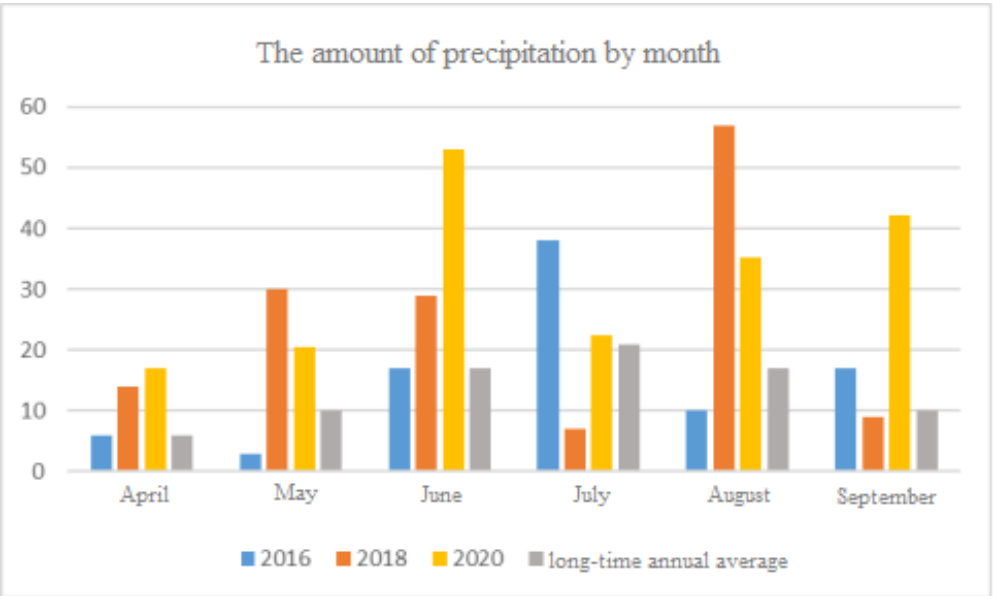

Fig. 2 The amount of precipitation during the growing season.
Source: "Compiled by the authors"

The climate creates a general background against which most of the processes affecting the formation of the chemical composition of natural waters take place. Climate, first of all, determines the balance of heat and humidity, on which the moisture content of the area and the volume of water runoff depend, and consequently the dilution or concentration of natural solutions and the possibility of dissolving substances or precipitating them.

3 Results

Multispectral images of the Landsat 8 spacecraft for 2016, 2018 and 2020 were used during the spatio-temporal analysis of the lakes of the Kamyshlovsky Log (Figure 3).

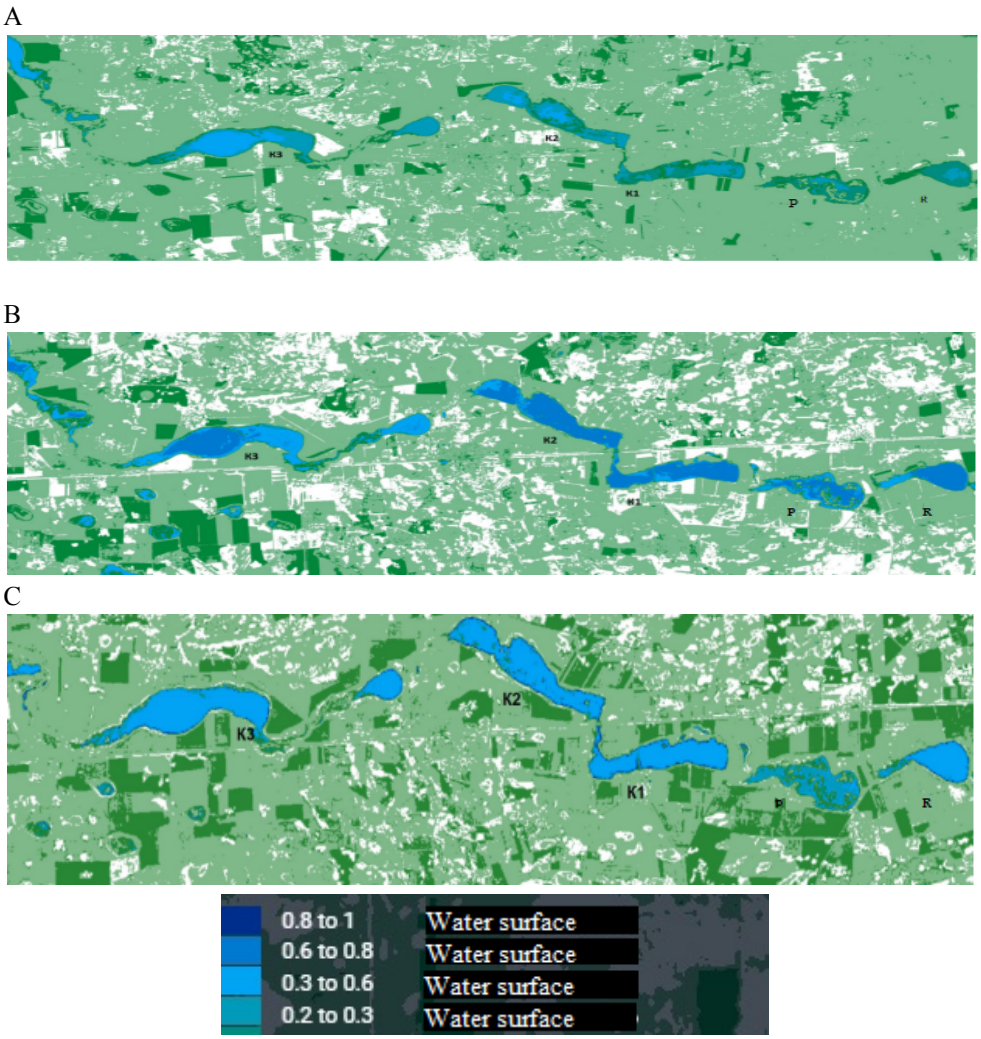

Fig. 3 Identification of changes in the water surface of the lakes of the Kamyshlovsky Log based on the use of remote sensing data: A – July 2016; B – July 2018; C-July 2020 (K3-Kamyshnoye Lake; K2-Kamyshlovskoye Lake; K1-Kamyshlovo Lake; P-Piketnoye Lake; R-Reinfeld Lake).

When confirming the hypothesis about the ongoing process of salinization of the studied water bodies, a spatio-temporal analysis of Earth remote sensing data was used to compare and identify changes in the water surface from 2016 to 2018 and 2020. Using the method of quasi-periodic variation, multispectral images of the Landsat 8 spacecraft were selected. During the initial analysis, no special differences were found in the visible range of the survey. In this regard, the method of image processing using the vegetation index NDWI (Normalized Difference Water Index) was used. This index is calculated using the formula:

NDWI-(Green-Nir)/(Green+Nir), where Green is 0.525 - 0.60 microns; Nir is 0.845 - 0.885 microns.

The Normalized Water Difference Index uses reflected Near Infrared Radiation and visible green light to enhance the presence of features, while eliminating the presence of ground noise and terrestrial vegetation.

This index made it possible to analyze the water surface of the studied objects (Figure 3). It was found that from 2016 to 2020, the water surface of the lakes increased significantly and swampy areas appeared near Kamyshnoye Lake, which do not dry out in the summer (even with the abnormal drought of 2020, the water surface did not decrease to the level of 2018).

First of all, it is necessary to evaluate water bodies.

Piketnoye Lake of the Maryanovsky district: the water is slightly brackish magnesium-sodium chloride, the reaction of the environment is alkaline, the vegetation along the lake is represented by reeds.

Reinfeld Lake Maryanovsky district (near the lake there is a meadow solonchak). The water is strongly brackish magnesium-sodium chloride, the reaction of the environment is alkaline, the vegetation is very sparse, represented by saltbush and saltwort, the water is used for irrigation purposes on arable soils located near the lake.

Kamyshlovskoye Lake is located on the territory of the Moskalensky district (meadow alkaline soil). The water is strongly brackish magnesium –sodium chloride, the reaction of the environment is alkaline, the vegetation is meadow, there are reeds along the shore, the water is used for irrigation of arable land near the lake.

Kamyshnoye Lake is in the territory of the Moskalensky district (there is a meadow solonchak near the lake). The water is strongly brackish magnesium – sodium chloride, the reaction of the environment is alkaline, the vegetation is very sparse, represented by saltbush and saltwort, the water is used for irrigation purposes on arable soils located near the lake.

Kamyshlovo Lake is located on the territory of the Isilkul district, the water is highly salted magnesium-sodium chloride, the reaction of the environment is alkaline, the vegetation is represented by Sivers wormwood.

Table 1 Reaction of the environment and chemical composition of the salt lakes of the Maryanovsky and Moskalensky districts of the Kamyshlovsky Log

Name of the lake	Reaction of the environment (pH)			Mineralization g/l					
	2016	2018	2020	2016		2018		2020	
1.Reinfeld	8.8	7.4	8.1	28.4	salty	9.4	strongly brackish	15.5	lightly salted
2.Piketnoye	7.9	7.7	7.7	18.5	lightly salted	4.2	brackish	12.1	lightly salted
3. Kamyshlovskoye	8.2	7.8	7.5	20.1	lightly salted	12.5	lightly salted	11.35	lightly salted
4. Kamyshnoye	8.4	8.0	7.8	20.6	lightly salted	12.2	lightly salted	13.4	lightly salted
5.Kamyshovo	7.3	7.2	6.85	9.3	strongly brackish	1.7	slightly brackish	10.7	lightly salted

Source: "Compiled by the authors"

Analyzing the data in Table 1, it can be concluded that in the studied lakes in 2018 there was a decrease in the total amount of salts compared to 2016, which could be caused by natural conditions, i.e. heavy precipitation during the growing season.

Table 2 presents the results of chemical analysis of salt lakes of the Maryanovsky and Moskalensky districts and Kamyshlovsky Log in the studied years.

Table 2 Water analysis of the lakes of the Maryanovsky and Moskalensky districts of the Kamyshlovsky Log in 2016, 2018 and 2020

Name of the lake	Anions mg*eq/100 g					Cations mg*eq/100 g			
	CO_3^-	HCO_3^-	CL^-	SO_4^-	Total	Ca^{2+}	Mg^{2+}	Na^+	Total
2016									
1.Reinfeld	-	2.8	424.51	62.5	489.81	25.05	130.25	334.51	489.81
2.Piketnoye	-	2.8	143.7	57.7	204.2	8.04	58.4	137.76	204.2
3. Kamyshlovskoye	-	7.0	237.35	14.69	259.04	4.49	59.91	194.64	259.04
4. Kamyshnoye	0.50	5.80	41.2	257.04	304.54	8.8	98.70	197.04	304.54
5.Kamyshlovo	1.60	11.1	100.9	32.5	146.1	7.50	15.9	122.7	146.1
2018									
1.Reinfeld	-	8.4	125.6	28.0	162	11.5	50.5	100.0	162.0
2.Piketnoye	-	4.5	35.4	23.2	63.1	5.7	13.4	44.0	63.1
3. Kamyshlovskoye	2.0	16.0	135.4	51.5	204.9	16.0	41.8	147.1	204.9
4. Kamyshnoye	-	18.0	152.0	38.0	208	15.5	47.6	144.9	208.0
5.Kamyshlovo	-	5.0	16.5	8.2	29.7	5.75	5.57	18.38	29.7
2020									
1.Reinfeld	-	8.4	228.7	32.5	269.6	26.0	74.0	169.6	269.6
2.Piketnoye		5.6	192.3	16.6	214.5	18.0	66.0	130.5	214.5
3. Kamyshlovskoye	-	5.6	171.5	19.7	196.8	21.0	45.0	130.8	196.8
4. Kamyshnoye	-	4.8	214.8	16.8	236.5	26.0	60.0	150.5	236.5
5.Kamyshlovo	-	10.0	168.0	9.7	187.7	17.0	57.0	113.7	187.7

Source: "Compiled by the authors"

Analyzing the data on the ionic composition (Tables 1 and 2), it is possible to determine the type of salinization and note the general trend towards the decrease in the mineralization of the studied lakes. Thus, all the studied mineralized lakes, according to the

type of salinity belong to sulfate-chloride sodium, with the exception of Lake Kamyshnoye: in 2016 its type of salinity was chloride - sulfate. This trend can be traced over the next few years, so in 2018 the type of salinity in the lakes corresponds to sulfate – chloride, including Kamyshnoye Lake. In the studied years, there was a significant predominance of sodium among cations. In accordance with the solubility table, calcium and magnesium bicarbonates are not soluble, therefore, the amount of bicarbonates did not decrease by 2018, but increased (with the exception of Kamyshlovo Lake). The concentration of chlorides decreased significantly, since easily soluble compounds can be formed with all cations. The concentration of sulfates also decreased (sodium and magnesium sulfates are easily soluble, calcium is slightly soluble).

The salt balance is closely related to the water balance — in the phase of elevation, the level of mineralization decreases, and vice versa, but the course of mineralization is very uneven. Most of the lakes have salty or brackish water.

The soil cover of the bottom of the ancient Kamyshlovka River is currently formed by solonchaks, solonetzes, meadow-boggy and marshy soils. All soils are of heavy loamy and clayey granulometric composition [9, 10, 11, 12, 5].

The laid sections in the territory near the salt lakes of the Maryanovsky district, and the Moskalensky district of the Kamyshlovsky Log have the following structure (Table 3).

Table 3 Soil cover of salt lakes of the Kamyshlovsky Log

Name of the soil	Profile form	Horizons	pH		Mineralization	
			2016	2018	2016	2018
Reinfeld: Meadow-bog chloride-sulfate surface clayey solonchak	A_{ck}-B_{1ckg}-$B_{2ckg}B_{3ckg}$–C_{ckg}	A_{ck}	7.9	7.0	22.3	2.6
		B_{1ckg}	8.4	7.3	10.0	2.32
Piketnoye: Meadow-chernozem slightly saline carbonate crusty low-sodium columnar heavy loamy solonetz	A_{d}-B_{1ckg}-B_{2ckg}-B_{3ckg}-B_{4ckg}-C_{ckg}	B_{1ckg}	7.8	7.25	35.0	0.51
		B_{2ckg}	7.86	7.7	27.1	0.55
Kamyshlovskoye: Meadow-bog sulfate – chloride surface clayey solonchak	A_{ck}-B_{1ck}-B_{2ckg}-B_{3ckg}-C_{ckg}	A_{ck}	-	7.5	-	3.07
		B_{1ckg}	-	7.4	-	1.61
Kamyshnoe: Meadow-bog chloride–sulfate surface clayey solonchak	A_{ck}-B_{1ckg}-B_{2ckg}-C_{ckg}	A_{ck}	7.6	7.6	15.3	2.52
		B_{1ckg}	7.82	7.5	68.2	1.83
Kamyshlovo: Meadow – chernozem alkaline saline minor low-humic clay soil	A_{d}-A_{c}-AB_{c}-B_{1}-B_{2k}-C_{k}	A_{c}	-	7.2	-	0.67
		AB_{c}	-	7.4	-	0.8

Source: "Compiled by the authors"

Saline soils – solonchaks (salts throughout the profile starting from the upper horizon) and solonetzes (salt depth from 30 to 80 cm) are formed in the soil cover near the salt lakes – Reinfeld, Piketnoye, Kamyshlovskoye and Kamyshnoye. In 2018, the mineralization in all studied soil varieties of the lakeside soils of the Kamyshlovsky Log was less than in 2016. This is most likely due to weather conditions, i.e. heavy precipitation and low air temperature. The reaction of the environment in the upper soil horizons also changed somewhat from the alkaline to slightly alkaline.

In order to study the influence of the salt lakes of the Kamyshlovsky Log on the agroecological properties of soils, in 2018 soil sections were laid in the adjacent territories.

Table 4 Results of chemical analysis of lakeside soils of Maryanovsky and Moskalensky districts of Kamyshlovsky Log in 2018

Name of the soil	Horizon	Anions mg*eq/100g				Cations mg*eq/100g			
		CO_2/ HCO_3	CL^-	SO_4^{2-}	total	Ca^{2+}	Mg^{2+}	Na^+	total
Reinfeld	A_{ck}	-/2	9.1	28.32	39.42	13.4	13.42	12.6	39.42
Meadow - bog solonchak	B_{1ckg}	-/2,2	8	25.84	36.04	15.13	12.01	8.9	36.04
Piketnoye Meadow-chernozem solonetz	B_{1ckg}	-/2	1.3	4.19	7.49	3.76	2	1.73	7.49
	B_{2ckg}	-/2,5	2.1	3.38	7.98	2.13	0.56	5.29	7.98
Kamyshlovskoye Meadow - bog solonchak	A_{ck}	1,7/6,1	45	36.13	88.93	18.13	11.57	59.23	88.93
	B_{1ck}	-/1,6	9.7	13.13	24.43	6.25	1.25	16.93	24.43
Kamyshnoye Meadow - bog solonchak	A_{ck}	-/2,1	14.3	23.57	39.97	12.34	11.88	15.75	39.97
	B_{1ckg}	-/1,4	3.8	22.69	27.89	14.25	8.94	4.7	27.89
Kamyshlovo Meadow – chernozem saline alkali soil	A_c	-/1,7	1.0	4.63	7.33	3.25	1.25	2.83	7.33
	AB_c	-/1.5	1.1	5.5	8.1	3.13	2.87	2.1	8.1

Source: "Compiled by the authors"

According to the data of water extracts (Table 4), taken from the upper horizons of soil profiles of lakeside soils, we determine the types of salinization.

Only in the upper horizon A in the soil profile on the lakeside territory of Kamyshlovskoye Lake, chlorides predominate in the water extract, therefore, the type of salinity is sulfate – chloride. In the rest of the studied objects, sulfates predominate in water extracts, therefore, the type of salinity corresponds to chloride – sulfate.

The maximum amount of chlorides toxic to plants is also observed in the profiles near lakes Reinfeld (Maryanovsky district) and Kamyshlovskoye (Moskalensky district). The smallest amount of chlorides in soil profiles is near lakes Piketnoye (Maryanovsky district) and Kamyshlovo (Moskalensky district).

In addition to determining the type of salinity, the degree of salinity was calculated taking into account the "Total effect" of toxic salts [9, 13, 5, 14].

Soil profiles near lakes Piketnoye and Kamyshlovo are medium saline in terms of salinity, the rest are very saline.

The influence of lakes on the soil cover of lakeside soils is considered on the example of lakes Piketnoye and Reinfeld. These lakes, being relatively close to each other, act differently on the soils adjacent to them.

Table 5 Results of chemical analysis of the meadow – bog solonchak near Reinfeld Lake – Maryanovsky district of the Kamyshlovsky Log in 2018.

Horizon	Anions mg*eq/100g				Cations mg*eq/100g			
	CO_2/ HCO_3	CL^-	SO_4^{2-}	total	Ca^{2+}	Mg^{2+}	Na^+	total
A_{ck}(0-17)	-/2	9.1	28.32	39.42	13.4	13.42	12.6	39.42
B_{1ckg}(17-40)	-/2,2	8	25.84	36.04	15.13	12.01	8.9	36.04
B_{2ckg}(40-52)	-/2.6	7.7	19.57	29.87	12.63	2.57	14.67	29.87
B_{3ckg}(52-75)	-/2,9	6.5	22.76	32.16	11.38	7.26	13.52	32.16
C_{ckg}(>75)	-/2.2	5.7	18.63	26.53	9.46	6.31	10.56	88.93

Source: "Compiled by the authors"

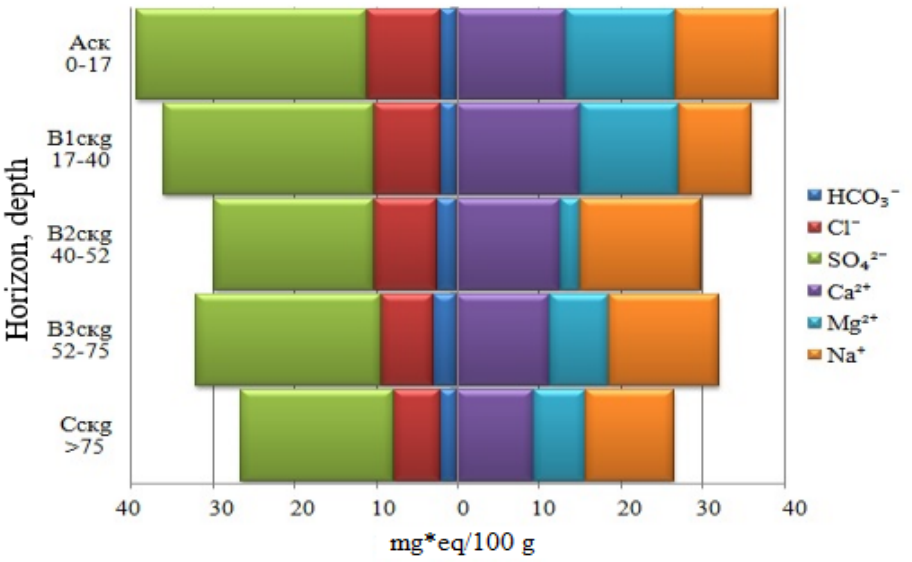

Fig. 4 Distribution of salts along the soil profile of the meadow – bog solonchak, Reinfeld Lake

Table 6 The results of the chemical analysis of meadow-chernozem solonetz near Piketnoye Lake, Maryanovsky district, Kamyshlovsky Log in 2018.

Horizon	Anions mg*eq/100g	Cations mg*eq/100g

	CO_2/ HCO_3	CL^-	SO_4^{2-}	total	Ca^{2+}	Mg^{2+}	Na^+	total
B_{1ckg}(2-18)	-/2	1.3	4.19	7.49	3.76	2.0	1.73	7.49
B_{2ckg}(18-37)	-/2,5	2.1	3.38	7.98	2.13	0.56	5.29	7.98
B_{3ckg}(37-64)	-/2.1	3.1	6.05	11.25	1.6	2.62	7.03	11.25
B_{4ckg}(64-88)	-/2,1	2.4	6.84	11.34	3.32	0.89	7.19	11.34
C_{ckg}(>88)	-	-	-	-	-	-	-	-

Source: "Compiled by the authors"

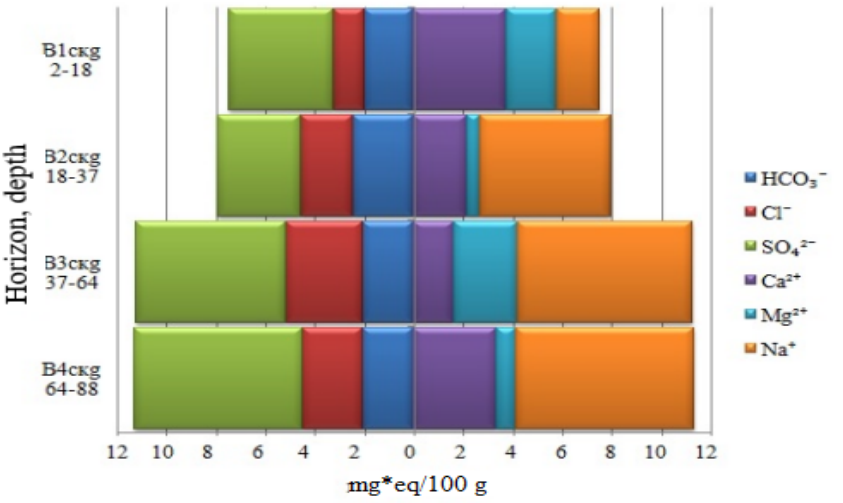

Fig. 5 Distribution of salts in the profile of meadow-chernozem solonetz, Piketnoye Lake.

According to the data on the distribution of salts along soil profiles (Table 5, 6, Figure 4, 5), laid near the lakes Reinfeld and Piketnoye, it is clear how the salt composition of the lakes affects the soil cover of the soils formed in this area. Thus, the source of easily soluble salts in the soils of adjacent territories is mineralized groundwater.

Near more saline lakes, meadow-bog solonchaks are formed, for example, Reinfeld (Maryanovsky district), Kamyshlovskoye and Kamyshnoye (Moskalensky district). Meadow – chernozem solonetzes have been diagnosed near less salty lakes Piketnoye (Maryanovsky district) and Kamyshlovo (Moskalensky district). At the same time, even near highly mineralized lakes, solonetzes are formed at some distance, which to a certain extent are absorbers for salts. Thus, with gradual distance from lakes, the salt composition in soils changes from very saline to medium saline.

4 Discussion

For the first time, spatio-temporal data analysis was applied in this territory, however, monitoring of the chemical composition of the lakes of the Kamyshlovsky Log is periodically carried out by scientists both in the territory of Kazakhstan and the Russian

Federation (the territory of the Omsk region). According to the research data, it was established that the chemistry of salt lakes has a significant impact on the soil cover of the adjacent territory and on agricultural and production assessments of soil. Among the soils, soils of the saline series were diagnosed: near lakes, solonchaks are predominant, and in the composition of agricultural lands there are complexes of meadow-chernozem solonetzic soils with solonetzes [15].

5 Conclusion

As a result of the research conducted to study the influence of the lakes of the Kamyshlovsky Log of the Moskalensky and Maryanovsky districts on the agroecological properties of soils, it was revealed:

In 2018, the mineralization of lakes was lower than in 2016, because on the territory of the Omsk region there was an increase in hydromorphism and, as a consequence, a decrease in the concentration of salts in lakes:

Reinfeld Lake 2018 – 9.42; 2016 – 26.4 (g/l);

Piketnoye Lake 2018 – 4.19; 2016 – 37.1;

Kamyshnoye Lake 2018 – 12,16; 2016 – 20,6.

According to the type of salinity, all the studied lakes, except for Kamyshlovo, belong to the sulfate-chloride sodium type. In Kamyshlovo Lake (Moskalensky district) the type of salinity is chloride – sulfate. The largest amount of chlorides is observed in the lakes Reinfeld (Marianovsky district) and Kamyshlovsky, Kamyshnoye (Moskalensky district). The smallest amount of chlorides was determined in Kamyshlovo Lake.

Hydrocarbonates in the amount of 2 g/l were found in Kamyshlovskoye Lake. In the soil profile adjacent to the lake, hydrocarbonates were also found in the amount of 1.7 mg * eq / 100 g of soil. This may be a consequence of anthropogenic activity. In soils located near more saline lakes, solonchaks are formed, next to less salty lakes – solonetzes. A pattern has also been revealed that with distance from lakes, soil profiles become less salty, but still remain in the range of saline soils. The type of salinization of the soil profiles of lakeside soils is chloride -sulfate, except for the upper horizon near Kamyshlovskoye Lake. Thus, it can be assumed that in wet years the soils adjacent to the lakes of the Kamyshlovsky Log change the type of salinity from sulfate –chloride to chloride-sulfate. In terms of salinity soil profiles at the lakes Reinfeld, Kamyshlovskoye, Kamyshnoye are very saline, the soils at the lakes Piketnoye and Kamyshlovo are medium saline.

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