ISSN 2518-170X (Online)
ISSN 2224-5278 (Print)

ҚАЗАҚСТАН РЕСПУБЛИКАСЫ
ҰЛТТЫҚ ҒЫЛЫМ АКАДЕМИЯСЫ

Satbayev University

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НАЦИОНАЛЬНОЙ АКАДЕМИИ
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КАЗАХСТАН
Satbayev University

NEWS

OF THE ACADEMY OF SCIENCES
OF THE REPUBLIC OF
KAZAKHSTAN
Satbayev University

SERIES

OF GEOLOGY AND TECHNICAL SCIENCES

2 (458)

MARCH – APRIL 2023

THE JOURNAL WAS FOUNDED IN 1940

PUBLISHED 6 TIMES A YEAR

ALMATY, NAS RK

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«ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы».
ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)
Меншіктеуші: «Қазақстан Республикасының Ұлттық ғылым академиясы» РҚБ (Алматы қ.).
Қазақстан Республикасының Ақпарат және қоғамдық даму министрлігінің Ақпарат комитетінде 29.07.2020 ж. берілген **№ KZ39VPY00025420** мерзімдік басылым тіркеуіне қойылу туралы куәлік. Тақырыптық бағыты: *геология, мұнай және газды өңдеудің химиялық технологиялары, мұнай химиясы, металдарды алу және олардың қосындыларының технологиясы.*
Мерзімділігі: жылына 6 рет.
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Редакцияның мекен-жайы: 050010, Алматы қ., Шевченко көш., 28, 219 бөл., тел.: 272-13-19 http://www.geolog-technical.kz/index.php/en/

Типографияның мекен-жайы: «Аруна» ЖК, Алматы қ., Мұратбаев көш., 75.

«Известия НАН РК. Серия геологии и технических наук».
ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)

Собственник: Республиканское общественное объединение «Национальная академия наук Республики Казахстан» (г. Алматы).

Свидетельство о постановке на учет периодического печатного издания в Комитете информации Министерства информации и общественного развития Республики Казахстан **№ KZ39VPY00025420,** выданное 29.07.2020 г.

Тематическая направленность: *геология, химические технологии переработки нефти и газа, нефтехимия, технологии извлечения металлов и их соеденений.*

Периодичность: 6 раз в год.

Тираж: 300 экземпляров.

Адрес редакции: 050010, г. Алматы, ул. Шевченко, 28, оф. 219, тел.: 272-13-19
http://www.geolog-technical.kz/index.php/en/

Адрес типографии: ИП «Аруна», г. Алматы, ул. Муратбаева, 75.

News of the National Academy of Sciences of the Republic of Kazakhstan. Series of geology and technology sciences.
ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)
Owner: RPA «National Academy of Sciences of the Republic of Kazakhstan» (Almaty).
The certificate of registration of a periodical printed publication in the Committee of information of the Ministry of Information and Social Development of the Republic of Kazakhstan **No. KZ39VPY00025420,** issued 29.07.2020.
Thematic scope: *geology, chemical technologies for oil and gas processing, petrochemistry, technologies for extracting metals and their connections.*
Periodicity: 6 times a year.
Circulation: 300 copies.
Editorial address: 28, Shevchenko str., of. 219, Almaty, 050010, tel. 272-13-19
http://www.geolog-technical.kz/index.php/en/

Address of printing house: ST «Aruna», 75, Muratbayev str, Almaty.

NEWS of the National Academy of Sciences of the Republic of Kazakhstan
SERIES OF GEOLOGY AND TECHNICAL SCIENCES
ISSN 2224-5278
Volume 2, Number 458 (2023), 17–25
https://doi.org/10.32014/2023.2518-170X.276
UDC 556.55 (574.25)
IRSTI 31.19.15

© K.I. Akhmetov[1*], G.M. Yessilkanov[2,3], A.Zh. Kassanova[1,3], A.V. Ubaskin[1], T.Zh. Abylkhassanov[1], 2023

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HYDROGEOCHEMICAL FEATURES OF THE WATER OF SALINE LAKES IN PAVLODAR REGION

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Abstract. The article is devoted to the hydrogeochemical study of salt lakes in Pavlodar region. Salt lakes are an integral part of the steppe ecosystem and have economic, recreational, scientific, environmental and ecological value. The study of the chemical composition of salt lakes in the Pavlodar region is a particularly urgent task, since these lakes are inhabited by populations of the branchial crustacean Artemia sp. This type of crustacean is a valuable commercial object: Artemia cysts have a commercial value. The purpose of this study is to study the hydrogeochemical state of saline lakes in Pavlodar region. The object of the study was monitoring data (2014–2021) of the chemical composition of the water of salt lakes in Pavlodar region. A total of 64 samples were taken. Sample analysis was carried out on the basis of the Kazakhstan Design and Research Institute «Kazakhstanproekt». The index of total mineralization was determined by the gravimetric method. The potentiometric method was used to determine the pH of the samples. Determination of the content of ions Cl-, and SO_4^{2-} and cations Na^+, K^+, Ca_2^+, Mg_2^+ was carried out by capillary electrophoresis. The total content of CO_3^{2-} and HCO_3^- ions was determined by titrimetric methods of analysis. The chemical composition of salt lakes in Pavlodar region has been studied. Water mineralization varies from 60 to 260 g/l, which corresponds to weak and strong brines. According to the pH values, the waters of the studied lakes are classified as weakly alkaline and alkaline. As a result of studying the chemical composition of waters, 2 types of water chemistry of chloride-sodium-potassium and sulfate-chloride-sodium-potassium compositions were established. Factor analysis was carried out to identify hydrogeochemical features. Two main factors have been identified, where the first reflects the relationship between the main components of the chemical composition of waters. The second factor characterizes the behavior of sulfates. Sulfates as a macrocomponent can reflect the feeding habits of a particular lake, as well as the degree of interaction between water and bottom sediments. Factor analysis was also used to identify the spatial differentiation of water bodies. The following 3 groups are distinguished: 1) Highly mineralized lakes Tuz and Kalatuz; 2) Aksor and Ashchitakyr with a high content of sulfates; 3) Shcherbakty, Seiten and Borli with unstable water balance. The identified features of the chemical composition of the waters of salt lakes will help in studying the biological characteristics of water bodies, as well as in conducting regional geochemical studies. Reservoirs less resistant to climate change have been identified.

Key words: chemical composition of water, salt lakes, hydrogeochemical analysis, macrocomponent composition of water, factorial analysis, multivariate analysis

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ПАВЛОДАР ОБЛЫСЫНДАҒЫ ТҰЗДЫ КӨЛДЕР СУЫНЫҢ ГИДРОГЕОХИМИЯЛЫҚ ЕРЕКШЕЛІКТЕРІ

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Аннотация. Мақала Павлодар облысының тұзды көлдерінің гидрогеохимиялық зерттеулер жүргізуге арналған. Тұзды көлдер дала экожүйесінің ажырамас бөлігі болып табылады және экономикалық, рекреациялық, ғылыми, табиғат қорғау мен экологиялық құндылыққа ие. Павлодар облысының тұзды көлдерінінің химиялық құрамын зерттеу аса маңызды мақсат болып табылады, өйткені осы көлдерде *Artemia sp*. желбезекаяқты шаянының популяциялары тіршілік етеді. Шаянның бұл түрі құнды кәсіп объектісі болып табылады: артемия цисталары коммерциялық бағаға ие. Бұл зеттеудің мақсаты Павлодар облысының тұзды көлдерінің гидрогеохимиялық жағдайы зерттеу болып табылады. Зерттеу объектісі Павлодар облысының тұзды көлдеріндегі судың химиялық құрамы мониторингісінің берілгендері (2014–2021 жж.) болып табылды. Үлгілердің талдауы "Қазақстанпроект" Қазақстан ғылыми-зерттеу институтының базасында жүргізілді. Жалпы минерализацияланудың көрсеткішін гравиметрикалық әдіспен анықтады. pH үлгілерін анықтау үшін потенциометрикалық әдіс қолданылды. Cl, SO_4^{2-} иондарын және Na^+, K^+, Ca^{2+}, Mg^{2+} катиондарын анықтауда капиллярлы электрофорез әдісі пайдаланылды. CO_3^{2-} және HCO_3 иондарының жалпы құрамы талдаудың титриметрикалық әдіспен анықталды. Павлодар облысының тұзды көлдерінің химиялық құрамы зерттелді. Судың минерализациясы 60 г/л бастап 260 г/л дейін аралығында өзгереді, бұл әлсіз және қатты тұздық көрсеткіштеріне сәйкес. pH мәндері бойынша зерттелген көлдердің сулары әлсіз сілтілі және сілтілі. Сулардың химиялық құрамын анықтау нәтижесінде сулар химизмнің 2 түрі анықталды: хлоридті-натрийлі-калийлі және сульфатты-хлоридті-натрийлі-калийлі. Гидрогеохимилық ерекшеліктерді анықтау үшін факторлы талдау жүргізілді. 2 негізгі фактор ажыратылды. Бірінші фактор сулардың химиялық құрамының негізгі компоненттерінің өзара байланысын, ал екінші фактор сульфаттардың күй-өзгерістерін көрсетеді. Сульфаттар макрокомпонент ретінде бұл немесе басқа көлдің қоректенудің ерекшеліктерін, сондай-ақ су мен түптік шөгінділердің өзара қатынас дәрежесін көрсетеді. Су айдындарының кеңістік дифференциацияны анықтау үшін тағы да факторлы талдау жүргізілді. Келесі үш топ бөлінеді: 1) жоғары минерализацияланған Тұз және Қалатұз көлдері; 2) құрамында сульфаттары артық Ақсор және Ащытақыр көлдері; 3) судың балансы тұрақты емес Шарбақты, Сейтен және Бөрлі көлдері. Тұзды көлдер суларының химиялық құрамының анықталған ерекшеліктері су айдындарының биологиялық ерекшеліктерін зерттеуде, сондай-ақ өңірлік геохимиялық зерттеулерді жүргізуде көмектеседі. Климаттық өзгерістерге аз тұрақты су айдындары айқындалды.

Түйін сөздер: судың химиялық құрамы, тұзды көлдер, гидрогеохимиялық талдау, судың макрокомпонентті құрамы, факторлы талдау, көп өлшемді талдау

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ГИДРОГЕОХИМИЧЕСКИЕ ОСОБЕННОСТИ ВОДЫ СОЛЁНЫХ ОЗЁР ПАВЛОДАРСКОЙ ОБЛАСТИ

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Аннотация. Статья посвящена гидрогеохимическому изучению соленых озер Павлодарской области. Соленые озера являются неотъемлемой частью степной экосистемы и имеют экономическую, рекреационную, научную, природоохранную и экологическую ценность. Исследование химического состава соленых озер Павлодарской области является особо актуальной задачей, поскольку в этих озерах обитают популяции жаброногого рачка *Artemia sp*. Данный вид рачка является ценным промысловым объектом: цисты артемии имеют коммерческую стоимость. Целью данного исследования является изучение гидрогеохимического состояния соленых озер Павлодарской области. Объектом исследования являлись данные мониторинга (2014–2021 гг.) химического состава воды соленых озер Павлодарской области. Всего отобрано 64 пробы. Анализ проб проводился на базе Казахстанского проектно-исследовательского института «Казахстанпроект». Показатель общей минерализации определяли гравиметрическим методом. Потенциометрический метод использовали для определения pH проб. Определение содержания ионов Cl-, и SO42- и катионов Na+, K+, Ca2+, Mg2+ проводилось методом капиллярного электрофореза. Общее содержание ионов CO32- и HCO3- определялось титриметрическими методами анализа. Изучен химический состав соленых озер Павлодарской области. Минерализация воды изменяется в пределах от 60 до 260 г/л, что соответствует слабым и сильным рассолам. По значениям pH воды изученных озер относятся к слабощелочным и щелочным. В результате изучения химического состава вод были установлены 2 типа химизма вод хлоридно-натриево-калиевого и сульфатно-хлоридно-натриево-калиевого составов. Для выявления гидрогеохимических особенностей был проведен факторный анализ. Выделены 2 основных фактора, где первый отражает взаимосвязь главных компонентов химического состава вод. Второй фактор характеризует поведение сульфатов. Сульфаты как макрокомпонент могут отражать особенности питания того или иного озера, а также степень взаимодействия воды и донных отложений. Для выявления пространственной дифференциации водоемов был также использован факторный анализ. Выделяются следующие 3 группы:1) высокоминерализованные озера Туз и Калатуз; 2) Аксор и Ащитакыр с повышенным содержанием сульфатов; 3) Щербакты, Сейтень и Борли с нестабильным водным балансом. Выявленные особенности химического состава вод соленых озер помогут в изучении биологических особенностей водоёмов, а также при проведении региональных геохимических исследований. Выделены водоемы, менее устойчивые к климатическим изменениям.

Ключевые слова: химический состав воды, соленые озера, гидрогеохимический анализ, макрокомпонентный состав воды, факторный анализ, многомерный анализ

Introduction

The study of saline lake ecosystems is of global importance due to their economic, recreational, scientific, environmental and ecological value (Hammer, 1986; Williams, 2002).

For example, saline lakes are capable of mitigating the anthropogenic effect on ecosystems by neutralizing various substances, especially nitrogen compounds (Valiente et al., 2022).

The steppe areas of central and northern Kazakhstan are rich in shallow lakes, which number over 14,000 in this area (Urivaev, 1959). In Kazakhstan, the estimated area of impounded surface water bodies, including permanent and interrupted wetlands, is approximately 1,008,800 km^2 which is 37 % of the total area of the country. Saline water bodies are one of the most important aquatic habitats in the steppes of Kazakhstan (Kolpakova et al., 2019).

The study of the chemical composition of saline lakes in Pavlodar region is a relevant objective since these lakes are inhabited by populations of the Branchiopoda crustacean, Artemia sp. These crustaceans have adapted to live in the salinity of water bodies from 10 to 340 g/l. This crustacean species – Artemia cysts – is a valuable commercial object.

Global climate change, along with the anthropogenic effect on the natural resources of saline lakes, leads to geochemical alterations in the environment of these living organisms. Therefore, careful monitoring of the state of these water bodies is necessary (Lebedeva et al., 2019). At the same time, it is important to systematize the studied lakes by their inherent parameters, which are, in general, hydrochemical characteristics of the ecosystem.

The purpose of the research is to study the geochemical features of saline lakes in Pavlodar region.

Study area description

Pavlodar region is located in the north-eastern part of Kazakhstan and occupies an area of more than 127.5 thousand km. Pavlodar region relief is represented by two major geomorphological zones – uplands, the eastern edge of the Central Kazakh Hummocks, and plains, the southern border of the West Siberian Plain.

Part of the lakes under study are located in the area of the accumulative lacustrine-alluvial plain, which dominates the territory of the region; there are a large number of intermittent lakes and swamps, the extent of which corresponds to the direction of the ancient depressions (from southwest to northeast) (Deferred expenses 011 report., 2008).

The climate of Pavlodar region according to Köppen is classified as cold semi-arid steppe - BSk. In July, the temperature varies from +20.4 to 22.4ºC, and in January from –13.3 to –19.0ºC. The average annual temperature is positive. Annual precipitation varies from 200 to 300 mm (Ubaskin, 2005).

Materials and basic methods

Seven saline lakes in Pavlodar region were chosen as the research objects. The work presents the results of years-long monitoring of the chemical composition of waters of the lakes: Aksor, Aschitakyr, Kalatuz, Tuz, Borli, Sherbakty and Seiten in the spring and autumn between 2014 and 2021. The sampling map is shown in figure 1. A total of 64 samples were analyzed.

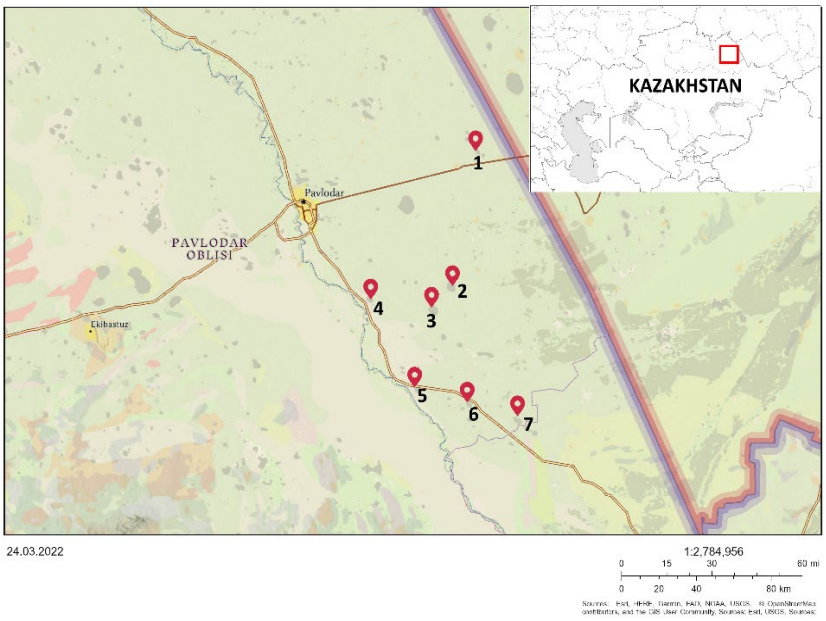

Fig. 1 – Water sampling map

Table 1 – Characteristics of the studied saline lakes

№	Lake	Coordinates	Area, km ^{2}	Mean depth, m
1	Aschitakyr	52º33'N, 78º19'E	4.20	1.1
2	Seiten	51º55'N, 78º07'E	15.50	1.9
3	Borli	51°49' N, 77°58' E	15.0	3.0
4	Kalatuz	51º53'N, 77º30'E	8.50	2.2
5	Aksor	51°27'N, 77°52'E	11.60	0.8
6	Sherbakty	51º23'N, 78º15'E	6.80	2.8
7	Tuz	51°18'N, 78°38'E	10.63	1.1
Note: the numbers of the lakes correspond to the numbers on the map				

Water sampling and preserving were carried out according to the generally accepted method (GOST 31861–2012). The water chemical composition was analyzed by the accredited laboratory of Kazakhstan Engineering Research Institute "Kazakhstanproject" LLP. The total salt content index was determined by the gravimetric method (GOST 26449.1–85). To determine the pH of the samples, the potentiometric method was used. The content of Cl^-, and SO_4^{2-} ions and Na^+, K^+, Ca^{2+}, and Mg^{2+} cations were determined by capillary electrophoresis (KZ.07.00.01998–2014, KZ.07.00.01529–2017). The total content of CO_3^{2-} and HCO_3^- ions was determined by the titrimetric method (GOST 26449.1–85). The reagents of AR grade were used for the analysis.

Statistical data processing was performed using Statistica 2019 and Microsoft Excel 2019.

Results

The average content of macrocomponents in the water of saline lakes is presented in Table 2. TDS concentration in the lakes varies from 60 to 260 g/l. Among the studied lakes the following types can be distinguished:

- Weak brines (50 to 100 g/l): Borli, Aschitakyr;
- Strong brines (100 to 320 g/l): Sherbakty, Aksor, Seiten, Kalatuz, Tuz.

According to pH values, the waters of the studied lakes belong to slightly alkaline and alkaline. As a rule, lakes with high TDS concentrations have lower pH values.

Table 2 – Chemical composition of waters in lakes of Pavlodar region (n=64), mg/l

Lake	TDS, g/l	Chemical water composition	pH	HCO_3	Cl^-	SO^{2-}_4	Ca	Mg	Na+K
TDS concentrations from 60-80 g/l									
Borli	60	Cl^- - Na+K	9.0	2060	27800	6400	16	170	22000
Aschitakyr	80	Cl^-- Na+K	8.4	540	33600	13200	90	2670	34900
TDS concentrations from 80-120 g/l									
Sherbakty	110	Cl^- - Na+K	8.9	775	57000	5150	25	460	40700
Aksor	110	SO^{2-}_4 Cl^- - Na+K	8.6	610	25500	45000	110	2500	34300

Seiten	120	Cl^- - Na+K	8.9	1950	49400	6500	45	130	48000
TDS concentrations >120 g/l									
Kalatuz	220	Cl^- - Na+K	7.8	610	116000	10000	280	12000	62700
Tuz	260	Cl^- - Na+K	7.8	510	142000	20600	90	6600	88000
Note: the table provides median values, TDS is total dissolved solids									

Alternation of high-water and low-water periods is typical for the lakes in the region. It is connected with a significant excess of inflow over evaporation in high-water years and, on the contrary, with a sharp predomination of losses over inflow in low-water years. The multiyear amplitude of lake water level fluctuations varies within wider limits – from 0.5 to 4.5 m (long-term average annual - 1.5–2.0 m). Climatic factors – temperature and precipitation in particular - play a crucial role in the functioning of saline lakes, and their physical and geographic location predetermine their present state. We can consider the modern period starting from 1989 as a certain climatic turbulent period towards global warming (Abylkhassanova et al., 2020).

Chronological fluctuations of hydrometeorological parameters affect the hydrochemical behaviour of saline lakes. In recent years in the studied region, there has been significant variability in air temperature and atmospheric precipitation (Figure 2). At the same time, fluctuations of these most important abiotic factors also affect changes in other environmental components. There was revealed a negative correlation between air temperature and precipitation in the studied period (Figure 2). A simultaneous increase in air temperature and decrease in precipitation negatively affects the hydrological state of saline water bodies, leads to an increase in the total TDS of water and negatively affects the living conditions of biota.

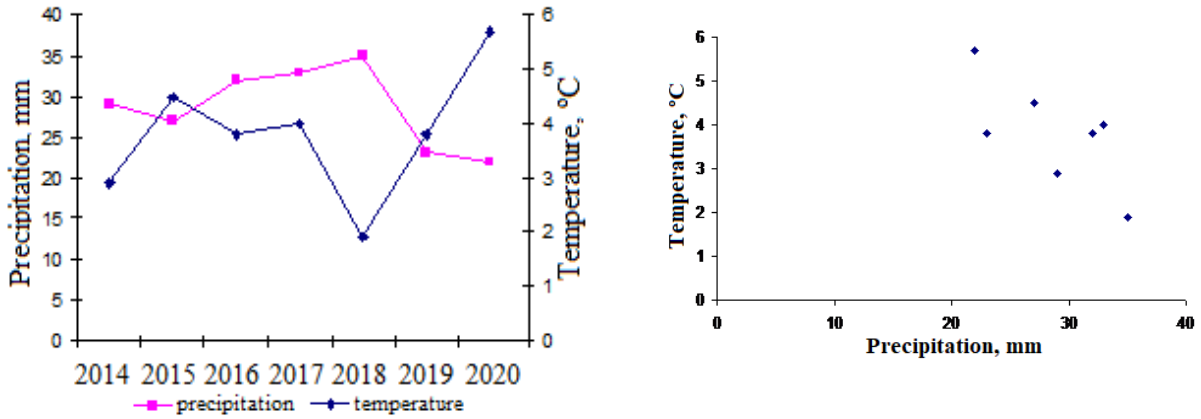

Figure 2 – Correlation of temperature and precipitation (correlation coefficient minus 0.77)

As a result of studying the chemical composition of the waters of 6 lakes, 2 types of water chemistry were established, which are determined by the predominant cations and anions (Alekin, 1970). Most of the studied lakes have waters of chloride-sodium-potassium composition. In the works on the study of saline lakes in Altai Krai, this type of water was characteristic of the dry-steppe zone on chestnut soils. Sulfate-chloride-sodium-potassium composition of waters was found only in Lake Aksor.

In order to identify landscape and geochemical features influencing the main macro-component composition a factor analysis with varimax rotation was conducted (Toropov, 2022; Reimann, 2008). The distribution of the studied hydrogeochemical parameters and lakes according to the value of factor loadings (principal component method) are presented in table 3 and figure 3.

Table 3 – Distribution of factor loadings of the chemical composition of water of Pavlodar region's saline lakes, (n=64)

	Factor 1	Factor 2
pH	-0.82	-0.39
HCO_3^-	-0.33	-0.59
SO_4^{2-}	-0.07	0.79
Cl^-	0.90	0.05
Ca^{2+}	0.32	0.61
Mg^{2+}	0.78	0.39
K^++Na^+	0.77	0.17
TDS	0.62	0.08
% of total variance	49	13

Note: Indicators with standard factor loading above 0.70 are marked in red

Table 3 shows that 2 factors explain 62 % of the variance in the experimental data.

Analysis of the obtained data allowed us to identify the main factors determining the chemical composition of the lakes:

– Factor 1 (49 % of the total variance) is the relationship between the main components of the chemical composition of waters, the evolution of water types as a result of evaporative concentration;

– Factor 2 (13 %) reflects the behaviour of sulfates. Sulfates as a macro-component can reflect the peculiarities of collecting of this or that lake, as well as the degree of interaction between water and bottom sediments. So, when crossing certain thresholds of mineralization sulfur-containing minerals – gypsum and tenardite are formed (Kolpakova et al., 2019).

In order to show the spatial differentiation of water bodies, we plotted the ratio of factor loadings between the lakes (Figure 3).

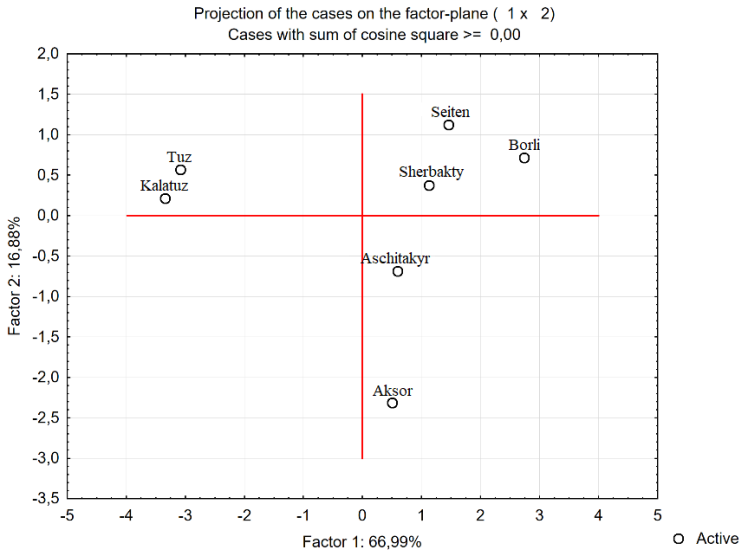

Figure 3 – Distribution of lakes by magnitude of factor loadings

The graph shows that there is a clear differentiation of the studied lakes, since the mechanisms of formation and the direction of changes in the chemical composition of such waters differ. The following three groups were identified:

Highly saline lakes Tuz and Kalatuz. These water bodies have high salinity above 120 g/l but the high influence of Factor 2 affects the behavior of sulfates. Perhaps these lakes have a stable inflow of groundwaters. Lake Kalatuz located in the zone of influence of the floodplain of the Irtish River.

Saline lakes Aksor and Aschitakyr with a high sulfates content. These lakes may have a mixed type of inflow and a higher level of water evaporation.

The largest group includes Lakes Sherbakty, Seiten and Borli. The analysis of factor loadings shows that the composition of their waters is strongly influenced by Factor 1 and 2. Most likely these water bodies have an unstable water balance which depends on precipitation and the evaporation intensity but with groundwaters inflow.

Identified groups of lakes, as a set of different processes, will respond differently to climate change. In order to show the differences between the selected lakes groups we plotted the water salinity range diagrams by years (Figure 5).

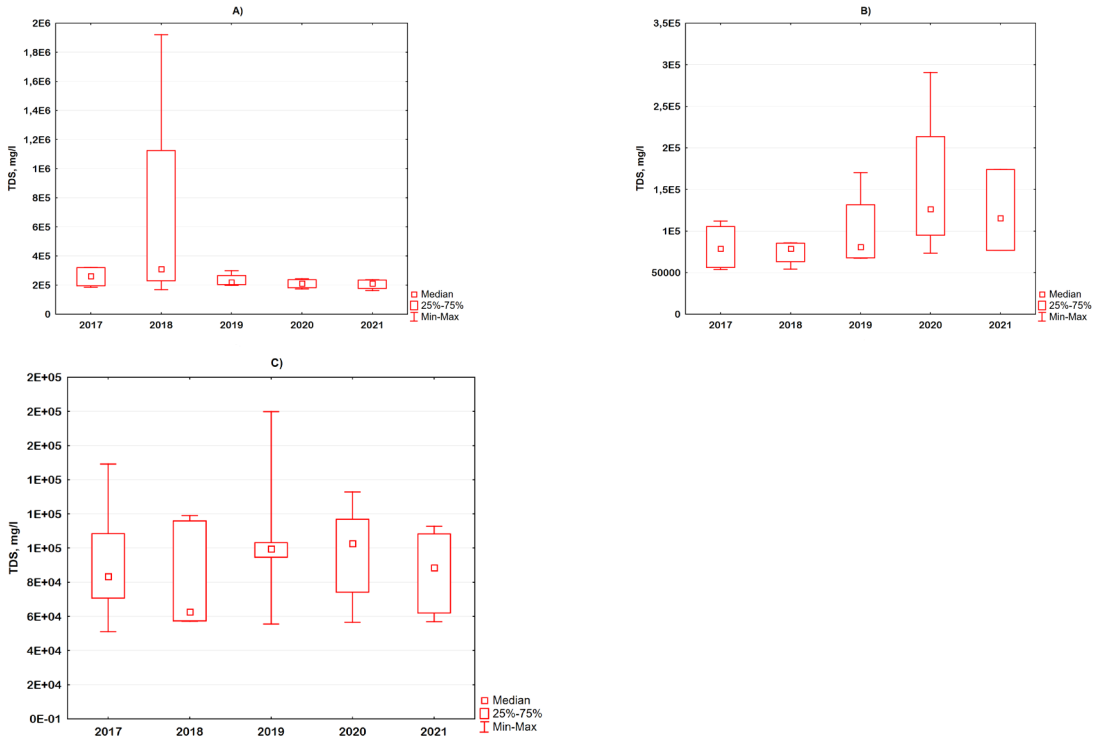

Figure 4 – Salinity range diagrams by years

A) Lakes Tuz, Kalatuz, C) Lakes Aksor, Aschitakyr , C) Lakes Sherbakty, Seiten, Borli.

The range diagrams confirm the results of factor analysis: Lakes Tuz and Kalatuz have the most stable salinity level without major picks, except in 2018, which is associated with an increase in precipitation.

Lakes Aksor and Aschitakyr tend to increase salinity in comparison with the beginning of observation in 2017. The diagram shows increase in the range and interquartile distance from 2019 to 2021, which indicates a possible intensification of the process of evaporative concentration in these lakes.

The largest group of lakes shown in Figure 3c characterized by a large range of salinity changes over the years which additionally indicates the instability of the dynamics of the chemical water composition. Most likely, different inflow sources of lakes (groundwaters and precipitation) have different dynamics depending on the year and season.

Important to note, that in order to make more accurate conclusions it requires expanding the range of studied elements in water and bottom sediments.

Conclusion

The studies have shown that the salinity of waters in the lakes of Pavlodar region varies greatly. In the studied series, the average waters salinity varies from 60 g/l (Lake Borli) to 260 g/l (Lake Tuz). The water composition characterized by a small variety: Cl^- - Na^++K^+ and SO_4^{2-} Cl^-- Na $^+$+K^+ type of waters.

Factor analysis has shown 2 main processes affecting the chemical composition of water: salinization processes (Factor 1) and the processes of water/bottom sediments interaction or groundwater inflow.

The use of the principal component method allowed us to identify 3 main spatial groups of lakes.

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ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)

Заместитель директор отдела издания научных журналов НАН РК *Р. Жәлиқызы*
Редакторы: *М.С. Ахметова, Д.С. Аленов*
Верстка на компьютере *Г.Д.Жадыранова*

Подписано в печать 14.04.2023.
Формат 70x90$^{1}/_{16}$. Бумага офсетная. Печать – ризограф.
20,0 п.л. Тираж 300. Заказ 1.

Национальная академия наук РК
050010, Алматы, ул. Шевченко, 28, т. 272-13-19