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CURRENT STATE OF SMALL LAKES ACCORDING TO ARCHIVAL AND AEROSPACE DATA

Annotation. The article is a review of studies on morphometric, hydrochemical and ecological characteristics of small lakes, including their classification, natural diversity and significance in a changing climate.

Small lakes are an important component of the country's ecosystems, playing a key role in maintaining biodiversity and ecological functions. The purpose of this study is to investigate morphometric and hydrochemical characteristics of small lakes in the Esil water basin, their classification and assessment of their ecological status under changing climate conditions.

The work has significant scientific and practical significance: the collected data allow to assess the impact of anthropogenic and natural factors on the water bodies ecosystems, which is important for their rational use and protection. The research methodology included remote sensing data analysis, field observations, hydrophysical and hydrochemical measurements, classification of lakes by morphometric characteristics.

Results showed that most small lakes in the basin have small area and depth, low water clarity, and moderate salinity levels, reflecting the influence of both freshwater feeding and evaporation processes. Chemical analyses revealed considerable variation in water composition, which is related to the geologic and climatic conditions of the region. Lakes located at 100-400 m elevation have high biological activity, as evidenced by high oxygen content and low CO_2 levels.

The study value lies in the creation of morphometric and hydrochemical characteristics database, which allows monitoring changes in aquatic ecosystems. The practical significance of the work is related to the development of strategies for sustainable nature use and water resources management under climate change.

Keywords: Remote Sensing; small lakes; GIS technologies; Esil WMB; lake classification; climate trend; vorphometric characteristics of lakes; hydrochemistry of lakes; satellite imagery; climate change

Introduction

Small lakes in Kazakhstan represent an important element of the country's natural ecosystems, providing biodiversity and performing key ecological functions. Despite their relatively small size, these water bodies play a significant role in maintaining local ecosystems, serving as a habitat for numerous species of flora and fauna.

The study of lakes in Kazakhstan and quantitative assessment of the lake fund at different stages of research differed in breadth of coverage, detail and methodological approaches. Similar situation took place in studies of chemical composition and qualitative indicators of lake waters. Especially active work in the direction of studying the chemical composition of lake waters began in 1954-1955. The greatest attention was paid to lakes in the northern regions of the republic, including Kostanay, North Kazakhstan, Kokshetau, Akmola and Pavlodar oblasts. Studies in these regions were largely conditioned by the development of virgin and fallow lands, which required a deep understanding of the hydrological and ecological characteristics of lakes to ensure rational nature management [1-5].

In the period from 1955 to 1958, M.N. Tarasov carried out a detailed analysis of the hydrochemical regime of Lake Balkhash [6]. From 1965 to 1971, comprehensive studies were also conducted on the Alakol and Korgalzhyn lake systems, as well as lakes in the Karaganda region and a number of saline water bodies in Kazakhstan [7-10]. In the first half of the 1980s, more extensive studies on the assessment of the condition and quality of lakes, covering all regions of the country, began. These works became the basis for the creation of an extensive database including morphometric characteristics of lakes and chemical composition of their waters [10-12].

Materials and methods of research

There are more than 48 thousand lakes in Kazakhstan with a total water surface area of 45 002 km^2 and a volume of about 190 km^2 (13). Small lakes, the area of which does not exceed 1 km^2, account for 94% of the total number of water bodies. At the same time, large lakes with an area of more than 1 km^2 with a total surface area of 40,769 km^2 make up 90% of the total water bodies (11). More than 270 lakes have a water surface area of more than 10 km^2, 16 lakes have a water surface area of more than 100 km^2, and two lakes have an area of more than 2000 km^2, including Balkhash and Alakol.

The North Kazakhstan region has been studied for the presence of lake ecosystems and their potential for tourism development [13]. Researchers have used various methods, including field expeditions, landscape analysis and remote sensing, to assess the characteristics of lakes and their recreational potential [14, 15]. Using geographic information systems and technologies, comprehensive databases of lake parameters, including cartometric and morphometric indicators, have been created [16]. These studies have revealed spatial differentiation in the distribution of lakes, with factors such as transportation accessibility affecting tourism potential [13]. In Central Kazakhstan alone, there are 1,910 lakes with an area of 926 km^2 [17]. These studies contribute to the development of strategies for sustainable development and balanced resource management in lake-rich areas of Kazakhstan [14].

Research results

The study of small lakes is relevant in the context of climate change, anthropogenic impact and degradation of water resources. This article considers the features of small lakes in Kazakhstan, their morphometric and hydrochemical characteristics under the conditions of changing climate.

The morphometric characteristics of the lakes

Lake morphometry plays a critical role in the classification and understanding of water bodies. The shape and size of lake basins influence physical, chemical and biological dynamics [18]. G. Yu. Vereshchagin noted the significance of morphometric characteristics both for individual description of lakes and for their comparative analysis [19]. Various classifications based on water surface area, water volume, depth, shape of the basin and other features have been developed.

Lake classification systems based on morphometric characteristics have been developed for various regions including Argentina [20], Alaska [21], and Russia [22, 23]. Comprehensive inventories and assessments of lake distribution and morphometry have been conducted in British Columbia [24] and other regions. Understanding lake morphometry is essential for assessing ecological condition, managing water resources, and predicting responses to environmental change.

П. V. Ivanov in 1948 proposed a classification of lakes according to their mirror area [3], dividing them into seven classes, from "lakes" with an area of 0.001-0.01 km² to "the greatest lakes" with an area of more than 10,000 km². Another classification divides lakes into very small (less than 10 km²), small (10-50 km²), medium (50-250 km²), large (250-1000 km²) and largest (more than 1000 km²) [14]. Normative documents distinguish four categories by mirror area, similar to Ivanov's classification [15]. S.P. Kitaev divided lakes by average and maximum depth into several groups, ranging from very shallow to very deep water bodies [16]. Lakes are also classified according to bank dissection: strongly, weakly and slightly dissected [19].

Recent studies have improved our understanding of global lake abundance and size distribution. Earth's lakes show a stepped distribution for areas ≥0.46 km², with smaller lakes deviating from this pattern [26]. Global estimates suggest that there are 64-304 million lakes covering 3.8-4.6 million km² of the Earth's surface [27-29]. Although small lakes dominate numerically, they do not necessarily dominate in terms of total surface area [28]. Regional topography affects the distribution of lake sizes, with flatter regions showing a more consistent degree distribution [26]. Long-term studies have observed changes in lake number and area over time as influenced by factors such as precipitation and human activities [30, 31].

The basic morphometric characteristics of lakes, which determine their horizontal and vertical dissection, play a key role in assessing the impact of meteorological factors on the water surface. These characteristics also influence the redistribution of the main limnological indicators such as hydrological and hydrochemical parameters.

Morphometric data are important not only for individual analysis of lakes, but also for their comparative study, as they allow to determine the belonging of a water body to a specific type.

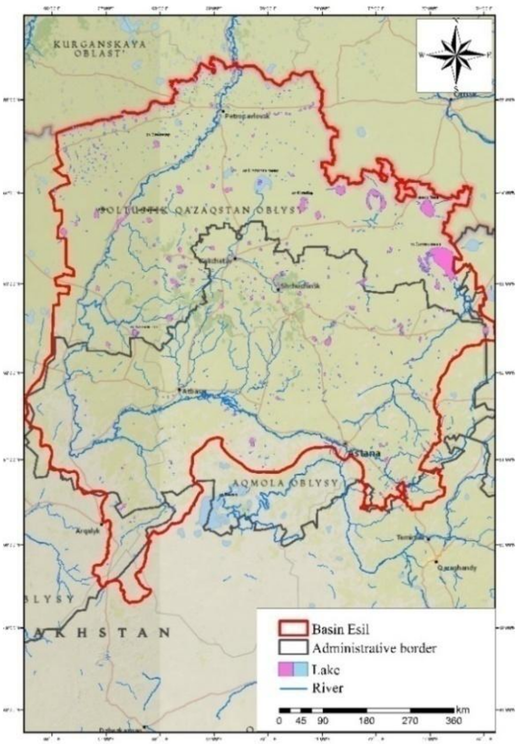

Figure 1 – Research area.

In this paper, small lakes in the Esil WMB were considered. The Esil River basin is described in several scientific articles [32-34], most of which are devoted to their influence on the formation and intra-annual distribution of river runoff, as well as the study of steppe lakes. The Esil water basin covers the territory of North Kazakhstan oblast, northern part of Akmola oblast and a small part of Karaganda oblast of Kazakhstan (Figure 1). This region is characterized by the presence of a large number of lakes, including both large water bodies and small steppe lakes.

The first stage was the identification of small lakes in the basin, which was carried out in two directions: updating the list of previously studied lakes based on interpretation results, as well as identification of previously unstudied small water bodies using multi-temporal remote sensing data and multi-scale cartographic materials. The lakes were identified by analyzing remote sensing data for different periods, visual study of water surfaces on images in different spectral combinations and their comparison with cartographic materials of different scales.

Table 1 presents data on the quantitative distribution of lakes and their gradation by areas [35].

Table 1 – Number of small lakes in the section of Esil WMB

Archival data	1360
Identified using remote sensing	651
Sum of water surface area, km^2	1479,8

Lake content, %	0,62

The key morphometric characteristics for the analysis were water surface area and depth. Lakes were classified by water surface area using the approaches of P. V. Ivanov and I. S. Zakharchenkov. It was found that most lakes (76.6%) are small, with an area of 1.0 to 5.0 km². Medium-sized lakes, with an area of 5.01 to 11.0 km², make up a smaller share – 23.4%. Thus, small lakes predominate in the overall distribution.

According to the data [35], in the Esil WMB, lakes with a small water volume (1.01-5.0 million m³) make up the majority – 61% of the total. Medium-sized lakes (5.01-10.0 million m³) are represented by 24.4%, and large and large lakes (with a volume of 10.01-20.0 and 20.01-100.0 million m³, respectively) make up 7.3% of each category. Very small lakes (less than 1.0 million m³) are absent and reservoirs with a small water volume predominate. Morphometric characteristics necessarily include the definition of averages as the ratio of volume to area and maximum depths. Most lakes (78%) have an average depth of less than 2.5 m, 19.5% - from 2.51 to 5 m, and only 2.4% reach a depth of 5.01-10 m. There are no lakes with a depth of more than 10 m.

The lakes are conventionally classified by the shape of the basin into three categories: round, oval and elongated, which reflects the diversity of their geometry and is associated with the formation features of reservoirs. Among the lakes of the Esil water management basin, 42.6% have a round shape (elongation coefficient less than 1.5), 21.3% are oval (1.5-2.0), and 36.2% are elongated (more than 2.0) [35].

To classify small lakes in the study region, a method based on the morphometric characteristics of reservoirs, such as depth, area and shape, was used. These parameters are the most important when studying both individual lakes and for conducting a comparative analysis between them. A comprehensive analysis of data collected from various meteorological, hydrological and ecological studies made it possible to classify lakes depending on their natural significance. The majority of the studied lakes are located at altitudes from 100 to 400 meters above sea level, which is typical for this region (Table 2).

Table 2 – Altitude distribution of lakes

Altitude	amount	% of total
0-100	28	5
100-200	341	58
200-300	84	14
300-400	107	18
400-500	23	4

The Hydrophysical and hydrochemical parameters of lakes

Hydrophysical and hydrochemical parameters of lakes are important indicators of the state of water bodies, affecting their ecosystem and resistance to external influences. Studies of these characteristics, such as water temperature, oxygen content, concentrations of dissolved substances and minerals, allow us to assess the quality of water, biological productivity and the process of enrichment of water bodies with nutrients. A comprehensive analysis of data on the physical and chemical properties of water is necessary for monitoring changes in aquatic ecosystems, predicting the impact of climate change and anthropogenic factors, as well as for developing effective methods for water resource management and ecosystem protection.

A study of the hydrophysical and hydrochemical parameters of lakes based on field data from the Institute of Geography and Water Security JSC revealed a significant diversity of their characteristics, reflecting the specifics of natural conditions and ecosystem processes. The depth of the studied reservoirs varied from 1 to 4 meters, and the transparency of the water was extremely low, reaching only 0.1-1.0 m. This indicates a high content of suspended particles of organic and mineral origin, as well as possible active development of phytoplankton, which is typical for shallow reservoirs in summer heating conditions. The water temperature in the studied lakes was 22.7-27.0 °C, indicating intense absorption of solar energy.

The chemical composition of the water also demonstrates the characteristic features of ecosystems with high biological activity. pH values varied within 8.0-8.6, indicating an alkaline reaction of the environment. The concentration of dissolved oxygen reached high values (up to 25 mg/dm^3), and the saturation of water with oxygen exceeds 270% (Lake Arykbalyk), which confirms intense photosynthesis caused by the activity of algae. This is also consistent with the virtually zero levels of carbon dioxide (CO_2), which is rapidly taken up by plant organisms under such conditions.

Hydrochemical analysis showed significant differences in the levels of total water hardness, which ranged from 4.40 to 68.00 mg-eq/dm^3. These differences reflect the diversity of geochemical conditions, such as the composition of bottom sediments and the sources of recharge of the lakes (groundwater or precipitation). Chemical oxygen demand (COD), which is in the range of 7.01-8.38 mg/dm^3, indicates a moderate content of organic matter in the water, which indicates an average trophic level of the reservoirs.

Thus, the studied field lakes are characterized by a combination of high biological activity and moderate organic pollution. Low water transparency, significant concentrations of dissolved oxygen and low CO_2 levels indicate an ongoing eutrophication process. At the same time, the chemical diversity of water indicates a complex geochemical structure of the studied systems. The data obtained can serve as a basis for monitoring changes in ecosystems exposed to anthropogenic and climatic impacts. A study of the ionic composition and mineralization of water in the region's lakes demonstrates a significant diversity of hydrochemical characteristics due to differences in natural, climatic and geological conditions. Water mineralization varies widely, reflecting different stages of hydrological and geochemical processes. The reservoirs range from slightly mineralized, such as Lake Arykbalyk, with a mineralization of 1077 mg/dm^3, to salt lakes, such as Gorky, where mineralization reaches 13.863 mg/dm^3.

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The chemical composition of the lakes' water emphasizes the differences in their hydrological nutrition and evaporation processes. For example, Lake Lobanovo, characterized by a mineralization of 1029 mg/dm³, belongs to the type of slightly mineralized waters. The main ions are $Na^{+}+K^{+}$ (247 mg/dm³) and HCO_3^- (286 mg/dm³), indicating a significant influence of freshwater nutrition. In contrast, Gorky Lake demonstrates a pronounced chloride-sodium type with a mineralization of 13.863 mg/dm³. The concentration of chlorides reaches 7520 mg/dm³, and $Na^{+}+K^{+}$ – 3945 mg/dm³, indicating intensive evaporation processes and salt accumulation.

Lake Baysary occupies an intermediate position with a mineralization of 1979 mg/dm³. Its chemical composition is characterized by a relatively high content of magnesium (99.7 mg/dm³) and chlorides (683 mg/dm³), which is typical for transitional conditions between freshwater and salt lakes. The water of Lake Arykbalyk, on the contrary, is characterized by lower mineralization (1077 mg/dm³) and a balanced content of ions, such as $Na^{+}+K^{+}$ (303 mg/dm³) and HCO_3 (280 mg/dm³), which may indicate a more active inflow of fresh water.

Water composition indices, such as ClNaII for Lakes Lobanovo and Baysary, as well as ClNaIII for Lake Gorkoye, indicate the predominance of chloride-sodium types of water under conditions of high mineralization. These data confirm that the formation of the chemical composition of lake water is associated with a complex interaction of factors, including mineral dissolution, evaporation, surface and underground runoff. The diversity of hydrochemical characteristics of water bodies reflects natural processes occurring in specific regional conditions and emphasizes their importance for assessing the ecological state and natural resources of lake systems.

Climatic conditions of the study region

To analyze temperature and precipitation fluctuations in the region, meteorological data provided by the Republican Hydrometeorological Fund of the RSE "Kazhydromet" for the period from 1961 to 2023 were used. The study includes data from the following meteorological stations: Blagoveshchenka, Yavlenka, Vozvyshenka, Timiryazevo, Saumalkol, Ruzayevka, as well as Kokshetau, SKFM Borovoe, Shchuchinsk, Akkol and Zhaltyr.

The analysis of the climatic conditions of the study area was carried out on the basis of observation data from meteorological stations using calculated linear trends and the least squares method. The graphs for each meteorological station present the results of a long-term analysis of average annual and summer temperatures, as well as annual precipitation (Figure 2, Figure 3).

Based on the data from the meteorological stations Blagoveshchenka, Yavlenka, Vozvyshenka, Timiryazevo, Saumalkol, Ruzayevka, Kokshetau, Shchuchinsk, Akkol, Zhaltyr for the period from 1961 to 2023, it was revealed that the linear trend indicates an increase in the average annual temperature. The temperature change over a decade shows the following results: 0.09ºC (Yavlenka), 0.12ºC (Shchuchinsk), 0.13ºC (Blagoveshchenka and Saumalkol), 0.15ºC (Ruzayevka and Zhaltyr), 0.16ºC (Akkol), 0.21ºC (Kokshetau), 0.23ºC (Timiryazevo), 0.30ºC (Vozvyshenka) per decade. There is also an increase in summer temperatures - by 0.014ºC Saumalkol, by 0.021ºC Akkol, by

0.024ºC Yavlenka and Vozvyshenka, by 0.037ºC Blagoveshchenka, by 0.043ºC Zhaltyr, by 0.048ºC Ruzayevka, by 0.053ºC Shchuchinsk, by 0.08ºC Kokshetau, by 0.09ºC Timiryazevo for the same period. According to the data of the SKFM Borovoe meteorological station for the period from 1982 to 2023, there is an increase in summer temperatures by 0.015ºC and the average annual temperature by 0.15ºC per decade.

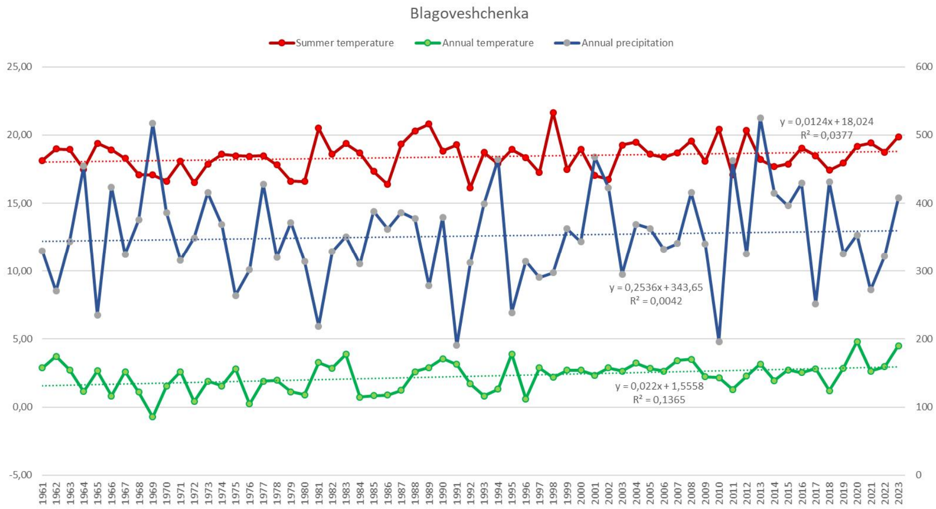

Figure 2 – Annual, summer temperature and annual precipitation at Meteo Station Blagoveshchenka

When analyzing data from the weather stations Yavlenka, Timiryazevo, Saumalkol, Ruzayevka, SKFM Borovoe, Shchuchinsk, Akkol and Zhaltyr, it was found that annual precipitation amounts vary greatly from year to year and the general trend indicates their increase. And at the weather stations Blagoveshchenka, Vozvyshenka, Kokshetau, annual precipitation amounts varied by year, the general trend remains relatively stable, without significant changes.

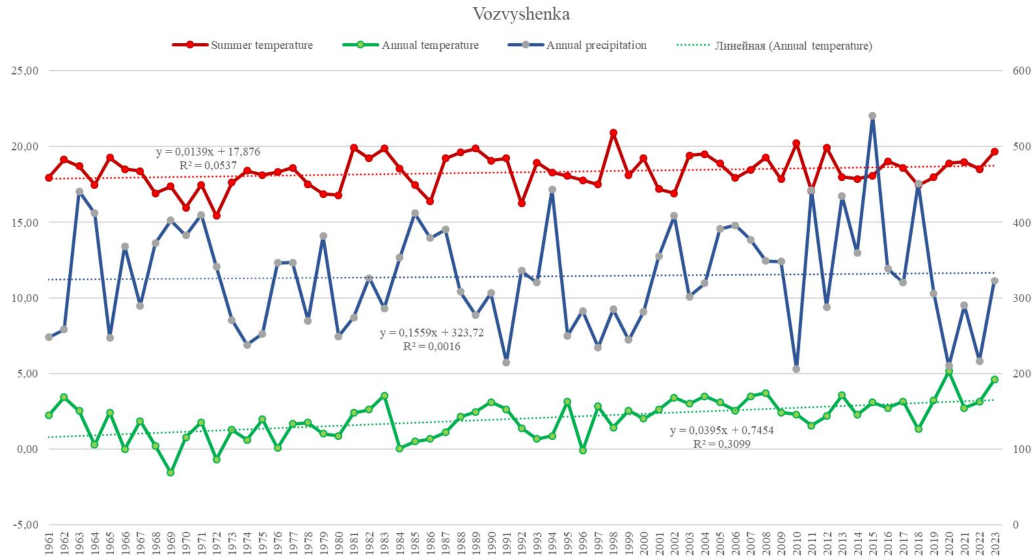

Figure 3 – Annual, summer temperature and annual precipitation at Meteo Station Vozvyshenka

In recent decades, the climate in Akmola and North Kazakhstan regions has undergone significant changes, primarily manifested in an increase in average temperatures by 1.5-2°C. This increase in temperature not only lengthens the growing season, but also changes the needs of agriculture, in particular increasing the need for irrigation in the summer. With temperatures reaching over 30°C in summer and extreme temperatures as low as -40°C in winter, agricultural practices become more susceptible to risks such as droughts and frosts, requiring adaptive technologies and land management practices.

Precipitation in these regions shows a pronounced seasonality, with the bulk of precipitation occurring in the summer. However, the increase in precipitation in recent years, especially in spring, has led to more frequent flooding and inundation. In North Kazakhstan region, there has been an increase in the intensity of spring rains, which, combined with snowmelt, contributes to increased flood risks. At the same time, in some areas, particularly those where winter precipitation decreases, this causes water shortages during the summer months when rainfall intensity decreases.

Winter precipitation, especially snow, plays a key role in replenishing water bodies, as it creates the necessary moisture and supplies the river and lakes with water in the winter and spring. Moisture, as well as snow cover, have a direct impact on the water level of water bodies. However, an increase in the intensity of winter precipitation, in particular more frequent and prolonged snowfalls, leads to an increase in snow cover, which in the spring, when the snow melts, can cause floods. This is especially dangerous for low-lying areas, where water cannot quickly go into the ground, creating a threat of flooding of agricultural lands and destruction of infrastructure.

Conclusion

The response to climate (low-snow winters, low-water years, etc.) is primarily noticeable on small lakes with small depths, especially in flat arid areas.

An increase in precipitation in the Akmola and North Kazakhstan regions does not always lead to an expansion of the area of lakes, despite the general trend towards an increase in their intensity. This is due to several factors that affect the hydrological cycle of the region. Precipitation mainly comes in the form of snow, which, although it has a large mass, does not always turn into liquid water quickly and effectively replenish reservoirs. Snow can remain on the surface for a long time, and, even with intense melting in the spring, if reservoirs cannot quickly discharge excess water or the soil is already saturated with moisture, the water can leave through outflows or evaporate, especially in the warm summer period.

In addition, climate change, such as shorter but more intense rainfall, means that water often flows into rivers and evaporates quickly, without having time to linger in lakes. Eutrophication, caused by intense rainfall, also worsens the quality of water bodies. At the same time, the leaching of nutrients such as nitrogen and phosphorus promotes the growth of algae, which can make it difficult to maintain lake ecosystems and reduce their area. It is also important to note the impact of human activity: the construction of reservoirs, the active use of water resources for irrigation, and the modification of natural waterways can reduce the level of lakes and disrupt the natural balance of water supply.

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REFERENCES

[1] Resursy poverkhnostnykh vod rayonov osvoyeniya tselinnykh i zalezhnykh zemel'. Akmolinskaya oblast' Kazakhskoy SSR [Surface water resources in areas of development of virgin and fallow lands. Akmola region of the Kazakh SSR]. Under the general editorship of V. A. Uryvaev. – L.: Gidrometeoizdat, 1958, vol. 1, – p. 790. (in Russian)

[2] Resursy poverkhnostnykh vod rayonov osvoyeniya tselinnykh i zalezhnykh zemel'. Kustanayskaya oblast' Kazakhskoy SSR [Surface water resources in areas of development of virgin and fallow lands. Kustanay region of the Kazakh SSR]. Under the general editorship of V. A. Uryvaev. – L.: Gidrometeoizdat, 1959, vol. 2, – p. 711. (in Russian)

[3] Resursy poverkhnostnykh vod rayonov osvoyeniya tselinnykh i zalezhnykh zemel'. Kokshetavskaya oblast' Kazakhskoy SSR [Surface water resources in areas of development of virgin and fallow lands. Kokshetau region of the Kazakh SSR]. Under the general editorship of V. A. Uryvaev. – L.: Gidrometeoizdat, 1959, vol. 3, – p. 563. (in Russian)

[4] Resursy poverkhnostnykh vod rayonov osvoyeniya tselinnykh i zalezhnykh zemel'. Pavlodarskaya oblast' Kazakhskoy SSR [Surface water resources in areas of development of virgin and fallow lands. Pavlodar region of the Kazakh SSR]. Under the

general editorship of V. A. Uryvaev. – L.: Gidrometeoizdat, 1959, vol. 4, – p. 577. (in Russian)

[5] Resursy poverkhnostnykh vod rayonov osvoyeniya tselinnykh i zalezhnykh zemel'. Severo-Kazakhstanskaya oblast' Kazakhskoy SSR [Surface water resources in areas of development of virgin and fallow lands. North Kazakhstan region of the Kazakh SSR]. Under the general editorship of V. A. Uryvaev. – L.: Gidrometeoizdat, 1960, vol. 5, – p. 419. (in Russian)

[6] Tarasov, M. N. Gidrohimija ozera Balkash [Hydrochemistry of Lake Balkash]. Publishing House of the USSR Academy of Sciences, 1961, p. 227. (in Russian)

[7] Kurdin, R. D. Gidrohimicheskij rezhim Alakol'skih ozer [Hydrochemical regime of the Alakol lakes] / R. D. Kurdin, L. S. Shilnikovskaya. Alakol depression and its lakes, 1965, p. 209-222. (in Russian)

[8] Amirgaliev, N. A., A. G. Dikanskaya, V. Ya. Dikansky. Gidrokhimicheskaya kharakteristika Kurgal'dzhinskoy sistemy ozer. [Hydrochemical characteristics of the Kurgaldzhin lake system]. Abstracts of the conference “Biological foundations of fisheries of the republics of Central Asia and Kazakhstan”. – Frunze: Publishing house “Ilim”, 1968. pp. 12-13. (in Russian)

[9] Amirgaliev N. A., Ya. Lopareva. Gidrokhimicheskaya kharakteristika poverkhnostnykh vod Karagandinskoy oblasti [Hydrochemical characteristics of surface waters of the Karaganda region]. Bulletin of the Academy of Sciences of the KazSSR, 1968, no. 12, pp. 56-61. (in Russian)

[10] Filonets, P.P., Omarov T.R. Ozera Tsentral'nogo i Yuzhnogo Kazakhstana [Lakes of Central and Southern Kazakhstan]. Alma-Ata, 1973, p.197. (in Russian)

[11] Omarov, T. R. Kazakhstan ozenderi men kolderi [Rivers and lakes of Kazakhstan] Alma-Ata, 1975, p. 85. (in Kazakh)

[12] Filonets, P.P., Omarov T.R. Ozery Severnogo, Zapadnogo i Vostochnogo Kazakhstana (Spravochnik) [Lakes of Northern, Western and Eastern Kazakhstan (Directory)] / P.P. Filonets. L.: Gidrometeoizdat, 1974, p. 137. (in Russian)

[13] Dmitriyev P. S., Fomin I. A., Nazarova T. V., Wendt J. A. Transport accessibility of the lake ecosystems in the North Kazakhstan region as a factor of tourism development. Geo Journal of Tourism and Geosites, 2021, vol. 35, no. 2, pp. 289-296, doi: 10.30892/GTG.35204-650

[14] Nazarova T. V., Fomin I. A., Dmitriyev P. S., Wendt J. A., Janaleyeva K. M. Landscape and limnological research of lake systems of the plain areas of the northeastern borderlands of the Republic of Kazakhstan and assessment of their recreational capacity, 2019, doi: 10.30892/gtg.25217-375

[15] Azbantayeva M. N., Sagynbayeva A. B., Sagatbayev Y. N., Pashkov S. V. Determination of the tourist position of lakes of Western and Central Kazakhstan by space survey. Geo Journal of Tourism and Geosites, 2022, vol. 45, pp. 1625-1632, doi:10.30892/gtg.454spl12-983

[16] Dmitriyev P. S. et al. Use of geoinformation technologies in the study of cartometric and morphometric characteristics of lakes in the North Kazakhstan, doi: 10.35595/2414-9179-2022-2-28-719-736

[17] Abuduwaili J., Issanova G., Saparov G. Lakes in the Central Kazakhstan. In: Hydrology and Limnology of Central Asia. Water Resources Development and Management. Springer, 2019, pp. 177-197, doi: 10.1007/978-981-13-0929-8_4

[18] Alcocer J., Oseguera L. A., Sanchez G., Gonzalez C. G., Martinez J. R., Gonzalez R. Bathymetric and morphometric surveys of the Montebello Lakes, Chiapas. Journal of limnology, 2016, vol. 75, doi:10.4081/JLIMNOL.2016.1343

[19] Vereshchagin, G. Yu. Metody morfometricheskoy kharakteristiki ozer [Methods for morphometric characteristics of lakes]. Proceedings of the Olonets scientific expedition, 1930, vol. 2, no. 1, p. 3. (in Russian)

[20] Bohn V. Y., Perillo G. M. E., Piccolo M. C. Distribution and morphometry of shallow lakes in a temperate zone (Buenos Aires Province, Argentina). Limnetica, 2011, vol. 30, no. 1, pp. 0089-102, doi: 10.23818/limn.30.08

[21] Hinkel K. M., Frohn R. C., Nelson F. E., Eisner W. R., Beck R. A. Morphometric and spatial analysis of thaw lakes and drained thaw lake basins in the western Arctic Coastal Plain, Alaska. Permafrost and Periglacial Processes., 2005, vol. 16, no. 4. pp. 327-341, doi: 10.1002/ppp.532

[22] Astashin A. Nikolaeva,E., Bayanov N., Badin M. Morphometric characteristics of lake bottoms of Lakes CHarskoe and Nuksenskoe (Volga upland, Russia) as the basis of their classification. E3S Web of Conferences, 2023, vol. 431, pp. 04004, doi: 10.1051/e3sconf/202343104004

[23] Potakhin M. S., Belkina N. A., Subetto D. A. The Lake Onego watershed: morphology of lakes and classification of the bottom sediments. Limnology and Freshwater Biology, 2022, pp. 1526-1528, doi: 10.31951/2658-3518-2022-a-4-1526

[24] Schiefer E., Klinkenberg B. The distribution and morphometry of lakes and reservoirs in British Columbia: a provincial inventory. Canadian Geographer/Le Géographe canadien, 2004, vol. 48, no. 3, pp. 345-355, doi: 10.1111/J.0008-3658.2004.00064.X

[25] Cael B. B., Seekell D. A. The size-distribution of Earth’s lakes. Scientific reports, 2016, vol. 6, no. 1, p. 29633, doi: 10.1038/srep29633

[26] Seekell D. A., Pace M. L., Tranvik L. J., Verpoorter C. A fractal-based approach to lake size-distributions. Geophysical Research Letters, 2013, vol. 40, no. 3, pp. 517-521, doi: 10.1002/grl.50139

[27] Downing J. A., Prairie Y. T., Cole J. J., Duarte C. M., Tranvik L. J., Striegl R. G., Middelburg J. J. The global abundance and size distribution of lakes, ponds, and impoundments. Limnology and oceanography, 2006, vol. 51, no. 5, pp. 2388-2397, doi: 10.4319/lo.2006.51.5.2388

[28] McDonald C. P., Rover J. A., Stets E. G., Striegl R. G. The regional abundance and size distribution of lakes and reservoirs in the United States and implications for estimates of global lake extent. Limnology and Oceanography, 2012, vol. 57, no. 2, pp. 597-606, doi: 10.4319/lo.2012.57.2.0597

[29] Verpoorter C., Kutser T., Seekell D. A., Tranvik L. J. A global inventory of lakes based on high-resolution satellite imagery. Geophysical Research Letters, 2014, vol. 41, no. 18, pp. 6396-6402, doi: 10.1002/2014GL060641

[30] Pshenichnikov A. E. Primenenie dannyh distancionnogo zondirovanija dlja izuchenija dinamiki ploshhadi i kolichestva ozer juga Tjumenskoj oblasti [Application

of remote sensing data to study the dynamics of the area and quantity of lakes south of the Tyumen region]. Geodesy and Cartography, 2018, vol. 935, no. 5, pp. 45-53 (in Russian), doi: 10.22389/0016-7126-2018-935-5-45-53

[31] Kubiak-Wójcicka K., Piątkowski K., Juśkiewicz W. W. Lake surface changes of the Osa River catchment,(northern Poland), 1900–2010. Journal of Maps, 2021, vol. 17, no. 2, pp. 18-29, doi: 10.1080/17445647.2020.1857856

[32] Moldakhmetov M. M. Tobıl özeniniñ ağındısına adamnıñ şarwaşılıq is-äreketiniñ tïgizetin äserin bağalaw [Assessment of the impact of human economic activities on the flow of the Tobyl]. Bulletin of the Geography Series, 2007. (in Kazakh)

[33] Moldakhmetov M. M., Makhmudova L. K. Esil jäne Tobıl özenderiniñ jıldıq ağındı ülestirimine bögenderdiñ tïgizetin ıqpalı jöninde [On the impact of dams on the annual flow distribution of the Yesil and Tobyl rivers], 2008. (in Kazakh)

[34] Iskaliyeva G.M., Sydyk N.K., Kalybayeva A.K., Sagat M.S, Samat A. Use of water indices for waterbodies in the esil water management basin. News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences, 2024, vol. 4, pp. 117-130, doi: 10.32014/2024.2518-170X.429

[35] Razrabotka pasportov malykh ozer Kazakhstana: otchet (promezhutochnyy) [Development of passports for small lakes in Kazakhstan: report (interim)]. JSC “Institute of Geography and Water Security”: director. Medeu A.R.; executor: Medeu A.R., et al. Almaty, 2021, p. 583. (in Russian)

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СОВРЕМЕННОЕ СОСТОЯНИЕ МАЛЫХ ОЗЕР ПО АРХИВНЫМ И АЭРОКОСМИЧЕСКИМ ДАННЫМ

Аннотация. Статья представляет собой обзор исследований морфометрических, гидрохимических и экологических характеристик малых озёр, включая их классификацию, природное разнообразие и значимость в условиях изменяющегося климата.

Малые озера являются важным компонентом экосистем страны, играя ключевую роль в поддержании биологического разнообразия и выполнения экологических функций. Целью данного исследования является изучение морфометрических и гидрохимических характеристик малых озер Есильского водохозяйственного бассейна, их классификация и оценка экологического состояния в условиях изменяющегося климата.

Работа имеет значительную научную и практическую значимость: собранные данные позволяют оценить влияние антропогенных и природных факторов на экосистемы водоемов, что важно для их рационального использования и охраны. Методология исследования включала анализ данных дистанционного зондирования Земли, полевые наблюдения, гидрофизические и гидрохимические замеры, а также классификацию озер по морфометрическим характеристикам.

Результаты показали, что большинство малых озер бассейна имеют небольшую площадь и глубину, низкую прозрачность воды и умеренный уровень минерализации, отражающий влияние как пресноводного питания, так и процессов испарения. Химические анализы выявили значительные различия в составе воды, что связано с геологическими и климатическими условиями

региона. Озера, находящиеся на высоте 100-400 м, имеют высокую биологическую активность, что подтверждается высоким содержанием кислорода и низким уровнем CO_2.

Ценность исследования заключается в создании базы данных морфометрических и гидрохимических характеристик, позволяющей проводить мониторинг изменений в водных экосистемах. Практическое значение работы связано с разработкой стратегий устойчивого природопользования и управления водными ресурсами в условиях климатических изменений.

Ключевые слова: Дистанционное зондирование Земли; малые озёра; ГИС-технологии; Есильский ВХБ; классификация озёр; климатический тренд; морфометрические характеристики озер; гидрохимия озер; спутниковые снимки; изменение климата.

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АРХИВТІК ЖӘНЕ АЭРОҒАРЫШТЫҚ ДЕРЕКТЕР БОЙЫНША ШАҒЫН КӨЛДЕРДІҢ ҚАЗІРГІ ЖАҒДАЙЫ

Аңдатпа. Бұл мақала шағын көлдерінің морфометриялық, гидрохимиялық және экологиялық сипаттамалары бойынша зерттеулерге шолу жасайды, олардың классификациясы, табиғи әртүрлілігі және климаттың өзгеруі жағдайындағы маңыздылығы қарастырылады.

Зерттелетін аумақтың шағын көлдері елдің экожүйесінің маңызды бөлігі болып табылады, олар биологиялық әртүрлілікті сақтауда және экологиялық функцияларды орындауда шешуші рөл атқарады.

Осы зерттеудің мақсаты – Есіл су шаруашылығы бассейніндегі шағын көлдердің морфометриялық және гидрохимиялық сипаттамаларын зерттеу, оларды классификациялау және климаттың өзгеруі жағдайында экологиялық жағдайды бағалау.

Жұмыстың ғылыми және практикалық маңызы зор: жинақталған деректер су айдындары экожүйелеріне антропогендік және табиғи факторлардың әсерін бағалауға мүмкіндік береді, бұл оларды тиімді пайдалану мен қорғау үшін маңызды.

Зерттеу әдістемесіне Жерді қашықтықтан зондтау деректерін талдау, далалық бақылаулар, гидрофизикалық және гидрохимиялық өлшеулер, сондай-ақ көлдерді морфометриялық сипаттамалары бойынша классификациялау кірді.

Нәтижелер бассейндегі шағын көлдердің көпшілігі шағын ауданы мен таяз тереңдігімен, судың төмен мөлдірлігімен және булану процестерін де, тұщы су қоректенуін де көрсететін минералданудың орташа деңгейімен ерекшеленетінін көрсетті. Химиялық талдаулар судың құрамындағы айтарлықтай айырмашылықтарды анықтады, бұл аймақтың геологиялық және климаттық жағдайларымен байланысты. 100-400 метр биіктікте орналасқан көлдер жоғары биологиялық белсенділікке ие, бұл оттегінің жоғары мөлшерімен және CO_2 деңгейінің төмендігімен дәлелденеді.

Зерттеудің құндылығы – су экожүйелеріндегі өзгерістерді бақылауға мүмкіндік беретін морфометриялық және гидрохимиялық сипаттамалардың деректер базасын құруда. Жұмыстың практикалық маңызы климаттық өзгерістер

жағдайында табиғатты тұрақты пайдалануды және су ресурстарын басқару стратегияларын әзірлеумен байланысты.

Кілт сөздер: Жерді қашықтықтан зондтау; шағын көлдер; ГАЖ технологиялары; Есіл су шаруашылық бассейні; көлдерді классификациялау; климаттық тренд; көлдердің морфометриялық сипаттамасы; көлдердің гидрохимиясы; спутниктік суреттер; климаттың өзгеруі.