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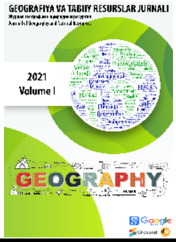

MAIN STAGES OF FORMATION AND TROPHIC STATUS OF THE AIDAR-ARNASAY LAKE SYSTEM

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ABOUT ARTICLE

Key words: Chardara Reservoir, collector-drainage waters, Central Golodnaya Steppe Collector (CGSC), mineralization, precipitation, water balance, chemical analysis, relative humidity, fisheries.

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Abstract: The article discusses the formation features of the Aydar-Arnasoy lake system, located in the middle part of the Sir Darya River basin. It is established that the system was formed in the 1960s–1970s as a result of the gradual accumulation of saline waters coming from the Mirzachul (Golodnaya Steppe) irrigated area in Uzbekistan. The first stage of the system's formation is associated with the creation of Lake Tuzkon. The second stage is linked to the breach of the Chardara Reservoir dam in 1969, which led to the flooding of vast lowland areas previously characterized by semi-desert landscapes and the merging of Lake Tuzkon with the newly formed water body. The lake system belongs to the category of anthropogenic water bodies, whose hydrological and ecological characteristics remain poorly studied. Based on the analysis of published works, field observations, and research, the current morphometric characteristics, features of changes in water pollution levels by individual components, as well as overall pollution indicators, which directly affect the formation and variability of ecological conditions in the lake system's water area, have been determined. These factors directly impact the formation and variability of ecological conditions, including the trophic status, within the lake system.

АЙДАР-АРНАСОЙ КЎЛЛАР ТИЗИМИНИНГ ШАКЛЛАНИШ БОСҚИЧЛАРИ ВА ТРОФИК ҲОЛАТИ

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МАҚОЛА ҲАҚИДА

Калит сўзлар: Чордарин сув омбори, коллектор-дренаж сувлари, ЦГК, минерализация, чўкинишлар, сув баланси, кимёвий таҳлил, нисбий намлик, балиқ хўжалиги.

Аннотация: Мақолада Сырдарё ҳавзасининг ўрта қисмида жойлашган Айдар-Арнасой кўл тизимининг шаклланиш хусусиятлари кўриб чиқилган. Ушбу тизим 1960–1970-йилларда Ўзбекистон Республикаси ҳудудидаги Мирзачўл (Ғолодностеп) суғориладиган массивларидан оқиб келган шўр сувларнинг аста-секин тўпланиши натижасида юзага келгани кўрсатилган. Бу жараён дастлаб Тузкон кўлининг шаклланиши орқали, яъни кўл тизимининг биринчи босқичида намоён бўлган. 1969-йилда Чордара сув омбори тўғонинг ёрилиши ва илгари ярим чўл ландшафтларига хос бўлган пасттекисликларнинг сув остида қолиши, шунингдек, Тузкон кўлининг янги ҳосил бўлган сув ҳавзаси билан қўшилиши натижасида морфометрик хусусиятлар, сув-туз режими ва экологик шароитларнинг нисбатан барқарорлашуви юз берган. Бу эса кўл тизими шаклланишининг иккинчи босқичига тегишлидир. Тадқиқотда ушбу кўл тизими антропоген омиллар таъсирида янгидан пайдо бўлган сув объектлари тоифасига мансублиги, унинг гидрологик-экологик хусусиятлари ҳанузгача етарлича ўрганилмаганлиги аниқланган. Нашр этилган ишлар таҳлили, муаллифларнинг дала кузатувлари ва изланишлари асосида ҳозирги даврдаги морфометрик кўрсаткичлар, сув таркибида айрим ифлослантирувчи моддаларнинг ўзгариш тенденциялари, умумий ифлосланиш даражаси аниқланган. Улар экологик шароитлар, хусусан, кўл тизимидаги трофик ҳолатнинг шаклланиши ва ўзгарувчанлигига бевосита таъсир кўрсатади.

ОСНОВНЫЕ ЭТАПЫ ФОРМИРОВАНИЯ И ТРОФИЧЕСКИЙ СТАТУС АЙДАР-АРНАСАЙСКОЙ СИСТЕМЫ ОЗЕР

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О СТАТЬЕ

Ключевые слова: Чардаринское водохранилище, коллекторно-дренажные воды, ЦГК, минерализация, осадки, водный баланс, химический анализ, относительная влажность, рыбное хозяйство.

Аннотация: В статье рассмотрены особенности возникновения Айдар-Арнасайской озерной системы, расположенной в пределах средней части бассейна р. Сырдарья. Показано то, что оно образовалось в 60-х --70-х гг. ХХв. в результате постепенного накопления соленых вод, поступающих с территории Мирзачульского (Голодностепского) орошаемого массива в пределах Республики Узбекистан. Это проявилось в виде формирования оз. Тузкан в составе первого этапа возникновения озерной системы. Формирование относительно стабильных морфометрических характеристик, водно-солевого режима и экологических условий произошло в результате прорыва дамбы Чардаринского водохранилища в 1969 г. и затопления обширных пространств низин, ранее представленных типичными ландшафтами полупустынь, а также слияния оз. Тузкан с вновь образовавшимся водоемом. Этот процесс следует отнести к второму этапу образования озерной системы. Выявлено то, что изучаемая озерная система относится к категории вновь сформировавшихся водных объектов антропогенного происхождения, гидролого-экологические характеристики которой до сих пор слабо изучены. На основании изучения и общения опубликованных работ, проведения собственных полевых наблюдений и изысканий определены современные морфометрические характеристики, особенности изменения показателей загрязненности воды отдельными ингредиентами, а также суммарные показатели загрязненности, которые оказывают непосредственное воздействие на формирование и изменчивость экологических условий, в том числе и трофического статуса в озерной системе.

Introduction. The Aydar-Arnasoy Lake System (AALS) belongs to the category of anthropogenic water bodies. The characteristics of the influence of external factors related to the basin (watershed), as well as intra-water body processes formed under the conditions of active human economic activity, play a key role in the hydro-ecological processes occurring in the studied water body. It should be noted that the process of forming this lake system is influenced by a number of factors, primarily related to the irrational use of water resources in the Sir Darya River basin within its middle course. Overall, the lake system initially included three relatively isolated bodies of water, which are named: Tuzkon, Arnasoy, Aydarkul. From the perspective of assessing potential changes in hydro-ecological conditions within the established lake system, as well as justifying possible options for the rational use and protection of water resources, it has been shown that the systematization of retrospective and contemporary information on water use in the basin of the specified lake system, the chemical composition of lake waters, and the justification of the types and scales of prospective development of economic facilities, taking into account the need to ensure favorable hydro-ecological conditions, is of great importance.

Statement of the problem. Based on the study, generalization, and analysis of published and archival materials, it has been identified that due to the recent origin of the lake system as a result of anthropogenic factors, it is currently possible to clearly identify the established morphometric characteristics, the role of collector waters coming from irrigated areas in the formation of water balance components, the salinity regime, as well as hydrochemical characteristics that change over time. From the perspective of addressing issues related to the assessment of the potential use of the lake system for solving economic tasks, recreation, tourism, etc., it should be noted that, in the future, certain characteristics remain poorly studied, such as comprehensive indicators of lake water pollution, the peculiarities of the formation and variability of ecological conditions (including trophic status), methods of managing water management complexes and systems within the basin while considering the need to preserve favorable hydro-ecological characteristics, and the justification of optimal parameters for its use in the future under changing climate conditions, among others.

As part of the main methods adopted by the authors during the course of this study, it is necessary to include methods of comparative analysis, statistical processing of long-term information, as well as graphical and cartographic representation of materials to identify the dynamics of ongoing changes.

The main (first) stage in the formation of a complex lake system can be considered the initial emergence of flooded areas and the formation of water bodies with the establishment of a lake regime as a result of regular inflow of collector waters. This phase is related to the development of the Mirzachul steppe in the 1960s and 1970s of the 20th century. A characteristic feature is that a surface (rather primitive) irrigation system was organized here, including river runoff diversion channels, a network of distribution canals, and drainage and irrigation furrows, followed by the placement of a drainage system and collectors to prevent soil salinization and waterlogging processes. In these conditions, the withdrawal and use of a large amount of freshwater from the Sir Darya River led to the infiltration of irrigation water to the groundwater level and a subsequent rise in their level and evaporation, which contributed to the formation of anthropogenically altered (secondary) landscapes in the form of marshy, saline areas, and others. The diversion of drainage waters in large quantities contributed to their accumulation in previously undeveloped lowlands, forming a characteristic hydrographic network, including the Tuzkon and Arnasoy lakes.

The second stage of the lake system's development is associated with the breach of the Chardara Reservoir dam during the flood in 1969, which led to the flooding of a vast area occupied by solonchaks and shors. As a result, the waters of the previously formed Arnasoy and Tuzkon lakes merged with the fresh waters coming from the Chardara Reservoir, leading to the formation of a common water body that constitutes the Aydar-Arnasoy lake system.

Overall, the formation of relatively stable parameters, including morphometric and water balance characteristics of the lake system, was completed by the 1970s-1980s of the 20th century. The characteristics of functioning, changes in hydrochemical indicators, and environmental conditions within the specified lake formations since the 1990s and up to the present are primarily determined by the specifics of water management activities within the irrigated areas and the operation of the Chardara Reservoir, as well as the influence of factors related to climate change. The characteristic features of the location of the newly formed water bodies are shown in Fig. 1.

Fig. 1. Formation of Lake Tuzkon (1968 without the influence of the Chardara Reservoir).

It should be noted that the water exchange processes in the specified system of lakes changed after the commissioning of the "Arnasoy" water redistribution facility with a capacity of 2100 m³/s in 1965. This ensured a regular water supply to the system. In years of abundant precipitation, the Syr Darya River overflowed, and excess winter season water accumulated in the Chardara Reservoir. Due to the limited capacity of the river, settlements in its lower reaches, especially the city of Kyzylorda in Kazakhstan, were at risk of flooding. To prevent a disaster, officials released 21 km³ of water (almost 60% of the average annual flow of the Sir Darya) from the Chardarya Reservoir into the Arnasai lowland. As a result, the Arnasoy lowland, currently representing the northeastern part of the AASO, filled with water and merged with Lake Tuzkan. Thus, a single lake system was formed, extending over an area of 2400 km² (Fig. 2).

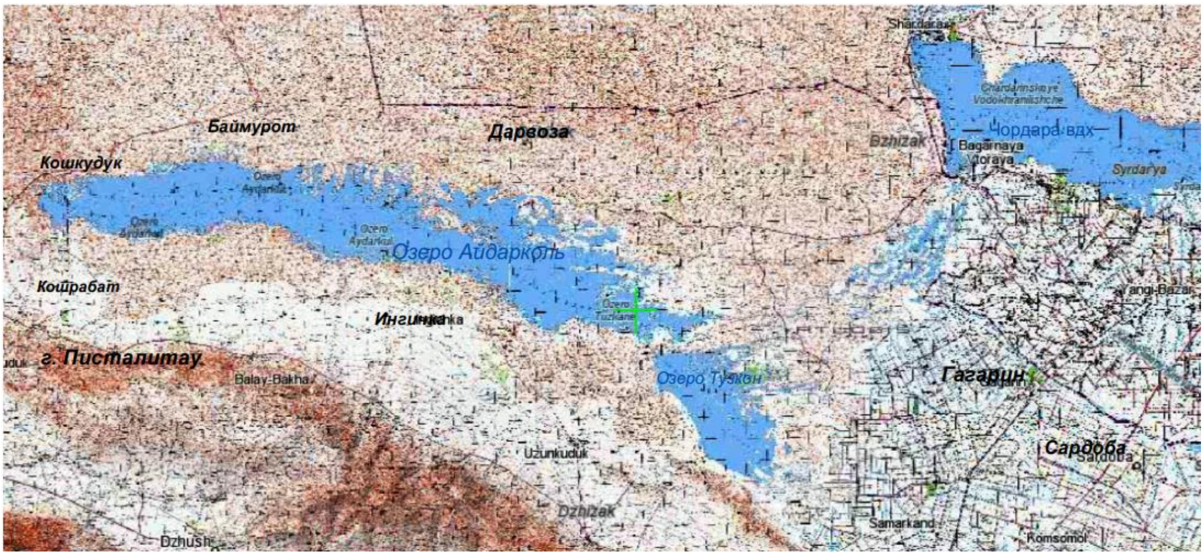

Figure 2. Map – scheme of the AASO after the breach of the Chardara Reservoir

Within the specified lake system, Lake Tuzkon is located in the southern part, bordered by the Nurota Range to the south and the Kizilkum Desert to the north. This is a shallow water body with a significant area, combined with depressions of 2-5 meters deep and marshy areas. The maximum depth of the lake is 7-11 meters, and its area is 320 km².

O Lake Aydarkul is the largest water body in the system within the Kizilkum. Its depth is determined by the relief forms against the backdrop of relatively flat lowlands and hilly terrain.

Since the lake is enclosed on all sides, the water is highly mineralized due to the large surface area and intense evaporation. The lake's elevation above sea level is 237 meters, its length is 145 km, and its maximum width is 12 km in the eastern part and 9 km in the western part. The maximum depth reaches 18 meters in the east and 25 meters in the west. A distinctive feature of Lake Aydarkul is the complex combination of islands, capes, bays, and dunes that occupy part of the coastal zone with a width of 1-5 km.

The Arnasoy Lakes are located on a higher watershed compared to the Aydarkul and Tuzkon Lakes. The elevation difference from the Chardara Reservoir to Aydarkol is about 8 meters. The main changes in the hydrographic network occurred in 1969, when the inflow of water from the mentioned reservoir reached up to 2000 m^3/s. As a result of the water overflowing the dam, most of the lake and the separate valleys merged, forming a single water body. Similar changes occurred in 1993-1998 during the subsequent floods.

From 2001 to 2005, the Arnasoy Reservoir was constructed, and the Central Golodnostepsky Collector was redirected to Lake Tuzkon. It is intended for the intra-annual redistribution of runoff. Its main task is to increase the water supply for irrigated lands covering an area of 60.4 thousand hectares in the Jizzakh region and to protect pastures and irrigated lands from flooding in the Arnasoy depression zone. The main parameters of the reservoir were determined based on topographical conditions and the results of water balance calculations, which provide water to 60.4 thousand hectares of irrigated land in the Jizzakh region.

It should be noted that the morphometric characteristics and hydrological regime of the studied lake system have changed repeatedly. Thus, this was observed in 1993, when the operation of the Toxtagul Reservoir, located in the upper reaches of the Sir Darya, as well as the restoration of water flow from the Chardara Reservoir to the basin of the Aydar-Arnasoy Lake System (AALS), led to significant changes. This alteration was due to the reduced water-carrying capacity of the Sir Darya River, especially during freezing periods. Subsequently, the transition of water management in the Sir Darya basin from irrigation to energy, as well as the lack of regulation of the amount of water coming from the Toxtagul, Kayrakum, Chardara, and Norin reservoirs, significantly affected the water balance of the AASO. Since 1993, as a result of water discharges from the Chardara Reservoir, the water level began to rise and reached 246 meters by 2005. In 2004, due to large-scale discharges from the Chardara Reservoir, 180 thousand hectares of land were flooded in the Jizzakh and Navoi regions of Uzbekistan. During this period, the main parameters of the AASO were formed.

In the following years, collector-drainage waters continued to flow into the lake system, but the volume of water discharged from the Chardara Reservoir began to decrease. For example, in

1994, a record amount of water—9285.8 million m³—was released through the Chardara Reservoir, whereas in certain years (for instance, in 2013 and 2020), no releases were made at all.

The total volume of water entering the AASO over these years has significantly increased, reaching a maximum value in 2006—42.1 billion m³. The dynamics of changes in water inflow volumes into the lake system are reflected in Fig. 4. It is revealed that over the long term (from 1993 to 2024), since 2006, there has been a consistent increase in the inflow of collector waters with a corresponding decrease in the discharge of water from the Chardara Reservoir (Fig. 3).

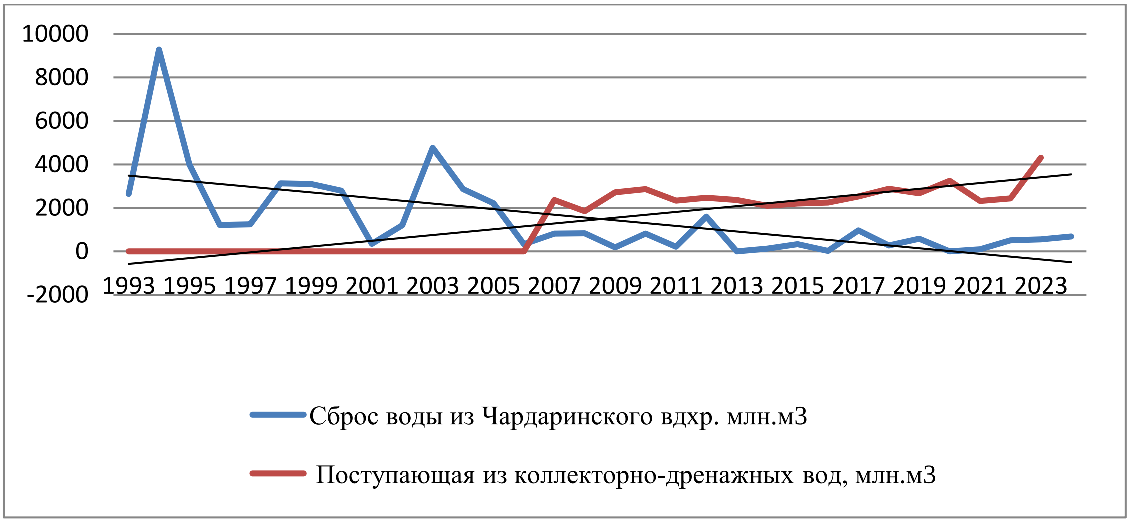

Figure 3. Long-term dynamics of changes in water inflow to the AASO from the Chardaryn Reservoir and collector-drainage waters. million m³. 3

Thus, during this period, the contribution of collector-drainage waters to the filling of the lake system increased, which is associated with high levels of water resource use for irrigating agricultural lands. As a result of the total inflow of collector drainage waters and releases from the Chardara Reservoir, the formation of water volume in the lake system occurred under conditions of slight changes over time. At the same time, starting from 2006, a slight decrease in volume and a drop in water levels have been observed, mainly due to the reduction in the volumes of releases from the Chardara Reservoir (Fig. 4).

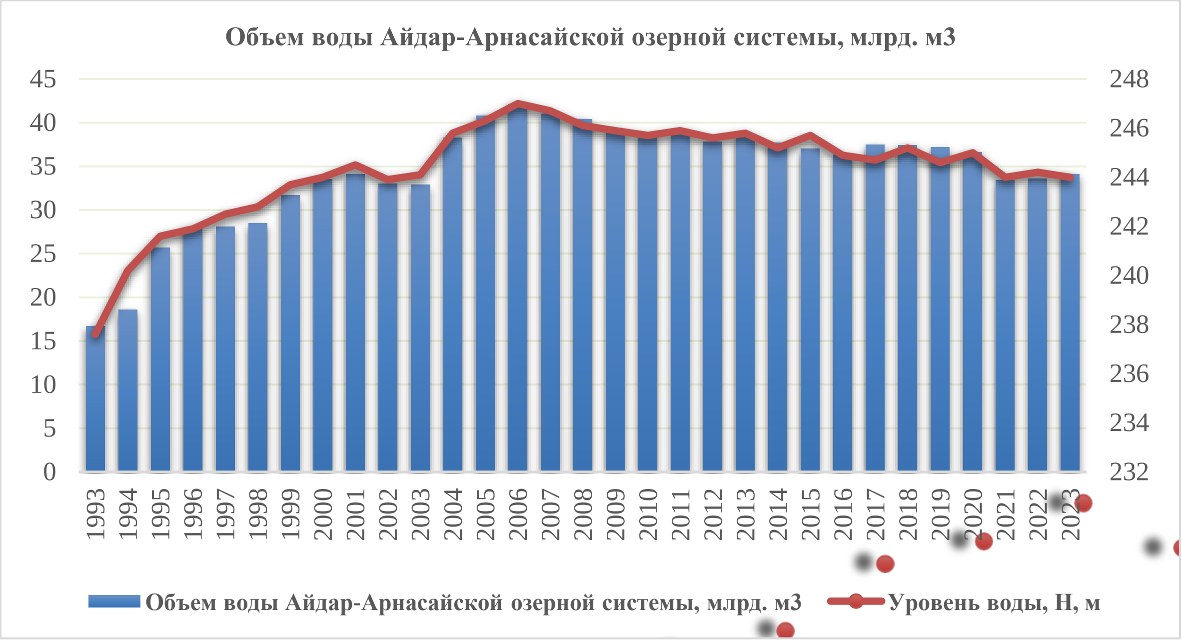

Fig. 4. Dynamics of changes in volume and water levels in the AASO

Based on the results of the conducted analysis, during this period, the water volume in the AASO fluctuated between 16.7 and 34.1 km³, the area ranged from 2,045 to 3,224 thousand km², and the water level varied from 237.5 to 244.7 meters. The highest indicators were recorded in 2006: the water volume reached 42.1 km³, the water surface area increased to 3599 km², and the water level was 247 m above sea level.

Thus, it should be noted that since 2006, the Aydar-Arnasoy lake system has entered a regressive phase of development, which contributes to the deterioration of the ecological situation of the entire water system and the surrounding areas. Over 15 years, the water level in the lake system has decreased by 3.12 meters.

Against the backdrop of long-term changes in water levels in the reservoir, there are intra-annual fluctuations associated with the redistribution of inflow-outflow components of its water balance. Thus, during the period from 2005 to 2021, the amplitude of the level fluctuations varied from 0.56 to 1.17 m. In the annual course of the water level, there is a rise during the winter-spring period and a decline during the summer-autumn period. Maximum levels are usually observed in May, while minimum levels are noted from November-December. Overall, in the comparison between 1970 and 2023, it can be observed that there has been a change in morphometric characteristics toward an increase, as reflected in Table 1.

Table 1. Morphometric characteristics of the Aydar-Arnasoy lake system

№	Morphometric indicators	1970 y*	2023 y**	Differences in indicators
1	Water level, H, м	237,1	243,0	5,9
2	Surface area of water,F, км^2	2300	3702	1402
3	Volume of water, W, км^3	19,94	34,19	14,25
4	Length, L, км	155	190	35

5	Maximum width, B_{Max}, kм	33	40	7
6	Average width, B_{aver},kм	15	19	4
7	Maximum depth, h_{Max}, м	22	26	4
8	Average depth, h_{aver}, м	8,6	9,2	0,6

Note: *N.E. Gorelkin and A.M. Based on Nikitin's data (1976)* *Based on satellite images (Google Earth Pro) and data from the Aydar-Arnasoy Lakes Administration (2023).*

It should be noted that the increase in the inflow of saline collector waters and the decrease in water discharge from the Chardara Reservoir have contributed to a significant change in hydrochemical indicators, which is reflected in the increase in water mineralization and salinity, as well as the overall pollution indicators of lake waters, which has certain ecological consequences.

It is noteworthy that collector-drainage waters form the main part of the inflow component of the water balance of the AASO. According to various estimates, their volume amounts to 1.8-2.5 km³ per year. From 1993 to 2002, the average salinity level of the collector waters was estimated at 4.3 g/l, with annual fluctuations ranging from 2.6 to 6.5 g/l. At the same time, the total amount of incoming substances reached up to 10.2 million tons per year. Moreover, it is necessary to take into account the inflow of a certain amount of salts in the form of atmospheric precipitation, from the surface of adjacent salt marshes, and groundwater, the salinity of which reaches up to 16 g/l. On average, the mineralization of groundwater in the areas adjacent to the AASO is estimated at 5.2 g/l, and their annual contribution to the salt balance of the lake is 200,000 tons. Thus, relatively high concentrations of pollutants are forming in the lake water for several ingredients. In their composition, it is necessary to note the presence of chlorides, sulfates, magnesium, sodium, calcium, ammonium nitrogen, copper, lead, and fluorine. At the same time, low levels of BOD5 are detected. The water transparency ranges from 1.1 to 1.8. Based on the comparison of water quality in different parts of the lake system, it can be observed that the water in the Arnasoy Reservoir has better indicators, which is mainly due to the inflow of freshwater releases from the Chardara Reservoir, currently located within Kazakhstan.

As is well known, Uzbekistan belongs to the category of countries that emerged after the collapse of the USSR. Accordingly, in the field of water management activities and water protection measures, many commonalities have been preserved, which are also characteristic of the territory of the Russian Federation. The scale of the impact of economic activities on the quality of natural waters is regulated based on the requirements of the fundamentals of water legislation.

All chemical substances that harm human health, sanitary conditions, and fish productivity of water bodies are divided into groups according to the so-called limiting harmfulness criterion (LHC). In the hygienic regulation of water quality, three groups of pollutants are distinguished: 1) substances with sanitary-toxicological action, which have a direct impact on public health (toxic substances, disease-causing agents, pesticides, etc.); 2) substances with general sanitary action, which adversely affect the overall sanitary regime of water bodies (oxidizable organic substances, active chlorine, etc.); 3) substances with organoleptic action, which impart taste, odor, and color to water (iron, manganese, phenol, oil, etc.). In fishery regulation, two additional groups of substances are identified: toxicological and fishery-related. These groups include substances that affect individual fish species both directly and the overall fishery productivity of the water body.

The limiting harmfulness characteristic (LHC) of a substance in water is defined by its lowest harmless concentration. The cumulative (additive) effect takes into account the overlap of the harmfulness of pollutants belonging to the first group of LVP. When several substances with the same MPC are introduced into water bodies, the sum of their exceedance factors over the MPC should not exceed 1, which is characterized by the expression

$$\sum_{i=1}^{n} \frac{s_i}{\mathrm{MPC}_i} \leq 1.$$

As is known, in water bodies located in the zones of influence of economic facilities, there is an increase in the concentrations of pollutants above their maximum permissible concentrations (MPC) for many ingredients. Such an increase necessitates the determination of comprehensive pollution indicators (CPI) for water contamination, distinguishing the corresponding pollution classes. Taking into account the aforementioned during the course of this study, we conducted zoning of the overall water area of the AASO based on comprehensive water pollution indicators, which is of great importance for determining the potential development of types and scales of water use (Fig. 5).

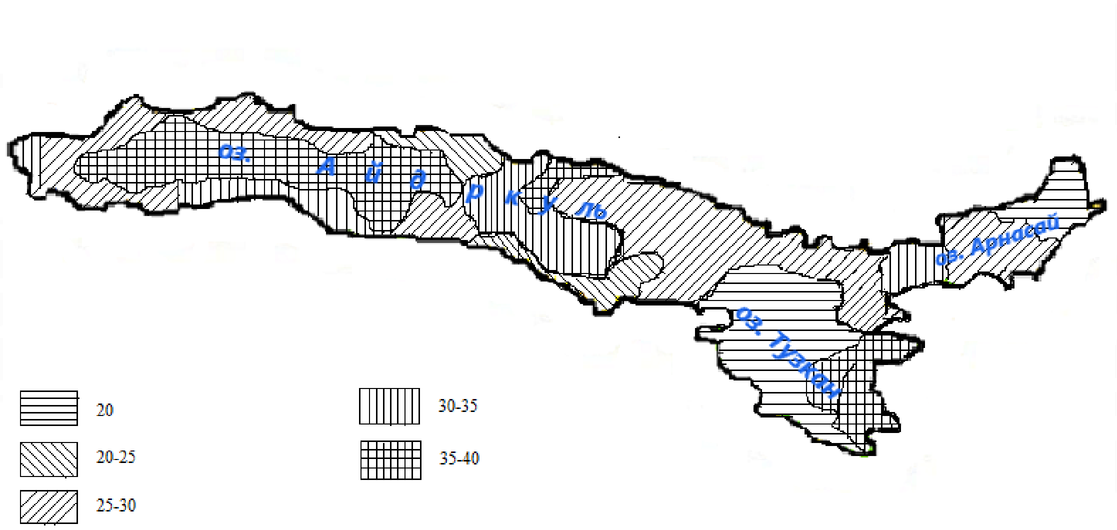

Figure 5. Zoning of the AASO water area based on comprehensive water pollution indicators.

As can be seen from Fig. 5, the comprehensive indicators of water pollution in the lake system's water area are quite high, reaching 20–25 to 35–40 times the permissible limits. This indicates that the quality of lake waters, significantly varying across the water body, falls into the category of dirty and extremely dirty.

From the perspective of assessing the impact of comprehensive water pollution indicators on hydrobiological and ecological conditions, it should be noted that no serious studies have been conducted on this lake system to date. Accordingly, the case necessitates the study of the dynamics of changes in species composition, population characteristics, and other indicators of hydrobionts, which will allow for the justification of optimal parameters for the use of the studied lake system to address economic and environmental tasks in the near and distant future.

Considering the previous information, we concentrated on analyzing the trophic status of the specified lakes during subsequent calculations and assessments, recognizing how this indicator influences the overall ecological conditions of water bodies.

The methodological provisions of this study are based on the applicability of the main principles of previously completed works, which are reflected in the publications of A.M. Gareev, as well as R. Fallenweider, P. Dillon, and F. Rigler, among others. It should be emphasized that the level of trophism serves as one of the main indicators reflecting the ecological conditions in lakes. For the purpose of substantiating the methodological provisions for the use of water bodies in the development of recreation and tourism, this work took into account the peculiarities of the influence of both intra-water (autochthonous) and external (allochthonous) factors, which contribute to quantitatively linking the trophic state of the lake with the influx of biogenic substances (nitrogen, phosphorus) from the catchment area per unit area of the water body. At the same time, a phosphorus budget model was taken into account, reflecting the level of water body eutrophication depending on its inflow, losses, sedimentation, and outflow with runoff based on the flow rate indicator. The formula (Dillon, Rigler, 1975) was applied.

$$P = Po\ (1 - R)/(hср*Kусл),$$

where P is the concentration of total phosphorus in the water of the water body, g/m³; Po - phosphorus load, g/(m2*year); R - phosphorus retention coefficient; Kusl.- coefficient of conditional water exchange; hcp- average depth, m.

It should be noted that to determine the permissible input of biogenic substances into a water body, it is necessary to know the trophic level and the actual specific biogenic load on the water object. If such information is absent, determining the permissible input of biogenic substances is mandatory. The calculated indicators for each of the lakes are reflected in Table 2.

Table 2. Lake parameters and phosphorus indicators

Lake	Area km²	Average depth m	Total Phosphorus mg/L (MAC 0.15)	Average inflow (over the last 10 years)
Tuzkon	705 km^2	9.2 м	0,014	347,51 mln. m^3
Aydarkul	2400 km^2	12 м	0,017	2083,08 mln. m^3
Arnasoy	408 km^2	4.0 м	0,012	2693,07 mln. m^3

For the purpose of determining the trophic status of the lakes, a modified Vollenweider diagram (Vollenweider, 1975) was applied. The obtained indicators are shown in Fig. 6.

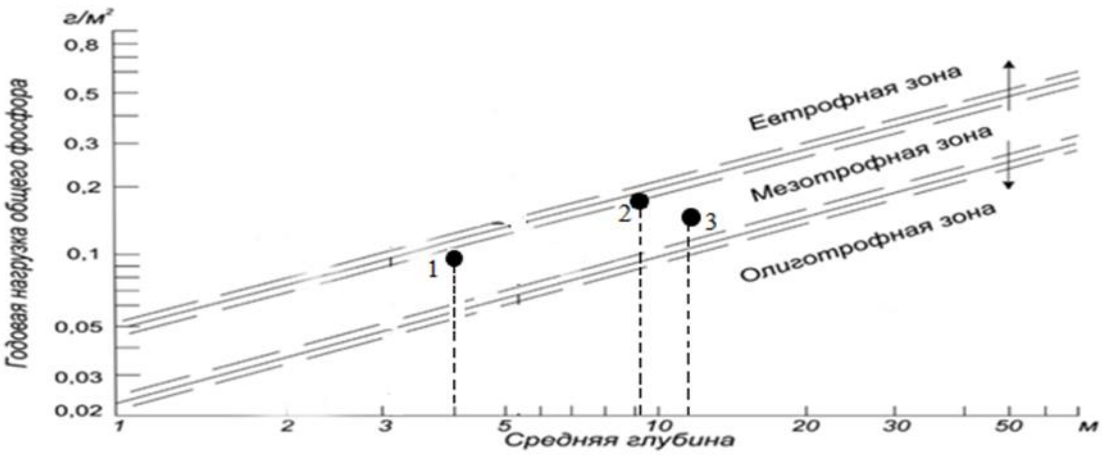

Figure 6. Trophic status of the AASO lakes

Note: 1- Arnasoy, 2- Tuzkon, 3- Aydarkul

As can be seen from Fig. 6, all the lakes belong to the mesotrophic category, except for Tuzkon, which is characterized by transitional conditions—from mesotrophic to eutrophic. This phenomenon occurs under conditions of its saturation with collector-drainage waters, which contain high levels of biogen export (including phosphorus) from the catchment area, predominantly occupied by irrigated lands.

Despite the high concentrations of pollutants, the mentioned lake system is currently quite actively used in fish farming, recreation, tourism, and other activities. Considering that it is a unique water body for Uzbekistan, covering significant areas, and has enormous landscape-forming and ecological significance, further comprehensive study of the prospects for the development of water use systems should be conducted, taking into account economic and ecological criteria to prevent the emergence of crisis situations.

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