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# REVIEW OF WATER VOLUME DYNAMICS AND ECOLOGICAL STATUS MODELING IN THE AYDAR-ARNASAY LAKE SYSTEM

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**Abstract:** The Aydar-Arnasay Lake System (AALS) is one of the largest artificial lake systems in Central Asia, formed as a result of irrigation development and water management practices in the Syr Darya River basin since the late 1960s. Over the past decades, the lake system has become an important component of the regional hydrological regime, ecological environment, fisheries, biodiversity conservation, and socio-economic development. However, continuous fluctuations in water volume, water level, and surface area caused by climate change, reservoir operation, irrigation return flows, and increasing water demand have significantly affected the ecological stability of the lake system. The southern coastal zone of Aydarkol is composed of relatively dense proluvial and alluvial deposits, covered with sand up to 4-5 meters thick. These hard bedrocks protect the coasts from severe erosion. On the other hand, the height of the ascent towards the Nurota Mountains changes significantly. For this reason , the rise of the underground water level on the southern shores of Aydarkol did not extend as far as the northern shores. Also, in the southern coastal zone, the influence of groundwater on the formation of landscapes is well known, up to several tens, sometimes several hundred meters. On the shores of the lake, where the groundwater is very close to the surface, swamp, marsh-meadow, meadow-swamp, meadow and barren soils have developed. The hydromorphic feature in them is variable, and the lakes are associated with changes in the water level. Finally, the review identifies current research gaps and discusses future perspectives for integrated monitoring and sustainable management of the Aydar-Arnasay Lake System under changing environmental and climatic conditions.

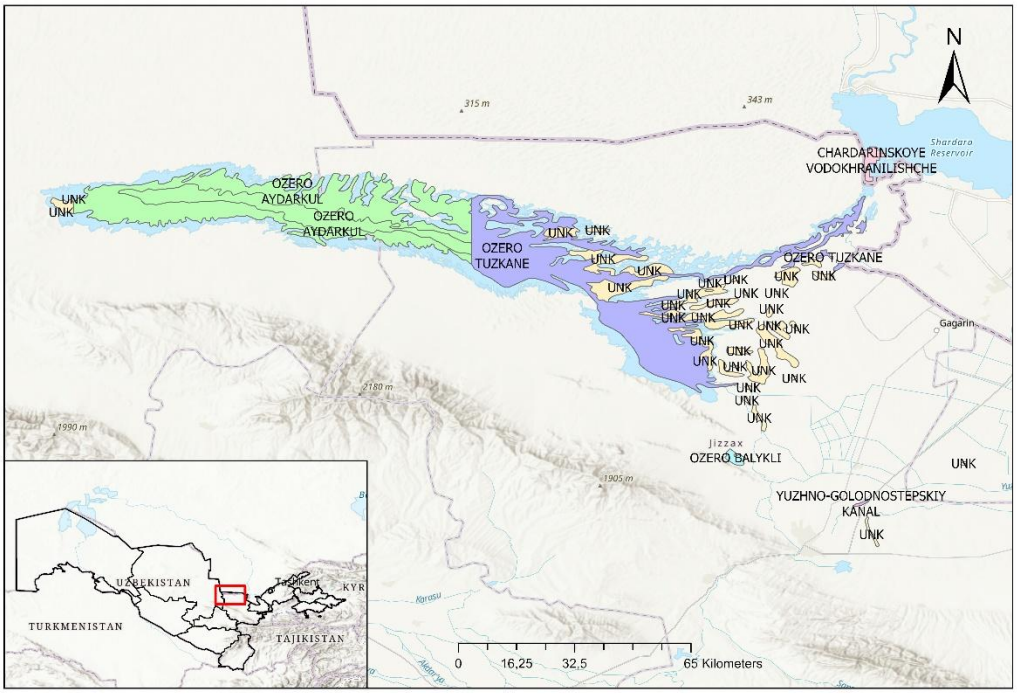
**Keywords:** Aydar-Arnasay Lake System, hydrological modeling, ecological assessment, water balance, GIS, sustainable water management.

## Introduction

Hydrology mainly investigates the movement, distribution, and management of water resources on the Earth. The themes of natural hydrology are groundwater, infiltration, surface wa ter flow, precipitation, and evaporation which all have an ex tremely significant contribution to the sustainable manage ment of water resources (Chinn, 1993) . Before the development of Mirzachol and the construction of the Chordara reservoir, Aydar, Arnasoy and Tuzkon lakes consisted of separate small lakes. During lean years, water flowed into the lakes from the streams on the western slopes of the Turkestan Mountains and the northern slopes of the Nurota Mountains, and during the floods of the Syrdarya River. As a result, saline lakes were formed in the depressions. During the dry years, the water in the lakes evaporated and became brackish and brackish (M. G'odalov, 2014).

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In the 60s of the last century, the intensive exploitation of land in Mirzachol led to the creation of collector-zovur systems. Due to the slope of the surface of the area towards the Aydarkol depression, the collector-zovur waters and underground waters began to move towards Aydar. In 1957, the highest amount of collector water flowing into Aydar, Arnasoy and Tuzkon was 82 million $m^3$ . In 1968, it increased by 880 million $m^3$ . As a result, water was always stored in the Tuzkon basin. Separate small lakes were formed in the deepest places of Aydarkol and Arnasoy depressions (E. Kholmatov et al., 2000). The Aydar-Arnasoy bog consists of salt marshes and marshes before being filled with water, separate shallow small lakes where the water dries up in the summer and salt remains at the bottom. Basically, plants of the halophyte group grew. Aydar, Arnasoy and Tuzkon lakes were filled with water in 1969 (E. Kholmatov, M. G'odalov, 2005). In 1969, one of the wettest years of the 20th century for the country of Central Asia, water was collected in excess of the useful water capacity of Tokhtagul, Qairaqqum and Chordara reservoirs. It was not possible to discharge excess water from the Chordara reservoir downstream along the Syrdarya basin. The reason for this was the great risk of flooding in Kyzylorda, Kazakhstan. As a result, from February 1969 to March 1970, 21.8 km 3 of water flowed into the Arnasoy bog through the Arnasoy hydroelectric system **Picture 1**.




**Pic. 1** Geographical location and spatial distribution of the Aydar–Arnasay Lake System and its major water bodies in Uzbekistan.

Following the rise in the water level of Arnasoy Bay, a portion of the excess water began flowing into Aydarkul Lake. The inflow reached approximately 400 million $m^3$ in 1971 and increased to about 580 million $m^3$ during March and April 1972. The increased water inflow subsequently

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caused a significant rise in the water level of Tuzkon Lake, reaching approximately 22 m. As a result, the Aydar–Arnasay Lake System (AALS) was formed, covering an area of approximately 2,300 km² and containing about 20 km³ of water. The subsequent flooding contributed to the stabilization of water levels and the development of substantial fish stocks in the lake system.

However, by the 1980s, the water level of the lake system began to decline as a result of high annual evaporation, which reached approximately 1,100–1,200 mm. A major change in the hydrological regime occurred after the collapse of the Soviet Union in the early 1990s, when the previously integrated water and energy management system of Central Asia was disrupted. The newly independent countries subsequently began to regulate their water and energy resources according to their own national priorities. In particular, since 1993, the Toktogul Reservoir in the Kyrgyz Republic, with a surface area of approximately 284 km² and a storage capacity of 19.5 km³, has been increasingly operated for hydropower generation. Consequently, water was primarily stored during the spring and summer months and released during the autumn and winter seasons, when electricity demand was highest. This change in the seasonal flow regime increased the amount of water released downstream, resulting in greater inflows from the Chardara Reservoir into the Aydar–Arnasay Lake System (AALS).

The increased inflow significantly affected the hydrological conditions of the AALS during the 1990s. According to data from the Hydrometeorological Service of Uzbekistan (www.Uzhydromet.uz ), the water level of the AALS was approximately 237 m in the early 1990s and increased to 244.2 m by 1998, representing a rise of approximately 6.5–7.0 m. The expansion of the lake system resulted in the inundation of surrounding pasturelands, shepherds' houses, livestock facilities, and sections of nearby roads. By November 1998, the absolute water level had reached approximately 243.7 m, while the total lake area was reported to be about 3,039 km² and the water volume approximately 31 km³. Seasonal fluctuations in water level generally ranged from 0.8 to 2.3 m. The water level typically increased during the winter and spring months in response to inflows from the Chardara Reservoir, with the maximum annual water level generally observed in May.

During the summer and autumn months, high evaporation rates resulted in water losses of up to approximately 3 km³, causing the lake level to decline by about 0.5–0.7 m. However, the hydrological conditions of the Aydar–Arnasay Lake System changed again after 2000 due to increased water inflows. Analysis of water inflow, changes in lake surface area, and water-level dynamics indicates that the water level increased by approximately 3.6 m between January 2000 and May 2005. During this period, approximately 11.2 km³ of water was discharged into the Arnasay Lowland, resulting in the inundation of an additional area of approximately 477 km².

By 2005, the Aydar–Arnasay Lake System (AALS) had expanded to approximately 3,175 km², with a total water volume of about 34 km³. Analysis of the period from 2005 to 2010 indicates that the water level generally increased in accordance with the expansion of the lake surface area and the growth in water volume. By 2018, the surface area of the AALS had increased further to approximately 3,719 km², while the total water volume reached about 44.19 km³. Despite the continued increase in lake area and water volume, the water level showed a slight decline during this period, reaching approximately 241 m.

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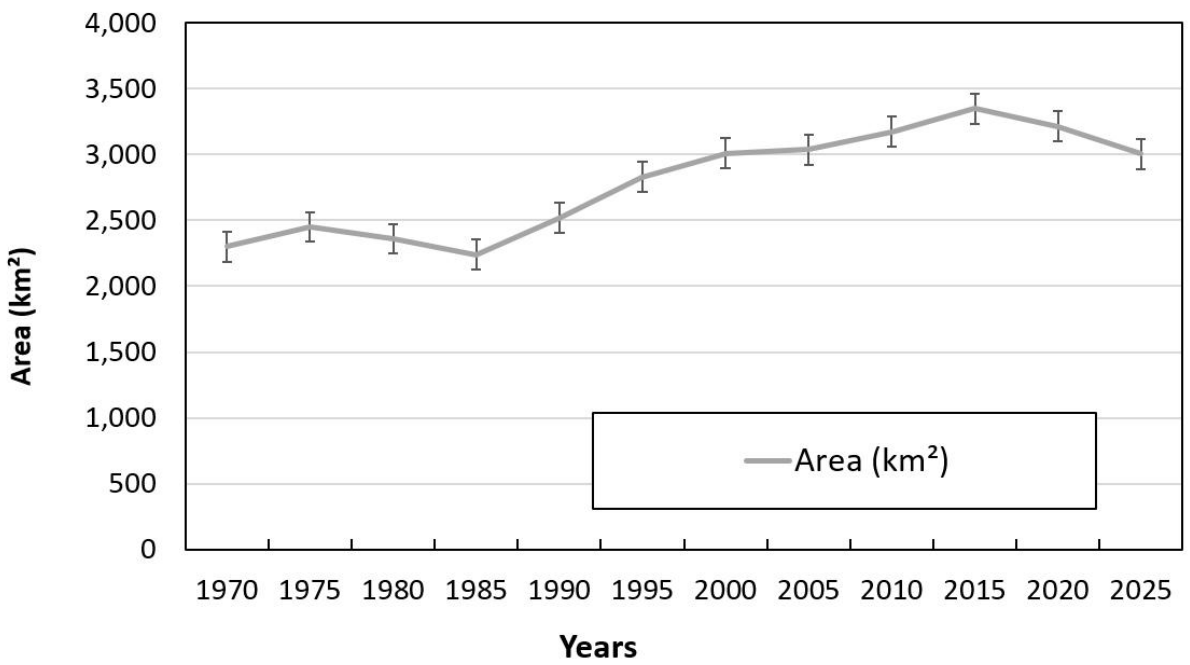



**Fig. 1** Temporal Changes in the Water Surface Area of the Aydar–Arnasay Lake System (1969–2018)

The lake area fluctuated during the 1970s and 1980s, reaching a minimum of approximately 2,240 km² in 1985. A substantial expansion occurred after 1990, with the area increasing to approximately 3,350 km² by 2015. However, the lake area subsequently declined, reaching approximately 3,000 km² by 2025, indicating a recent reduction in the spatial extent of the lake system.

During the period from 1970 to 2018, changes in other morphometric parameters depending on water volume and area were also observed in AAKT. It is possible to assess the impact of AAKT on environmental landscapes by determining the changes in its morphometric indicators during half a century (M. G'odalov, 2012).

**Table 1** illustarated the information about the water resources balance of the Aydar–Arnasay Lake System during 1993–2021. The data show substantial interannual variability in water inflows from the Chardara Reservoir, Arnasay Reservoir, and collector-drainage systems. The total water volume increased considerably during the late 1990s and reached its highest values in the mid-2000s, followed by a gradual decline in subsequent years. By 2021, the water volume had decreased to 33.44 billion m³, indicating a recent reduction in the overall water storage of the lake system.

**Table 1.** Annual Water Resources Balance and Water Volume of the Aydar–Arnasay Lake System,

1993–2021

| **Water Resources Balance of the Aydar–Arnasay Lake System** |
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| **Years** | Chardara Reservoir discharge *(million m³)* | Arnasay Reservoir discharge Aydarkul Lake (million m³) | Collector-drainage water inflow (million m³) | Aydar–Arnasay Lake System water volume (billion m³) |
|---|---|---|---|---|
| 1993 | 2650.5 | - | - | 16.7 |
| 1994 | 9285.8 | - | - | 18.6 |
| 1995 | 4005.2 | - | - | 25.7 |
| 1996 | 1207.9 | - | - | 28 |
| 1997 | 1244.2 | - | - | 28.1 |
| 1998 | 3134.7 | - | - | 28.5 |
| 1999 | 3098 | - | - | 31.7 |
| 2000 | 2793 | - | - | 33.5 |
| 2001 | 351 | - | - | 34.1 |
| 2002 | 1207 | - | - | 33 |
| 2003 | 4757 | - | - | 32.9 |
| 2004 | 2865 | - | - | 38.3 |
| 2005 | 2220.5 | 2279 | - | 40.8 |
| 2006 | 325 | 369 | - | 42.1 |
| 2007 | 822 | 671 | 2366,3 | 41 |
| 2008 | 827.6 | 781,3 | 1848,6 | 40.4 |
| 2009 | 184.9 | 0 | 2721,5 | 39.1 |
| 2010 | 823.8 | 574,7 | 2859,7 | 38.5 |
| 2011 | 216 | 0 | 2328,6 | 38.6 |
| 2012 | 1597.1 | 1488,3 | 2463,8 | 37.8 |
| 2013 | 0 | 0 | 2370,6 | 38.5 |
| 2014 | 119.2 | 0 | 2104,5 | 37.7 |
| 2015 | 337.8 | 0 | 2195,7 | 37 |
| 2016 | 22.5 | 0 | 2238,5 | 36.3 |
| 2017 | 969.4 | 771 | 2532.37 | 37.5 |
| 2018 | 269.7 | 2,1 | 2882,4 | 37.4 |
| 2019 | 588 | 411 | 2667,3 | 37.2 |
| 2020 | 0 | 0 | 3243.52 | 37 |
| 2021 | 100 | 0 | 2314.23 | 33.44 |

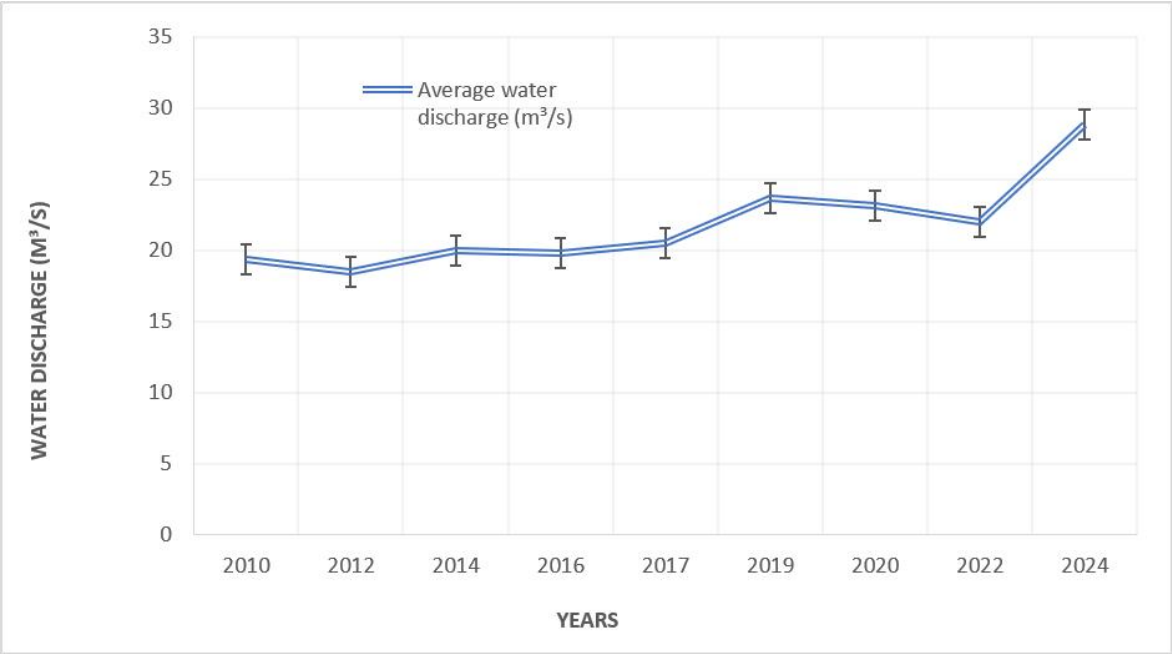
The inundation of the Aydar–Arnasay Lake System has significantly affected the groundwater regime in the surrounding areas. The rise in lake water levels has resulted in an increase in groundwater levels extending from several hundred meters to approximately 10–12 km from the shoreline in some areas. The spatial extent of this influence varies depending on the local topography, shoreline slope, and geological composition of the coastal zone. The most pronounced long-distance effects have been observed along the northern shore of Aydarkul and the western shore of Arnasoy

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Lake. These areas are characterized by a highly fragmented shoreline, elongated bays, numerous islands, and peninsulas, which are clearly visible in satellite imagery.

The strong influence of lake water on the surrounding groundwater system in these areas can be explained by the relatively small difference in elevation between the lake surface and adjacent land, gentle coastal slopes, and the presence of unconsolidated lacustrine and alluvial sediments. These deposits are locally covered by sand layers reaching 15–30 m in thickness, which facilitate the interaction between surface water and groundwater. As lake levels rise, the resulting hydrostatic pressure affects the groundwater regime in the coastal zone. Monitoring of artesian wells indicates that groundwater levels have risen by up to approximately 20 m along the northern shores of Aydarkul. Consequently, groundwater occurs close to the land surface in many coastal areas, promoting the development of waterlogged and marshy landscapes. Swamp, meadow-swamp, and marsh-meadow soils are therefore widespread in these zones.

Collector-drainage water represents an important component of the water balance of the Aydar–Arnasay Lake System (AALS). The lake system acts as a natural receiver of return flows generated from irrigated agricultural lands, particularly in the Syrdarya and Jizzakh regions. Previous studies have shown that collector-drainage inflows can contribute substantially to the annual water supply of the AALS, while also influencing its hydrochemical conditions because of the relatively high mineralization of these waters. Therefore, changes in collector discharge are important for understanding the long-term hydrological dynamics of the lake system. The following figure presents the temporal variation in average collector-drainage water discharge in Jizzakh Region during 2010–2024.




In contrast, the southern coastal zone of Aydarkul is mainly composed of relatively dense proluvial and alluvial deposits, locally covered by sand layers approximately 4–5 m thick. These

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relatively resistant deposits reduce the susceptibility of the shoreline to severe erosion and limit the lateral propagation of groundwater. In addition, the terrain rises more rapidly toward the Nuratau Mountains, resulting in a different groundwater response compared with the northern coast. Therefore, the increase in groundwater levels along the southern shore is generally less extensive than that observed in the northern coastal zone. Nevertheless, groundwater remains an important factor in landscape formation, particularly in areas where the water table is located close to the surface. Such conditions have contributed to the development of swamp, marsh-meadow, meadow, and saline soils. The degree of hydromorphism varies spatially and is closely associated with fluctuations in lake water levels.

The reason for the increase in the mineraliza tion and other components of the Arnasay Lake water in the2019 data compared to 2011 is that in 2011–2019, the Syrdarya River water outflowing through the Shardara Reservoir, which has satisfactory water quality compared to the lake water, negligibly discharged into the Arnasay Lake (Mirzaev et al. 2019). However, during these years, the Sirdarya and Jizzakh provinces of Uzbekistan had been discharged with the CDW, the mineralization and other chemical components of which were much higher than the PN due to the irrigation of croplands.

**Conculusion.** The plains on the eastern side of the AALS are composed of ancient alluvial rocks, and the upper part is covered with thick loess rocks. In this coastal zone, the rate of water filtration is much lower than in sandy areas, so wetlands are mainly developed in the lowlands near the coastline. The eastern shores of Lake Tuzkon are less fragmented. Only the north-eastern shores of Tuzkon Lake are low relative to the lake's water level, so when the water level rises, the water invades several kilometers away. Arnasoy and Tuzkon lakes are fed from Mirzachol by about ten collector-zovur 49 waters. Swampy soils have also developed in the lowlands crossed by these ditches. In general, this landscape, similar to the landscapes of other coastal zones, has marshy, swamp-meadow, and meadow-swamp soils near the lake. Further away from the lake, these soils alternate with meadow, grass-meadow and meadow-gray soils. The purpose of analyzing the changes in the water volume in AAKT is to study the natural geographical processes that occur or may occur in the surroundings of the lake with the increase and decrease of water.

- Changes in the water balance of the Aydar–Arnasay Lake System (AALS) have significant implications for the surrounding landscapes and ecological conditions. An increase in lake water volume leads to the expansion of the inundated area, which may result in the flooding of adjacent pastures and irrigated agricultural lands. At the same time, rising lake levels can increase groundwater levels over several kilometers in the surrounding areas, contributing to the development of waterlogged, saline, and hydromorphic or semi-hydromorphic landscapes. In contrast, a decline in the water volume reduces the lake surface area and exposes previously inundated sediments. The exposed sediments can become a source of wind-blown salts and other mineral particles, potentially degrading the ecological conditions of the surrounding environment.
- A reduction in water volume can also increase the salinity of the remaining lake water, creating unfavorable conditions for fish and other aquatic organisms. Therefore, fluctuations in the AALS water balance can influence both aquatic ecosystems and terrestrial landscapes surrounding the lake system. Evaporation represents one of the major components of the water output from the AALS, and

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when evaporative losses exceed water inflows, dissolved salts become increasingly concentrated in the remaining water. This process may intensify salinization within the lakes and promote the expansion of salt-affected soils and vegetation adapted to saline conditions along the surrounding shores. Consequently, understanding the water balance of the AALS is essential for assessing its long-term hydrological, ecological, and landscape responses.

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