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Determination and assessment of water resources balance of Aydar-Arnasay Lake System in Uzbekistan

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Determination and assessment of water resources balance of Aydar-Arnasay Lake System in Uzbekistan

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Abstract. Determining and assessing the water balance of the Aydar Arnasay Lakes System (AALS) is important for the development of fisheries, ecotourism and efficient use of water resources in the region. The amount of water included in the water balance of the AALS is the addition of Syrdarya water, collector drainage water, snow-rain and groundwater, which are poured into the lake system through the Chordara reservoir. The amount of water released from the lake system includes water released from the water basin by evaporation into the atmosphere, used for infiltration and irrigation. The article identifies and evaluates changes in the amount of AALS water balance for 2004-2018.
Key words. lake system, water balance, water volume, collector drainage waters, infiltration.

1. Introduction

The Aydar-Arnasay lake system is currently the largest indoor water body in the Republic of Uzbekistan. Today, more water is stored in the lake system than in all reservoirs in the region [1, 2]. The Aydar-Arnasay lake system (including water resources of Aydarkul, Tuzkan and Arnasay lakes) is located 250 km from Tashkent, in the middle of the Syrdarya River, south of the Chordara Reservoir, in the Jizzakh and Navoi regions of the Republic of Uzbekistan. This system of lakes was formed in the middle of the twentieth century, and in recent years its formation has gone through several stages, and each stage is defined by a separate direction and level of ecological and economic activity [3].

The incoming part of the Aydar Arnasay Lake System (AALS) water balance includes Syrdarya water entering Lake Arnasay from the Chordara Reservoir, collector-drainage water discharged into the lake basins, atmospheric precipitation and groundwater. Output water from the lake system includes surface water evaporation into the atmosphere, irrigation water, and groundwater infiltration infiltration. Determining the amount of inlet and outlet water provides the water balance in the lake system.

Eshchanov and Belikov [3] conducted research on the water balance of AALS and its effect on the hydrochemical regime, and partially studied the water balance of the lake system from 2000 to 2010 [3]. According to the study, between 2006 and 2010, the amount of water discharged from the Chordara Reservoir decreased and the amount of water discharged from the inlet to the lake system increased. It has been found that the level of mineralization has increased in Tuzkon and Aydar lakes belonging to the lake system. Studies have shown that the construction of a dam between Arnasay and Tuzkon Lake can reduce the salinity of Tuzkan Lake. However, in determining the water balance of the lake system in the study, the amount of water evaporation from the surface into the atmosphere, groundwater infiltration (infiltration) has not been accurately estimated [4-7].

Research by Vereshchagina et al. [4] has been conducted to identify the main environmental factors affecting AALS and its surroundings. The main environmental factor affecting the lake system is the fact that the discharge of Syrdarya water through the Chordara Reservoir varies over the years. Another environmental factor affecting the lake system and its surroundings is the increase in the amount of outlet water from the inlet water due to the high evaporation of water from the surface of the lake system into the atmosphere. As a result, the water in the small ponds around the lakes evaporates, leading to an increase in saline areas and deteriorating the ecological situation. The study did not study the water balance of the lake system and the assessment of the ecological situation in the lake system and surrounding areas through the study of these factors [8, 9].

Vuglinsky and Albul [6] conducted research on the calculation of surface evaporation using the GGI-3000 evaporation calculator and proposed a method for calculating the average monthly values of evaporation from the water surface. According to the method of calculating evaporation using the equipment GGI-3000, it was concluded that it would be expedient to carry out evaporation on the width of the water surface during the summer season from June to September. The calculation error was ± 15-20% [10].

Wahyuni et al [6] conducted research on lake water balance around AALS and suggested sustainable groundwater management (GW) as an important component [11, 12]. The specificity of the water balance in the lake system here includes the distribution of groundwater and its interactions. The change in the water level of the lake was calculated on a monthly basis. The results show that from March to July, the amount of groundwater increased, varying from 0.13 to 0.83 km^3 per month. From August to February, the amount and level of groundwater decreased and ranged from 0.05 to 0.51 km^3 during these months [7].

Research has been conducted on the use of modern geoinformation technologies in solving environmental problems of AALS. In the research work, the hydrology of the lake system - the amount of water, water area, level was studied using modern geoinformation technologies. Maps were made on the basis of space photographs and recommendations were given on the dependence of the ecological situation in the lake system on the parameters of water resources. However, the water balance of the lake system and its importance in the use of water resources of the lake system are not covered in the research [8].

In the above-mentioned research, the dynamics of changes in the balance of AALS water resources, methods of calculating the water balance have not been fully studied. In the future, it will be necessary to develop scientific and practical recommendations for determining and assessing the water balance of the lake system in the protection and sustainable use of AALS water resources, which are important for the region. The aim of this work is to determine and assess the water balance of the lake system by calculating the amount of inlet and outlet water to the AALS and determining the dynamics of change.

2. Materials and methods

AALS is the second largest indoor water body in the region after the Aral Sea. The Aydar-Arnasay lake system is located in the middle reaches of the Syrdarya River in the Jizzakh and Navoi regions of the Republic of Uzbekistan.

The size of the surface area of the lake system leads to high evaporation and remains an important factor in climate change in the region. In summer, high evaporation is typical for shallow lakes located in the desert zone where the maximum water temperature reaches 30 °C. The amount of evaporation varies from 1300 mm (in the eastern part of Aydarkol) to 1500 mm (Eastern Arnasay lakes) depending on the morphology of the basins, the ratio of shallow and deep water areas, the degree of reproduction.

In the study, the water balance of the Aydar-Arnasay lake system was determined by estimating the amount of water entering and leaving the lake system. The amount of water entering the lake system is the Syrdarya water flowing through the Chordara Reservoir, collector-drainage water (CDW) water, atmospheric precipitation and the addition of groundwater. Output water to the lake system consists of atmospheric evaporation from the surface of the lake system water, water taken to irrigate agricultural areas around the lake system, and infiltration water infiltrated underground from the lake system.

The average evaporation value for the entire lake system is assumed to be 1300 mm. Based on these data, it was calculated that the loss of water from the lake system due to evaporation of 4 to 4.7 km^3 per year, taking into account the water surface area [3, 7].

3. Results and discussion

The amount of water entering the AALS from the Syrdarya River through the Chordara Reservoir has changed over the years as follows.

The dynamics of changes in the amount of water discharged into the lake system through the Chordara Reservoir over the years was 2,650 km^3 in 1993, 1,207 km^3 in 2002, 0.840 km^3 in 2010, and 0.025 km^3 in 2016 [10]. The largest amount of water discharged from the Chordara Reservoir was 9,286 km^3 in 1994, and the lowest amount (0.025 km^3) was observed in 2016. In 2013, 2017 and 2018, no water was pumped into the lake system from the Chordara Reservoir.

The water area and water level of AALS fluctuate over the years as a result of the discharge of Syrdarya water and CDW water flowing through the Chordara Reservoir. The water area of the lake system in 1993 was 2045 km^2, the water level was 237.6 m, in 2000 it was 3140 km^2, the water level was 244.3 m, in 2010 the water area was 3412 km^2, the water level was 245.8 m, and in 2017 it was 3224 km^2 and level was 244.7 m [10] (Figures 1 and 2).

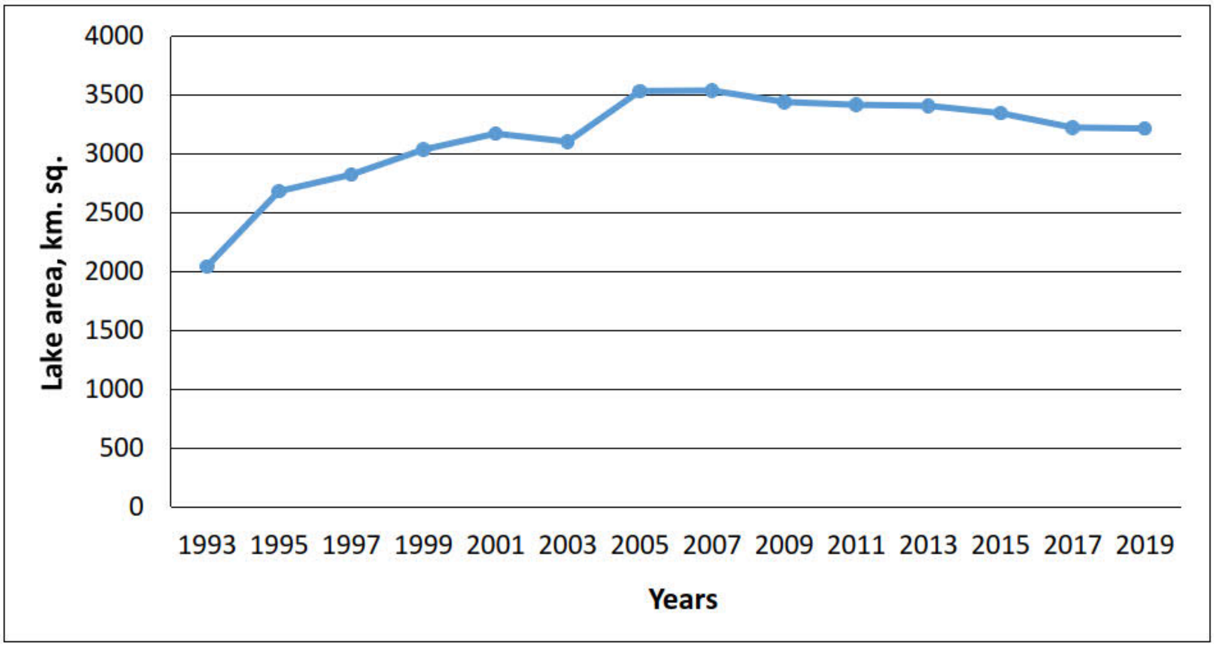

Figure 1. Dynamics of AALS water area change over the years.

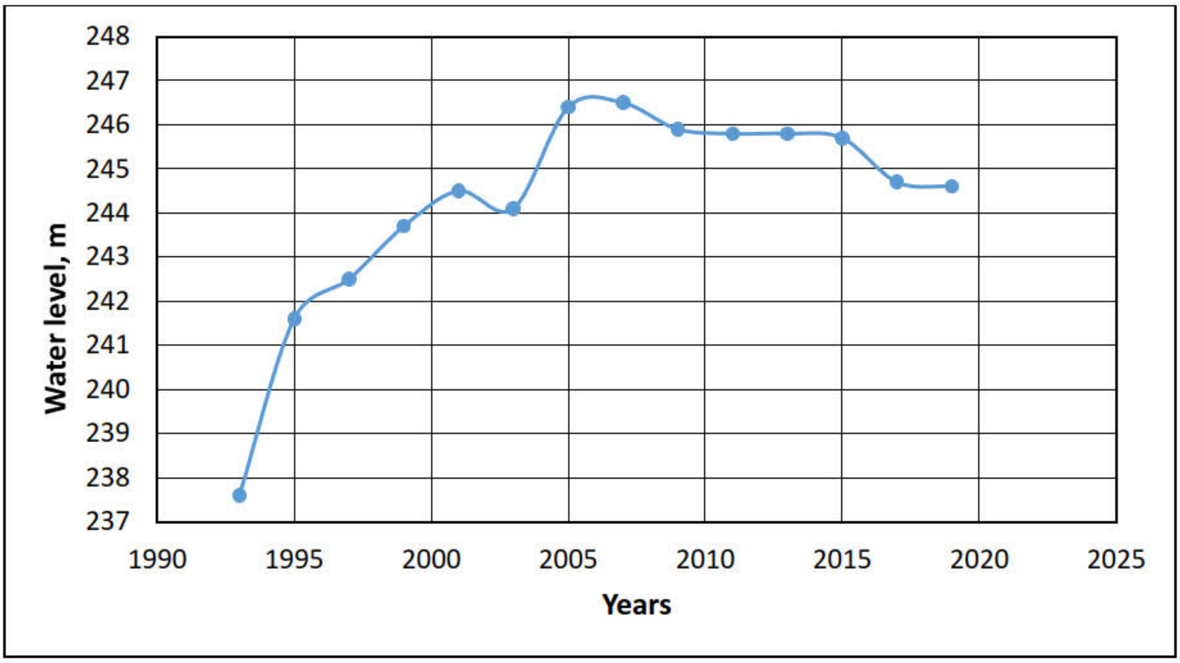

Figure 2. Dynamics of AALS water level change over the years.

The change in the amount of CDW poured into AALS during the research years (2004-2018) is shown in Table 1 below.

Table 1. Average annual consumption and annual flow rate of CDW poured into AALS.

Years	2004	2006	2008	2010	2012	2013	2014	2015	2016	2017	2018
Yearly discharge, m^3/sec	61.2	70.1	65.2	86.8	69.8	68.6	72.4	71.6	67.4	66.5	68.2
Yearly flow, million m^3	1930.0	2213.8	2056.1	2737.3	2201.2	2163.4	2283.2	2258	2125.5	2097.1	2150.8

An analysis of the dynamics of change in the amount of CDW poured into AALS between 2000 and 2019 showed that a small amount of CDW fell in 2000 and a relatively large amount of CDW in 2010. The mineralization of CDW was less than the mineralization of AALS waters, i.e., 2–4 g/l (Figure 3).

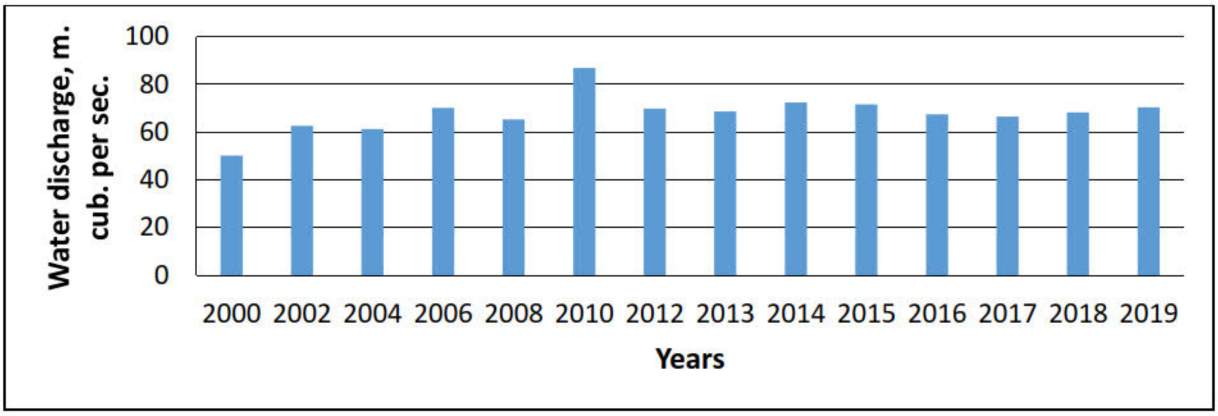

Figure 3. Dynamics of quantitative change of CDW poured into AALS.

In the AALS water balance calculation study, the average amount of groundwater infiltrated was 50 million m^3 [3]. But this amount can change over the years. Therefore, the amount of groundwater added to the AALS by infiltration was calculated using the method of the French scientist Darcy [11].

The amount of groundwater added to the AALS calculated during the study was 31.0 million m^3 in 1993, 42.9 million m^3 in 2001, 45.5 million m^3 in 2011, and 43.4 million m^3 in 2019. In the current study, the amount of groundwater infiltrated (infiltrated) from AALS is also given as an average of 50 million m^3. However, this data also changes over the years.

In the study, the amount of groundwater infiltrated by the lake system was calculated using the Darcy method [11]. The amount of groundwater infiltrated into the identified AALS varied between 1993 and 2019 as follows:

$$Q_{1993} = 2045 * 10^2 * 1 * 237.6/156.8 *10^4 = 31.0 \text{ million } m^3$$
$$Q_{2001} = 3173 * 10^2 * 1 * 244.5/182.1 *10^4 = 42.6 \text{ million } m^3$$
$$Q_{2003} = 3106 * 10^2 * 1 * 244.1/184.6 *10^4 = 41.1 \text{ million } m^3$$
$$Q_{2006} = 3599 * 10^2 * 1 * 246.8/192.4 *10^4 = 46.2 \text{ million } m^3$$
$$Q_{2009} = 3441 * 10^2 * 1 * 245.9/189.6 *10^4 = 44.6 \text{ million } m^3$$
$$Q_{2015} = 3348 * 10^2 * 1 * 245.7/182.4 *10^4 = 45.1 \text{ million } m^3$$
$$Q_{2019} = 3216 * 10^2 * 1 * 244.6/181.4 *10^4 = 43.4 \text{ million } m^3$$

During the research years, the amount of water used for irrigation purposes from Arnasay lake in AALS varied as follows: 20.8 million m^3 in 2004, 75.2 million m^3 in 2008, 99.4 million m^3 in 2012, 129.0 million m^3 in 2016, and, in 2018, 150.5 million m^3.

The amount of groundwater infiltrated and infiltrated (capillary) from the lake system (1993-2019) is shown in Table 2. In 2006, AALS's water resource indicators reached the highest values. The water area of the AALS, the length of the groundwater flow, and the amount of groundwater broken down, as well as the amount of groundwater added, are given in Table 2.

Table 2. AALS water area and groundwater flow length change over the years.

Years	1993	1997	1999	2001	2003	2006	2009	2011	2013	2015	2017	2019
Water area, km^2	2045	2824	3038	3173	3106	3599	3441	3418	3410	3348	3224	3216
Groundwater flow length, km	156.8	164.3	172.5	182.1	184.6	192.4	189.6	184.8	183.5	182.4	181.6	181.4
Infiltrated water, million m^3	31.0	41.7	42.9	42.6	41.1	46.2	44.6	45.5	45.7	45.1	43.4	43.4
Flowed groundwater million m^3	31.0	41.7	42.9	42.6	41.1	46.2	44.6	45.5	45.7	45.1	43.4	43.4

The AALS water balance equation, as in any lake, can be written in general terms as follows:

$$\Sigma\text{Inflow} = \Sigma\text{Outflow} \pm S \quad (1)$$

where: ΣInflow – the amount of water poured into the AALS; ΣOutflow – the amount of water discharged from the AALS, ± S – changes in the amount of water in the lake.

In the above equation (1):

$$\Sigma\text{Inflow} = I + R \pm GW_{change} \quad (2)$$

$$\Sigma Outflow = E+Q_{flow} \tag{3}$$

where: I – the amount of water discharged into the AALS from the Chordara Reservoir and discharged into it from the collector drainage; R – the amount of atmospheric precipitation that falls on the surface of the lake; GW_{change} – exchange of groundwater with lake water; E – the volume of evaporation from the water surface of the lake, Q_{flow} – the amount of water taken for irrigation from the lake (Lake Arnasay). All of these components of the water balance equation are expressed in units of volume (km^3).

Substituting the above equations (2) and (3) into the equation (1), the water balance equation of AALS looks like this:

$$I+R\pm GW_{change} = E+Q_{flow} \pm S \tag{4}$$

Typically, the absorption of water from a lake into the ground or the addition of groundwater to a lake basin represents the exchange of groundwater. We determine its value from expression (4) by the following equation:

$$\pm GW_{change} = I + R-(E + Q_{flow}) \pm S \tag{5}$$

It is possible to verify the value of GW_{change} based on groundwater level monitoring data located near the lake [13, 14]. It is known that the movement of groundwater is subject to the law of the French scientist Darcy [11] and its consumption is determined by the following expression:

$$Q = F \cdot K \cdot h/l \tag{6}$$

where: Q – groundwater discharge, m^3/sec; F – the surface of the transverse shear of the layer through which these waters pass, m^2; K – filtration coefficient; h – pressure height, m; l – groundwater flow path, m. The dynamics of water balance of the AALS is given in Table 3 below.

Table 3. Dynamics of water balance of Aydar Arnasay lake system.

#	Water balance components	Years							
		2004	**2006**	**2008**	**2010**	**2012**	**2014**	**2016**	**2018**
		Inflow (million m^3)							
1	Water discharged from the Chordara Reservoir	2865.0	337.0	956.0	840.0	1623.0	124.0	25.0	132.0
	Groundwater inflow	41.1	46.2	44.6	45.5	45.7	45.1	43.4	43.3
	Precipitation	380.0	241.5	280.7	220.2	263.6	192.5	363.2	230.6
	CDW	1789.4	1848.4	2531.5	2596.4	2640.9	2587.7	2666.6	2629.5
	Total	**5075.5**	**2473.1**	**3812.8**	**3702.1**	**4573.2**	**2949.3**	**3098.2**	**3035.4**
		Outflow (million m^3)							
2	AALS surface evaporated water	3909.1	4161.6	4278.2	4282.8	4224.7	4163.4	4103.2	4206.7
	Infiltrated water	41.1	46.2	44.6	45.5	45.7	45.1	43.4	43.3
	Irrigation purposes	20.8	32.4	75.2	176.4	99.4	245.8	129.0	150.5
	Total	**3971.0**	**4240.2**	**4398.0**	**4504.7**	**4369.8**	**4454.3**	**4275.6**	**4400.5**
		Total water balance							
	Balance difference	**+1104.5**	**-1767.1**	**-585.2**	**-802.6**	**+203.4**	**-1505.0**	**-1177.4**	**-1365.1**

The water balance of the Aydar-Arnasay lake system for 2004-2018 (Table 3) shows that the AALS water balance for 2006 and 2018 was negative, ie the part of water consumption (outgoing water) during this period exceeded the amount of receipts (inbound water) bulgan. This was due to a sharp decrease in the amount of water flowing into the AALS from the Chardara Reservoir, which began in 2006. At the same time, the amount of CDW water entering the lake system during this period increased from 1930 million m^3 to 2283 million m^3. The increase in the amount of CDW water flowing into the lake system has prevented the lake system from a sharp drop in water level and total water volume.

4. Conclusions
The study assesses the dynamics of the water balance of the lake system for the period 2004-2018. The AALS water balance varies depending on the amount of water entering and leaving the lake system.

The volume of inlet water to AALS in 2004 was 5075.5 million m^3, outlet water 3971.0 million m^3, balance amount +1104.5 million m^3, in 2008 the volume of inlet water 3812.8 million m^3, outlet water 4398.0 million m^3, balance volume -585.2 million m^3, the volume of inlet water in 2012 was 4573.2 million m^3, the outlet water 4369.8 million m^3, the balance volume was +203.4 million m^3, the amount of inlet water in 2016 was 3098.2 million m^3, the outlet water was 4275.6 million m^3, the balance volume -1177.4 million m^3, in 2018 the volume of inlet water was 3035.4 million m^3, outlet water 4400.5 million m^3, the balance volume was -1365.1 million m^3.

The main environmental factors affecting the water balance of the lake system are the fluctuations in the discharge of Syrdarya water through the Chordara reservoir over the years, the high level of evaporation from the surface of the lake system into the atmosphere, the increase in outflows. As a result, the water in the small ponds around the lakes evaporates, leading to an increase in saline areas and deteriorating the ecological situation.

The analysis, study and implementation of various options for regulating the water balance of the lake system is important in the development of fisheries, and in the conservation and efficient use of water resources in the basin.

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