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RESEARCH ARTICLE | JULY 15 2025

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AIP Conf. Proc. 3256, 020043 (2025)
https://doi.org/10.1063/5.0267002

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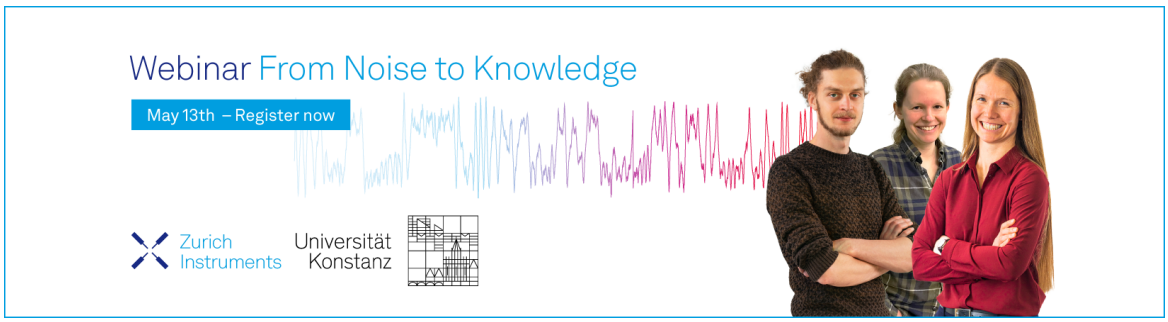
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Quantitative Assessment of Hydrological Regime Changes in Kuyimazar Water Reservoir

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Abstract. This article examines the volume of water flowing into and out of the Kuyimazar reservoir via its channel. Additionally, it investigates the factors influencing changes in the hydrological regime of the Kuyimazar reservoir. The components of the reservoir's water balance and the alterations in its temperature regime were analyzed. Based on the monitoring data, the working mode of the reservoir was studied.
Utilizing historical data spanning a significant timeframe, our analysis uncovers notable fluctuations in the reservoir's hydrological characteristics. Seasonal variations have been identified and scrutinized, particularly in temperature and water levels. Furthermore, correlations between external factors, such as climatic variations and human interventions, and the observed hydrological shifts are explored.

Keywords: Hydrological regime, reservoir, channel, water consumption, air temperature, water balance, water levels, river, temperature regime, hydrological parameters, climatic factors.

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INTRODUCTION

The Kuyimazar Reservoir is situated between the Kuyimazar and Kogon railway stations in the Bukhara region, Republic of Uzbekistan (Fig. 1).

It was constructed in 1957 around one of the depressions at the base of the Zarafshan River. The reservoir basin is situated in sedimentary deposits composed of a mixture of mudstone and sandstone.

The initial water volume was 280 mln. m^3 with an area of 15.9 km^2. The widest part measures 5.3 km, with an average depth of 18.8 meters and a maximum depth of 33 meters. In 1966, the reservoir banks were raised by ridges over 2 meters high around the bowl. Consequently, its water volume increased to 306 mln. m^3, and its area expanded to 16.3 km^2 [2].

Water is conveyed to the Kuyimazar reservoir from the Zarafshan River via a dedicated 18-kilometer channel.

The Kuyimazar pumping station, capable of pumping 40 cubic meters per second of water, was constructed to feed the Amu-Bukhara canal. The stored water is distributed to irrigation stations through a 72-kilometer channel, maintaining a flow rate of 100 cubic meters per second. The water level in the reservoir fluctuates.

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Water is conveyed to the Kuyimazar reservoir from the Zarafshan River via a dedicated 18-kilometer channel. The Kuyimazar pumping station, capable of pumping 40 cubic meters per second of water, was constructed to feed the Amu-Bukhara canal. The stored water is distributed to irrigation stations through a 72-kilometer channel, maintaining a flow rate of 100 cubic meters per second. The water level in the reservoir fluctuates [1, 2].

The Khorkhor and Duoba hydroelectric reservoirs are components of the Kuyimazar reservoir. Since 1965, the Kuyimazar reservoir has been employed to regulate the water flow of the Amu-Bukhara canal. It irrigates 94,000 hectares of land through the main canal.

Water, Energy and Food Security in the Context of Global Climate Change and Water Scarcity
AIP Conf. Proc. 3256, 020043-1–020043-10; https://doi.org/10.1063/5.0267002
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FIGURE 1. Top view of Kuyimazar Reservoir and its location on map of Republic of Uzbekistan.

MATERIALS AND METHODS

Studying the hydrological regime of a reservoir involves various methods and techniques to assess water quantity, quality, and related parameters. Here are some common methods used in the study of the hydrological regime of a reservoir [5, 8].:

1) Flow Measurement:

Hydrometry: This involves measuring water flow rates using instruments like current meters, flow meters, and stage-discharge rating curves [1].

Weir and Flume Measurements: Using weirs and flumes to measure water flow over a structure with known characteristics can provide information about flow rates.

2) Water Level Monitoring:

Stage Gauges: Installation of gauges to monitor water levels regularly, helping track variations and trends over time [6].

Remote Sensing: Using satellite imagery or aerial surveys to monitor changes in water levels and surface area.

3) Meteorological Data Collection:

Weather Stations: Collecting data on precipitation, temperature, humidity, wind speed, and solar radiation to understand the impact of meteorological conditions on the reservoir [10].

4) Hydrodynamic Modeling:

Numerical Models: Using mathematical models to simulate water flow, sediment transport, and water quality within the reservoir [8].

5) Hydrological Forecasting:

Predictive Models: Developing models to forecast reservoir inflows based on meteorological data, historical patterns, and other relevant factors [15].

A comprehensive understanding of the hydrological regime often involves integrating multiple methods to capture the complex interactions within and around the reservoir.

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It's understood that reservoirs are constructed by filling natural depressions and basins outside the riverbed. When these depressions aren't sufficiently deep, the water capacity is increased by raising dams around them or deepening the basin. As they are situated outside the riverbed, water is brought in through specific canals. For instance, the Kuyimazar reservoirs under study are also filled using dedicated channels and are considered reservoirs [10-13].

The water quantity in reservoirs is not constant. Suppose it decreases due to various factors (such as evaporation from the water surface or seepage into the reservoir bed). In that case, this decrease is compensated for by additional water entering the reservoir (from rivers, canals, or atmospheric precipitation). The water balance of reservoirs is studied by considering these consumptive and replenishing elements [16-21].

RESULTS AND DISCUSSION

Over the studied years, the annual fluctuations in the flow dynamics of the channel feeding into the Kuyimazar reservoir varied. For instance, the highest average annual flow reached 11.2 m³/s between 2011 and 2018, while the lowest, recorded in 2003, was only 0.6 m³/s. That year, 6.8 m³/s of water was directed into the reservoir during February, March, and December (table 1).

TABLE 1. Dynamics of long-term inflow into Kuyimazar reservoir, m³/s.

Years	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Average
1999	4.2	13.4	1.7	0.7	0	3.2	0	0	0	7	19.6	15.2	5.4
2000	0	7.3	6.9	0	23.7	11.1	0	0	0.2	17.3	24.9	15.3	8.9
2001	2.1	0.8	0.4	0.5	13.9	5.2	0	6.2	24	3.1	0	0	4.7
2002	0	0.5	15.2	30	14.7	5.5	1	0	15	4.5	5	4.1	8
2003	0	2.5	3.6	0	0	0	0	0	0	0	0	0.7	0.6
2004	0	0	0	0	0	10.7	0	0	6.8	1.5	4.6	0	2
2005	0.2	0	0	0	3	13.9	0.8	0	0.8	6.4	3.3	0	2.4
2006	0	2.5	12	2	10	7.1	0	3.8	10.9	20.1	9.8	2.8	6.7
2007	0.6	2	3.9	50.2	2	1.8	0	0	4.7	10	12.7	15.6	8.6
2008	0	5.6	1.7	0	1.5	14.2	0	0	10.7	20	16	0	5.8
2009	1.4	28.8	12.5	7.5	10.3	0	0	0	0	4.2	0	0	5.4
2010	0	19.5	17.2	0	11.3	11	0	0	0	8.5	25.3	14	8.9
2011	0	13.3	10.7	0	16.1	11.3	0	10.1	50	23.2	0	0	11.2
2012	0	0	3.07	7.73	5.7	5.57	0	0	0	0	0.9	1.7	2.1
2013	0	3.17	47	8.83	0	0	0	0	0	6	22.6	2.4	7.5
2014	2.17	26.53	8.27	11.17	0	2.17	0	0	2.7	19.8	19.3	1.6	7.8
2015	0	33.77	21.3	0	0	0	0	0	0	14	24.2	8.8	8.5
2016	0	11.63	26.2	38.93	4.37	0	0	0	0	4.2	20.8	2.2	9.1
2017	0	14.17	15.63	15.8	19.3	6.5	0	0	0	0	14.8	14.4	8.4
2018	3.03	3	13.3	6	29.1	18.3	0	0	0	9.2	22.1	30.2	11.2
2019	0	0	0	14.9	10.7	22.5	0	0	0	0	0	13.4	5.2

The inflow into the reservoir exhibited irregular fluctuations throughout the months. For instance, the highest flow rate, reaching 50.2 m³/s, was recorded in April 2007 due to substantial rainfall, causing an increase in the channel's flow. The lowest value, observed in January 2005 during water regulation, amounted to 0.2 m³/s. The flow entering the reservoir through canals was not measured in certain months.

Using the data from the above table, the graph of the annual change of the dynamics of the amount of flow flowing into the Kuyimazar reservoir through the channel was studied (Fig. 2).

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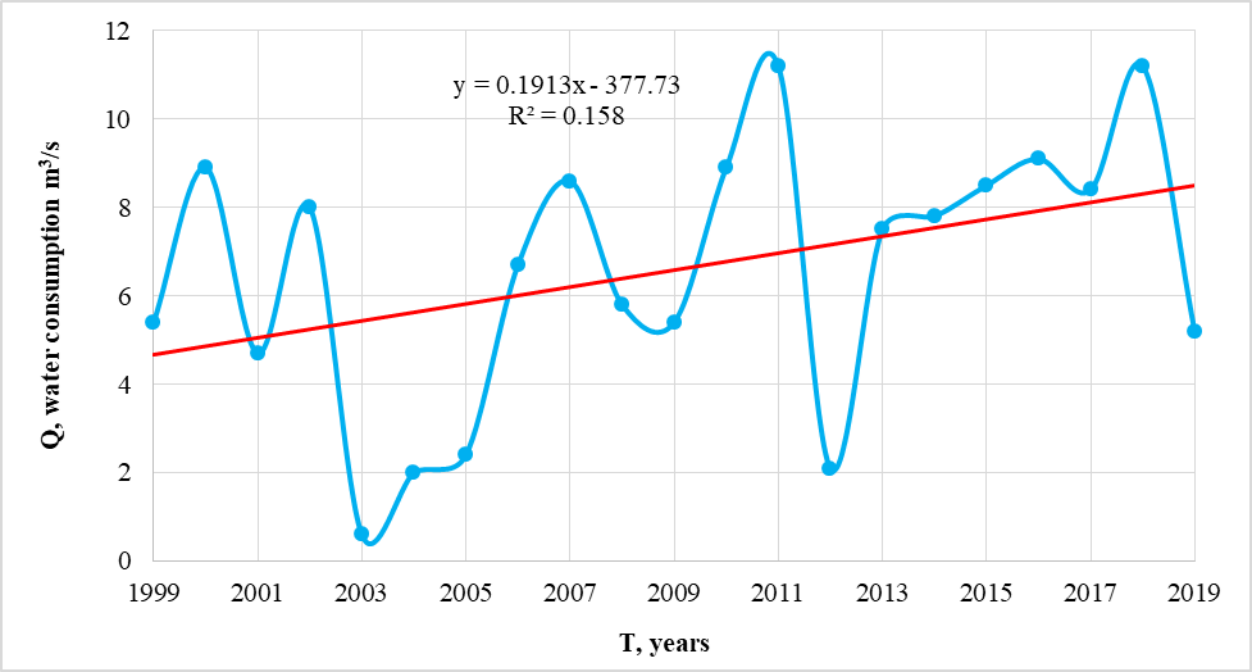


FIGURE 2. Flow dynamics of channel that flows into Kuyimazar reservoir

We can see from this picture that the annual fluctuation of the channel flow rate flowing into the Kuyimazar reservoir (1999-2019) corresponded to different values. The main reason for the uneven annual distribution of the flow of the channel flowing into the water reservoir is the different distribution of atmospheric precipitation over the years.

Also, as can be seen from the graph, the amount of water poured into the reservoir has been increasing over the years. Therefore, the water collected in the reservoir is effectively used in agriculture and other fields.

The water collected in the reservoir is delivered through special channels for irrigation, energy, water supply, and other purposes. Canals are built in different sizes depending on the function and the amount of water taken from the river. As mentioned above, the amount of water leaving the reservoir varies in different values. These changes mainly depend on the water demand. For example, in the spring, the amount of water flowing from the canal is somewhat larger and is used to irrigate cultivated fields. Very little water is poured into the canal in winter, mainly because water accumulates in the reservoir at this time.

We know that water is released from each reservoir through special channels, and water is supplied for various sectors of the national economy. The flow dynamics of these channels vary in different years. Based on the main tasks of the article, we will consider the changes in the dynamics of the flow leaving Kuyimazar reservoirs through channels.

To study the annual change of the flow coming out of the reservoirs, data on the amount of water taken from the Kuyimazar reservoir through the canal from 1999-2019 were collected (Table 2). The flow rate of the channel leaving the Kuymozore reservoir has changed dramatically, mainly covering the years 2000-2007.

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TABLE 2. Dynamics of annual flow volume of Kuyimazar reservoir, m^3/s

Years	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Average
1999	0.9	2	1.3	1.6	3.9	2.3	19.9	18.6	10.3	3	3	3	5.8
2000	2.8	3	3	16	0.1	3.5	24	21.6	10.4	2.1	2	1.8	7.5
2001	2.2	6.1	2.6	0	0	0	13.5	12.6	4.2	0	0	0	3.4
2002	5.9	2.8	0.7	0	0	0	0	0	0	0	0	0	0.8
2003	1.9	9.5	0	0	0	0	0	0	0.8	3	2.9	0	1.5
2004	0	0	0	0	0	1.9	3.5	3.4	1.2	0.9	3	3	1.4
2005	4.3	4	3.7	4.6	2.5	1	3.9	4	3.9	4	3.5	3	3.5
2006	3	3.1	3.7	4	4	4.4	10.5	14.3	4.1	3.5	3.5	3.5	5.1
2007	3.5	3.7	3.8	4	4	4	5	5	5	5	5	5	4.4
2008	5	5	5	9.2	5	5	12.3	19	6	4	4	4	6.9
2009	4	4	3.6	5	4.7	4	5	14.1	4.7	4.4	4	4	5.1
2010	4	4	4	4	3.6	3.5	12.5	18.8	14	0.6	1	1	5.9
2011	0.9	2.2	4.5	9.1	3	17.5	38	17.8	3	3	3	3	8.7
2012	3	3	3	3	3	3	9.4	20.1	4.7	4	4	3.6	5.4
2013	3	3	3	3	3	4.5	23.9	13.2	3.6	3	3	3	5.8
2014	3	3	3	3	3	4.5	19.7	14.4	2.9	3	3	7.9	5.9
2015	22	3	3	3.1	3	3.4	23.3	18.1	3	3	3	3	7.6
2016	24.9	10.2	3	2.2	2	3.7	22.8	20.7	5.3	3	3	3	8.7
2017	14.4	7.4	3	3	3	5.3	25.7	25.7	3.9	3	3	3	8.4
2018	13.1	3	3	3	3	3.8	29.2	29.1	4.1	3	3	3	8.4
2019	12.9	3	3	3	3	3	16.2	18.9	3	3	3	3	6.3

The maximum value of the flow from the reservoir through the channel is equal to 8.7 m^3/s, observed in 2006 and 2011. In 2011, the amount of water brought into the reservoir through the canal was equal to 11.2 m^3/s, while in 2006 it was equal to 6.7 m^3/s.

Based on the collected data, a graph of the annual change in the dynamics of the amount of flow leaving the Kuyimazar reservoir through the channel was drawn (Fig. 3).

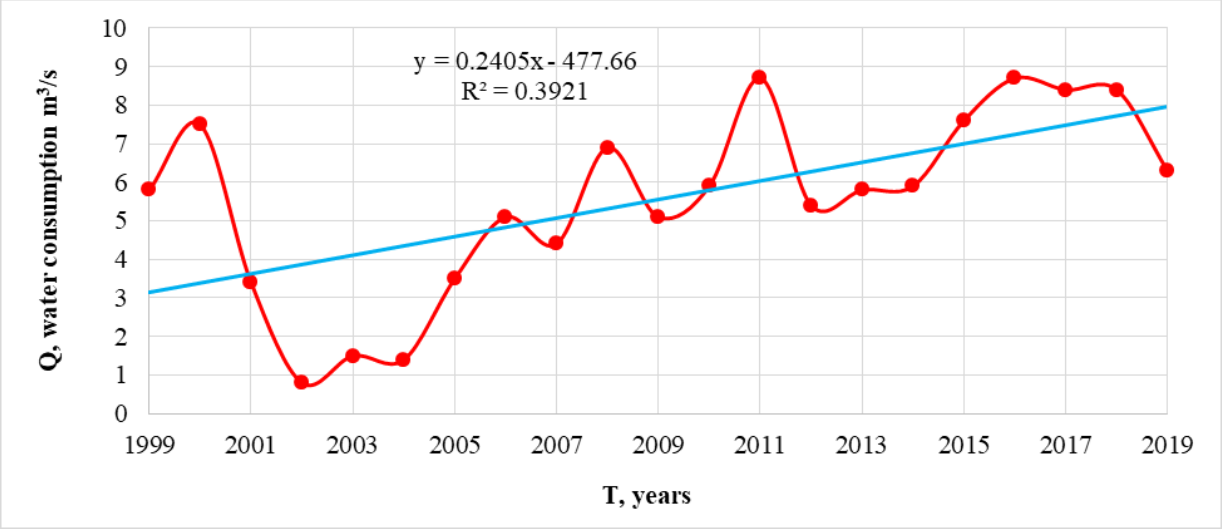


FIGURE 3. Dynamics of amount of flow leaving Kuyimazar reservoir through channel.

The hydrometeorological regime of the reservoir, i.e., the difference in the amount of water between the elements of the input and output part, was 1.8 m^3/s. In 2002-2004, the amount of water coming out of the reservoir was 0.8-1.5 m^3 per second, and we can see that this value is relatively low compared to other years.

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In general, in the seasonal and annual management of the Kuyimazar reservoir, it is important to collect the water that flows through the canals during the high water period and to use the collected water efficiently during the low water period.

The volume of water in a reservoir is not constant and varies due to several factors, such as evaporation from the water surface and seepage into the reservoir bed. This fluctuation is replenished by water sources, including inflow from rivers and canals, and atmospheric precipitation. The channels constitute the primary network for both consuming and replenishing the Kuyimazar reservoir, which is under study. Depending on the flow dynamics through these channels, the quantity of water collected in the reservoir fluctuates yearly [8, 10].

In this article, we analyzed the variations in the volume of water collected in the Kuyimazar reservoir between 1999 and 2019. Using the data from the tables, we created separate graphs illustrating the annual changes in the volume of water collected in the Kuyimazar reservoir within the basin and during typical years.

The volume of water stored in the Kuyimazar reservoir has varied significantly over the years. Specifically, the highest volume recorded in the reservoir was 303.4 million m^3 in 2006, whereas the lowest value was observed in 2018, amounting to 186 million m^3 (Table 3).

TABLE 3. Yearly changes in volume of water collected in Kuymazar reservoir.

Years	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Average
1999	218	258	258	295	281	280	238	169	165	123	160	209	221.2
2000	221	217	232	237	220	282	181	107	129	108	159	216	192.4
2001	234	226	219	213	217	257	228	133	185	203	200	189	208.7
2002	156	127	152	225	286	282	278	273	282	294	300	311	247.2
2003	313	289	299	293	293	293	293	293	293	286	281	279	291.1
2004	279	279	279	279	279	296	295	285	290	292	292	292	286.4
2005	288	280	280	269	262	299	312	306	304	296	310	309	292.9
2006	302	296	304	309	307	328	314	266	286	294	316	319	303.4
2007	311	301	305	307	303	299	288	269	270	268	277	307	292.1
2008	306	302	304	244	228	242	231	173	180	183	213	218	235.3
2009	212	236	263	290	311	306	297	266	261	230	226	215	259.4
2010	203	206	236	258	254	295	282	227	221	167	209	252	234.2
2011	264	269	284	247	256	289	198	123	208	286	297	290	250.9
2012	284	277	276	289	293	306	290	240	210	198	187	182	252.7
2013	176	171	241	302	293	283	233	174	157	153	195	212	215.8
2014	232	253	268	298	294	290	247	208	179	205	248	256	248
2015	198	225	301	299	291	281	233	159	138	143	188	225	223.7
2016	182	138	188	288	309	301	258	189	158	125	181	197	209.6
2017	175	150	227	240	283	300	244	161	128	116	122	162	192.4
2018	145	153	195	193	231	235	241	157	119	120	156	224	186
2019	229	202	193	201	238	295	271	216	191	178	166	177	198.1

Using the data from this table, a diagram depicting the annual variation in the volume of water collected in the Kuyimazar reservoir was generated (Fig. 4). As depicted in the diagram, the highest values of water collected in the reservoir correspond to the years 2003-2007.

Analysis of the graph indicates that the volume of water collected in the Kuyimazar reservoir was 302 million m^3 in January 2006, during high water levels. This volume gradually increased in the subsequent months, peaking at 328 million m^3 in June, then declining to 266 million m^3 in August. It then rose to 286 million m^3 in September and reached 319 million m^3 in December.

In January 2011, during average water levels, the volume of water collected in the reservoir was 264 million m^3. It increased to 284 million m^3 by March and slightly decreased to 256 million m^3 in April and May. By June, it reached 289 million m^3, but in August, it hit its lowest point at 123 million m^3. As mentioned earlier, the reservoir's water volume began to rise again from September, reaching its peak at 297 million m^3, corresponding to November.

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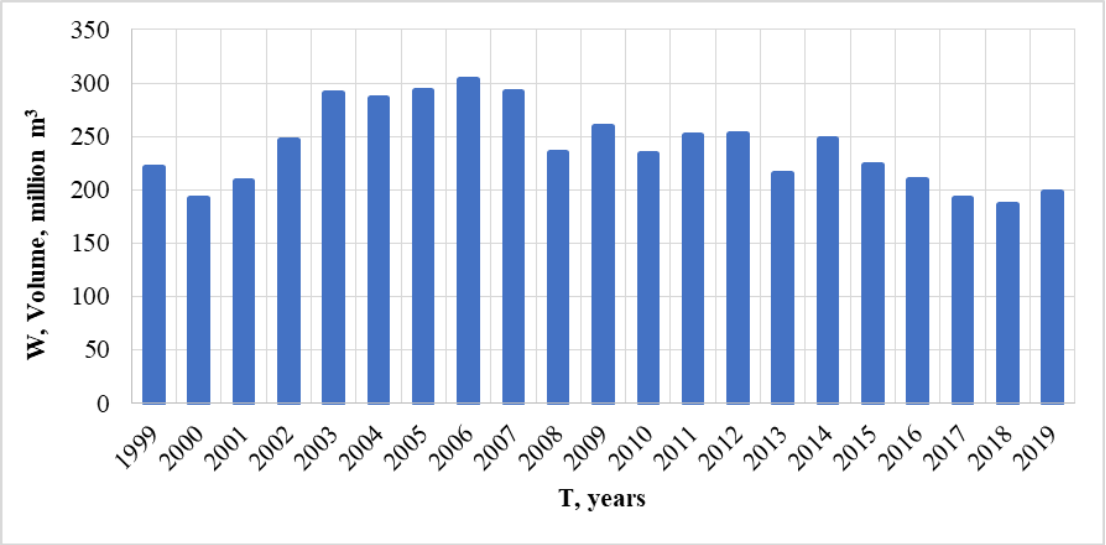


FIGURE 4. Yearly changes in volume of water collected in Kuyimazar reservoir.

Using the data concerning variations in the volume of water accumulated in the Kuyimazar reservoir over the years under study, specific years were chosen as benchmarks: 2006 representing abundant water, 2011 depicting average water levels, and 2018 reflecting minimal water levels. Graphs illustrating the changes in the volume of water accumulated in the reservoir were drawn and analyzed based on these characteristic years (Fig. 5).

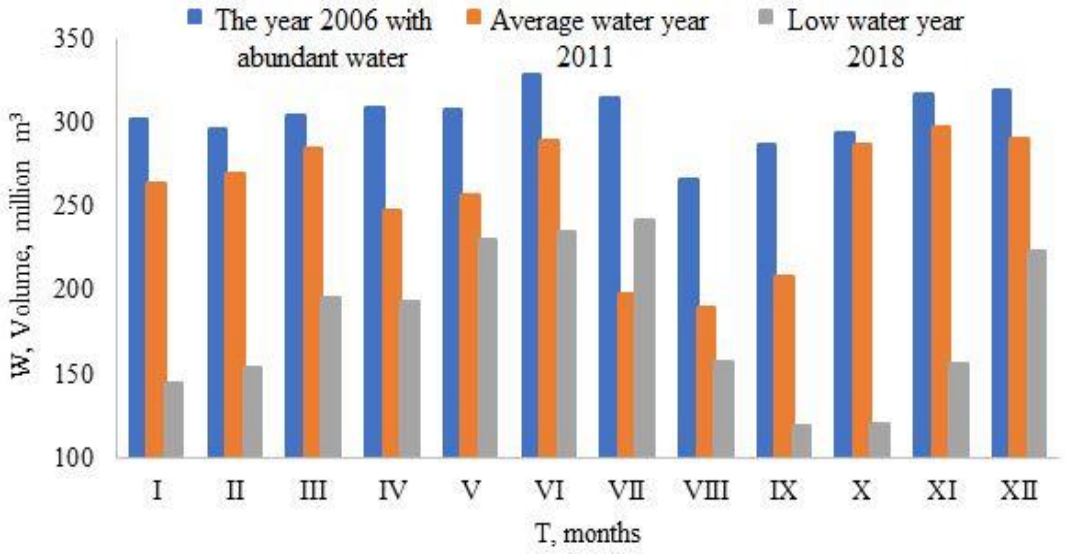


FIGURE 5. Variations in volume of water collected in foundry reservoir for typical years.

In January 2000, a year marked by low water levels, the volume began at 221 million m^3 and steadily increased, reaching its peak at 282 million m^3 by June. However, in August, the volume dropped to 107 million m^3.

The temperature regime of water reservoirs is studied in two aspects: the water surface and depth. The water surface temperature in reservoirs begins to increase during the spring months. The annual variation in water surface temperature depends on factors such as the volume and temperature of water added to the reservoir and the conditions governing its filling or emptying.

One crucial task in studying a reservoir's temperature dynamics is to ascertain the water temperature in its surface layer. Numerous pieces of literature propose methodologies for monitoring the temperature regime of water reservoirs or determining the parameters influencing it [7, 11]. For instance, under the conditions of Uzbekistan, F.A. Gapparov recommended the following equation to determine the surface temperature of the reservoir [9, 11]:

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$$t_{water} = 0{,}78 \cdot t_{moon,air} + 0{,}17 \cdot t_{the\ air} - 0{,}19 \cdot (h : h_{MDS}) \cdot [(t_{the\ air})_{n+1} - (t_{the\ air})_{n-1}] \quad (1)$$

here:

$t_{moon.water}$ is average monthly water temperature, °C;

$t_{the\ air}$ is average annual air temperature, °C;

$(t_{the\ air})_{n+1}$ and $(t_{the\ air})_{n-1}$ are average monthly air temperature in the month preceding and following the month under consideration, °C;

h is average monthly depth of the reservoir, m;

h_{MDS} is average depth of the reservoir in MDS, m;

The suggested formula for computing the average monthly temperature of the reservoir's surface layer considers the average monthly and yearly air temperatures, variations in air temperature over time, and alterations in reservoir depth based on the water level.

Utilizing the formula above, the average monthly surface temperature of the Kuyimazar reservoir for 2016 was computed (Table 4).

TABLE 4. Average monthly temperature of surface of Kuyimazar reservoir.

Indicators	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year
Air temperature, °C	6.8	7.8	13.5	16.2	23.4	28.0	29.5	27.6	23.5	12.3	6.1	5.2	16.7
Water surface temperature, °C	8.5	10	14.8	17.4	23.6	25.8	25.8	24.8	20.0	10.6	6.3	6.4	16.2

The average annual temperature on the reservoir's surface was 16.2 °C, which is lower than the average annual air temperature recorded at the meteorological station (16.7 °C).

The highest water surface and air temperature values correspond to the summer seasons. It is known that the opposite process occurs in the lower, i.e., deep layers of the reservoir. This phenomenon is crucial in studying the variations of water within the reservoir basin concerning depth.

Based on the obtained results, the relationship between the surface temperature of the Kuyimazar reservoir and the air temperature was studied (Fig. 6).

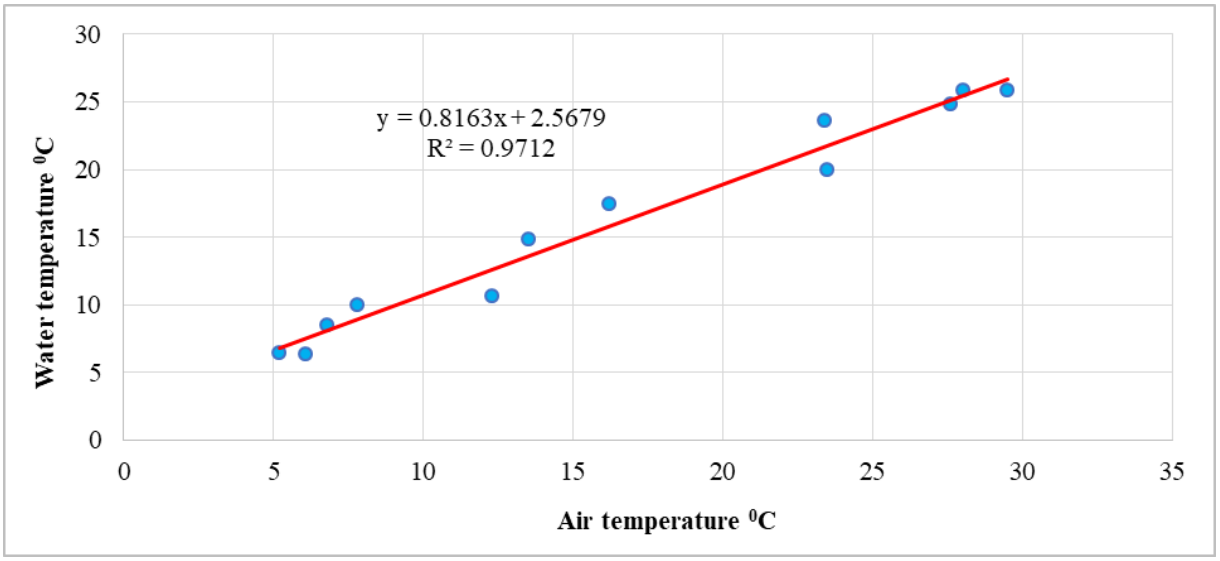


FIGURE 6. Kuyimazar reservoir graph of relationship between water surface temperature and air temperature.

Similar to the seasonal changes in air temperature, the reservoir water's surface temperature also varies according to the air temperature. In most cases, the temperature of the reservoir's surface layer rises or falls according to the air temperature in the reservoir area. However, as the reservoir deepens, the water temperature begins to change opposite to the air temperature in the area.

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For example, when the air temperature rises during the summer, the water temperature at depth begins to cool down compared to the external temperature. Conversely, when the air temperature starts to cool down in the winter, the water temperature at depth warms up (Fig. 7).

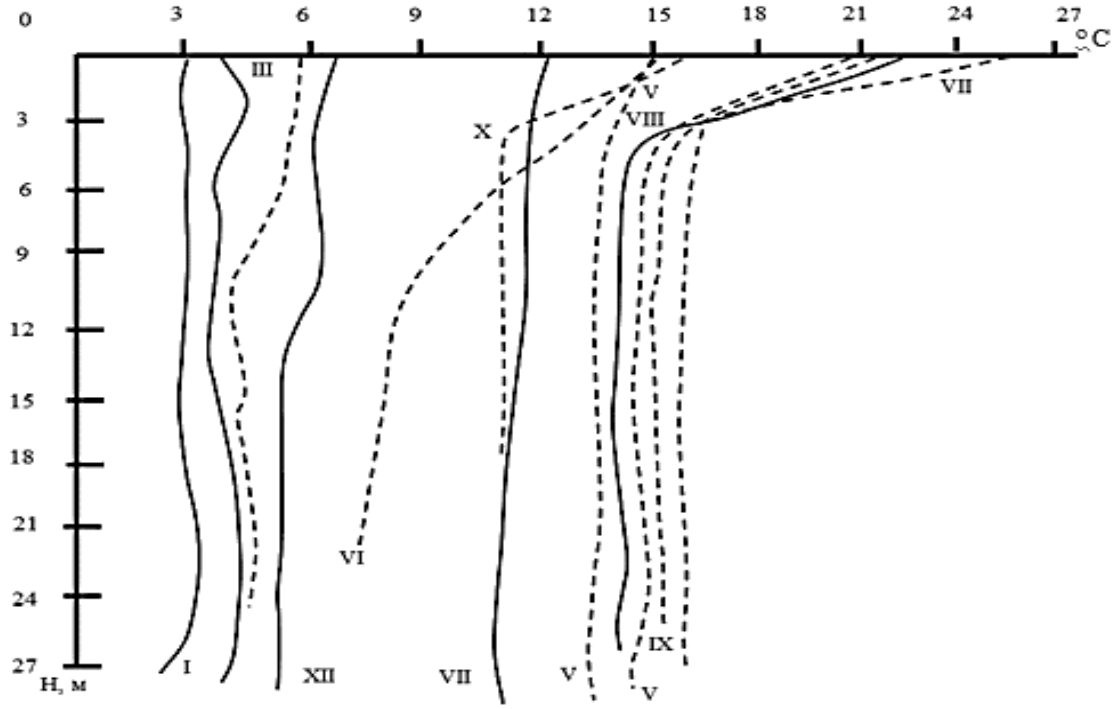


FIGURE 7. Variation of temperature in reservoir with depth.

In most reservoirs, due to well-mixed water masses across different layers, their temperatures vary minimally with depth throughout the year. Only at the end of spring and the beginning of summer, when the water level reaches its peak, can temperature changes be observed at various depths in almost all reservoirs in the mountainous regions of Uzbekistan [13, 15].

Overall, alterations in the reservoir's temperature regime can lead to adverse consequences. This situation can impact the water quality within the reservoir, the proliferation of algae in its basin, and the elevation of air temperatures. These negative effects are particularly swift in the shallow areas of the reservoir basin.

CONCLUSION

1. The annual fluctuations in the flow dynamics of the channel entering the Kuyimazar reservoir exhibit diverse values. The highest average multi-year water consumption corresponds to 2011, at 11.2 m^3/s, while the lowest value, 0.6 m^3/s, was recorded in 2003;
2. In the seasonal and annual management of the Kuyimazar reservoir, it is crucial to collect the water flowing through the canals during the high-water period and effectively utilize the collected water during the low-water period.
3. The water quantity values in the Kuyimazar reservoir during periods of high, average, and low water range from 107 to 328 million m^3.
4. The change in temperature with Kuyimazar reservoir depth was analyzed. The highest temperature recorded was 25°C in July, while the lowest was 3°C in January.

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