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RESEARCH ARTICLE
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Methodological Foundations for Assessing the Water Management Balance of Water Bodies in the Tobyl River Basin

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ABSTRACT

The study estimates the water and water management balance of the Tobyl River basin in the Kostanay region, Kazakhstan in the context of non-stationary climate and river flow conditions. The research aims to determine the current deficit and surplus of water resources to develop recommendations on regional water supply needs, especially for urban territories and agricultural sectors. Hydrometeorological data from regional monitoring stations were analyzed using probabilistic statistical methods. The Mann-Kendall test is applied to assess long-term trends in river flow. A comprehensive water balance model is developed for the reservoirs of the Tobyl River. The study shows statistically significant upward trends in water consumption at the Tobyl-Kostanay and Tobyl-Grishenka stations from 1972 to 2021. The developed water management balance indicates that in average and high-water years, the Tobyl River reservoirs accumulate water, and low-water years (95% non-exceedance probability) are marked by water shortage. Evaporation accounts for a significant share of water losses in the reservoir system, especially in low-water years. The findings underscore the urgent need for advanced water-saving methods and adaptive water resource management strategies to mitigate the consequences of water shortage, especially in low-water years. To ensure a stable water supply in the region, it is recommended to strengthen the coordination of transboundary water resources use and employ technological solutions.

Keywords: Water management complex; Water balance; Water management balance

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INTRODUCTION

One of the most important activities of the UN has long been the struggle against the global crisis caused by the underdevelopment of the water supply system, critical to meeting basic human needs (Asadulagi et al., 2024). The problem is further aggravated by the rising demand for water for domestic use and commercial and agricultural activities (Yernazarova et al., 2023). According to a recent report prepared by the participants and partners of the UN Water mechanism and published by UNESCO, 2.2 billion people live without access to pure drinking water, and 3.5 billion do not have access to safe sanitation facilities. As the global water crisis progresses, ensuring equal and sustainable access to water resources has become a crucial goal for national governments and international organizations, which includes the UN Sustainable Development Goals to achieve universal access to clean water and sanitation by 2030. Many regions, particularly those with developing and transition economies, face significant obstacles to achieving these goals (Mustafayev et al., 2024).

Kazakhstan's arid and semi-arid climate combined with the uneven distribution of water resources poses a serious obstacle to sustainable water supply. Kazakhstan's water resources are considerably dependent on Transboundary Rivers, and its rapid economic development has led to an increase in water consumption

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by the agricultural, industrial, and municipal sectors. These problems are exemplified by the Tobyl River basin in the Kostanay region (Abuduwaili et al., 2021). The basin has experienced major interventions in water resources management, including the construction of reservoirs to regulate river flow and ensure water supply for agricultural, industrial, and municipal needs. The basin water resources are subjected to increasing pressure due to rising temperatures, fluctuations in precipitation patterns, and intensive water use for irrigation and industrial purposes (Tleubergenova et al., 2023).

The creation of large reservoirs in river basins leads to significant changes in the components of ecological systems and water exchange processes in the adjacent basin areas and the formation of new natural-technogenic systems in river-reservoir basins (Musabekov et al., 2018). The theoretical and practical significance of studying these reservoirs is connected with the optimal resolution of the problem of rational water use and water resource protection.

As indicated by several researchers (Uryvaev, 1959; Vendrov, 1979; Vuglinskii, 1981, 1991; Babkin & Vuglinskii, 1982; Voropaev & Avakian, 1986; Shiklomanov, 1989; Skaugen et al., 2012), total water resources in basins do not decrease under the influence of reservoirs, but moisture reserves are redistributed between the main components of water exchange. A river basin is not an isolated natural complex. Atmospheric moisture transport plays a dual role in the river basin's water cycle: it brings external moisture into the basin, while simultaneously carrying a portion of the moisture evaporated within the basin to areas beyond its boundaries via air currents (Yapiyev et al., 2019). Whereas a cascade of large reservoirs built in the basin cannot change the moisture reserves in the inflow of atmospheric air into the basin, the water vapor generated by additional evaporation from the flooded and submerged areas has to be carried outside of the basin. If this transfer does not occur, the additional moisture evaporating from the basin turns into precipitation, enters the river network, and compensates for the moisture expended on additional evaporation due to the creation of reservoirs. River flow decreases not only when reservoirs are filled, but also in the course of their operation. This loss owes to the fact that the water vapor formed by additional evaporation in the basin is released outside the basin. The occurrence of this process in the Tobyl River basin is still poorly understood (Cao et al., 2024).

Our study focuses on the dynamics of water balance and water resource management in the Tobyl River basin in the context of non-stationary climate and river flow conditions. The study aims to outline the water management balance to establish the deficit or surplus of water resources in the Tobyl River basin, substantiate measures to meet the needs of water users and consumers, and develop measures to improve the effectiveness of water management systems.

MATERIALS & METHODS

Region and Objects under Study

The Tobyl River basin is located in the Kostanay region, characterized by a semi-arid and continental climate (Fig. 1). The basin is critical for agricultural production and supports several urban centers including Kostanay, Rudny, and Lisakovsk. The region’s water resources are heavily influenced by climatic variability, with significant seasonal fluctuations in precipitation and temperature. Several reservoirs have been constructed since the 1960s to address these challenges, regulate river flow, and meet growing water demands. The basin remains vulnerable to water scarcity during dry years, which necessitates a comprehensive assessment of the water balance.

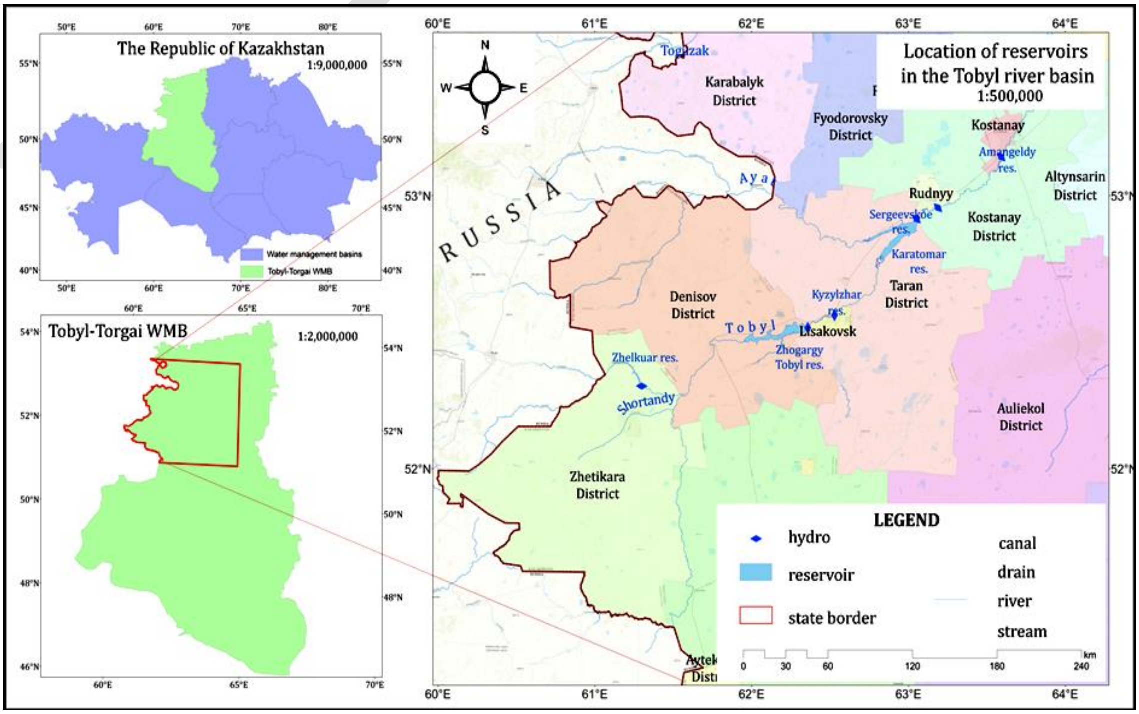


Fig. 1: The Tobyl-Torgai water management basin

The Tobyl River basin is located deep in the continent and is remote from oceans and seas. Due to the absence of high natural barriers in the north and south, the territory is exposed to the flow of warm and dry subtropical air from the deserts of Kazakhstan and Central Asia and cold and moisture-poor Arctic air traveling in the meridional direction. The access of humid Atlantic air masses is hindered by the Ural Mountains, and Pacific air masses are blocked by the Middle Siberian Plateau and the Altai mountain massifs. As a result, the climate is sharply continental, with cold and snowy winters. The average annual air temperature varies from 1.2°C in the north to 4.4°C in the south.

Source Data

Our study relies on the data of hydrometeorological observations from stations and posts belonging to the stationary network of the Kazhydromet Republican State Enterprise in the Tobyl River basin and stock materials of the Committee on Water Resources of the Republic of Kazakhstan. The methodological and theoretical foundation of the study consists of scientific works and policy documents on the economic and social development of the Kostanay region (Chebotarev, 1966; Gerasimov, 1969; Kazhydromet website, n.d.; Nauchno-prikladnoi spravochnik po klimatu SSSR, 1989a, 1989b; Galperin, 2012; Alekseicheva, 2019; Committee for Construction and Housing and Communal Services of the Ministry of Investment and Development of the Republic of Kazakhstan, 2017; Ekonomicheskii obzor, 2019).

Assessment of the Flow Regime of the Tobyl River

Flow changes under the influence of the cascade of reservoirs on the Tobyl River were assessed at the Kostanay city dam site through the method of hydrological analogy based on the following dependence (1):

$$Q = f(Q_a) \quad (1)$$

where Q is the annual flow of the Tobyl River near Kostanay; Q_a is the sum of annual water outflows from the Tobyl River near Grishenka village and the Ayat River near Varvarinka village.

According to regulatory documents (Mezhgosudarstvennye svody pravil, 2005; Rozhdestvensky et al., 1984; State Construction Committee of Russia, 2004), the flow of the river can be reconstructed based on ordinary pairwise correlation (1) and using double integral curves of the flow in the following form (2):

$$\sum_{1}^{n} Q = f\left(\sum_{1}^{n} Q_a\right) \quad (2)$$

Trends in the river flow over the studied period were identified using the non-parametric Mann-Kendall test. This method is widely used to discover monotonic trends in hydrological and climatic data. The test was applied to data on the flow of the Tobyl River at the key hydro posts Tobyl-Grishenka and Tobyl-Kostanay over two time periods: 1931-1971 and 1972-2021. The trend analysis allowed us to detect statistically significant changes in water flow, particularly increases or decreases in flow rate over time.

The null hypothesis (H_0) for this test is that the time series of river flow data shows no trends (upward or downward), meaning that the observed changes in flow are attributed to random fluctuations and not a fundamental trend.

After testing the time series for trends, an important and critical step is to test for homogeneity. Thus, the examined time series of observations of the Tobyl River flow were tested for homogeneity. The homogeneity assessment of the statistical characteristics of the Tobyl River flow time series was conducted using the Student, Fisher, and nonparametric Wilcoxon tests.

Evaporation from the water surface. The assessment of evaporation is necessary to determine the water balance of a water body or a territorial basin. Evaporation from the water surface can be estimated using several methods. This considerable range of methodologies owes to the fact that the complex mechanism of interaction between the water surface and the adjacent air mass has not yet been exhaustively described (Ministry of Natural Resources of the Russian Federation, 2007).

Evaporation from the water surface of the reservoir is the main component of the consumption part of its water balance (evaporation is the process by which the molecules of a liquid leave its surface and enter a gaseous state; a key role in this process is played by air temperature). Using data from the weather stations in the Tobyl River basin, specifically in Zhetikara, Kostanay, Karasu, Kushmurun, and Dievsky, we analyzed the temperature regime from the beginning of instrumental observations until 2023. We used the average monthly values of air temperature. The analysis showed that the coefficient of determination of the trend line estimated from annual average air temperature values ranged from 0.31 to 0.52. However, when plotting 10-year moving averages of air temperatures, this coefficient increased to values from 0.84 to 0.95.

Water management balance in the areas over the 10 years, representing a quantitative comparison of the available water resources and demand for them, was obtained from the Kazvodkhoz stock materials. The basis of the inflow part of the water management balance is river flow from upstream areas. For the Verkhnetobolskoye reservoir, this is the flow of the Tobyl River near the Grishenka dam site and precipitation on the reservoir surface. For the Karatomarskoye reservoir, the inflow part of the balance is provided by the flow of the Ayat River near the Varvarinka dam site and the release from the Verkhnetobolskoye reservoir. The major share of consumption is the volume of water abstracted from reservoirs, evaporation and filtration losses, and the water protection release into the downstream pool.

RESULTS

Table 1 presents the results of the Mann-Kendall test indicating the presence or absence of significant upward and downward trends on the key hydro posts, including Tobyl-Grishenka, Ayat-Varvarinka, and Tobyl-Kostanay. Based on the results, the Mann-Kendall trend test rejects the null hypothesis (H0) in the following two cases.

Table 1: Trend analysis of annual river discharge using the Mann-Kendall test (1931-2021)

Name of gauging stations	Period	Z (variation value of S)	P (maximum value of lag)	S (Kendall coefficient)	Tau T(S/D)	D (maximum value of S)	Test interpretation*
Tobyl-Grishenka	1931-2021	0.45939	0.646	135.00	0.032975	85,083	SNST
Ayat-Varvarinka	1931-2021	-0.19542	0.8451	-58.00	-0.014172	85,080	SNST
Tobyl-Kostanay	1931-2021	-0.88108	0.3783	-258.00	-0.063027	85,082	SNST
Tobyl-Grishenka	1931-1971	0.90979	0.3629	82.00	0.100	7,927	SNST
Ayat-Varvarinka	1931-1971	0.73017	0.4653	66.00	0.0806	7,925	SNST
Tobyl-Kostanay	1931-1971	0.42684	0.6695	39.00	0.0476	7,926	SNST
Tobyl-Grishenka	1972-2021	1.9993	0.04558	240.00	0.1959984	14,291	SSUT
Ayat-Varvarinka	1972-2021	0.81148	0.4171	98.00	0.0801	14,289	SNST
Tobyl-Kostanay	1972-2021	2.6768	0.007434	321.00	0.2620	14,292	SSUT

SNST: Statistically Non-significant trend. Statistically significant upward trend: SSUT; *Significant at 5%

Tobyl-Grishenka (1972-2021): The p-value (0.04558) is lower than the common significance level (usually 0.05). This statistically significant result ($P<0.05$) indicates the rejection of H_0 (no trend) and the presence of a trend in the discharge data. Further analysis of Kendall's tau (0.1959984) suggests a weak to moderate upward trend in discharge.

Tobyl-Kostanay (1972-2021): Similar to the findings for Tobyl-Grishenka, the Mann-Kendall test shows a statistically significant trend (P-value=0.007434, $P<0.05$). This suggests the rejection of H_0 (no trend) in favor of an alternative hypothesis indicating a trend in the data. Kendall's tau (0.2620408) is positive, suggesting an upward trend. Compared to Tobyl-Grishenka, the higher tau value indicates a stronger upward trend in discharge. The results of homogeneity testing are shown in Table 2.

Testing the series for homogeneity has allowed us to conclude their homogeneity across all periods based on the mean value and the Wilcoxon test. The empirical values of Student's criterion for all posts do not exceed its critical values. The assessment of time series variance homogeneity using Fisher's criterion shows that at the 1% significance level, the flow of the Tobyl River in the periods does not always have homogenous variances. This test does not reject the hypothesis of the homogeneity of the sample variance for 1972-2021. The empirical value of Fisher's test for the compared series F_{emp}=1.66-1.76 is less significant compared to its critical value for the examined conditions F=2.27. Heterogeneity in variance is detected in the data of the Tobyl-Grishenka post for 1931-1972 and the Tobyl-Kostanay dam site for the multiyear period 1931-2021 and the conditionally natural period 1931-1971. The same result is obtained for the Ayat-Varvarinka dam site. Since Student's test is more informative, the time series should be considered statistically homogenous.

The additional analysis of temperature time series for various time intervals allowed us to identify directional changes in air temperatures annually and in the context of cold and warm seasons. Long-term temperature changes were divided into two periods starting from 1985. Their comparison demonstrates that from 1986 to 2023, average air temperatures were 0.1-3.0°C higher compared to the period before 1985. The difference in temperature values amounted to 2.0-3.0°C in the cold season and 0.1-0.8°C in the warm season. This indicates a marked increase in air temperatures in the region over the last decades, especially during winter.

Losses to evaporation from the reservoir surface are composed of two parts: evaporation from the open water surface in the warm period and evaporation from snow and ice on the frozen reservoir surface. Evaporation from the snow surface on reservoir ice from the time of ice formation to the point of maximum snow accumulation is measured directly during snow measurement surveys and is not considered in this article. Evaporation from the snow and ice surface from the beginning of the snowmelt to the disappearance of ice on the reservoir is insignificant.

Evaporation is a determining parameter in developing specific schemes for the rational use of water and land resources for optimal logistic development of the regional economy. While some researchers define evaporation as evaporation from the water surface, others consider it the maximum possible evaporation from an optimally wetted land surface.

The first map of annual evaporation isolines for Kazakhstan according to the Budyko-Zubenok method was created by M.H. Sarsenbayev. This map has scientific and practical significance, covering changes across all landscapes in Kazakhstan (Sarsenbaev & Kaldarbekova, 2014; Smagulov et al., 2019). Monthly evaporation values according to the Budyko-Zubenok method for the forest-steppe zone are provided in Table 3.

The values of evaporation from the water surface in some years may differ from their mean annual values due to the varying duration of the ice-free period and variability of the main meteorological elements determining the intensity of evaporation from year to year. However, the variability of evaporation values for water bodies is relatively small and is characterized by the coefficient of variation 0.08-0.11. The coefficient of asymmetry is equal to *2Cv*. The volume of evaporation with varying non-exceedance probability can be assessed using the ratio of evaporation to mean evaporation, i.e., the modular coefficient (Table 4).

For the studied cascade of the Tobyl River reservoirs, the value of evaporation from the water surface over the warm period is as follows: the mean value – 721mm, for 3% non-exceedance probability – 865mm, and for 5% non-exceedance probability – 844mm. The distribution of evaporation by months during the ice-free period is determined by the hydrometeorological conditions and the water body's depth. Monthly evaporation from water bodies on the studied territory can be found in Table 5. Table 6 shows the distribution of evaporation by months in fractions of the total.

In water management calculations, the lowering of the water level in drainless reservoirs is assessed by determining the difference between evaporation and

Table 2: Testing of the annual flow of rivers in the Tobyl River basin for homogeneity

River-point	Period	Fisher		Student		Wilcoxon			Homogeneity testing		
		F	Fa	t	ta	U	U1	U2	Fisher	Student	Wilcoxon
Tobyl-Grishenka	1931-2021	1.60	1.87	0.13	1.98	989	788	1,282	homogenous	homogenous	homogenous
	1931-1971	4.15	2.74	0.82	2.04	177	135	285	non-homogenous	homogenous	homogenous
	1972-2021	1.76	2.27	0.56	2.01	233	211	414	homogenous	homogenous	homogenous
Tobyl-Kostanay	1931-2021	2.60	1.87	1.70	1.99	1,197	788	1,282	non-homogenous	homogenous	homogenous
	1931-1971	3.55	2.74	0.86	2.04	199	135	285	non-homogenous	homogenous	homogenous
	1972-2021	1.66	2.27	0.49	2.01	198	211	414	homogenous	homogenous	homogenous
Ayat-Varvarinka	1931-2021	2.56	1.87	0.90	1.99	1,023	788	1,282	non-homogenous	homogenous	homogenous
	1931-1971	4.17	2.74	1.22	2.04	211	135	285	non-homogenous	homogenous	homogenous
	1972-2021	1.68	2.27	0.37	2.01	260	211	414	homogenous	homogenous	homogenous

Table 3: Evaporation values calculated according to the Budyko-Zubenok method,mm (Shagidullin et al., 2011)

Natural zone	Month												Year
	1	2	3	4	5	6	7	8	9	10	11	12	
Forest-steppe	0	1	10	68	121	149	139	120	84	40	6	1	739

Table 4: The modular coefficient of evaporation over the ice-free period

Non-exceedance probability, %	1	3	5	10	25	50	75	90	95	97	99
Modular coefficient	1.25	1.20	1.17	1.13	1.07	1.00	0.93	0.87	0.84	0.82	0.78

Table 5: Coefficients of the distribution of evaporation over the ice-free period by months

IV	V	VI	VII	VIII	IX	X	XI
0.092	0.164	0.202	0.188	0.162	0.114	0.054	0.008

Table 6: Distribution of evaporation over the ice-free period by months (as a fraction of the total)

Evaporation, mm	Month								
	V	VI	VII	VIII	IX	X	XI	III	VI
Norm (721)	118	146	136	117	82	39	6	10	67
3% non-exceedance probability (865)	142	175	163	141	99	47	7	12	80
5% non-exceedance probability (844)	139	171	159	137	96	46	7	11	78

Table 7: Modular coefficients of evaporation rate minus precipitation $U_0 = h_{0ev} - h_{0pr}$

$U_0 = h_{0ev} - h_{0pr}$, cm	Non-exceedance probability, %								
	1	3	5	10	25	50	75	90	95
48	1.43	1.36	1.32	1.27	1.16	1.02	0.86	0.71	0.61
49	1.39	1.33	1.29	1.24	1.14	1.03	0.88	0.75	0.67
51	1.35	1.29	1.25	1.20	1.11	1.03	0.90	0.79	0.73

Table 8: Difference between evaporation and precipitation with different non-exceedance probabilities

$U_0 = h_{0ev} - h_{0pr}$, cm	Non-exceedance probability, %								
	1	3	5	10	25	50	75	90	95
48	69	65	63	61	56	49	41	34	29
49	68	65	63	61	56	50	43	37	33
51	69	66	64	61	57	53	46	40	37

precipitation (cm). The variability of this difference is higher than the variability of evaporation and is determined by the coefficient of variation 0.12-0.22. The asymmetry coefficient is equal to -0.21-0.53. The norm of evaporation minus precipitation in the Kostanay region varies from 48 to 64 cm.

The modular coefficients of the norm of evaporation minus precipitation with varying non-exceedance probability are given in Table 7. Table 8 shows the difference between evaporation and precipitation in years with different water content.

Average multiyear losses from the Tobyl reservoir cascade to evaporation. The area of the water surface at normal retaining level (NRL) is 200.11mln.m^2. Taking the average value of the evaporation layer from the water surface equal to 48 cm, total evaporation losses amount to 96.0mln.m^3. In dry years with 5% non-exceedance probability of evaporation from the water surface, evaporation losses reach 47.0mln. m^3, and in very dry years with 3% non-exceedance probability of evaporation from the water surface – 51.0mln.m^3.

Naturally, factual evaporation losses can be lower, since the water area typically reduces by the start of autumn. In early summer, the water body can be below the NRL. The current water management balance of the Tobyl River reservoir cascade is provided in Table 9. Water inflow to the cascade of reservoirs is calculated according to the data of the Tobyl-Grishenka and Ayat-Varvarinka hydrological stations. The inflow part of the water management balance is as follows: in dry years with 97% non-exceedance probability – 61.72mln.m^3, in low-water years with 75% non-exceedance probability – 153.58mln.m^3, in years with 50% non-exceedance probability – 306.81mln.m^3, and in high-water years with 25% non-exceedance probability – 601.06mln.m^3. In dry and arid years, the reservoir is depleted, and in years with a water content of 50% and below, it accumulates water. The current water balance of the Tobyl River basin in years with different water content is given in Table 10.

When the non-exceedance probability is high (approximately more than 75%), the entire volume of high water irrespective of the previous years' water content is used for water consumption. Years with 50% non-exceedance probability and lower allow creating reserves. In years with average water content, the reservoir is replenished with 530.93mln.m^3 of water, which amounts to 38% of the usable volume of the Tobyl River reservoir cascade. In average water content years, water can also be released during flooding.

The filling of the cascade of reservoirs is regulated by the inflow volume. The replenishment of the reservoir with river flow is achieved at 50% non-exceedance probability and below. The NRL mark can only be reached in years with low non-exceedance probability.

Filtration losses from the reservoir are not considered, largely due to the fairly wide distribution of loamy soils and siltation of the reservoir bed (the layer of silty sediments at the bottom of the reservoir reaches 0.5-1.0m). The annual evaporation layer from the water area of the reservoir cascade is 0.739m. The volume of evaporation from the water surface in an average climatic year with the reservoir area at the NRL equals 47.0mln.m^3. Real evaporation losses can naturally be lower, as the area of water typically shrinks by the start of autumn, and in early summer, the water body can be below the NRL.

The volume of industrial and drinking water supply includes the abstraction of water from the reservoir as

Table 9: Water management balance of the reservoir cascade of the Tobyl River

Years with varying water content	Inflow part, mln. m^3				Consumption part, mln. m^3			Idle discharge, mln. m^3	Accumulation, mln. m^3
	Total	Inflow	Precipitation	Snow on ice	Total	Evaporation	Abstraction of water from the reservoir		
Very low-water year, 95% non-exceedance probability Ppr=95% Pev=5%	61.72	24.32	29.0	8.4	273.1	47.0	26.1	200.0	-211.38
Low-water year, 75% non-exceedance probability Ppr=75% Pev=25%	153.58	94.08	47.4	12.1	273.1	47.0	26.1	200.0	-119.52
50% non-exceedance probability year Ppr=50% Pev=50%	306.81	234.21	57.0	15.6	273.1	47.0	26.1	200.0	33.71
Average water content year	452.43	373.93	61.0	17.5	273.1	47.0	26.1	200.0	179.33
High-water year, 25% non-exceedance probability Ppr=25% Pev=75%	601.06	515.66	66.0	19.4	273.1	47.0	26.1	200.0	327.96

Table 10: Current water management balance of the Tobyl River basin

Water resources, mln. m^3	Year with water availability at, %			Average water content year
	95	75	50	
Natural flow	61.72	153.58	306.81	452.43
Reservoir drawdown	211.38	119.52		
Precipitation on the reservoir surface	29.0	47.4	57.0	61.0
Water reserve in the snow on reservoir ice	8.4	12.1	15.6	17.5
Total	310.5	332.6	379.41	530.93
Water consumption	26.1	26.1	26.1	26.1
Reservoir and pond filling			33.71	179.33
Losses to evaporation	47.0	47.0	47.0	47.0
Total	73.1	73.1	106.81	252.43
Balance	237.4	259.5	272.6	278.5

Table 11: Utilization regime of the Verkhnetobolskoye reservoir in 2014-2023

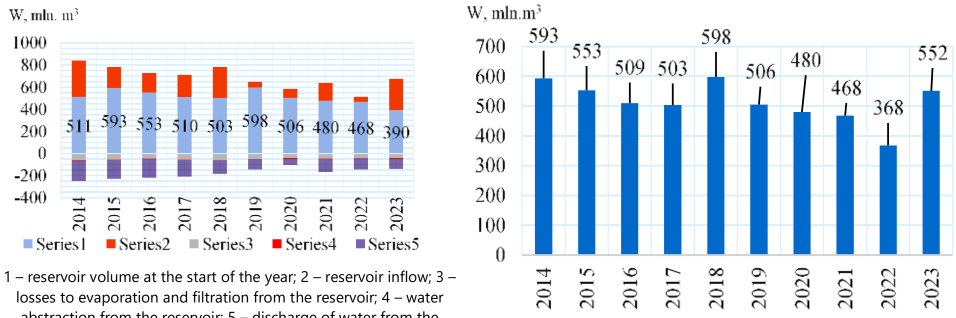
Year	Balance components, mln. m^3						Note
	Reservoir volume at the beginning of the period	Reservoir inflow	Losses to evaporation and filtration from the reservoir	Water abstraction from the reservoir	Discharge of water from the reservoir into the downstream pool	Reservoir volume at the end of the period	Inflow according to "Kazhydromet" RSE
2014	511.28	330.37	59.78	3.94	184.5	593.37	387.45
2015	593.37	188.06	55.50	3.93	169.13	552.87	209.475
2016	552.87	175.49	46.39	3.43	169.1	509.44	161.595
2017	509.44	202.06	55.20	3.58	149.89	502.82	138.285
2018	502.82	277.91	57.92	3.87	121.16	597.77	314.37
2019	597.77	51.90	48.40	3.39	92.32	505.56	11.655
2020	505.56	79.34	43.40	3.42	58.49	479.59	58.58
2021	479.59	156.53	46.65	6.19	115.06	468.22	155.61
2022	468.22	45.07	38.76	7.15	99.37	368.00	-
2023	389.70	284.94	59.78	6.69	88.38	551.65	-

reported by Kazvodkhoz. As a result, in the worst-case scenario, the current water management balance shows 237mln.m^3 excess of water resources over water consumption.

The current water management balance for the Verkhnetobolskoye and Karatomarskoye reservoirs separately across the years with varying water content is presented in Table 11. The components of the reservoirs' water management balance are presented according to stock materials of the Kostanay branch of Kazvodkhoz. The analysis of quantitative indicators of the annual flow of the Tobyl River enabled an integral assessment of the water resources of the Verkhnetobolskoye and Karatomarskoye reservoirs. The quantitative assessment was conducted using water balance data from 2014 to 2023.

Fig. 2 and 3 present the plots of changes in the components of water in the reservoirs for 2014-2023. 2019 was a very dry year in the observation of the Tobyl River. Annual inflow into the Verkhnetobolskoye reservoir through the Grishenka dam site in 2019 was 18.9 times lower than the multi-year average. 2019 inflow into the Karatomarskoye reservoir was 10.7 times lower than the multi-year average. 2020 was also a low-water year, with inflow into the Karatomarskoye reservoir 11.1 times lower than the multi-year average. Even lower annual inflow values were observed in 1938, 1975, 1977, and 2009. The water management situation in the Tobyl River reservoir cascade zone in 2019 fully complied with the design indicators and the limitations of existing regulations on water resource use and flow. The flow deficit for the low-water year was compensated for by the redistribution of flow in the high-water year.

The annual water management balance of the Karatomarskoye reservoir for average and low-water years (95% non-exceedance probability) is negative. During low-water years, the negative part of the water balance of the Karatomarskoye reservoir is compensated by water from the Verkhnetobolskoye reservoir and the multi-year management. In the overall water balance, the volume of water consumed by enterprises amounts to only 0.58% of the water reserve in the Verkhnetobolskoye section and 3.5% in the Karatomarskoye section. This indicates that these enterprises do not influence quantitative changes in water resources significantly. The use of water flow



1 – reservoir volume at the start of the year; 2 – reservoir inflow; 3 – losses to evaporation and filtration from the reservoir; 4 – water abstraction from the reservoir; 5 – discharge of water from the reservoir into the downstream pool

reservoir volume at the end of the year

Fig. 2: Dynamics of changes in the components of the water balance of the Verkhnetobolskoye reservoir

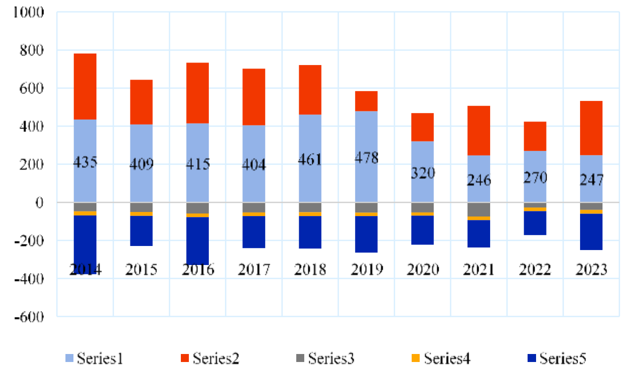


Fig. 3: Dynamics of changes in the components of the water balance of the Karatomarskoye reservoir
1 – reservoir volume at the start of the year; 2 – reservoir inflow; 3 – losses to evaporation and filtration from the reservoir; 4 – water abstraction from the reservoir; 5 – discharge of water from the reservoir into the downstream pool

including deliberate releases to control downstream water levels in 2014-2023, averaging 23% in the Verkhnetobolskoye reservoir section and 46% in the Karatomarskoye section, with occasional surges to 67%.

In high-water years, the amount of water retained by the end of the season in the Karatomarskoye reservoir is 70-80% of the total volume, while in very low-water years with 75 and 95% non-exceedance probability, the reservoir retains 40-43%. In the fluctuations of the Tobyl River flow, in addition to a well-defined cyclicity, there is a tendency for low-water and high-water years to be grouped. In the case of frequent recurrence of the groupings of low-water years, water shortage necessitates a drastic revision of the approaches to water consumption by economic sectors with the application of new water-saving methods and deep regulation in the management of the Tobyl River reservoir cascade, especially of the multi-year regulation reservoirs. The water reserve management system of the transboundary Tobyl River needs to be improved with the introduction of advanced and adaptive technologies.

DISCUSSION

Our methodology for the study on water management balance of water balance in the Tobyl river basin, aligned with the work of (De Girolamo et al., 2022), who implemented flow regime analysis to study the impact of long-term climate change in the Mediterranean basin. Our study also applied the Mann-Kendall analysis, which displayed an upward trend in river flow. This process correlates with the methods of (Saedi et al., 2022), who observed changes in flow rates due to precipitation regime and human activity. However, contrary to our result, they observed a decrease in flow rate over 49 years, and this creates a gap in the relationship between the influence of long-term climate change in semi-arid basins and flow rates.

Our results reveal significant changes in water balance across the Tobyl River basin caused by human and climate intervention. These results agree with recent studies on water resource management in semi-arid regions (e.g., Kazakhstan). Our study agrees with (Kakabayev et al., 2023), who reported on the impact of climate change in the Yesil River basin in Northern Kazakhstan and concluded that the climatic conditions and constant population growth will cause a potential decrease in water supply from 2036-2065. The work of (Tursunova et al., 2022) also agrees with our findings and highlights Kazakhstan's topography as another obstacle in water resource management. They highlight the essence of considering anthropogenic and climatic activity and using this information to develop efficient ways of water resource management.

Our results showed a marked increase in evaporation losses during low-water years and months with increased temperatures, consistent with recent research. (Yessenzholov et al., 2024) reported that in Kokshetau, a place in Kazakhstan, rising temperatures had a high chance of leading to higher evaporation rates, which may reduce the lake's water volume and, therefore, its area. Our claim that evaporation is a determining factor in developing water management schemes is supported by (Sun et al., 2023), who highlight the importance of evaporation rates in water basin analysis and management.

Our study shows that anthropological actions, such as reservoir construction, positively contribute to water retention and management. Multiple studies claim that water reservoirs can disrupt natural flow regimes, lead to community displacement, and often require high maintenance costs. (Rodriguez et al., 2023), also highlights the problem of sedimentation, which reduces reservoir capacity and water quality. We partially agree with these authors and suggest that mitigation strategies that consider these negative factors should be implemented for optimal water retention and management.

Our study also highlights the importance of transboundary water management of the Tobyl River and the essence of cooperative international efforts between Kazakhstan and its neighboring regions. It suggests that adaptive management and international collaborations could mitigate water shortages in the Tobyl River basin. Enhancing conservation measures, improving transboundary policies, and implementing modern technologies could collectively improve the water management system. With continued research on evaporation reduction and adaptive reservoir management, these recommendations could address both local and global challenges in sustainable water resource management, improving resilience against future water scarcity.

This notion is supported by the work of Englezos et al. (2022), who stressed that cooperative water management policies could alleviate shortages and also suggested a novel hydro-economic-econometric approach to water management that ensures the maintenance of water balance, quality, and cost while preventing conflicts.

Conclusion

For urban and agricultural needs but contribute to significant water losses through evaporation, particularly during dry years. In high-water years, the reservoirs tend to accumulate more water, leading to an overall surplus; in years of water scarcity (up to 95% probability), the basin faces a notable water deficit. The Mann-Kendall trend test applied to long-term hydrological data showed statistically significant upward trends in river flow at the Tobyl-Grishenka and Tobyl-Kostanay stations from 1972 to 2021. These trends result from climate changes, such as increased precipitation, human activities, and water management interventions. The findings underscore the need for adaptive water management strategies in the Tobyl River basin. The study suggests that modern water conservation techniques, such as improved evaporation control measures, should be implemented to mitigate water losses. Coordinating transboundary water resources and technological solutions are essential for ensuring long-term water security in the region.

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Author's Contribution: AMB, MMM, LKM, AU, VNCh, SBK, AAJ, conceived and designed the study. AU and ABN performed experiments, while VNCh and SBK conducted laboratory analyses. ABN supervised the project and coordinated the experimental work. LKM and MMM performed statistical analyses of the collected data. All authors critically revised the manuscript and approved the final version.

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