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The Influence of Toktogul Reservoir on the Variability of Naryn River Flow

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Abstract. The article is devoted to assessing the impact of the Toktogul reservoir based on variability of the annual flow of the Naryn River. Toktogul Reservoir is the largest reservoir in Central Asia; its construction began in 1962 and was completed in 1975. The reservoir's total (designed) water capacity is 19.5 km^3, and the useful volume is 14.0 km^3. In the study, special attention is paid to the study of the influence of the conditions of the reservoir used in the irrigation and energy regimes on the river flow. Statistical indicator of the river flow variability - coefficient of variation (C_v) was determined for three calculation periods. The value of the variation coefficient of the annual flow of the Naryn River for the natural water regime, i.e., accounting period I (1930-1974), was equal to C_v=0.22. During accounting period II (1975-1994), when the Toktogul reservoir was operated in the irrigation mode, the variation coefficient of the annual flow of the Naryn River was equal to C_v=0.24. It was determined that the value of the variation coefficient calculated for accounting period III (1995-2020), when the Toktogul reservoir operated in the energy mode, was equal to C_v=0.10. As a result, it has been shown that the value of the variation coefficient of Naryn River flow has decreased with the transition of the water reservoir from irrigation mode to energy mode operation.
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1. Introduction

The annual flow rates of rivers vary from year to year; that is, if the amount of water in the river is high in one year, it may be less or, on the contrary, even more in the next year. These quantitative changes depend on climatic factors such as atmospheric precipitation falling on river basins with a natural hydrological regime change in air temperature, and they are not subject to a specific law. However, any annual variation in the river flow fluctuates in a range of a certain average value. So, under natural conditions, annual changes in the river flow occur due to the influence of meteorological variables - atmospheric precipitation, air temperature, and other natural factors.

Besides these, anthropogenic factors also affect the interannual variation of river flows. One of them is a reservoir, which was built in the river bed. According to historical data, small reservoirs - ponds were built in the territory of the Central Asian countries at the end of the old era and the beginning of the new era. The main purpose of their construction was to collect water from small streams and then use it for irrigation and other purposes.

To use river water more effectively, in the last 100 years, about 10 large reservoirs with a water capacity of more than 1 billion km^3 have been built in Uzbekistan and neighboring countries. Most of them can be used in a "complex" way, that is, for irrigation, energy, and other purposes. Most of these reservoirs are located in the river beds. Due to this, they have a significant impact not only on the distribution of the flow of rivers that flow out from them throughout the year but also on the interannual change of their flow. For example, Toktogul - on the Naryn River, Nurek - on the Vakhsh River, and Roghun reservoirs, which are still under construction, belong to this type [9-12].

It should be noted that the influence of the above-mentioned large reservoirs on the water regime of the rivers that supply them with water is not comprehensively covered in hydrological literature. In particular, the problems of assessing the variability of the annual flow and the quantitative changes in its distribution throughout the year, calculated from the main indicators of the water regime of the rivers flowing out from the reservoirs, remain out of the attention of researchers.

The main purpose of this work is to evaluate the impact of the Toktogul Reservoir on the annual variability of the annual flow of the Naryn River and its distribution throughout the year. To achieve this goal, the following tasks were determined and solved in the research:

1) Collecting the data of water consumption measured on the Uchkurgon hydrological station in the Naryn River, their primary processing;

2) Dividing the total observation years into different accounting periods, taking into account the operating conditions of the reservoir;

3) Calculate variation coefficients for each accounting period, making relevant scientific and practical conclusions by analyzing the results.

2. Materials and Methods.

The research work used the water consumption data recorded in the hydrological posts belonging to the Hydrometeorological Service Center under the Ministry of Natural Resources of the Republic of Uzbekistan - Uzgidromet. Therefore, these hydrometeorological data are the results of standard measurements and observations and are considered reliable.

In the article, the methods of hydrological calculations were used in the assessment of water resources of the Naryn River basin. To cover the topic more widely, it was necessary to work with the data obtained in previous years. This made it possible to use the work's historical approach and geographical comparison methods of hydrological research. Geographical generalization and mathematical statistics methods were also widely used in the work.

The mathematical statistics method was widely used to calculate the variability of the river flow, that is, the variation coefficient (C_v) [Evstigneev, Magritsky, 2016]. The values of the variation coefficients were calculated on a computer using standard programs based on the following expressions:

1) in the case when the condition of the number of years of observation $n \leq 25$ is satisfied:

$$C_v = \sqrt{\frac{\sum_{i=1}^{n}(K_i - 1)^2}{n-1}} \qquad (1)$$

2) and when the condition of the number of observation years n > 25 is satisfied:

$$C_v = \sqrt{\frac{\sum_{i=1}^{n}(K_i - 1)^2}{n}} \qquad (2)$$

In the above expressions, n is the number of observation years; K_i is the rate of discharge of the river flow; the following expression calculated its values:

$$K_i = \frac{Q_i}{Q_0} \qquad (3)$$

where Q_i is the average water consumption of the relevant year; Q_0 is the average multi-year water consumption during the accounting period [Chontoev, Mamatkanov, 2022].

3. Materials and Methods.

The construction of the Toktogul reservoir, located in the upper reaches of the Naryn River, at the confluence of the Big Naryn and the Small Naryn rivers, began in 1962 and was completed in 1975. This reservoir, considered the largest one in Central Asia, was put into operation this year. Its total (designed) water capacity is 19.5 km^3, and its useful volume is 14.0 km^3 [Khikmatov, Rapikov, 2021]. It is planned to use the reservoir for complex purposes, i.e., irrigation and hydropower. However, we remind you that during the former Soviet Union, reservoir exploitation for irrigation purposes was considered the first priority goal (Fig.1).

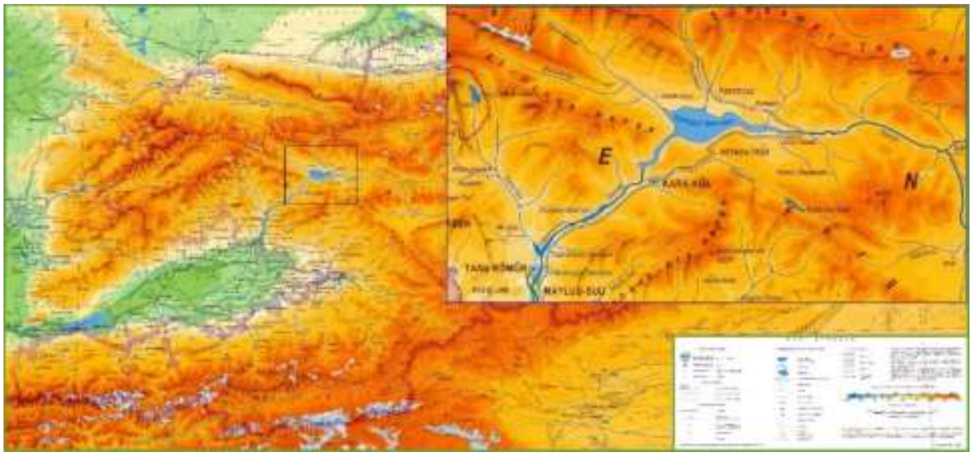

Figure 1. Location of Toktogul reservoir

From the first years when the Toktogul reservoir was put into operation, sharp changes were noted in the amount of the annual flow of the Naryn River and its distribution by months and seasons throughout the year. More precisely, the amplitude of the extreme (the largest and the smallest) water flows of the river flow has decreased. The average annual water consumption for several years was much lower than the norm (Fig. 2).

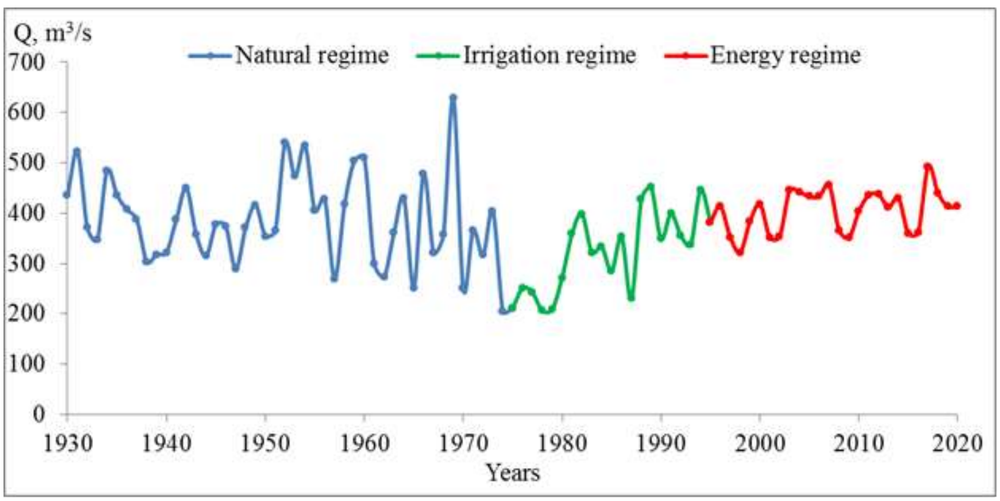

Figure 2. Graph of annual change in water consumption of Naryn River (Uchkurgon hydrological station)

These conditions are reflected in the chronological graph of the flow of the Naryn River, presented in Figure 1. This graph was analyzed to examine the subject identified in the case further. Special attention was paid to the mode of operation of the water reservoir. As a result, the total series of the average annual water consumption observed from 1930 to 2020 on the Uchkurgan hydrological station of the Naryn River was divided into the following 3 accounting periods:

Accounting period I - includes the period of 1930-1974, covering a 45-year period when the Naryn River had a natural water regime;

Accounting period II - includes the period of 1975-1994, more precisely - a 20-year period during which exploitation of the Toktogul reservoir in the irrigation regime was a priority;

Accounting period III - refers to the years 1995-2020; during these 26 years, the Toktogul Reservoir first began to transition to the energy regime, and this process has been a priority one for the last 15-20 years.

The following variability of the annual flow of the Naryn River from the Toktogul Reservoir was estimated based on the data of the Uchkurgan hydrological station, as mentioned above. Statistical indicators of river flow variation coefficients were estimated for three calculation periods distinguished above.

The value of the coefficient of variation of the annual flow of the Naryn River for the natural water regime, i.e., the calculation period of 1930-1974, was equal to 0.22. This result was compared with the data of V.L.Shults and “Resources...” (Table 1).

TABLE 1. Values of variation coefficient determined by different authors for first calculation period

Sources	V.L.Shults	"Resource..."	The author
Accounting periods (years)	1925-1960	1925-1962	1930-1974
Variation coefficient, C_v	0.17	0.19	0.22

The value of the variability coefficient of the Naryn River for the period of the natural water regime determined by V.L. Shults was equal to C_v=0.17, and according to "Resource..." it was equal to C_v=0.19. As it can be seen from the table, the value of the variation coefficient determined by us was slightly larger than the values obtained by V.L. Shults and "Resource...". The main reasons for this can be explained, first of all, by the difference in the calculation years, and also by the fact that we took into account the year 1965 when there was very low water amount in the Naryn River, and the year 1969 when there was anomalous high water.

As mentioned above, until the beginning of the 90s of the last 20th century, the irrigation regime was the priority goal in the Toktogul reservoir. In the study, considering this situation, the variation coefficient was estimated for accounting period II (1975-1994). The variation coefficient of the annual flow of the Naryn River during the second accounting period, when the reservoir was operating in the irrigation mode, was slightly higher than the value estimated in the natural water mode period and equaled 0.24. This value showed that during the operation of the Toktogul Reservoir in the irrigation mode, the annual flow values' annual variation was close to the natural mode.

However, it is worth noting that during accounting period II, a large part of the flow of the Naryn River was used to fill the Toktogul reservoir. As a result, the Naryn River's annual flow was significantly lower than the norm for several years during this accounting period.

As soon as the Toktogul reservoir began to transit to the energy mode, the annual changes in the flow of the Naryn River and the distribution of the river flow by months during the year began to undergo drastic changes. In the process of the water reservoir transition to the energetic regime, the amplitude of the interannual variability of the river flow was also much lower. The effect of this situation is also reflected in the fact that the value of the variation coefficient calculated for accounting period III when the Toktogul reservoir worked in the energy mode is equal to C_v=0.10 (Tab. 2).

TABLE 2. Variation coefficients determined for different calculation periods of Naryn River flow

№	Accounting periods (years)	Number of years of observation, n	Variation coefficient, C_v
1	I (1930-1974)	45	0.22
2	II (1975-1994)	20	0.24
3	III (1995-2020)	26	0.10

The exploitation of the reservoir for energy purposes, in turn, had a drastic effect on the distribution of the river flow by months throughout the year. At the next research stage, the river flow distribution by months during the year was carried out for the calculation periods specified above (Fig. 3).

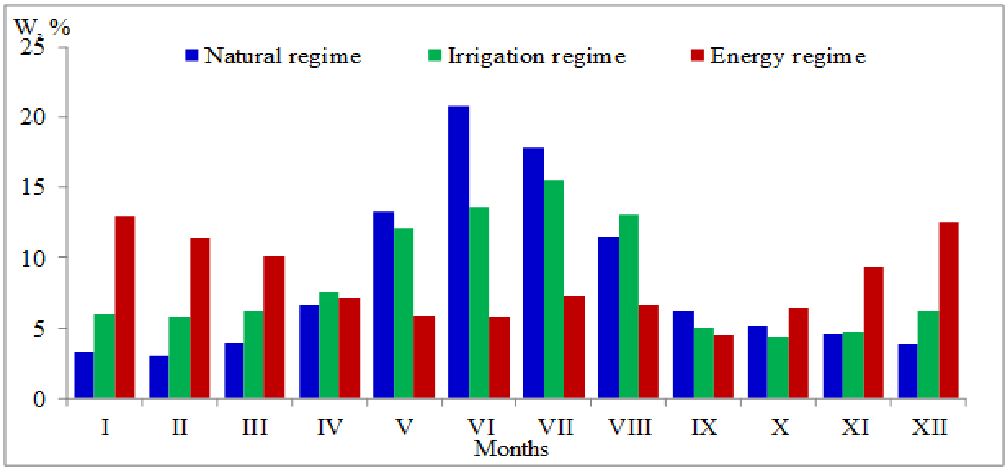

Figure 3. Distribution of flow of Naryn River in different accounting periods by months during the year

Based on the above graphic data, it can be concluded that the distribution of the river flow values by months during the year was relatively close from month to month when the reservoir was operated in the irrigation mode. As expressed in digits, the river's annual flow in the irrigation regime was only 2.1 km^3 less than the annual flow value in the natural regime. The main reason for this is that between 1970 and 1980, a large part of the river flow was used to fill the reservoir's useless (dead) volume. When the water reservoir switched to the energy regime, the situation in the lower reaches of the Naryn River began to change radically because the river flow was collected in the water reservoir in the spring-summer months, and its use for energy purposes was carried out in the autumn-winter months. If we consider the month of June alone, during the natural water regime, it turns out that 20.8% of the annual flow flowed in this month, while during the energetic regime, it was only 5.8%.

5. Conclusion/Recommendations.

1. The value of the coefficient of variability of the annual flow of the Naryn River in the first accounting period, which belongs to the natural water regime, i.e., 1930-1974, was equal to 0.22. So, during the first accounting period, the river's annual flow was highly variable from year to year. This result was compared with the data of V.L. Shults and "Resource...", and their closeness was shown;

2. When the Toktogul Reservoir was put into operation, and it worked primarily in the irrigation mode, the variation coefficient representing the interannual variability of the flow of the Naryn River slightly increased as compared with the natural mode, that is, during that period it was equal to C_v=0.24. The reasons for this are related to the fact that a large part of the flow of the Naryn River is used to fill the reservoir;

3. Between 1995 and 2020, when the Toktogul reservoir began to work in full energy mode, the coefficient of variability of the river flow decreased sharply and equaled 0.10. The reason for this is explained by the fact that the flow of the Naryn River is controlled interannually using the Toktogul Reservoir;

4. Operation of the Toktogul Reservoir for irrigation and energy purposes dramatically affected the distribution of the Naryn River flow by months throughout the year. This is because the river flow is collected in the reservoir in the early spring-summer months. Its use for irrigation is mainly in the summer when the demand for water increases, and its operation for energy purposes is carried out in the autumn-winter months. As soon as the Toktogul Reservoir comes into full energy mode operation, sharp deviations from the natural hydrological regime are visible in the flow of the Naryn River.

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