The influence of water masses to local climate of the Toktogul reservoir

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Abstract. The article is devoted to the analysis of the impact of the Toktogul Reservoir on the local climate in the context of global climate change. There is a global warming trend. In this regard, since the process of global warming is taking place on the territory of Kyrgyzstan, one of the most important scientific and practical issues is the assessment of the impact of the reservoirs built in Kyrgyzstan on the climate. The study found the Toktogul Reservoir has the effect of increasing air temperature. In the Ketmen-Tyube valley, the increase in air temperature depends on the volume of water in the Toktogul Reservoir. So, in the years of low water in the reservoir (1-6.5 billion m³), the average annual air temperature was 10.4°C, and in average water years (6.6-14 billion m³) 11.1 °C and increased to 11.3°C in high-water years (14.1 - 19.5 billion m³).

1. Introduction

In Kyrgyzstan, weren’t done scientifically generalized and quantitative and qualitative conclusions on the impact of reservoirs on the environment of adjacent areas. At the same time, in future it will be planned to build 18 more large and about 100 small reservoirs, more than 60 small hydropower plants (HPP). Therefore, the main purpose of the analysis of the impact of the built reservoirs on the climate of adjacent areas is to assess the environmental and socio-economic impact of future reservoirs, one of the most important scientific and practical issues.

To reliably assess climate change, it is necessary to analyse instrumental observations in the field of meteorological stations. During the last hundred years (1901-2000) the surface air temperature in the Northern Hemisphere increased by 0.6 ± 0.2°C [1-5]. According to the United Nations the average air temperature increased by 0.85°C between 1880 to 2012, and by the end of the 21st century the average air temperature is expected to increase by 1.5 to 2.5°C compared to 1990 levels.

In the territory of Kyrgyzstan in the XX century, rather for 100 years the average annual air temperature increased by 1.6°C or 0.6°C compared to global warming. The highest warming was observed in winter (2.6°C) and the lowest in summer (1.2°C). In 2100 the average air temperature is expecting to rise by 1.8 to 4.4°C [6].

2. Materials and methods

The article uses materials as factual and analytical material by the State Service for Hydrometeorology under Ministry of Emergency Situations of the Kyrgyz Republic and State Agency for Industry,
Energy and Subsoil under Government of the Kyrgyz Republic. Was used the obtained materials were analysed on the basis of statistical and meteorological, geographical extrapolation and analogy methods, and the Student's statistical accuracy criterion.

3. Results and discussions
Due to the lack of a network of meteorological stations around reservoirs built in Kyrgyzstan, there are difficulties in studying their impact on the climate. However, based on long-term data from meteorological stations, it can be concluding that the construction of reservoirs in Kyrgyzstan has changed the climate on its shores. Shapar [7] who analysed the impact of the Toktogul Reservoir on the Ketmen-Tobo valley according to the data of 1956-1991, said that the average annual air temperature increased by 2.3°C. For example, under the influence of the water mass of the Toktogul Reservoir, the value of the average annual air temperature per m/s Toktogul in 1953-2020 increased by 2.3°C (table 1).

Table 1. Long-term average monthly air temperature before and after construction of Toktogul Reservoir at Toktogul meteorostation.

| Years      | I  | II | III | IV | V  | VI | VII | VIII | IX | X  | XI | XII | Year |
|------------|----|----|-----|----|----|----|-----|------|----|----|----|-----|------|
| 1952-1974  | -14.3 | -10.7 | 1.6 | 13.5 | 18 | 21.7 | 24.4 | 24 | 19.4 | 10.9 | 2.7 | -6 | 8.8 |
| 1979-2019  | -5.1 | -2.6 | 4.9 | 13.1 | 17.3 | 21.1 | 24.2 | 24.3 | 19.9 | 12.3 | 5.5 | -1.6 | 11.1 |
| Difference | 9.2 | 8.1 | 3.3 | 0.4 | 1.3 | 0.6 | 0.2 | 0.3 | 0.5 | 1.4 | 2.8 | 4.4 | 2.3 |

To determine the validity of these changes we used a Student's statistical validity criterion.

\[
\tau = \frac{\bar{y} - \bar{x}}{\frac{S^2}{\sqrt{n+m}}} \sqrt{\frac{m \cdot n}{n+m}}
\]

In this case, \(\tau\) is a sign of a statistical criterion.

If \(|\tau| < 2\), the accuracy of the reservoir effect is uncertain. If \(|\tau| > 2.5\), then the statistical validity of the effect is accurate.

\(\bar{y}\) – average value of indicators of long-term climate elements in the period after construction the reservoir;

\(\bar{x}\) – average value of indicators of perennial climate elements for the period before construction the reservoir;

\(S^2\) – variance of the statistical series;

m – number of years after construction the reservoir;

n – is the number of years used before construction the reservoir.

According to the Student's criteria, only the Toktogul Reservoir has the effect of raising the air temperature. Calculations show that this criterion is equal to 5.34.

Therefore, this article discusses the impact of the Toktogul Reservoir water mass on the local climate. The volume of water in the Toktogul Reservoir from 1975 to 2020 was divided into years with different amount of water. Thus, the years of low water in the reservoir (1-6.5 billion m³), years of medium water (6.6-14 billion m³), years of high water (14.1-19.5 billion m³). These 3 parts correspond to the technical parameters of the Toktogul Reservoir (6.5 billion m³ – unchanged volume, 14 billion m³ – useful volume and 19.5 billion m³ – full volume). The analysis covers the average annual volume of water in the reservoir. Because in some years the water level was low until the middle of the year, but after half a year the water level rose sharply to 3 times [8]. For example, from January to June 1987 is caught less than 5 billion m³ of water, the water level is rise from June to December 14.4 billion cubic meters.
During the 1983, 1984, 1985 and 1986 the water level in the reservoir was low (1-6.5 billion m$^3$), the average annual air temperature was 10.4°C. In the years when the water level was moderate (6.6-14 billion m$^3$), it increased by 11.1°C, and in the years when the water level was high (14.1-19.5 billion m$^3$) it increased by 11.3°C (table 2). Therefore, it observed that the increase in air temperature depends on the volume of water.

Table 2. Long-term average monthly air temperature in low, medium and high concentration years in Toktogul Reservoir.

| I  | II | III | IV | V  | VI  | VII | VIII | IX | X  | XI | XII | Year |
|----|----|-----|----|----|-----|-----|------|----|----|----|-----|------|
| -6.7 | -5 | 2   | 13 | 16.9 | 21 | 26.3 | 26.3 | 20.6 | 11.9 | 4.2 | -5.3 | 10.4 |
| -5.2 | -2.5 | 4.9 | 13.6 | 17.7 | 21.2 | 24.2 | 24 | 19.8 | 12.2 | 4.9 | -1.3 | 11.1 |
| -4.5 | -2.2 | 5.5 | 12.8 | 16.9 | 20.9 | 23.9 | 24.2 | 19.9 | 12.6 | 6.5 | -1.1 | 11.3 |

Examination of table 2 shows that due to the impact of the reservoir, the average long-term air temperature increased from -6.7°C to 11.9°C during the years of low water content in the reservoir in autumn-winter. In the years when the average volume of water in the reservoir was -5.2°C to 12.2°C, in the years of high water it increased from -4.5°C to 12.6°C. Therefore, it can be seen that the more water is retaining in the reservoir, the greater the warming effect on the environment.

Prior to the construction of the Toktogul Reservoir the foothills of the Ketmen-Tobo valley were located at an altitude of 700-900 m above sea level and the relief was narrow. Therefore, according to Table 1, long-term stagnation of cold air was observed in winter, the long-term average temperature was 8.8 °C, and the long-term average monthly temperature in January reached -14.3°C.

With the construction of the Toktogul Reservoir the water level in the reservoir is rise to 900 m, where it reaches 19.5 billion m$^3$ of water. As a result, the warming effect of the reservoir was formed, and in January the long-term average monthly air temperature was -5.1°C. Thus, the air temperature increased by 9.2°C. We believe that this figure was affected by changes in the general natural environment, as well as the location of the meteorological station. It before the construction of the reservoir the Toktogul meteorological station was located at a depth of 821 m above sea level, but after the construction of the reservoir it was moved to a flat surface at an altitude of 983 m above sea level [9, 10]. Under these conditions the temperature of the environment changed in the direction of heat gain without the accumulation of cold air in the area of the station. Therefore, it can be considered that the Toktogul Reservoir has a direct impact on the increase in the long-term average air temperature in the Ketmen-Tobo valley by 2.3°C after the construction of the Toktogul Reservoir.

The reason of this the water mass in the reservoir affected not only the autumn-winter period but also the spring-summer period. Thus, under the influence of cooling of the reservoir in spring and summer, the average long-term air temperature in the years of low water content in the reservoir ranges from 13°C to 26.3°C, in the years when the average volume of water in the reservoir is 13.5°C to 24.2°C, in years with high water content decreased from 12.8°C to 23.9°C. Therefore, depending on the volume of water in the reservoir, it can be noted that in the spring-summer period the reservoir environment has a cooling effect around 0.7 - 2°C.

After construction of the Toktogul Reservoir, the amount of precipitation in the Ketmen-Tobo valley has also changed (table 3).
The amount of precipitation increased during the years when there was a lot of water in the reservoir. In particular, the amount of precipitation increased by 12.7 mm during the years when there was a lot of water in the Toktogul reservoir. According to Table 3, 368.6 mm of precipitation fell before the construction average annual precipitation at Toktogul Reservoir at Toktogul meteostation.

Table 3. Pre-construction and post-construction average annual precipitation at Toktogul Reservoir at Toktogul meteostation.

| Years       | I  | II | III | IV | V  | VI | VII | VIII | IX  | X  | XI | XII | Year |
|-------------|----|----|-----|----|----|----|-----|------|-----|----|----|-----|------|
| 1952-1974   | 26.2 | 32 | 44.8 | 37 | 49.3 | 42.2 | 34.7 | 16   | 7.4 | 17 | 27.6 | 34.4 | 368.6 |
| 1979-2019   | 23.3 | 26.7 | 31.6 | 42.9 | 52.3 | 42.7 | 24.9 | 16.1 | 13.2 | 23.7 | 24.2 | 30.2 | 351.8 |
| Difference  | 2.9 | 5.3 | 13.2 | -5.9 | -3 | -0.5 | 9.8 | -0.1 | -5.8 | -6.7 | 3.4 | 4.2 | 16.8 |

The analysis of the long-term average monthly precipitation in Table 3 shows that after construction of the reservoir, the long-term average annual precipitation decreased by 4.6 %. Thus, during the cold periods of the reservoir - late autumn (November - 12.3 %), winter (11.1 - 16.6 %) and early spring (March - 29.5 %), the amount of precipitation decreased under the influence of global warming. In spring (106 - 115.9 %), summer (100.6 - 101.2 %) and autumn (139.4 - 178.4 %) the amount of precipitation increased. According to Table 4, the highest rainfall was recorded in 1969 (713 mm) and the lowest in 1982 (166 mm). However, since 2011 the amount of precipitation has been decreasing.

Table 4. Long-term average monthly precipitation in low, medium and high concentration years in Toktogul Reservoir.

| I   | II  | III | IV  | V   | VI  | VII | VIII | IX  | X   | XI  | XII | Year | Water level |
|-----|-----|-----|-----|-----|-----|-----|------|-----|-----|-----|-----|------|-------------|
| 18.6 | 21.4 | 28.2 | 28.9 | 52.1 | 31.1 | 8.5 | 4.9  | 5.4 | 24.9 | 19.6 | 32.4 | 276 | Low water level |
| 22.9 | 25.1 | 29.2 | 49  | 48.7 | 45.7 | 25.9 | 18.5 | 15.6 | 30.4 | 19.2 | 22.6 | 352.8 | Medium water level |
| 25.4 | 30.3 | 34.9 | 43.4 | 55.4 | 44.8 | 30.5 | 18.6 | 14.4 | 22.9 | 25  | 35.7 | 381.3 | High water level |

In the months when there was a lot of water in the reservoir, the amount of precipitation was higher in October (less than 2 mm) than in the years when there was less water. Especially in April (150.2%), July (358.8%), August (379.6%), and September (266.6%). Compared to the average flood years, there are no sharp changes in other months than December (157.9%).

After the construction of the reservoir the amount of precipitation has decreased, especially in arid climates. For example, after the construction of the Nurek Reservoir, the air temperature rose to 0.8°C and the amount of precipitation decreased [11]. At a distance of 2 to 5 km from the shores of the Kama and Novosibirsk reservoirs in Russia, the air temperature rose to 1.2-4.5°C, and precipitation increased by 15% [12, 13]. In the years when there was a lot of water in the Toktogul Reservoir, on the contrary, the amount of precipitation increased. According to Table 3, 368.6 mm of precipitation fell before the construction of the reservoir, while according to Table 4, 381.3 mm of precipitation fell during the years when there was a lot of water in the reservoir. In particular, the amount of precipitation increased in April (117.2%), May (112.4%), September (194.6%), and October (134.7%).

Based on the analysis of the impact of the Toktogul Reservoir on the climate of adjacent areas, the following conclusions can be drawn. The more water is retained in the reservoir, the warmer it is in the cold season and the cooler it is in the hot season. Thus, before the construction of the Toktogul Reservoir, the average January temperature was -14.3°C, in the years of low water level it was -6.3°C, and in the years of high water level it was -4.5°C. Prior to the construction of the reservoir, the average July temperature was 24.4°C, while in the years of high water level it decreased by 23.9°C. The amount of precipitation increased by 12.7 mm during the years when there was a lot of water in the
reservoir compared to the years before the construction of the reservoir. Therefore, in the spring and autumn months, the amount of precipitation increased under the influence of global warming.

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