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Hydrological Regime of Neighboring Basins of Mountain Rivers in Central Asia

Sergey Myagkov [1], Bekhrus Makhmudov [2], Faizulla Agzamov [1], Indira Khudoybergamova[1]

[1] Department of Hydrology, Hydrometeorological Research Institute, Bodomzor-72, Tashkent, 100052, Uzbekistan
[2.] Department of Climate, Uzhydromet, Osyo street-72, Tashkent, 100032, Uzbekistan
sergik1961@mail.ru, sergik1961@yahoo.com

Abstract: The basis for the flow of a mountain river is the precipitation regime in the form of snow accumulation in winter, liquid precipitation, and the temperature regime of the surface layer of the atmosphere. The object of study is the formation of river flow from two neighboring river catchments. The research method uses a graphical comparison of runoff hydrographs over a long period of hydrological observations and statistical data analysis. The construction of polynomial trends in hydrological series was carried out using sets of statistical functions and calculation methods using widely used programs. The possibility of constructing river flow trends to analyze the dynamics of the formation of water resources is considered and various time periods of flow formation in neighboring drainage basins located in the same geographical areas are determined. The results obtained show significant differences in the runoff characteristics of neighboring river basins under different input regimes of precipitation and air temperature.
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Keywords: climate change, hydrological regime, hydrological calculations, watershed, river basin, snow cover, polynomial trend, annual flow.

1. Introduction

The relevance of the study lies in the need for the most accurate forecasting of river flows, the water resources of which are used for irrigation of agricultural land and water supply to populated areas in the region. The Sokh and Shakhimardan rivers are transboundary; for this reason, water disputes often arise during water distribution not only between water management entities, but between the population of different countries. Therefore, accurate forecasting of transboundary river flows is important. The population of the Fergana Valley is about 15 million people, the area of the territory is about 22 thousand km², and together with the surrounding mountains up to 80 thousand km². In plan, the Fergana Valley resembles an ellipse about 300 km long and up to 170 km wide.

The Sokh River flows through the territory of Kyrgyzstan (Batken region) and Uzbekistan (Fergana region). The length of the river is 124 km, the catchment area is 3510 km². The Sokh River originates near the village of Korgon on the northern slopes of the Alai Range at an altitude of over 3000 m, and is formed by the confluence of the Ak-Terek and Khodzha-Achkan rivers. The river flows mainly north. In the middle reaches it serves as the main source of water supply for the Sokh region (an exclave of Uzbekistan). In the Fergana Valley, it is completely dismantled for irrigation, getting lost in irrigation fans and alluvial cones.

The Syrdarya River has not been reached since the late 1940s. The average long-term water flow near the village of Sarykanda is 42.1 m³/s. The food is mixed, glacial and snow, also underground. Flood occurs during the period of intense glacier melting from June to September.

The waters of the Sokh River are used for irrigation and water supply to the population. Due to the rapid population growth in the Sokh River valley, there is a shortage of water, aggravated by political and administrative confusion. Thus, in the mountainous regions of the upper Sokh valley, water flowing to the Tajiks of the Sokh enclave is retained, then the Tajiks limit water to the Kyrgyz of the lower river valley, and they, in turn, retain the remainder flowing into Uzbekistan. According to estimates, Kyrgyzstan uses almost 23-30% of the river flow water to irrigate rice paddies in the foothills of the Burgandy massif. The development of the foothills located above the main territory of the Fergana region has already led to an increase in groundwater levels in the Rishtan and Altyaryk regions of Uzbekistan. As a result, the Rishtan region lost 6,313 hectares of farmland as a result of the destruction of orchards and a decrease in the yield of other crops.

The Shakhimardan River is a river in Uzbekistan and Kyrgyzstan, a left tributary of the Syrdarya. It originates in Shakhimardan on the territory of the Shakhimardan exclave of Uzbekistan at the confluence of the Aksu and Koksu rivers, which originate on the northern slopes of the Alai and Turkestan ranges.

It begins in the Osh-Aravan depression beyond the Adyrs, cuts the entire strip of Adyrs and cuts through the intermountain plain east of the Katrantau Mountains (Katrang-Too). Has a permanent watercourse. Flows to the northwest, crosses the border of Kyrgyzstan and Uzbekistan. East of the village of Orozbekovo it turns north, flows through Dzhyidelik, Kadamzhay and Pulgon, again crosses the border of Kyrgyzstan and Uzbekistan and enters the Fergana Valley in the village of Vuadil.

Below Vuadil is known as Marg'ilonsoy. The city of Fergana is located on the Margilansai River. Margilansay crosses the city of Margilan and the Great Fergana Canal. The waters of the river are completely used for irrigation due to the construction of numerous drainage canals and do not carry their waters to the mouth.

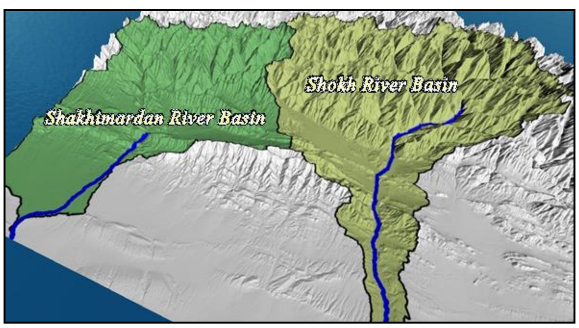

Figure 1. Drainage basins of the Shakhimardan and Sokh rivers on a digital elevation model

Feeding is snow-glacial with peak floods in June. From the east, Margilansai (a continuation of Shakhimardan) is fed by the waters of the Isfairamsay River through the Yangiarik and Lovon canals, and from the west by the waters of the Sokh River along the Sokh-Shakhimardan Canal. The catchment area is 1300 km². In turn, the waters of Margilansay feed the Great Fergana Canal (via the Altyaryk fault), the South Fergana Canal (from the discharge from Margilansay). In this regard, the river waters of Margilansay in the Fergana region are mixed with the waters of the Sokh irrigation system, the Great Fergana Canal system and the Southern Fergana Canal, which naturally affects its qualitative composition.

During the growing season, the waters of the Shakhimardan River, after leaving the territory of Kyrgyzstan at the Vuadil hydroelectric complex and at the hydroelectric complex No. 6 on Margilansai, are completely withdrawn through diversion canals for irrigation of agricultural crops and other needs.

After “Waterworks No. 6” during the growing season, there is practically no water discharge into Margilansai and recharge in these conditions occurs due to groundwater wedging out, recharge from canals, waste water from small collector-drainage systems and discharges from irrigated agricultural lands, as well as due to discharges during floods or during the non-growing season, when there is no special need for irrigation.

The average long-term water flow is 11.6 m³/s, the flow rate is 9.66 m³/s, the average annual flow is 304 million m³ (at the Pavulgan site), in the average year for water availability - 275 million m³, which is 1.5% of the flow Fergana Valley. During floods, the flow reaches 64 m³/s. The average mineralization of water during the growing season is 0.24 g/l, during the non-growing season - 0.18 g/l. From the dividing structure in the village of Damkul (Damkol) there is a branch to the Fergana fault, which feeds the Yangiaryk canal (diversion of the Beshalyshsay River) at hydroelectric complex No. 5, located at the point of their intersection. 1.5 km above the Chekshura hydroelectric complex, Margilansai mixes with the waters of the Yangiarik canal.

At the exit from the city of Fergana, it flows through the settlement of Khajamagiz (Khuzhamagiz), where at the Surkhtepa hydraulic section it merges with the South Fergana Canal and for 1.8 km of the Margilan hydraulic section they flow along the same channel. Further, at the Gorchakov hydroelectric complex (Margilan city), the channel is divided into the South Fergana Canal and the Margilan fault. Further, at the exit from the city of Margilan at the Eshonguzar hydroelectric complex, the river waters are diverted into the Namuna, Gishmon and Langar canals. Downstream, Margilansai is fed by the waters of the Great Fergana Canal at their intersection (the river passes under the Great Fergana Canal through a siphon) to supply water to the underlying agricultural areas. In the village of Dorman (Durma), after crossing Margilansai of the Great Fergana Canal, the river is referred to as collector K-2-4, which, connecting with collector P-2, forms the Achchikul collector with access to the Syr Darya River.

The construction of large canals, such as the Big Fergana Canal, the South Fergana Canal, the Big Andijan Canal and the carried out hydraulic engineering measures contributed to the looping of the entire irrigation system of the Fergana region into a single system, where, depending on the water content of the year and season, the Shakhimardan-Margilansai, Isfairamsay-Beshalyshsay, Big Fergana rivers canal, the South Fergana Canal and the Great Andijan Canal mutually feed each other and the irrigated lands are on mixed feed from these systems.

Note that despite the neighboring location of the rivers Sokh and Shakhimardan differ in the type of food. The Sokh River is a glacial-snow-fed river with peak floods in the period July-August. The Shakhimardan River belongs to the snow-glacier fed rivers, with peak floods in the period June-July, and the main source of water in the river is the melting of seasonal snow. As noted in (Water and Climate Chang; 2020), extensive snowfields and numerous mountain glaciers give rise to most rivers on a global scale. Within the Fergana Valley, annual precipitation is about 150 mm, in the foothills 250-300 mm. Observed climate change is manifested in the form of increased air temperature and changes in precipitation patterns. For mountain rivers, these factors are the main ones in the formation of runoff. Surface runoff directly depends on the precipitation regime (Mallakpour, I., Villarini G.; 2015). The air temperature affects the melting of snow that falls in winter. The temperature regime shapes the melting of glaciers located in the highlands, which are one of the sources of river flow. The insufficient reliability of the forecast of temperature and precipitation regime makes it almost impossible to forecast river flow during the growing season (Lins, H.F.; 2012).

The precipitation regime is uneven, most of it falls in the period October-March and heavy rains are often observed, leading to flooding of areas and the occurrence of floods. Knowledge of the problem. Currently, in many studies (Bubin M.N.; 2013, Krivenko V. G.;1992) of river flow in the mountains reflects the study of trends in air temperature and precipitation regime in river basins with the subsequent use of the obtained data in mathematical models of runoff formation and, thus, trends in runoff dynamics, which are built in depending on climate change scenarios (Water and Climate Change; 2020).

The assessment of mountain river runoff trends directly from runoff dynamics for different climatic periods using linear and polynomial statistical dependencies is considered as a scientific basis. According to numerous studies of the mountainous territory of the Aral Sea drainage basin (the basins of the Syrdarya and Amu Darya rivers), it is noted that during the period 1980-2010 the area of glaciation decreased significantly, which, in turn, can lead to a reduction in the volume of glacial runoff (Myagkov S.V., Gavrilenko N.N., Myagkov S.S., Gofurov T.K.; 2020).

The work (Kuzmenko Ya.V., Lisetsky F.N., Pichura V.I.; 2012) notes that current global warming will lead to an increase in the level of evapotranspiration and, consequently, to a reduction in the replenishment of groundwater reserves. In such circumstances, any simple but effective means of increasing water supplies, such as artificial groundwater recharge, becomes vital for the sustainability of water supply and survival in desert ecosystems. Increasing population density and economic activity, especially in urban areas, and changing water use patterns are challenging the limited water resources available to people. In the study (Fillon R.H., Williams D.F.; 1984) provide evidence that in the Northern Hemisphere there is a slight increase in water flow in rivers due to the melting of glaciers and general processes of deglaciation associated with climate warming.

Studies in (Arnell N.; 1999) show that the processes of degradation of the ice sheet in Asia continue, but the melting of the ice sheet is not linked to the hydrological indicators of the flow of rivers located downstream, and the amount of seasonal snow cover in the basins is not taken into account rivers, which has a direct impact on the characteristics and volume of river flow. In the scientific article Krivenko V.G. (Krivenko V. G.; 1992) outlines the concept of multi-century and intra-century cyclical climate variability of the continents of the Northern Hemisphere, which has taken place in the last 12 thousand years and occurs in time intervals of 7-11, 32-45 and 70-80 years. Climate variability is regarded as an integral part of unified natural cycles (hydroclimatic, geophysical, biological). This position is proven by material on changes in hydrological changes in lakes in arid areas. In the work of Kuzmenko Y.V., Lisetsky F.N., Pichur V.I. (Kuzmenko Y.V., Lisetsky F.N., Pichura V.I.; 2012) indicates that small rivers are especially sensitive to anthropogenic impacts and serve as an integral indicator of complex natural-anthropogenic processes occurring in their catchment areas.

In modern studies, basin territorial structures are considered as hierarchical communities of spatial relationships determined by water flow. International scientific organizations (IPCC, 2007: Climate Change; 2007, Wigley T.M.L.; 2008, Wuebbles DJ, DW Fahey, KA Hibbard, DJ Dokken, BC Stewart, and TK Maycock; 2017) note that climate change manifests itself, in particular, in changes in the hydrological regime of rivers and the glaciation regime of water bodies.

The Earth's climate and the Earth's water cycle have a very close and complex relationship (Teller J.; 2017), thus the dynamics of climate change will affect water resources. For example, rainfall deficits will reduce soil moisture, stream flow and groundwater recharge, but the magnitude of this flow effect will depend on local conditions such as soil properties, geology, vegetation and water use. Due to the different time scales of the processes involved, the impact on groundwater deficits (although these are usually less pronounced than for surface water and come with a delay) can last much longer than the original meteorological drought that caused it, thus initiating a "memory effect" .

On the other hand, floods can affect the availability of water, sanitation and other aspects of people's livelihoods through damage to key infrastructure and services. At the same time, the hydrological cycle itself is an important component of the climate system, controlling the interaction between the atmosphere and the earth's surface and providing feedback mechanisms in the transport, storage and exchange of mass and energy. The relationship between climate and water resources is influenced by many anthropogenic factors, including, but not limited to, land use and land cover change, water regulation and abstraction systems, and water pollution.

Climate change affects the terrestrial water cycle through many different processes (Teller J.; 2017). Feedback and interactions between these processes, which are not all fully understood or measurable at appropriate scales, make it very difficult to quantify and predict impacts.

Although hydrological data collected in the past provide valuable information about processes and events, they are not necessarily indicative of future hydrological regimes. Moreover, even when hydrological changes are detected, the explanation of the causes, including climate change, often remains uncertain (Myagkov S.V.; 1995).

Spektorman T.Yu. in the study (Spectorman T.Yu.; 2015) argues that assessing the impact of climate change on the water resources of the basin will make it possible to take into account possible changes in hydrological characteristics when planning the development of agricultural and other sectors of the economy, as well as for the development of adaptation measures. The purpose and objectives of the work. The main goal of the work is to show that the study of dynamic climate changes directly changes river flow, at the same time, it is necessary to assess the impact of climate change directly on river flow. This paper shows that river flow is affected not only by global climate change, but also changes occurring in neighboring rivers change the water regime itself and increase the difficulty in assessing the impact of climate change from local weather influences, which are more determined by orography and terrain.

The terrain often changes the precipitation regime in the river basin. Moreover, precipitation may fall in the higher part of the basin, while in the middle part there may be no precipitation. This difference is especially expressed in the uneven distribution of precipitation throughout the drainage basin. The objectives of the work include assessing changes in the flow regime of mountain rivers for various time periods of increase and decrease in river flow, not only in connection with air temperatures and seasonal snow accumulation, but also short-term changes in the parameters of the hydrological cycle, the measurement of which is not possible using instrumental observation methods, as well as consideration of trends flow changes for neighboring catchments, which reflect local flow dynamics.

2.Materials and methods.

For hydrological analysis, the watersheds of the Sokh and Shakhimardan rivers and the southern slopes of the Fergana Valley were selected. Both rivers are located in neighboring basins (Fig. 1). Streams flowing down the slopes of the Fergana Valley are of great importance for agricultural production, but their flow is small and hydrological measurements are organized only on these main rivers. But even annual runoff volumes vary significantly. The average long-term flow of the Sokh River is about 1.26 km3 per year, the catchment area is 3510 km², while the flow of the Shakhimardan River is up to 0.304 km3 per year, and the catchment area is 1300 km². The Sokh River has mixed feeding, glacial-snow and underground. Flood occurs during the period of intense glacier melting from June to September. The Shakhimardan River originates on the territory of the Shakhimardan exclave of Uzbekistan at the confluence of the Aksu and Koksu rivers, which originate on the northern slopes of the Alai and Turkestan ranges. To analyze the flow regime, a multivariate statistical model and regression analysis of river flow based on the water balance formation model were used (Denisov Yu.M.; 1972, Merkulova N.N., Mikhailov M.D.; 2014).

3.Main part.

The formation of a mountain river flow occurs as a result of the melting of snow cover that falls in winter, the melting of glaciers in summer, the influx of groundwater and rain. Provided that the runoff is formed in proportion to the precipitation that fell on the territory of the drainage basin, the melting of seasonal snow and glaciers, then in general the water balance equation for a certain period can be written as:

$$Q=\alpha X+\beta T+\gamma , \quad (1)$$

where Q is the flow of water into the river bed, X is in the drainage basin, T is the air temperature at the meteorological station, α, β are the proportionality coefficients, γ is some constant coefficient characterizing the influx of groundwater and the melting of snowfields in the ravines.

Using equation (1) as a statistical multiple regression equation for the Sokh and Shakhimardan rivers, multiple coefficients of determination for a long-term period (1931-2019) were obtained equal to 0.672 and 0.647, respectively, with a multiple correlation coefficient equal to 0.45 and 0. 42.

Figure 2 shows a combined hydrograph of the flow of the Sokh and Shakhimardan rivers. Hydrographs are given before 1997 due to the passage of a destructive mudflow along the Shakhimardan River on July 7, 1997, which destroyed the hydrological post, which was restored later. But most importantly, during the formation of the mudflow, dams were broken and several moraine lakes were destroyed, which served as some kind of accumulator of glacial melt water and directly influenced the hydrological structure of the Shakhimardan River.

Due to the fact that the absolute values of water discharge along the Sokh and Shakhimardan rivers have different values, in order to compare hydrographs, it is necessary to bring them to comparable values. For this purpose, the normalization formula was applied, namely:

$$Q_{norm}=1-(Q_{max}-Q_i)/(Q_{max}-Q_{min}), \qquad (2)$$

where Q_{max} is the maximum value of the series, Q_{min} is the minimum value of the series, Q_i is the value of the series at the current time, Q_{norm} is the normalized flow rate, varying within the range $0 \leq Q_{norm} \leq 1$.

Thus, Fig. 2 shows hydrographs of normalized water flows along the Sokh and Shakhimardan rivers. The figure shows that in many cases the hydrographs do not coincide, which indicates a weak connection between the water flows of two rivers whose catchments are located next door.

Note that for the period 1964-1979 the coincidence of hydrographs of different rivers is almost perfect. In other cases, there is a coincidence in the direction of the maxima and minima, but the values differ. In many cases, reverse deviations are observed. On one river there is a maximum, on another there is a minimum. This suggests that these rivers differ in hydrological regime, despite the fact that their catchments are located next door and are in the same geographical area.

Let's look at the smoothing lines on the hydrographs of both rivers. For the period 1930-1960. The smoothing lines for both rivers practically coincide. However, the minima differ in time for the river. Sokh, the minimum occurs in 1962, for the river. Shakhimardan minimum – 1972, the difference is 10 years. In the period from 1972, the smoothing line begins to rise for the Shakhimardan River, and for the Sokh River, starting from 1992, a decline begins, with a maximum in 1991. Now let's look at the hydrographs themselves. In the period 1930-1962.

There are differences and discrepancies, although in some cases there is a tendency to repeat the peaks of maximums and minimums - 1943, 1951, 1957, 1959. Let us pay attention to the period 1953-1956; during this period there is an absolute discrepancy between hydrographs. In the period 1964-1977. Almost the same course of normalized hydrographs of both rivers is observed. In the period 1978-1997. again, the hydrograph lines often diverge, although It can be argued that in some cases, local landscape-geographical and climatic conditions of runoff formation have a great influence on river flow; in other periods, climatic factors of a regional nature, common to both river basins, have a greater influence.

Using this method of analyzing the dynamics of river flow, it is possible to determine periods of predominant influence on the flow of local or regional climatic factors. Figure 3 shows a graph of the relationship between the normalized water flows of the Sokh and Shakhimardan rivers. It is clearly noticeable that there is practically no connection. Linear equation regression coefficient: $y = 0.6298x + 0.1715$, total $R^2 = 0.1992$ and correlation coefficient $K = 0.41$. For an equation converging to zero, which means that with zero runoff in one basin, there will also be zero runoff in the other basin: $y = 0.9422x$, $R^2 = 0.1433$, and correlation coefficient $K = 0.38$.

The practically insignificant connection between the flows of the Sokh and Shakhimardan rivers suggests that in the formation of the flow of these rivers, the local distribution of precipitation and air temperature is of significant importance; they cannot be used to restore hydrological series, like their analogue rivers.

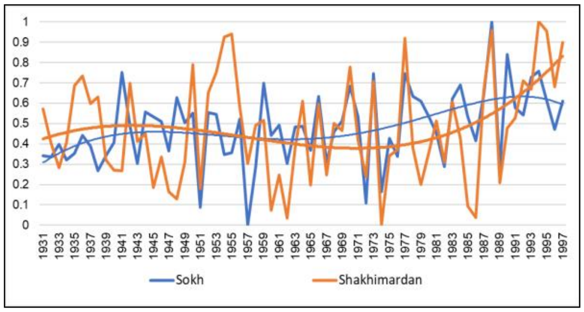

Figure 2. Hydrographs of normalized water flow values of the Sokh and Shakhimardan rivers. Polynomial trends are presented.

Let us pay attention to the precipitation regime during the growing season. Figure 4 shows the precipitation regime by month of the growing season at the Sarykanda weather station, Sokh river basin. There is significant variation in precipitation amounts. The greatest amount of precipitation is observed in May, the least in September.

At the same time, there is an increase in precipitation in June in some years. Moreover, the range of fluctuations in precipitation in June is from 10 to 151 mm per month. In September, the range of monthly precipitation amounts varies from 0 mm to 47 mm. For the observation period 1935-2020. The temperature range in the Sokh River basin is also changing ambiguously. In April the range changes from 9 to 15 C^o, in July from 20 to 24.4 C^o.

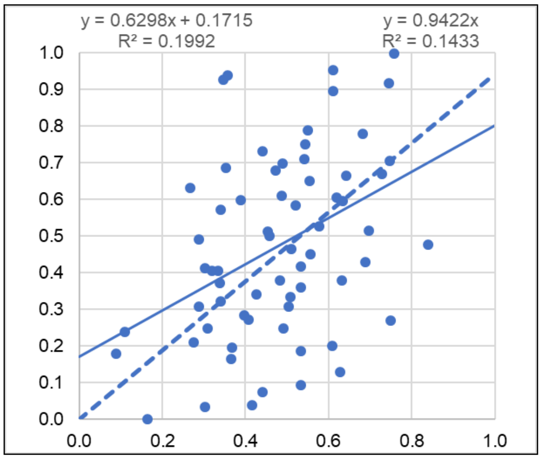

Figure 3. Relationship between normalized water flows along the Sokh and Shakhimardan rivers. A linear dependence (solid line) and a dependence with convergence at zero (dashed line) are shown.

Figure 5 shows a “bundle” of hydrographs of the average monthly temperature of the surface layer of the atmosphere, observed at the Sarykanda meteorological station. For rivers with glacier-snow feeding type, the temperature regime determines the intensity of glacial melting in the summer. Of course, glacial melting is influenced by solar radiation. In the case of glaciers, solar radiation hits a flat surface, with virtually zero exposure. If we take this circumstance into account, we can assume that the glacial component is determined entirely by air temperature.

For this reason, climate change has a greater impact on the melting of glaciers than precipitation on the surface of the glacier, including the firn formation zone.

4.Conclusions

Based on the results of the studies, it was revealed that in the normalized flow values for the basins of neighboring rivers there are periods with deviations in the flow of one river from another, under similar geographical, geomorphological and landscape conditions.

Over a long observation period (1933-2020), periods of decrease and increase in water discharge values for the Sokh and Shakhimardan rivers are observed against the general climatic background of changes in precipitation patterns and air temperature. The similarity of geographical and landscape conditions is evidenced by periods of very close agreement between normalized hydrographs.

Analysis of hydrographs shows that, against the background of differences, there are close coincidences of normalized river flow hydrographs, from which we can draw a conclusion about the influence of general factors in the formation of river flow on the flow formation itself, as well as the strong influence of local weather conditions and climatic phenomena on the formation of mountain river flow .

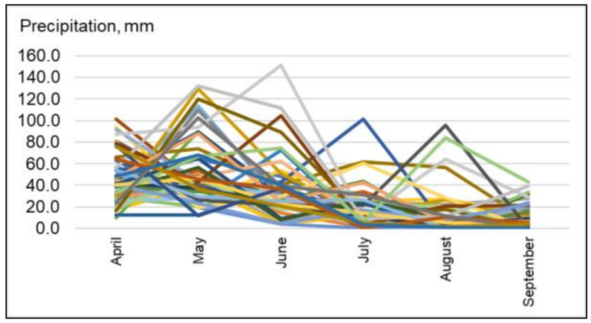

Figure 4. The course of the average monthly precipitation during the growing season at the Sarykanda meteorological station for the period 1933-2020 (Sokh River basin).

The use of normalization of runoff values for different river basins makes it possible to analyze the similarities and differences in the conditions for the formation of the flow regime. This is especially important for analyzing the impact of climate change on specific territories and geographical conditions in mountain river basins.

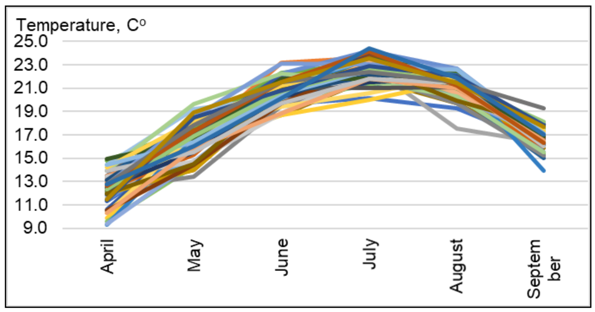

Figure 5. The course of the average monthly air temperature at the Sarykanda meteorological station (the Sokh river basin) for the period 1933-2020 during the growing season.

Analysis of the correlation between normalized values of mountain river flow showed that in a long-term observation period there are periods of increase and decrease in river flow. Talking about the unambiguous impact of climate change on an increase or decrease in river flow in the future is a controversial issue and requires further research.

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Corresponding Author:
Prof. Sergey Myagkov,
Department of Hydrology,
Hydrometeorological Research Institute,
Bodomzor-72, Tashkent, 100052, Uzbekistan
Telephone: +998 99 320 83 28
E-mail: sergik1961@mail.ru, sergik1961@yahoo.com

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