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Hydrology and Mudflows of the Shakhimardan river

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Abstract: The emerging runoff of the rivers of the glaciers of the Pamir-Alai system is transboundary and affects Kyrgyzstan, Tajikistan and Uzbekistan. The basis of the mountain river runoff 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 changing climate inevitably affects the hydrological regime of the rivers of the glacial-snow type of feeding. The occurrence of mudflows of the Shakhimardan River leads to the threat of mudflow floods against the background of hydrological floods. The research method is a graphical comparison of runoff hydrographs for a long-term period of hydrological observations and statistical analysis of the data. Long-term trends are constructed based on the normalized values of water discharge of the Sokh and Shakhimardan rivers. Polynomial trends in hydrological series were constructed using sets of statistical functions and calculation methods using widely used programs. Periods of increase and decrease in glacial runoff over a long period are revealed. In the Shakhimardan River valley there are many rock falls reaching the river bed. During major floods, a large amount of rock debris is drawn into the water flow, which increases the flow speed and its destructive power. The paper presents a hydrological analysis of flood development in the Shakhimardan River.
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1. Introduction

Glaciers have a significant impact on the amount of river runoff in Central Asia. High-mountain glaciation of the Pamir-Alai system, with climate change, also changes the hydrological regime of rivers, which are formed due to precipitation in the winter and the melting of glaciers in the summer.

The formation of runoff in the summer occurs due to the melting of the glaciers themselves and snowfields located in the hollows of river valleys (Kuzmenko Ya . V ., Lisetsky F. N. , 2012 , Arnell N. , 1999)) .

The Pamir-Alai glacial system includes the Zaalai range in the north, the Kashgar and Sarykol ranges in the east, the Vakhan range and its western continuation, the Shakhdara range, in the south, and the high ranges of the Western Pamirs, which abut the Academy of Sciences range, form the elevated edges of the Pamir plateau. Numerous glaciers are located in the highlands of the Pamir-Alai system (IPCC , 2007: Climate Change 2007) .

The snow line in the Pamir-Alay Mountains rises from the west-northwest to the east-southeast. On the Turkestan Range it is located at an altitude of about 3,500 meters above sea level, in the area of the Fedchenko Glacier - 4,400 meters above sea level, in the central and eastern regions of the Pamirs it rises to 5,200 - 5,240 meters above sea level (Myagkov S. V. , Gavrilenko N . N ., 2020) .

The glaciers of the Pamir-Alai are in most cases in a state of retreat. In the central and eastern parts of the Pamirs there were foothill glaciers. They were also widespread in the Alai Valley along the foot of the Trans-Alai Range, where long moraine ridges now lie.

Relevance. Changes in runoff due to climate change have a significant impact on human activities. Of particular importance are the water resources of transboundary rivers, which are the Shakhimardan and Sokh rivers. In the high-mountain region of the Aral Sea basin, changes in the elements of the hydrological cycle are occurring due to climate change.

Many studies indicate a reduction in the area of high-mountain glaciation from 20% to 40% from 1960 to 2020, which leads to a shortage of water resources. The risk of floods , which lead to mudflows and floods, increases (Fillon R. H. , Williams D. F. , 1984) .

The possibility of constructing river runoff trends for analyzing the dynamics of water resource formation is considered and various time periods of runoff formation are determined.

The results obtained show significant differences in the runoff characteristics of neighboring river basins under different precipitation and air temperature regimes

Research object and methodology. The rivers of the Pamir-Alai belong to the Amu Darya basin. Large rivers originating in the highlands are fed by glaciers and snow; in comparison with the rivers of the Tien Shan, the share of glacial feeding is greater (Myagkov S. , Makhmudov B ., 2024) .

The winter precipitation regime leads to the accumulation of seasonal snow cover and its melting leads to the formation of the main mass of water during the spring-summer snowmelt. In the summer, when the layer of seasonal snow is almost finished, the melting of glaciers begins with an increase in temperature above zero degrees Celsius.

The resulting floods can serve as the appearance of mudflows on the Shakhimardan River (Mallakpour I., Villarini G., 2015) .

In the summer, precipitation falls in the highlands as rain and almost immediately flows into river beds. The main volume of water in the summer comes in the form of melting glacier masses.

Determining the glacier melting regime is possible by determining the flow of water into river beds with the minimum amount of precipitation in the Pamir-Alai region (Fig. 1). The minimum amount of precipitation in the Pamir-Alai region falls in September (Table 1).

In the foothills of the Pamir-Alai and in the lowlands, winter is comparatively short and mild, summer is long, with high temperatures; the amount of precipitation is greater than in the neighboring deserts (350-700 mm/year).

At altitudes of 1500-3500 m , the climate already has the characteristic features of a mountain climate, it is cooler and more humid in the predominant part of the territory: in these altitude limits there is a belt of the greatest humidity and in places precipitation exceeds 1000 and even 1600 mm/year (Spektorman T ., 2015) .

The Shakhimardan River flows through the territory of Uzbekistan and Kyrgyzstan. Shakhimardan river begins at the confluence of the Aksu and Koksu rivers, which originate on the northern slopes of the Alay and Turkestan ranges. The catchment area is 1300 km². The average long-term water flow is 11.6 m³/s, the flow rate is 9.66 m³/s, the average annual runoff is 304 million m³. The runoff modules of the Sokh River are 12 liters per km2 , and of the Shakhimardan River 7.69 liters per km2 .

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 average water flow at the Sarykanda post is 42.1 m³/s. Flooding occurs during the period of intensive glacier melting from June to September.

Glacier nutrition is formed by the melting of perennial ice and firn reserves. This is the main hydrological role of glaciers - to accumulate the annual excess of precipitation, redistributing its melting over many years. Seasonal snow on glaciers, melting in the warm season, participates in the rapid moisture cycle.

The remains that do not melt in firn areas are transformed into firn, and then into ice, which participate in the slow moisture cycle.

This approach is used in the mathematical modeling of the runoff of mountain rivers (Merkulova N., Mikhailov M., 2014) .

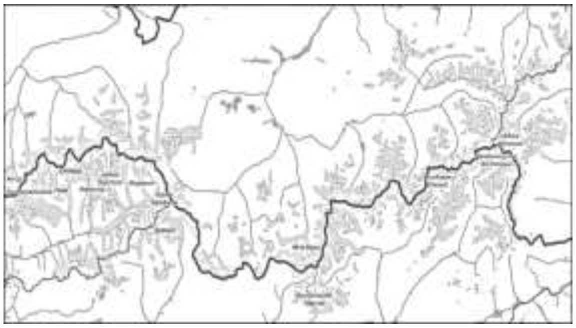

Figure 1. Scheme of high-mountain glaciation of the upper reaches of the Shakhimardan and Sokh river basins in the Pamir-Alay territory (39°35'N, 70°56'E).

The changes in water flow rates in the Shakhimardan and Sokh sections comprise a large range. For the Sokh River, the difference between the minimum and maximum values is 64.4 m3/sec, while for Shakhimardan it is 8.12 m3/sec. Placing the hydrographs on one graph will not reveal the difference due to the different scales in water flow rates (M . L . Parry , O. F. Canziani , J . P . Palutikof , P . J , 2012) .

2.Materials and methods.

Due to the fact that the flow rates of the Shakhimardan and Sokh rivers have different ranges for comparing hydrographs, it is necessary to standardize them and bring them to common values.
To compare the hydrographs of the Shakhimardan and Sokh rivers on one graph, the values were normalized using the equation:

$$Q_{Norm} = 1 - (Q_{Max} - Q_i)/(Q_{Max} - Q_{Min}),$$

where Q_{Norm} is the normalized value of water consumption, the value varies within the range ($0 \leq Q_{Norm} \leq 1$), Q_{Max} is the maximum value, Q_{Min} is the minimum, Q_i is the water consumption for a specific year.

For an equation that converges to zero, which means that if there is zero flow in one basin, there will also be zero flow in the other basin: y = 0.9422 x , R^2 = 0.1433, and the correlation coefficient K = 0.38.

It can be argued that in some cases local landscape-geographical and climatic conditions of runoff formation have a great influence on river runoff, while in other periods a greater influence is exerted by regional climatic factors common to both river basins. Using this method of analyzing river runoff dynamics, it is possible to determine periods of predominant influence of local or regional climatic factors on runoff (Rodriguez - Iturbe I . , 1987) .

The almost insignificant connection between the flows of the Shakhimardan and Sokh rivers indicates that the local distribution of precipitation and air temperature is of significant importance in the formation of the flow of these rivers; they cannot be used to restore hydrological series, as in the case of analogous rivers.

3.Main part.

Due to the fact that in September there is significantly less precipitation than in other months (Table 1), a graph of changes in water flow along the Shakhimardan and Sokh rivers for the month of September was constructed (Figure 2).

This makes it possible to assume that the contribution of the melted glacial component to the river runoff is the greatest in comparison with other periods or seasons of the year.

Figure 2 shows the normalized combined hydrographs of the Shakhimardan and Sokh rivers for the period 1931–2001 for September.

Figure 2 shows frequent coincidence of hydrographs, but also significant discrepancies. Polynomial trends were constructed, which show their good coincidence in terms of runoff dynamics.

Thus, in the period 1931-1940, a decline in the line of both trends is observed, then in the period 1940-1956, an increase in runoff is observed, then in the period 1958-1976, a decline in trends is observed again, for the period 1976-1995, an increase is observed, continuing for the Sokh River until 1997, and for the Shakhimardan River until 2001.

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

Table 1.Precipitation totals at the weather station in the Shakhimardan River basin for the period 1931-2023

Months	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Total	983	1283	1899	2296	2605	1820	806	630	491	1076	1047	1131
%	6.1	8.0	11.8	14.3	16.2	11.3	5.0	3.9	3.1	6.7	6.5	7.0

The use of standardization of runoff values for the basins of different rivers allows us to analyze the similarities and differences in the conditions for the formation of the runoff regime. This is especially important for analyzing the impact of climate change on specific territories and geographical conditions in the basins of mountain rivers.

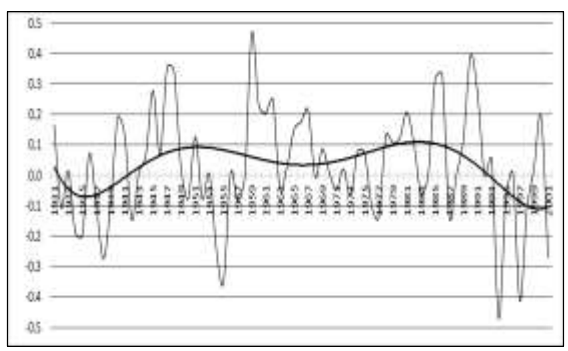

Figure 2. Difference in normalized hydrographs of the Shakhimardan and Sokh rivers, and polynomial trend for September period 1931-2001.

4.Conclusions

The results of the conducted studies revealed that in the normalized values of runoff for the basins of neighboring rivers, there are periods with deviations in the runoff of one river from another, under similar geographical, geomorphological and landscape conditions.

Over a long period of observations (1933-2020), there are periods of decrease and increase in water flow values for the Sokh and Shakhimardan rivers against the general climatic background of changes in precipitation and air temperature regimes.

The similarity of geographical and landscape conditions is evidenced by periods of very close coincidence of normalized hydrographs.

The proposed methodology for standardizing runoff values allows us to determine the share of the glacial component in the runoff of glacier-snow fed rivers.

Current changes in mountain glaciation affect river water resources and lead to changes in the intra-annual flow distribution. It would be useful to perform similar calculations for a number of river basins. However, further clarifications, if they can be made on the existing rough and not always reliable initial data, will not change the qualitative picture.

The rate of glaciation reduction in different river basins, located in different climatic and orographic conditions, varies significantly.

Winter temperatures are rising faster than summer temperatures. The resistance of the temperature regime in the highlands to global climate warming increases with increasing altitude.

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