Modern State of the Transboundary Amudarya Main Tributaries

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Abstract. The hydrograph of the tributaries of the Vakhsh River show two extreme periods during the year: May-June and August-September. The period 1931-1961 is characterized by more stable temperatures with a significant increase since 1981. Also during the period 1931-1961 water flows in the Zeravshan River's has had a decreasing trend. The calculations show that the average annual volume of runoff reduced from 6.08 km^3 for the period 1931-1961 to 5.36 km^3 for the period 1981-2011.

1. Introduction

Water resources in the Aral Sea Basin, which encompass five states, are mostly used for irrigation and hydropower. These water uses require very different water flow regimes. The aim of the hydropower plants is to maximize the revenue from power production, hence, they release most water through their turbines during the winter period when energy demand and prices are highest. Contrary, Irrigation requires the largest volume of water during the summer period when crops are growing. River flows are regulated by large reservoirs, which, combined with hydropower stations, are operated as part of complex multipurpose hydro-schemes. The largest hydropower stations have been constructed in the republics in the upper reaches of the Amudarya and Syrdarya rivers—in Kyrgyzstan and Tajikistan, while the major land areas to be irrigated are concentrated in the republics in the lower reaches of the rivers—Kazakhstan, Turkmenistan, and Uzbekistan.
The analysis shows that irrigation and hydropower plants are not inevitable competitors in Central Asia. Moreover, the interaction between the two uses can contribute to the mutually beneficial cooperation of Central Asian states with the aim to jointly use the available water and power resources. The most important indices for economic activity are the total volume of water runoff and its variations (seasonal and long-term) (Petrov and Normatov, 2010).
However, the problem of accurately predicting seasonal river flows will persist and even gain in significance. The construction of a number of large reservoirs in the region has resulted in the water regime of the rivers (in terms of both the runoff volume and its seasonal, and, sometimes, long-term variability) largely being determined by human activity. The problems arising here are due not only to engineering restrictions, but also to poor relationships between states, since the existing hydroelectric complexes are located in the different Central Asian states.
The Vakhsh River is the main river of the Republic of Tajikistan and one of the tributaries of the Transboundary Amudarya River in Central Asia. It has a length of 691 km and the area of the basin is 39160 km^2. The Vakhsh River originates when the Surkhob and Obikhingoy rivers merge at a height of 1151 meters. The right inflow to the Vakhsh Rivers, the Surkhob River has a length of 81 km, and the basin covers an

area of 1760 km^2 at an average altitude of 3140 m. There are 246 glaciers in the Sorbog River basin covering a total area of 105.6 km^2. The left component of the Vakhsh - the Obikhingoy River is 196 km long and covers an area of 6660 km^2.
The aim of this paper is to identify the main trends in annual and low-flow runoff of the Vakhsh and the nature of intra-annual distribution of runoff. An analysis of the meteorological conditions of the Zeravshan River basin, the monitoring of changes in the Zeravshan River and the contribution by its tributaries during the 1931-2011 period was also carried out.

2. The Hydrological Characteristics of Tributaries and Transboundary Vakhsh River

The hydropower plants on the tributaries and Vakhsh River and the location of hydrological stations is shown on Fig. 1.

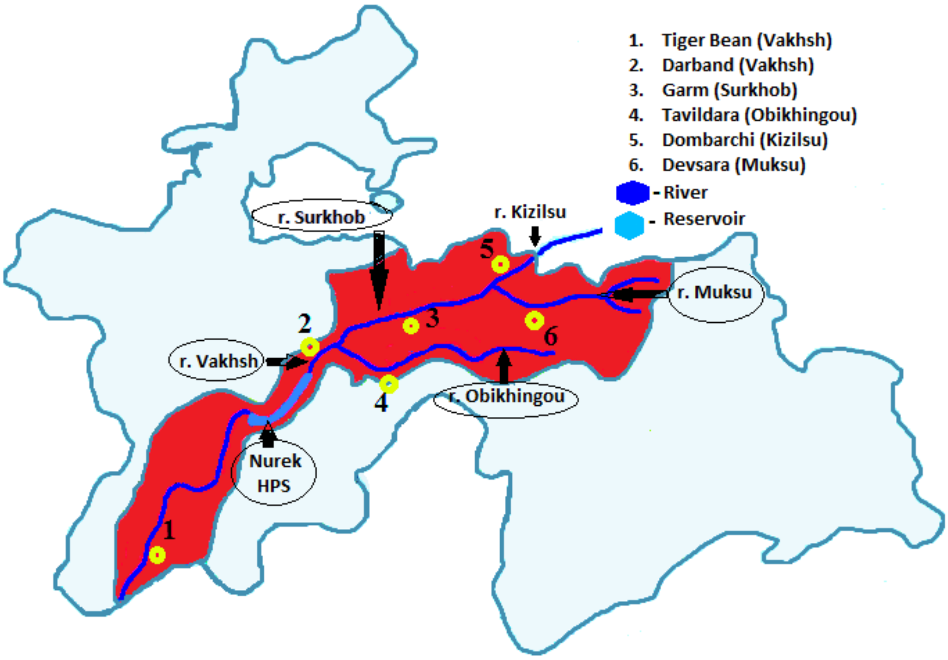

Fig.1. Vakhsh River Basin

The increase in the volume of river flows of the Vakhsh River and its tributaries- Surkhob and Obikhingou rivers (Figure 2) reflect that currently there is a reduction of the Tajikistan glaciation areas resulting in increased snow melt, probably due to the overall temperature increase in the region and changing precipitation patterns.

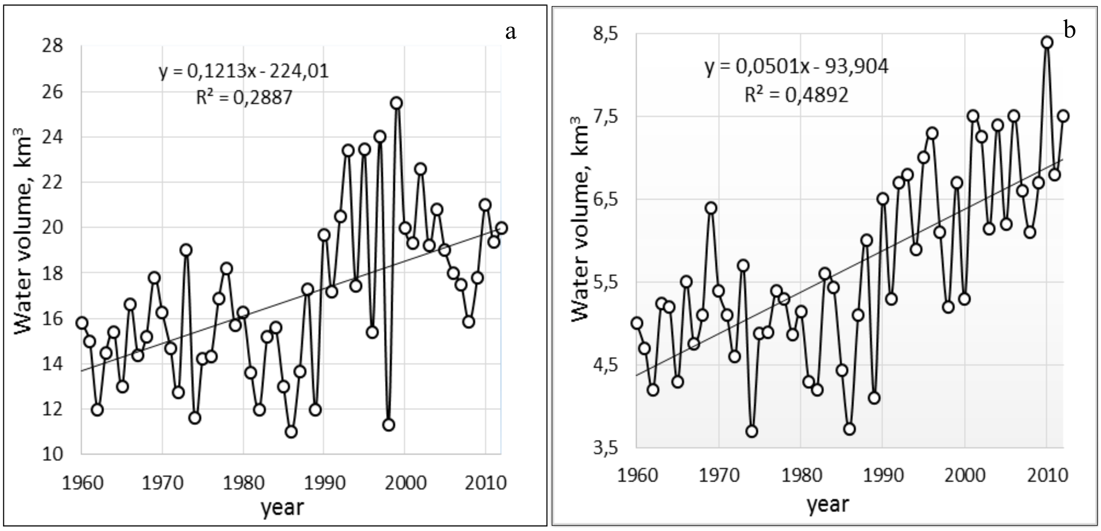

Fig. 2. The water volume change of the Surkhob (a) Obikhingou (b) rivers for the period 1960-2012

In the Surkhob River basin, there are intensively melting small glaciers of the Northern slopes in the Western part of a ridge of Peter the Great. On the southern slopes of the Alay Ridge, glaciation decreases slower as there are larger glaciers. In the Obikhingou River basin, the largest glacier Garmo is intensively melting. During the XX century, it became shorter by almost 7 km, having lost more than 6.0 km^2 in area. It is currently retreating at an average speed of 9 m/year, and the surface settles up to four meters per year due to melting. Another glacier in the same basin, Skogach, retreats at a rate of 11 m annually.

Another important aspect of the hydrology of the rivers, the cyclical nature of the water flow, should also be considered.

Assessing the long-term fluctuations of annual runoff and their periodicity is important. On the other hand, there are attempts to link fluctuations in water availability with various geophysical processes. The lack of a clear periodicity in long-term fluctuations of flow does not rule out the tendency to have continuously alternating high water years, called cyclical fluctuations of water flow. The length of these cycles, their sequence and the degree of deviation varies over a period year. It is not always possible to make clear boundaries between wet and dry periods. Cyclical changes of the Vakhsh River runoff for the period 1932-2012 are shown in Figure 3.

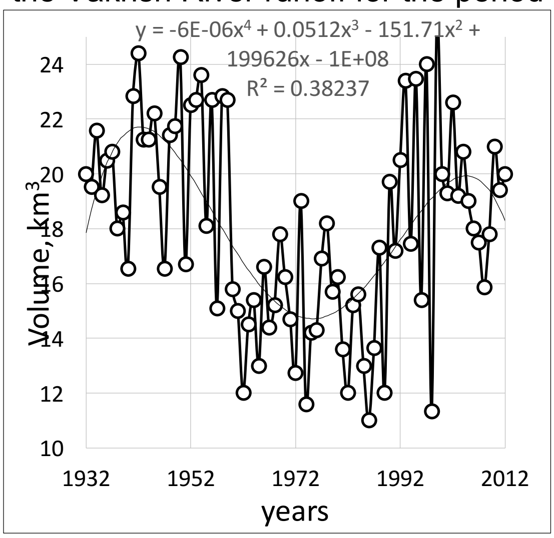

Fig. 3. The water volume changes of the Vakhsh River for the period 1932-2012

The differential integral curves of average annual discharge are used to identify periods with high and low water run-off. The differential integral curve takes into account the fluctuations of the flow over relatively short periods. It is defined by summing the deviations of modular coefficients from the middle, i.e. the ordinates are calculated as Σ (K-1). Thus, the ordinates of the curve at the end the cumulative sum of the annual modular coefficients gives the deviations from the long-term average (K=1). The use of differential integral curves gives a vision of cyclical fluctuations without the effect of the boundaries displacement between the phases of the low and high duration cycles (Alexeevsky, 2013).

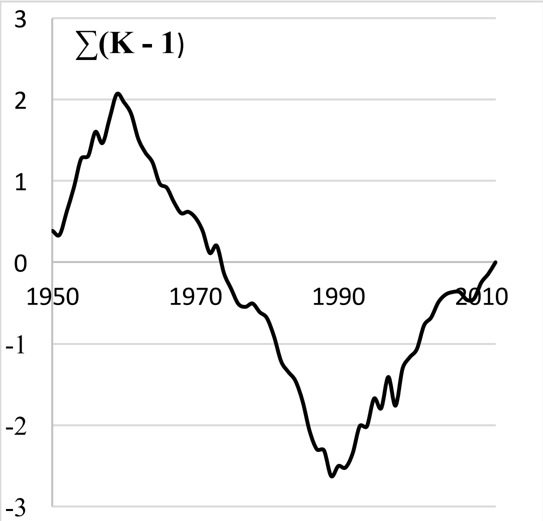

Fig.4 The differential integral curve of the Vakhsh River annual average water discharge

The presence of average annual water flows in the differential integral curve allows defining the periods of high and low water availability of the Vakhsh River (Fig. 4). It should be noted that the appearance of cyclicality in the water flow of rivers allows predicting the future scenarios of changes in the water flow of the river (Fig.5).

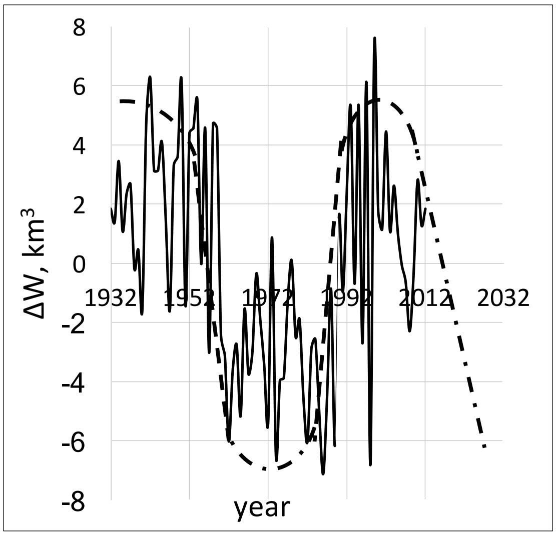

Fig. 5. Cycle of the Vakhsh River water flow for the period 1932-2012

3. Meteorological Condition of the Tributaries and Vakhsh River Basins

Another important factor in the water flow change is the meteorological condition of the river basins. The data from meteorological stations in Garm, Lyakhsh (basin of the Kyzilsu River), and Tavildara (Obikhingou River basin) for the period 1960-2012 was used for monitoring the meteorological conditions of the respective rivers basins.

The analysis of the date from meteorological stations shows that in the Vakhsh River basin (including the basins of the tributaries of the river) the change in temperature has an increasing trend (Fig.6, 7). On the other hand, as it is shown in Fig. 7 (b, d), atmospheric precipitation on the Kyzilsu River basin has a decreasing trend with almost constant value on the Obikhingou River basin.

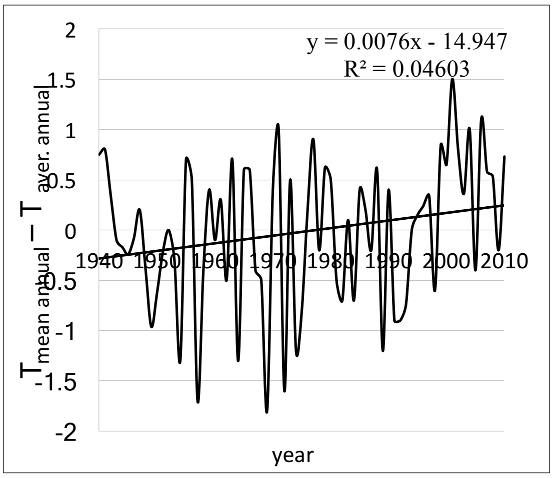

Fig. 6. Dynamics of the temperature change in the Vakhsh River basin (Meteostation Garm)

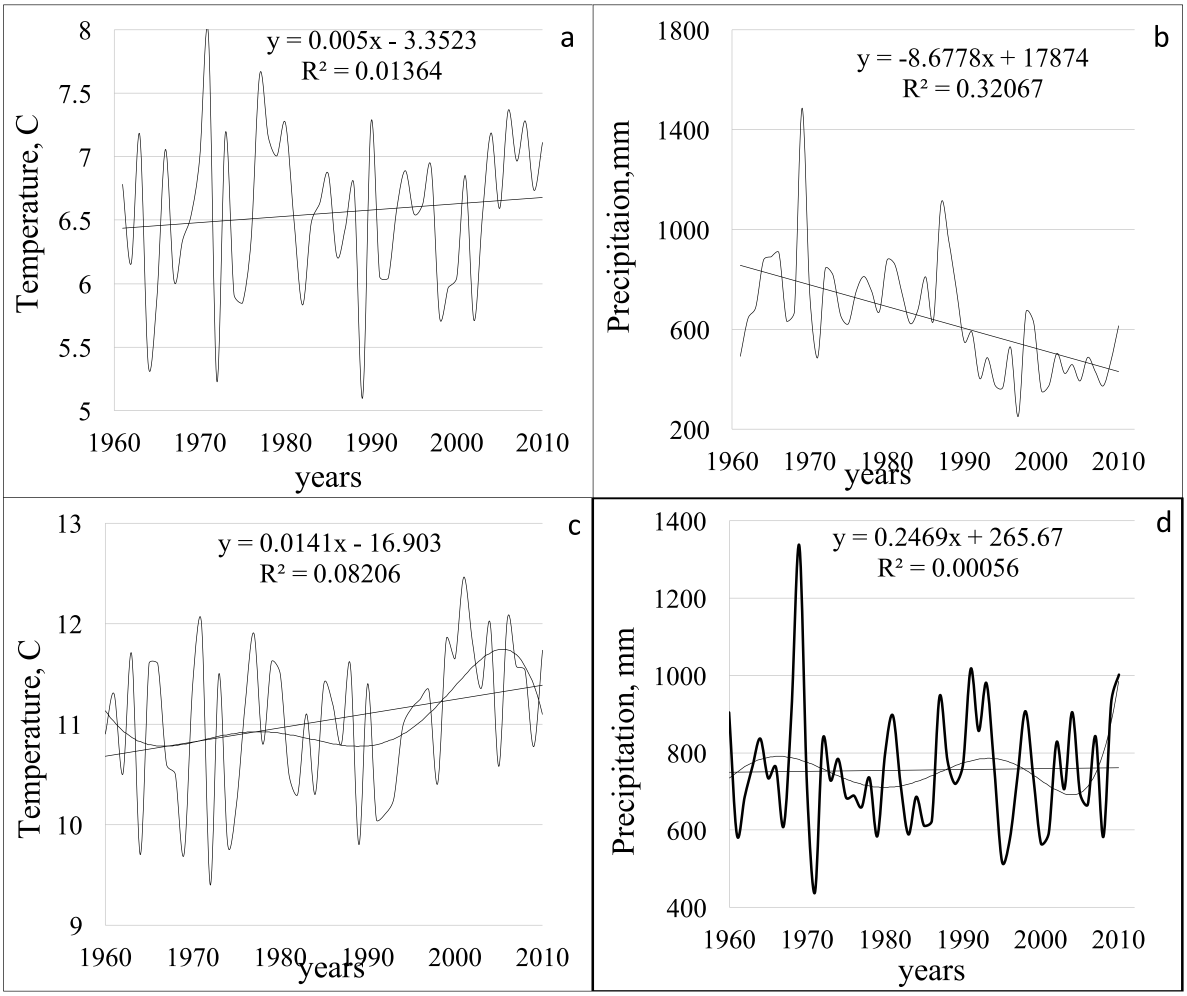

Fig. 7. The average annual precipitation and temperature according to meteorological stations Lyakhsh (a, b) and Tavildara (c, d) for the period 1960-2012

As was noted above, for the period 1960-2012, the water runoff in most of the rivers of the Vakhsh River basin has an increasing trend. Thus, the increase in water volume and the decrease in precipitation give reason to believe that in the Vakhsh River basin there is a continued reduction in the size of the glaciers.

4. Water flows of the Zeravshan River and its tributaries under climate change

The Zeravshan River is one of the transboundary tributaries of the Amu Darya River that is formed in Tajikistan and flows into Uzbekistan. The average flow of the Zeravshan River is about 5.0 km^3 with an average annual flow of 158 m^3/sec (Normatov et. al., 2015; Olsson et. al., 2010). The meteorological and hydrological monitoring of the conditions of the Zeravshan River Basin on the territory of the Republic of Tajikistan are conducted at four meteorological stations the Dupuly hydrological station.

The total area of the glaciers in the Zeravshan River basin is 437.9 km^2. The Zeravshan glacier is the largest among the 632 glaciers with a length of 27.8 km and an area of 132.6 km^2. According to the Agency of Hydrometeorology of the Republic of Tajikistan, there have been significant changes of geometric dimensions and mass loss of Zeravshan glacier during the period 1927-1991. The glacier retreated 88-94 m/year for the period 1991-2001 and its area decreased by 700.000 m^2 and by 2050 is expected to decrease by 30-35 % (Khomidov, 2016). The next section provides an analysis of the meteorological condition of the Zeravshan River Basin.

5. Meteorological observation

The meteorological data from the Dehavz station was used as it is close to the Zeravshan glacier and Iskanderkul in the Yagnob River basin. The deviation of average annual temperature at Zeravshan Glacier for the period 1931-1961 (a) and 1981-2011 (b) is presented in Fig. 8. The period 1931-1961, as it can be seen from Figure 8, is characterized by low temperature and also by high levels of precipitation in the form of snow. This suggests that the meteorological conditions during the period 1931-1961 were favorable for increasing the mass of the glacier.
The trend in temperature reversed during the period 1981-2011 compared to 1931-1961 (Fig. 8b) and precipitation remained almost constant. The temperature change of the Yagnob River basin for the period 1931-1961, as it is shown in Fig. 8 (c, d) is similar to the Zeravshan River basin and has a near-constant value. A significant increase is observed for the period 1981 - 2011.

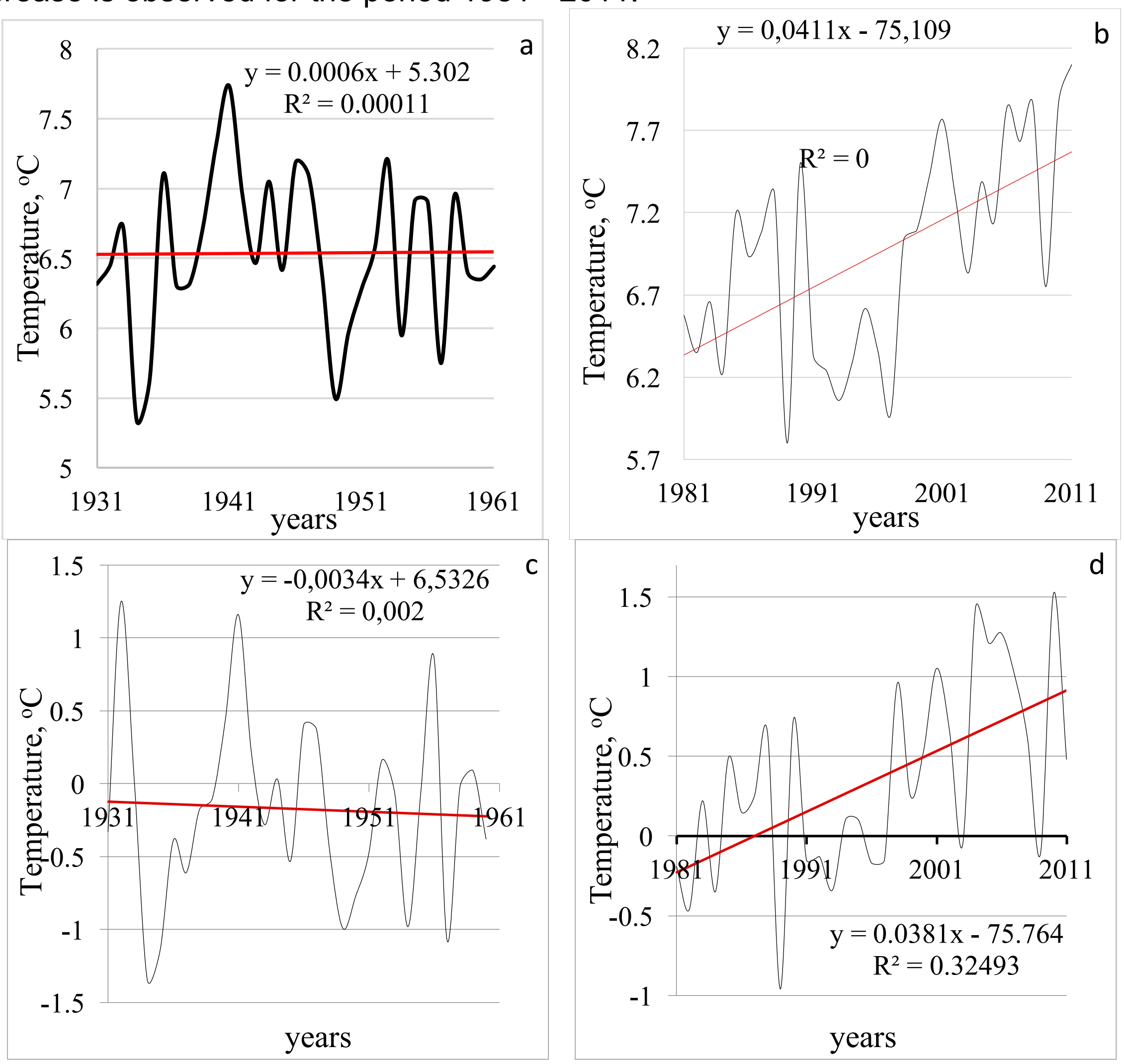

Fig. 8. The average annual temperature for the periods of 1931-1961 and 1981-2011 in the area of the glacier Zeravshan (a, b) and in the Yagnob River basin (c, d)

6. The hydrograph of the water flow of the Zeravshan River and its tributaries

Water flow of the Zeravshan River was measured at the Dupuly Hydropost that is the only operating station on the Zeravshan River. The average annual water discharge for the periods 1931-1961 and 1981-2011 is presented in Fig. 9 (a, b). The decreasing trend of water discharge for the period 1931-1961 can be explained by the low and near-constant value of the temperature resulting in the snow accumulating and expanding the glacier rather than melting and contributing to river flow. This interpretation is supported by the fact that Yagnob River water flow has been almost constant during period 1931-1961 (Fig. 9c). A completely different pattern in runoff is observed for the period 1981-2011 which experienced a significant increase in water discharge (Fig.9 b).

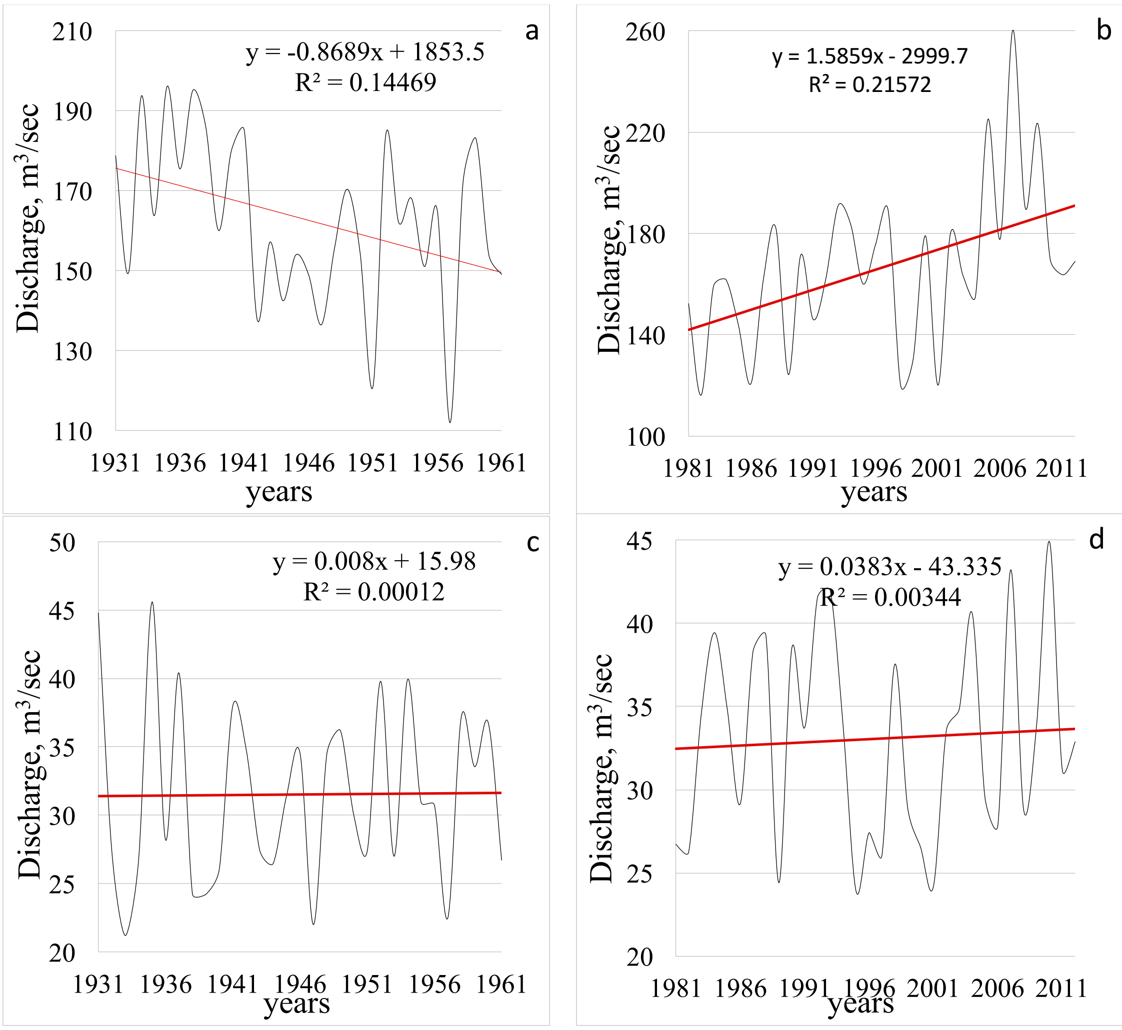

Fig. 9. The water discharge value of the Zeravshan (a, b) and Yagnob (c, d) rivers for the periods 1931-1961 and 1981-2011, respectively

Fig.10 shows the hydrographs of the Zeravshan (a) and Yagnob (b) Rivers for the periods 1931-1961 and 1981-2011, which demonstrate that for the Zeravshan and Yagnob rivers water discharge is the maximum in July and June, respectively.

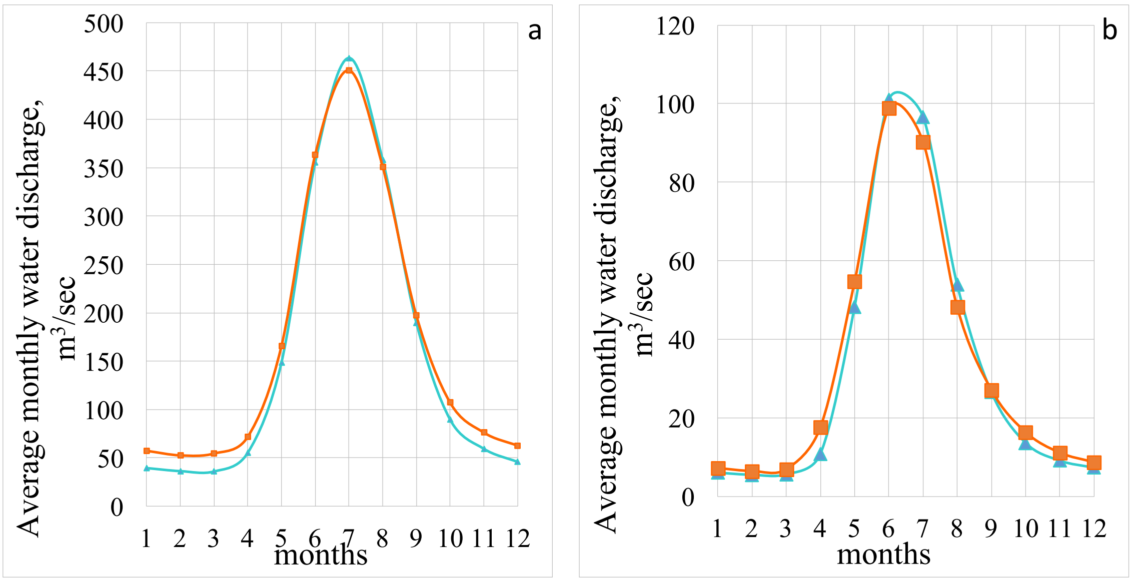

Fig. 10. The hydrograph of the Zeravshan (a) and Yagnob (b) rivers for the periods 1931-1961 (▲) and 1981- 2011 (■)

The period 1981-2011 for the Zeravshan River (Fig. 10(a)), is characterized by a flow reduction compared to the period 1931-1961. According to the estimated data, the mean annual runoff for the period 1981-2011 is 5.36 km^3, compared to 6.08 km^3 of the period 1931-1961 that is a decrease of the mean annual runoff by 12 %. The mean annual flow of the Yagnob River for the periods 1931-1961 and 1981-2011 are 1.02 and 1.04 km^3 respectively, an increase of no more than 2%.

The impact of climate change on the water flow was calculated for Zeravshan River based on the deviation of annual runoff from the mean (Fig.10):

$$\Delta Q = Q_i - Q_o$$

where Q_i is total water flows for i^{th} year and Q_o is the mean annual water flow for the period 1931-2011.

The trends in the flow of the Zeravshan River for the periods 1931-2011(a), 1931-1961 and 1981-2011 are shown in Fig. 11(b) and Fig. 11(c).

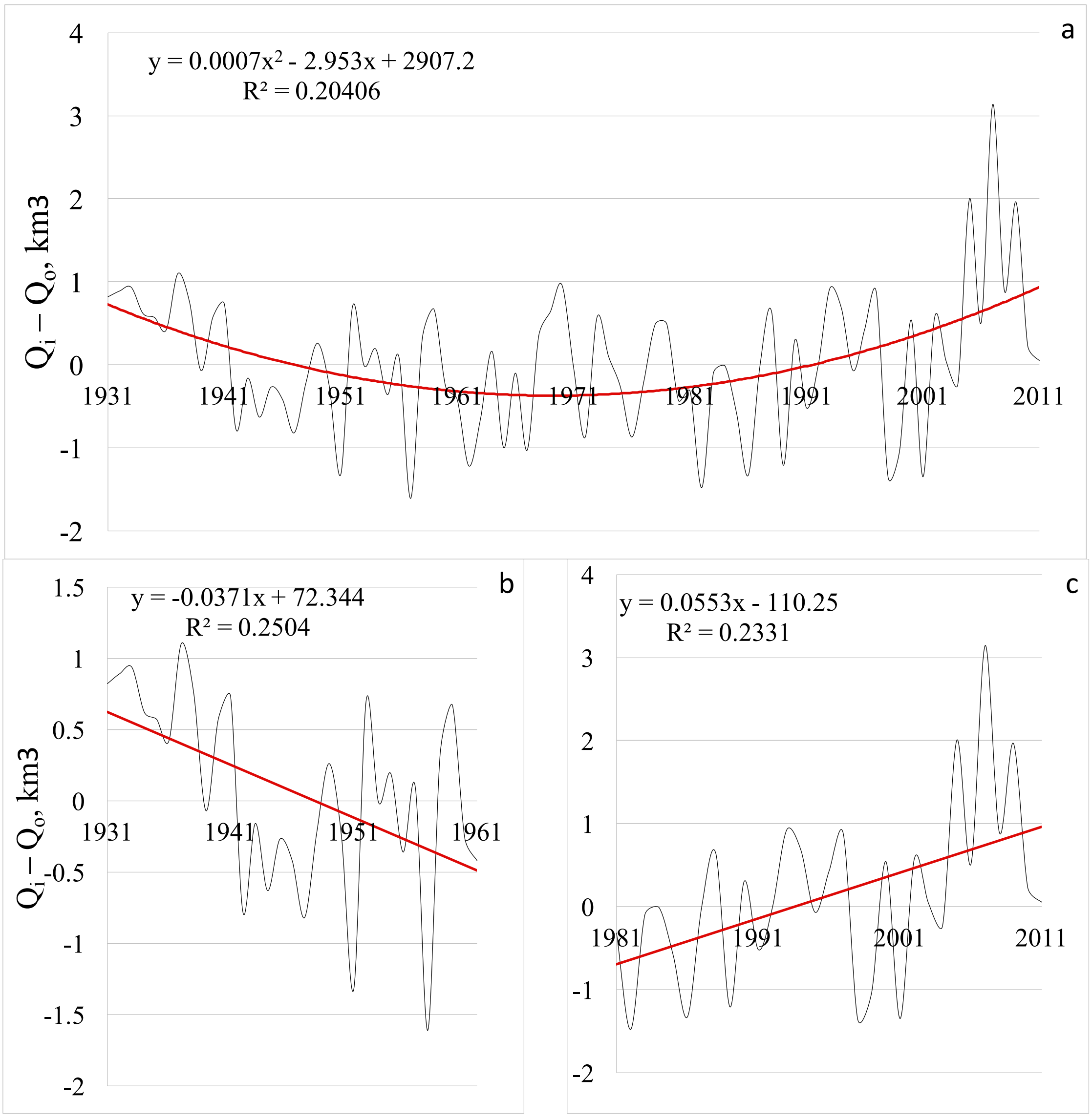

Fig. 11. The actual water content of the Zeravshan River (a) for the period 1931-2011(a) and for the periods 1931-1961 (b) and 1981-2011 (c)

A comparison of meteorological conditions of the Zeravshan glacier for the periods 1931-1961 and 1981-2011, shows a changing trend in temperature. If the period 1931-1961 was characterized by almost constant temperature, significant increases were observed for the period 1981 to 2011(Fig.8). A similar situation was evident in the Yagnob River basin. The reduction of water flow in the Zarafshan River for the period 1931-1961 changed to a significant decrease during the period 1981-2011 from 6.08 km^3 to 5.36 km^3.

7. Meteorological conditions of the Transboundary Pyanj River upstream

The Basins of the two main tributaries (the Pyanj and Vakhsh rivers of the Transboundary Amudarya River) is divided into the following zones depending on meteorological condition:
- The Southern zone and the Pamir-Alay
- Eastern Pamir

- Central Pamir
- Eastern Pamir

Climatic features of the Western, Central and Eastern Pamir are recorded at the stations Khorog (2075 m a.s.l., Gorbunov (Fedchenko glacier, 4169 m a. s. l.) and Murgab (3576 m a. s. l.). With respect to hydrology and hydrography, the meteorological conditions of mountain regions are very important for the prediction of, and determining the scenarios for, the dynamic changes in water resources. This paper deals with the analysis of meteorological conditions in the Southern, Western, Central and Eastern zones of the Pamir and the dynamic change of temperature and precipitation for the period 1934-1994. Fig.12 shows the results of temperature change for the Pamir four zones.

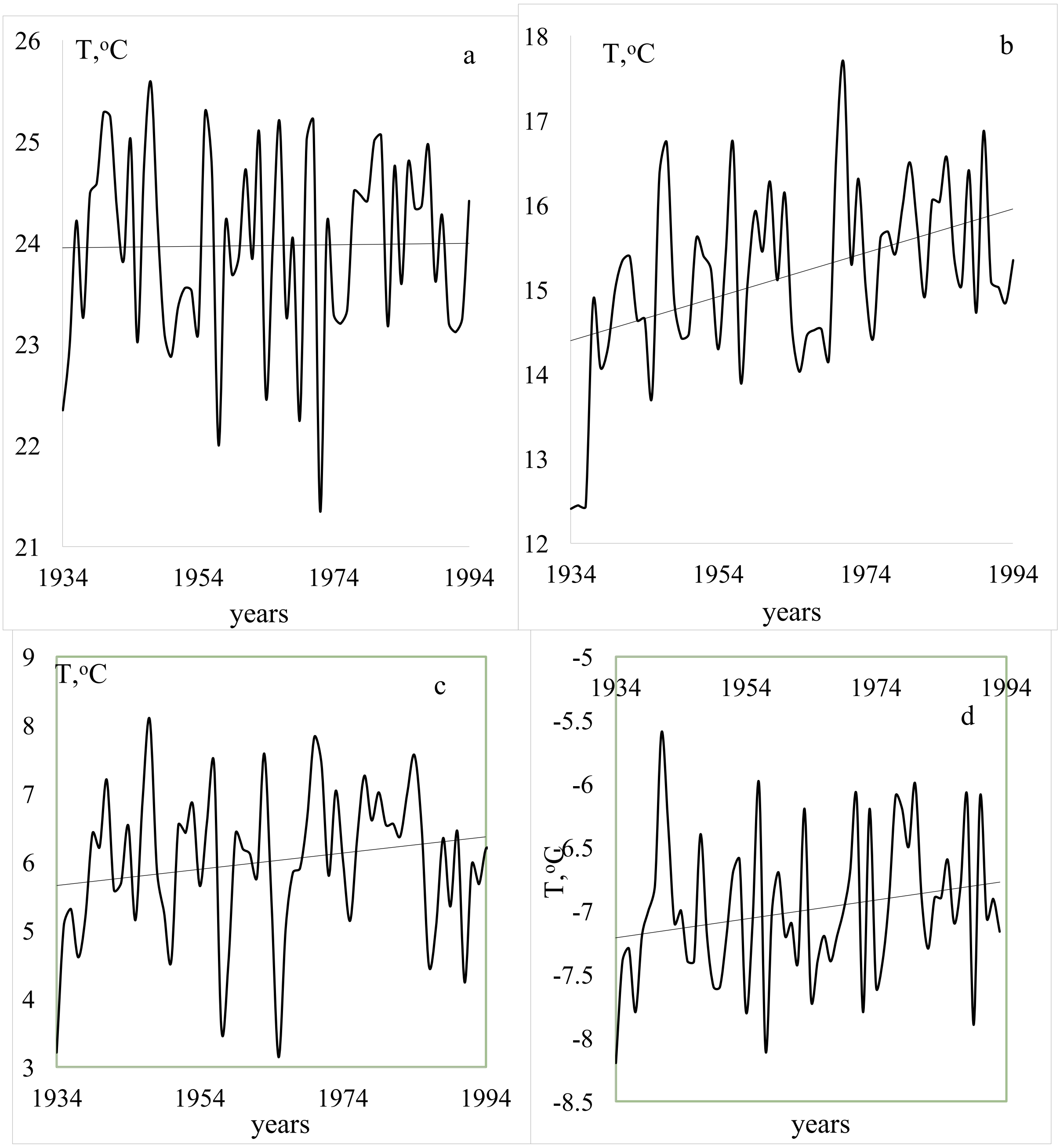

Fig.12. The average annual temperature at meteorological stations Parkhar (a), Khorog (b), Murgab (c) and Gorbunov (d)

Estimation of the temperature increase for the periods 1934-1994 compared to the period 1960-1990 are shown in Table 1.

Table 1. The average annual temperature at the Pamir meteorological stations for the periods 1960-1990 and 1934-1994

Meteostation/ Temperature, °C	Parkhar	Khorog	Ishkoshim	Dzavshangoz	Murgab	Gorbunov
Altitude, m a.s.l	448	2077	2600	3500	3576	4164
T (1934-1994)	23,970	15,171	13,615	5,646	5,990	-6,990
T (1960-1990)	24,052	15,530	13,800	5,778	6,208	-6,900

For the period 1934 -1994 the average temperature increased by 0.03°C for every 10 years (table 1).

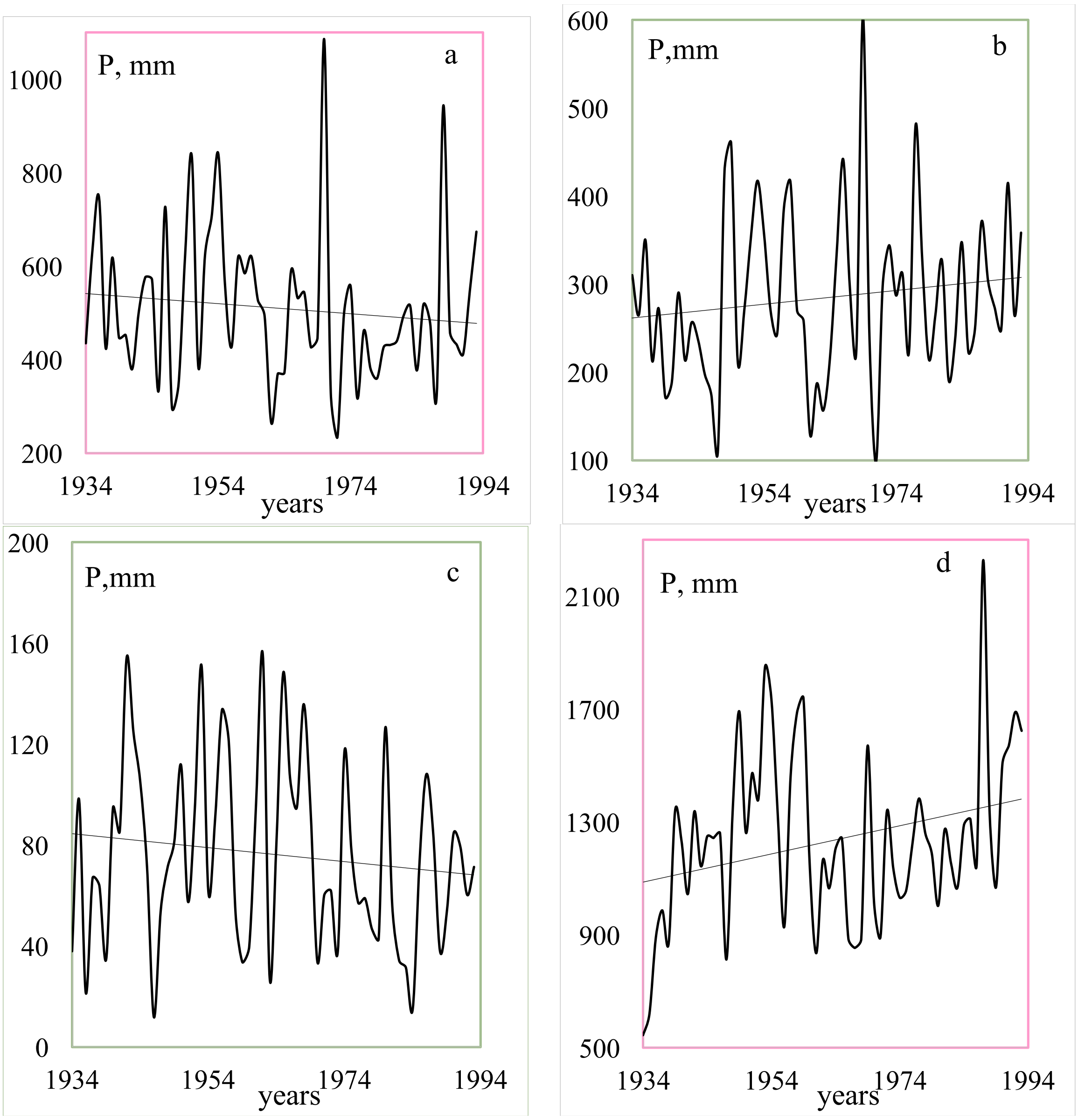

Fig.13. The average annual value of precipitation at meteorological stations Parkhar (a), Khorog (b), Murgab (c) and Gorbunov (d)

A comparison of the precipitation data from four meteorological stations shows that the trends are not influenced by altitude. For example, rainfall at the stations Parkhar and Murgab, located at an altitude of 448 m and 3576 m a. s. l both have a decreasing trend (Fig.13).

The Murgab meteorological station reflect the climate of the Eastern Pamir. Fig.13(c) shows that the average annual rainfall in the Eastern Pamir is small and ranges from 40-140 mm with a long-term average of about 76 mm. The deficit rainfall in the Eastern Pamir is influenced by a discharge of moist air with heavy rainfall on High Mountains (5000-6000 a.s.l) while in the Western Pamir air becomes dry. Mean rainfall in Southern, Central, Western and Eastern Pamir for the periods 1934-1994 and 1960-1990 are presented in Table 2.

Table 2. The average annual precipitation at the Pamir meteorological stations for the periods 1960-1990 and 1934-1994

Meteostation/ Precipitation, mm	Darvaz	Khorog	Dzavshangoz	Murgab	Gorbunov
Altitude, m a.s.l	1279	2077	3500	3576	4164
P(1934-1994)	509,192	284,570	143,032	76,303	1225,158
P(1960-1990)	471,377	280,813	146,300	73,602	1184,745
Δ P	38,82	3,76	-3,27	2,71	40,42

According to Darvaz meteorological station, located on the border of the southern and central zones of the Pamir (Table 2), the vertical gradient of precipitation is about 40 mm on 100 m uplift. The annual atmospheric precipitation is an important aspect, especially in mountainous regions, according to the formation and dynamics of glaciation, mass balance and behavior of glaciers and, consequently, in the formation of river runoff, which is important for the Central Asian region. The first attempts to determine the type of the annual cycle of precipitation in the Pamir were conducted by the authors when describing the climatic characteristics of Central Asia, the results of which are summarized in [Balashova, 1960]. According to Balashova, the Western and Eastern Pamir have completely different annual pattern of precipitation. In the Western Pamir, the maximum annual precipitation falls in spring (March-April), and in Eastern Pamir it falls in summer (June-July).

However, according to (Kurbonsho, 2014), the maximum annual precipitation takes place in May. In order to study this problem the annual variation of precipitation in the Western and Eastern Pamir was analyzed according to data from the Khorog and Murgab meteorological stations (Fig. 14). From Figure 14 it is evident that the maximum annual precipitation in the Western Pamir falls in spring (March). However, in the Eastern Pamir there are two seasons with the maximum quantities of precipitation falling in spring (March) and summer (July-August).

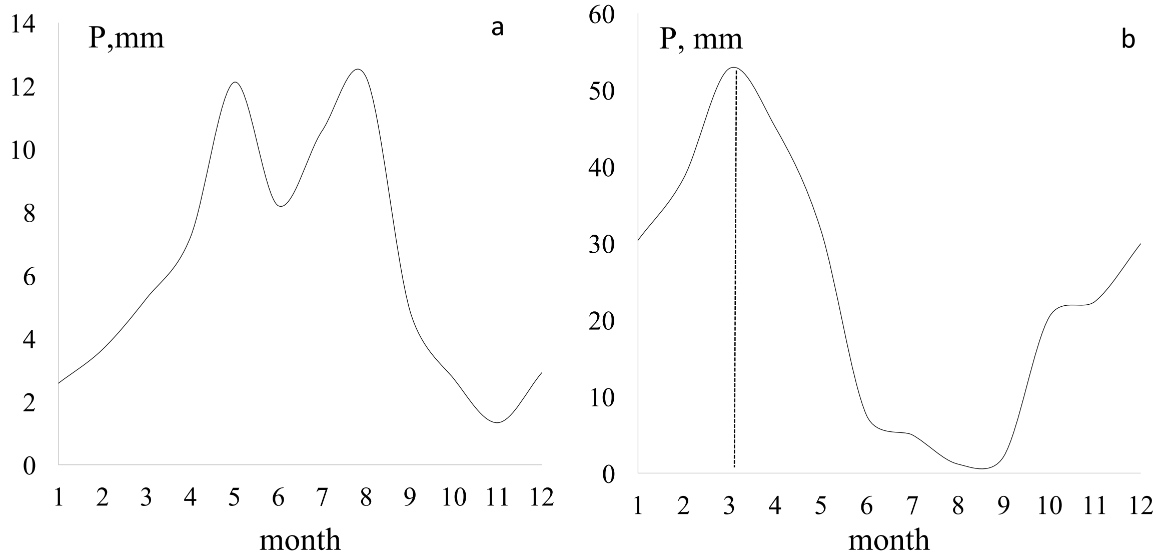

Fig.15. The monthly average precipitation at meteorological stations Khorog (a) and Murgab (b)

The appearance of the maximum annual precipitation in March (Fig. 14a) is probably due, as specified in [Balashova, 1960], to the intensification of cyclonic activity, due to the fact that the planetary high-altitude frontal zone moves to the east. The observed maximum annual precipitation in the Eastern Pamir faflls in summer (July-August); as described by Balashova (1960) this is due to mixing of the warm humid air masses from India with a cold air stream flowing from the north (Fig.14b).

Conclusion

Results show that the water resources of the upstream of the Transboundary Rivers depends on temperature and precipitation and therefore subject to constant fluctuations. In order to avoid conflicts over allocation of water between upstream and downstream countries it is necessary to improve the exchange of information and timely notification of downstream countries about the estimates of future runoff.

For this to happen requires a systematic monitoring of water resources in the upper reaches of the rivers. In this regard, the accumulation of meteorological and hydrological data can be a good basis for the creation of mathematical models to forecast rainfall and precipitation ass associated flow scenario of transboundary river basins.
An analysis of meteorological data of the Zeravshan glacier area for the periods 1931-1961 and 1981-2011, revealed different trends of temperature changes. The period 1931-1961 was characterized by near-constant temperature, significant increases took place during the period 1981 to 2011. A similar situation was also evident in the Yagnob River basin. Reduction of water flow of the Zarafshan River for the period 1931-1961 resulted in a significant decrease in the period 1981-2011 from 6.08 km^3 to 5.36 km^3. There has been an increasing trend in temperature in all parts of the Pamir for the period 1934-1994. Within Pamir precipitation differed significant between the zones independently of altitude. Within the Eastern part of Parmir precipitation is highest during March and July-August.

Acknowledgments

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References

Alexeevsky N.I., Frolova N.L., Antonova M.M. et al (2013) Climate change's impact on regime and runoff of Volga Basin Rivers. *Water: Chemistry and Ecology.* 4, 3-12.

Balashova E.N., Zhitomirskaya O.M., Semenova O.A. Climatic description of the Middle Asia republics. Leningrad, Hydromet Publ., 1960, 242p (rus).

Khomidov A. Sh. Dynamics of glaciers and mountain lakes in Zeravshan River Basin. Availablefrom:http://www.untj.org/files/Publications/DRMP/resource_page/12.%20Khomidov%20A.pdf [Accessed 20 June 2016].

Kurbonsho Yo., Krauducen T.M., Mukhabbatov Kh.M. (2014) Climatic specify of Pamir. *Report AS R. Tajikistan, 3, 121-133 (rus).*

Olsson O., Gassmann M., Wegerich K. et al (2010) Identification of the effective water availability from stream flows in the Zarafshan River basin. *J. Hydrology, 390, 190-197*.

Petrov G., Normatov I. (2010) Conflict of Interests between Water Users in the Central Asian Region and Possible Ways to Its Elimination. Water Res., 37(1), 113-120.