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CHANGES OF AIR TEMPERATURE IN THE AMUDARYA RIVER BASIN

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Abstract: In this article, the changes of air temperature in three basins where the formation of the Amudarya River flow takes place: namely, the Surkhandarya River basin, basins of the Tajikistan rivers, basins of the northern part of Afghanistan are considered. Their role as flow-formation factor is investigated. The graphs of intrannual air temperature distribution are created; the correlations between air temperature values and absolute elevation are derived. The trends of air temperature by periods are revealed. The relationship between the flow of the Amudarya River and mean monthly temperatures for June – August measured at Mingchukur meteorological station in the Kerki cross-section was derived, and it was used for calculation of the river flow in Kerki.
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Key words: air temperature, intrannual temperature distribution, correlation between precipitation distribution over absolute elevation, temperature trends, anthropogenic impact, natural losses, evaporation, infiltration, flow coefficient.

Introduction.

As V.L. Schultz noted [14], already in 1884 A.I. Voyeikov [26] supposed that “with other equal conditions the country will be richer in flowing water if it has abundant precipitation and less evaporation both from the soil surface and from vegetation”. All investigators of the later years approved the ideas expressed by A.I. Voyeikov [8, 11, 21].

The rivers of Central Asia, including Amudarya, are not exclusion in this respect: an average long-term flow of rivers with all alimentation types depends on precipitation and evaporation [8, 14, 15].

Big basin length of the Amudarya River, diversity of relief and landscape forms, location inside continent of Asia determine the diversity of climate features in the basin. Atmospheric processes passing over the Central Asia have significant impact on the formation of climate in the basin [22, 24].

During the cool half year the most frequent synoptic processes are presented by the south-western periphery of anticyclone and cyclones’ breakthroughs from the territories of Iran and Afghanistan which cause the rise of temperature and bring precipitation. Usually, the rear parts of cyclones contain cold-air surges from middle latitudes from west and north, bringing decrease of air temperature and precipitation falling on the plain territories, but often without influence on the general temperature background in mountain areas due to their low intensity. In the closed valleys and troughs the passing of the cold waves is usually accompanied with the temperature rise. With set up of the clear anticyclone weather conditions the intensive temperature decrease is observed both on plains, and in mountains, especially, in the closed relief forms [1, 2, 10].

During the warm period of the year frequent occurrence of the anticyclone weather conditions causing general temperature rise is highly probable; the air masses are especially warmed over the desert regions.

This time, cold-air surges mostly come from the middle latitudes also from north and west. These surges cause negligible changes of the regime of meteorological elements over deserts due to strong warming of the low atmospheric layer and intensive turbulent mixing. While in mountains they are accompanied by precipitation and temperature decrease [22, 27].

Mountain systems create vast variety in distribution of climatic elements. In summer, inside mountain massifs the lowering of temperature with elevation is observed, while in winter such regularity is not traced everywhere: in several mountain regions deep inversions are formed related to the radiative cooling over the snow surface in the period of clear anticyclone weather conditions. Big mountain ridges highly protruded to the free atmosphere are characterized by the leveled yearly temperature trend

[4, 6, 12, 13].

Existence of glaciers, eternal snow cover and snowfields, big quantity of rivers and streams, with more complex (comparing with plain territory) horizontal air exchange, facilitates the increase of the moisture content in the air in the deep valleys and troughs. On high plateaus the high aridity is observed, as air masses rising on the windward slopes loose a lot of moisture, and flat relief does not facilitate front deepening.

Thus, the upland of the Eastern Pamir is a typical highland desert where due to formation of the orographic anticyclone air sinking takes place which contributes to its drying.

Usually, substantial amount of precipitation is observed in the heads of valleys which are open to moisture-laden south-western and southern air flows or oriented along the flows. In the valleys located perpendicularly to the moisture-laden air flows the local precipitation minimum values are recorded.

Local circulation plays significant role in the climate formation, as well. In the absence of the planetary frontal elevation zone a mountain-valley circulation is being developed. When this zone is located over mountains, then cold-air surge or cyclone breakthrough are unfolding, and mountain-valley circulation is disturbed; foehns, winds of mountain passages, pass winds, etc. occur. Calms which are frequently observed in winter in the closed valleys and troughs favor a strong radiative cooling, causing minimum values of local temperature and strong inversions - “lakes” of cooled air. [3, 7, 16, 17, 22, 28].

Materials and methods.

As it was mentioned above, river flow is a product of precipitation and evaporation. Evaporation depends on the air temperature. In the former works we considered the impact of precipitation falling in three main basins and on flow of the Amudarya River in Kerki cross-section.

The goal of this work is to consider the impact of air temperature on flow of the Amudarya River. To reach this goal we used data on the mean monthly air temperature measured at 17 meteorological stations of Tajikistan, 5 meteorological stations of Uzbekistan located in the basin of the Surkhandarya River. The results of observations of Tajikgidromet and Uzbekgidromet were used in the work. For investigation of temperature regime in the eastern and north-western basins of the rivers in Afghanistan the fragmentary data presented in [5] were used. Description of performed tasks and conclusions made by their results are presented below.

Results and their discussions. Regime of air temperature in the basin of the Surkhandarya River.

For the estimation of distribution of the air temperature in studied basins the graphs of the intrannual distribution of the mean long-term monthly air temperature were constructed. The graph for Shurchi meteorological station is given as an example. Data for all studied meteorological station are presented in Table 1.

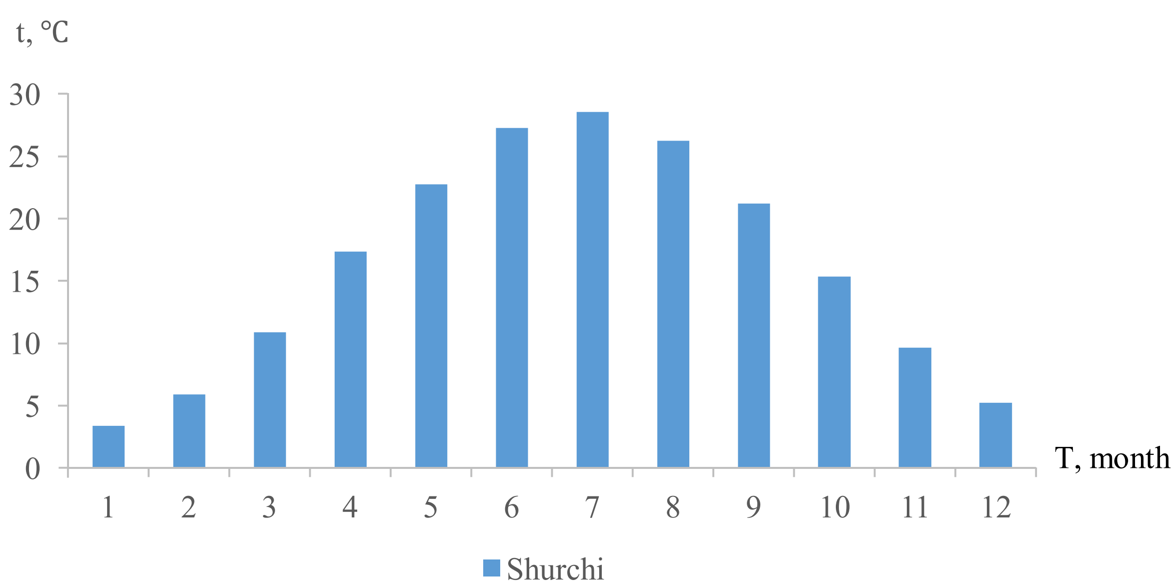

Fig.1. Graph of intrannual distribution of the mean long-term monthly air temperature for Shurchi meteorological station

Table 1. Data on intrannual distribution of the mean long-term monthly air temperature measured at meteorological stations of the Surkhandarya River basin

MS	H, km	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Mean for year
Baisun	1,24	1,7	3,0	7,8	13,4	18,1	23,2	25,4	23,9	19,0	12,8	7,7	4,0	13,3
Denau	0,52	4,1	6,5	11,0	17,2	22,0	27,5	28,5	26,7	22,0	16,0	10,4	6,1	16,5
Dehkanabad	0,94	2,7	4,5	8,9	14,7	20,6	25,7	28,4	26,7	21,4	14,7	8,8	4,7	15,1
Sherabad	0,42	4,7	7,1	12,3	18,9	24,8	30,0	31,4	29,3	24,6	18,4	11,4	6,7	18,3
Shurchi	0,45	3,6	5,9	11,1	17,2	22,9	27,4	28,7	26,3	21,3	15,4	9,6	5,3	16,2

After analysis of the data of graphs and Table 1 it can be concluded that in general, January is the coldest month in the basin, while July is the hottest one. In January the air temperature varies from + 4,7 °C in lower zones and to +1,7 °C in the upper ones. In July air temperature varies from + 31,4 ° C to + 25,4 °C, but at the same time, it should be noted that air temperature in June and August is high, and their values are almost similar.

In the basin of the Surkhandarya River the relationship between the mean annual temperature and elevation is clearly revealed (Fig. 2). It lowers with 0,5 – 0,6 °C gradient every hundred meters of elevation.

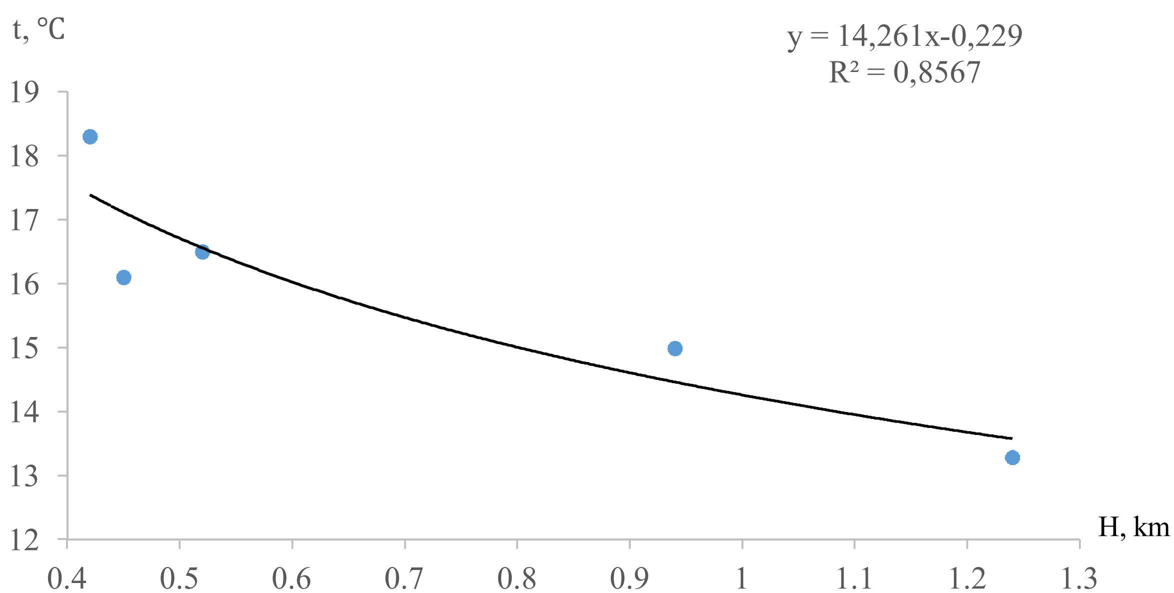

Fig.2. Graph of relationship between mean annual air temperature and elevation of location

Mean annual temperature in the basin of the Surkhandarya River is 13–18 °C. In autumn (September – November) mean values of air temperature are positive everywhere: it varies from 19 to 25 °C on the plain territory in September and from 8 to 12 °C in November. In spring (March – May) mean monthly air temperature is also positive everywhere: at elevation lower 1,0 km it is 8–12 °C in March to 20–25 °C in May; at higher elevation it is from 2–7 °C to 12–18 °C, respectively. This gives the ground to conclude that the flow from the basin is formed the whole year round with availability of precipitation.

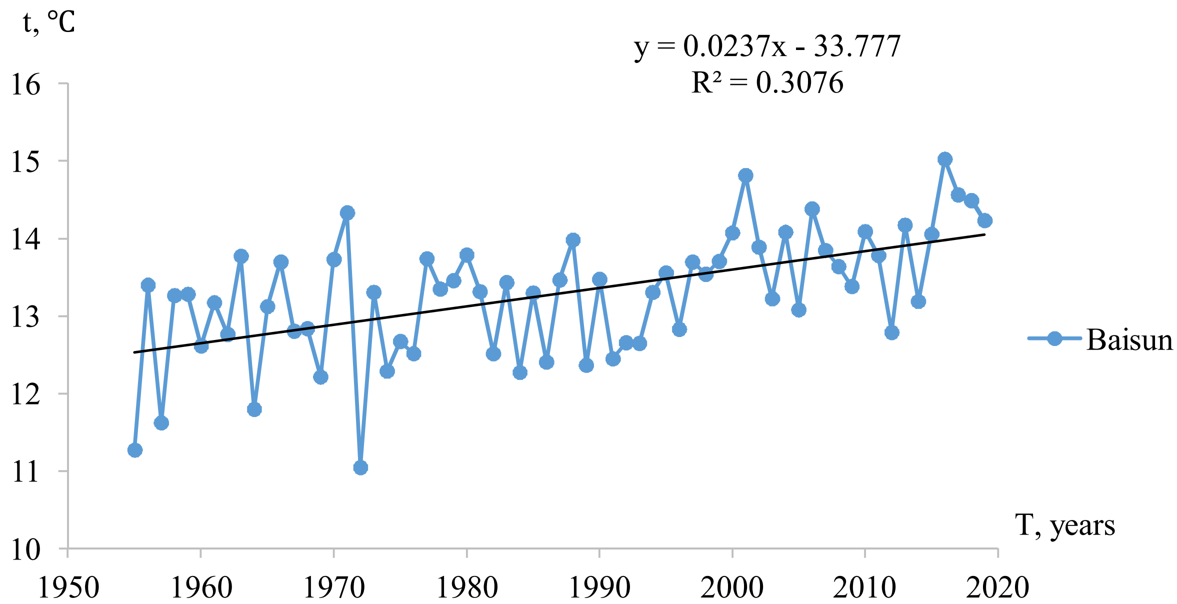

Fig.3. Graph of variation of mean annual air temperature with time for Baisun meteorological station

Further it was interesting for us to consider variations of the mean annual air temperature in relation to time. For this purpose we constructed graphs of these quantities variations for observation periods. The graph for Baisun meteorological station is given in Fig. 3. In Table 2 the equations of relationships are presented for the whole observation period, from the period of beginning of observations up to 1990 and for the period from 1991 to 2019.

Table 2. Equations of relationships of variations of the mean annual air temperature for meteorological stations of the Surkhandarya River basin

MS	H, km	For the whole observation period	From beginning of observations to 1990	From 1991 to nowadays
Baisun	1,24	У = 0,0237X - 33,777	У = 0,016X - 18,598	У = 0,0458X – 78,214
Denau	0,52	У = 0,0318X – 46,403	У = 0,0348X – 52,286	У = 0,0708X – 124,7
Dehkanabad	0,94	У = 0,0173X - 18,985	У = 0,0216X - 27,468	У = 0,0311X – 46,851
Sherabad	0,42	У = 0,0209X - 23,09	У = 0,018X - 17,421	У = 0,0271X – 35,443
Shurchi	0,45	У = 0,0188X – 20,531	У = 0,0043X + 7,3932	У = 0,0407X – 64,847

After an analysis of graphs of variations of the mean annual air temperature over meteorological stations of the Surkhandarya River basin it was revealed that:

– Trends of relationships for the whole observation period are positive at all stations and vary from 0,0173 to 0,0318;

– For the observation period from beginning of observations till 1990 the trends are also positive. Their values are significantly lower than during the whole observation period and vary from 0,0043 to 0,0348. Thus, it can be concluded that during that period the increase of air temperature was recorded but it was negligible;

– During the last period the trends at all stations were positive, but their increase was significant: they increased 3,5 – 10 times comparing with preceding period. Their variations were in the range of 0,0271 – 0,0708. It should be mentioned that trends at three stations: Baisun, Dehkanabad and Shurchi are rather similar and are 0,0458; 0,0311 and 0,0407, respectively.

Regime of air temperature in Tajikistan river basins.

Procedure of making investigation for 17 meteorological stations of Tajikistan was the same as for the stations in the Surkhandarya River basin.

In general, January is the coldest month in the basin, while July is the hottest one. However, due to the wide variety of the relief forms and big sizes of the basin area there are several regional peculiarities in distribution of the air temperature over the basin, and in this connection, the temperature regime over separate regions is considered below.

Basins of the Pyani, Vahsh and Kafirnigan Rivers are characterized with considerable diversity of orographic features which influence the formation of air temperature regime.

January is the coldest month in the region. Up to 1,5 km elevation practically all stations record positive temperature values. Only in deep narrow valleys and troughs at these elevations the temperature values recorded at Garm and Horog meteorological stations they are negative; this is determined by substantial cooling on these relief forms with complicated air exchange along horizontal.

Above 1,5 km elevation the air temperature is negative everywhere: from -2 °C (at 1,5 km) to – 20°C and less (at elevation higher 3,5 km) (Table 3, Fig. 4).

Table 3. Data on intrannual distribution of the mean long-term monthly air temperature measured at meteorological stations in Tajikistan river basins

MS	H, km	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Mean for year
Anzob	3,58	-12,3	-11,9	-8,0	-2,8	1,4	6,0	9,6	9,3	5,1	-1,1	-6,6	-10,3	-1,7
Dehauz	2,5	-6,8	-5,9	-1,8	4,1	8,8	12,2	15,1	15,2	11,4	5,3	-0,8	-5,1	4,3
Dzhavshangoz	3,5	-18,0	-15,6	-9,9	-1,7	4,8	8,6	12,5	12,4	7,2	0,3	-7,9	-14,9	-1,9
Fedchenko Glacier	4,17	-17,1	-16,2	-12,6	-7,7	-3,7	-0,2	3,4	3,8	-0,1	-6,3	-11,3	-15,0	-6,9
Garm	1,32	-3,8	-2,1	3,7	11,4	15,7	19,8	23,5	23,8	19,4	12,3	5,8	0,1	10,8
Horog	2,08	-7,5	-5,1	1,7	9,6	14,7	18,8	22,6	22,7	18,0	10,8	3,4	-3,3	8,9
Irht	3,44	-13,5	-11,9	-6,0	1,3	6,6	10,7	14,6	14,2	9,2	2,6	-4,4	-10,1	1,2
Isfara	0,83	-1,0	1,5	7,2	14,6	19,7	24,3	26,5	24,9	19,7	12,5	5,7	0,8	13,1
Ishkashym	2,6	-7,9	-5,2	1,2	7,8	12,2	16,4	19,6	19,3	15,1	8,5	1,0	-5,2	6,9
Iskanderkul	2,2	-5,4	-4,2	0,4	6,7	11,3	14,9	18,2	17,8	13,5	7,4	1,4	-3,0	6,6
Kalaihumb	1,34	-0,7	1,2	6,9	13,8	18,6	23,3	27,6	28,0	23,3	15,3	7,5	2,4	14,0
Karakul	3,99	-18,1	-14,6	-9,6	-3,4	1,0	4,7	8,3	8,2	3,7	-2,4	-9,0	-14,7	-3,8
Murgab	3,64	-17,8	-13,5	-6,7	0,5	5,1	8,9	12,8	12,5	7,0	-0,6	-8,6	-15,4	-1,3
Dupuli	0,99	-0,3	1,8	6,5	12,9	17,8	22,7	25,3	23,5	18,7	12,4	6,3	1,9	12,4
Sangiston	1,52	-1,2	1,2	5,8	12,0	16,3	20,6	23,9	23,2	18,5	12,0	5,5	0,8	11,6
Shahristan	3,2	-9,5	-8,8	-5,4	-0,2	3,7	7,8	10,9	10,4	6,6	1,2	-3,6	-7,2	0,5
Uratube	0,99	-1,7	0,1	5,0	11,8	17,1	22,2	24,7	22,9	17,7	11,1	4,7	0,4	11,4

July is the hottest month for the whole territory: +28 – +31°C up to 1,0 km elevation and from +22 °C to +4 °C and less – at high altitude (Fedchenko Glacier).

The most diverse distribution of the mean monthly air temperature is observed in autumn (September – November) and spring (March – May) months (Table 3, Fig. 5). The occurrence and disappearance of negative values of air temperature are rather clearly observed in these seasons. As an example, Figs. 4 and 5 present the distribution of air temperature at different stations. In Table 3 the data on distribution of the average long-term monthly air temperature over all stations are given.

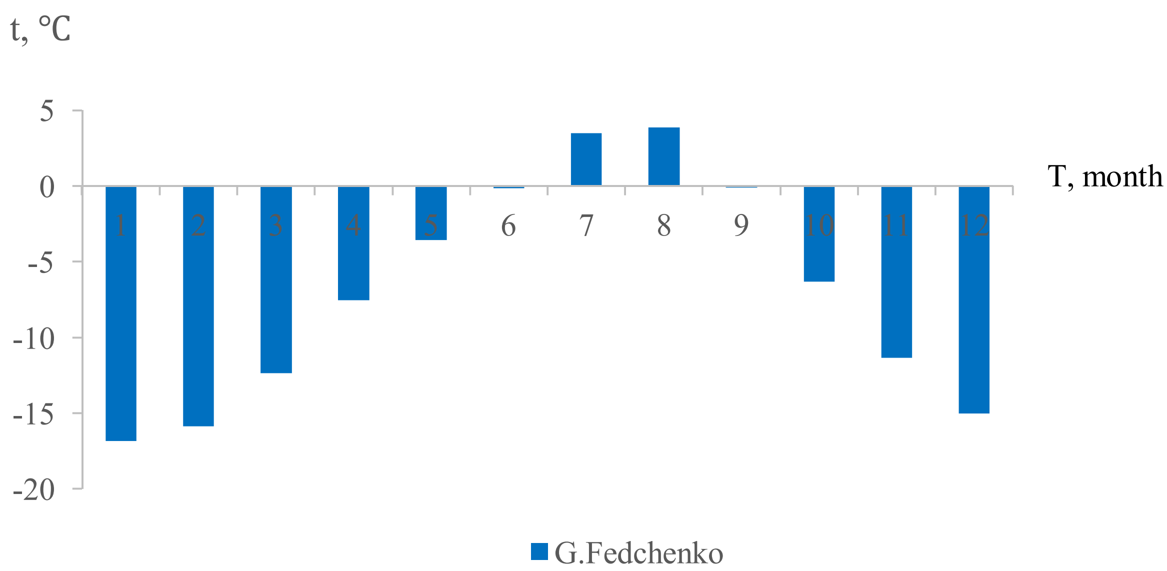

Fig.4. Graph of intrannual distribution of mean long-term monthly air temperature at meteorological station of Fedchenko Glacier

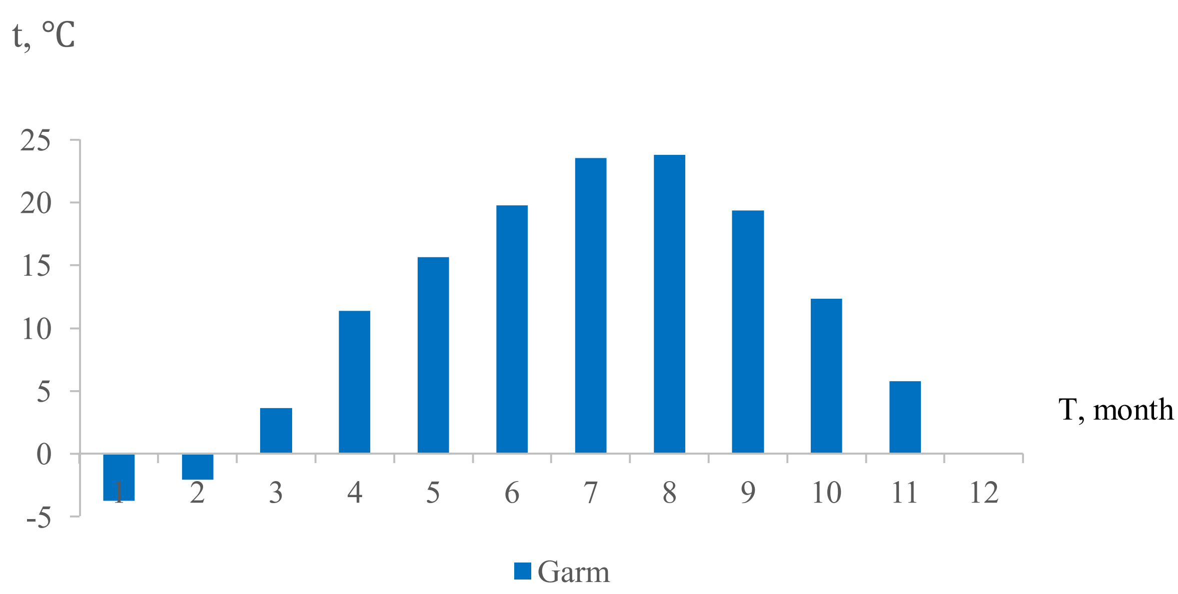

Fig.5. Graph of intrannual distribution of mean long-term monthly air temperature at Garm meteorological station

In the basin of the Zerafshan River there is great diversity of both elevations and of relief forms: from the low plain parts to the high-altitude mountain valleys (Dehauz – 2,5 km) and mountain passes (Anzob mountain pass – 3,58 km).

January is also the coldest month: from zero values on the plain to significantly low ones in mountains (Anzob mountain pass: –12,3 °C) (Table 3, Fig. 6).

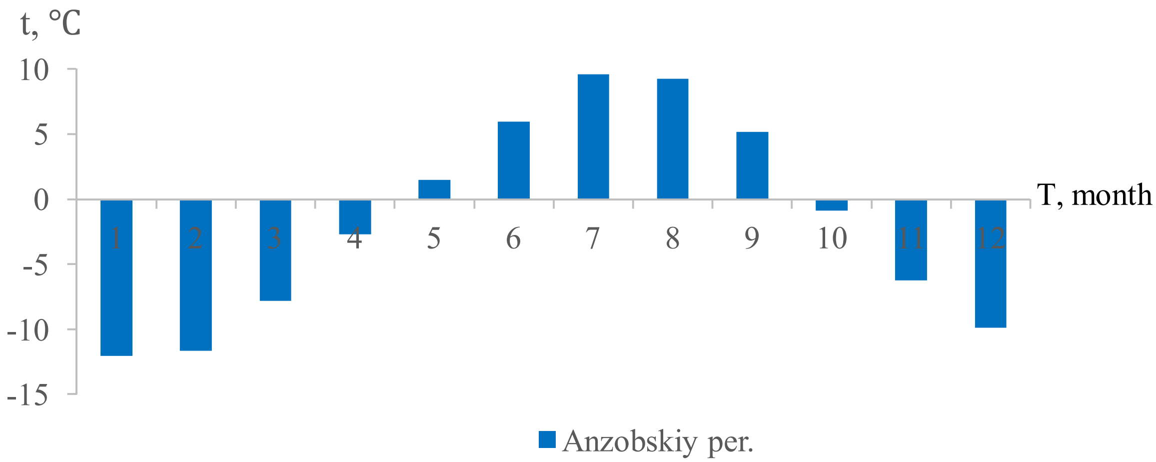

Fig.6. Graph of intrannual distribution of mean long-term monthly air temperature at meteorological station I Anzob mountain pass

Up to 1,0 km the hottest month is July, and upwards it is August. Mean monthly air temperature in July up to 1,5 km elevation is +25 – +29 °C, upwards it is +10 – +18 °C (Table 3).

In spring (March – April) mean monthly air temperature is rather different at different elevations. Thus, at elevation less than 2,0 km, mean monthly air temperature values are only positive, while at high elevation levels the values are negative in March and April, while in May they are positive everywhere.

In autumn (September – November) air temperature values are rather high in September and October up to 2.0 km elevation. Negative temperature values are set higher 3,0 km elevation in October and higher 2,5 km elevation – in November (Table 3).

For all stations in river basins of Tajikistan there is close relationship between mean annual air temperature and elevation of locality with mean air temperature gradient of 0,5 – 0,6 °C. Figure 7 clearly presents the relationship between mean annual air temperature and elevation of locality.

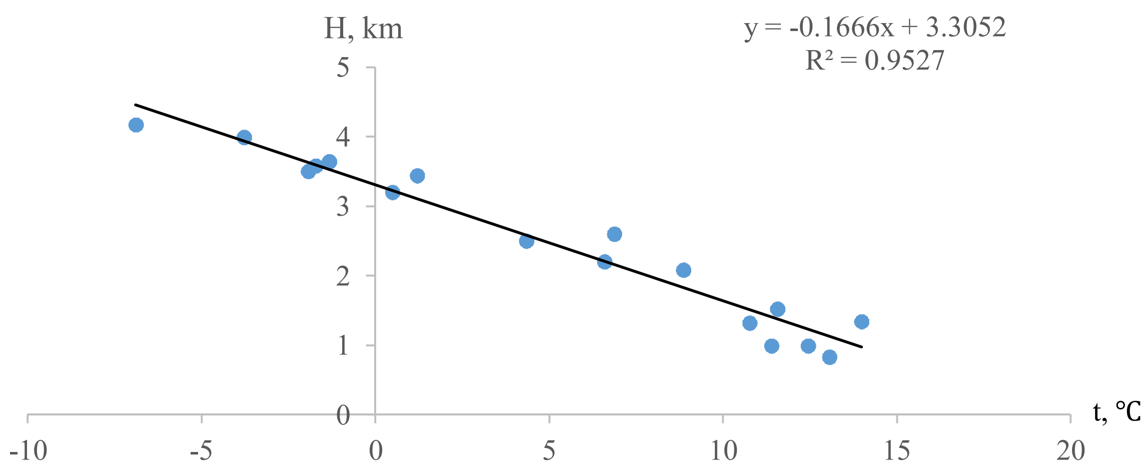

Fig.7. Graph of relationship between of mean long-term monthly air temperature and elevation of locality for stations in river basins of Tajikistan

Further we considered variations of mean long-term monthly air temperature with time. For this purpose we have constructed graphs of these quantities' variations for observation periods. The graph for Irht meteorological station is presented in Fig. 8. In Table 4 the equations and trends of relationships are presented for the whole observation period over all studied meteorological stations in Tajikistan river basins.

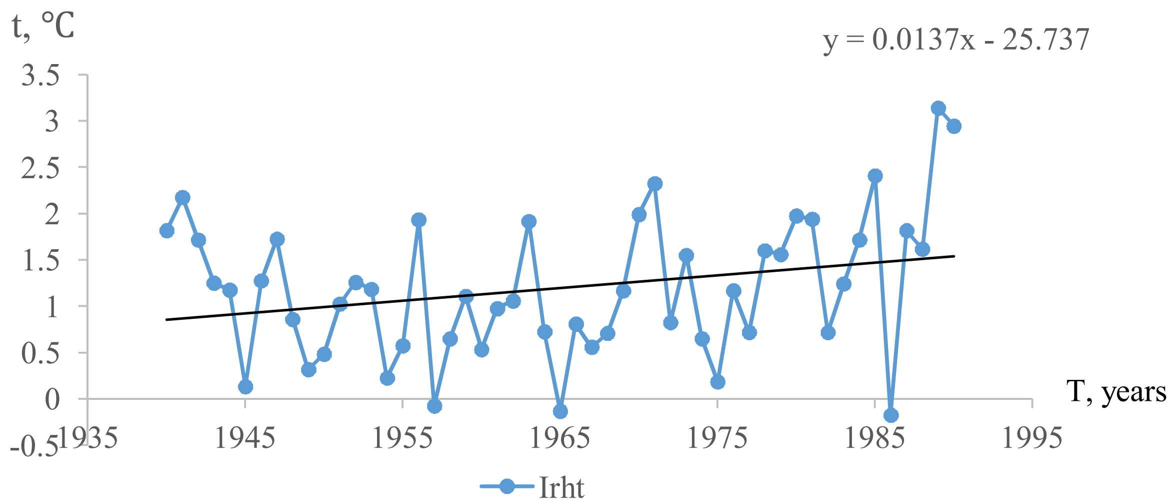

Fig.8. Graph of variations of mean annual air temperature with time for Irht meteorological station

Table 4. Equations of relationships of variations of the mean annual air temperature for meteorological stations of the river basins in Tajikistan

MS	H, km	For the whole observation period	Trends
Anzob	3,58	У = 0,0045X – 10,656	0,0045
Dehauz	2,5	У = 0,0054X – 6,3518	0,0054
Dzhavshangoz	3,5	У = 0,0144X – 30,228	0,0144
Fedchenko Glacier	4,17	У = 0,0119X – 30,304	0,0119
Garm	1,32	У = 0,0055X + 0,0339	0,0055
Horog	2,08	У = 0,0115X – 13,784	0,0115
Irht	3,44	У = 0,0137X - 25,737	0,0137
Isfara	0,83	У = 0,0174X – 21,050	0,0174
Ishkashym	2,6	У = 0,0156X – 23,893	0,0156
Iskanderkul	2,2	У = 0,0041X – 1,3567	0,0041
Kalaihumb	1,34	У = 0,0069X + 0,3948	0,0069
Karakul	3,99	У = 0,0157X – 34,607	0,0157
Murgab	3,64	У = 0,0065X – 14,009	0,0065
Дупули	0,99	У = - 0,0028X + 17,894	- 0,0028
Sangiston	1,52	У = - 0,0016X + 14,636	- 0,0016
Shahristan	3,2	У = 0,0181X – 35,075	0,0181
Uratube	0,99	У = 0,0071X – 2,4528	0,0071

In the analysis of graphs of variations of mean annual air temperatures recorded at meteorological stations in Tajikistan it was found out that:

- Trends of relationships for the whole observation period are positive at 15 stations and vary from 0,0041 to 0,0181 which is substantially less than it was recorded at meteorological stations of the Surkhandarya River basin. At two stations trend was negative: from 0,0016 to 0,0028;

- Large length of the Amudarya River basin, diversity of relief forms and landscapes, location inside the Asian continent determine variety of climate features in the basin. In this regard, the change of trends has taken place in three regions: 1. At stations located on the right bank of the Pyanj River; 2. At stations located in the basins of Vahsh, Kafirnigan and Zerafshan rivers; 3. At stations the absolute elevation of which is higher 3,5 km;

- Relationships between trend and elevation of location were derived for each of the aforementioned region

n. They are presented in Fig.9.

Unfortunately, because of lack of data measured at meteorological stations in Tajikistan, the studies were carried out at all stations till 1990. After getting additional information the studies will be continued [18, 19, 20].

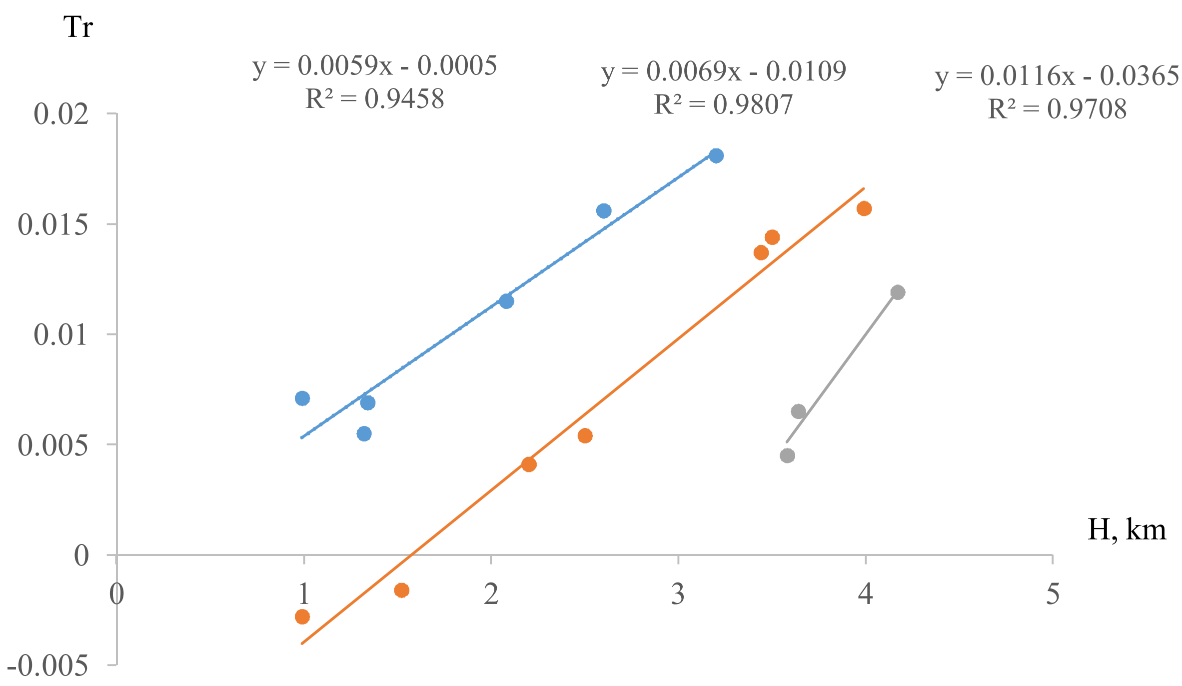

Fig.9. Graph of relationship between trends of mean annual air temperature and elevation of locality for meteorological stations of the river basins in Tajikistan

Regime of air temperature in the northern basins of Afghanistan.

As the materials of systematic observations of air temperature over Afghanistan territory were not available at our disposal, we used materials presented in [5].

Systematic observations of air temperature changes recorded by different stations on the territory of Afghanistan conducted during 1961–1980, give the ground to point out high stability of their mean values.

Typically continental climate is displayed in sudden daily variations of air temperature and in big difference between air temperature of summer and winter periods. In Table 5 mean long-term data for the period of 1961 – 1980 are given by the main meteorological stations of the northern part of Afghanistan.

Basing on these data rather good relationship between mean annual values of air temperature and elevation above sea level was determined. The relationship for the northern regions of Afghanistan is shown in Fig. 10.

Linear relationship reveals the relation between mean annual values of air temperature and elevation of stations rather good. Good linear relationship is traced also for mean long-term values of air temperature in July. Scatter of points for January is the highest, but correlation is also rather high in this case.

Table 5. Information on air temperature by data recorded at meteorological stations of Afghanistan [2, 5]

River basin	Meteorological station	H, km	Mean air temperature, ^{0}C		
			Annual	January	July
Kunduz	Baglan	0,55	14,7	0	27,7
	Bamian	2,25	6,7	-6,9	17,9
	Kunduz	0,433	16,5	1,4	31,2
	Talukan	0,804	15	-0,3	28,3
	Chardara	0,405	15,3	1,8	29,8
Rivers in the northern part	Aibak	0,90	15,6	-4,0	29,4
	Mazari-Sharif	0,378	17,1	1,6	32,6
	Meimene	0,815	14,2	1,2	27,1
	Shibirgan	0,36	16,3	0,9	30,5
Murgab	Gelmin	2,07	7,7	-8,5	19,6
	Kadis	1,28	12,3	-0,2	23,5
	Kalaii-Nau	0,914	13,0	-1,2	27,6
	Murgab	0,47	15,9	-5,4	29,6

Change of air temperature during year is characterized by fast rise from January to March, relative stability in June, July and August and fast drop in September, October and November. Air temperature in winter is characterized by relative stability (Fig.11).

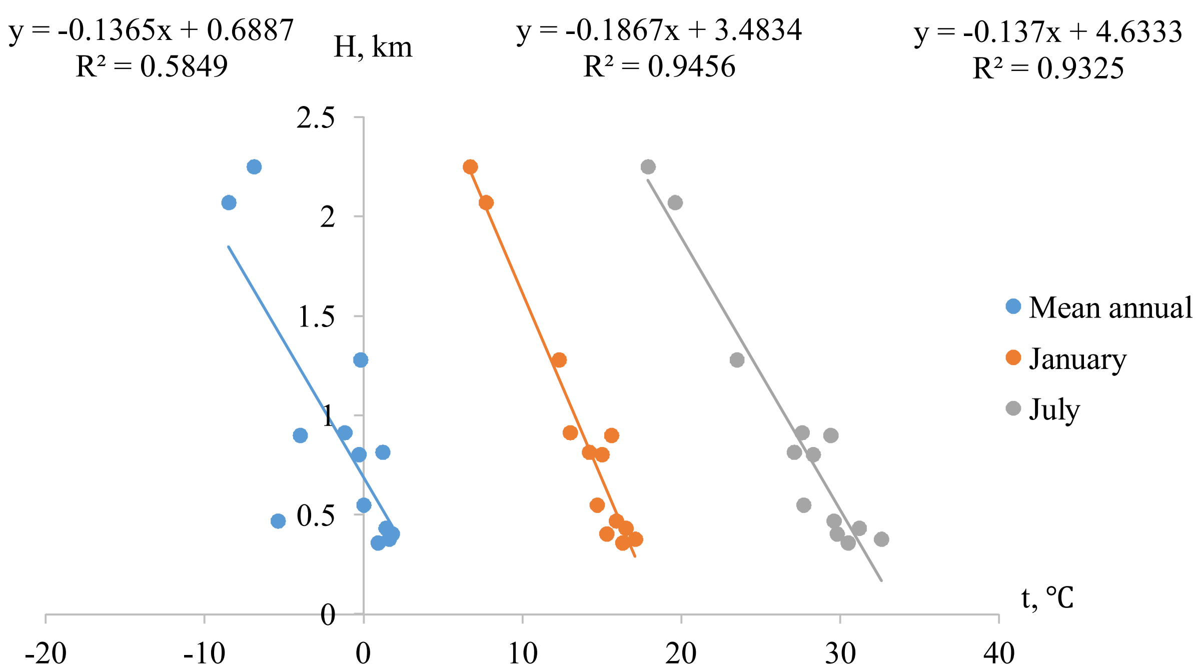

Fig. 10. Graphs of relationship between air temperatures over meteorological stations of Afghanistan and elevation of locality

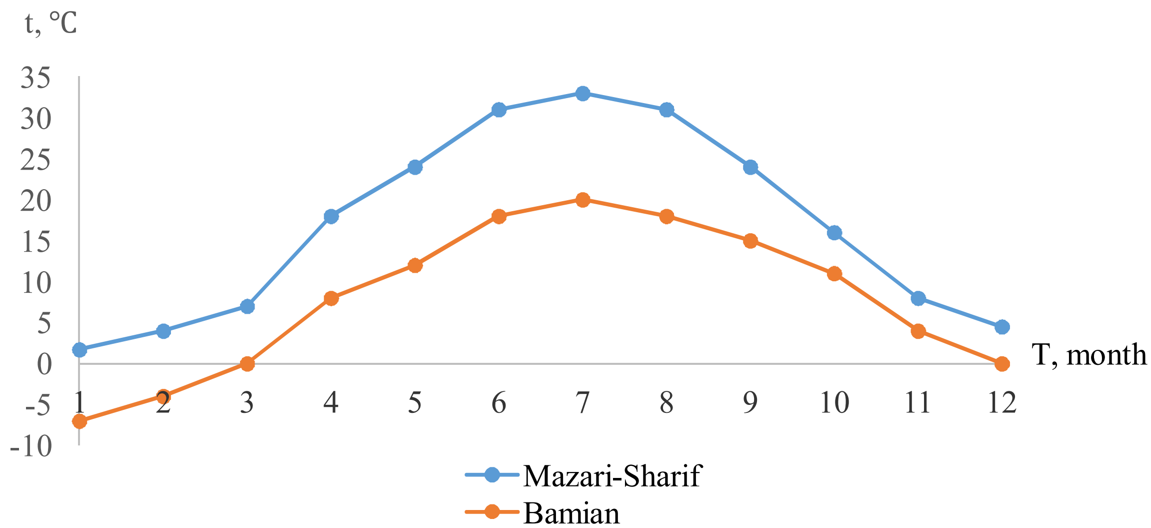

Fig.11. Graph of intrannual distribution of air temperature at several meteorological stations in the northern zone of Afghanistan

In all climate zones in Afghanistan the hottest month is July, and the coldest one is January. Mean difference between air temperature values in July and in January for the considered long-term period is 28,2 °C.

After performing aforementioned tasks, we approached the solution of important problem: revealing the relationship between air temperature in the zone of flow formation and flow of the Amudarya River in Kerki hydrological station for the conditionally-natural period.

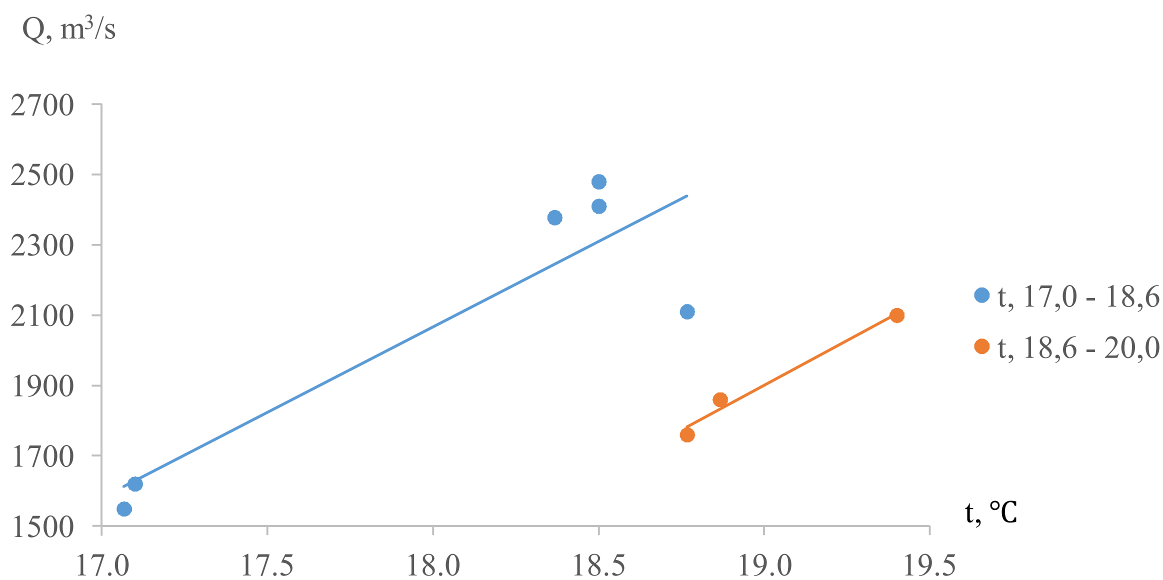

Fig.12. Graph of relationship between flow at Kerki hydrological station and mean air temperature for June – August period at Mingchukur meteorological station

After conduction series of developmental work it was defined that the best relationship was estimated between mean values of air temperature in July – August period at Mingchukur meteorological station and flow on the Amudarya River – Kerki for 1951 – 1960 period. The derived relationships are shown in Fig.12. The derived relationships are approximated by following expressions: - for air temperatures in the range of 17,0 °C – 18,5 °C – У = 485,93·X – 66,79,8 with r = 0,90; – for air temperatures in the range from 18,6 °C and higher – У = 507,99·X – 7750,7 with r = 0,99 [23, 25].

Further for us it was interesting to evaluate total loss basing on results of anthropogenic effect and on the impact of natural factors in cross-section of Kerki hydrological station. Results of calculations are presented in Fig.13 and in Table 6.

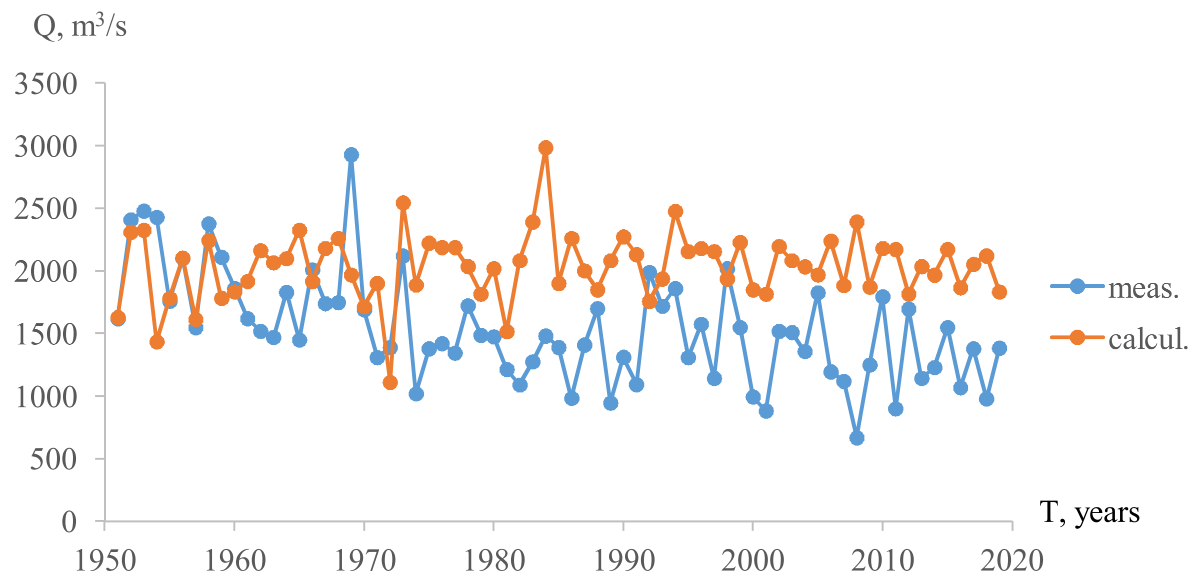

Fig. 13. Graph of variations of calculated discharge values and measured at Kerki hydrological station

Difference between discharge values means the value of losses.

Table 6. Mean flow characteristics at Kerki cross-section in the result of anthropogenic effect and on the impact of natural factors in cross-section of Kerki by periods

№	Period	Discharge (Q m³/s) at Kerki		Losses in %	Average losses in %
		$Q_{meas.}$	$Q_{calcul.}$		
1	1951 - 1960	2070	1906	+ 41 - -4,2	6,8
2	1961 - 2019	1444	2058	+ 33 - -258	-55,0
3	1951 - 2019	1535	2036	+ 41 - -258	-46,2

Main conclusions.

After an analysis of the obtained results the following conclusions can be made:

– Losses for conditionally natural period of 1951 – 1960 were 6,8 % which is within the range of admissible error in discharge measurement;

– Losses during the period of operation of the Karakum Canal from 1961 to 2019 varies from + 33 to -258 %, and their average percentage is -55,0 %;

– Losses for the whole investigated period from 1951 to 2019 were -46,2 % in average.

It is foreseen to use the obtained results for study of flow dynamics and flow losses in low reaches of the Amudarya River. Studies will be continued after getting new information.

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