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Glacier runoff and regime of rivers with glacial power (a case of study: Naryn river, Kyrgyzstan)

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Abstract. In this paper, we considered the glacial runoff of the Bolshoi and Kichi Naryn rivers, as well as their large tributaries which are main sources of the Toktogul water reservoir. Taking into account that rivers with glacier melting feeding form their water flow mostly during summer months, it would be interesting to analyse their water regime during warm seasons. All tributaries of the Naryn River demonstrate the runoff decrease from June to August; while the main channels of the Chon and Kichi Naryn themselves have another dynamic. In July, the seasonal snow cover already melted and the runoff formation occurs as a result of glacier melting that depend on monthly average temperatures. In August, the monthly amounts of precipitation and temperatures have decreasing trends that lead to immediate decline of the runoff volumes. Interestingly those fluctuations of precipitation and air temperatures and their impact on the glacier runoff forming have little impact on the total runoff volume of rivers. So, the glacial component in the run-off forming has exceptional value for the Naryn River during the summer period.

1. Introduction

The Naryn River is the largest water artery of Kyrgyzstan. In the closing section (the Uchkurgan gauging station), the basin area is 58,400 km^2 [9], the annual consumption reaches 397 m^3/s or even 432 m^3/s according to the corrected data [6]. The water volume proportion of the Naryn River forms 28% from the total volume of water resources of the Republic. In contrast to the most of the Tien-Shan river basins, the waters of which are used for irrigation [13], the surface runoff of the Naryn River provides year-round operation of the cascade of hydroelectric power stations, which satisfies energetically needs of agricultural, industrial, municipal and domestic demands.

Significant altitudinal relief differentiation, spatial unevenness in wetting, generally small amounts of precipitation with their maximal amounts during warm seasons and availability of quite great glaciation caused a large unevenness of the annual distribution of runoff. Only during June-August, almost half (48.8%) of annual flow volume passes through the closing section, and 74% of yearly water runoff discharge occurs during the entire vegetative season [8, 9].

Usage of the water resources from the Naryn River in the republic is quite limited - only 4.3% from the entire water amounts, from which 579 million m^3 are taken for various needs, 577 million m^3 are spent for irrigation and agricultural water supply for neighboring areas. Despite the presence of large deserts and prairies with very low precipitation and extremely dry climates, Central Asian mountains hold one of the greatest concentrations of perennial snow and ice in the mid-latitudes of the North

Hemisphere, that are the vital source of water for Central Asian rivers and lakes [14]. Considering the usage of water resources in countries of the Aral Sea basin, we can underline the important role of high-mountain regions of Kyrgyzstan and Tajikistan for the runoff formation and the providing by water all bordering states. In these republics, 25.3% and 55.4% (respectively) of the total river flow of Central Asia is formed. Herrwith, Kyrgyzstan uses only 4.6% of the total flow, Tajikistan utilizes 10.9%, while the main water consumers of the Naryn River are Turkmenistan - 21.6% and Uzbekistan - 53% [3, 5, 9, 12]. In this case, the assessment of the regime and dynamics of ice resources has a great practical importance not only for Kyrgyzstan, but also for entire Central Asian region.

2. Materials and methods

To assess the glacier runoff of the Naryn River were used the hydrological and meteorological data from the archives of the Hydrometeorological Services of the Kyrgyz Republic for the period of 1980-2017. The analyses of impact of the hydrometeorological factors on runoff are made by calculation of correlation dependences.

3. Results and discussion

All tributaries of the Naryn River, located within the Inner Tien Shan (to eastern from the Fergana Ridge), the portion of summer runoff within annual volume varied from 34.4% in the At-Bashy River to 62.1% in the Kichi Naryn River [4]. At the same time, only two rivers from ten large rivers in this region have the maximal flow in July, the rest of them in June. In the Karasu River that flows down from the southwestern slopes of the Atoynok ridge, the highest water amounts are observed in May, when reaches 22.6% of the annual flow, while the river stock during June-August is only 35% [11].

　　The year distribution of runoff in rivers is determined by spatial position, moisture, and degree of catchment glaciation. Depending on ratio of the catchment height, glaciation degree and annual precipitation amounts, the monthly water expenditures vary for different rivers. In June-August, almost even runoff course is typical for the At-Bashy River, the same water amounts is characteristic for the Chon Naryn River during first and last summer months. A sharp decrease (3.5 times) the water runoff is observed in the river Karasu Right from May to August, in the Chychkan River, in June water expenses are 2.5 times higher than during August. Irregularity of water runoff distribution among seasons is typical for all tributaries in the Naryn basin. This phenomenon should be recognized as a positive one, since a significant decrease in water amounts from June to August in some rivers is compensated by an increase in runoff in others. In contrast, the flow of the Naryn River itself is quite stable; the coefficient of variation CV of the annual flow in the closing section is 0.17, although for individual tributaries these values can range from 0.14 to 0.35. The variability of the summer runoff is greater and the variation coefficients vary from 0.19 to 0.46 [1].

　　The maximal fluctuations in the average monthly summer expenditures are characteristic for rivers with a small degree of glaciation. Jergetal and Kekzherty rivers have practically no glaciers, and summer CV values reach 0.51 and 0.46, with annual values of 0.32 and 0.35 [1, 2].

　　Using the revealed dependence of glacier melting from air temperature, was calculated a layer of melted ice over the summer period. The dependence has the following form: $Ab = (0{,}73t_{cp.\ м.} + 1{,}2)\ n$, where: Ab is the melting layer in cm, $t_{cp.\ m.}$ - the average monthly temperature, n - the number of days, during which the glacier melting occurred per each month. The start of the glacier melting was determined by amounts of accumulated snow from the period of the establishment of negative temperatures on glacier in September. Taking into account that with increasing temperature for 1°C snow cover melts for 5.5 mm in water equivalent and having data for positive monthly average temperatures and precipitation, collected during the period with negative temperatures, it is possible to calculate the time when ice starts to melt.

　　Assuming that at the height of the firn line, the glacier melting is zero and extrapolating the calculated value from 3,600 m until the level of firn line, we obtain the value of ice ablation per each altitude zone. Similarly, it has been determined the melting degree in different levels from 3,600 m to lower glaciation border. Thus, volumes of glacier waters were determined for all tributaries of the

Naryn River. In table 1, we showed the distribution of glacier water portions of the annual and summer volumes from the total flow for the current period. It does not include data on small left tributaries of Kambarata, Kaindy, Terek, Tuurasuu rivers, in the basins of which is formed 5.5 million m^3 of glacier water. There is also no information on the right tributaries of Kobuksuu, Torkent, Toluk, Padysha-Ata rivers, the glacier flow of which is estimated in 10.2 million m^3.

In general, the ratio of the contribution of glacier waters to volumes of annual and summer runoff varies from 1.6 to 3 times. In the closing section, this ratio is 2. Obviously, the portion increase of the glacier waters from 0.4% in annual volume until 1.1-1.2% in summer along the rivers Kokirim and Karasu is incomparable with the contribution of glacier waters to the flow of June-August for rivers At-Bashy and for Kichi and Chon Naryn [9, 7].

Table 1. Total and tributaries glacial runoff in the Naryn River.

River - target	Volume of flow, mln. M3			$\frac{Wglacier}{Wyear}\%$	$\frac{Wglacier}{Wsummer}\%$
	W year	W summer	W glacier		
Chon Naryn - estuary	1488	811	446	30	55,0
Kichi Naryn - mouth	1350	819	308	23	37,6
On-Archa - village On-Archa	325	173	14,2	4,4	8,2
Kekzherty - hr. Aktala	163	79	1,2	0,7	1,5
At-Bashy - village Jangistal	1044	362	97,1	9,3	26,8
Kokomeren - 0.5 km below the river of Jumgal	2479	1304	68,9	2,8	5,3
Alabuga - village Coshtobo	978	461	84,2	8,6	18,3
Kokirim - village Kara-Tabylga	646	192	2,3	0,4	1,2
Chychkan - 0.5 km above the r. Bala Chichkan	574	333	10,0	1,7	3,0
Karasu left - mouth	284	118	4,4	1,5	3,7
Uzun-Akhmat - the mouth of the river Ustasai	880	449	1902	2,2	4,3
Karasu right - mouth	1252	441	4,7	0,4	1,1
Naryn - Uchkurgan	12520	6147	1065,4	8,5	17,3

The peculiarity of the formation of glacier runoff is change in the role of temperature and precipitation depending on climatic conditions of particular period - a month. The air temperature has constant prevailing role for the runoff formation, though precipitation may be a leading factor during some months. Indicative in this respect are data on runoff, air temperature and precipitation in years with different heat and moisture regimes.

Table 2. Drain (Q m^3/s) in different temperature ratios (t) and precipitation (X mm) in the Naryn River.

Years	Characteristics	Month				
		V	VI	VII	VIII	IX
2016	t	11.9	16.4	17.0	16.9	15.5
	X	74.1	79.4	114.7	16.7	29.1
	Q	785	1375	1048	652	371
2017	t	17.9	21.0	24.3	23.6	20.6
	X	43.7	54.2	70.7	12.9	14.8
	Q	844	1300	1008	580	401

Based on the data of table 2, we can conclude that the fairly clear dependence of a flow from air temperature or precipitation was found in years with increased or decreased heat and moisture. The data for July and September are especially characteristic in this respect. In the first case, lower temperatures, but high humidification ensured a large flow in 2016 compared to 2017, in the second case, increased temperatures with a double difference in precipitation provided an increase in flow in September 2017 over September 2016. A similar phenomenon was noted in June and July. The dependence runoff on precipitation or air temperature in the summer months makes it very difficult to forecast the runoff from main climatic elements, since in some months the runoff is determined by precipitation (June 2016), in others by temperatures (July-September 2017), in the third case by the joint effect of temperatures and precipitation (May 2017) [10]. The different impact of main climatic elements on the intensity of runoff formation was clearly manifested in monthly values of the correlation coefficient between runoff, air temperature and precipitation. In July the correlation coefficients are low for both air temperature and precipitation. In August, both parameters increase.

4. Conclusion

In August, the river Chon Naryn shows a close dependence of runoff on temperature, $r = 0.72$, in the river At-Bashy the close relationship between rainfall and runoff ($g = 0.76$) is found. August is also distinguished by the close dependence of the joint effect of precipitation and air temperature on the runoff for four rivers - Chon and Kichi Naryn, Naryn – c. Naryn and At-Bashy. The correlation coefficient fluctuates in range of 0.60-0.76 and in two rivers - Kokomeren and Chychkan, in the interval 0.30-0.40, which generally exceeds values of the correlation coefficient in other months. It is characteristic that the change in the ratio of the effects of precipitation and air temperature on the formation of glacier flow volume has little effect on the total flow of the river. This is the significance of the glacial component in the summer runoff in the Naryn River. It should be noted that the amplitude of fluctuations in monthly precipitation is significantly greater than for air temperature in average, maximum and minimum flow rates.

References

[1]   Akmatov R, Alamanov S and Choduraev T 2017 Glacial runoff of the Naryn River *Scientific research: Theory, Methods and Practice: Collection of materials of the III International Scientific and Practical Conference* **1** (Cheboksary) p 19-22

[2]   Akmatov R, Alamanov S, Choduraev T 2017 The long-term regime of runoff of the Naryn River. // *Priority directions of the development of education and science: Collection of materials of the III International Scientific and Practical Conference*. Cheboksary, pp. 43-44.

[3]   Alamanov S and Akmatov R 2006 Water reservoirs of Kyrgyzstan (Bishkek)162 p

[4]   Alamanov S, Sakiev K and Akhmedov S 2013 Physical Geography of Kyrgyzstan (Bishkek) 216 p

[5]   Alamanov S, Lelevkin V, Podrezov O and Podrezov A 2006 Climate change and water problems in Central Asia (Moscow-Bishkek, OJSC "Lev Tolstoy") 105 p

[6]   Bolshakov M 1974 Water resources of the rivers of the Soviet Tien Shan and methods of their calculation (Frunze, Ilim) 306 p

[7]   Kamalov B. Modern glaciation and runoff from glaciers in the Syr-Darya basin. Tr. SARNIGMI **12 (93)** (M.: *Hydrometeopublishing)* 1974 80 p

[8]   Mamatkanov D 2001 Integrated use and protection of water resources in Central Asia *Water and sustainable development of Central Asia* (Bishkek) p 69-77

[9]   Racek I 1991 Fluctuations and evolution of glacier runoff in the basin of the r. Naryn *Abstract of dissertation for the degree of Candidate Geographical Sciences* (M) 20 p

[10]   Usubaliev T 1998 Water is more expensive than gold (Bishkek: Sham) 21 p

[11]   *Report* Sustainable development of mountain areas, their potential and response to various types of impacts (the Naryn river basin) Project Manager Ph D S Alamanov (Institute of Geology M Madysheva NAS KR Bishkek) 2005 p 116-123

[12]   *Report*. Hydrological forecast of the Naryn River. Project Manager Doctor of Geological Sciences Professor T Choduraev (Department of Science MES KR Bishkek) 2017 p 23-26

[13]   Weinthal E 2002 State making and environmental cooperation: Linking domestic and international politics in Central Asia (MIT Press Cambridge MA)

[14]   Aizen V, Aizen E and Kuzmichonok V 2007 Glaciers and hydrological changes in the Tien Shan: simulation and prediction *Environmental Research Letters* **2(4)** 045019. doi:10.1088/1748-9326/2/4/045019