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STATISTICAL ASSESSMENT OF ANNUAL RUNOFF VARIABILITY OF RIVERS IN THE CHIRCHIK-AKHANGARAN BASIN UNDER CLIMATE CHANGE

Abstract. *Assessing changes in the interannual variability of river runoff is essential for water resources management and hydropower planning under a changing climate. The aim of this study is to evaluate the variability of annual runoff of five rivers in the Chirchik-Akhangaran basin (Uzbekistan). Coefficients of variation (Cv) of mean annual discharge were calculated using the method of moments for the baseline climatic period (BCP, 1961–1990) and the current climatic period (CCP, 1991–2020) and compared with earlier estimates. In the CCP, Cv decreased for four of the five rivers (by 12–31%, most strongly for the Chatkal River, from 0.32 to 0.22) and increased only for the Oigaing River (from 0.17 to 0.20). The changes, however, lie within or close to the sampling error of Cv (about 13–14%), indicating a consistent tendency rather than a statistically proven shift.*

Keywords: *river basin, annual runoff, water discharge, coefficient of variation, statistical assessment, climate change, Chirchik-Akhangaran basin.*

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СТАТИСТИЧЕСКАЯ ОЦЕНКА ИЗМЕНЧИВОСТИ ГОДОВОГО СТОКА РЕК ЧИРЧИК-АХАНГАРАНСКОГО БАССЕЙНА В УСЛОВИЯХ ИЗМЕНЕНИЯ КЛИМАТА

Аннотация. *Оценка изменений межгодовой изменчивости речного стока важна для управления водными ресурсами и планирования гидроэнергетики в условиях изменения климата. Целью исследования является оценка изменчивости годового стока пяти рек Чирчик-Ахангаранского бассейна (Узбекистан). Коэффициенты вариации (Cv) среднегодовых расходов воды рассчитаны методом моментов для базового климатического периода (БКП, 1961–1990 гг.) и текущего климатического периода (ТКП, 1991–2020 гг.) и сопоставлены с ранее полученными оценками. В ТКП значения Cv уменьшились для четырёх из пяти рек (на 12–31%, наиболее значительно для р. Чаткал – с 0,32 до 0,22) и увеличились только для р. Ойгаинг (с 0,17 до 0,20). Выявленные изменения находятся в пределах или вблизи случайной ошибки Cv (около 13–14%), что указывает на устойчивую тенденцию, но не на статистически доказанный сдвиг.*

Ключевые слова: *речной бассейн, годовой сток, расход воды, коэффициент вариации, статистическая оценка, изменение климата, Чирчик-Ахангаранский бассейн.*

Introduction

The interannual fluctuations of annual runoff of Central Asian rivers and their statistical assessment were studied in detail during the twentieth century by L.K. Davydov [3], K.P. Voskresensky [2], V.L. Shults [8], M.N. Bolshakov [1] and other researchers, and the resulting estimates were summarized in the fundamental reference work “Surface Water Resources of the USSR” [5]. However, these results were obtained from observation series that ended in the 1960s–1970s and therefore do not reflect the current state of rivers that form in Uzbekistan and the adjacent mountain areas.

Over recent decades, climate warming has substantially affected the runoff of Tien Shan rivers. Long-term observations in the northern Tien Shan show positive discharge trends in catchments with significant glacier cover [12], and glacier melt contributes a considerable share of runoff in the headwaters of the Syr Darya [10]. Projections for the Chirchik basin also indicate further changes in flow dynamics in the coming decades [11]. Climate-driven changes in the water resources of the mountain rivers of Uzbekistan have been examined in [6, 7]. Re-examining runoff variability on the basis of hydrological data for the last 30 years, and refining the earlier estimates, is therefore of considerable scientific and practical importance, in particular for the design and operation of hydropower facilities and reservoirs in the basin.

Interannual fluctuations of river runoff are caused mainly by meteorological factors, primarily precipitation and air temperature. For rivers fed by rain and seasonal snow, annual precipitation above the norm leads to increased annual runoff. For rivers fed by perennial snow and glaciers, summer air temperatures above the norm are the main cause of increased runoff. In both cases, other factors are of secondary importance [4, 9].

The aim of this study is to perform a statistical assessment of the variability of annual runoff of the rivers of the Chirchik-Akhangaran basin and to compare its characteristics for the baseline and current climatic periods.

Materials and methods

The study used mean annual water discharges measured at the gauging stations of the Hydrometeorological Service Agency (Uzhydromet) under the Ministry of Ecology, Environmental Protection and Climate Change of the Republic of Uzbekistan. Five gauging stations were considered: the Pskem River at Mullala, the Chatkal River at the mouth of the Khudaydodsay River, the Ugam River at Khodjikent, the Akhangaran River at the mouth of the Irtash River, and the Oigaing River at its mouth. Two 30-year periods were analyzed: the baseline

climatic period (BCP, 1961–1990) and the current climatic period (CCP, 1991–2020).

The interannual variability of runoff was characterized by the coefficient of variation Cv, which describes the degree of deviation of annual runoff from its norm:

$$C_v = \frac{\sigma}{Q_0} \qquad (1)$$

where σ is the standard deviation of the series and Q_0 is the mean annual discharge (runoff norm), m³/s. The standard deviation is determined as:

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(Q_i - Q_0)^2}{n-1}} \qquad (2)$$

where Q_i is the mean annual discharge of the i-th year and n is the length of the series. Substituting (2) into (1) and dividing the numerator and denominator by Q_0, we obtain:

$$C_v = \sqrt{\frac{\sum_{i=1}^{n}(K_i - 1)^2}{n-1}}, \quad K_i = \frac{Q_i}{Q_0} \qquad (3)$$

where K_i is the modular coefficient of annual runoff. The coefficient of skewness was taken as $C_s = 2C_v$, the ratio conventionally adopted in Central Asian hydrological practice for annual runoff of mountain rivers [4, 5].

To evaluate whether the differences between the periods are meaningful, the standard (sampling) error of C_v was estimated for $C_s = 2C_v$ as:

$$\sigma_{Cv} = \frac{C_v}{\sqrt{2n}}\sqrt{1 + {C_v}^2} \qquad (4)$$

and the difference between the periods was assessed by the statistic $z = \Delta C_v / (\sigma_{Cv,BCP}^2 + \sigma_{Cv,CCP}^2)^{0.5}$, with $|z| \geq 1.96$ corresponding to a significance level of 0.05.

Results

The sequence of calculation of the coefficient of variation is shown for the Ugam River at Khodjikent for the BCP (Table 1). Similar calculations were performed for all other rivers of the basin for both the BCP and the CCP.

Table 1

Calculation of the coefficient of variation of mean annual discharge, Ugam River at Khodjikent (1961–1990)

Year	Q_i, m³/s	Q in descending order, m³/s	K_i	$K_i - 1$	$(K_i - 1)^2$
1961	14.7	43.5	0.68	−0.32	0.10
1962	16.4	31.7	0.76	−0.24	0.06
1963	24.9	27.7	1.16	0.16	0.03
…	…	…	…	…	…
1990	27.7	14.3	1.29	0.29	0.08
Mean / Sum	**Q_0 = 21.5**				**Σ = 2.34**

Based on the results in Table 1, the coefficient of variation of the Ugam River for 1961–1990 is:

$$C_v = \sqrt{\frac{2.34}{30-1}} \approx 0.28 \qquad (5)$$

The coefficients of variation and skewness of mean annual discharge of the rivers of the Chirchik-Akhangaran basin obtained for the BCP and CCP are given in Table 2.

Table 2

Coefficients of variation and skewness of mean annual discharge of rivers in the Chirchik-Akhangaran basin

No.	River – gauging station	BCP (1961–1990)		CCP (1991–2020)	
		C_v	C_s	C_v	C_s
1	Pskem – Mullala	0.22	0.44	0.19	0.38
2	Chatkal – mouth of Khudaydodsay	0.32	0.64	0.22	0.44
3	Ugam – Khodjikent	0.28	0.56	0.24	0.48
4	Akhangaran – mouth of Irtash	0.32	0.64	0.28	0.56
5	Oigaing – mouth	0.17	0.34	0.20	0.40

Note: C_v – coefficient of variation of annual runoff; C_s – coefficient of skewness ($C_s = 2C_v$).

In the BCP, the largest coefficients of variation were obtained for the Chatkal and Akhangaran rivers (Cv = 0.32), and the smallest for the Oigaing (Cv

= 0.17) and Pskem (Cv = 0.22) rivers. In the CCP, the largest value again belongs to the Akhangaran River (Cv = 0.28), which is lower than in the BCP, while the smallest value was obtained for the Pskem River (Cv = 0.19). Overall, Cv ranged from 0.17 to 0.32 in the BCP and from 0.19 to 0.28 in the CCP. Compared with the BCP, Cv decreased in the CCP for four rivers: the Chatkal (by 31%), Ugam (14%), Pskem (14%) and Akhangaran (13%). The only increase (by 18%) was found for the Oigaing River.

The results were compared with earlier studies (Table 3). In the monograph "Surface Water Resources of the USSR" [5, pp. 130–143], with the calculation period ending in 1966, Cv for the studied rivers ranged from 0.21 to 0.35. The values obtained by V.E. Chub from hydrological data up to 2002 ranged from 0.23 to 0.31 [7, pp. 78–93].

Table 3

Coefficients of variation of annual runoff obtained by different researchers

No.	River – gauging station	C_v			
		1	2	3	4
1	Pskem – Mullala	0.21	0.23	0.22	0.19
2	Chatkal – mouth of Khudaydodsay	0.23	0.27	0.32	0.22
3	Ugam – Khodjikent	0.25	0.27	0.28	0.24
4	Akhangaran – mouth of Irtash	0.35	0.31	0.32	0.28
5	Oigaing – mouth	–	–	0.17	0.20

Note: 1 – data of "Surface Water Resources of the USSR" [5]; 2 – data of V.E. Chub [7]; 3 and 4 – values obtained by the author for the BCP and CCP, respectively; "–" – not calculated.

Discussion

The values obtained in this study agree well with earlier estimates: for the BCP the differences from the data of [5] and [7] do not exceed 0.04–0.09, which confirms the reliability of the calculations. At the same time, the CCP values are systematically lower for most rivers, indicating a tendency towards smoothing of interannual runoff fluctuations in the basin.

To assess the reliability of the detected changes, the sampling errors of Cv were calculated using formula (4) (Table 4).

Table 4

Change in the coefficient of variation between the periods and its sampling error

River – gauging station	ΔC_v, %	σ_{Cv} BCP	σ_{Cv} CCP	z	Significant ($p < 0.05$)
Pskem – Mullala	−14	0.029	0.025	−0.78	no
Chatkal – mouth of Khudaydodsay	−31	0.043	0.029	−1.91	no ($p \approx 0.06$)
Ugam – Khodjikent	−14	0.038	0.032	−0.81	no
Akhangaran – mouth of Irtash	−13	0.043	0.038	−0.70	no
Oigaing – mouth	+18	0.022	0.026	+0.87	no

The relative sampling error of Cv for 30-year series is about 13–14%. Consequently, the changes for individual rivers are not statistically significant at the 0.05 level; only the decrease for the Chatkal River (by 31%) approaches significance ($p \approx 0.06$). Nevertheless, the decrease of Cv in four of the five rivers indicates a consistent regional tendency. A possible explanation is the growing contribution of glacier and snow melt under rising air temperatures, which partly compensates for low-precipitation years and smooths interannual fluctuations of runoff [10, 12]. Confirming this hypothesis requires longer series and joint analysis of runoff with air temperature and precipitation data.

Conclusion

Based on the analysis of mean annual discharges of five rivers of the Chirchik-Akhangaran basin, the following conclusions can be drawn:

1) The coefficients of variation of annual runoff range from 0.17 to 0.32 in the baseline climatic period (1961–1990) and from 0.19 to 0.28 in the current climatic period (1991–2020).

2) In both periods, the largest variability is characteristic of the Akhangaran River (Cv = 0.32 and 0.28); in the BCP the Chatkal River had the same high value (Cv = 0.32).

3) In the current period, Cv decreased for four of the five rivers (by 13–31%, most strongly for the Chatkal River) and increased only for the Oigaing River (by 18%); the changes are within or close to the sampling error and represent a tendency rather than a statistically proven shift.

4) The values obtained agree well with the estimates of earlier researchers [5, 7], which confirms their reliability.

5) The updated Cv and Cs values can be used to calculate annual runoff of given exceedance probability for water management, for the design and operation of hydropower plants and reservoirs, and for assessing the hydropower potential of the rivers of the basin.

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