Advances in Biology & Earth Sciences
Vol.8, No.3, 2023, pp.272-287

FEATURES OF FORMATION AND LONG-TERMFLUCTUATIONS OF THE LOW FLOW OF RIVERS IN THE GREATER CAUCASUS

A.V. Sikan[1], F.A. Imanov[2*]

[1]Russian State Hydrometeorological University, St. Petersburg, Russia
[2]Baku State University, Baku, Azerbaijan

Abstract. A far-ranging analysis of the minimum winter runoff of the rivers of the Greater Caucasus within Azerbaijan has been carried out. The series on the minimum winter monthly water discharges of 18 hydrological stations for the period from 1930/61 to 2017 were used. It is shown that formation of the minimum river flow occurs in various climatic, landscape and hydrogeological conditions, which regularly varies due to the elevation of the area. These conditions are considered for each of the three high-altitude zones that are identified in the basins of the studied rivers. It is noted that at present the influence of anthropogenic factors on the minimum winter runoff of the analyzed rivers is practically absent. It was revealed that there is a synchronic regime of phase in the fluctuations of the minimum winter monthly water discharge for studied rivers, however, the absence of strict synchrony in fluctuations of the minimum winter runoff leads to a decrease in spatial correlation coefficients. Almost all the series under the study have a significant upward trend, while the reason for the non – stationary trend is climate change, the effect of which on the minimum winter runoff has become noticeable in recent decades. For majority of the series, the hypothesis of homogeneity according to the Student and Fisher criteria is rejected. Since all series of minimum winter monthly water discharges are heterogeneous, truncated probability curves were used for calculation. Weibull two-parameter distribution curve was used as an analytical curve. The median flow was taken as the truncation point.

Keywords: *Greater Caucasus, minimum flow, long-term fluctuations, linear trend, mass curve, truncated distribution.*

Corresponding Author: *F.A. Imanov, Baku State University, Z. Khalilov 23, Baku, Azerbaijan, e-mail: farda_imanov@mail.ru*

Received: *12 September 2023;* ***Accepted:*** *28 November 2023;* ***Published:*** *12 December 2023.*

1. Introduction

The minimum river runoff is an integral component of the water regime of any river (Methods of calculation, 1984; Smakhtin, 2001; WMO, 1994) and belongs to the category of basic hydrological characteristics used in solving various problems of water management design (Determination of the basic, 2004; Viessman *et al*., 1979; Abi-Zeid & Bobee, 1999). The development of projects for drinking, industrial and agricultural water supply should be emphasized. Various indicators of the minimum flow are certainly taken into account in assessing the environmental flow of rivers by hydrological methods (Ecological flows, 2015; Tharme, 2003). Hydraulic modeling and complex methods used for this purpose also envisage the use of low flow characteristics. The minimum water discharge is an important parameter when calculating the permissible discharge of substances and microorganisms into water bodies for water users (Karaushev, 1987). The

How to cite (APA):
Sikan, A.V., Imanov, F.A. (2023). Features of formation and long-termfluctuations of the low flow of rivers in the Greater Caucasus. *Advances in Biology & Earth Sciences, 8*(3), 272-287.

minimum values of water discharge are widely used to determine the stable part of groundwater flow, which is an indicator of the natural resources of groundwater (Sokolov & Sarkisyan, 1981). Minimum flow data is a critical indicator of hydrological drought for water use planning and management, (Tallaksen & VanLanen, 2004; Marsel *et al*., 2014; Chaoxing & Xiong, 2020).

The formation and long-term fluctuations of river flow characteristics, in particular the minimum river runoff, are dynamic processes, and since middle 20th century anthropogenic activity in river basins (Shiklomanov, 1989; Shiklomanov, 2008) and climate change (Cecilia Svensson *et al*., 2004; Bates *et al*., 2008) since the 70s and 80s is an integral part of this process. Usually, due to a sharp decrease in absolute water amount during periods of minimum flow, rivers react very quickly to anthropogenic impacts, especially to direct water intakes from river channels. Not only the value of the minimum flow, but also the patterns of its long-term fluctuations are disrupted under the conditions of changes in climatic factors such as the amount of atmospheric precipitation and air temperature. Stationarity of the flow series can be disrupted depending on the extent of change in these two climatic factors (Dzhamalov *et al*., 2013; Bolgov *et al*., 2018; Sikan & Baiduk, 2015), which requires adequate methods for calculating the river flow values.

Studies of the minimum river runoff of the entire Greater Caucasus and its individual subregions began in the 50s of the XX century. In these early works, the main attention was paid to the influence of individual physical and geographical factors on the runoff quantity. Regularities of the spatial distribution of the minimum runoff values had been revealed. All researchers, without exception, pointed to the leading role of vertical zoning in the formation of the minimum flow and suggested empirical regional dependences of the flow on the average height of river catchment for ungauged rivers. The first works about the analysis of the influence of anthropogenic factors on the minimum runoff appeared in 1980s. In these works, the dates of beginning of a significant anthropogenic impact on the minimum river runoff were identified and an estimate was made of the decrease in flow as a result of water withdrawals from rivers for irrigation purposes. A detailed review of these works is contained in the work of Imanov (2000).

In the territory of Azerbaijan, the most intensive rise in temperature began in the 1995-1998. The revealed changes are in good agreement with the course of long-term fluctuations in the level of the Caspian Sea, in the basin of which the entire territory of Azerbaijan is located. After a significant rise in the water level that took place in 1978-1995 (2.35 m), since 1996, its intensive decline began (1.39 m in 2019) (Imanov & Sikan, 2022). The average long-term air temperature for the period from 1995 to 2018 increased by 1.1°C compared to the previous period (Mahmudov, 2018).

Climate change affects the regime and runoff characteristics of the rivers of Azerbaijan: the annual runoff, the maximum water flow during spring floods and the minimum summer runoff decrease, while the minimum winter runoff increases (Alieva, 2020).

Researchers of the minimum runoff of rivers throughout Azerbaijan, including the rivers of the Greater Caucasus, focused on the issue of the impact of climate change. However, in these studies, the authors limited themselves to identifying heterogeneity and non-stationarity in the series of minimum flow, using statistical criteria through the linear trend method, as well as assessing runoff changes for different periods, using the comparison method. For example, a comparative analysis of the minimum winter flow for 1930-1961 and 1962-1995 showed that the flow of small and medium-sized rivers increased by 20-40% in all regions of Azerbaijan in winter months (Verdiev, 2002). Later, using the linear trend method, this trend of long-term fluctuations in the series of the minimum winter flow (1960-2015/2017) was confirmed (Imanov *et al*., 2018). However, the following questions still remain open: when did the minimum winter flow of the rivers of Greater Caucasus begin to respond to climate changes and how to calculate the minimum flow in the event of nonstationarity of observation series?

The aim of this study is to assess the frequency of occurrence of the minimum winter water discharge in the rivers of the Greater Caucasus under the conditions of a changing climate and an increasing anthropogenic load on river catchments.

2. Materials and research methods

18 time series of the minimum winter monthly flow (1930 / 1961-2017) of the rivers of the Greater Caucasus have been used in this study. 16 out of 18 hydrological posts are located in the mountainous part of the river basins, i.e. on the territory of specially protected zones (national parks and reserves) and therefore these rivers have a natural regime. Thus, sustainable management of water resources of the studied rivers is ensured. The exception is two posts (No.10 and 12) (Figure 1).

Figure 1. Map of the region under study and observation points
I - North-eastern slope of the Greater Caucasus; II - Shirvan region; III - Basin of the Ganikh River (Alazani)

The series of observations involved in the analysis are representative, since their minimum length is 57 years and they contain several wet and dry phases. The analysis of conditions for formation of considered flow characteristic was carried out on the basis of genetic method.

The analysis of synchronous fluctuations of minimum river runoff was carried out using the difference integral curves and the correlation method. To assess linear trends in series of minimum winter water discharge, the criterion of significance of sample correlation coefficient (R) was used at a significance level of $2\alpha = 5\%$ (t-test) for the dependences Qmin = f (t).

Chronological graphs and mass curves of the form $\Sigma X = f(t)$ were plotted to identify the dates of disruption of conditions for formation of minimum runoff. The Student and Fisher tests were used to check the series for homogeneity. The truncated distribution curves were used to calculate the probability values of runoff. As an analytical curve had mainly been used the curve of the two-parameter Weibull distribution and in four cases the

Gumbel distribution with negative asymmetry. The median value of the series was generally taken as the truncation point.

The results obtained are summarized in relation to three hydrological regions, which are shown in Figure 1.

3. Discussion of results

Conditions for the formation of the minimum winter river flow

The basins of the studied rivers are located in the Greater Caucasus, which occupies the northern part of the Republic of Azerbaijan. The main rivers form their flow in mountainous zone and then go to the plains. The exception is small rivers (Damarchik, Kaynar, Chukhadurmas), the basins of which are completely located in mountainous zone. The mountainous part of the basins is composed of rocks of the Jurassic and Cretaceous periods of the Mesozoic and the plains are predominantly alluvial deposits of the Quaternary period of the Cenozoic. Three hydrogeological regions are distinguished here: the porous-fractured water basin of the Greater Caucasus, the porous-stratal waters of Ganikh-Ayrichay and Kusar-Devechi basins (Geology of Azerbaijan, 2008). The region is dominated by various types of climate of the temperate zone and only for the estuarine areas of the basins of relatively large rivers (Goychay, Girdimanchay) the climate of semi-deserts and dry steppes is typical. Amount of precipitation increases from 300-400 mm to 900-1200 mm per year in a direction from the plains to the middle mountains, after which their decrease is observed. Their average long-term values for river catchments are 657 mm (region I), 1059 mm (region II), and 1313 mm (region III) (Rustamov & Qashgai, 1978).

The hydrological regime of the studied rivers is typical for the temperate climatic zone, i.e. on the hydrographs of the rivers, spring floods; autumn floods and low-water periods are clearly expressed. Almost all rivers have two types of low water regime-summer-autumn and winter. The exception is Kusarchay River, in which glacial waters are partly involved, and therefore only winter low-water period stands out in its water regime. The rivers are fed by groundwater in both dry seasons. For the rivers of the first two regions, the value of the coefficient of underground feeding of rivers is on average 40-41% and for the third region, it is 48%. As in many other mountainous regions, the value of this coefficient increases with the height of the area, which is associated with geological and geomorphological structure of river basins, which contribute to the infiltration of snow-melting waters (Imanov, 2016).

The winter low-water period is longer than the summer-autumn one in all three regions. So, duration of the summer-autumn low-water period for the rivers of region I is on average 91 and 127 days for the winter low-water period. In region II, these figures are 106, 113, respectively, and 95 and 133 days are in region III. However, in all regions, the values of the river runoff in the winter low-water period (13-21% of the annual flow) are slightly less than in the summer-autumn period (15-27%). This pattern is also typical for the ratio of the minimum winter and summer-autumn flows, which is explained with participation of groundwater from temporary aquifers in feeding of rivers during the summer-autumn period (Imanov, 2000).

In mountainous regions, including the Greater Caucasus, the natural conditions for formation of the minimum river runoff are changing in two directions: on the one hand, with the height of the area and on the other, in the latitudinal direction.

The basin of each mountain river can be divided into zones of formation, transit and distorted flow, which especially stand out during periods of the minimum flow. These zones differ in climatic and hydrogeological features, as well as in the nature of the interaction of stream and ground waters. The transit zone is not separately identified in this study since it is actually a formation zone during periods of liquid precipitation and thaws. In addition, the part of the basin area occupied by this zone is insignificant.

The flow formation zone covers the main mountainous part of the river catchments. As a rule, the areas of formation and discharge of groundwater, which is the main source of river runoff during periods of minimum river flow, coincide within this zone. Groundwater is discharged into rivers most often in the form of descending springs at the intersection of aquifers with negative landforms or directly drained by rivers. The ratio of the spring and drainage components of the minimum flow changes regularly with the height of the area. Usually, the number of springs increases with height and, accordingly, the share of spring flow increases. However, an increase in the number of springs and their debits occurs up to certain heights. Taking into account the water content of water-bearing rocks, the amount and flow rate of springs, as well as geomorphological features, the formation zone can be divided into three parts: high-mountain, mid-mountain and low-mountain foothills.

The high-mountainous part (H> 2500 m) of the studied basins is composed of poorly water-permeable rocks and is characterized by large slopes of the area. The rivers flow through deep gorges, the slopes are very steep. Alluvial deposits are almost absent and all this is advantageous for formation of surface flow. About 15% of atmospheric precipitation is spent on underground feeding of rivers (Sokolov & Sarkisyan, 1981). Groundwater discharges in the form of springs are rarely met. They are distinguished by insignificant yields and greatest dynamism. There are no springs in some areas. It should be noted that there is a decrease in the amount of atmospheric precipitation in the high-mountainous part of the first zone. This part of the formation zone occupies a small territory, in comparison with the middle mountain,

In general, the Greater Caucasus is characterized by mid-mountain relief forms (1000-2500 m), which are distinguished by smoother forms of the earth's surface. Here deluvial, alluvial and proluvial deposits are developed, which, together with small slopes of the area, are advantageous for the formation of groundwater aquifers. The main part of springs that feed rivers during periods of minimum flow are confined to this part of the formation zone. These springs are less dynamic, and their regime generally repeats the course of atmospheric precipitation, however, in a significantly smoothed form and with a lag of 1-3 months. The mid-mountainous part of the formation zone is characterized by an increase in proportion of drained flow, which often exceeds the value of spring flow (Zadorozhnaya, 1972).

The low-mountain foothill part of the mountainous zone is a transitional zone from mountainous denudation to accumulative relief. It is characterized by moderate or weak dissection of the relief and the ridges have heights of 500-1000 m. The rivers flow through wide valleys, which are composed of alluvial deposits. The groundwater of these sediments is directly drained by rivers and fed throughout the year. In the low-mountain-foothill part of the formation zone, a small amount of atmospheric precipitation falls and the amount of evaporation is quite large. Accordingly, there are few springs here and their yields are generally insignificant. Therefore, this part of the formation zone during periods of absence of rains and thaws practically represents a flow transit zone.

The distorted flow zone covers the foothill and inter - mountinous plains and lowlands of the Greater Caucasus (up to 1000-1200m). Its upper boundary runs along the tops of the alluvial fans and is formed by merged alluvial fans of permanent and temporary streams. Here, the thickness of alluvial deposits reaches 300-500 m, and sometimes 2000 m (Listengarten & Krasilnikov, 1977).

In the near-top parts of the alluvial fans, which are composed of permeable boulders, pebbles and gravel with sandy, silt and loamy filler, river flow is partially (30-50%) and in some years it is completely absorbed and feeds groundwater aquifers. As we move towards the periphery of the fan, well and less permeable sediments are inter-bedded. The groundwater level approaches the earth's surface and groundwater is unloaded in the form of springs. However, only some of this water flows into the nearest rivers and the rest forms bogs. Due to the drought in the plains and lowlands, the bulk of these waters is evaporated in the summer-autumn season (Geology of Azerbaijan, 2008).

In the summer-autumn season, the groundwater levels within the alluvial fans decrease significantly, and many springs stop their existence. Only those springs that receive additional feeding from the bedrock of the formation zone (10-15%) differ in constant flow rates. In addition to natural factors, anthropogenic factors also affect the regime of rivers during periods of minimal summer-autumn flow: it is within the distorted zone that practically all irrigated lands of the Greater Caucasus are located. As a result, some of the rivers do not carry its waters to the mouth in the summer-autumn period (Imanov, 2000).

The influence of local factors should be noted in some basins in addition to the above general patterns information of the minimum river runoff. So, in the upper part of the river basin Gudyalchay (above the Kriz post) karst rocks are widespread and here there is an underground water exchange between the basins of the main river and its tributary Khinaligchay. For this reason, the average long-term value of the minimum winter monthly flow of the main river is 46% higher than its zonal value (Imanov, 2000).

On the rivers of the studied region, the minimum winter water discharge is observed in January-February.

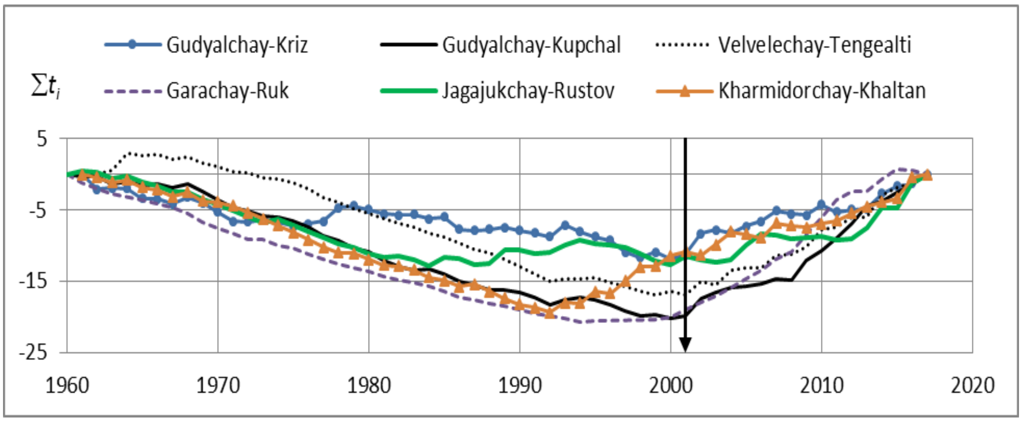
Analysis of the spatial-temporal variability of the minimum monthly winter flow

Combined difference integral curves were plotted for the period from 1960 to 2017 (Figure 2) to analyze the spatial-temporal variability of winter flow for three regions of the Greater Caucasus (Table 1).

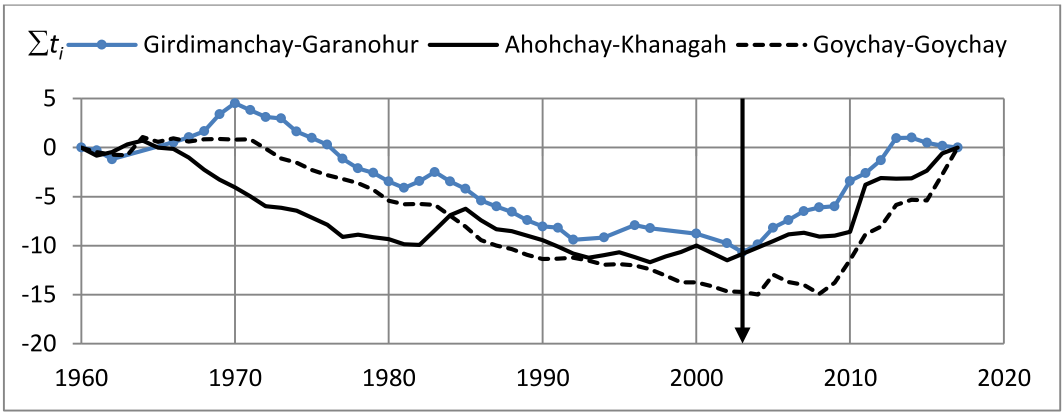
Table 1. Spatial correlation matrix of minimum winter monthly water discharges for rivers of the northeastern slope of the Greater Caucasus
(the numbers of the rivers correspond to the numbers of the stations in Figure 1)

No	***1***	***2***	***3***	***4***	***5***	***6***	***7***
1	1						
2	-0,07	1					
3	0,12	0,45	1				
4	-0,09	0,47	0,69	1			
5	-0,05	0,39	0,70	0,68	1		
6	-0,03	0,35	0,43	0,39	0,26	1	
7	0,00	0,14	0,42	0,47	0,45	0,36	1

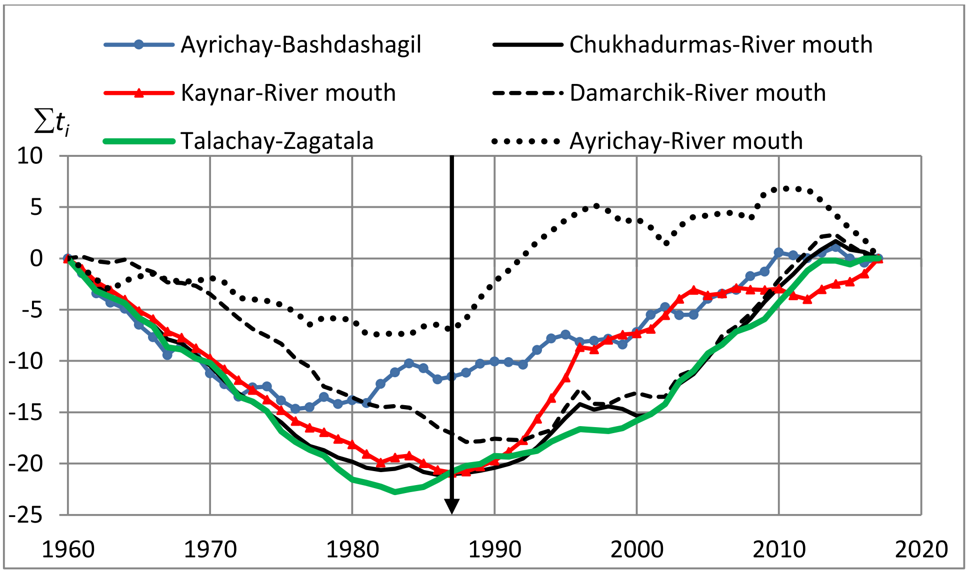
As seen in Figure 2, for the rivers under study, there is a synphase in fluctuations of the minimum winter monthly water discharge. Although the contours of the difference integral curves have noticeable differences, the periods of increased and decreased water flow generally coincide, and, most likely, reflect fluctuations in the total humidity of the analyzed area associated with climate fluctuations.



Rivers of North-eastern slope of the Greater Caucasus



Rivers of Shirvan region



Rivers of the Ganikh (Alazani) River Basin

Figure 2. Combined difference integral curves of minimum winter monthly water discharges for the rivers of the Greater Caucasus (1960-2017)

High-water phase is observed on all rivers at present, but the beginning of this phase falls on different dates. Beginning of the high-water phase on the rivers of the northeastern slope of the Greater Caucasus and the rivers of the Shirvan zone falls on early 2000s and in Ganikh river basin, the high-water phase on most rivers began in the 80s of last century.

The lack of strict synchronicity in fluctuations of the minimum winter flow leads to a decrease in the spatial correlation coefficients. Analysis of the spatial correlation matrices composed for the rivers of the northeastern slope of the Greater Caucasus (Table 1) showed that the pair correlation coefficients for the rivers of the northeastern slope of the Greater Caucasus and the rivers of the Shirvan zone do not exceed 0.7 and for the region of the basin of the river Ganikh only 5 coefficients out of 28 have values of more than 0.7 (from 0.71 to 0.76), but these coefficients are also artificially overestimated, since the series under study have significant positive trends. As a result, in most cases it is impossible to find a reliable reference river for the extension of short series. Apparently, this is due to the fact that each of the rivers has its own combination of flow-forming factors in conditions of mountainous terrain, such as the mean height of the catchment area, the exposure of slopes, the slope, the nature of the underlying surface, etc.

Checking the series of the minimum winter monthly flow for homogeneity and stationarity

The criterion of significance of the sample correlation coefficient *(R)* for the dependences $Q_{\text{min, winter}} = f(t)$, was used to assess linear trends in the series of minimum winter water discharge. The hypothesis of the absence of a trend was not refuted if the term was given by

$$|\boldsymbol{R}| < \boldsymbol{t_{2\alpha}\sigma_R} \tag{1}$$

where, $t_{2\alpha}$ – theoretical value of Student's statistic at significance level 2α = 5%;

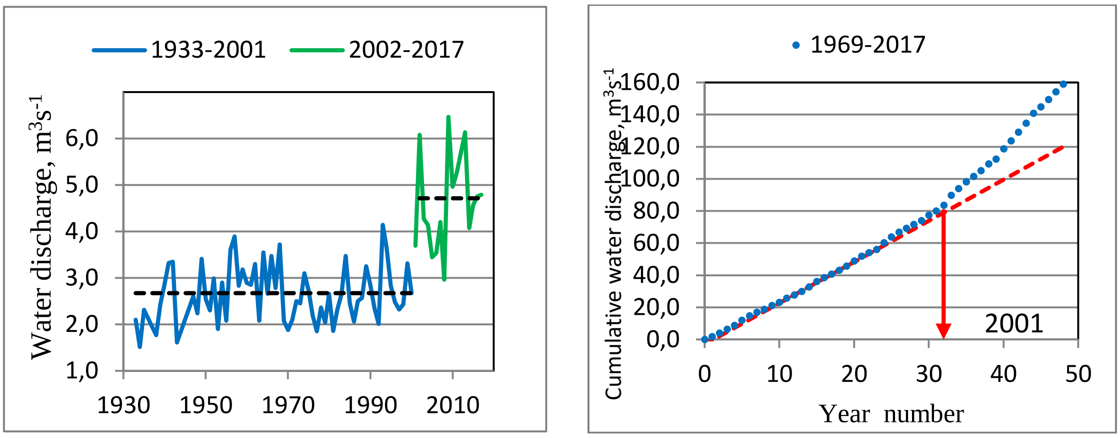
σ_R–standard error of the correlation coefficient, calculated by the formula:

$$\sigma_R = \sqrt{\frac{1-R^2}{n-2}}, \tag{2}$$

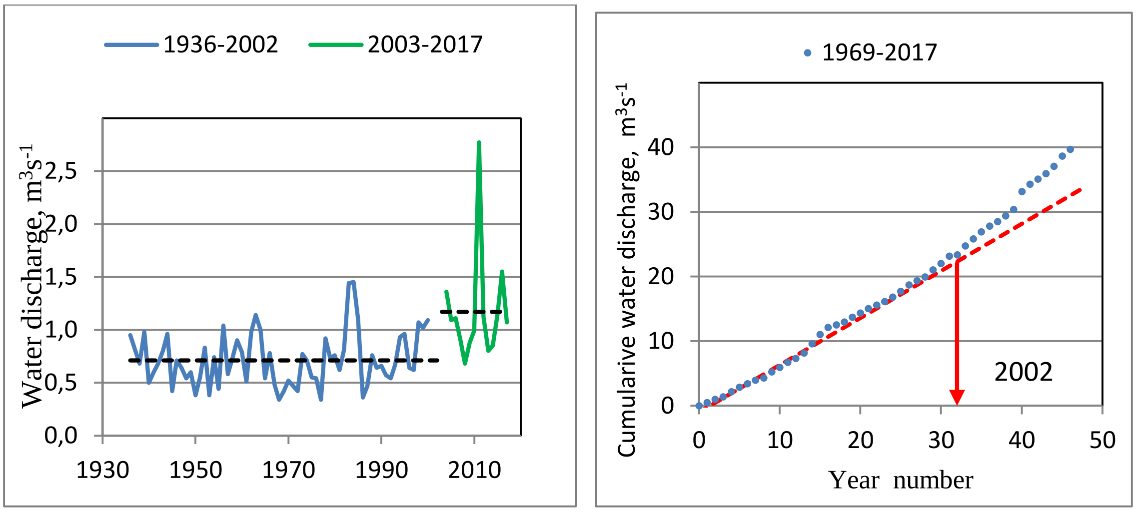
The test results are presented in Table 2.

As can be seen from the Table 2, almost all the series under study have a significant upward trend, while the reason for the non-stationarity was climate change, the effect of which on the minimum winter flow became noticeable in recent decades.

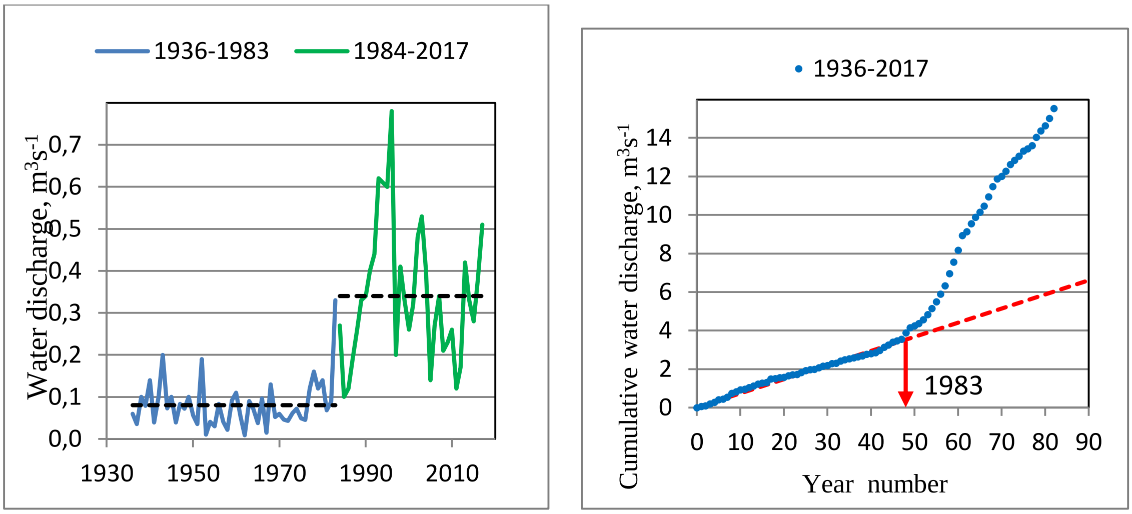
A break point is clearly traced in the figures of the summary curves of the minimum winter flow for all series, which fixes the transition from a low-water phase to a high-water phase, but the date of the break even within one region varies within a fairly wide range (Figure 3).



Gudyalchay River at Kupchal station (Region I)



Ahohchay River at Khanagah station (Region II)



Kaynar River at Mouth (Region III)

Figure 3. Chronological graphs and mass curves of the minimum winter monthly water discharges of rivers of the Greater Caucasus

The series was checked for homogeneity at the next stage using the Student and Fisher criteria. When checking, the series were divided into two equal parts, the significance level was taken 2α = 5%. The test results are presented in Table 2.

The hypothesis of homogeneity for majority of the series according to the Student's test is rejected. This result is expected, since all studied series have a significant upward trend. Moreover, for many series, the hypothesis of homogeneity according to Fisher's criterion is also rejected (13 cases out of 18). This indicates that, not only the water discharge of the winter period has increased as a result of climate change, but also significantly increased their variance.

Table 2 summarizes the results of checking the series for homogeneity and stationarity.

Table 2. Cases of rejection of the hypothesis about the homogeneity and stationarity of the series of the minimum winter monthly runoff (rejection is marked with a "+" sign)

River - Station	Criterion		
	Significance of the trend	Student's test	Fisher's test
Rivers of North-eastern slope of the Greater Caucasus			
Gusarchay– Kuzun	+	+	
Gudyalchay– Kriz	+	+	
Gudyalchay – Kupchal	+	+	+
Velvelechay– Tengealti	+	+	+
Garachay – Ruk	+	+	+
Jagajukchay–Rustov	+	+	+
Kharmidorchay–Khaltan	+	+	+
Rivers of Shirvan region			
Girdimanchay–Garanohur	+		
Ahohchay– Khanagah	+	+	+
Goychay– Goychay			+
Rivers of the Ganikh (Alazani) River Basin			
Ayrichay-Bashdashagil	+	+	
Ayrichay – Mouth	+	+	+
Chukhadurmas – Mouth	+	+	+
Kaynar– Mouth	+	+	+
Damarchik– Mouth	+	+	+
Talachay– Zagatala	+	+	+
Balakanchay– Balakan	+	+	
Kurmukchay– Ilisu	+		+

Application of distribution curves for calculation of minimum winter monthly water discharges

Truncated probability curves were used for the calculation as all the series of minimum winter monthly water discharges are heterogeneous (Sharma & Panu, 2008; Sikan, 2020). Weibull's two-parameter distribution curve was used as an analytical curve (Sikan, 2007; David & Chin, 2006). The median flow was taken as the truncation point.

For the two-parameter Weibull distribution, function of exceedance probability calculated by the formula:

$$P(x) = \exp\left\{-\left(x/a\right)^b\right\}, \tag{3}$$

where a – is the scale factor, a> 0; b – is the shape factor; b > 0; $0 \le x < \infty$. It follows from formula (3):

$$z = g \cdot y + c, \tag{4}$$

where

$$\begin{cases} z = \ln(x) \\ y = \ln(-\ln P), \end{cases} \tag{5}$$

P – Exceedance probability in unit fractions. The parameters g and c are related to the parameters of the Weibull distribution by the formulas:

$$\begin{cases} g = 1/b \\ c = \ln a. \end{cases} \tag{6}$$

As can be seen from expression (4), for the new variables z and y, the relationship is linear; therefore, the parameters g and c were defined by the least squares method.

Using this method, truncated probability curves were plotted for 14 series out of 18. The calculation results for some rivers are presented in Figures 4-7.

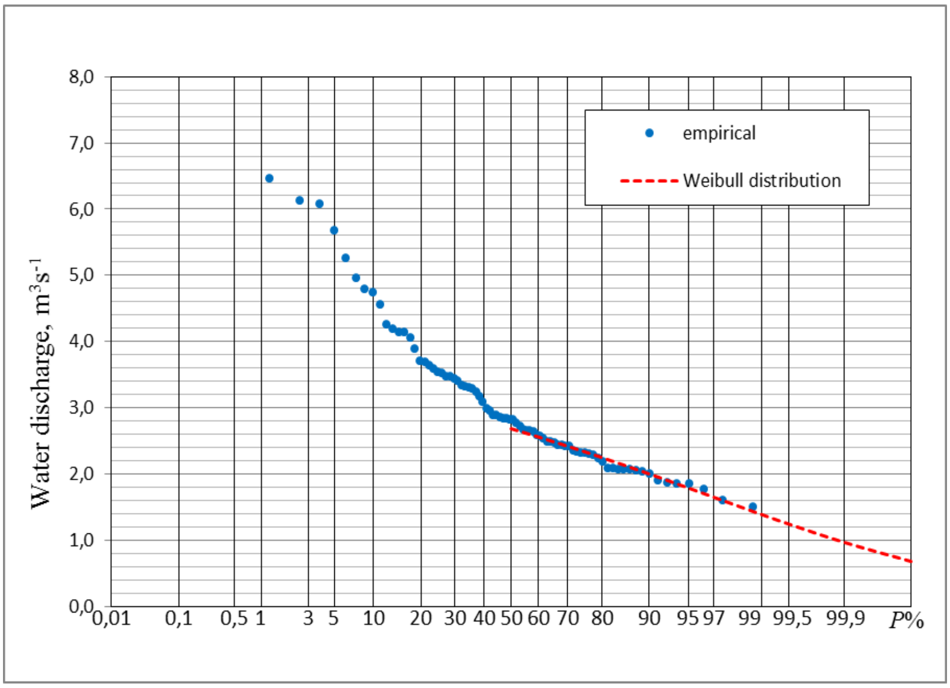


Figure 4. Truncated curve of the minimum winter monthly water discharges of Gudyalchay River at Kupchal station: a = 2.84, b = 6.43.

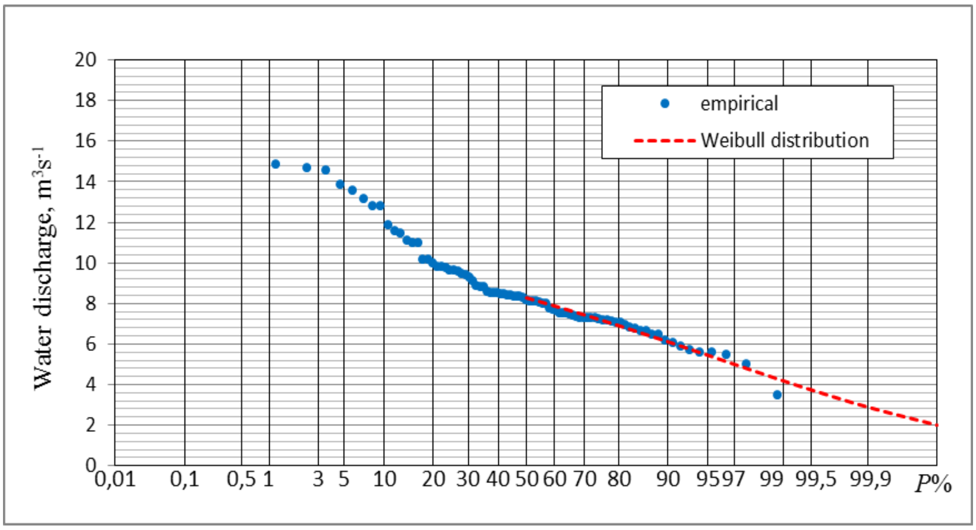


Figure 5. Truncated curve of the minimum winter monthly water discharges of Goychay River at Goychay station: a = 8.76, b = 6.20.

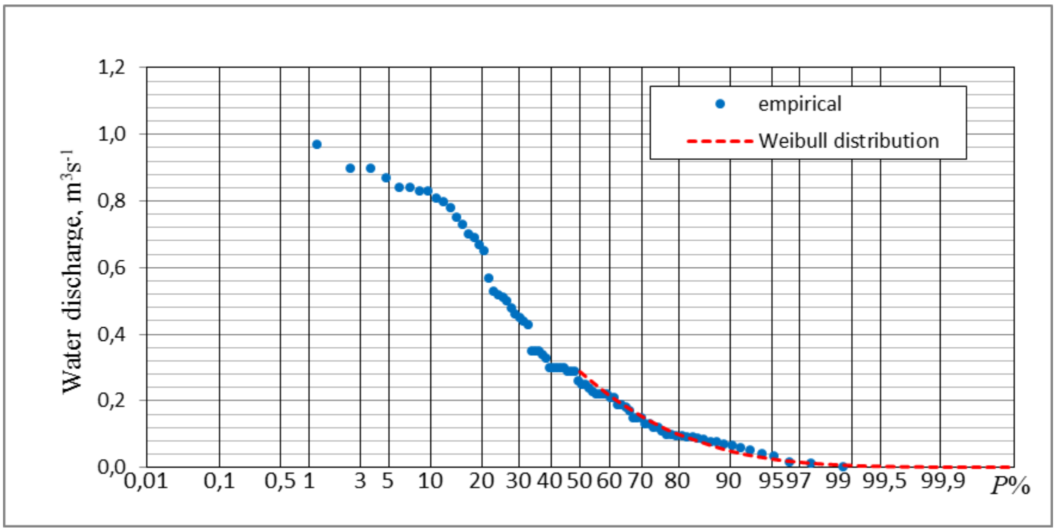


Figure 6. Truncated curve of the minimum winter monthly water discharges of Chukhadurmas River at Mouth: a = 0.40, b = 1.07.

It was impossible to plot a truncated curve for four series using the method described above. All abnormal series refer to the Ganikh river basin.

The truncation point was shifted to the probability P = 70% on the Balakanchay river for correct approximation of the empirical data (Figure 7).

The truncation point was shifted to the probability P = 85% on the Talachay river and the Gumbel distribution with negative asymmetry was used to approximate the upper part of the curve (Figure 8). The average value over two truncated curves is taken as calculated value of the water discharge at P = 85%.

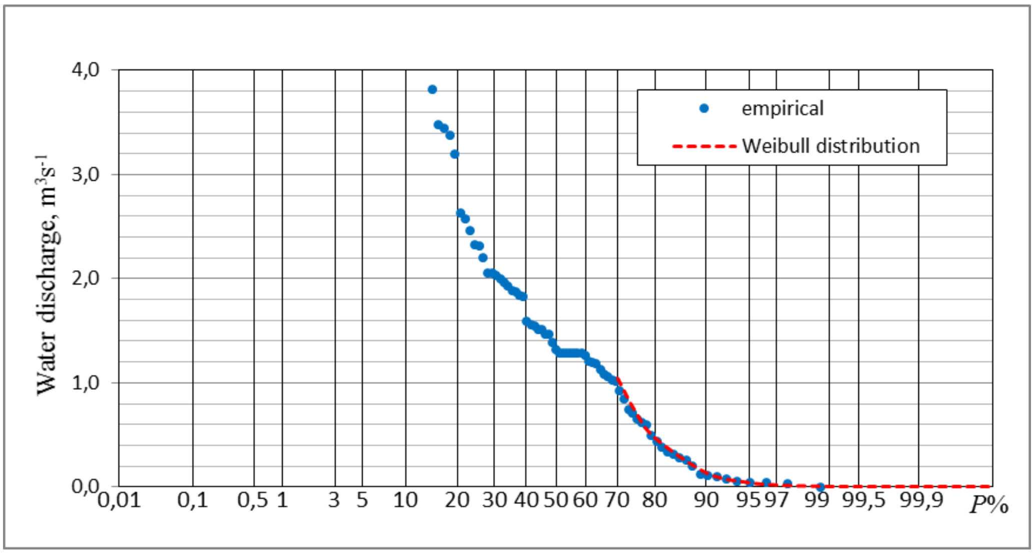


Figure 7. Truncated curve of the minimum winter monthly water discharges of Balakanchay River at Balakan station: truncations points P = 70%; a = 5.99; b = 0.59.

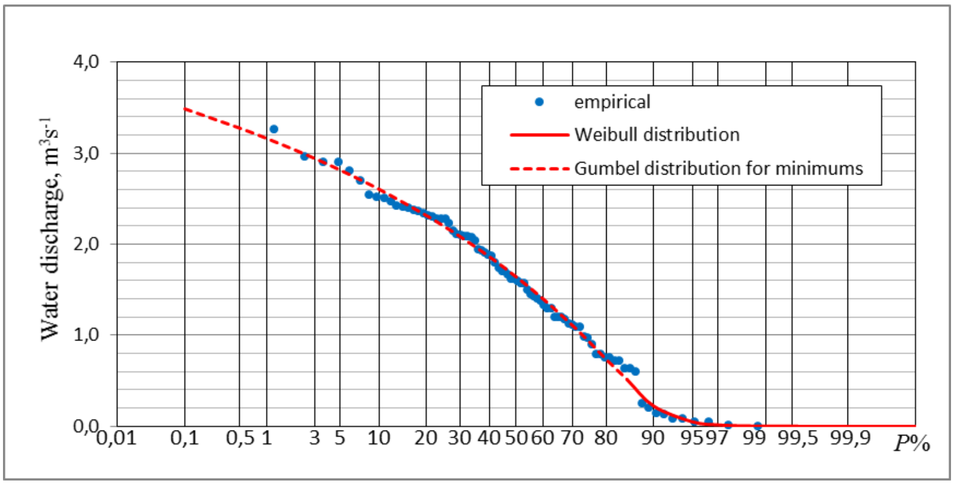


Figure 8. Truncated curve of the minimum winter monthly water discharges of Talachay River at Zagatala station: truncations points P = 85%; μ = 1.93; λ = 0.80; a = 24.8, b = 0.48.

The Gumbel probability function with negative asymmetry is defined by the following expression:

$$P(x) = \exp[-\exp(y)] \tag{7}$$

where $y = (x - \mu)/\lambda$; μ – the mode of random variables x; λ – the scale parameter.

From (7) it follows:

$$x_p = \lambda g_p + \mu \tag{8}$$

where $g_p = \ln[-\ln(P)]$, P – exceedance probability in unit fractions.

Thus, if the sample is described by the Gumbel distribution, then the dependence between x_p and g_p is linear. The parameters λ and μ were found by the least squares method.

For the Damarchik River at Mouth and Kurmukhchay River at Ilisu station, the empirical probability curves in the area of low discharges go down steeply, therefore, for them, the Gumbel probability curve with negative asymmetry was used as a truncated curve (Figure 9).

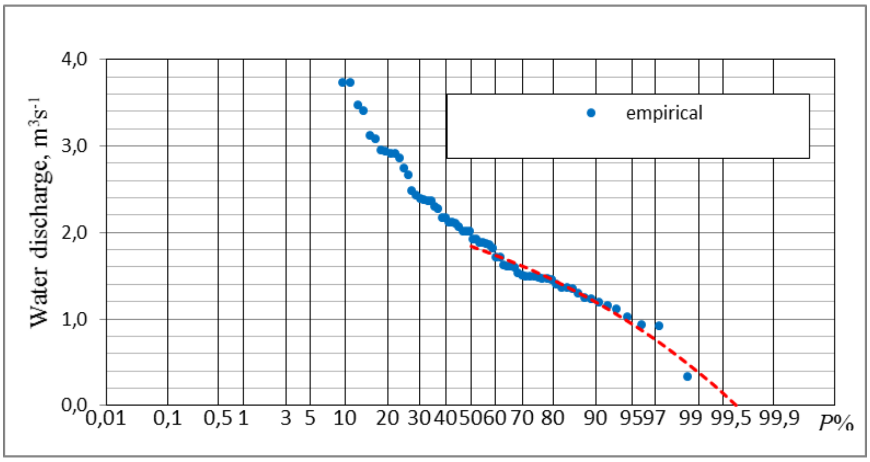


Figure 9. Truncated curve of the minimum winter monthly water discharges of Kurmukchay River at Ilisu station: $\mu = 1.97$, $\lambda = 0.34$.

4. Conclusion

Given the prevailing arid climate, the limited water resources of Azerbaijan, in particular the Greater Caucasus, are widely used for irrigation. However, in contrast to the minimum summer-autumn river flow, the minimum water discharge of the studied rivers is characterized by a natural regime in winter season. As in other mountainous regions of the globe, in the Greater Caucasus, the conditions of formation and value of the minimum winter flow of rivers are influenced by the altitude position of the river catchment. Zones of formation, transit and use of river waters are clearly distinguished in all river basins, with exception of a few small catchments. During the periods of minimum winter flow, the zone of transit and use of the flow is essentially a single zone - the flow transit zone. Synchronism is weakly expressed in long-term fluctuations in the minimum flow; therefore, in most cases, it is impossible to find a reliable analog river for extending short series. The minimum flow of rivers has been significantly influenced by climate change in recent decades. For this reason, the stationarity and homogeneity of almost all studied series are disrupted, and these series have a significant upward trend. As a result of changes in conditions for formation of the minimum winter flow, the empirical probability curves of the minimum winter monthly water discharges have a complex shape, and it is very difficult to select an analytical distribution curve for them. Given this circumstance, truncated probability curves were used to calculate the probability values of the flow and the Weibull two-parameter distribution curve was used as the analytical curve. At the next stage of research, the parameters of this distribution will be summarized, and a calculation scheme will be developed that is suitable for determining the minimum winter flow of ungauged rivers.

References

Abi Zeid, I., Bobée, B. (1999). The stochastic modeling of low-flows: a literature review. *Revue des Sciences de l'Eau*, 12(3), 459-484.

Alderlieste, M.A., Van Lanen, H.A. & Wanders, N. (2014). Future low flows and hydrological drought: how certain are these for Europe? In *Hydrology in a Changing World*, *363*, 60-65.

Alieva, I.S. (2020). Spatial and temporal patterns of surface and underground runoff of the rivers of the Greater Caucasus. *Journal of Hydrometeorology and Ecology, 58*, 41-48. DOI: 10.33933/2074-2762-2020-58-41-48 (In Russian).

Bates, B.C., Kundzewicz, Z.W., Wu, S. & Palutikof, J.P. (2008). *Climate Change and Water*. Intergovernmental Panel on Climate Change Secretariat, 228 (In Russian).

Bolgov, M.V., Filippova, I.A., Osipova, N.V., Korobkina, E.A. & Trubetskova, M.D. (2018). Modern features of the Volga Basin Rivers' hydrological regime. *Voprosy geografiyi. Collection 145 Hydrological changes*, 206-218 (In Russian).

David, A. (2006). *Water-Resources Engineering* (second edition). USA, New Jersey: Pearson Education International, 572.

Determination of the basic calculated hydrological characteristics (2004). SP 33-101-2003. Moscow: Stroyizdat, 72 (In Russian). DOI:10.1623/hysj.53.3.503

Dzhamalov, R.G., Frolova, N.L., Kireeva, M.B. & Telegina, A.A. (2013). Changes in surface and underground flow of rivers in Russia and their regimes in a non-stationary climate. *Bulletin of the RFBR, 6*(78), 78-87 (In Russian).

Ecological flows in the implementation of the Water Framework Directive. (2015). European Commission Guidance Document. No 31.

Geology of Azerbaijan. (2008) Volume VIII. Hydrogeology and engineering geology. Baku, Nafta-Press, 380 (In Russian).

Gustard, A., Demuth, S. (2009). Manual on low-flow estimation and prediction. Operational hydrology report, No. 50 WMO-No. 1029. *World Meteorological Organization, Geneva, Switzerland*, *136*.

Imanov, F.A. (2000). Minimum Flow of the Rivers of the Caucasus. Baku: Nafta-Press, 298 (In Russian).

Imanov, F.A. (2016). Water resources and their use in the transboundary Kura River basin. St. Petersburg: Svoe izdatel'stvo, 164 (In Russian).

Imanov, F. A., Hasanova, N. I., & Agayev, Z. B. (2018). Long-term fluctuations of river flow in Azerbaijan. *Voprosy geografii*, 145, 277-284.

Imanov, F.A., Sikan, A.V. (2022). Analysis of climate change in the territory of Azerbaijan. Journal of Hydrometeorology and Ecology, (69), 607-619. Doi:10.33933/2713-3001-2022-69-607-619 (In Russian).

Karaushev, A.V. (1987). *Methodological foundations for assessing and regulating the anthropogenic impact on surface water quality*. Leningrad, Gidrometeoizdat Publ., 288 (In Russian).

Listengarten, V.A., Krasilnikov, L.A. (1977). Natural water resources of groundwater in the plains and lowlands of the Azerbaijan SSR. *Water resources*, *2*, 79-88 (In Russian).

Mahmudov, R.N. (2018). *Modern climate changes and dangerous hydrometeorological phenomena*. Baku: NAA, 232 (In Azerbaijani).

McMahon, T.A., Diaz Arenas, A. (1984). *Methods of Calculation of Low Streamflow.* Gidrometeoizdat, 127 (In Russian).

Rustamov, S.G., Kashgai, R.M. (1978). *Water Balance of the Azerbaijan SSR*. Baku, Elm, 110 (In Russian).

Sharma, T.C., Panu, U.S. (2008). Drought analysis of monthly hydrological sequences: a case study of Canadian rivers. *Hydrological Sciences Journal, 53*(3), 503-518.

Shiklomanov, I.A. (1989). The impact of economic activities on river flow. Leningrad, *Gidrometeoizdat*, 330 (In Russian).

Shiklomanov, I.A. (2008). *Water resources of Russia and their use.* State Hydrological Institute, St. Petersburg, 600.
Sikan, A.V. (2007). *Methods for statistical processing of hydrometeorological information*. RSHU, 279 (In Russian).
Sikan, A.V. (2020). *Probability distributions in hydrology*. St. Petersburg: RGGMU, 285 (In Russian).
Sikan, A.V., Baiduk, O.V. (2015). The impact of climate change on rivers water regime over southern and eastern part of the Republic of Belarus. *Uchenye zapiski RGGMU*, 40, 61-70 (In Russian).
Smakhtin, V. (2001). Low flow hydrology: a reviev. *Journal of Hydrology*, *240*, 147-186. DOİ: 10.1016/S0022-1694 (00) 00340-1.
Sokolov, B.L., Sarkisyan, V.O. (1981). *Underground feeding of Mountain Rivers*. Leningrad, Gidrometeoizdat Publication, 240 (In Russian).
Sun, C., Zhou, X. (2020). Characterizing hydrological drought and water scarcity changes in the future: A case study in the Jinghe River Basin of China. *Water*, *12*(6), 1605. https://doi.org/10.3390/w12061605.
Svensson, C., Kundzewicz, Z.W. & Maurer, T. (2004). *Trends in flood and low flow hydrological time series*. World Meteorological Organization-Publications-WMO TD, 1241, 26.
Tallaksen, L.M., Van Lanen, H.A.J. (2004). *Hydrological drought: processes and estimation methods for streamflow and groundwater*. *Developments in Water Science,* 48. Elsevier Science B.V., Amsterdam.
Tharme, R.E. (2003). A global perspective on environmental flow assessment: emerging trends in the development and application of environmental flow methodologies for rivers. *River Research and Applications*, *19*(5-6), 397-441.
Verdiyev, R.H. (2002). *Water resources of the rivers of the Eastern Caucasus in the context of climate change*. Baku, 224 (In Russian).
Viessman, W., Lewis, G.L., Knapp, J.W. & Harbaugh, T.E. (1989). *Introduction to hydrology*. New York-London, 467.
WMO, G. (1994). Guide to hydrological practices: data aquisition and processing, analysis, forecasting and other applications.
Zadorozhnayam, R.G. (1972). Formation and calculation of the components of the minimum runoff of the tributary of the Araks River. *Proceedings of Ukr. NIGMI, 116*, 119-127 (In Russian).