CHANGES IN THE RIVER FLOW OF WESTERN GEORGIA IN THE CONTEXT OF GLOBAL CLIMATE WARMING

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Abstract. *An analysis of long-term stationary observation data revealed that, by decade, the annual discharge of rivers in western Georgia exhibited only minor fluctuations up to 1980. Over the following two decades (1981–2000), discharge increased, particularly in glacier-fed rivers. Looking ahead, changes in air temperature and atmospheric precipitation are expected to cause a decline in river discharge, primarily due to glacier retreat. Along the coastal zone, increased evaporation will condense into torrential rains, heightening the risk of hazardous events. Further east, rising temperatures and decreasing precipitation will reduce river discharge. These findings should be taken into account in the design of various facilities, as well as in planning measures for conserving and replenishing water resources. In the coastal zone, preventive actions must be developed to mitigate the negative impacts of hazardous events.*

Key words: *formative factors, glacial waters, mean annual discharge*

Water is a natural resource of paramount importance for sustaining human, animal, and plant life, as well as for national economic development, since no sector of the economy can function without it. The water resources within Georgia's territory constitute a national asset protected by the state, which entails the rational use of all water bodies – seas, lakes, rivers, groundwater, springs, glaciers, and others – prioritizing the population's need for clean, fresh drinking water.

Unlike other water bodies, rivers provide a constant, renewable supply accessible to all. Consequently, settlements of all sizes have historically developed along riverbanks. River water is used for municipal and industrial supply, electricity generation, and crop irrigation.

In terms of hydropower potential per square kilometer, Georgia ranks among the world's leading countries. The Enguri, Rioni, Tskhenistskali, and Kodori rivers, among others, are distinguished by their high energy capacity. At present, about 60 hydroelectric power plants operate in Georgia, producing a total of 10 billion kWh annually. In total, the country could operate up to 300 medium and small hydroelectric plants, with a potential output of 40 billion kWh [1].

Given the exceptional importance of river water resources, accurate measurement and study of river discharge are essential for the efficient use of water resources and the reliable operation of hydraulic structures.

Ongoing global climate warming is transforming river runoff and altering its intra-annual distribution. In winter, when temperatures remain above freezing, precipitation falls as rain rather than snow, leading to higher river discharge instead of low-flow conditions. This change can improve water use conditions. However, increased discharge also poses environmental challenges: in summer, elevated temperatures accelerate evaporation, and the resulting condensation often manifests as torrential rain, triggering major floods, flash floods, and landslides, thereby increasing the risk of severe adverse impacts.

In recent decades, in addition to climate warming, human economic activities have had a significant impact on changes in river discharge, disrupting the natural conditions of river basins. In this regard, the effect on forest cover is noteworthy: logging alters the forest's regulatory capacity. Due to the high infiltration capacity of forest soils, the runoff volume during high-flow periods decreases, while that during low-flow periods increases. The greater the forest cover in a river basin, the more regulated the river discharge. In western Georgia, the degree of forest cover in river basins varies considerably, ranging from 95% to 40%. The forest cover of individual river basins, along with other hydrographic and hypsometric characteristics, is provided in [2].

Modern climate warming exerts a particularly strong influence on glaciers located in the headwaters of rivers along the Caucasus Range. According to the existing [3] catalog, glaciers with a total area of 466 km² were recorded within the basins of six rivers in western Georgia. In [4], the distribution of these glaciers was studied for three time periods based on satellite remote sensing data (Table 1), revealing that, by 2020, the total glacier area in the river basins had decreased by 191 km², or 41%. The greatest reduction (37%) occurred in the glaciers of the Enguri River basin.

Table 1. Glacier Areas (sq. km) in the River Basins of Western Georgia

River / Periods	Bzipi	Kelasuri	Kodori	Enguri	Khobi	Rioni	Total
Catalog, 1975	8,0	1,2	64,3	321	0,2	70,7	466
2010	4,7	0,9	50,0	229	0,2	57,2	384
2015	3,1	0,7	41,7	227	0,1	45,8	319
2020	1,7	0,6	33,3	197	0,1	41,2	275

Thus, as a result of both climate warming and anthropogenic impacts, the natural conditions previously existing in river basins have changed, and, accordingly, so has river discharge. To study this change, stationary observation data on rivers, published in reference works up to 1981 [5–8], were analyzed. It should be noted that, after 1981, observation data on river discharge in Georgia were no longer published, and until recent years, obtaining such data was prohibitively expensive for financially constrained researchers, making it impossible to conduct appropriate studies. This situation changed with the adoption of the *Law of Georgia on Water* [9], which made it possible to access observation data for 10 active gauging stations [10].

For the purposes of the study, an additional 11 previously operational stations with long-term observation records were selected. To reconstruct missing observation periods, analogous rivers were identified through correlation analysis of concurrent observation data. In cases of strong correlations, missing data were restored through graphical interpolation. As a result, a database was compiled containing annual mean discharge records for 21 gauging stations, covering 56–86 years. Using appropriate software [11], statistical analysis yielded long-term mean annual discharge values, as well as mean values for individual decades (Table 2).

The analysis shows that, for rivers fed in part by glacial waters, changes in discharge prior to 1980 were not characterized by significant fluctuations. Thereafter, over the next two decades, a marked increase in discharge occurred, associated with active glacier melting. Since 2000, the absence of observation data on rivers has prevented comparison of river discharge trends with the glacier changes presented in Table 1.

In [12], Georgian specialists used the international RCP4.5 scenario to prepare forecasts indicating that, in western Georgia, the mean annual temperature in 2041–2070 will rise by 1.8°C to 3.0°C compared to 1971–2000, and in 2071–2100 will increase by an additional 0.4°C to 1.7°C.

Atmospheric precipitation is projected to decrease during both forecast periods. The highest precipitation totals (> 2,800 mm) will occur along the Black Sea coastal zone of Adjara; to the east of this zone, annual precipitation decreases with increasing elevation above sea level. In 2041–2070, the most significant decrease in precipitation is expected in Imereti (18% in Sachkhere). In other regions, the reduction will range between 3.6% and 15%. An increase in precipitation of 8–10% is projected only for Poti and Zugdidi. During 1971–2000, the highest precipitation was recorded in Batumi (2,481 mm); in 2041–2070, it is projected to be 2,363 mm, and in 2070–2100, 2,322 mm.

Against the background of global climate warming, under such forecasts for the main formative factors of river discharge, rising temperatures are expected to reduce and ultimately eliminate glaciers in river headwaters, which will significantly diminish summer river flow. This will have a highly negative impact on power generation at hydropower plants (HPPs) located along these rivers. In this regard, the Enguri River is of particular concern, as it hosts the Enguri HPP – the largest-capacity plant in Georgia and the entire South Caucasus, with a high-arch dam. A risk of reduced water resources is also anticipated for the Rioni River and its tributaries, where both operational and planned HPPs are located.

Table 2. Multiannual and Decadal River Mean Discharges (m³/s) in Western Georgia

River Point	Number of Years	Multi-Year Aver	1921-1930	1931-1940	1941-1950	1951-1960	1961-1970	1971-1980	1981-1990	1991-2000	2011-2020
Bzipi – Jirkva	60	97,6	–	96,9	103	96,4	95,6	93,2	108	–	–
Kodori – Lata	60	92,2	–	89,6	83,4	91,8	83,4	101	104	–	–
Enguri – Khaishi	86	122	121	111	108	119	109	118	142	131	–
Rioni – Alpana	86	104	105	102	103	94,7	99,5	97,9	107	110	–
Rioni – Namokhvani	86	147	149	133	144	128	143	149	164	159	–
Rioni – Chala-didi	86	429	410	413	388	418	408	403	475	495	–
Kvirila – Sachkhere	84	16,7	–	16,9	17,0	16,1	16,9	18,4	18,5	14,2	16,0
Kvirila – Zestaponi	84	60,0	–	65,9	62,3	58,0	58,5	54,9	66,4	68,8	53,1
Dzirula – Tse-va	84	23,1	–	28,3	28,0	26,5	20,8	27,3	26,4	21,4	23,2
Khanistsqali-Bagdati	61	15,7	–	–	15,2	17,5	14,7	14,1	18,0	14,0	–
Tskhenistsq. Luji	65	23,8	–	22,5	23,5	22,8	20,8	24,8	27,7	23,6	–
Tskhenistsq. Rtskhmeluri	65	67,0	–	67,3	61,0	63,0	60,9	65,8	75,0	68,6	–
Tskhenistsq. Khidi	65	56,9	–	87,1	76,3	72,1	38,4	38,8	48,3	39,9	–
Tekhuri – Na-kalakevi	67	33,7	–	36,1	27,6	30,1	33,5	36,5	38,7	36,6	–
Supsa – Cho-khatauri	60	13,7	–	–	15,0	12,9	12,6	13,8	14,2	13,5	–
Supsa – Khidmagala	60	48,7	–	–	44,0	47,5	45,3	46,7	56,0	48,0	–
Natanebi – Natanebi	59	25,0	–	27,2	21,7	25,8	23,7	23,4	28,6	–	–
Kintrishi – Kokhi	59	13,1	–	14,5	13,2	11,4	11,5	13,8	14,5	–	–
Chorokhi – Erge	61	274	–	304	290	255	253	269	274	–	–
Acharistsqali Khulo	56	8,06	–	–	8,20	8,50	8,50	–	9,60	–	–
Acharistsqali Keda	56	46,3	–	–	44,4	44,3	44,3	42,6	53,9	–	–

For rivers not fed by glacial waters, the decade 1981–1990 was characterized by high discharge, as this period experienced high precipitation across the entire territory. According to the compiled forecasts, however, a decline in precipitation – and correspondingly in river discharge – is expected, especially in the Qvirila River basin. In coastal areas, increased evaporation will result in greater condensation in the form of torrential rains, thereby contributing to the occurrence of hazardous events in the coastal zone, which will also be facilitated by the rising level of the world ocean.

All of the above factors must be considered in the design of projects aimed at the utilization of river water – particularly for energy production – as well as in planning measures for the conservation and replenishment of water resources. In addition, preventive measures must be implemented in coastal zones to mitigate or avert the negative consequences of hazardous events.

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