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The Scale of the Expected Largest Maximum High Water Discharges on the Rivers of Eastern Georgia

Tsisana Basilashvili[1,*], Khatuna Basilashvili[2], Magda Janelidze[2]
[1] Institute of Hydrometeorology, Georgian Technical University, Tbilisi, Georgia
[2] Caucasus University, Tbilisi, Georgia
* Corresponding author: ts.basilashvili@gtu.ge

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Abstract

Based on a 70–100-year empirical series of stationary observations from 27 principal hydrological stations on the rivers of Eastern Georgia up to 2023, the probable maximum discharges of high waters have been estimated for exceedance probabilities of 0.01%, 0.1%, 1%, 2%, 5%, and 10%. These correspond to recurrence intervals of approximately 10,000, 1,000, 100, 60, 20, 10, and 5 years, respectively. The derived data provide a valuable resource for scientific, economic, and engineering applications, and should be utilised by relevant organisations for water management calculations. They are essential for the planning and design of hydraulic, civil, and industrial infrastructure—including roads, bridges, pipelines, and communication facilities—located along rivers and within their coastal zones. Moreover, these data underpin the substantiation of technical and economic parameters of such projects. The application of these findings will contribute significantly to enhancing the safety of populations, infrastructure, and the environment, thereby reducing the risks of structural damage, environmental degradation, and potential casualties associated with high-water events.

Keywords: probabilistic value, repeatability, provision, safety

Introduction

Since the second half of the 20th century, climate warming and increasing anthropogenic pressure on the environment have contributed to the intensification of elemental processes, accompanied by a clear upward trend and the emergence of critical ecological challenges.

The complex mountainous landscape of Georgia—with its diverse climatic, relief, and soil conditions, and numerous deep river valleys—creates a favourable environment for the occurrence of destructive floods. Such events have frequently resulted in the destruction of residential buildings and infrastructure, damage to agricultural land, and significant losses to the land fund. The presented flood photograph serves as documentary evidence of the urgent need for an objective and impartial assessment of flash floods, which is essential for developing recommendations to prevent catastrophic events and mitigate associated damages.

Floods and high-water events in the rivers of Eastern Georgia (fig. 1), along with the damage they have caused, are discussed in previous studies (Basilashvili et al., 2011; Basilashvili et al., 2012), which are based on observational data prior to 1991 and include corresponding estimates of maximum river discharges and their probable values.

More recently, under the conditions of ongoing global warming, Basilashvili (2024) extended this work by incorporating data from 1991–2021, updating the multi-year characteristic parameters of annual maximum flash flood discharges, and providing an appropriate statistical analysis of observational series spanning 70–100 years.

Looking ahead, continued climate warming is expected to further intensify natural hazards such as floods, avalanches, landslides, and erosion, often occurring in conjunction with frequent flooding events. Given the increasing scale of damage and casualties associated with such phenomena, determining the magnitude of expected maximum river discharges and refining their numerical estimates has become essential. These parameters are critical for the effective planning and management of hydroeconomic calculations, and for the development of strategies to mitigate the adverse effects of hydrological disasters.

Figure 1. Gori flooded by flash flood on June 11, 1983

Methods and Materials

To estimate the expected changes in maximum river discharges, probability theory provision curves were applied to determine the scale of anticipated largest flash flood discharges (Ukleba, 1967; Luchsheva, 1976).

This study utilised long-term observational data from 27 hydrological stations in Eastern Georgia. Data prior to 1981 were sourced from published references, including Fundamental Characteristics (1967, 1977, 1978) and the State Water Cadastre (1987). More recent observations, up to 2022, were obtained from the National Environment Agency of Georgia (NEA).

Due to the inherent difficulties in measuring water discharges of mountain rivers during flash flood events, some observational records were incomplete. To address these gaps, correlation analyses of discharge relationships between analogous rivers were conducted, complemented by graphical interpolation methods. This approach enabled the reconstruction of missing data points. Correlation analysis was performed to establish relationships among maximum river discharges, followed by the formation of descending ranks of multi-year data and the determination of their corresponding exceedance probabilities, in accordance with the methodology proposed by Basilashvili (1977), implemented using computer software tools.

As a result of this comprehensive research, a robust database of multi-year (70–100 years) empirical series of annual maximum river flood discharges was compiled. The hydrographic and hypsometric characteristics of the river basins monitored at the 27 hydrological stations are presented in Table 1.

Table 1. The hydrographic and hypsometric characteristics of the river basins at the 27 hydrological stations

№	River - Point	Area of Basin	Length of River	Height of Basin	Woodiness of Basin	Height of Source	Height of Point	Fall of River	Slope of Basin	Slope of River
		F km^2	L km	H m	W %	H_S m	H_P m	H_Δ m	S_B ‰	S_R ‰
1	Mtkvari - Khertvisi	4980	223			2720	1120	1600		
2	Mtkvari - Minadze	8010	265			2720	944	1776		
3	Mtkvari - Borjomi	10500	315			2720	781	1939		
4	Mtkvari - Dzegvi	18000	444			2720	456	2264		
5	Mtkvari - Tbilisi	21100	474			2720	391	2329		
6	Faravani - Khertvisi	2350	73	2120	0	2080	1120	960	91	13.8

7	Potskhovi - Skhvilisi	1730	54	1870	11	1231	969	262		32.2
8	Kvabliani -Mlashe	468	19	1940	38	2540	1162	1378	132	35.0
9	Abastumani - Abastumani	99	10	1830	32	1373	1272	101	360	94.0
10	Borjomula - Borjomi	165	18	1810	65	2400	781	1619	256	50.7
11	Didi Liakhvi - Kekhvi	924	59	2100	25	3032	960	2072	373	38.2
12	Patara Liakhvi - Vanati	422	41	1940	35	2966	1015	1951	373	46.2
13	Ksani – Korinta	461	46	1830	50	2820	909	1911	260	45.0
14	Aragvi - Zhinvali	1900	28	1890	45	3126	718	2408	380	35.5
15	White Aragvi - Fasanauri	335	41	2140	22	3126	1035	2091	362	51.2
16	Black Aragvi - Shesartavi	235	29	2030	27	3392	1070	2322	416	66.4
17	Pshavis Aragvi - Magaroskari	736	38	2060	40	2731	920	1811	452	40.6
18	Yori - Lelovani	484	43	1640	59	2827	1090	1731	262	31.3
19	Alazani - Birkiani	282	9	2200	42	2750	758	1992	469	61.7
20	Alazani - Shakriani	2190	72	1260	61	2750	340	2410	270	26.2
21	Ktsia Khrami - Edikilisa	544	51	2040	0	2422	1516	906	135	18.9
22	Ktsia Khrami - Dagetkhachini	2150	136	1720	17	2422	526	1896	142	14.0
23	Ktsia Khrami - Imiri	3840	171	1510	29	2422	345	2077	147	12.6
24	Ktsia Khrami - Red bridge	8260	196	1530	33	2422	265	2157	179	11.3
25	Algeti - Partskhisi	359	40	1320	50	1900	672	1228	191	23.4
26	Mashavera - Dmanisi	570	25	1660	19	1358	795	623	155	43.0
27	Debeda - Sadakhlo	3790	150	1680	18	480	413	67	174	12.0

Results

To determine the probabilistic values of maximum river discharges, the annual peak discharges from all individual hydro-catchments were arranged in descending order, from largest to smallest. This approach, representing the simplest form of their distribution, demonstrates that a given maximum discharge on a river can occur multiple times during the observation period, corresponding to the number of values exceeding it in the descending sequence.

The integration of values arranged in descending order produces the provision curve, with provision typically expressed as a percentage. According to Luchsheva (1976), the corresponding percentage value for each member of the descending sequence is calculated using the following formula:

$$P\ \% = ((m - 0.3) / (n + 0.4)) \cdot 100,$$

where m represents the sequence number in the descending order of maximum discharges, and n denotes the total number of members in the sequence.

Based on the parameters reported by Basilashvili (2024), the coefficients of variation for the maximum discharges of the rivers under study are notably high ($Cv \geq 0.5$and asymmetry $Cs \geq 2.0$). Therefore, in accordance with Luchsheva (1976), provision curves were constructed using high-asymmetry cells rather than moderate-asymmetry cells to better reflect the statistical characteristics of the data.

Using the ordinates of the provision curves and relevant calculations, the probable values of the largest maximum discharges at different provision levels are presented in Table 2. Each probability value corresponds to a specific recurrence interval, indicating the average number of years in which the corresponding maximum discharge is expected to occur at least once.

Table 2. Probable values of the largest maximum discharges (Q m3/s) of the rivers of Eastern Georgia with different provision (%) and frequency (years)

№	Provision (%)	0,01	0,1	1	2	5	10	20
	Recurrence (years)	10000	1000	100	80	20	10	5
	Characterization of waterfalls	Disastrous		Very strong	Strong	High	Moderate	Average
1	Mtkvari - Khertvisi	930	770	610	560	495	445	390
2	Mtkvari - Minadze	1900	1430	1040	920	770	660	540
3	Mtkvari - Borjomi	2280	1780	1350	1220	1050	920	780
4	Mtkvari - Dzegvi	3880	2960	2180	1950	1700	1440	1200
5	Mtkvari - Tbilisi	4080	3220	2460	2220	1940	1700	1450
6	Faravani - Khertvisi	330	255	198	179	154	135	114
7	Potskhovi - Skhvilisi	960	700	490	425	350	298	240

8	Kvabliani -Mlashe	450	328	230	204	168	142	115
9	Abastumani - Abastumani	92	64	42	36	28	24	19
10	Borjomula - Borjomi	187	100	64	56	47	43	37
11	Didi Liakhvi - Kekhvi	550	432	330	300	260	228	192
12	Patara Liakhvi - Vanati	484	300	173	142	105	80	60
13	Ksani – Korinta	523	376	245	210	158	136	105
14	Aragvi - Zhinvali	1005	960	840	780	660	530	360
15	White Aragvi - Fasanauri	290	235	178	158	133	110	76
16	Black Aragvi - Shesartavi	600	420	260	211	155	114	60
17	Pshavi Aragvi - Magaroskari	1450	1100	685	540	390	270	160
18	Yori - Lelovani	556	522	470	430	400	350	250
19	Alazani - Birkiani	820	560	340	280	205	150	90
20	Alazani - Shakriani	1560	1100	890	770	623	504	360
21	Ktsia Khrami - Edikilisa	200	160	126	117	104	98	92
22	Ktsia Khrami - Dagetkhachini	790	594	420	360	285	230	155
23	Ktsia Khrami - Imiri	1200	840	580	490	388	306	280
24	Ktsia Khrami - Red bridge	2660	1860	1240	1030	790	600	420
25	Algeti - Partskhisi	490	360	240	203	256	123	84
26	Mashavera - Dmanisi	790	540	335	274	200	147	88
27	Debeda - Sadakhlo	880	744	600	555	485	426	346

It should be emphasised that any probable value of maximum discharge derived at a given provision level provides critical information for assessing the safety of structures and other engineering measures under specific hydrological conditions. Such estimates are therefore essential for informed decision-making in hydraulic engineering and water resource management.

Discussions

Probable values of the largest maximum river discharges, based on observational data available before 1981 and 1991, have been published in earlier studies (Water Resources, 1988; Basilashvili, 2017). A comparison of these historical estimates with the values presented in Table 2, derived from data up to 2022, reveals a general reduction in the largest maximum discharges of flash floods across nearly all hydro-catchments in Eastern Georgia. This reduction is particularly pronounced for high-recurrence discharge events.

This trend is likely attributable to changes in the precipitation regime in Northeastern Georgia, notably a reduction in snow cover. In mountainous terrain, snowmelt during melting periods typically contributes meltwater directly to river channels, and under conditions of heavy rainfall, this process can trigger substantial floods. However, climate warming has extended the warm season, and liquid precipitation is increasingly lost to evaporation and infiltration into dry soils within river basins due to higher air temperatures. Consequently, the magnitude of flood discharges has diminished. Furthermore, in certain river basins, the area of existing glaciers has already decreased, leading to a corresponding decline in glacial runoff, which further contributes to the observed reduction in maximum flood discharges.

Conclusion

Thus, based on stationary observation data up to 2022 from 27 hydro-catchments of rivers in Eastern Georgia, the projected development of the largest maximum flood discharges has been analysed. Through rigorous statistical analysis of a 70–100-year empirical dataset of river discharges, updated and refined probabilistic estimates of the largest maximum flood discharges have been obtained for various provision levels (0.01%, 0.1%, 1%, 2%, 5%, 10%, 20%), corresponding to specific recurrence intervals of 10,000, 1,000, 100, 80, 20, 10, and 5 years, respectively.

These results are of critical importance for hydroeconomic planning, as they provide the basis for justifying the technical and economic parameters of hydraulic structures and other measures planned along rivers and within their floodplains. Moreover, such data support informed decision-making in water resource management and help mitigate potential damages from future flood events.

Competing interests

The authors declare that they have no competing interests.

Authors' contribution

T.B. and K.B. performed the analytic calculations. M.J. took the lead in writing the manuscript. All authors provided critical feedback and helped shape the research, analysis and manuscript.

ORCID iD

Tsisana Basilashvili https://orcid.org/0000-0002-9976-4670

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