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RECOMMENDATIONS OF MITIGATING DAMAGES CAUSED BY RIVER FLOODING IN GEORGIA

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Summary: *In the recent years, with respect to climate change, in the mountainous river gorges, floods become more frequent and they bear serious hazard and damage as well has casualties. The historical informational and literary sources regarding flooding have been studied. For the water management calculations in order to present the water-related disasters of main rivers of Georgia, the maximum discharge parameters are specified.*
To mitigate the hazards of floods a complex is proposed, in particular: purification and deepening of river beds, reinforcing and complete construction of river bank protecting edifices, laying spillway canals, terracing of slopes, enlargement of forest cover. The main way of water bodies safety is the forecasting of river runoff, which are necessary for the rational use of water resources, too. With the use of the multifactorial model, we obtained the forecast of floods and flooding in advance and accuracy level. The timely awareness about forthcoming high river runoff will give an opportunity to make respective preventive measures and safe human lives, as well as avoid damages.

Key Words: *Disaster, maximum water discharge, parameters, reservoir.*

Introduction. In connection with global climate change on the Earth the number of catastrophic floods has been enormously increased and caused great damages. This problem is especially urgent for Georgia where high waters and continuous floods are preconditioned by the landscape-climatic state. 60-80% of river annual discharge flows during floods. It is formed by simultaneous participation of the melting waters of seasonal snow, rain, eternal snow and glaciers in different ratio. In highland basins flood lasts 5-6 months (from March till August), and in lowland where eternal snow and glaciers are absent it covers March-June months [1].

I ndeed floods are the reason of enormous damages but it is fact that on Georgian rivers there has been built 51 reservoirs, due to the hydro power stations, also irrigate and water supply systems are functioning [2]. The annual restore and operation of reservoirs depend especially on the river flood discharges. So floods are the reason as of damages as of great benefit, because at the expense of flood water storages electricity is generated, crop is growing and population and industrial objects water supply is secured.

Except of spring floods on Georgian rivers take place also high waters at any season of year that in rainy periods take catastrophic character. Besides because of the growth of anthropogenic impact (elimination of lakes and growth) the high water increases, that caused irreversible destruction to the separate regions, population, industry, nature and ecological state. Especially during last 20 years in Georgia there were repeated large-scaled catastrophes in several times, that damaged economy significantly (1.5 billion GEL), especially were damaged bridges, rail and high ways, communications, canals, seeding, animals and also humans have been lost.

Method. Within this research various information has been studied, as well stationary observation and expedition materials about phenomena itself also on caused damages were investigated. The formation of Georgian river discharge has been realized in different hydrometeorological and physical-geographical conditions. The water regime of each one is characterized by individuality and thus they aren’t identical. For this reasons for each river the different forecasting methodic is needed.

The general physical base of modern hydrological forecasting models is the solution of water balance equation for forecasting period, including many different factors. But in our case under complex mountain relief conditions because of the lack of required information the identification of those regulations that are essential for applying mentioned model isn’t available. So we elaborated multi factorial statistical prognostic model [3] (Basilashvili Ts. 2006), that fully discuss those hydrometeorological factors on which the information exists during operational forecasting: atmospheric precipitation (R mm), air temperature (θ^0C), snow water-content (W mm) and river water discharge (Q m^3/sec). For this reason firstly using definite mathematical criteria less efficient and duplicated factors have been subtracted. From the rest using multi sieve method the optimal prognostic model has been deduced [4]. To calculate all possible variants of prognostic relationships the multi factor dependence was directly and indirectly expanded, when two equation systems have been calculated by gradual adding of separate predictors (X_1, X_2, X_3 … , X_m):

$$
\begin{gathered}
Y' = a'_0 + a'_1 X_1; \\
Y'' = a''_0 + a''_1 X_1 + a''_2 X_2; \\
Y''' = a'''_0 + a'''_1 X_1 + a'''_2 X_2 + a'''_3 X_3; \\
\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \\
Y^{(m)} = a_0^{(m)} + a_1^{(m)} X_1 + a_2^{(m)} X_2 + a_3^{(m)} X_3 + \ldots + a_m^{(m)} X_m
\end{gathered}
\tag{1}
$$

$$
\begin{gathered}
Z' = b'_0 + b'_1 X_m; \\
Z'' = b''_0 + b''_1 X_m + b''_2 X_{m-1}; \\
Z''' = b'''_0 + b'''_1 X_m + b'''_2 X_{m-1} + b'''_3 X_{m-2}; \\
\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \\
Z^{(m)} = b_0^{(m)} + b_1^{(m)} X_m + b_2^{(m)} X_{m-1} + b_3^{(m)} X_{m-2} + \ldots + b_m^{(m)} X_1
\end{gathered}
\tag{2}
$$

Such method is realized by special soft [5], using them the prognostic methods have been elaborated for inflow water discharges in main reservoirs of Georgia for flooding, vegetation periods, quarters, months, decades, daily and flooding maximal discharges [6].

Discussion. To eliminate damages and increase safety it is essential to assess past flood- high waters. But unfortunately during Soviet period the information on great damages and human losses haven't been disseminated. It is remarkable that in the earliest record on floods in Georgia dated by VIII Century great number of losses is fixed. It happened on 735 when invader Murvan the Deaf's 3500 fighters with their horses were lost in river Tskhenistskali flood. Thus after this river was called Tskhenistskali (Horse Water).
Catastrophic high waters are frequent on river Rioni within Kolkheti lowland, where high intensive precipitations are common. On October 25, 1922 on river Rioni passed greatest catastrophic flood, which's extreme water discharge (1470m^3/sec) in river basin upper part (vill. Alphana) was regarded as the greatest. In Rioni lower part on April 2 1982 there has been happened greatest flood with maximal discharge (6000 m^3/sec). River Rioni water discharge on February 1, 1987 while high water was 5000 m^3/sec, that was strengthened by 1600 m^3/sec water from Vartsikhe reservoir emptying that was resulted in break of right bank dike and surrounding settlements were flooded. Material losses amounted in 500mln GEL [7].

Catastrophic high waters are frequent especially in Black Sea rivers. Annual precipitations in Adjara reach 2000-3000mm. Two days precipitation sum is 200-350mm. In river Chorokhi near village Erge maximal water discharge (3840m^3/sec) was passed on May 8,1942. Adjara River levels rose up to 4-5m and water flow velocity was up to 5m/sec. Sudden flood on August 31,1979 broke buildings, bridges,roads,gardens [8].
The investigation of last year floods revealed the fact that they aren't decayed but strengthened. The 2005 flood was distinguished, were resulted in catastrophic floods that covered country's many regions. The damage was enormous (Basilashvili Ts. 2008). It is remarkable that in Georgia except snow and rain high waters are caused also by accumulated water discharges resulted from snow slides and ice encumbering. Besides on Georgian rivers it happen ice, stone-avalanches and landslide encumbers, resulted in formation of lakes [9].

Floods are observed every year but they aren't always destructive. They are catastrophic if intensive snow melting coincides with heavy rains, when river basin can't fit water from catchments area, flows over banks and floods surrounding territories. For example on river Mtkvari during observation 76 year period the flood passed only 30 times which's maximal discharge exceeds its mean value. The exceptional flood was on 1968 when in river Mtkvari bank protecting constructions, roads, bridges were destroyed, railroad and vehicle traffic were broken. Mtkvari highest water peak passed in city of Tbilisi with 2450 m^3/sec water discharge that exceeded river basin those capacity -1800 m^3/sec, calculated for last year maximum on 650 m^3/sec or by 36%. In result water overflowed and flooded surrounded territory.

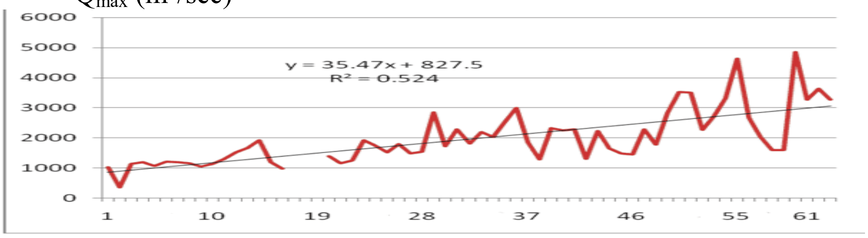
To avoid such situations it is necessary to specify river features especially maximal runoff characteristics, considering new data. Thus firstly river runoffs and their maximal discharge norms, extreme and probable values with 10%, 5%, 1%, and 0.1% support and starting from 10 till 1000 year repeatability have been specified [10] (Table 1). This data are essential for projecting organizations in water industry calculations for building safety.

Table 1. Average Annual Water Discharge of the Rivers of Georgia and Maximum Discharge of Flooding Period (Q m^3/sec)

River-Point	Area of basin km^2	Annual Q m^3/sec	Q_{max} (m^3/sec)			Provision (%)			
			Ave-rage	Maxi-mum	Mini-mum	0.1	1	5	10
						Frequency, year			
						1000	100	20	10
Enguri-Khaishi	2780	118	534	1440	250	2220	1360	930	770
Rioni-Alpana	2830	103	467	825	276	1270	900	690	615
Kvirila-Zestaphoni	2490	60.7	395	1030	140	1700	1070	721	605
Khanistskali-Bagdati	655	15.9	86.6	209	27.1	484	277	178	146
Mtkvari-Tbilisi	21100	203	1152	2450	448	3500	2300	1760	1580
Didi Liakhvi-Kekhvi	924	27.0	136	330	42.2	1200	470	200	134
Ksani-Korinta	461	9.39	64.3	262	16.9	560	293	165	124
Aragvi-Jhinvali	1900	45.1	243	660	67.0	1000	700	500	420
P.Aragvi-Magaroskari	736	19.3	118	338	50.1	530	340	245	200
Tetri Aragvi-Pasanauri	335	12.1	61.1	173	24.8	324	200	130	80
Shavi Aragvi-Shesartavi	235	7.76	47.1	156	21.6	266	160	104	85
Alazani-Birkiani	282	13.9	75.4	365	30.0	1000	350	170	122
Alazani-Shaqriani	2190	43.4	318	1160	94.3	1730	1080	700	550

Multiyear change dynamics analysis of floods revealed maximal discharges growth tendency in Western Georgia on the Caucasus south slopes rivers (Bzipi, Kodori, Enguri, Rioni, Kvirila), and on south-western and eastern Georgian rivers they reduced. During last years the growth of flood maximal discharge is caused basically by global climate change, but also in past years forests were intensively felt down, they deter water surface runoff and reduce its maximal peaks. Besides river basins aren't cleaned that reduces its water discharge ability and causes environment flooding [11]. On fig. 1 is presented maximal discharges dynamics.

a) Q_{max} (m^3/sec)



b) Q_{max} (m^3/sec)

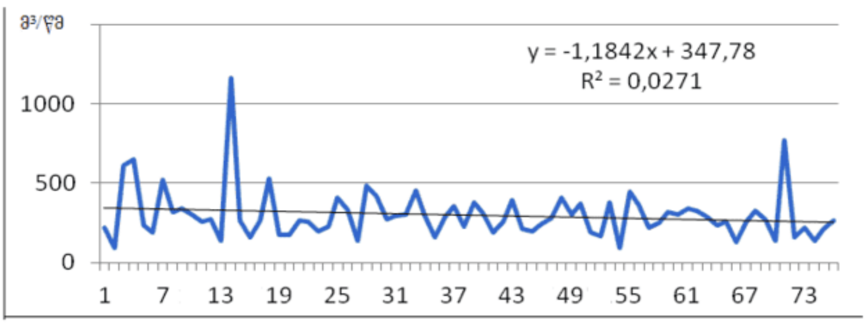


Fig. 1. The multiyear variation dynamics of river water maximal discharges in river a) - Rioni – Saqochakidze (1928 – 1990) and b) - Alazani – Shaqriani (1933 – 2010).

For the passing flood smoothly the slopes have to be terraced, and woodland has to be renewed and widened. Also reservoirs significantly reduce flood hazard, which accumulate a great amount of flowing water and provide water resources conservation: for electricity generation, water supply and melioration. Reservoirs are also base for enlargement of sports and fitness and tourist- recreation zones. Using reservoirs energetic problems in mountain regions became possible to resolve, deforestation process will be decelerated, populations social-economical state will be improved. Thus in mountainous river conditions it will be useful to construct small size reservoirs, that will be the most safe and efficient facility [12].

Academician Givi Svanidze indicated on the necessity of reservoir construction in Georgia: “The reservoirs net have to be widening to renew water resources that are the most safety and efficient means” [13]. Together with construction of reservoir it is necessary to draw up its emergency emptying schedule based on the exact hydrological calculations in the way that in flood it emptied ahead of peak reaching step by step no simultaneously, that at its end, can caused flood strengthening. In future reservoir net would be enlarged. Their construction needs significant expenditures but mountainous small rivers upwelling may be the reason of more losses. Reservoirs water resources may multiply be used to improve state economy.

For present because new reservoirs are unconstructed in Georgia and also forest recover in short period of time is impossible, then for the mitigation of flooding hazard and safety of flood catastrophes the following activities are recommended: river basins to be cleaned and deepened after flooding, picked stones may be used to strengthen and rebuild bank protecting constructions; tunnel in the mountain bottom spillways; identify flooding margins, where settlements, building and industry would be prohibited.

For flooding safety most appropriate is to elaborate flood long-term and high water short-term forecasting methods that are essential also for water resources conservation and reservoir exploitation. The forecasting development can’t avoid event but makes possible to mitigate its negative impact.

Long-term operative forecasts of flood maximal discharges are generated in March, when the observation data of passed winter period have been known, and maximal discharges will pass after 1-3 months (in April-June) in that extreme situation when snow intense melting coincides with rains. In this period the impact of existing factors on the formation of maximal peak is too significant, but its consideration in prognostic computation is really impossible, because of lack of corresponding numerical prognosis.

The forecasting methods were formed using statistical model [4], where the predictors selection was carried out using multistep exclusion rule, and the equation is worked out the multifactor equation system was directly (1) and indirectly (2) expanded by corresponding assessment criteria. Using such method it is possible to reduce prognostic information, increase operability and accuracy. In the result of research for 17 industrial hydro section of Georgia the prognostic equation of maximal discharges (Q m^3/sec) have been obtained considering following factors: atmospheric precipitations (H mm), air mean temperature (θ^0 C), water-content of snow cover (W mm) and river water discharge of last period (Q m^3/sec) [6]. Gradual adding of those factors makes possible to precise prognosis step by step. The forecasting results are presented in table 2.

Table 2. Examples of river maximal discharges (Q_{max} m^3/sec) long-term and high water (Q_m m^3/sec) short-term forecasts with their stepwise accuracy

Prognostic equation	**Assessment criteria**		
	S/σ	**P%**	**r**
River Mtkvari-city of Tbilisi			
Q_{max}=6.16H_{XII-II}+551	0.73	62	0.70
Q_{max}=5.65H_{XII-II}-57.7θ_{III}+745	0.68	66	0.75
Q_{max}=4.76H_{XII-II}-84.67θ_{III}+2.21Q_{III}+538	0.67	70	0.76
Q_{max}=2.60H_{XII-II}-1177θ_{III}+2.78Q_{III}0.63W_{III}+752	0.64	72	0.80
River Rioni-village Namokhvani			
Q_m=0.71Q_b+269	0.65	75	0.76
Q_m=0.73Q_b+0.87θ_{n-1}+233	0.63	77	0.77
Q_m=0.72Q_b-9.1 $\bar{\theta}_{n-1}$-5.72 θ_{n-1}+249	0.62	79	0.78
Q_m=.73Q_b+14.0 $\bar{\theta}_{n-1}$13.8 θ_{n-1}+12.3H_b+296	0.61	80	0.79
Q_m=0.71Q_b+7.5 $\bar{\theta}_{n-1}$-9.2 θ_{n-1}+13.9H_b+1.7H_{n-1}+283	0.60	82	0.80

Marks: S/σ is the ratio of prognosis mean square deviation (S) with mean square deviation of prognostic element (σ); P% - prognosis justification; r-correlation factor between actual and prognostic values.
In this prognosis (1-3 month beforehand) winter precipitation sum ($H_{XII-II-mm}$) and March month data: air mean temperature (θ_{III} °C), river water expenditure (Q_{III} m^3/sec) and snow water content (W_{III} mm) are used. For short-term forecast (24 hr. beforehand) high water pre-day (b) and passed maximal discharge pre-day (n-1) data; for air temperature as its mean daily ($\bar{\theta}$ °C) also its maximal (θ °C) values have been taken.

Conclusion. The received prognosis give possibilities to conduct all preventable measures in case of expected high peaks, to secure all objects and avoid damages and losses. River water high peak forecast urgently have to be passed to corresponding bodies and organizations, for timely alert population and carry out evacuation and safe tangible property. Besides reservoirs must be emptied to receive water flows in what follows.

In future for the elaboration of perfect prognostic methods except hydrometeorological net it is necessary to use satellite and vertical aerial photograph data. Also it is necessary to create radiolocation and remote sensing net. Scientific analysis of those data makes possible to create prognostic methods of anomaly hydrometeorological processes.

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