IMPACT OF CLIMATIC CHANGE ON RIVER RUNOFF IN GEORGIA

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Against the background of the ongoing global warming on the Earth reaction of climatic system in South Caucasus has turned out to be extremely inhomogeneous. One of the significant results of in homogeneity of climate changes might be varied reaction of river, change of their hydrological regime and water resources of Georgia in whole.

By application of average yearly air temperature in basins, annual total of precipitations on water-collectors and water-balance calculations and statistical-correlation analysis of 40-50-year synchronous rows of average annual river in the dam of the river, empirical-statistical and water-balance models of formation of annual river has been received. On the basis of the models, reaction of river on climatic changes revealed in the basin has been determined; sensitivity) of river on the water collector against ongoing climatic changeshas been evaluated.

INTRODUCTION

Againast the background of the ongoing global warming on the Earth, which based on the world meteorological network data has been evaluated as approximately 0.6 ^{0}C during the XX century, reaction of climatic system in South Caucasus has turned out to be extremely inhomogeneous. In particular, there has been revealed significant century-lasting warming on the territory of East Georgia with maximal evaluations of average annual temperature in separate cases 0.5-0.7^{0}C and moderate falling of temperature in West Georgia with the maximal fall of temperature in its some districts 0.3-0.5^{0}C. Change of total of precipitations duting the 60-year period of observations conducted during 1936-1995 turned out be inhomogeneous as well.

During selection of priority regions and river basins, it is necessary to consider the comparatively strong sensitivity of the runoff of rivers with respect to expected climatic changes, vulnerability of water resources connected to their intensive utilization in different sectors of economy, in particular in agriculture and hydro-energy. In future, we shall consider also socio-economic development of regions and intensification of utilization of water resources. That's why, the given below were selected as priority regions and water basins [2] –**In the West Georgia:**

- The delta of river Rioni (vil. Sakochakidze), where main climatic risks are being observed, caused by surplus precipitations, floods, raise of the sea level, also average runoff of the river in Imereti (vil. Alpana) with risks, linked to surplus precipitations, flash floods and floods.
- Lower Svaneti (Lentekhi region), basin r. Tskhenistskhali (vil. Rtskhmeluri) with main climatic risks, caused by surplus precipitations, flash floods, floods, mudstreams, landslides.

In the East Georgia:

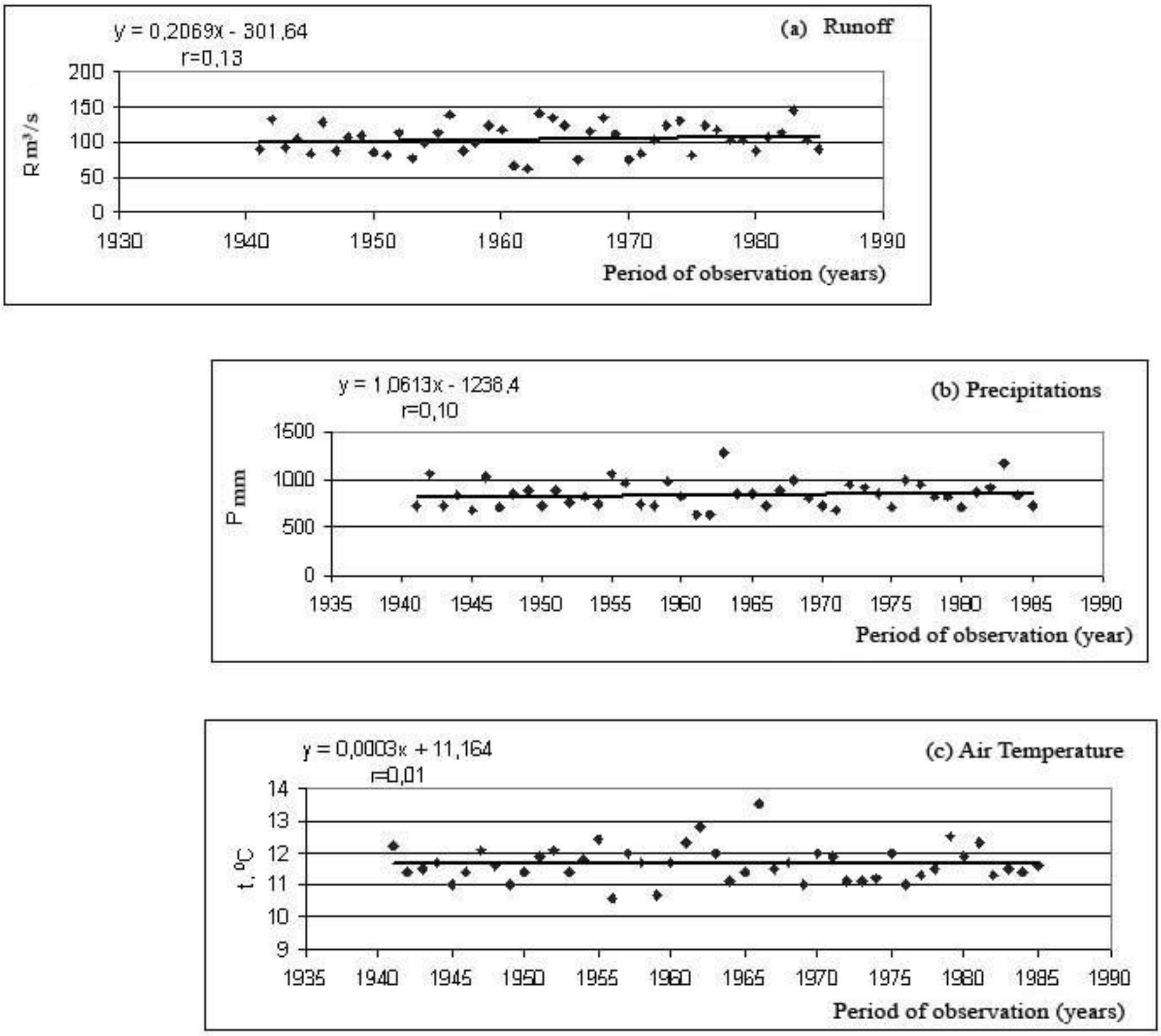
- Dedoplistskharo district, with neighbor basins of river Alazani (mouth of river Agrichai) and Iori (vil. Salahli), with main climatic risks – hail damage, drought, desertification.
- Basin of river Mtkvari (Tbilisi) with risks, caused by flash floods and floods, drought and desertification.

Methodic of investigation included:

- Development of information base of monthly meanings of air temperature, total precipitations and runoff of the rivers based on the observation data of almost 100 meteo-stations and hydro-posts on the territory of Georgia for the period 1905-2006. Restoration of missed elements in empirical rows, also their reduction to the mentioned period was conducted via the method of expansion of the fields of random functions for the compounding orthogonal components (vectors). The method enables control of the accuracy of restoration of the meanings of elements [3].
- Making of statistic-correlation analysis of synchronous age-old rows of average meanings of air temperature and total precipitations on water collector, runoff of rivers in locked cross sections; construction of dynamic trends, representing the linear approximation of fluctuation of elements in time; receipt of empirical-statistical and water-balance models of formation of runoff of rivers [4,5].
- Identification of sensitivity and reaction of runoff against climatic changes in river basins; assessment of possible changes of runoffs in this century on the basis of the approved climatic scenarios of variations of air temperature and total precipitations on water collector.

As an example, below are given results of investigation for the basin of river Alazani – locked cross section (hydro-post) in 2 kilometers from the mouth of river Agrichai.

Picture 1 reflects dynamics of averaged annual meanings of air temperature and total precipitations on water collector, also annual runoff in the locked cross section of the river. Linear trends relevant to equation of regression and coefficients of correlation are also included. As it is shown on picture 1 and table 1 (data), in the conditions of the actually stable air temperature on water collector (warming happens only at 0.01^{0}C) and insignificant growth of total precipitations at 47 mm (6% from the norm) little expansion of river runoff is observed at the magnitude of 9 m^3/s (9% from the norm). The discussed 45-year period is characterized with the indicated speeds of change of parameters. In table 1, these speeds are given for the various intervals of time, including the 100-year period. Though, it would be absolutely wrong if we discussed them as forecasted assessment at the end of this century. Development of climatic system in the XXI century will not be similar to the dynamics of the XX century. Extrapolation of the trendal speed of change of parameters is possible only for the nearest 10-20 years, which gives them the meaning of inertial forecasted assessment. It is assumed that identification of climatic norms, as a rule, is conducted for minimal temporary periods of 20-30 years.



Picture1. Dynamics and relevant trends: (a) of runoff (R), (b) annual total precipitations (P), (c) air temperature (t) in 1941-1985 in the basin of river Alazani

Table 1. Magnitudes of change of speed of runoff, precipitations and temperatures in 1941-1985 in the basin of river Alazani, brought to 1-, 10-, 45-, 100-year periods.

Calculated meanings of runoff R, m^3/s	R_0 m^3/s	Change of runoff $\Delta R=R_2-R_1$ m^3/s				Relative change to norm, $\|\Delta R\|/R_0$ %			
		1	10	45	100	1	10	45	100
R_2 =0,2069x1985+ 301,64=109,06; R_1 =0,2069 x 1941+301,64 =99,95	104,5	0,20	2,02	9,11	20,24	0,19	1,94	8,72	19,37
Calculated meanings of precipitations P, mm	**P_0, mm**	**Change of precipitations $\Delta P=P_2-P_1$ mm**				**Relative change to norm, $\|\Delta P\|/P_0$ %**			
		1	10	45	100	1	10	45	100
P_2 =1,0613x1985 -1238,4=868,28; P_1 =1,0613x1941-1238,4=821,58	844,8	1,04	10,38	46,70	103,78	0,12	1,23	5,53	12,28
Calculated meanings of temperature t, ^0C	**t_0, ^0C**	**Change of temperature $\Delta t=t_2-t_1$ ^0C**				**Relative change to norm, $\|\Delta t\|/t_0$ %**			
		1	10	45	100	1	10	45	100
t_1=0,0003 x1985 +11,164=11,76; t_2=0,0003x1941 +11,164=11,75	11,7	0,0002	0,002	0,01	0,02	0,002	0,017	0,085	0,170

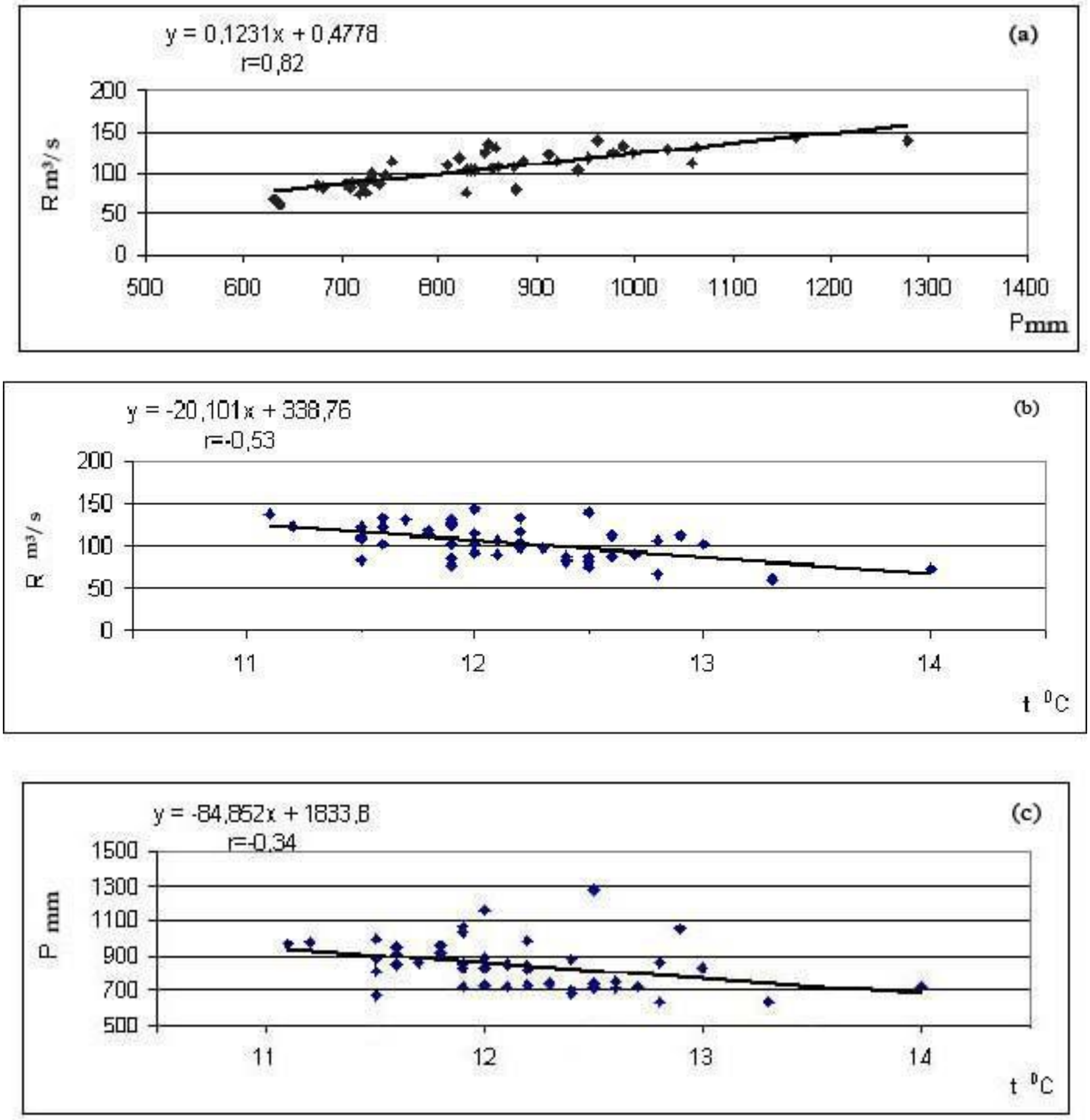
Relative high correlation ties are characteristic to the dependence of the runoff of river Alazani on total precipitations occurring on water collector ($r = 0.82$) and air temperature ($r = 0.53$), also dependence of total precipitations on the temperature ($r = 0.34$). Graphics of these dependencies that correspond to equation of regression and meaning of coefficients of correlation are given on picture 2. Satisfying correlation dependence enables their application for construction and application of empirical-statistical and water-balance models of formation of annual runoff of river. Let's note that both approaches result in similar analytical dependencies like

$$R = 0.108P - 10.834t + 139.59,$$

under the meaning of coefficient of multiple correlation$r = 0.86$. Here Rm^3/s-runoff of river, Pmm-total precipitations and t^0C-air temperature on water collector. Absolute error of equation constituted $|\Delta R| = 8 - 10$m^3/s, relative - $|\Delta R|/_R = 8 - 10\%$ for the whole observation period.

By receiving the full differential of the given equation, we may identify the reaction of the runoff against the variations of temperature and total precipitations, or change of runoff, caused by climatic variations. And after to made it dimensionless and find of individual differentials (derivatives) equation may be assessed, also sensitivity of change of runoff with respect to variations of temperature and total precipitations in separate according to these variations and later their comparison [4,5]. In particular, pursuant to the fulfilled assessment, relation of sensitivity of change of runoff of river Alazani that corresponds to the variations of precipitations (n_2) and temperature (n_1) appears in the range of

$$n = \frac{n_2}{n_1} = 1 - 2.$$



Picture 2. (a) Link between runoff of river Alazani (hydro-post in 2 kilometers down the mouth of river Agrichai) and annual precipitations, occurring on water collector; (b) between the runoff and average annual air temperature in the basin region; (c) between the precipitations and air temperature

Table 2 includes the results of assessment of reaction of runoff of river against the climatic change. With this purpose, comparatively "mild" scenario was chosen of development of climatic system throughout the XXI century, pursuant to which, the expected rise of air temperature in West and East Georgia in the end of the century may reach 1^0C and 2^0C accordingly, while decrease of total precipitations -5% and 10% from the norm is expected. Based on the data on table 2, these climatic variations may have serious impacts for water content of rivers in East Georgia, runoff of which significantly decreases within the frames of 20-50% from the norm of runoff of river in the locked cross section. For the rivers of west Georgia, runoff will decrease by 5-6%. In the conditions of more "strict" scenario of climatic changes, which is more possible [2], by the end of the century, variations of temperature and precipitations will double in comparison to the previous scenario. Taking into account the linear dependence between change of runoff and variations of temperature and precipitations in the equation of reaction (see table 2), all the assessments of magnitude of reduction of runoff will double as well. This way, in the conditions of the "strict" scenario of development of climatic processes, when air temperature will reach 2-4^0C and precipitations reduce by 10-20% from the climatic norm, water content of rivers, in particular in the region of East Georgia, will catastrophically fall from 35% (river Iori), to 60% (for river Alazani) and 100% (for river Mtkvari) from the magnitude of runoff in the indicated locked cross section.

Table 2. The Reaction of a runoff of river to the climatic change under the "mild" scenario.

№№	The River-Hydro-post (locked cross section)	The Equation of the Reaction of a Runoff	The Norm of Temperature, ^{0}C $\bar{t}$	Variation of Temperature, ^{0}C dt	Norm of the Total Precipitations $\bar{P}$ mm	Variation of the Total Precipitations, dP mm (% from norm)	Norm of a Runoff, $\bar{R}$ m^3/s	Change of a Runoff, dR m^3/s (% from norm)
1	**Rioni (mouth) – vil.Sakochakidze**	$dR = 0.22dP - 8.98dt$	12.2	1	1425	-71.25 (-5%)	407	-25 (-6%)
2	**Rioni – vil.Alpana**	$dR = 0.083dP - 0.021dt$	7.9	1	1224	-61.2 (-5%)	101	-5 (-5%)
3	**Inflow of RioniRiv.Tskhenis tskali – vil.Rtskhmeluri**	$dR = 0.01dP - 0.157dt$	3.7	1	1390	-69.5 (-5%)	62	-0.85 (-1%)
4	**Iori – vil. Salakhli**	$dR = 0.009dP - 0.749dt$	9.8	2	835	-83.5 (-10%)	13	-2.25 (-17%)
5	**Alazani – locked cross section in 2 kilometers down the stream from the mouth of the river Agrichai**	$dR = 0.108dP - 10.834dt$	11.7	2	845	-84.5 (-10%)	104.5	-31 (-30%)
6	**Riv.Kura – Tbilisi (st.Mushtaid)**	$dR = 0.683dP - 22.263dt$	6.7	2	795	-79.5 (-10%)	204	-99 (-48%)

Conclusion

Main results of investigation may be formulated as the following conclusions (magnitudes of change of hydro-meteorological characteristics of river basins are given for the 100-year period).

- In the basin of the main river of West Georgia – Rioni, in the conditions of actually changing air temperature and moderate increase of precipitations by 253 mm (18% from the climatic norm) the runoff in the locked cross section of village Sakochakidze actually remains unchanged – runoff is reduced by only 6 m^3/s or 2% from the norm. From one side, the essential factors like large areas covered with forest (70-75% of the territory of water collector), bog of Colchis lowland particularly in the region of the delta of the river and developed hydrographical network, contributes to detention of atmospheric precipitations via forests, accumulation of water in underground horizons of basins and in the system of bog, also to development of evaporation processes. From the other side, artificial regulation of the runoff of the existing system of water storage basins explains the weak impact of increase of precipitations on water discharge in the locked cross section, located in the region of the delta of the river.

- In the basins of one of the inflows of Rioni, runoff of river Tskhenistskhali under the secular increase of air temperature by almost 1^0C and total precipitations by 481mm (35%) significantly increases in the cross section of hydrological post of Tskhmeluri up to 40 m^3/s (around 60%). The indicated post actually appears in the zone of formation of runoff. This kind of increase of runoff may occur as a result of noticeable expansion of precipitations, also due to intensification of glacial nutrition under the marked rise of air temperature in the upper reaches of the basin.
- For the two basins of the main rivers of East Georgia, Iori and Alazani turned out to be characterized with moderate increase of precipitations up to 87mm (10%) and 104mm (12%) accordingly against the background of actually unchanged air temperature (secular warming in the basin occurs only at 0.08 and 0.02^0C), which led to growth of runoff up to about 1 m^3/s (7%) in the cross section of Salakhli and 20 m^3/s (19%) in the cross section of hydrological post, located in 2 kilometers down the stream from the mouth of river Agrichai.
- Common consequence for all discussed basins of rivers has been revealed – expansion of precipitations and runoff against the background of unchanged temperature, reduction of precipitations and runoff under rise of air temperature on water collector.
- Basin of river Rioni in West Georgia (village Sakochakidze) covers the big part of the region territory, where both mountainous/high-mountainous and submontane/low-lying zones of water collector are presented. That's why, in the conditions of surplus atmospheric precipitations, relatively high meanings of annual coefficient of runoff k=0.60 – 0.90 (average meaning $\bar{k}$=0.70) are characteristic to locked cross-section. As a result, sensitivity of change of runoff with respect to variations of total precipitations turned out to be several times more (n=1-3) the sensitivity of runoff under the variations of air temperature in the basin. In case of river Tskheniskhali (village Rtskhmeluri) water collector is located in the region of the Big Caucasus range, characterized by surplus precipitations. The meaning of coefficient of runoff here appears in the range of k=0.80 – 0.90 and sometimes exceeds this magnitude. This indicates at high effectiveness of transformation of precipitations into runoff characteristic to small mountainous basins. In such conditions, sensitivity of runoff with respect to change of precipitations turned out to be quite above the sensitivity of runoff under variations of temperature (n=10-20).
- For the neighbor basins of river Iori and Alazani, located in semi-arid and arid regions of Dedoplistskharo district, coefficient of runoff significantly decreases compared to rivers with the same characteristics in West Georgia. In case of river Iori basin (vil. Salakhli) k=0.07-0.15 ($\bar{k}$=0.12), and for Alazani river basin (below the mouth of river Agrichai) – k=0.25-0.50 ($\bar{k}$=0.35). In these conditions, sensitivity of river Iori under the variations of precipitations on water collector actually equals to the sensitivity with respect to change of air temperature (n=1). Roughly to say, this kind of relationship is characteristic to the sensitivity of runoff of river Alazani under the variations of the same characteristics (n=1-2).
- In the conditions of global warming under the commonly accepted scenarios of climatic changes, expected by the end of this century in the region of South Caucasus, water content of the rivers of East Georgia may significantly decrease. For the relatively "mild" scenario of development of climatic processes in the XXI century in Georgia, when air temperature is expected to rise by 1-2^0C and precipitations reduce by 5-10%, water content of East Georgian rivers will fall from 20% (river Iori), to 35% (river Alazani) and 50%(river Mtkvari) from the norm of runoff in the locked cross section. Water content in West Georgian rivers in the conditions of similar climatic changes is expected to decrease by far less quantity – approximate 5% from the norm of runoff.

Impact of Climatic Change on River Runoff in Georgia

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