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RECENT TRENDS OF RIVER RUNOFF IN THE NORTH CAUCASUS

ABSTRACT. Based on observational data from 70 hydrological stations in the North Caucasus an evaluation of present values of mean annual runoff, minimum monthly winter and summer runoff was carried out. Series of maps was drawn. Significant changes in mean annual. minimum monthly and maximum runoff during last decades have been revealed in the North Caucasus. A rise in both amount of water availability and potential natural hazard is characteristic of the most of the North Caucasus that is considered to be caused by recent climate change. Mean annual runoff during 1978-2010 increased compared to 1945-1977 by 5-30 % in the foothills and by 30-70% in the plain area. An increase in winter minimum monthly runoff is as well most intensive in the plain part of study area (>100%). Within the foothills it amounts to 50-100%. In mountainous area long-term oscillation of winter minimum monthly discharge strongly depends on local factors, such as geological structure. The rate of the increase in summer minimum monthly discharge regularly grows from central foothill part of Northern Caucasus (30-50%) to the Western plain territory (70-100%). In Kuban river basin 30% of analyzed gauging stations show positive trend in maximum instantaneous discharge, while 9% negative. On the contrary, in the Eastern part – Terek river basin – negative trend in maximum instantaneous discharge is prevalent: 38% of gauging stations. Positive trend in Terek river basin is characteristic of 9.5% of analyzed gauging stations.

KEY WORDS: Water resources, mean annual runoff, minimum monthly runoff, maximum discharge, climate change, hydrological hazards, North Caucasus

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INTRODUCTION

Due to specific climatic conditions, contrasts in relief, high density of population the North Caucasus is one of the most complicated in terms of hydrological conditions parts of Russia. Herewith problems connected with both scarcity and abundance of water resources is characteristic of this region. Mean annual damage caused by river flooding in the North Caucasus amounts to 700 mln USD (Grishenko et al. 2003). That is almost equal to the corresponding value for Volga and Amur river basins (Grishenko et al. 2003), whereas the total area of the North Caucasus region (258 000 km^2) is 5 times less then the Volga river basin (1 360 000 km^2) and 7 times less than the Amur river basin (1 855 000 km^2). The North Caucasus is also leading in terms of dangerous floods occurrence (from 1 to 20 a year) (Semenov and Korshunov 2008). Floods are observed in the North Caucasus during the spring-summer period and are usually aroused by imposition of heavy rainfall on intensive melting wave. The same factors bring about other various hazardous natural processes in this region, such as debris flows, snow avalanches and glacier lakes outburst floods.

The foothill and lowland part of the North Caucasus is one of the most important agricultural regions in Russia with high level of irrigation. Severe water shortages are occasionally observed here during low-flow periods.

In the beginning of the 21th century frequency and intensity of dangerous hydrological processes in North Caucasus was substantially higher then during the previous years that is usually associated with recent climate change (Frolova et al. 2017, Semenov and Korshunov 2008; Bazeluk and Lurie 2014; Rets et al. 2016; Rets and Kireeva 2010; Malneva and Kononova 2012; Seynova 2008).

Some components of hydrological regime in certain parts of North Caucasus were recently analyzed by different authors. Lurie (2002) gives a thorough description of physic-geographical conditions of river runoff forming in the North Caucasus, calculates water balance in North Caucasus according to Lvovich method. Rets and Kireeva (2010) provides information on main features of water regime in Terek river basin and dependencies of mean annual and minimum monthly runoff and maximum water levels on characteristics of river basin. Regional dependencies of mean annual runoff on mean elevation and mean annual runoff mapping for Kuban river basin for the period 1967–2008 is given in (Melnikova 2010). The conditions of formation of the maximum runoff in the rivers of the North-West Caucasus were analyzed by Melnikova (2011), maximum river discharges are provided for some gauging stations in the study region as well.

However, the last thorough and generalized study of water resources in North Caucasus as whole dates back to the 70s (Resources… 1973). Consequently, it is of current interest to reassess river water resources in North Caucasus for the modern period and reveal present-day trends in main runoff characteristics.

STUDY AREA AND METHODS

The North Caucasus region with the total area of more then 350 000 km^2 is situated on the southern border of European territory of Russia. It can be divided into three parts: plain territory on the north, foothills and mountainous part in the south. The alpine zone extends above the orographic snowline which height is approximately 2000 m in North Caucasus. Elevation of the basin ranges from –28 to 5642 m. The climate here is moderate continental. The precipitation decreases both southeastwards and with a decrease in elevation. Annual precipitation sum varies from 400-600 mm in Eastern plain part and 600-800 mm in Western plain part to 800-1300 and more in mountainous part with the maximum of 3242 mm (Achishkho plateau). Annual distribution of precipitation differs greatly through the region this combined with altidudinal zonality of climate results in great differences in river flow regime in North Caucasus. The overall main source of river water in North Caucasus basin is snow and ice melting, though snow melting flood can be distinguished not for all rivers of the region. The main river basins in North Caucasus are the Kuban river basin (57 900 km^2), Terek river basin (43 200 km^2), Kuma river basin (33 500 km^2), Sulak river basin (15 200 km^2) and Samur river basin (7 330 km^2).

Mean annual. minimum monthly winter and summer unit discharges were estimated for 70 hydrological stations for the period 1945-2010 (Fig. 1). The analysis of maximum annual discharge trends was based on instantaneous data for the period from 1920s to 2015 from 23 and 21 hydrological stations in the Kuban and Terek basins respectively. Methods of mathematical statistics were used to reveal statistically significant directed changes in main characteristics of annual. minimum river runoff and maximum annual discharges. Fisher and Student test were used to reveal the statistical heterogeneity in mean annual and minimum monthly discharges time series.

The trends in maximum discharges were tested using Spearman's rank order correlation coefficient with 5% significance level.

Series of maps have been drawn covering the reassessment of annual and minimum river runoff characteristics for the modern period and their change compared to the previous period. The threshold year (1978) was detected by analysis of difference-integrating curves of river runoff characteristics.

RECENT CLIMATE CHANGE IN NORTH CAUCASUS

Tendencies in main climatic characteristics are appear to be not homogeneous throughout the study region (Toropov et al. 2018). However, some main features can be outlined. According to the majority of studies (Alekseev et al. 2014; Toropov et al. 2018; Rets and Kireeva 2010) a statistically significant positive trend in air temperature is observed in the summer period in the region amounting to 0.7 – 1°C/10 years. According to (Rets and Kireeva 2010) this tendency is more clear cut in plain territory and foothills. In winter period the observed tendencies in air temperature are very inhomogeneous: Alekseev et al (2014) report statistically insignificant positive trend. Toropov et al. (2018) claim a statistically significant rise in air temperature of winter period is observed in the Eastern Caucasus, close to the Caspian Sea and in the Krasnaya Polyana vicinity. In the study (Rets and Kireeva 2010) a decrease in air temperature of winter period was revealed in the mountainous part of the North Caucasus.

Tendencies in precipitation sums in the North Caucasus have been multidirectional and complicated in the last 30-40 years. Observed tendencies in precipitation characteristics differ to a great extent seasonally (Toropov et al. 2018). According to different studies either positive trend in annual precipitation sum (5%/10 years (Alekseev et al. 2014), or no statically significant trend is observed for the most of the territory (Toropov et al. 2018). Alekseev et al. (2014) report rise in precipitation mostly in spring and autumn. Most distinct positive trend in annual precipitation is characteristic of the Eastern part of North Caucasus close to the Caspian Sea (Alekseev et al. 2014). In the same region a statistically significant rise in precipitation intensity up to 0.5 mm/day per 10 years is observed (Toropov et al. 2018). An increase in annual precipitation sum was revealed for the most of mountainous station and a number foothill of the central part of Northern Caucasus (Rets and Kireeva 2010). Decrease in precipitation sum and precipitation intensity in winter period is detected on the Black Sea shore and in steppe regions of Krasnodarky kraj (Toropov et al. 2018).

The intensive degradation of glaciation is observed in the North Caucasus (Zemp et al. 2015; Shahgedanova et al. 2014). The area of glaciers in the North Caucasus dropped by 12.6% during 1970–2000 (Voitkovskiy et

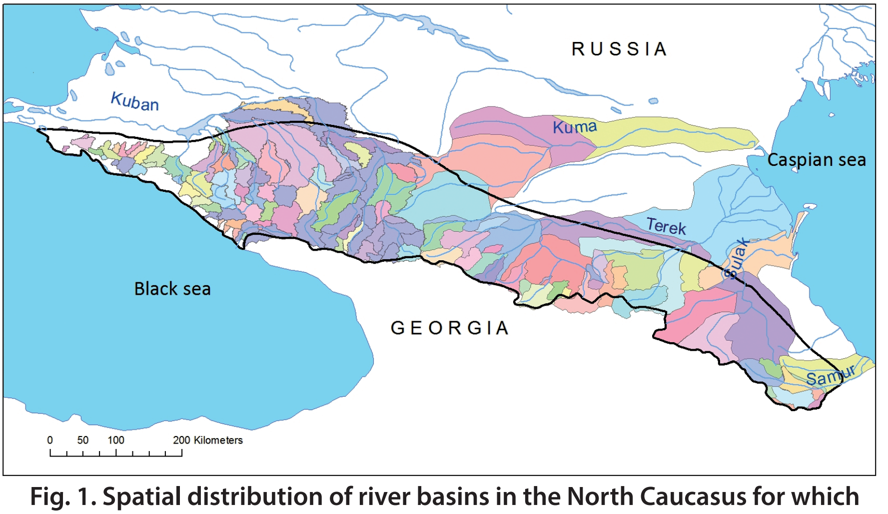

Fig. 1. Spatial distribution of river basins in the North Caucasus for which characteristics of mean annual and minimum monthly unit discharge were calculated

al. 2004), and by 4.7% between 2000 and 2010/2012 (Shahgedanova et al. 2014), amounting to approximately 17% in total during 1970–2012. A substantial intensification of deglaciation during the last decade in the region is reflected in mass-balance measurements on representative of the central part of the North Caucasus, Djankuat glacier. Mean rates of ice mass loss increased from -0.13 m w.e./yr (meters of water equivalent per year) in 1966-2003 (Shahgedanova et al. 2007) to -1.03 m w.e./yr in 2010-2015 (www.wgms.ch).

ANNUAL WATER RESOURCES

Mean annual river runoff rate decreases with the decrease in elevation from Southwest to Northeast and from West to East with the increase in aridity (Fig. 2). The maximum value of mean annual unit discharge (60-70 litres/(s*sq.km)) is observed on the southern slopes of the Western part of the Caucasian mountain range where local climatic conditions result in a high precipitation rate. In the most alpine zone of the North Caucasus annual unit discharge varies from 20-30 to 50-60 litres/(s*sq.km). In the foothills mean annual runoff unit discharge sharply declines to 5-15 litres/(s*sq.km). The vast plain territories not add much to the total runoff of rivers: the values of unit discharge decrease gradually in the Northeast direction down to zero and even less. Here the most evident changes in annual runoff occurred during last 3 decades: it has increased by 30-70%. Whereas in the mountainous part only a slight positive tendency can be observed. In the orographicaly highest areas and in the Eastern part of the North Caucasus the long-term mean value on annual runoff remains stable.

MINIMUM RUNOFF PERIOD

Contrasts in climatic conditions in the region results in great differences in river nourishment structure and, consequently, annual river runoff regime (Rets et al. 2017a). Rivers with a substantial share of glacial and high-elevation snowfield melt in nourishment structure are characterized by a high-water period lasting from late spring up to September and stable winter low-flow period (Rets et al. 2017b). With a decrease of mean elevation of river watershed the share of snowmelt in river runoff diminishes, simultaneously, the beginning of high-water and winter low-flow periods shifts to earlier dates, rain floods start playing a more substantial role in maximum discharges, winter low flow period is more often interrupted by snowmelt winter floods. Annual water regime of rivers with watersheds situated mostly in the plain territory depends on annual distribution of precipitation. In the central and Eastern North Caucasian plain territory precipitation occurs mostly in summer that results in summer flood period and both winter and summer low-flow periods. Winter precipitation maximum is characteristic of the Western part of North Caucasus. Hence, no

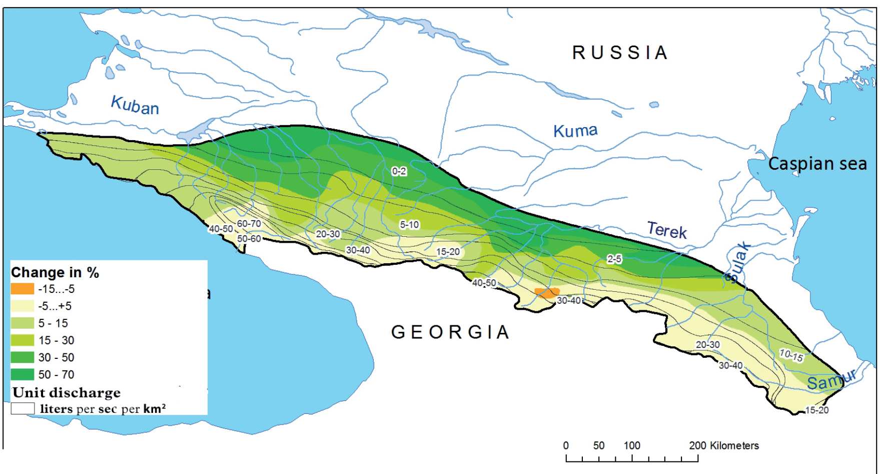

Fig. 2. Spatial distribution of mean annual unit discharge in the North Caucasus (averaged for 1978-2010), and its change compared to the previous period (1945-1977)

winter low-flow period is observed here.

Summing up, a winter low-flow period is observed on the most of territory of North Caucasus (except for the utmost Western part) (Fig. 3). Summer low-flow period is characteristic only of Northern and Eastern part (Fig. 4). Winter and summer minimum monthly unit discharges are practically equal in central Northern are (from 0-1 to 1-2 litres/(s*sq.km). Summer low flow period is higher then winter in central foothills (2-7 compared to 2-5 litres/(s*sq.km). Distribution of winter minimum monthly unit discharge in mountainous part is not so even, that is connected with geological structure. Also a maximum in Western mountainous part (20-30 litres/(s*sq.km) is raised by closeness to the territory with prevailing winter precipitation. Summer minimum monthly unit discharge is also correspondingly maximum in the neighboring area.

A dramatic rise in minimum monthly discharges (both for winter and summer) is characteristic for the study area. The peculiarities of modern climate bring about the increase in amount, duration and extent of thaws and general reduction of annual cold period duration in region. These tendencies

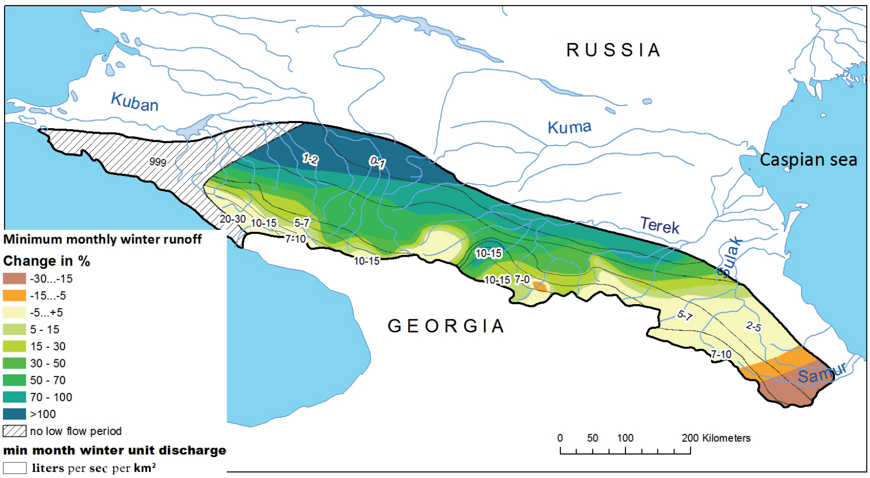

Fig. 3. Spatial distribution of winter minimum monthly unit discharge in the North Caucasus (averaged for 1978-2010), and its change compared to the previous period (1945-1977)

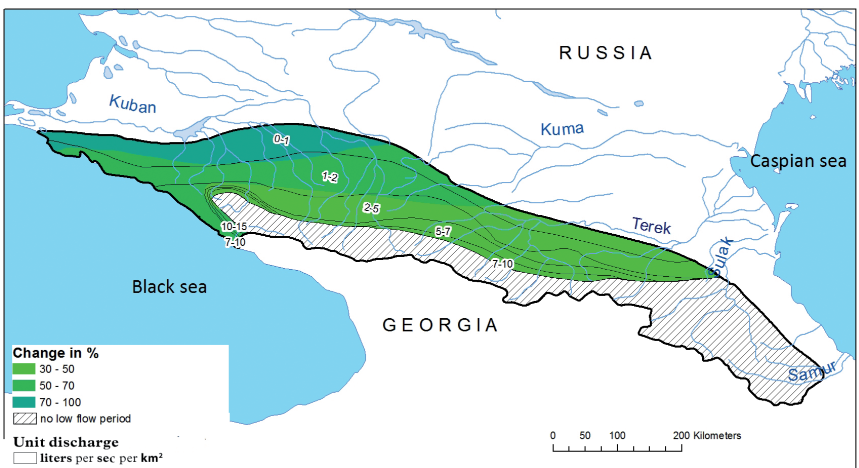

Fig. 4. Spatial distribution of summer minimum monthly unit discharge in the North Caucasus (averaged for 1978-2010), and its change compared to the previous period (1945-1977)

lead to a decrease in soil freezing depth, registered on agrometeorological stations in all regions of European Russia. Groundwater resources have been significantly more replenished during last decades compared to previous period due to melt water losses on infiltration (Kireeva et al. 2015). A respective increase in winter minimum monthly discharge is most intensive in the North of study area (>100 %) (Fig. 3). Within the foothills it amounts to 50-100%. In mountainous area long-term oscillation of winter minimum monthly discharge strongly depends on local factors, such as geological structure. In the upper reaches of some tributaries of Terek and Kuban river positive trends are still not observed, while in neighboring macrovalleys long-term variations of winter minimum monthly discharges correlate with the corresponding variations in the foothills and on plain. However, a decrease in positive tendency rate is observed throughout the study area with movement from plain to alpine zone. On the highest elevation belts, where the temperature is still strongly negative in winter for frequent thaws generation, winter minimum monthly discharge remains stable on the long-term scale. In the most arid Southeastern part of study area the negative trend in precipitation result in decrease of minimum monthly discharges by 15–30%.

The rate of the increase in summer minimum monthly discharge regularly grows from central foothill part of Northern Caucasus (30-50%) to the Western plain territory (70-100%) (Fig. 4).

TRENDS IN MAXIMUM RIVER DISCHARGES

The water-abundant period is observed from April/May to September in the North Caucasus. The fundamental wave or the runoff hydrograph, formed by snow and ice melting is overlain with sharp peaks of rain floods that usually form annual maximums of discharges. Maximum river discharges are usually associated with flood hazard (Shiklomanov et al. 2007; Frolova et al. 2017). However, tendencies in maximum water level tendency which results in out-of-bank flow does not always correlate with tendencies of maximum discharge in North Caucasus, owing to sedimentation processes and anthropogenic factors (Rets and Kireeva 2010; Frolova et al. 2017; Vishnevskaya et al. 2016; Kotlyakov et al. 2016). Accordingly, changes in maximum river runoff can be referred to as climatic prerequisites of modification of present-day flood hazard. Maximum annual river discharges tend to increase in the Western part of the North Caucasus. In Kuban river basin 7 of 23 (30%) analyzed time-series show positive trend in maximum instantaneous discharge at 5% significance level (Table 1), while 2 of 23 (9%) – negative. On the contrary, in the Eastern part – Terek river basin (Table 2) – negative trend in maximum instantaneous discharge is prevalent: 8 of 21 (38%) of time series. Positive trend in Terek river basin is characteristic of 9.5% of analyzed gauging stations (2 of 21).

Table 1. Statistically significant trends in maximum river discharges in Kuban river basin revealed by Spearman test

River	Gauging station	p-value	Observed trend
Kuban	Kosta Hetagurova	0.012	positive
Kuban	Armavir	0.288	none
Kuban	st. Ladozhskaya	0.124	none
Ullu-Kam	aul Hurzuk	0.236	none
Teberda	Teberda	0.540	none
Maruha	Maruha	0.112	none
Nevinka	h. Ust-Nevinskij	0.380	none
Bolshoj Zelenchuk	st. Zelenchukskaya	0.002	positive
Urup	st. Udobnaya	0.950	none
Urup	h. Steblitskij	0.093	none

Laba	h. Doguzhiev	0.000	positive
Malaya Laba	s. Burnoe	0.003	positive
Bolshaya Laba	nizhe Aziatskogo mosta	0.004	positive
Fars	st. Dondukovskaya	0.009	positive
Belaya	pgt Kamenomostskij	0.036	negative
Dah	st. Dahovskaya	0.029	negative
Kurdzhips	st. Nizhegorodskaya	0.982	none
Psekups	Goryachij Kluch	0.116	none
Afips	st. Smolenskaya	0.044	positive
Shebsh	s. Shabanovskoe	0.253	none
Ubinka	st. Severskaya	0.374	none
Adegoj	st. Shapsugskaya	0.867	none
Adagum	Krimsk	0.429	none

Table 2. Statistically significant trends in maximum river discharges in Terek river basin revealed by Spearman test

River	Gauging station	p-value	Observed trend
Terek	Vladikavkaz	0.025	negative
Terek	Kotlyarevskaya	0.251	none
Terek	Stepnoe	0.023	negative
Ardon	Tamisk	0.363	none
Tseya	Buron	0.003	negative
Fiagdon	Tagardon	0.461	none
Gizeldon	Dargavs	0.002	positive
Kambileyevka	Ol'ginskoye	0.050	negative
Belaya	Kora-Urusdon	0.000	negative
Malka	Kamennomostskoye	0.535	none
Malka	Prokhladnaya	0.013	negative
Baksan	Zayukovo	0.033	negative
Chegem	Nizhny Chegem	0.172	none
Cherek	Kashkhatau	0.165	none
Cherek Balkarsky	Babugent	0.174	none
Nalchik	Belaya rechka	0.000	negative
Sunzha	Karabulak	0.941	none
Sunzha	Grozny	0.025	positive
Assa	Nesterovskaya	0.893	none
Fortanga	Bamut	0.642	none
Belka	Gudermes	0.151	none

CONCLUSION

A directed increase in mean annual river runoff and summer minimum monthly discharge is observed in North Caucasus. The main reason of increase in water abundance of winter period is more often winter thawing due to overall warming of the winter period. The most pronounces changes occurred in the western part of the plain territory. In mountainous part, especially in the areas of certain geological structures expansion, the analyzed characteristics of river runoff remain stable. In the most arid Southeastern part a decrease in river runoff during low-flow periods is detected. Positive trend in maximum runoff is observed for one third of gauging stations in Kuban river basin that can be interpreted as a favorable climatic background for an increase in flood hazard. An opposite tendency is observed in Terek river basin for almost 40% of the gauging stations. It is an urgent need for the local economy to adapt to the new conditions.

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