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Georgian climate change under global warming conditions

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ABSTRACT

Georgian Climate change has been considered comprehensively, taking into account World Meteorological Organization recommendations and recent observation data. On the basis of mean temperature and precipitation decadal trend geo-information maps for 1936–2012 years period, Georgian territory zoning has been carried out and for each areas climate indices main trends have been studied, that best characterize climate change - cold and hot days, tropical nights, vegetation period duration, diurnal maximum precipitation, maximum five-day total precipitation, precipitation intensity simple index, precipitation days number of at least 10 mm, 20 mm and 50 mm, rainy and rainless periods duration. Trends of temperature indices are statistically significant. On the Black Sea coastline and Colchis lowland at high confidence level cold and hot days and tropical nights number changes are statistically significant. On eastern Georgia plains at high level of statistical significance, the change of all considered temperature indices has been fixed except for the number of hot days. In mountainous areas only hot day number increasing is significant. Trends of most moisture indices are statistically insignificant. While keeping Georgian climate change current trends, precipitation amount on the Black Sea coastline and Colchis lowland, as well as in some parts of Western Caucasus to the end of the century will increase by 50% and amounts to 3000 and 6000 mm, respectively this will strengthen humidity of those areas. Besides increasing of rainy period duration may constitute the risk for flooding and high waters. On eastern Georgia plains, in particular Kvemo Kartli, annual precipitation amount will decrease by 50% or more, and will be only 150–200 mm and the precipitation daily maximum will decrease by about 20 mm and be only 10–15 mm, which of course will increase the intensity of desertification of steppe and semi-desert landscapes.

Introduction

Global warming is one of most urgent problem of modernity. The gradual increasing process of Earth atmosphere annual temperature and World Ocean in the XX and XXI centuries is the result of both natural causes and the consequence of human activity. According to estimates of the Intergovernmental Panel on Climate Change (IPCC) the average temperature on Earth has risen by 0,7 °C since the beginning of industrial revolution (from the second half of the XVIII century), and “a large proportion of the warming observed in the last 50 years, attributable to human activities” [1,2].

Under the conditions of global warming, climatic changes in different parts of world reveal different character. The nature of regional climate changes is determined by the features of physical -geographical and landscape-climatic conditions. More sensitive to global warming are the Arctic, also continental and mountain areas and less sensitive are coastal areas [3–5].

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Georgian climate change has been considered since the middle of last century. The first statistical analysis of temperature series was made by Kurdiani and Chirakadze [6,7] In air temperature long-term changes they found the cycles of varying duration. And Tsutskiridze [8] tried to identify the effect of urbanization by comparing temperature series in Tbilisi and Gardabani.

The first monograph devoted to this issue is by Mumladze [9]. In monograph based on the analyzed data results up to 1990 year period, it was shown that in Georgia greatest temperature increasing has been observed in 1966–1977 years, and mainly due to the winter months. During 150 year period January temperature rose to 2.1 °C.

The work carried out within the framework of National Communication of UN on Climate Change [10], identified the main patterns of Georgian climate change over 1905–1996 year period-intensive temperature rise in East Georgia and substantially lowering the temperature in Western Georgia.

Also within the framework of National Communication on Georgian Climate Change according to observation data for 1937–1990 year period, were studied long-term monthly, seasonal and annual precipitation course peculiarities [11]. It was established that in large parts of Georgia annual precipitation decreasing has been marked. The largest decrease in precipitation trend is characteristic for the Greater Caucasus and amounts to 9 mm per year. With the rate of 6 mm per year rainfall increased in the coastal zone, in the Colchis Lowlands and Adjara mountains.

In collective monograph "The long-term change and cyclical fluctuation of Tbilisi climate" [12], based on observations of Tbilisi hydrometeorological observatory for 150 years (1844–1995) was conducted multilateral study of long-term change and cyclical variations of Tbilisi climate. For the period up to 1908 it was marked cooling in 1909–1963years - warming, then cooling again, which was replaced by warming in 1974. It was identified that in the era of maximum solar activity the average temperature is higher than in the years of minimal activity. There were tendencies of temperature changes in the distinctive landmark periods of atmospheric circulation forms. Phase activation of western circulation (1890–1930) corresponds to the low level of average annual temperature and the phase of weakening of the same circulation form - corresponds to the high level of temperature. Inverse pattern is marked in conditions of eastern circulation form. Meridional circulation has no significant impact on temperature change.

More detailed Georgian climate were conducted by group of scientists at the beginning of XXI century. It was ascertained that for western Georgia is characteristic spring warming and autumn cooling which accelerated snow cover and glaciers melting, keep flooding in spring season, and in autumn activates frosts [13,14].

The dynamics of extreme anomalies frequency of mean monthly air temperature and its influence on rainfall and river flow has been analyzed. Extremely high temperature anomalies repeatability was greatest in the 1961–1970 period and the high frequency of extreme low-temperature anomalies were characteristic for the 1941–1950 years [15].

And finally within the framework of the Project of Rustaveli National Scientific Foundation geoinformation maps of temperature and precipitation variation over Georgian territory for the years 1936–2008 have been realized [16].

In all above given investigations with rare exceptions [17–21] monthly mean, seasonal and annual values of temperature and precipitations have been basically investigated, rarely – their extreme values.

However, an exhaustive description of climate change process considered parameters are insufficient. For this purpose, the World Meteorological Organization (WMO) and expert group on monitoring and indices of Intergovernmental Panel on Climate Change (IPCC) developed indices describing extreme deviation of climate phenomena and encouraged individual countries to carry out research of these indexes, purposing their generalization for large regions or for Globe in general, and of corresponding comparative analysis [22,23].

In this paper, in contrast to previous studies, the problem of Georgian climate change is considered comprehensively, taking into account recommendations of World Meteorological Organization and observational data in recent years (until 2013). Based on the GIS maps decadal trend of average temperature and precipitation for 1936–2012 year period, Georgian territory zoning has been carried out and for each region were studied trends of main climate indices best describing the process of climate change - cold and hot days, tropical night, the length of vegetation season, diurnal maximum precipitation, the maximum five-day sum precipitation, precipitation intensity simple index, number of days with precipitation of at least 10 mm, 20 mm and 50 mm, the length of rainy and rainless periods. This integrated approach has expanded our understanding of Georgian climate change in conditions of global warming.

Objectives and methods

Georgia is the mountainous country located in the south-western part of the Caucasus. Its area is 69.875 km^2 at all. From the west it is washed by The Black Sea, from south it borders with Turkey and Armenia, from south-east- with Azerbaijan and from north-with the Russian Federation (Fig. 1).

The location at the turn of the Mediterranean, arid Aral-Caspian depression and Forward Asia highlands with continental climate led to the variety of topography, landscape, natural and plant world. The territory of Georgia is steep terrain and combines lowland, midland, hilly, lowland-plains, and the relatively flat plateau-like reliefs. Part of lowlands is at sea level, and some of the peaks of mountain ridges reach over 5000 m above sea level. In the northern part of the territory from north-west to south-east stretches the Main Caucasian ridge. In the southern part of Georgia almost parallel to the Greater Caucasus Range extends South Georgian Highlands (part of the Lesser Caucasus).

The main Caucasian ridge connects with the South Georgian Plateau Likhi Range, which is the watershed of the Black and Caspian Seas, and divides Georgia into two physical - geographical areas- Western and Eastern Georgia. Between the Greater Caucasus and the South Georgian Plateau lies tectonic depression, which is represented by lowlands, river valleys, plains and flatlands-in the direction from west to east: the Colchis Lowland, upland Imereti, Shida and KvemoKartli, Alazani valley, Iori Plateau. From the Main Caucasian ridge parallel to Likhi Ridge, come meridional directed Svaneti, Luchhumsky and Egrisi Ridges (Western Georgia) also Kakheti, and Gudamakhary, Haruli and other Ridges (Eastern Georgia). In the southern part of Georgia Javakheti plateau is located (Fig. 2).

The complexity of the orographic structure of Georgian territory, along with other physical -geographical factors is the cause of wide variety of climates and landscapes. There are almost all types of climates observed on the Globe, from the climate of eternal snows of high mountains and glaciers to steppe continental climate of eastern Georgia and humid climate of the Black Sea coast subtropical [24].

Climate change research in the conditions of such complex region, from physical-geographical and climatic point of view, has important theoretical and practical significance [25]. Characterizing climatic changes helps scientists and policy makers understand the effects of such changes on water resources, economic development, and the health of ecosystems [26–28].

Fig. 1. Georgian location and borders.

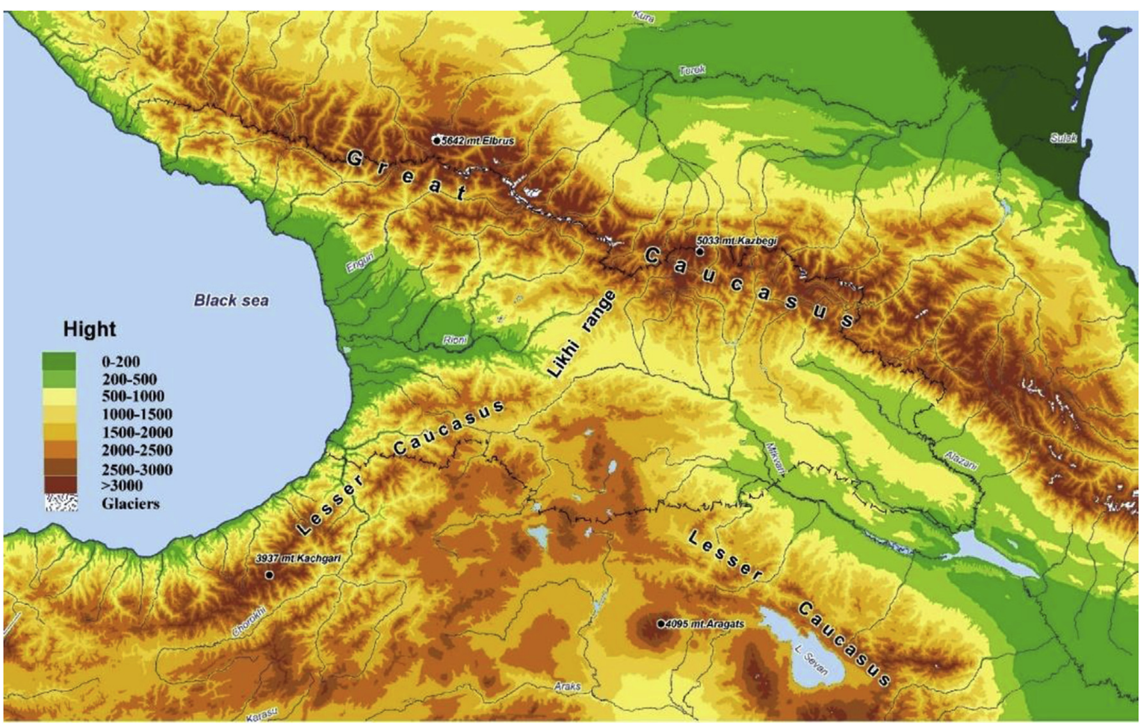

Fig. 2. Caucasus relief.

For exhaustive description of Georgian climate change in addition to average climatic characteristics in this article are considered some climate indexes recommended by World Meteorological Organization - cold days when the minimum temperature was negative (FDO); hot days, when the maximum temperature exceeds 25^{O}C (SU25); tropical nights number when the minimum temperature exceeded 20^{O} (TR20); vegetation season duration, when temperature exceeded 5^{O}C (GSL); diurnal maximum precipitation (RX1), the maximum five-day precipitation totals (RX5), a simple index of precipitation intensity (SDII), number of days with precipitation of at least 10 mm (R10), 20 mm (R20) and 50 mm (R50); rainless duration (CDD) and rainy (CWD) periods (Peterson 2005).

Cold, hot and tropical days are calculated for annual intervals. Rainy days were considered when total daily precipitation exceeded 1 mm, and the rainless periods were considered with daily rainfall of less than 1 mm, precipitation intensity simple index has been calculated as the ratio of annual precipitation to the number of days with precipitation per year.

As initial material were used Data Archive of the Institute of Hydrometeorology, created with preparation of the first National Communication to the UN Climate Change Convention [10,11], and database created while realization of Shota Rustaveli National Science Foundation Project [29], as well as observation data of functioning meteorological stations. In total, data from 90 meteorological stations of 1936–2012 year period were used (Fig. 3).

Linear trends were built and magnitude, temperature and precipitation indices change rate for different periods of global warming for all stations were determined. The intensity of warming or cooling as well as precipitation changes was estimated by the temperature and precipitation change rate. Temperature thresholds have been chosen in accordance with specific levels of statistical significance. Changes in air temperature within 0–0.02 °C per decade were statistically insignificant. In the speed range of 0.02–06^{O}C trends of annual and monthly temperatures during the summer period, in some cases are statistically significant, mostly at level of 90–95%, so we consider these changes as slight warming (cooling). Temperature change rate in range 0.06–0.1^{O}Cis statistically significant for average temperature at the confidence level of 98–99%, and for temperatures in a hot July mainly at confidence level of 90–95%. This temperature change can be considered as moderate warming (cooling). Temperature change at rate more than 0.1^{0} was considered a strong warming (cooling).

The precipitation change intensity was estimated taking into account their long-term variations. Total precipitation deviation for more than 5% per decade from the norm, which corresponds to the precipitation secular change by 50% or more, was considered significant, and precipitation amount change in the of in 3–5% range was considered moderate, etc.

Results and analysis

Considering the selected intensity gradation of warming (cooling) and precipitation changes GIS maps have been constructed. air temperature and precipitation decadal trends changes maps over Georgian territory for 1936–2012 year period are presented on Figs. 4 and 5.

From these maps, it follows that in the background of global warming temperature and precipitation change on the territory of Georgia is heterogeneous in nature, due to the complex physical-geographical mainly orographic and landscape-climatic conditions. The largest centers and areas of strong warming, where decadal trend of mean annual air temperature was more than 0.1 °C, are found in eastern Georgia. This is the southern part of Kakheti Ridge, regions of Haruli and Gudamakhari Ridges, Javakheti Plateau. Centers of severe and moderate warming, when decadal temperature trend is 0.02–0.1 °C are fixed in Western Georgia, mainly in the areas of Svaneti, Lechkhumi and Egrisi Ridges. On small part of Georgian territory temperature remained almost unchanged or changed not significantly. Temperature lowering is observed mainly in western Georgia. Strong cooling takes place in large parts of Adjara and in the northern part of The Black Sea coastline, where mean annual temperature was decreased at rate of more than 0.1 °C per 10 years.

Such character of long-term changes in air temperature in Georgia is due not only orography, but also the whole complex of natural and landscape conditions. Areas subject to strong warming spread in moderately dry subtropical dry and semi-desert landscapes as well as moderately cold and dry mountain-steppe landscapes of eastern Georgia. Areas of greatest cooling (Adjara and the northern part of the Black Sea coast) took Colchis moist moderately warm and moderately humid Caucasian mid cold forest landscapes. Thus, in terms of global warming arid landscape of eastern Georgia is warming faster than the humid landscapes of western Georgia, which, in connection with expenditure of considerable part of heat for evaporation, heat slowly, and often even cooled, which once

Fig. 3. Location of used meteorological stations data.

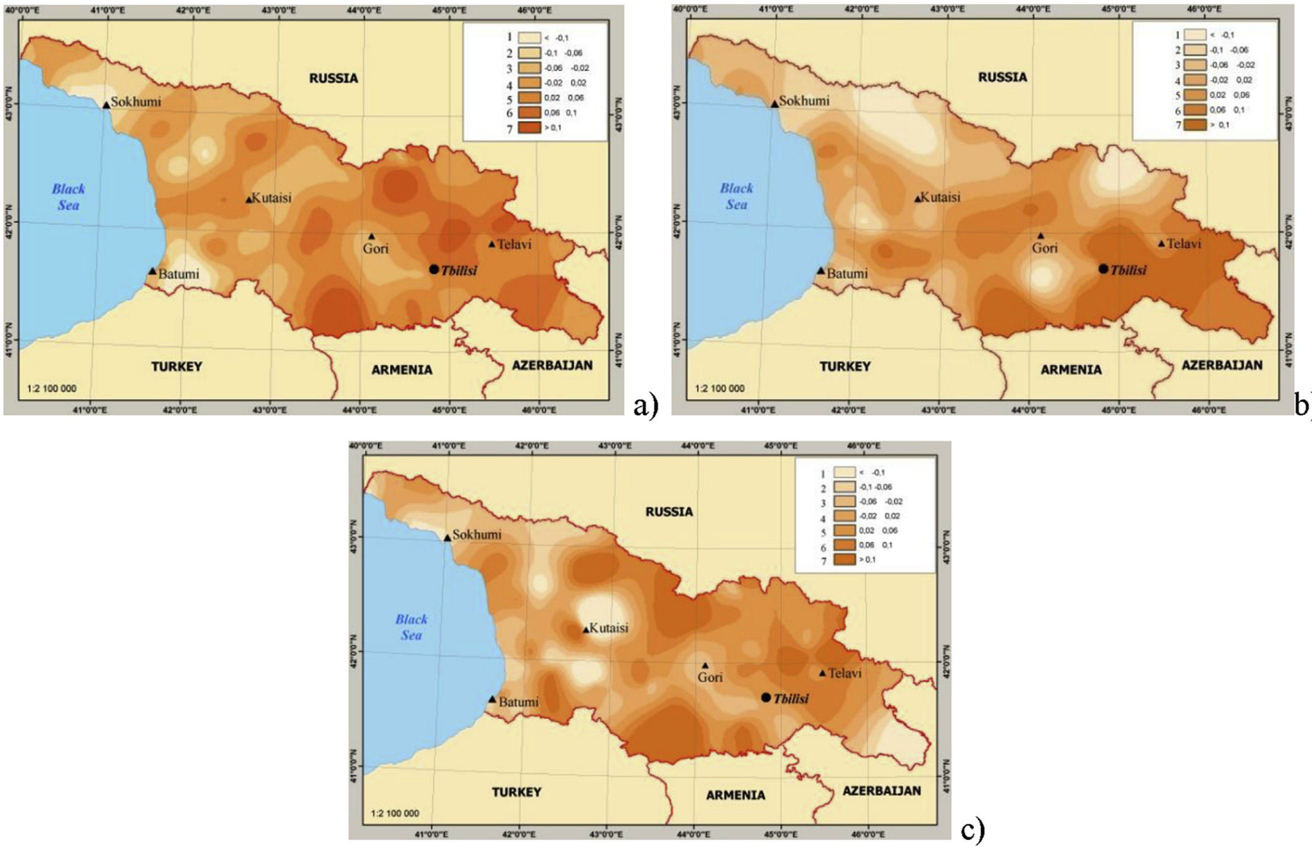

Fig. 4. Decadal trend of mean air temperature °C: a) -year; b)-January; c)- July.

again confirms accuracy of previously expressed our views on the essential role type of natural landscape, on different responses of different types of landscapes to global warming [30].

In the large parts of eastern Georgia, annual precipitation decreases, decadal trend composes 1–3%. The largest decreasing in rainfall trend is observed in Kvemo Kartli, south of Tbilisi, and is more than 5%. In extreme eastern part of eastern Georgia, characterized by steppe and semi-desert landscapes, as well as in large parts of western Georgia, significant change in precipitation wasn't observed. Annual precipitation increasing is observed in some parts of western Georgia, Lechkhumi and Egrisi Ridges, in the central part of Colchis lowland, in eastern part of Adjara, as well as in the central part of the Iori Plateau in Eastern Georgia, where annual precipitation decadal trend was 1–3%. In the mountainous Adjara and in some areas of the Black Sea coast precipitation increase rate has reached 5%.

The same trends are reserved for precipitation in warm and cold periods of the year. During the warm season precipitation zone decreasing in Kvemo Kartli is considerably expanded. In cold season in western and eastern parts of Great Caucasus has been observed some increasing in precipitation reducing zone and change rate increasing, even in center, near Mamisoni Passing cold period precipitation has been increased at rate of 5% per decade.

Thus, by nature of long-term changes in average temperatures and precipitation amounts can be identified 5 areas in the territory of Georgia:

1. Black Sea coastline. It is characterized by insignificant temperature change, cooling in some places; precipitation annual sum generally increases in some places more than 5% per decade.
2. Colchis lowland. It is also characterized by insignificant temperature change and precipitation increasing in some places up to 5% per
3. The plains of eastern Georgia. It is characterized by warming, strong warming in some places when temperature decadal trend is greater than 0.1^{O}C. In large parts of the annual precipitation slightly reduced at rate of 1–3% per decade.
4. South Georgian Highlands. IT is characterized by strong warming and a precipitation slight decreasing up to 3% per decade.
5. Greater Caucasus. In the western part cold snap is dominated with annual precipitation slight increasing, and in the eastern part warming is dominated with precipitation slight reduction.

Climate change is characterized by significant heterogeneity in general and in Caucasus region. If air temperature trend in Russian northern regions and in Far East has low provision at residual variability small values then in southern regions bordering with Georgia, trend significance increases in almost all seasons for small values of residual variation. On the whole territory of Russia is significantly more sensitive to global warming than the Globe as whole. Mean annual temperature anomalies swipe reaches 3-4^{O}C there, while for the Globe it is only slightly more than 1^{O}C [31–36].

Temperature on plains and foothills of Azerbaijan has been significantly increased, and in coastal and mountainous areas - somewhat smaller temperature increasing, but precipitation change has random character [37,38]. In Armenia, in recent years annual and seasonal temperatures change rate has been increased substantially in relation to 1961–1990 period (base period recommended by World Meteorological Organization). During 1935–2011 period mean annual temperature has been increased by more than 1^{O}C and annual precipitation sum over the same period

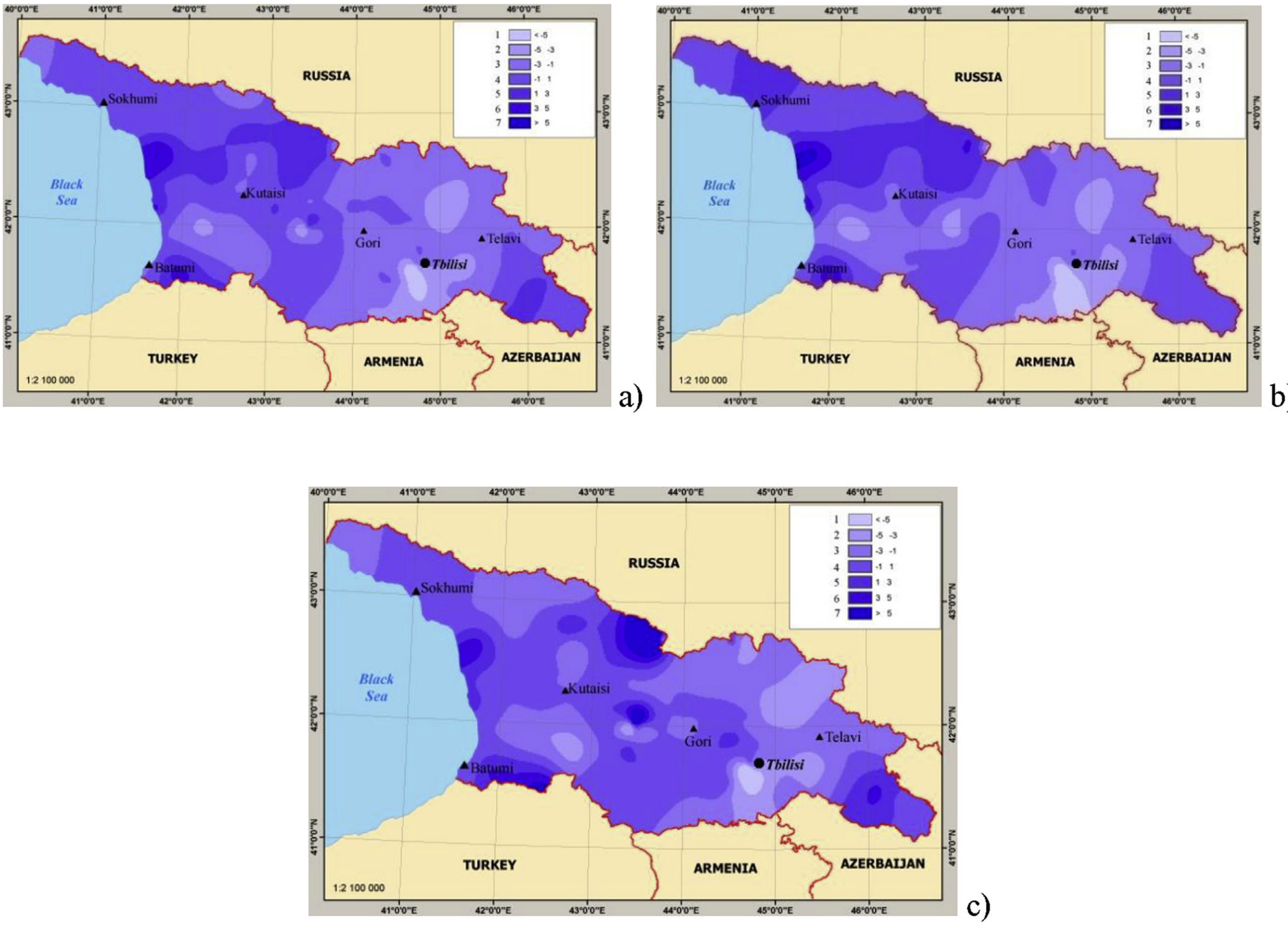

Fig. 5. Decadal trend of precipitation sum %: a)-year; b)-warm period; c)-cold period.

has been decreased by 6–10%. According to Armenian climate scenarios by PRECIS regime model temperature greatest increasing in to 4–6 °C, is expected in summer, and precipitation amount will be decrease significantly [39] (see Table 1).

Against the background of mean air temperature and precipitation amount changes in the territory of Georgia, heat and moisture climatic indices also have experienced changes. Let's discuss the change nature of these indices in selected areas. In Table 2 the average values of some most sensitive to global warming, temperature indices for different averaging periods of 5meteorological stations located in different geographical conditions and characterized areas we have identified have been compared. 1961–1990 period data as the basic period recommended by the WMO and data for the period after 1990 also have been compared.

Table 2 shows that on Georgian Black Sea coastline, the differences between mean values for different averaging periods are recorded in three presented indices. Thus, the cold days number for 1991–2012 year period has been decreased by 3 days in comparison with the WMO basic period (1961–1990). During the same period, hot days number has been increased by 17 days, and the number of tropical nights is increased by 11 days. In the Colchis Lowland in the second averaging period tropical night numbers has been significantly, for 10 nights, increased. Insignificant differences are noted in cold and hot day numbers. In Tbilisi, cold day number is decreased for 11 days, and hot day numbers is increased on 4 days and tropical night number is increased by 3 in comparison to the basic period of the WMO, also increasing of vegetation period duration has been noted. Significant change in the number of hot days in mountainous regions of Georgia was found. During 1991–2012 years period compared to the averaging period

Table 1
Warming (cooling) intensity gradation, and precipitation changes.

Warming intensity (cooling)		Precipitation change intensity	
Temperature decadal trend °C	Intensity	Precipitation decadal trend %	Intensity
less than −0.10	Strong cooling	less than −5	Significant decreasing
−0.06 to −0.10	moderate cooling	−3.1 to −5.0	moderate decreasing
−0.02 to −0.06	weak cooling	−1.1 to −3.0	insignificant decreasing
−0.02 to 0.02	changeless	−1 to 1	changeless
0.02 to 0.06	weal warming	1.1 to 3.0	insignificant increasing
0.06 to 0.10	moderate warming	3.1 to 5.0	Moderate increasing
more than 0.10	strong warming	more thane 5	significant increasing

Table 2
Temperature indices mean values for different averaging period.

Region	Station (elevation m)	Period	Indices			
			FDO	SU25	TR20	GSL
Black Sea coastline	Poti (3)	1961–1990	14	88	32	350
		1991–2012	11	105	43	350
Colchis lowland	Kutaisi (114)	1961–1990	16	122	30	350
		1991–2012	15	125	40	350
Eater Georgia plains	Tbilisi (404)	1961–1990	63	116	23	300
		1991–2012	52	120	26	305
South Georgia highlands	Akhalkalaki (1717)	1961–1990	172	27	0	200
		1991–2012	170	39	0	200
Easter part of Great Caucasus	Pasanauri (1070)	1961–1990	130	48	0	235
		1991–2012	128	65	0	238

recommended by the WMO (1960–1990), the number of hot days in the South Georgian Plateau (Akhalkalaki) has been increased by 12, while on the southern slope of the Greater Caucasus (Pasanauri) the number of hot days has been increased by 17 days.

Decadal trends of temperature climatic indices and corresponding determination coefficients giving the indication on trend contribution to their total variability, and their statistical significances for the above mentioned meteorological stations are presented in Table 3.

Based on the statistically significant values the trends of lot of temperature indices are statistically significant (Table 3). On the Black Sea coast (Poti), where temperature change is insignificant, on the high confidence level cold and hot days and tropical nights number changes are statistically significant. Trends of these indexes are statistically significant at confidence level higher than 95%. The number of cold days decreases by 1.3 days per decade, the number of hot days increase at a rate of more than 7 days and the number of tropical nights increase at rate 5.7 days per decade. According to the determination coefficient contribution to global processes in the index change is 8%, 34% и 42% ($p = 0.05$; 0 and 0) respectively.

In Colchis lowland at confidence level 99% ($p = 0.01$) tropical nights number increasing at rate of 2.7 days per decade is statistically significant.

On the plains of eastern Georgia, characterized by warming, and places by strong warming at high level of statistical significance, all considered temperature indices are detected to be changed except for of hot days number. The cold days number has been decreased at rate of 2.6 days, the tropical nights number has been increased at rate of 1.4 days, and the vegetation period duration has been increased by more than 3 days per decade.

In mountainous areas, hot days number increasing is statistically significant, the increasing rate in the South Georgian Highlands, characterized by strong warming exceeds 3 days, and in the Caucasus is about 1.7 days per decade.

The climatic indices decadal trends of moisture and corresponding determination coefficients as well as their statistical significances for same weather stations are presented in Table 4.

Table 4 shows that most of the moisture indices trends are statistically insignificant. For Poti (Black Sea coast) days number change with precipitation of at least 10 mm are statistically significant, as well as the duration of the rainy and rainless periods. Trends of called indices are statistically significant at confidence level of 93%, 99% and 96% respectively. The days number with precipitation of at least 10 mm is increased at rate of 2 days per decade, the duration of rainless period is decreased by 1.2 days, and the rainy period duration is increased at rate of 0.7 days a decade. According to determination coefficient the contribution of global processes in the change of these indices is 8%, 15% and 10% respectively.

In Kutaisi, in the Colchis lowland, statistically significant changes in moisture indices aren't observed. However, in other areas of the Colchis lowlands are meaningful changes in some of moisture indices, in particular rainless period duration decreasing and the rainy period duration increasing have to be marked.

Despite the general increasing of precipitation level and duration of rainy periods in some areas of the Black Sea coast, the Colchis lowland and mountainous Adjara, the average from precipitation daily maximum in some areas has been decreased.

Table 3
Decadal trends of temperature climatic indices (K), corresponding determination coefficients (R^2) and statistical significances (p) for different physical-geographical conditions.

Region	Station (elevation m)	Parameter	Indices			
			FDO	SU25	TR20	GSL
Black Sea coastline	Poti (3)	K	−1.3	7.3	5.8	0.4
		R^2	0.08	0.34	0.42	0.01
		p	0.05	0	0	0.79
Colchis lowland	Kutaisi (114)	K	1.1	0	2.7	−1.4
		R^2	0.03	0	0.15	0.02
		p	0.18	0.94	0.01	0.26
Eater Georgia plains	Tbilisi (404)	K	−2.6	0.3	1.4	3.1
		R^2	0.33	0.01	0.25	0.13
		p	0	0.35	0	0
South Georgia highlands	Akhalkalaki (1717)	K	0.4	3.7	–	−0.6
		R^2	0.01	0.19	–	0.01
		p	0.77	0.01	–	0.76
Easter part of Great Caucasus	Pasanauri (1070)	K	−1.0	**1.7**	–	1.1
		R^2	0.02	**0.07**	–	0.02
		p	0.18	**0.03**	–	0.28

Note: statistically significant changes are marked bold.

Table 4
The climatic indices decadal trends of moisture (K) and corresponding determination coefficients (R^2) and statistical significance (p) under various physical-geographical conditions.

Indices	Station (elevation)														
	Poti (3)			Kutaisi (114)			Tbilisi (404)			Akhalkalaki (1717)			Pasanauri (1070)		
	K	R^2	p	K	R^2	p	K	R^2	p	K	R^2	p	K	R^2	p
RX1	−1.1	0	0.79	–	–	–	0.2	0	0.77	−0.8	0.01	0.53	−1.6	0.03	0.18
RX5	−3.7	0	0.59	–	–	–	−0.4	0	0.64	1.4	0.01	0.43	0.2	0	0.93
R10	2.0	0.08	0.07	1.6	0.04	0.63	−0.1	0.01	0.32	1.6	0.14	0.01	0.4	0.02	0.28
R20	1.3	0.05	0.17	0.7	0.02	0.67	−0.1	0.01	0.64	0.2	0.04	0.19	0	0	0.84
R50	0.4	0.02	0.35	0.5	0.01	0.30	_	_	_	_	_	_	0	0	0.65
CDD	−1.2	0.15	0.01	−1.5	0.12	0.24	−0.7	0.03	0.07	0.1	0	0.87	0.6	0.04	0.12
CWD	0.7	0.10	0.04	0.8	0.1	0.30	−0.1	0	0.47	0.1	0	0.87	0	0	0.94
SDII	−0.1	0	0.93	0	0	0.95	−0.1	0	0.58	0.3	0.19	0	0	0.06	0.54

Note: statistically significant changes are marked bold.

While keeping these trends on the Black Sea coastline and Colchis lowland, as well as in some parts of the Western Caucasus precipitation will increase by 50% to the end of the century and amount 3000 and 6000 mm respectively that will strengthen these humid areas. Besides increasing of the rainy period duration may constitute the risk for high waters and flooding.

In Tbilisi, characterizing the plains of eastern Georgia, only trend of duration of rainless period is statistically significant. Duration of rainless period has been decreased at rate of 0.7 days per decade.

Increasing of precipitation days number at least 10 mm is statistically significant at high confidence level in Akhalkalaki (South Georgian Highlands), the trend was 1.6 days per decade. In this connection, in this area increasing of precipitation intensity also is high-leveled significant, though the annual precipitation amount does not increase. Trend contribution to increasing of precipitation intensity is 19%.

In Pasanauri, located in the mountainous zone of the Greater Caucasus statistically significant changes in moisture indices haven't been marked.

Conclusion

1 The main feature of air temperature change in Georgia in terms of global warming is more intense warming in eastern continental part of Georgia. Areas of strong warming spread in moderately dry and subtropical dry landscapes of semi-deserts, also in moderately cold and dry mountain-steppe landscapes of eastern Georgia. Areas of greatest cooling (Adzharia and the northern part of the Black Sea coastline) occupy Colchis humid moderately warm and Caucasus humid moderatelycold forest landscapes.

2 In large parts of eastern Georgia annual precipitation sum decreased at a rate of 1–3% per decade. Most precipitation decreasing decadal trend is observed in Kvemo Kartli region, south of Tbilisi, and is more than 5%. In the extreme eastern part of eastern Georgia, characterized by steppe and semi-desert landscapes, as well as in large parts of western Georgia, a significant change in precipitation hasn't been observed. The annual precipitation sum increasing is observed in some parts of Western Georgia-central part of Colchis lowland, the eastern part of Adjara, as well as in the central part of the Iori Plateau in Eastern Georgia, where the decadal trend of annual precipitation was 1–3%. In the mountainous Adjara and in some areas of the Black Sea coastline precipitation increase rate has reached 5%.

3 By the nature of mean temperature long-term changes and precipitation amount in the territory of Georgia there have been allocated 5 regions:Black Sea coastline, characterized by insignificant temperature changes, cooling in some places, the annual precipitation generally increases in some places more than 5% per decade; Colchis Lowland, also characterized by insignificant temperature changes and precipitation increasing in some places up to 5% per decade; The plains of eastern Georgia, characterized by warming, strong warming places and basically by precipitation decreasing; South Georgian Highlands, characterized by strong warming and a insignificant precipitation decreasing and the Greater Caucasus, where in the western part is dominated cooling with a slight annual precipitation increasing, in the eastern part warming is dominated with precipitation insignificant reduction.

4 Trends of most moisture indices are statistically significant. On the Black Sea coastline at high confidence level changes in cold and hot days and the numbers of tropical nights are statistically significant. In Colchis lowland the increasing the number of tropical nights is statistically significant. On eastern Georgia plains, at high statistical significance level, all considered temperature indices change has been detected except for hot days number. The cold days number has been decreased and tropical nights number and vegetation period duration has been increased. In mountainous areas only hot days increasing is significant.

5 Trends of most moisture indices are statistically insignificant. On the Black Sea coastline change in day number with precipitation of at least 10 mm are statistically significant, as well as the duration of the rainy and rainless periods. The day number with precipitation of at least 10 mm increases the duration of rainless period decreases and increases the duration of the rainy period. In Colchis lowland essential statistically significant changes in moisture indices haven't been observed. In Eastern Georgia, statistically significant is only trend of rainless period duration. Duration of rainless period decreases. On the South Georgian Plateau statistically significant at high confidence level is the increasing precipitation of at least 10 mm days. In this connection, in this area also at high level, the precipitation sum intensity increase is significant. In the mountainous zone of the Greater Caucasus substantial statistically significant moisture indices changes haven't been found.

6 While keeping current Georgian climate change trends, precipitation on the Black Sea coastline and Colchis lowland, as well as in some parts of Western Caucasus will increase by 50% and amount to respectively 3000 and 6000 mm, which will strengthen humidity of these areas to the end of the century. Besides, the increase of rainy period duration may constitute risks for flooding. By the end of the century on the eastern Georgia plains, in particular in KvemoKartli, annual precipitation amount will decrease by 50% or more, and will be only

150–200 mm, and the precipitation daily maximum will decrease by about 20 mm and be only 10–15 mm, which naturally intensifies desertification processes of steppe and semi-desert landscapes.

The conducted research expands our understanding of Georgian climate change under the conditions of global warming. New results have been obtained characterizing the change of complex climatic features in difficult geographical conditions in Georgia. However, this does not exhaust the problem of Georgian climate change, many issues and problems still remain unsolved. It is advisable to develop further research of this issue, in the direction of detailed study of spatial and temporal patterns of individual climatic indices, their frequency, intensity and cyclicality, depending on morphometric factors and atmosphere circulation patterns.

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