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Agroclimatic Challenges in the Mountainous and High-Mountain Areas of Georgia under Climate Change (on the Example of Mtskheta-Mtianeti and Samegrelo-Zemo Svaneti)

[1]Maia M. Meladze, [1]Giorgi G. Meladze, [1,2]Mikheil G. Pipia

[1]Institute of Hydrometeorology of the Georgian Technical University, Georgia,
[1,2]M. Nodia Institute of Geophysics of the I. Javakhishvili Tbilisi State University, Georgia,
[1]e-mail: m.meladze@gtu.ge

ABSTRACT

Based on the 70-year-long meteorological observations (in 1948-2017) carried out in the areas of the mountainous and high-mountainous areas of Mtskheta-Mtianeti in east Georgia and Samegrelo-Zemo Svaneti in west Georgia, a trend of changing the agroclimatic features (sum of active temperatures (>10ºC) and atmospheric precipitations (mm)), rise/decline in particular, has been identified under the impact of global warming (as per the designed scenario, at 1ºC and 2ºC increase in temperature). Under the same scenario, the trends of decreasing atmospheric precipitations and hydrothermal coefficients are also seen. Such a decrease results in more frequent drought. As the equations drafted by considering the above-said future (2020-2050) scenarios (1ºC and 2ºC temperature increase), the sums of active temperatures (>10ºC) and agroclimatic zones with the prospect to grow relevant crops were identified.
As per the scenarios developed for global warming, the temperature increase will not have any significant negative impact on the agricultural crops provided it is not higher than the increase forecasted by the scenario. On the contrary, it may be beneficial to grow the agricultural crops at different altitudes from the sea level, by considering vertical zoning, where the 1ºC temperature increase will make it possible to grow the agricultural crops 100-200 m higher and 200-300 m higher with the 2ºC temperature increase as compared to the present zones. However, proper agrotechnical measures against the negative processes caused by the decreased atmospheric precipitations must be developed.

Key words: *climate change, active temperatures, atmospheric precipitations, agricultural crops*

Introduction

In terms of contemporary global climate warming, the problem of slowing down the ongoing climate change and vulnerability and adaptation to it has become a world-wide issue, which was recognized as the major challenge of the UNO at the beginning of the present century. Consequently, the study of the impact of irregular climate change on the productivity and vulnerability of the agricultural crops and expected transformation of the existing agroclimatic zones is necessary and topical.

Global climate warming started in the 1970-80s and it still continues in the XXI century. As per IPCC, under the influence of global warming, the temperature on earth has increased by 0.6ºC. The trend of a temperature increase was confirmed by the studies of the World Meteorological Organization (WMO) and it is an important event for the world, as it influences the ecological balance of the environment established many years ago and the macroclimate as a whole. The global warming may lead to the melting of eternal glaciers, floods, storms, hurricanes, droughts and other natural calamities. As a result, many branches of economy of the world countries, including the agricultural sector, suffer a lot. As the researchers conclude, the present-day frequent natural calamities are caused by both, natural and unforeseen anthropogenic actions. By the end of the XX century, the content of CO_2 in the atmosphere reached 10%. Unless the exhaust fumes are limited, by 2030-2050, the content of carbon gas may double and the temperature may rise by another 2-3ºC. This will lead to the establishment of an absolutely different system of industry and transport and particularly agricultural sector and other branches of economy [1]. Therefore, most world countries must agree to take preventive measures to reduce the emissions of such natural resources as oil, coal, as well as CO_2 and other greenhouses gases from big factories and vehicles into the air. The said emissions create so called “greenhouse effect” in the atmosphere, with an increased near-earth surface temperature as its major outcome. Following the above-mentioned, global warming is a problem to solve by the joint action of the word countries [2, 3, 4].

Global warming has affected the territory of Georgia as well as evidenced by the processing and analysis of the data of many-year meteorological observations. As the studies accomplished in Georgia evidence, a temperature increase of 0.2 and 0.5°C is fixed from humid subtropics in the west of Georgia through the high-mountainous region of Kakheti in the east of Georgia, respectively [5, 6, 7]. These temperatures are to be considered for the future, as in terms of the prolonged global warming, after three or five decades, the temperature increase may reach 2°C or more. Therefore, the impact of global warming on the branches of economy of the country, particularly, on the vulnerable agricultural sector, is to be identified in advance. The increased temperature may have a negative impact on the adapted agricultural crops, particularly in the lowland areas (400-600 m above sea level) as more heat will accumulate at such locations. Therefore, without the irrigation measures, satisfactory yield of such vulnerable cultures, as cereal crops, fruits, vegetable, vineyard, etc. will be very difficult to maintain. Following the above-mentioned, it is important to specify the transformation of agro-climatic zones according to various scenarios of the climate change and relevant agro-technical changes are to be incorporated in it.

In terms of global warming, interesting data of meteorological observations are fixed in relation to the glacier melting on the Caucasioni [8] in the high-mountainous zone of Mestia, where a many-year average air temperature increase of 0.1ºC is observed what supports the melting of glaciers. Another reason for the reduction of glaciers is an increase in temperature by 0.3 and 0.2ºC in the high-mountain zone of east Caucasioni (Jvari Pass, Kazbegi). The given studies, alongside with the increasing trend of sum of active temperatures identified by us, evidence the trend of another kind of (many-year average) temperature increase in terms of global warming, what activates the glacier melting process.

As regards the global warming, the upper limit of the plantation of young birch forest fixed in the high-mountainous zone of Mtskheta-Mtianeti region of east Georgia (on the territory of Kazbegi Municipality) at 2685 m above sea level is noteworthy, while as suggested by the census of 2002, the upper forest limit ended at 2560 m asl. As a result of global warming, the upper limit of the forest is subject to vertical migration [9].

The impact of global warming on the natural environment is immense. For instance, a rise in the near-land air temperature of the crop plantations may be negative in respect of propagation of twice or thrice more new generations of the organisms causing plant diseases. They may appear in the areas where they were not seen before. This will cause problems for agrarian specialists (entomologists, phytopathologists). Therefore, it will be necessary to take relevant efficient measures against them to avoid expected plant diseases reducing the productivity (harvest) by 40-50%. In this connection, we would like to note that in 2017, in Samegrelo-Zemo Svaneti and Imereti regions in west Georgia was seen a massive raid of invasive plant pest brown marmorated stink bug, which was not seen in the region before. The pest badly damaged annual and perennial crops. The agricultural specialists assume that their mass propagation is expected in east Georgia as well and relevant measures were planned against them. Global climate warming is named as the major reason for the propagation of this pest during the vegetation period.

Aims and methods

The goal of the study was, by using the relevant trends, to identify the trend of change of agroclimatic properties (increase/decrease (of the sums of active temperatures (>10°C) and atmospheric precipitations (mm)) under the influence of global warming on the territories of the mountainous and high-mountainous zones of eastern and western regions of Georgia during the vegetation period, which is the major determinant of the plant growth and development and harvest formation and productivity. By using these trends, the dynamics of their change in time could be specified. Another goal of the study was to identify the agroclimatic zones suitable for the satisfactory yield and spread of agricultural crops according to the current (baseline) and future scenarios - in terms of a 1-2ºC temperature increase. A mathematical statistical method was used to process and analyze the data of many-year (70-year-long) meteorological observation for Khaishi and Mestia Municipalities of mountainous and high-mountainous Samegrelo-Zemo Svaneti region in west Georgia and Dusheti and Kazbegi Municipalities of mountainous and high-mountainous Mtskheta-Mtianeti region in east Georgia. Besides, the following materials were used for the same purpose: the meteorological and agro-meteorological databases of the Institute of Hydrometeorology of Georgian Technical University; the data of many-year (1948-2017) baseline (current) meteorological observations of the vegetation period obtained from the National Environmental Agency of Georgia (the sums of average daily air temperatures and atmospheric precipitations); besides, the data of future scenarios (1 and 2ºC temperature increase by 2020-2050) were processed, which were obtained by regional climatic model RegCM-4 and social-economic development scenario A1B1 [10].

Results and discussion

Samegrelo-Zemo Svaneti region in west Georgia is located on the south-eastern slope of the West Caucasioni. The humid subtropical climate in the region is spread from the Black Sea coastline to north-west, up to 500-600 m above sea level, (moderate) mountainous climate dominates up to 1400-1500 m a.s.l., and high-mountainous (continental) climate dominates up to 2500 m a.s.l., Mtskheta-Mtianeti region of east Georgia is located on the southern slope of the Great Caucasioni, stretching from west to north-east. It has dry subtropical climate up to 400-600 m above sea level, as well as moderate mountain climate up to 1400 m a.s.l., and high-mountainous continental climate up to 2500 m a.s.l. As a result of the treatment and analysis of the data of current (baseline) average monthly air daily temperatures in the given regions, the dates of spring and autumn temperature shift above and below 10ºC were identified with equations:

$$y=-2.4_X+79 \text{ (in spring)}$$
$$y=3.2_X-33 \text{ (in autumn)}$$

where y - is the dates of temperature shift above and below 10ºC in spring and autumn;

x - is the sum of average temperature of two months in spring and autumn (in particular, of February and March or March and April in spring and of September and October or October and November in autumn) [11, 12].

In addition, the monthly sums of atmospheric precipitations in the warm period (IV-X) were calculated for different years (Tab. 1).

Table 1. Agroclimatic characteristics of mountainous and high-mountainous regions of Georgia (1948-2017)

Region/ Zone	Meteo-station, (mm) a.s.l.	Data of transition air temperature t>10°C	Data of transition air temperature t<10°C	Duration of the vegetation period	Sums of active temp. >10°C (IV-X)	Sums of active temp. <10°C (VI-VIII)	Atmospheric precipitations (mm), (IV-X)	Hydrothermal index (HTC) (IV-X)
Samegrelo-Zemo Svaneti, west Georgia/ mountainous	Khaishi, 730	11.IV	22.X	194	3336	1846	662	2.0
high-mountainous	Mestia, 1441	10.V	28.IX	141	2014	1447	440	2.2
Mckheta-Mtianeti, east Georgia/ mountainous	Dusheti, 922	18.IV	20.X	185	3095	1792	509	1.6
High-mountainous	Kazbegi, 1744	21.V	22.IX	124	1628	1288	476	3.0

The Table shows that in the mountainous zone of Samegrelo-Zemo Svaneti region (west Georgia), the date of the temperature transition above 10ºC in spring is observed on 11.IV, while the date of the temperature transition below 10ºC in autumn is observed on 22.X. As the scenario suggests, in the given zone, in case of a temperature increase by 1ºC, the date of the temperature transition above 10ºC in spring is observed on 6.IV and the date of the temperature transition below 10ºC in autumn is observed on 28.X (Tab. 2).

Table 2. The dates of air temperature transitions above and below 10ºC, duration of the vegetation period (days) and sums of active temperatures (>10°C) in the mountainous and high-mountainous regions of Georgia under the scenarios of the air temperature increase by 1ºC and 2ºC

Region/ Zone	Meteo-station	t>10°C Starting time	t<10°C Finishing time	duration of vegetation period (day)	ΣT>10°C
Samegrelo-Zemo Svaneti/ mountainous	Scenario, rise of temperature by 1°C				
	Khaishi	6.IV	28.X	205	3525
high-mountainous	Mestia	6.V	3.X	150	2206
Mckheta-Mtianeti/ mountainous	Scenario, rise of temperature by 2°C				
	Dusheti	10.IV	31.X	204	3581
High-mountainous	Kazbegi	12.V	1.X	142	2128

In spring, in case of the scenario, the date of the temperature above 10ºC in spring is observed 5 days earlier and the date of the temperature below 10ºC in autumn is observed 6 days later as compared to the current (baseline) value (Tab. 1), i.e. the vegetation period is prolonged from 194 days (current, Tab. 1) to 205 days (scenario, Tab. 2), or by 11 days. The vegetation period in the high-mountainous zone of the same region is prolonged by two days less. For instance, in the high-mountainous zone, the date of the temperature above 10ºC in spring is observed on 6.V in case of 1ºC temperature rise under the scenario (Tab. 2) making a difference of 4 days as compared to the current value (10.V) (Tab. 1), while in autumn, the date of the temperature shift below 10ºC is observed on 3.X (scenario, Tab. 2) making a difference of 5 days as compared to the baseline value (28.IX) (Tab. 1). The above-given prolonged days in spring (at the expense of date of the temperature transition above 10ºC occurring 4-6 days earlier) and in autumn (at the expense of date of the temperature transition below 10ºC occurring 6 days later), in the mountainous and high-mountainous zones allow realizing the agrotechnical measures within relevant terms.

Following the global warming, the sums of active temperatures (>10°C) in the mountainous and high-mountainous zones of the considered regions are given. Such a sum in the mountainous zone is 3336ºC (baseline, Tab. 1) and 3525ºC in case of a 1ºC temperature increase under the scenario (Tab. 2). In the future, the sum of temperatures increased above the baseline value (189ºC) will be beneficial (in terms of satisfactory soil moisture) to get rich harvest of cereals (corn, wheat, barley), legumes, vegetable, vineyard, fruit and other crops.

The sum of active temperatures in the high-mountainous zone is 2014ºC (baseline, Tab. 1) and is 2206ºC in case of a 1ºC temperature increase under the scenario (Tab. 2). In the future (2020-2050), the sum of active baseline temperatures is expected to increase by 192ºC, what, in the high-mountainous zone will improve the productivity of cereals, vegetable, early fruit varieties, berries, roots for animal forage („Kuuziku", „ESCO") and support the development and high yield of pastures and hayfields and sustainable development of forest landscapes.

Mtskheta-Mtianeti region in east Georgia has somewhat different climatic features as compared to Samegrelo-Zemo Svaneti region in east Georgia [13]. Here, as the meteorological observation data in the mountainous zone of Dusheti Municipality suggest, the date of the temperature above 10ºC is observed on 18.IV, while the date of the temperature below 10ºC is observed on 20.X (baseline, Tab. 2). As per the scenario of the future, in case of a 2ºC rise in temperature (such a rise is considered as in the eastern regions of Georgia, the trend of the temperature increase is more obvious), the date of the temperature above 10ºC is observed on 10.IV, while the date of the temperature below 10ºC is observed on 31.X (Tab. 2). In other words, in case of the scenario, in spring, the date of the temperature above 10ºC occurs 8 days earlier, while in autumn the date of the temperature below 10ºC occurs 11 days later (Tab. 2) as compared to the baseline values (Tab. 1). The vegetation period in the mountainous and high-mountainous regions in question is prolonged by 19-18 days (Tab. 1 and 2, respectively). With such extra days, in spring, the vegetation of pasture and hayfield grasses will be possible to start earlier and prepare nomadic cattle to take to the pastures. In autumn, it is possible to produce more and better forage for winter from hayfields and accomplish other agricultural activities. The given zone will also be beneficial to grow and propagate berries.

By considering the global warming, the sum of active temperatures in the mountainous and high-mountainous zones of the given region in case of a 2ºC temperature rise under the scenario (2030-2050), is 3581ºC in the mountainous zone (Tab. 1) what significantly exceeds (by 486ºC) the sum of baseline active temperatures - 3095ºC (Tab. 1). The temperature in the high-mountainous zone, in case of a 2ºC temperature rise under the scenario, rises similarly (by 500ºC) as compared to the sum of baseline active temperatures (1628ºC) (Tab. 1).

An increase in the sums of active temperatures in the mountainous and high-mountainous zones of the given region by 500ºC on average will be absolutely suitable to develop and ensure satisfactory yield of crops and forest landscapes. As per Tab. 1, following the analysis of the amount of atmospheric precipitations in the above-considered regions, such an amount is actually sufficient to grow crops and develop other forest landscapes in the vegetation period. However, in some droughty years, lack of precipitations may be the case. In such a case, the desirable yield of the crops can be maintained by increasing soil humidity (by irrigation, soil surface tillage, etc.).

The data of the above-mentioned 70-year-long (1948-2017) meteorological observations cover the initial period of global climate warming, the 1970-80s in particular, marked by the onset of the general influence of global warming on a near-surface temperature rise and agroclimatic resources (sums of active temperatures (>10°C) and atmospheric precipitations (mm), etc.) consequently. In order to present these values clearly, the data of 70-year-long observations mentioned above were divided into two 35-year-long periods. The I period covers the years of 1948-1982, and the II period covers the years of 1983-2017 (Tab. 3).

Table 3. Agroclimatic characteristics according to the periods (1948-1982; 1983-2017) of the mountainous and high-mountainous regions of Georgia

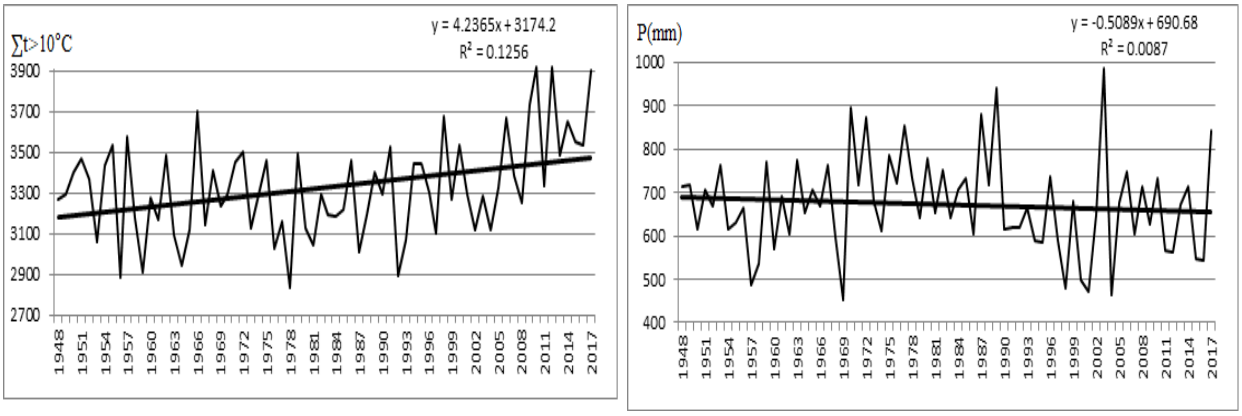
Region/ Zone, Meteostation	I and II periods	Data of transition air temperature t>10°C	Data of transition air temperature t<10°C	Duration of the vegetation period	Sums of active temp. >10°C (IV-X)	Sums of active temp. <10°C (VI-VIII)	Atmospheric precipitations (mm), (IV-X)	Hydrothermal index (HTC) (IV-X)
Samegrelo-Zemo Svaneti/ mountainous, Khaishi (Mestia)	1948-1982	12.IV	21.X	192	3298	1824	664	2.0
	1983-2017	9.IV	24.X	198	3374	1869	659	1.9
high-mountainous, Mestia	_ ,, _	11.V	26.IX	138	1945	1411	451	2.3
	_ ,, _	10.V	30.IX	143	2084	1483	428	2.0

Mckheta-Mtianeti/ mountainous, Dusheti	1948-1982	20.IV	20.X	183	3049	1751	522	1.7
	1983-2017	15.IV	21.X	189	3141	1832	495	1.6
High-mountainous, Kazbegi	_ ,, _	22.V	18.IX	119	1571	1271	516	3.2
	_ ,, _	21.V	25.IX	127	1684	1305	435	2.9

The analysis of the Table demonstrates that in different municipalities of the region, in the second period, the date of the onset of active air temperatures (>10°C) occurs earlier and the date of the temperature below 10°C ends later as compared to the first period. In the same period, the sums of active temperatures are increased and the vegetation period is prolonged. In the second period, the sums of atmospheric precipitations, as well as hydrothermal coefficients (HTC) in the warm period (IV-X) are decreased at all locations. The sums of atmospheric precipitations (mm) in high-mountainous zones (Mestia, Kazbegi) are given for the periods of IV-IX months and VI-VIII months, respectively, as the warm period (with temperatures above 10ºC) in the given months starts late and ends early. In the second period, i.e. for the last 35 years, the amount of precipitations and consequently, the hydrothermal coefficients have decreased. Despite this, if the precipitations do not reduce further, they will be sufficient to grow cereal crops, vegetable and other annual crops, as well as succulent roots for animal forage („Kuuziku", „ESCO") and pasture and hayfield grasses with (one-time) irrigation in some years.

The dynamics of the course of the said indices was presented with trends, according to which, the trends of increasing sums of active temperatures (>10°C) and decreasing sums of the atmospheric precipitations (mm) were identified in the mountainous and high-mountainous regions of west Georgia and mountainous and high-mountainous regions of east Georgia (Fig. 1, 2).

Khaishi



Mestia

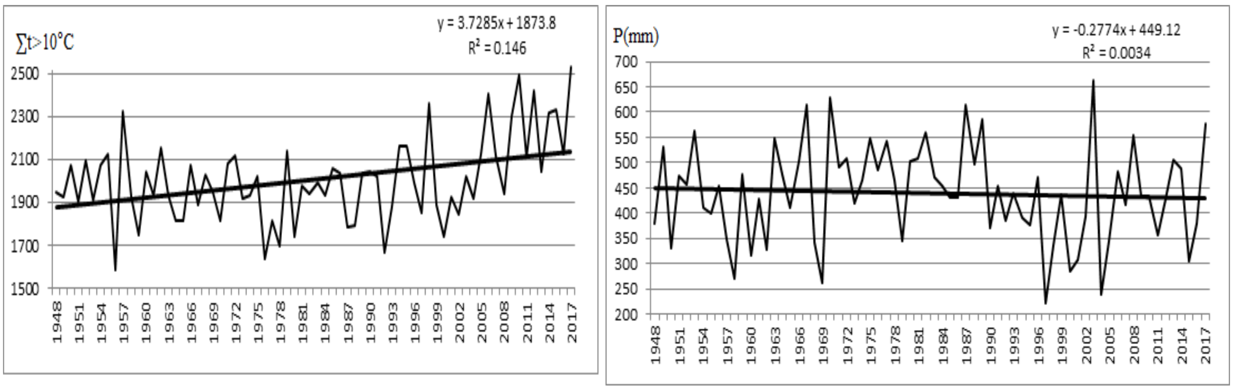


Fig. 1. Dynamics of the sums of active temperatures (>10°C) and atmospheric precipitations (mm) in Samegrelo-Zemo Svaneti region of the mountainous and high-mountainous zones of Georgia (1948-2018)

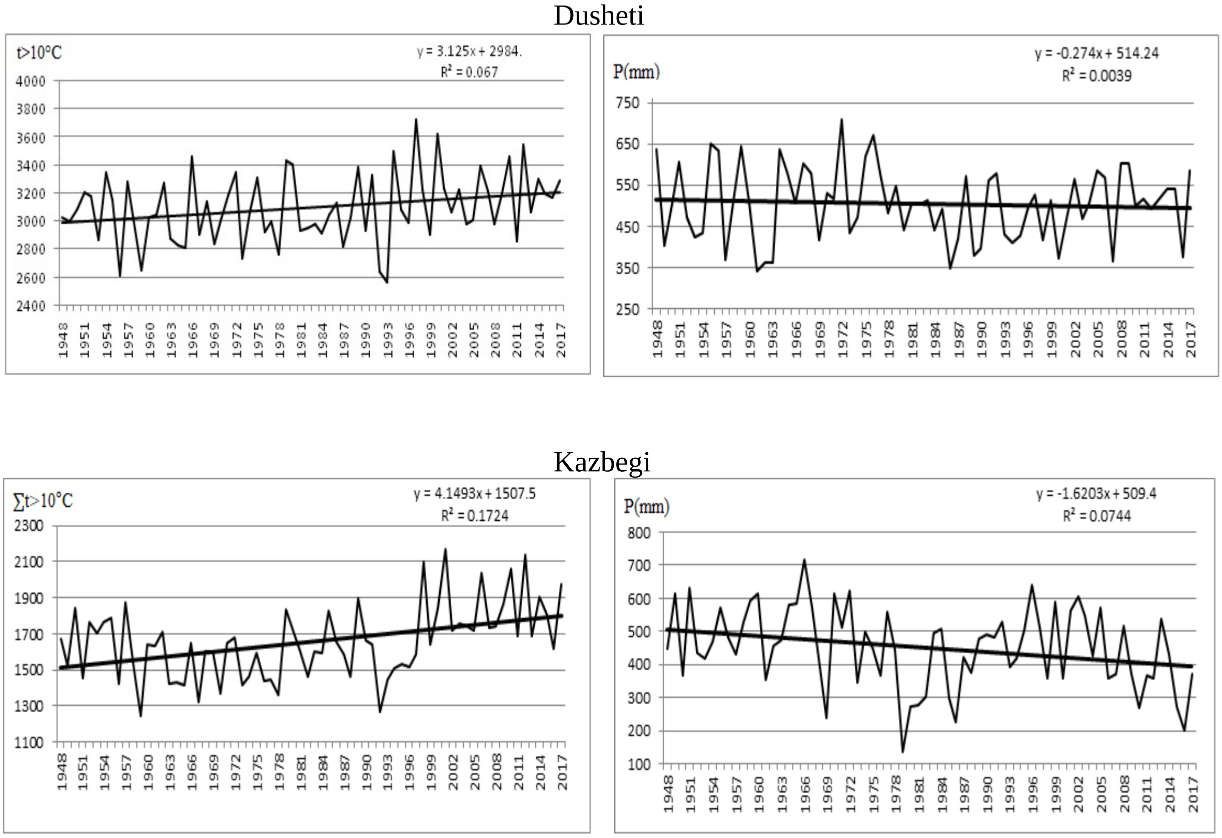


Fig. 2. Dynamics of the sums of active temperatures (>10°C) and atmospheric precipitations (mm) in Mcxeta-Mtianeti region of the mountainous and high-mountainous zones of Georgia (1948-2018)

The equations of the trends were used to calculate increasing and decreasing trends of the sums of active temperatures (>10°C) and atmospheric precipitations (mm) (Tab. 4).

Table 4. The sums of active temperatures (>10°C) and atmospheric precipitations (mm) according to trends

Region/ Zone	Meteo-station	Sum of active temperatures (>10°C)					
		Beginning of the period	End of the period	Increase	Decrease	Average speed in every 10 years	
						Increase	Decrease
Samegrelo-Zemo Svaneti/ Mountainous	Khaishi	3178	3470	292		41.7	
High-mountainous	Mestia	1877	2134	257		36.7	
Mckheta-Mtianeti/ Mountainous	Dusheti	2987	3203	216		30.7	
High-mountainous	Kazbegi	1511	1797	286		40.8	
Samegrelo-Zemo Svaneti/ Mountainous	Khaishi	Sum of atmospheric precipitations (mm)					
		690	655		35		5.0
High-mountainous	Mestia	449	430		19		2.7
Mckheta-Mtianeti/ Mountainous	Dusheti	514	495		19		2.7
High-mountainous	Kazbegi	507	388		119		17.0

As the given Table shows, there is a trend of decreasing atmospheric precipitations (119 mm) in the high-mountainous zone of east Georgia. The average velocity of the given reduction is 17 mm in every 10 years. The increasing and decreasing trends of agroclimatic values in other zones are relatively less.

If, under the influence of global warming, the sum of active temperatures in a similar period continues to increase, after 4 or 5 decades, the sum of current (baseline) temperatures may increase significantly (reaching 300ºC or more) in the mountainous and high-mountainous zones of eastern and western regions of Georgia. This may be beneficial to grow crops in the mountainous and high-mountainous zones successfully (in terms of sufficient atmospheric precipitations). It seems that the amount of precipitations decreases in the given zones. Therefore, unless the proper soil moisture is maintained, no satisfactory development or yield of the crops is possible.

In order to identify the agroclimatic zones in the above-said regions, the scenarios consider a 1ºC temperature increase in the regions of west Georgia and a 2ºC temperature increase in the regions of east Georgia. The dates of average daily air temperature above 10ºC, sums of active temperatures and altitude above sea level (m) were used for this purpose. The latter is in direct correlation with the regular change in air temperature depending on the altitude [14]. The given data were processed by using the mathematical statistics method adopted in agrometeorology with close correlations established. Following the obtained reliable associations, relevant regression equations were drafted (Tab. 5). At different times, the equations of the given type were used to identify the sums of active temperatures to identify the relevant zones of crops [15].

Table 5. Regression equations to determine the dates of average daily air temperature transition above 10ºC and sums of active temperatures in the mountainous and high-mountainous regions of Georgia

Determination of starting date t>10°C and ∑T	Current (baseline), mountainous and high mountainous (west Georgia)	Scenario, increase by 1°C, mountainous and high mountainous	Current baseline, mountainous and high mountainous (east Georgia)	scenario, increase by 2°C mountainous and high mountainous
determination of starting date (t>10°C)	n=0.025h+57	n=0.028h+51	n=0.029h+55	n=0.035h+38
determination of ∑T	T=-36.53n-0.75h+6537	T=-16.711n-1.127h+5496	T=-30.923n-0.57h+6085	T=-44.25n-0.15h+6742

In the equations: n - is the number of days from the 1st of February to the date of the temperature above >10ºC; h - is the altitude above sea level (m); T - is the sum of active temperatures (>10°C).

By using the given equations, the sums of active temperatures by considering the current (baseline) values and future (2020-2050) scenarios (a temperature increase by 1 and 2ºC) were identified and the agroclimatic zones of the distribution of crops in the regions were defined [16].

The mountainous area of the region spreads from 500 to 1500 m above sea level of the humid subtropical zone of Samegrelo-Zemo Svaneti region of west Georgia, where two agroclimatic zones (I and II) were identified:

The I agroclimatic zone extends from 500 m to 1000 m altitude above sea level. The sum of baseline active temperatures is 3620-2790°C and is 3800-3110°C under the scenario with a 1°C temperature increase. Juglandaceous plants, fruit and vegetable varieties and other crops grow well in the given zone. Under the future scenario with a 1°C temperature increase, vine varieties (Tsolikauri, Tsitska) may be grown from 700-800 to 1000 m and tea culture may be grown slightly higher, at 600-700 m.

The II agroclimatic zone extends from 1000 m to 1500 m altitude above sea level. The sum of current (baseline) active temperatures is 2790-1960°C and is 3110-2430°C under the scenario. Under the future scenario, the areas with wheat, (winter, spring) barley, oats, potato and vegetable crops at the altitude of 1400-1500 m (baseline) well extend to reach 1600-1750 m altitude and higher, while the area with grain maize may be extended from 900 m (baseline) to 1200 m s.l., for industrial purposes; the areas with fruits may be extended from 1300 m (baseline) to 1400-1450 m a.s.l., or higher.

Higher mountainous area of the given region, from 1500 to 2500 m altitude, there extends the high-mountainous area of the region, where two agroclimatic zones are identified (III and IV).

The III agroclimatic zone extends from 1500 to 2000 m altitude. The sum of baseline active temperatures in the given zone is somewhat reduced and makes 1960-1130°C on average and 2430-1760°C in case of the scenario. With its heat regime, the region will offer more suitable conditions to grow (winter, spring) wheat, barley, oats, potatoes, berries (blackcurrant, redcurrant, sea-buckthorn, raspberry and haw) as compared to the baseline conditions. The areas with juicy roots as animal forage („Kuuziku",„ESCO") and pastures and hayfields will be possible to expand.

The IV zone agroclimatic zone extends from 2000 m to 2500 m altitude above sea level. The sum of baseline active temperatures in the given zone is 1130-300°C. The sum of temperatures is obviously reduced, and it is 630°C (baseline) at the altitude of 2300 m. Growing the given crops (juicy root forage) at the given temperature is not profitable. Under the scenario (a 1ºC temperature rise), the sum of active temperatures (>10°C) is 1760-1080°C. At the altitude of 2300 m (under the scenario), the sum of active temperatures is up to 1350°C what, as compared to the baseline temperature, is suitable to grow the above-mentioned root crops as cattle forage and expand pastures and hayfields.

In respect of global warming, the air temperature in Mtskheta-Mtianeti region in east Georgia is increasing more. As it was noted, the temperature is risen by 0.5°C here unlike Samegrelo-Zemo Svaneti region in west Georgia. Therefore, a 2ºC temperature increase is considered by the scenario, where 3 agroclimatic zones were identified [17, 18, 19]:

The I agroclimatic zone spreads from 1000 m to 1500 m altitude above sea level in the west and south-east of the region. This zone covers the mountainous areas of Dusheti and Tianeti Municipalities. The sum of current (baseline) active temperatures is 2920-2180°C and is 3360-2500°C under the scenario (a 2ºC temperature increase). Wheat (winter, spring), barley, oats, maize (at 1300 m and higher), vine (early and mid ripening varieties), nut, potatoes and vegetable crops can be grown and produced in the given zone. It is desirable to irrigate (once or twice) or loosen the soil in the given zone, particularly in the period of the VI-VIII months.

The II agroclimatic zone belongs to the high-mountainous region, which is located up to 2000 m in the east. The sum of current (baseline) active temperatures is 2180-1450°C and 2500-1660°C under the scenario. Under the future scenario (a 2ºC temperature increase), the sum of temperatures, as compared to the sum of baseline temperatures, is almost 300°C more. The sum of the temperature increase will favor the growth of wheat, barley, oats, potatoes, vegetables, berries (blackcurrant and redcurrant), willow-leaved sea-buckthorn and early fruit varieties, as well as juicy roots as animal forage („Kuziku", „ESCO") and development and extension of pastures and hayfields.

The III high-mountainous agroclimatic zone spreads from 2000 m to 2500 m altitude above sea level. It covers the upper border of the subalpine zone. In this high-mountainous region, the sum of baseline active temperatures is obviously reduced (to 700ºC) making the area non-favorable to grow vegetables or juicy root forage, particularly at 2400-2500 m a.s.l., while at 2300 m, the sum of baseline temperatures is approximately 1000°C. With such a temperature range, growing the said crops or developing pastures and hayfields will be non-profitable. Under the future scenario (a 2ºC temperature increase), the sum of active temperatures will be 1150-800°C; however, at the altitude of 2500 m, the temperature of 800°C is not sufficient to grow the above-listed crops, while at the altitude of 2300-2400 m, the sum of temperatures is 1150-1000°C offering better conditions to grow the same crops.

Conclusion

The results of our studies evidence the impact of global climate warming on Mtskheta-Mtianeti mountainous and high-mountainous regions of east Georgia and Samegrelo-Zemo Svaneti mountainous and high-mountainous regions of west Georgia. It is obviously responsible for the increased sums of active temperatures (>10°C), prolonged vegetation period, decreased atmospheric precipitations (mm) and decreased hydrothermal coefficient (HTC) causing droughts.

The increase of the sum of active temperatures above the current (baseline) value in the mountainous (3525ºC) and high-mountainous (2206ºC) areas of Samegrelo-Zemo Svaneti in the west is 189ºC and 192ºC, respectively. The vegetation period in the mountainous and high-mountainous areas has increased by 11 and 9 days, respectively. An increase in the sum of active temperatures in the mountainous (3581ºC) and high-mountainous (2128ºC) areas of Mtskheta-Mtianeti in the east is 486ºC and 500ºC, respectively, and the vegetation period has increased by 19 and 18 days, respectively.

The mountainous zone of Samegrelo-Zemo Svaneti region in west Georgia spreads above the humid subtropical zone of the region, 500 to 1500 m above sea level, where two agroclimatic zones were identified, and the high-mountainous zone of the same region spreads from 1500 to 2500 m above sea level, with two agroclimatic zones. Three agroclimatic zones were identified in Mtskheta-Mtianeti region in east Georgia. The I mountainous zone spreads from 1000 to 1500 m altitude, the II high-mountainous zone spreads up to 2000 m altitude, and the III high-mountainous zone spreads from 2000 to 2500 m altitude.

The future scenarios (2020-2050), or 1 or 2ºC temperature rise in terms of global warming will not have a significant influence on the agricultural crops in the zones of the study regions unless the temperature in the process of global warming is higher than that envisaged by the scenario. Just on the contrary, it may be suitable to grow agricultural crops at different altitudes above sea level, where in the future, in case of 1ºC temperature rise, growing the agricultural crops will be possible 100-200 m higher and 200-300 m higher in case of 2ºC temperature rise as compared to the present-day zones.

In the considered region, in the zones designated to grow the above-listed crops, where high-mountainous villages of Mestia Municipality (e.g. Ushguli (2200 m asl)), villages of Dusheti Municipality (Khone (2150 m a.s.l.), Roshka (2050 m a.s.l.)), villages of Kazbegi Municipality (Juta (2200 m asl)) and other villages (Akhieli, Shatili, at relatively lower altitudes) are located, the agricultural specialists and agricultural farmers, together with the local residents, with the future perspective, will be able to grow the crops profitable for them and to produce high-quality products with them to be used by the residents of the above-listed villages. If necessary, they will even realize some of the products. This will promote the employment and establishment of the local residents what will support the reduction of depopulation in the mountainous and high-mountainous zones of the country. As a result, the social-economic conditions will improve. These activities are supported by the Law of Georgia ,,On the Development of High Mountainous Regions" adopted by the Government of Georgia on July 16, 2016 as well. In particular, the goal of the Law is to ensure the wellbeing of the residents in the high-mountainous regions of Georgia, support employment and improve the quality of life and social-economic conditions. In line with this major Law, the results of the study conducted by us for high-mountainous regions given in the present work are worthwhile. It should be noted that the given regions with their natural location (relief and orographic conditions, diversified forest landscape, etc.) are interesting and attractive. They have good prospects to develop tourism and recreation activities in summer, autumn and winter seasons. On the territory of Mestia (located at 1500 m above sea level and higher), ski mountaineering is very popular sports in autumn and winter seasons, while sporting activities organized in Gudauri Ski Resort (at 2200 m above sea level and higher) are also very important.

Following the global warming, certain mitigation and adaptation measures against some negative events are recommended to use in the agrarian sector at present and in the future. Growing selective crops, which are resistant to higher temperatures and droughts, is a good choice. Besides, it is important to make terraces over the mountain and high-mountain slopes (with >10° gradient) to reduce intense evaporation of water runoff and water from soil; soil surface cultivation and loosening to reduce water evaporation from the soil is another efficient measure. Besides, efficient use of modern irrigation and drip irrigation and other methods will be beneficial.

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აგროკლიმატური გამოწვევები საქართველოს მთიან და მაღალმთიან ტერიტორიებზე კლიმატის ცვლილების პირობებში (მცხეთა-მთიანეთის და სამეგრელო-ზემო სვანეთის მაგალითზე)

მ. მელაძე, გ. მელაძე, მ. ფიფია

რეზიუმე

საქართველოს აღმოსავლეთ მცხეთა-მთიანეთის და დასავლეთ სამეგრელო - ზემო სვანეთის მთიანი და მაღალმთიანი რეგიონების ტერიტორიებზე ჩატარებული 70 წლიანი (1948-2017) მეტეოროლოგიური დაკვირვებების საფუძველზე, გამოვლენილია გლობალური დათბობის გავლენით აგროკლიმატური მახასიათებლების (აქტიურ ტემპერატურათა (>10°C) და

ატმოსფერული ნალექების (მმ) ჯამების) ცვლილების ტენდენცია - მატება/კლება (სცენარით, ტემპერატურის 1 და 2°C-ით მატებისას).
საკვლევ ტერიტორიებზე აღნიშნული სცენარების მიხედვით, გამოვლენილია ატმოსფერული ნალექების და ჰიდროთერმული კოეფიციენტების კლების ტენდენციები, რაც გვალვების განმეორადობის გახშირების მიზეზია.
ზემოაღნიშნული მომავლის (2020-2050) სცენარების (1 და 2°C-ით მატება) გათვალისწინებით შედგენილი განტოლებებით, განისაზღვრა აქტიურ ტემპერატურათა ჯამები (>10°C) და გამოიყო აგროკლიმატური ზონები, შესაბამისი კულტურების გავრცელების პერსპექტივით. სადაც, 1°C-ით მატებისას აგროკულტურების გავრცელება შესაძლებელი იქნება 100-200 მ-ით, ხოლო 2°C ით მატებისას 200-300 მ-ით უფრო მაღლა, არსებულ ზონებთან შედარებით. თუმცა, გასათვალისწინებელია შემცირებული ატმოსფერული ნალექებით გამოწვეული ნეგატიური პროცესების მიმართ შესაბამისი აგროტექნიკური ღონისძიებების შემუშავება.

საკვანძო სიტყვები: კლიმატის ცვლილება, აქტიური ტემპერატურა, ატმოსფერული ნალექები, აგროკულტურა

Агроклиматические вызовы в горных и высокогорных регионах Грузии в условиях изменения климата (на примере Мцхета-Мтианети и Самегрело-Земо Сванети)

М.Меладзе, Г.Меладзе, М.Пипиа

Резюме

На основе 70-летних (1948-2017) метеорологических наблюдений, проводимых в горных и высокогорных регионах Восточной Мцхета-Мтианети и Западной Самегрело-Земо Сванети Грузии, выявлена тенденция изменения агроклиматических характеристик (суммы активных температур (>10°C) и атмосферных осадков (мм)) под влиянием глобального потепления - повышение/снижение (сценарий с повышением температуры на 1 и 2°C).
По указанным сценариям на территориях исследований выявлены тенденции снижения атмосферных осадков и гидротермических коэффициентов, что является причиной повторяемости засух.
С использованием уравнений, разработанных с учетом выше указанных сценариев будущего (2020-2050 гг.) (повышение температуры на 1 и 2°C), определены суммы активных температур (>10°C) и выделены агроклиматические зоны с учетом перспектив распространения соответствующих сельскохозяйственных культур. Где при повышении температуры на 1°C можно распространение сельскохозяйственных культур на 100-200 м выше, а при повышении температуры на 2°C - на 200-300 м выше по сравнению с существующими зонами. Однако необходимо рассмотреть вопрос разработки соответствующих агротехнических мероприятий по устранению негативных процессов, вызванных уменьшением количества атмосферных осадков.

Ключевые слова: изменение климата, активная температура, атмосферные осадки, сельскохозяйственная культура