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Geophysics

East Georgia Glacial Basins Degradation Dynamics Under the Impact of Current Climate Change

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Modern glaciation is unevenly distributed between different regions of the Earth. Glaciers in Georgia are spread on the ridge of the Greater Caucasus concentrated in the Enguri, Rioni, Kodori, Tergi and some other rivers basins. The impact of current climate change on the glaciers is most visible in the changes in the characteristics of the glacial basins. The only way to scientifically study the effects of current climate change on glaciers is to use high-resolution satellite remote sensing, as this technology allows simultaneously studying the state of glaciers over a large area with the required resolution and accuracy, with limited material resources and restricted time. The authors address these issues along with SRS data using complex, integrated applications of historical data on glaciers (glacier catalogue), existing fieldworks, and expert knowledge. The East Georgia rivers' glacial basins degradation dynamics were researched to study the current climate change impact on the glaciers by making a comparison of the characteristics of glaciers (area and number) for three-time moments. A comparison of these conditions showed that the area and number of glaciers are greatly decreasing due to climate change. The glacier's degradation is nonlinear, which makes the melting of glaciers in the second period more intense than in the first one. This result fully reflects the main thesis of the Sixth Report of the Intergovernmental Panel on Climate Change that climate change is not as troubling as its speed. The issues of Georgian glacier degradation due to the current climate change were discussed at various high-level forums. For the latest time, it is worth noting that at the end of 2021, at the Glasgow Climate Change Conference (COP 26) the Georgian delegation has a presentation on the dynamics of glacial degradation in East Georgia due to climate change. The main results of glaciers' degradation due to the climate change impact were included in the Fourth National Communication of Georgia to the UN Framework Convention on Climate Change. *© 2022 Bull. Georg. Natl. Acad. Sci.*

Glacial basins, glaciers, degradation dynamics, climate change, satellite remote sensing

Glaciers are a unique part of the Earth's geographic crust, where solid atmospheric precipitation is transformed into ice after accumulation. They are the largest reservoirs of fresh water and one of the

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most important resources. Modern glaciation is unevenly distributed between different regions of the Earth and various river basins. The study of glaciers has gained more importance since the second half of the twentieth century due to the negative impact of the anthropogenic nature of global warming [1]. Current climate change has a very negative impact on the cryosphere, in particular, on glaciers [2].

Glaciers in Georgia are spread in the North part of the country on the ridge of the Greater Caucasus located in the Enguri, Rioni, Kodori, Tergi and some other rivers basins, where there are 3500 m and higher peaks. Due to the degradation of glaciers, a change in the water balance and degradation of landscapes, an increase in the level of the Black Sea and the growth of the natural disasters' frequency and intensity of glacial origin [3] are having a place. This poses a serious threat to the sustainable development of the country and, therefore, the study of glaciers has become a priority in the research program of Georgia.

Methodology and Data

Large-scale glaciological scientific studies of glaciers of Georgia were started in 1860 by researchers from the Russian Empire and then were prolonged by glaciologists from the former Soviet Union mainly by field works in 1917-1970. The gathered data regarding the glaciers of Georgia in the time range 1960-65 were systematized and cataloged as part of the Caucasian glacier system and several editions of the glacier catalogue (hereinafter – the catalogue) of the former Soviet Union [4] was issued.

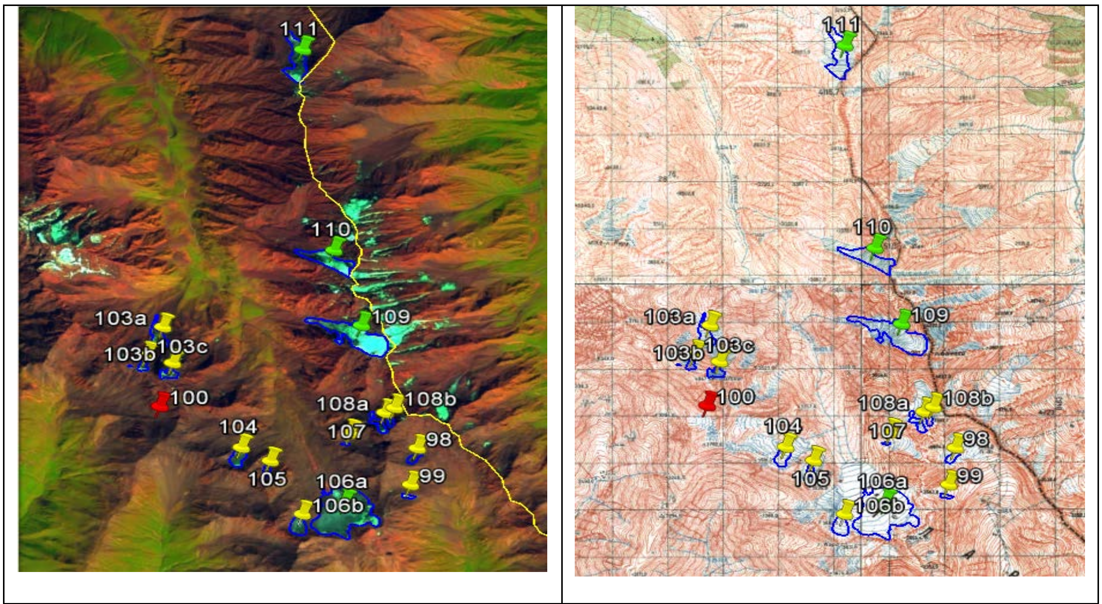
Georgia's Second and Third National Communications to the UN Framework Convention on Climate Change [5,6] analyze climate change's influence on glaciers, particularly those existing in the Zemo and Kvemo Svaneti regions of Georgia. The information highlighted in these papers is incomplete because the complexity of field glaciological research makes simultaneous monitoring of all glaciers impossible. The only way to reduce significantly these uncertainties existing in the abovementioned communications is to carry out the glaciological studies with the help of high-resolution satellite remote sensing (SRS).

After the collapse of the Soviet Union, field glaciological monitoring was significantly reduced in Georgia. To give a science-based response to glacier melting caused by the current climate change, it is necessary to use a high-resolution SRS for two reasons. First, currently, it is impossible to carry out the costly ground observations at a necessary scale; and second, in resource- and time-constrained environment, SRS allows conducting simultaneous glacier monitoring on large territories with the necessary resolution and accuracy in conditions of limited resources and restricted time.

The processing of glaciers images has made it possible to identify the main characteristics of glaciers: maximum length, area, minimum and maximum heights, firn line altitude, ablation and accumulation areas. This was achieved by processing images of glaciers from the SRS along with integrated use of available historical data, schematic illustrations (maps) of glacial basins existing in the catalogue. It should be noted that this approach involves data quality assessment and quality assurance (QA/QC) procedures. Technological and methodological researches proved that the study of glacier degradation based on innovative high-resolution SRS be effective since the best practices [7-9] were used in conjunction with the methods developed by the authors [10-12].

To ensure the effectiveness of the research, the following are used: 1. Data from several high-resolution satellites, 2. Databases of the National Aeronautics and Space Administration (NASA) and the Global Land Project "Ice Measurements from Space" (GLIMS). Various GIS applications are used to process satellite data. Effective software is Google Earth, which offers satellite images of high spatial resolution (0.5- 0.8 m), which allows determining the contours of glaciers with great accuracy.

Fig. 1. presents small glaciers of the r. Terek glacial basin (№98 − 111) and corresponding



a	b

Fig.1. Small glaciers of the r. Terek Basin (№98 − 111) and their contours in the satellite image (a) and topographic map of the 1960s (b).

contours were determined based on the processing of SRS data (part a) and at the topographic map of 1960 (part b). This gives the possibility to adjust the magnitudes for needed small glaciers.

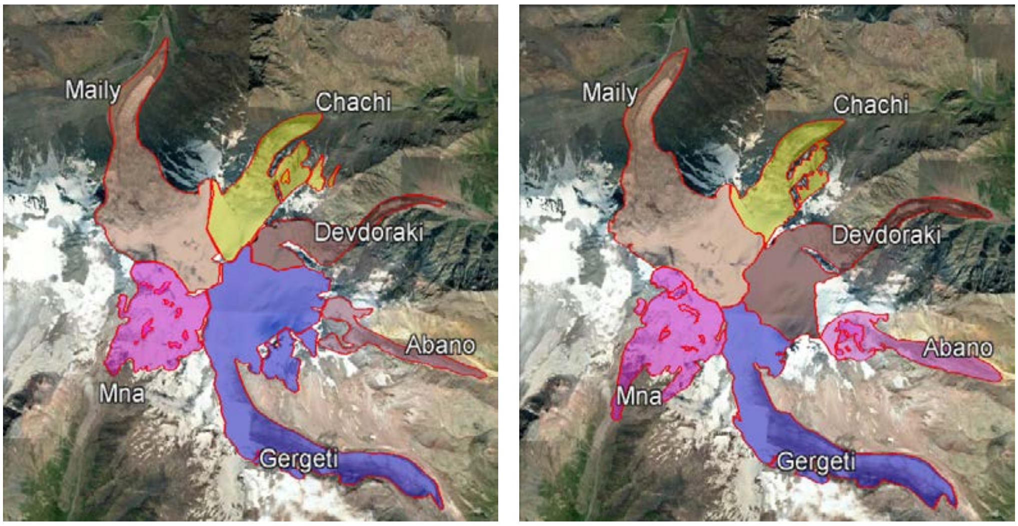
Completing the methodology of research related to the study of glaciers using high-resolution satellites, it should be noted the complex problems that we face in the processing of satellite images. The first of these problems is associated with the difficulty of correctly identifying the location of all glaciers, mostly small ones, on satellite images. To identify the locations of glaciers on satellite images, special schemes (maps) of glaciers available in the catalogue were used. This makes it possible with a high degree of reliability to determine the locations of glaciers in the study area.

The second problem is inaccuracies identified in the catalogue mainly related to the small glacier's areas. The solution was found in the refinement of the data on glaciers areas using topographic maps (Fig.1) from the 1960s. The solution proved to be effective and it allowed the initial conditions of the glacier areas to be obtained with high confidence.

The colour of the pins in the satellite images conveys the following information: the glacier is marked in green, the glacier turned into a snowfield – in yellow, and the place where the glacier once existed i.e fully melted is marked in red.

The third problem is connected with the difficulties that accompany the use of archival data. As an example, r. Terek glacial basin can be considered. In the left part of Fig. 2 the glaciers located on Kazbegi mountain from the r. Terek glacial basin are presented according to the archive data of the GLIMS.

Therefore, using the satellite ASTER DEM data for the determination of the watersheds between the glaciers revealed that the watershed between the glaciers Devdoraki and Gergeti was not correct. The adjusting of the border between these glaciers



a b

Fig. 2. The Kazbegi glaciers initial (a) and adjusted (b) contours

using height isolines generated by the digital terrain model changed the picture. According to the GLIMS, most of the plateau belonged to the Gergeti glacier (see Fig. 2.a). After adjusting Devdoraki glacier includes this space (see Fig. 2.b).

The impact of current climate change on glaciers can be researched in several ways. One of the effective ways is to study the degradation dynamics of the glaciers from the glaciation basins.

The study area is located in the East and partially Central parts of the Greater Caucasus ridge. The study area consists of glacial basins of rivers Terek, Aragvi, Liakhvi, Arguni, Pirikita Alazani and Assa. These glacial basins are located in a high mountain region on the watershed ridge of the Caucasus.

The objective of the study is to research East Georgia's glacial basins degradation dynamics. This is possible by comparing information about glaciers areas and numbers existing in the past with the currently available ones. The data from the catalogue is used as initial data. The next state (medium data) is the conditions of glaciers area and numbers determined by processing the SRS images for the period 2006−2015 mainly from 2015 [13]. Conventionally this data is called SRS 1. The time difference between initial and SRS1 data is equal to nearly 50 years. For having the data characterizing the dynamics of glaciers characteristics changes we added processed data (final data) derived mainly from Landsat 8 satellite September 13, 2020 images. Conventionally this data is called SRS 2. The time difference between SRS 1 and SRS 2 data is five years.

Results and Discussion

Six rivers' glacial basins exist in East Georgia (Table 1). Using above mentioned methodology, all glaciers area and numbers in the glacial basins were determined (Table 1).

Table 1 can be easily transformed into Table 2, which shows glaciers areas and numbers distribution in the East Georgia glacial basins according to the glaciers' sizes. Using these data, the dynamic of changes in areas and numbers of the small, medium and large glaciers of East Georgia due to current climate change can be analyzed.

According to the catalogue, there were 132 glaciers in East Georgia's rivers' glaciation basins. From this amount, small glaciers number was 99, medium glaciers amount – 24 and large glaciers number was 9. After 50 years small glaciers number decreased by 46 (46.5%) and was 53, correspondingly the medium glacier's amount decreased by 15 (62.5%) and made 9 and the large glacier's amount decreased by 2 (22.2%) and were equal to 7. After 5 more years, the number of small glaciers decreased by 28 (52.8%), the medium glaciers amount decreased by 1 (11.1%) and large glaciers quantity decreased by one (14.3%).

Table 1. Distribution of the number and area of glaciers by sizes in the glacial basins of East Georgia according to the data of the Catalogue, SRS 1 and SRS 2

East Georgia							
Glacial basins		Glaciers' number			Glaciers' area		
Name	Size	Catalogue	SRS 1	SRS 2	Catalogue	SRS 1	SRS 2
Liakhvi	Small	20	3	2	4.1	0.6	0.3
	Medium	2	1	1	2.5	1	0.9
	Large	0	0	0	0	0	0
	Subtotal	**22**	**4**	**3**	**6.6**	**1.6**	**1.2**
Aragvi	Small	4	1	1	0.8	0.3	0.3
	Medium	1	0	0	0.8	0	0
	Large	0	0	0	0	0	0
	Subtotal	**5**	**1**	**1**	**1.6**	**0.3**	**0.3**
Terek	Small	43	22	14	10.5	4.3	2.4
	Medium	16	7	7	14.1	6.9	5.7
	Large	9	7	6	42.9	29.2	26.2
	Subtotal	**68**	**36**	**27**	**67.5**	**40.4**	**34.3**
Assa	Small	1	2	2	0.3	0.5	0.5
	Medium	2	1	0	1.1	0.5	0
	Large	0	0	0	0	0	0
	Subtotal	**3**	**3**	**2**	**1.4**	**1.0**	**0.5**
Arguni	Small	6	5	0	1.0	0.1	0
	Medium	0	0	0	0	0	0
	Large	0	0	0	0	0	0
	Subtotal	**6**	**5**	**0**	**1.0**	**0.1**	**0**
Pitikiti Alazani	Small	25	20	6	6.7	3.7	0.9
	Medium	3	0	0	2.1	0	0
	Large	0	0	0	0	0	0
	Subtotal	**28**	**20**	**6**	**8.8**	**3.7**	**0.9**
Total		**132**	**69**	**39**	**87**	**47.5**	**37.2**

Table 2. The number and area of glaciers by sizes in East Georgia according to the data of the Catalogue, SRS 1 and SRS 2

Size	**Glaciers number**			**Glaciers area, km^2**		
	Catalogue	**SRS 1**	**SRS 2**	**Catalogue**	**SRS 1**	**SRS 2**
Small	99	53	25	23.5	9.9	4.4
Medium	24	9	8	20.6	8.4	6.6
Large	9	7	6	42.9	29.2	26.2
Total	**132**	**69**	**39**	**87.0**	**47.5**	**37.2**

The total number of glaciers in East Georgia was 132 and it decreased by 63 (47.7%) in 50 years. After 5 more years, the number of glaciers decreased by 30 i.e. by 43.5% and due to the destructive influence of current climate change remains only 39 glaciers, i.e. the total amount of East Georgia glaciers decreased by 70.5%.

It is necessary to approach with caution regarding the analysis of changes in the number of glaciers in the glacial basins and, consequently, to the change in their number corresponding to glaciers sizes, since complex processes occur during the degradation of glaciers, that is, a decrease is not proportional to the effects, since several small glaciers may arise during the destruction of medium and large glaciers. Despite this, it should be taken into account that a strict physical characteristic of the dynamics of degradation of glaciological basins is provided by an analysis of the degradation of glacier areas, which follows below.

The area of small glaciers was 23.5 sq. km, correspondingly medium glaciers area – 20.6 sq. km and large glaciers – 42.9 sq. km. After 50 years small glaciers area decreased by 13.6 sq. km (57.9%) and was equal to 9.9 sq. km, correspondingly the medium glaciers area decreased by 12.2 sq. km (59.2 %) and was equal to 8.4 sq. km and the large glaciers area decreased by 13.7 sq. km (31.9%) and is equal to 29.2 sq. km.

After 5 more years, the small glaciers area decreased by 5.5 sq. km (55.6% for only 5 years) and was equal to 4.4 sq. km, correspondingly the medium glaciers area decreased by 1.8 sq. km (21.4%) and was equal to 6.6 sq. km and large glaciers area decreased by 3.0 sq. km (10.3 %) and is equal to 26.2 sq. km.

The glacier's total area for these two periods decreased by 39.5 sq. km (45.4%) and by 10.3 sq. km (21.7%). The decrease of glaciers total area from the initial condition is 49.8 sq. km that is 57.2%. We must note that at the beginning the East Georgia glacier's total area was 87.0 sq. km while after the negative impact of global warming the area is only 37.2 sq. km.

The large glaciers exist only in r. Terek glacial basin (Table 1). It is the most developed glacial basin in East Georgia. It would be noted that future trends of r. Terek glacial basin degradation is determined based on data of the large glaciers' retreat. The Business as Usual (BaU) climate change scenario predicted the complete disappearance of glaciers in Eastern Georgia in the basin in 2140 [13].

Conclusion

Studying the degradation of glaciers due to the impact of current climate change in Georgia is an important national economic task. To determine the degradation dynamics of the glacial basin of East Georgia under the impact of global warming, it is necessary to use a high-resolution SRS because currently, it is impossible to carry out the costly ground observations at a necessary scale and in a resource- and time-constrained environment.

Processing of the satellite images, using the several data archives gave the possibility to receive the dynamic picture of the degradation of East Georgia glacial basins for the periods of 50 years from the issue of the initial conditions (catalogue data) and then for the latest 5 years. Calculations showed that the area of small glaciers decreased correspondingly by 57.9 and 55.6%. Correspondingly, the same numbers for the medium glaciers are 59.2 and 21.4%. For the large glaciers, these numbers are consequently 31.9 and 10.3%.

It would be noted that the glacial basin of r. Arguni did not exist nowadays and 4 other rivers basins (Aragvi, Liakhvi, Assa, Piriqita Alazani), also significantly decreased after 55 years and in nearest future, they also will be vanished. Using the climate change scenario BaU it was forecasted the full complete disappearance of East Georgia glaciation basins in 2140.

Climate change has a significant impact on the degradation of East Georgia glacial basins.

Comparison of the speed of glaciers degradation in 50- and 5-years period show that glacier degradation speed is much more intense in the second period than in the first one i.e. glacial basin degradation is nonlinear.

This conclusion also proves the main thesis of the IPCC 6th report that the main problem is not climate change, but its speed.

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გეოფიზიკა

აღმოსავლეთ საქართველოს მყინვარული აუზების დეგრადაციის დინამიკა კლიმატის მიმდინარე ცვლილების ზემოქმედებით

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***ივანე ჯავახიშვილის თბილისის სახელმწიფო უნივერსიტეტი, ე. ანდრონიკაშვილის სახ. ფიზიკის ინსტიტუტი, თბილისი, საქართველო*
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(წარმოდგენილია აკადემიის წევრის თ. ჭელიძის მიერ)

თანამედროვე გამყინვარება არათანაბრად არის განაწილებული დედამიწის სხვადასხვა რეგიონს შორის. მყინვარები საქართველოში გავრცელებულია დიდი კავკასიონის ქედზე, კონცენტრირებულია ენგურის, რიონის, კოდორის, თერგის და სხვა მდინარეების აუზებში. კლიმატის მიმდინარე ცვლილების გავლენა მყინვარებზე ყველაზე თვალსაჩინოა მყინვარული აუზების მახასიათებლების ცვლილებებში. მყინვარებზე კლიმატის მიმდინარე ცვლილების ზემოქმედების მეცნიერულად შესწავლის ერთადერთი გზა არის მაღალი გარჩევადობის თანამგზავრული დისტანციური ზონდირების გამოყენება, რადგან ეს ტექნოლოგია საშუალებას იძლევა ერთდროულად შევისწავლოთ მყინვარების მდგომარეობა დიდ ფართობზე საჭირო გარჩევადობითა და სიზუსტით, შეზღუდული მატერიალური რესურსებისა და დროის პირობებში. ავტორები ამ საკითხებს განიხილავენ თანამგზავრულ მონაცემებთან ერთად, მყინვა-

რების შესახებ ისტორიული მონაცემების (მყინვარების კატალოგი), არსებული საველე სამუშაოების და საექსპერტო ცოდნის ინტეგრირებული, კომპლექსური გამოყენების საფუძველზე. აღმოსავლეთ საქართველოს მდინარეების მყინვარული აუზების დეგრადაციის დინამიკა შესწავლილ იქნა მყინვარებზე კლიმატის მიმდინარე ცვლილების ზემოქმედების დასადგენად მყინვარების მახასიათებლების (ფართობი და რაოდენობა) შედარების გზით სამ დროით მომენტში. ამ პირობების შედარებამ აჩვენა, რომ კლიმატის ცვლილების გამო მყინვარების ფართობი და რაოდენობა მნიშვნელოვნად მცირდება. მყინვარების დეგრადაცია არაწრფივია, რაც მეორე პერიოდში მყინვარების დნობას უფრო ინტენსიურს ხდის, ვიდრე პირველში. ეს შედეგი სრულად ასახავს კლიმატის ცვლილების სამთავრობათაშორისო საბჭოს მეექვსე ანგარიშის მთავარ თეზისს, რომ კლიმატის ცვლილება არ არის ისეთი შემაშფოთებელი, როგორც მისი სიჩქარე. საქართველოს მყინვარების დეგრადაციის საკითხები კლიმატის მიმდინარე ცვლილების გამო განიხილებოდა სხვადასხვა მაღალი დონის ფორუმებზე. აღსანიშნავია, რომ 2021 წელს, გლაზგოს კლიმატის ცვლილების კონფერენციაზე (COP 26) ქართულ დელეგაციას ჰქონდა მოხსენება აღმოსავლეთ საქართველოში მყინვარების დეგრადაციის დინამიკის შესახებ კლიმატის ცვლილების გამო. კლიმატის ცვლილების გავლენის გამო მყინვარების დეგრადაციის ძირითადი შედეგები მოყვანილია გაეროს კლიმატის ცვლილების ჩარჩო კონვენციისადმი საქართველოს მეოთხე ეროვნულ შეტყობინებაში.

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