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RIVER TEREK GLACIAL BASIN DEGRADATION DYNAMICS ON THE BACKGROUND OF CURRENT CLIMATE CHANGE

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Summary: *In Georgia, on the ridge of the Greater Caucasus, there are well-developed, rather high glaciers. The study of glaciers has gained more importance since the second half of the twentieth century due to the negative impact of current climate change, which has led to significant and rapid degradation of glaciers, exacerbating natural disasters of glacial origin. Due to the degradation of glaciers in the country, 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 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. Using satellite remote sensing, GIS technologies, glacial catalogue, field ground observations and expert knowledge, the negative impact of modern climate change was revealed and, as a consequence, the dynamics of degradation of glaciers in the glacial basins of East Georgia was studied in detail. In this article, the dynamics of the degradation of glaciers in the glacial basins of River Terek is overviewed. For this purpose, a comparison is made of the state of glaciers (area and number) for three time periods. The initial state is taken to be the state of glaciers in this basin at the time of the finish of the glaciers researches (1960). The data gathered were published in several editions of the glacier catalogue. Subsequent states - middle (2015) and final (2020) are determined using high-resolution satellites. Technological and methodological research proved to be effective for studying the dynamics of glacier degradation based on innovative high-resolution satellite remote sensing since the best practices were used in conjunction with the methods developed by the authors. A comparison of these conditions showed that the area and number of glaciers are greatly decreasing due to climate change. It should be noted that the dynamics of glacier degradation is nonlinear, which makes the melting of glaciers in the second period more intense than in the first. This conclusion also confirms one of the main theses of the 6th IPCC report that the main problem is not climate change, but its speed.*

Keywords: *climate change, satellite remote sensing, glacial basin, glaciers, degradation dynamics.*

Introduction. Glaciers are important climatic and economic resources of Georgia. They contain large amounts of freshwater and play a decisive role in water regime and regional climate forming. Current climate change has a very negative impact on the cryosphere, in particular on the glaciers [1]. The study of glaciers has gained more importance since the second half of the twentieth century due to the negative impact of climate change. With high confidence this has led to significant and rapid degradation of glaciers, exacerbating natural disasters of glacial origin. 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 are having a place [2]. 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.

Georgia's Second and Third National Communications to the UN Framework Convention on Climate Change analyze climate change influence on glaciers, particularly those found in Zemo Svaneti and Kvemo Svaneti regions of Georgia. The papers explain that available information is incomplete, because the complexity of glaciological research makes simultaneous monitoring of all glaciers impossible, and note that the research uses several assumptions.

The uncertainties found in the above communications can be significantly reduced if glaciological researches will be carried out with the help of satellite remote sensing (SRS).

Methodology and data. Following large-scale glaciological researches, conducted mainly by field works in 1860-1960 the data about glaciers characteristics were systematized and catalogued as part of the Caucasian glacier system. After these activities, the glacier catalogue (hereinafter – the catalogue) of the former Soviet Union [3] was issued.

At present to give a science-based response to glacier melting caused by climate change, 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 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.

For the determination of the conditions of the glaciers, we have conducted works based on processing satellite data and determined the conditions and characteristics of Georgian glaciers [4]. For data accuracy along with SRS information, historical data and expert knowledge are used. The technological-methodological approaches of the research proved to be effective for the study of glaciers based on innovative high-resolution satellite remote sensing, as the best practices [5] were used together with the methods developed by the authors [6].

To ensure the effectiveness of the established surveys, high-resolution SRS images are used, namely: 1. Landsat satellite data (15–30 m resolution), 2. Satellite information free databases are stored in the archives of the National Aeronautics and Space Administration (NASA) and the Global Land Ice Measurements from Space (GLIMS) project. 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.

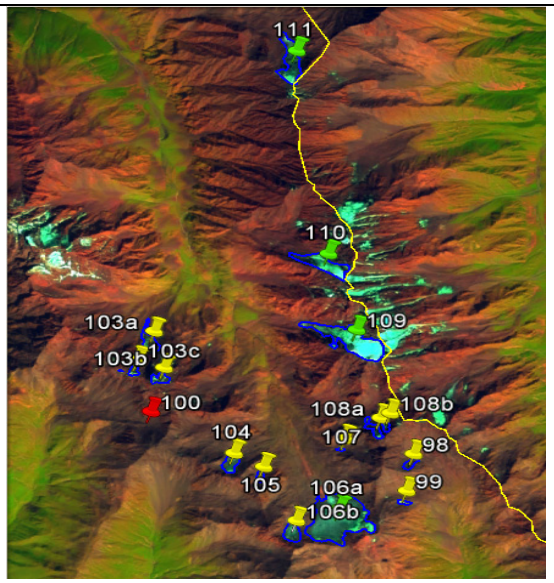
The impact of current climate change on glacial basins can be researched in several ways. One of the effective ways is to study the degradation dynamics of the glaciers from the glaciation basins.

The study region is the glacial basin of the river Terek (East Georgia). This well-developed glacial basin is located in a high mountain region on the watershed ridge of the Caucasus, where mountain ranges are more than 3,500 m high. Our objective is to research r. Terek glacial basin degradation. This is possible by comparing information about glaciers areas and numbers existing in the past with the data currently available. As initial data, we are using the data from the catalogue about glaciers areas and their numbers. The second condition (medium data) is the information regarding glaciers areas and numbers from the Terek glacial basin received by processing satellite data for the period 2006−2015 (mainly the SRS images from 2015) [6]. Conventionally this data we call SRS 1. For having the data characterizing the dynamics of glaciers we added processed data (final data) derived from Landsat 8 satellite September 13, 2020 images. Conventionally this data we call SRS 2. The data received from the SRS (SRS1 and SRS2) were compared with each other and the initial data.

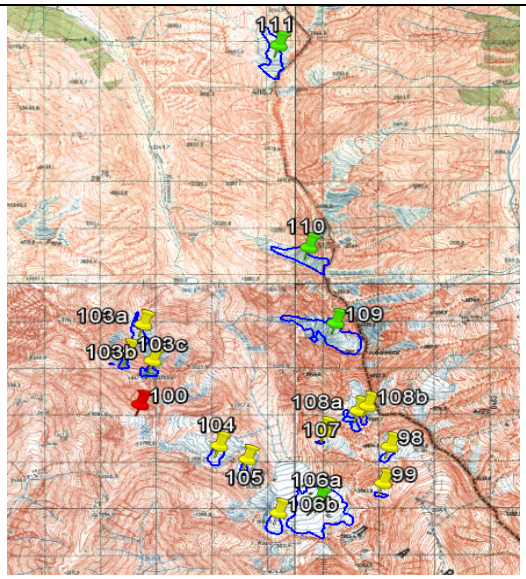
To complete the studies carried out in the basin, two problems needed to be clarified. Specifically, the issue of identification, mainly of small glaciers in the satellite images, and the issue of inaccuracies identified, mainly of the areas of small glaciers in the catalogue. For the identification i.e. determination of locations of the small glaciers on satellite images was used the special schemes (maps) of the glaciers existing in the catalogue. Regarding the second problem, the solution was found in the refinement of the data on glaciers areas using topographic maps from the 1960s [7].

Results and discussion. The river Terek glacial basin is interesting by the fact that all large glaciers spread in East Georgia are located in this basin. Fig. 1. presents: Part a. Small glaciers of the Terek Basin (№98 − 111) and corresponding contours determined based on the methodology of the processing of SRS data mentioned above and part b. same glaciers (№98 − 111) and their contours on the topographic map of 1960.

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



a.



b.

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

Table 1 is compiled for the river Terek glacial basin glaciers. It represents the glacier's area values and the numbers from the catalogue, SRS 1 and SRS 2 data.

Table 1. R. Terek Glaciation Basin Glaciers Number and Area according to Sizes determined to Catalogue, SRS 1 and SRS 2 data

Glaciers № according to the catalogue	**Size**	**Glaciers number**			**Glaciers area, km^2**		
		Catalogue	**SRS 1**	**SRS 2**	**Catalogue**	**SRS 1**	**SRS 2**
44−111	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
	Total	**68**	**36**	**27**	**67.5**	**40.4**	**36.3**

According to the catalogue, there are 68 glaciers in the r. Terek glaciation basin. From this amount, small glaciers number was 43, medium glaciers amount – 16 and large glaciers number was 9. After 50 years small glaciers number decreased by 21(48.8 %) and was 22, correspondingly the medium glaciers amount decreased by 9 (56.2 %) and made 7 and the large glaciers amount decreased by 2 (22 %) and were equal to 7. After 5 more years, the number of small glaciers decreased by 8 (36.3 %) and large glaciers quantity decreased by one (14.3 %). The glaciers total amount for these two periods decreased by 32 (47 %) and 9 (25 %).

The area of small glaciers was 10.5 sq. km, correspondingly medium glaciers area – 14.1 sq. km and large glaciers – 42.9 sq. km. After 50 years small glaciers area decreased by 6.2 sq. km (59 %) and was equal to 4.3 sq. km, correspondingly the medium glaciers area decreased by 7.2 sq. km (51 %) and was equal to 6.9 sq. km and the large glaciers area decreased by 13.7 sq. km (31.9 %).

After 5 more years, the small glaciers area decreased by 1.9 sq. km (44.2 % for only 5 years) and was equal to 2.4 sq. km, correspondingly the medium glaciers area decreased by 1.2 sq. km (17.4 %) and was equal to 5.7 sq. km and large glaciers area decreased by 4.1 sq. km (31.9 %). The glaciers total area for these two periods decreased by 27.1 sq. km (40.1 %) and by 4.1 sq. km (10.1 %).

Conclusion. Studying the degradation of glaciers due to the impact of current climate change in Georgia is an important national economic task to obtain a scientifically sound answer on the present conditions of the glaciers. To determine the degradation dynamics of the glacial basin of the r. Terek under the impact

of the current climate change, 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 gave the possibility to receive the dynamics of the degradation of river Terek glacial area for the periods of 50 years from the issue of the initial conditions and then for the latest 5 years. Calculations showed that the area and number of small glaciers decreased correspondingly by 59 and 49.8 % after 50 years and 44.2 and 36.4 % after 5 more years. Correspondingly, the same numbers for the medium glaciers are 51 and 56 % after 50 years and the medium glaciers area decrease was equal to 17.4% after 5 years and the total number of the medium glaciers did not change after 5 years. For the large glaciers, these numbers are consequently 40.1 and 22.2 after 50 years and 10.1 and 14.3% after 5 years.

The glaciers total area of the river Terek glacial basin for these two periods decreased by 27.1 sq. km (40.1 %) and by 4.1 sq. km (10.1 %). The glaciers total amount for these two periods decreased by 32 (47 %) and 9 (25 %).

The analysis of the given numbers clearly shows that climate change has a significant impact on the degradation of r. Terek glacial basin. 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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