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Glaciers Reduction and Climate Change Impact over the Last One Century in the Mulkhura River Basin, Caucasus Mountains, Georgia

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Abstract

The reduction of glaciers of Mulkhura River basin over the last century is revised in the paper. Mulkhura River basin is located on the southern slope of the central Caucasus from the Mount Bashili (4148 m) to the Mount Gistola (4860 m) and it is the main center of the contemporary glaciations in the Enguri River basin. The percentage reduction of areas of compound valley glaciers with the relation of air temperature and atmospheric precipitation is given in this paper. Also the paper considered the dynamics of the Tviberi and Tsaneri glaciers, which were the Georgia's largest glaciers at the end of the 19th century. We used the catalog of the glaciers of the southern slope of the Caucasus compiled in 1911 by a well-known researcher of the Caucasus K. Podozerskiy, which was drawn up on the basis of the 19th century maps. In order to identify the area and number of the glaciers of the 60s of the 20th century, we used the work of R. Gobejishvili—the Georgian glaciologist of the 20th-21st centuries, composed on the basis of 1:50,000 scale topographic maps of 1960. The data of 2014 have been obtained by the Landsat aerial images of L8 OLI/TIRS (Operational Land Imager and Thermal Infrared Sensor) taken in August 2014. In the mentioned study, except of the old topographic maps and aerial images, we used the climate information especially air temperature and precipitation data of the Mestia weather station.

Keywords

Glaciers Dynamic, Remote Sensing, Glaciers of Georgia, Caucasus Mountains, Tviberi and Tsaneri Glaciers

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1. Introduction

The glaciers are indivisible part of the environment and are a good indicator of the current change of climate. Researches of glaciers became very important especially in the last period, when climate change was observed in every mountainous region of the world. Especially important is studying of mountain glaciers as they are important natural resources and they response to climate change. The glacier melting is observed in every mountainous region after the finishing of max phase of the Little Ace Age (LIA). This process continues even today.

Mountain glaciers are a relatively reliable indicator of climate change, and their recent decline across the world has been linked to global warming [1]. Retreat of mountain glaciers has more localized consequences, affecting the geomorphology and hydrology of the glacial valleys which they occupy [2] [3]. The most serious impact of vanishing mountain glaciers undoubtedly concerns the water cycle from regional to global scales. Glacier melting will probably dominate sea level rise during our century [4]. Changes in the dynamic parameters even of relatively small glaciers may have a disproportionately large impact on climate [5].

2. Study Area

One of the main glaciated areas of the Eurasia is the Great Caucasus Range, which stretches for about 1300 km from the north-west to the south east. It is located between the Black Sea and the Caspian Sea and represents the natural border between Georgia and Russia. The current area of glaciation is ~1100 km^2.

Great influence on the climate of the Caucasus have the cyclones shifted from the southwest and west of the Atlantic and the Mediterranean Seas and the branch of Asian anticyclone, which extends in the region from the north and north-west. Cyclonic processes are formed in the warm period of the year, while the anticyclonic—in the cold period. Because of this the high peaks of the Caucasus are under the influence of these processes throughout the year, which provides their feeding by precipitation.

High Caucasus range is favorable for the existence of glaciers in Georgia. There are places in certain sections of the range, where its height exceeds 3000 - 3500 meters, by foreseen of the relief and climatic conditions, where the accumulation of solid atmospheric precipitation fallen in the cold period occurs during many years [6] [7].

Mulkhura River basin is located on the southern slope of the central Caucasus from the Mount Bashili (4148 m) to the Mount Gistola (4860 m) (**Figure 3**). Mulkhura River basin is the main center of the contemporary glaciations in the Enguri River basin. Share of the glaciers of this basin is 27.4% in the total area of the contemporary glaciation of the Enguri River basin. Glaciers are located in the southern slope of the Greater Caucasus, which is distinguished by the deep fragmentation of the relief and high peaks, with the heights of over 4500 meter.

3. Data and Methods

During this research we used the catalogue and maps of glaciers compiled by K. Podozerskiy in 1911. The data by K. Podozerskiy are obtained just from the maps of 1880-1890, which were compiled by the plain table surveying method in 1880-1890 [8]. Military topographic maps with the scale of 1:50,000 drawn up in the 1960s in the former Soviet Union were also used in research; there are marked glaciers with ice tongue on the southern slope of the Greater Caucasus. The topographic maps are in Pulkovo-1942 projection, but with the help of ArcGis we made georeferencing and registered them in WGS 1984 projection after this perfectly tied to the coordinate system (projected coordinate system: WGS-1984-UTM-zone-38N).

Because many glaciers lie in remote mountainous regions, remote sensing methods have often been employed in performing glacier surveys, beginning with aerial photography [9] [10]. Therefore, the remote sensing method was used for the study of the dynamic of glaciers (to determine area change, glacier length and elevation of the ice tongue). The spectral images of the Landsat L8 OLI/TIRS (Operational Land Imager and Thermal Infrared Sensor) (USGS) taken from "Landsat" satellite on August 3, 2014, present the materials for our study.

Then composite band function was used and with the help of ArcGis images were fixed with the sequence of the 7-5-3. As a result of the use of this method, we have estimated the variability of Mulkhura River basin glaciers area of 1911-1960-2014 years, as well as its ice tongue length and altitudinal variation during these years.

It is important the existence of climate elements especially air temperature and precipitation data to study the dynamics of glaciers [11]. We managed to obtain the average daily air temperature data of Mestia weather station since 1906 till 2013 from the National Agency of Environment, and precipitation data since 1961 till 2010.

4. Results

By the data of 1911 there were 11 glaciers in the Mulkhura River basin with the area of ~100.0 km^2 [12]. By the data of 1960 there were 31 glaciers, with the area of 81.2 km^2 [13] and by the data of 2014 there are 42 glaciers with the total area of 61.2 km^2. During the past century, such increase in glaciers' number and a sharp reduction in their area is caused by the fact that still in the 19th century there was one of the largest glaciers of Georgia—the Tviberi glacier, which was represented as an individual glacier, and also the Tsaneri glacier, which was one of the largest glaciers of Georgia. Today, these glaciers are fragmented and are represented as an individual simple valley glaciers.

Share of only six glaciers in the total area of the glaciers of the Mulkhura River basin is 76.8%, their areas are as follows: southern Tsaneri—12.6 km^2, northern Tsaneri—11.5 km^2, Kvitlodi—9.8 km^2, Nageba—4.5 km^2, Asmashi—4.5 km^2 and Seri—4.2 km^2, which shows that the basic background for glaciations are made by these glaciers.

The rest of the 36 glaciers are relatively small in size; they are located on the slopes of the major glaciers and end within the altitude of 2650 - 3500 meters. The ice tongues of the valley glaciers come down to a lower altitude, to 2140 - 2480 m above sea level.

According to morphological types the valley glaciers form the basic background for glaciation in the Mulkhura River basin; they occupy 83.0% of the total area of the glaciers of the basin (**Figure 1**).

As for the exposition, the first place by the number and area occupy the glaciers of the overall southern exposition; their share is 45.2% in the total number and 46.1% in the total area of the glaciers (**Figure 2**).

Tviberi glacier is located in the river basin with the same name (the Tviberi River is a mouth of the Mulkhura River). It is located on the southern slope of the Caucasus. In spite of this the peaks located there, are not distinguished by the high altitude. The highest peak is of 4250 m and is lower than the peaks located next to it by 600 - 800 meters. Morphological conditions of the relief play an important role in the forming of the powerful glaciations in the basin together with the climatic conditions. The Tviberi River basin is surrounded by the quite high ranges. Glacial forms are deeply sat in the relief, built by the crystal rocks and create the favorable conditions

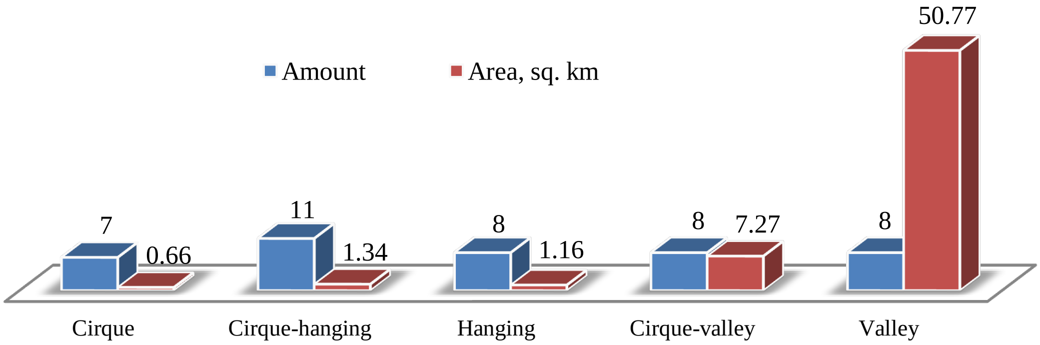

Figure 1. Distribution of the glaciers in the Mulkhura River basin according to the morphological types.

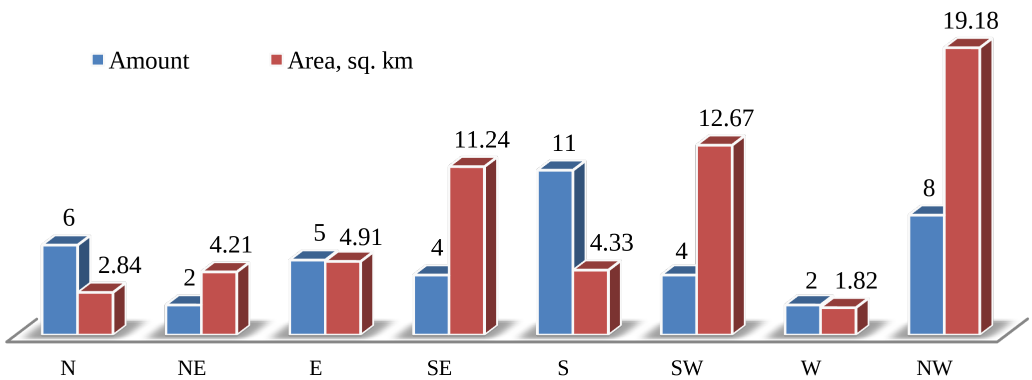

Figure 2. Distribution of the glaciers in the Mulkhura River basin according to the exposition.

for accumulation of snow-icy cover. From the beginning of the 19th century to the second half of the 20th century the Tviberi River basin's glaciers were combined and they formed the compound-valley glacier. Their joint tongue was flowing down to the 2030 m above sea level (**Figure 3**). Tviberi glacier was the largest in area in Georgia for that time. Identification of the glacier maximum borders during the Fernau stage is not difficult, because the glacial morphosculptural forms (moraines, ram forheads) have been remained in the relief. They are created due to the glaciers advancing during the last stade glaciation.

From the year of 1810 the glaciers of the Caucasus are retreating. In the topographical map of 19th century the Tviberi glacier is presented as a united system (**Figure 3**). Its area was 49.0 km^2. Decoding of the aerial images of 1959-1960 and the analysis of the topographical maps showed, that the Tviberi glacier has been greatly changed. Glacier area was decreased by 24.3 km^2. The greatest branch—Kvitlodi was separated from the glacier's left side, which became an independent glacier. The Kvitlodi glacier tongue was located ~300 - 400 m away from the Tviberi glacier and ended at a height of 2290 m. Five small size of glaciers were separated from the Tviberi glacier system as well.

In 1960 the Tviberi glacier tongue was ended at a height of 2140 m. The surface of its tongue was covered by the weathered material of ~1.0 m thick, which greatly reduced the surface ablation. A clean surface of the glacier was melting realtively greatly in the area of the joint tongue than the surface covered by the weathered material. Because of that the clean section of the glacier was located ~10 - 15 meters lower. The area of the Tviberi glacier was 24.7 km^2 in 1960 [13].

Decoding of the 19th-20th centuries topographical maps and aerial images of 2014 showed that due to retreat the compound-valley glacier of Tviberi was divided into the following valley types of glaciers: Seri, Asmashi, Toti, Iriti, Lichati, Laskhedari and Dzinali. The glacier tongues are ~1.0 km away from each other. The Asmashi glacier is the largest in area and length; its tongue ends at a height of 2540 m. The sides of the ice-tongue surface is covered by the ~0.5 - 1.0 m thick weathered material and the ~200 m wide clean ice flow is intruded among them in the form of a wedge. Its surface is lower than the sides by ~5 - 10 m.

Similar geomorphological conditions has the Dzinali glacier tongue. The tongues of the rest of the glaciers are poorly covered by the boulder materials. All of the glaciers develop the 100 - 300 high icefalls on flowing from the vast firn valley and form the sharply expressed step in the relief. Because of this the glacier is divided into the two parts. The upper step is a feeding area and the lower one is a melting area. The small size cirque glaciers were separated from some of the valley types of glaciers.

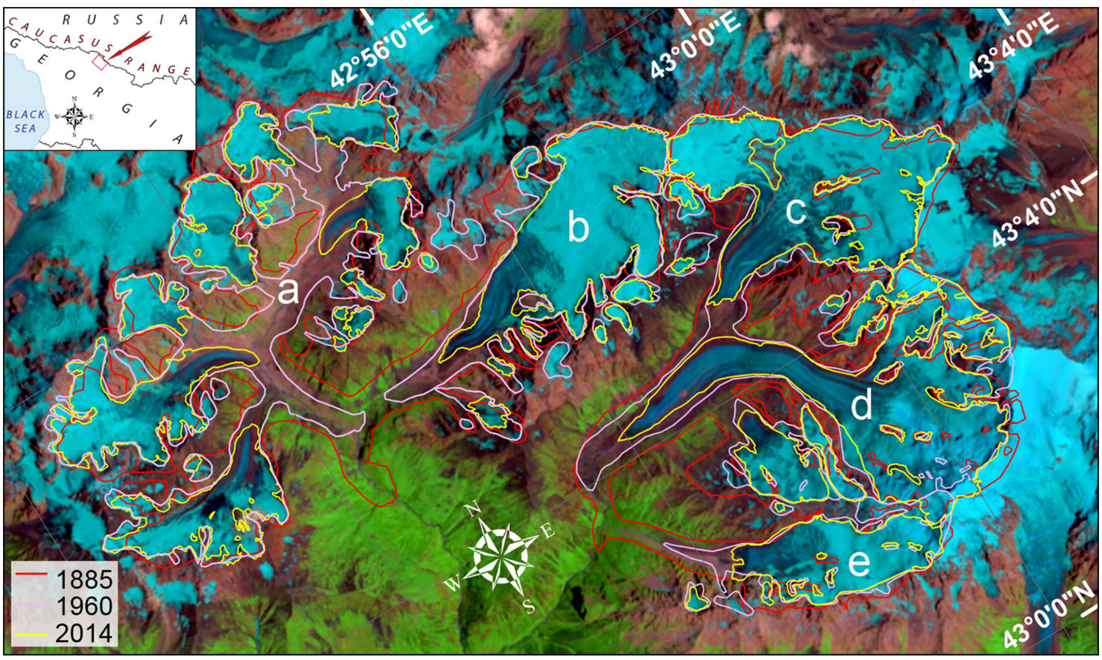

Figure 3. Reduction of the Mulkhura River Basin Glaciers in 1885-1960-2014. (a) Tviberi glacier; (b) Kvitlodi glacier; (c) Northern Tsaneri glacier; (d) Southern Tsaneri glacier; (e) Nageba glacier.

From the 80s of the 19th century till 2014 the Tviberi glacier tongue retreated by ~4.1 km. Such a sharp change of the tongue can be observed with the help of the old and contemporary images as well (**Figure 4**). Such a rate of retreat was characteristic to the Kvishi glacier in Svaneti, but after its destruction the rates of retreat of single glaciers have reduced sharply. Same process is in the Tviberi basin glaciers as well. Such a reduction of the Tviberi glacier is natural and meets general situation that is common for the glaciers of the Caucasus and other mountainous areas in the mentioned period.

Kvitlodi glacier was connected to the Tviberi glacier tongue untill the first part of the 19th century. By the data of 1960 Kvitlodi was already separated from Tviberi and was ended at a distance of ~700 - 800 m at a height of 2290 m (**Figure 5**). The area of the Kvitlodi glacier was 12.2 km^2 in 1960. By the data of 2014 its area is 9.8 km^2. The firn valley of the glacier is quite vast. And the tongue inclination reduces below. The glacier tongue is almost free of moraine cover entirely. The surface is slightly fractured. Stade moraines stretch along the both sides of the ice tongue.

Tsaneri glacier with the Nageba glacier was the second glacier in Georgia by its size after the Tviberi glacier in the 80s of the 19th century and its area was 48.9 km^2 (**Figure 3** and **Figure 6**). Division of the glaciers took place at the end of the 19th century. In 1960, the Tsaneri glacier still was the compound-valley type of glacier and its area was 28.3 km^2. For this period the Tsaneri glacier was the second glacier in Georgia by its size after

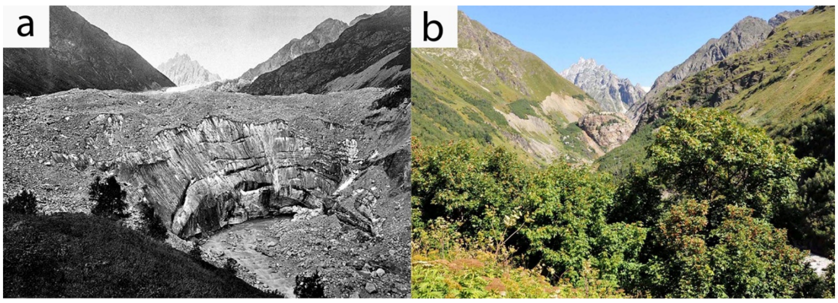

Figure 4. Reduction of the Tviberi glacier in 1884. (a) (Photo: M. V. Dechy)-2011; (b) (Photo: L. Tielidze)

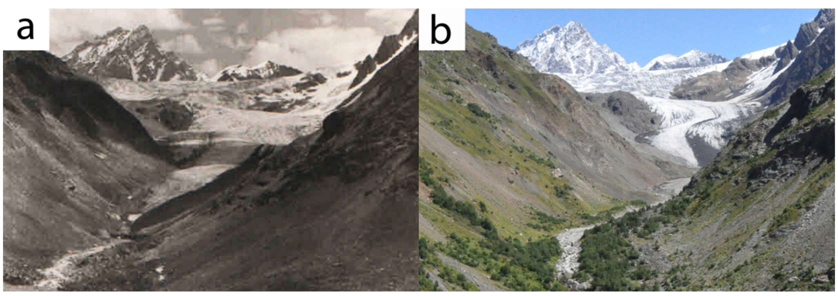

Figure 5. Reduction of the Kvitlodi glacier in 1960. (a) (Photo: G. Kalandadze)-2011; (b) (Photo: L. Tielidze)

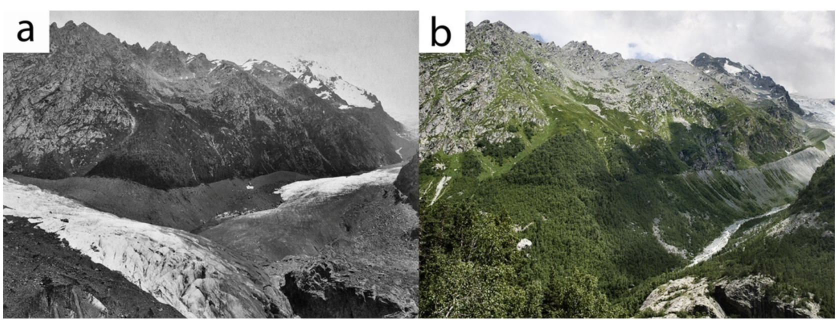

Figure 6. Reduction of the Tsaneri (a-left) with Nageba glacier (a-right) in 1884 (Photo: M. V. Dechy)-2011 (b) (Photo: F. Ventura).

the Lekhziri glacier. The mentioned glacier now is presented in the form of two glaciers (northern Tsaneri and southern Tsaneri), which descend from the firn valleys that are independent from each other (**Figure 3(c)** and **Figure 3(d)**). The space images of 1986 show that these two flows have little contact with each other. And the space image of 2000 shows that their contact are split and the northern flow is quite far away from the southern flow. Their division is likely to be happened in the years of 1986-1990. Glaciers firns are separated from each other by a branch of the Greater Caucasus mountain range. The ice tongues were joined at 2750 m above sea level and a uniform ice tongue of western exposition was created, which was ended at an altitude of 2380 meters (**Figure 3(c)** and **Figure 3(d)**, **Figure 6**).

Southern Tsaneri is the second largest glacier in Georgia with the area of 12.6 km^2. Glacier surface cracks are weakly developed. The ice tongue surface is rich in ablation forms (wells, glacier tables, sunbcups, grooves made by melted water, etc.). The glacier tongue ends at an altitutde of 2525 m above sea level. The well expressed lateral stade moraines stretch along to its both sides (**Figure 3(d)**).

Georgia's third largest glacier is the northern Tsaneri with the area of 11.5 km^2. It is a valley glacier and is of south-western exposition. The last part of the ice tongue is hanged over the ledge and it ends at an altitude of 3020 meters above sea level (**Figure 3(c)**).

Nageba glacier is a valley glacier of north-western exposition. The glacier firn starts from the Tetnuldi Peak at a height of 4858 m and is surrounded by the Lakchkhilda and Kvarashi ranges. The glacier tongue creates the icefall with the cracks of different direction after flowing out from the firn. By the data of 2014 the glacier area is 4.5 km^2 and its tongue ends at a height of 2800 meters.

Well-expressed lateral stade moraines stretch along to the both sides of the glacier, which join the stade moraine of Fernau of the Tsaneri glacier. This fact indicates that the glaciers were combined and represented one glacier during the last stade glaciation. There are several short stade moraines into the stade moraines on the slopes and at the base of the valley. Reduction of the glacier is best seen when comparing the old and new images (**Figure 7**).

5. Discussions

To investigate the dynamics of glaciers it is important to analyze the climatological information, mainly the air temperature and precipitation data for the same period. Nowadays the Mestia meteorological station is the only current station and is located at 1440 m above sea level [14].

As our research period comprises approximately the last one century, we divide it into two periods 1906-1960 and 1961-2013. As we have mentioned above, the Mestia multi-year mean air temperature made +5.9˚C. In the same period the temperature trend is a positive (**Figure 8**). The analyze of only 1906-1960 period shows that the air temperature is same as multi-year mean and still makes +5.9˚C. Also the temperature trend is stable (**Figure 8**). The multi-year mean of 1961-2013 period is the highest and makes +6.0˚C. The temperature trend is a sharply positive (**Figure 8**).

One of the necessary conditions for the feeding of the Caucasus glaciers is the intensity of solid precipitation, which most often comes in December-January months in the south Caucasus. We have developed the Mestia meteorological station's precipitation data of the period of 1961-2010, which showed that in the mentioned period the annual sum of the precipitation increases, and relatively, the overall trend is also positive (**Figure 9**).

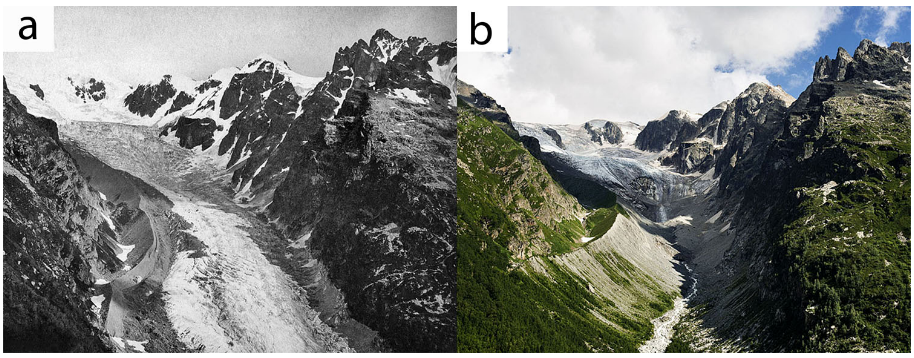

Figure 7. Reduction of the Nageba glacier in 1884 (a) (Photo: M. V. Dechy)-2011; (b) (Photo: F. Ventura).

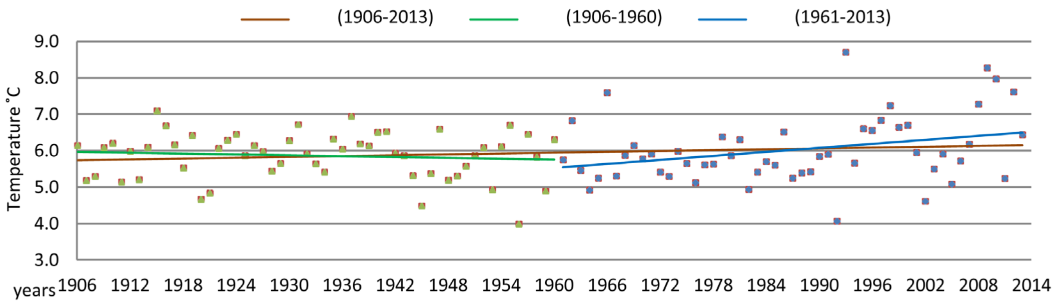

Figure 8. Trends of mean anual air temperatures for 1906-2013, 1906-1960, 1961-2013.

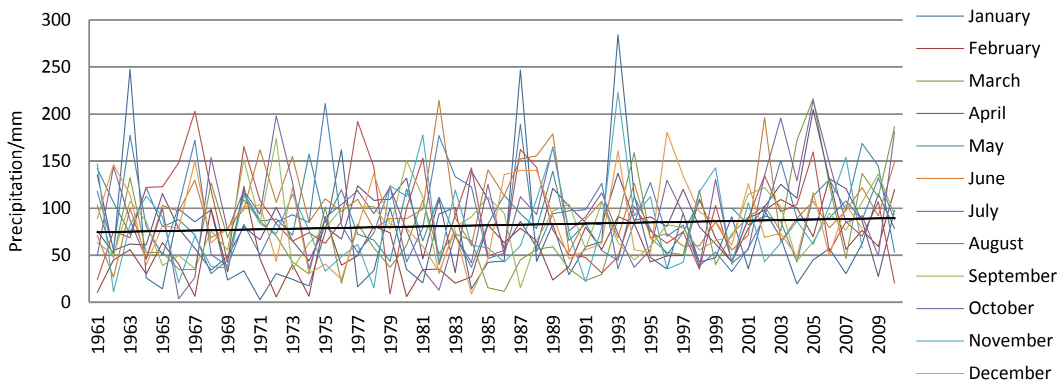

Figure 9. Mestia weather station's annual sums of precipitation in 1961-2010.

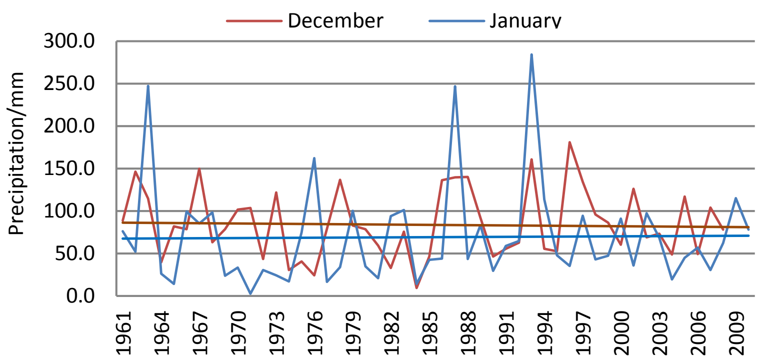

Figure 10. Mestia weather station's December-January atmospheric precipitation sums in 1961-2010.

But if we take only the winter months of December and January, here we can see that the trend is stable in case of January and December and precipitation sum obviously decreases; accordingly, the trend is negative (**Figure 10**).

Of course, we cannot state solely that the reduction of the Mulkhura River basin's contemporary glacial areas is related only to the reduction of the December precipitation, but we can say that during the last half century along with the temperature increase the mentioned fact is also causes the reduction of the glaciers.

6. Conclusions

The study had concluded that during the last century the area of the glaciers in the Mulkhura River basin decreased by 34%, while their number increased by 281%. In the mentioned period such largest increase of the glaciers was not observed among the other river basins on the southern slope of the Caucasus. This situation was stipulated by the fact that by the end of the 19th century and in the early 20th century the area of the glaciers of the Mulkhura River basin made 17% of the total area of the glaciers of Georgia and the Mulkhura basin was the main center of glaciations at that time. In this basin were located two largest compound-valley types of glaciers of Georgia—Tviberi and Tsaneri (together with Nageba) glaciers. These are the glaciers due to degradation of which the relatively small size of simple valley and even smaller cirque type of glaciers emerge.

As for the atmospheric precipitation and air temperature, we had identified that the mean annual air temperature trend was positive in the years of 1906-2013. And the mean multi-year air temperature of separate period of 1961-2013 was more by 0.1˚C than the same parameter of the period of 1906-1960. Therefore, it made +6.0˚C. In addition, in the last half century, against the background of the overall increase in precipitation in the region the reduction of the December-January (especially in December) rainfall was observed, which had a negative impact on the glaciers feeding regime.

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References

[1] Barry, R.G. (2006) The Status of Research on Glaciers and Global Glacier Recession: A Review. *Progress in Physical Geography*, **30**, 285-306. http://dx.doi.org/10.1191/0309133306pp478ra

[2] Kaser, G., Juen, I., Georges, C., Gomez, J. and Tamayo, W. (2003) The Impact of Glaciers on the Runoff and the Reconstruction of Mass Balance History from Hydrological Data in the Tropical Cordillera Blanca, Peru. *Journal of Hydrology*, **282**, 130-144. http://dx.doi.org/10.1016/S0022-1694(03)00259-2

[3] Fischer, L., Kaab, A., Huggel, C. and Noetzli, J. (2006) Geology, Glacier Retreat and Permafrost Degradation as Controlling Factors of Slope Instabilities in a High-Mountain Rock Wall: The Monte Rosa East Face. *Natural Hazards and Earth System Sciences*, **6**, 761-772. http://dx.doi.org/10.5194/nhess-6-761-2006

[4] Meier, M.F., Dyurgerov, M.B., Rick, U.K., O'Neel, S., Pfeffer, W.T., Anderson, R.S., Anderson, S.P. and Glazovsky, A.F. (2007) Glaciers Dominate Eustatic Sea-Level Rise in the 21st Century. *Science*, **317**, 1064-1067. http://dx.doi.org/10.1126/science.1143906

[5] Meier, M.F., *et al.* (2007) Glaciers Dominate Eustatic Sea-Level Rise in the 21st Century. *Science*, **317**, 1064-1067. http://dx.doi.org/10.1126/science.1143906

[6] Tielidze, L.G. (2014) Glaciers of Georgia, Monograph. Publ. Color, 254 p.

[7] Tielidze, L.G., Chikhradze, N. and Svanadze, D. (2015) Glacier Amount and Extent Change in the Dolra River Basin in 1911-1960-2014 Years, Caucasus Mountains, Georgia, Observed with Old Topographical Maps and Landsat Satellite Imagery. *American Journal of Climate Change*.

[8] Tielidze, L.G., Lomidze, N. and Asanidze, L. (2015) Glaciers Retreat and Climate Change Effect during the Last One Century in the Mestiachala River Basin, Caucasus Mountains, Georgia. *Earth Sciences*, **4**, 72-79.

[9] Ostrem, G. (1975) ERTS Data in Glaciology—An Effort to Monitor Glacier Mass Balance from Satellite Imagery. *Journal of Glaciology*, **73**, 403-415.

[10] Hall, D.K., Williams Jr., R.S. and Bayr, K.J. (1992) Glacier Recession in Iceland and Austria as Observed from Space. *EOS*, **73**, 135-141. http://dx.doi.org/10.1029/91EO00104

[11] Tielidze, L.G., Gadrani, L. and Kumladze, R. (2015) A One Century Record of Changes at Nenskra and Nakra River Basins Glaciers, Causasus Mountains, Georgia. *Natural Science*, **7**, 151-157. http://dx.doi.org/10.4236/ns.2015.73017

[12] Podozerskiy, K.I. (1911) Glaciers of the Caucasus Mountain Range. Zap. KORGO, 14.

[13] Gobejishvili, R.G. (1989) Glaciers of Georgia. Monograph. Publ. Metsniereba.

[14] Tielidze, L.G., Lominadze, G. and Lomidze, N. (2015) Glaciers Fluctuation over the Last Half Century in the Headwaters of the Enguri River, Caucasus Mountains, Georgia. *International Journal of Geosciences*, **6**, 393-401. http://dx.doi.org/10.4236/ijg.2015.64031