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Catastrophic Debrisflow in Dariali (Georgia) in the Year 2014

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Abstract

River Tergi, Aragvi and Asa-Arghuni, which occupy significant area of mountainous region of central Caucasus, by its geographic location, strategic meaning, peculiarities of natural landscape and infrastructural objects (Trans-Caucasian highway, gas pipeline, water supply of the capital, Gudauri ski-mountainous complex) minerals, historic-ethnographic monuments, opportunities for development of mountainous tourism and mountaineering, where more important engineering projects are being planned; all the above give perspective of development of economic base, employment of the population and restoration of motivated villages, more over that the major part of their perimeter represents state border. At the same time, extremely complex relief, landscape-climatic conditions and sensitive geologic environment have been always defining peculiarities of settlement of population and agricultural activities and determining landscape-ecologic balance of geographic environment. However, whereas amount of land for optimal adaptation is extremely limited, its irregular adaptation causes critical degradation-devastation of lands. Consequently, this causes development of scaled and diverse geologic processes (land-slides, debrisflow, erosion, etc.), which have been complicated anyway and are followed by enormous material loss, forcing thousands of people to leave their homes, emptying if tens of villages and human sacrifice. The article considers conditions of development of a catastrophic debrisflow, which occurred in Dariali in the year 2014 and its negative consequences.

Keywords

Georgia, Debrisflow, Landslide, Geological Hazards, Disaster, Dariali

1. Introduction

Study area includes central part of Kavkasioni's main range, namely the Tergi Valley (coordinates: 42˚43'34.39"N;

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44˚37'47.37"E). Tergi Valley is situated on a north plateau of Kavkasioni and includes ethnic Khevi (**Figure 1**). The lowest point on the territory under examination is 1330 meters, the highest point is Mkinvartsveri 5033 m. Main morphometric, and morphological figures of Tergi gorge are formed by interaction of tectonic and erosive-accumulative processes [1]. Glacial and gravitational forms [2] complicate main background of the relief [3].

Tergi gorge is antecedent down Stepantsminda settlement. It is cut in axial zone and represents narrow mountainous corridor. From the left side, the river Tergi is joined by the river Devdoraki and the river Amali, which after joining are known as the river Amali. Gorges of the river Devdoraki and Amali are of glacial origin. Devdoraki and Chachi, big glaciers of Kazbegi massif fall into the upper part of the gorge. Ice stream of the glacier Devdoraki goes down by 2290 meters. River Devdoraki has formed a narrow channel-shaped deeply cut gorge with steep and scarp gorges [4].

To the West of the junction of rivers Devdoraki and Amali there is formed a step, which rises over the existing bed by 60 - 75 meters. Inclination of the step towards the river varies from 65˚ - 80˚. Track of the last flow in different places is observed on the height of 25 - 30 m.

From the point of junction of the rivers Devdoraki and Amali in both ways towards the flow there is observed 2 terraced steps, which rise over the bed by 30 - 60 m. They are located on a comparative height. Terraced steps have leveled surface tilted in the direction of low undulatory flow. Inclination of plateau of river gorges is within 40˚ - 60˚, however the left plateau comparing to the right one is distinguished with more inclination. After comparison of the river Devdoraki with the river Amali, the lower part of the river Tergi is deeply cut. In this section of the gorge, there is a 300 - 500 m length step of Vurmian glaciation, which is paved with moraine plain Holocene glaciation, on the surface of which lakes are formed.

2. Climate

Climate in the lower part of Kazbegi Municipality (up to 2000 m.) is moderately humid; the winter is comparatively dry, cold winter and long cool summer. Average temperature in January–from 3˚C to 8˚C, in July 17.8˚C - 13.8˚C, amount of precipitation annually is 650 - 1000 mm (maximum in May, minimum in January). Snow cover lasts for 3 - 4 months. Climate in 2000 - 2600 m zone is moderately humid, winter is comparatively dry, cold winter and short summer. Average temperature over 10˚C lasts for 1 - 3 month, temperature over 5˚C 4 - 5 months. Temperature of the warmest month is 10˚C - 14˚C. Mountainous and gorge wind prevail. Amount of precipitation is 1000 - 1200 mm per year. Snow cover lasts for 5 - 7 months. Climate in 2600 - 3600 m zone is

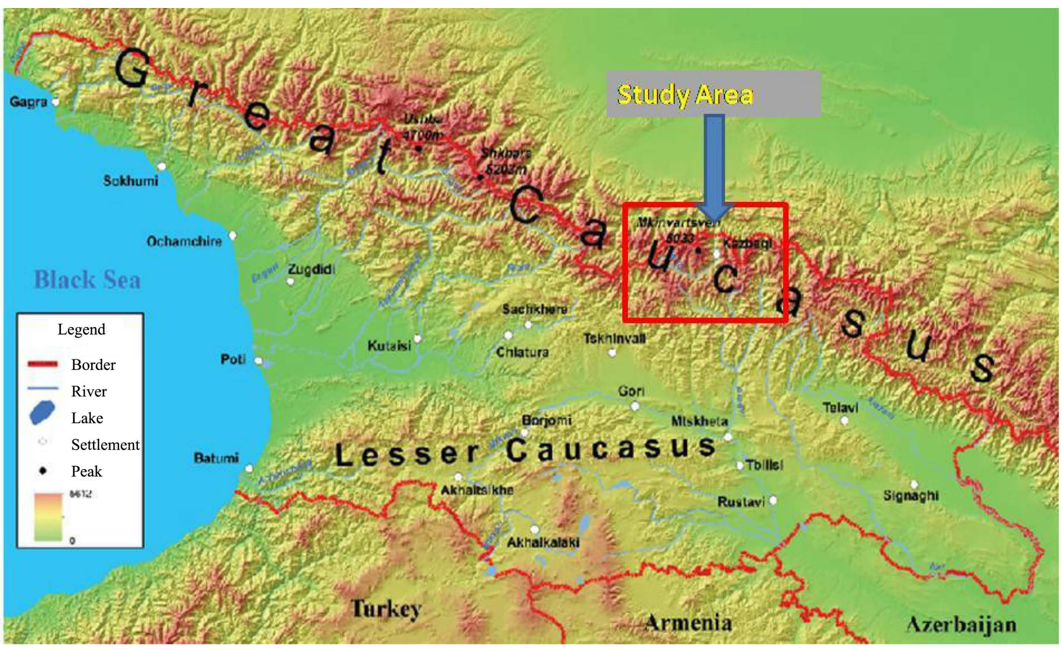

Figure 1. Georgia and study area.

moderately humid, there is no real summer. Average temperature in January 11˚C - 15˚C in July, is 10˚C lower. Climate of highland over 3600m is moderately damp with continuous snow and glaciers. Average temperature in January and February is 13˚C - 16˚C. July, August is positive. Precipitations are mainly in the form of snow.

3. On May 17, 2014 Debrisflow Process in the Gorge of Rivers Amali-Devdoraki and Tergi

On May 17, 2014 a catastrophic debrisflow process occurred in the area of junction of rivers Tergi and Devdoraki-Amali, which completely paralyzed functioning of infrastructure objects having strategic meaning for the country. Debrisflows have damaged Georgian military road, "North-South" connecting 700 and 1200 mm gas pipelines, knocked down transmission line, means of transportation, isolated base of border guards, customs point, residence of Georgian Patriarchate, and caused serious problems to employees (**Figure 2** and **Figure 3**) and also caused 8 victims (including foreign citizens) [5].

Figure 2. Destroyed gas pipeline.

Figure 3. Destroyed trucks.

Dariali gorge represents a canyon from the village Tsdo Latitude to the state border, which is significantly narrowed in the place of junction of rivers Tergi and Devdoraki-Amali.

The river Devdoraki-Amali gorge begins at the Northern part of the river Mkinvartsveri (5033 m) in 4225 - 4250 m hemispheric interval and sub-latitude is extended to Eastern direction. Morphology of the primary gorge of the river Devdoraki from the beginning to the joining area is characterized with typical trog genesis, however, further it is greatly transformed by erosive process. Specifically after the lobe of the glacier Devdoraki the depth of cutting of the gorge gradually increases towards direction of the flow, from the junction it is distinguished with very steep sides and pan shaped (trog) base. Morphology of gorge from the 2045 m point to the river Devdoraki and to the bottom of the junction of the river Amali (1715.0 m) to the meridian of Gveleti lake is typically trog, and its trapezoidal bed is completely in fluvioglacial and debrisflow fallouts, from the meridian of Gveleti to the junction of the river Tergi formed with fluvioglacial and granitoid on the areas of narrowing the cross section receives "V" morphology.

Unlike the events, occurred in the gorge in the past, when ice masses were disrupted from the edge of the ice stream, the zone of formation and disruption of debrisflow events is located on a considerably high level. Namely, on a height of 4500 m of a very steep (65˚ - 70˚) hem of Mkinvartsveri (**Figure 4**), falling mostly rocky material and higher part of the glacier as well as vast masses of snow occurred in the rightmost part of the rock zone of the glacier Devdoraki, which coincided with the latest precipitations in the gorge in the form of the rain.

The fallen mass was transformed into rocky-iced avalanche, which was divided in three flows and fell on a high speed above steep ice stream. One of flows rounded about rocky prominence and transformed mass collapsed on the right steep rocky side, but major part of the mass fell on the glacier again. Red-pink trace of falling in the form of large spot is observed on the higher level of the left side (**Figure 5**). The largest left flow transferred central part of the ice stream into dynamical zone and a caused significant deformation of the said part of the ice stream and cracking into different iced blocks.

Below this section, all flows merged into one enormous flow and fell with ice stream on a high velocity in the direction of the gorge. On its way it caught up glacier fallouts of trapezoidal bed of the river Devdoraki and its borders. High structure material transported by debrisflows deposits in the changeable bed (up to 18 - 30 m) of the river Devdoraki. The flow, which came out of the section of sharp bend at the junction of the river Amali on the height of 30 - 35 m washed away a fragment of the right side (the trace of such event was observed in the past on the height of 55 - 60 m from the bed in the morphology created by the recent debrisflows). Down the turn the gorge and its bottom have gradual conical extension to the junction of the river Amali. On the above-mentioned section of the river bed a large size boulders (up to 3 - 6 m) and moraine genesis (the so-called pellets) were sludging in the river bed (**Figure 6**), which was explained by the extension of the section of the gorge after the sharp turn, reduction of the kinetic energy of flow and transfer of motion vector in the direction of the

Figure 4. Debrisflow source area.

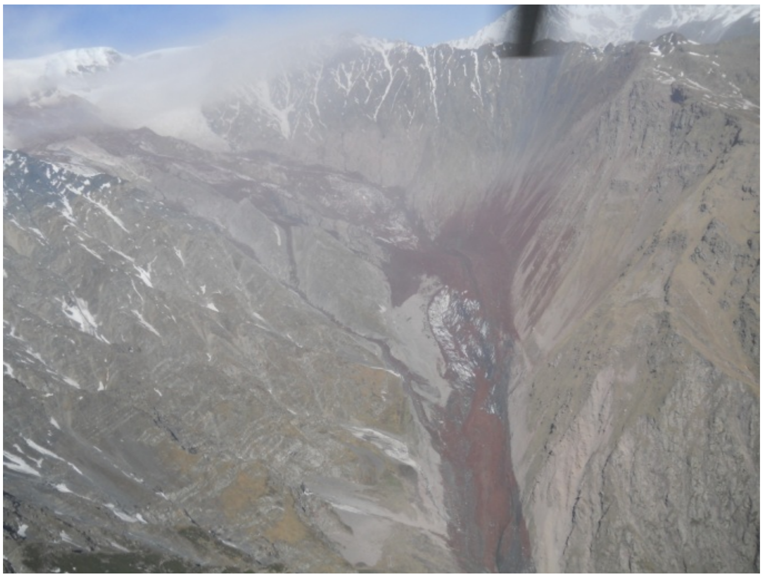

Figure 5. Devdoraki Valley (arrow indicates level of debris material).

Figure 6. Debris material.

right side. That's why the wavy trace of the flow on the side is not homogeneous and changes on the sides up to 3 - 15 m. After junction of rivers Devdoraki and Amali the flow moved in coil bed of trapezoidal cross section, which was worked out in deposits of fluvioglacial-debris flow with the depth of average cut is 20 - 25 m and the distance between the brows is in the range of 35 - 50 m. From the point of junction of rivers Devdoraki and Amali to meridian of Gveleti Lake the trace of debrisflows on the sides of the bed are observed on different height levels and ranges from 10 - 20 m from talveg. It should be noted that along with gradual melting of the ice, icicles are formed in material deposited on the side of gorge and falling-out of comparatively large factional material into the bed. On meridian of Gveleti Lake bed of the river abruptly turns to North-East. Also, comparatively wide bed of trapezoidal cross section is transformed into narrow "V" cross section bed, consequently, its possibility is restricted, that caused temporary short-term damming of the debrisflow on the section of abrupt turning of the bed, as a result of which the wave deposited debrisflow material on the right side up to the brow, height of which as compared to the right side is 20 - 30 m. Depth of cut of the given section is up to 23 - 25 m, its pressure increased due to temporary damming of the flow and it erupted in the direction of the river Tergi, reached deposits formed by granitoid and solid growth was deposited at its bottom, at the same time the flow continued its movement in Northern direction and stopped in about 50 - 60 meters of the hydro-technical building of “Larsi HPP” (sluice and sedimentation basin) (**Figure 7**).

Alluvial fan (with approximate volume of about 1.5 min·m^3) formed by accumulation of solid growth material transported by debrisflow, which blocked the Dariali gorge. The total amount of debrisflow mass taken from the wall of abruption to the junction of the river Tergi makes up 5 min·m^3, the most part of which is accumulated in the area of circus of abruption, on Glacier devdoraki tongue and Transit zones of Valley (**Figure 8**). Granulometric composition of material is: 50% - 55% is more than 200 mm material, from 10 mm to 200 mm 25% - 30% and <10 mm (gravel-sand-clay mass) 15% - 20%. Size of separate boulders varies in the range of 5 - 6 m. The so-called pellets of moraine genesis have the same sizes and they began to thaw and decompose.

On average debrisflows containing of stones and mud are characterized with high durability (density). Without high durability (density) and corresponding rheological nature, it would be impossible to move such large boulders to the base level. Moreover, debrisflow is characterized with such high durability, that even after their

Figure 7. Larsi HPP station.

Figure 8. Accumulated debris material in Devdoraki Valley.

movement into the main bed the river Tergi didn't manage to dilute stones and mud containing flow and its movement into the lower course of the river. It's also worth mentioning that on the first stage of accumulation of debrisflows in the gorge of the river Tergi, the positive role in its transportation in the lower course of the river was played by the transport tunnel of "Dariali HPP" (**Figure 9**).

Petrographically debrisflow material is mainly represented: red-pink andesite-dacite, basalt, diabase, quartzite, flaky schist, pumice stone etc. In the first days intensive movement of stone-mud flows was observed in the bed of the river, gravitational processes take place on both sides of the river nowadays. Debrisflows have blocked the river Tergi, the water was dammed and amount of water in the created reservoir made up 150,000 m^3 (**Figure 10**). Average depth of reservoir was 10 - 15 meters.

4. Debrisflow Occurred in Amali-Devdoraki Gorge on August 20, 2014

At 22:00 p.m. on August 2014, a catastrophic debrisflow reoccurred in the gorge of Devdoraki River (left tribu-

Figure 9. Dariali Valley (arrow indicates HPP transport tunnel).

Figure 10. Blocked Tergi river and created reservoir.

tary), which was provoked by pouring rains. Debrisflows, which occurred in the gorge of the river Tergi have caused 2 victims and failure of infrastructure objects having importance for the country, namely:

- "North-South" 1200 mm diameter gas-main pipeline was damaged;
- 2.0 km of highway was washed off (**Figure 11**);
- Current Larsi HPP was over sanded;
- Customs checkpoint building was over sanded and deformed (**Figure 12**).

The most grievous result was the death of two persons, who worked in the tunnel of Dariali HPP.

In the center of forming of the catastrophic debrisflow of May 17, 2014, which was characterized with avalanche of rocky-avalanche type rock and glacial mass, which was followed by interaction of the given mass and ice stream and its transfer into the gorge of the river Tergi, new deformations and abruptions are not observed if not take into account crevice in the glacier. However, it should be noted, that the ice stream of the glacier Devdoraki was insignificantly deformed during the debrisflow on August 20 (**Figure 13**).

As we have already mentioned, transformation of the recurrent debrisflow was caused by pouring rain, which as followed by interaction of solid mass, with the volume 440,000 m^3 in the bed of the river Devdoraki (transit

Figure 11. Destroyed highway.

Figure 12. Damaged customs checkpoint building.

zone) on May 17, 2014. It should be noted that rheological nature of debrisflows, which occurred on May 17, was of high durability, fluctuation and viscosity, which was mainly accumulated in base of the gorge of the river Tergi. Flows, which occurred on August 20 were characterized with low durability and amount of water and were followed by deep and lateral erosive washouts and transit movement in the lower course of the base of the river Tergi (**Figure 14** and **Figure 15**).

5. Reasons of Debrisflow Process

Interaction of natural processes in Dariali gorge is pre-conditioned by high-energy potential and by the following factors:

- Domination of rock with low engeneering-geologic peculiarities on main part of the territory (Liassic schist, flaky schist etc.), durability of which is in the highest zone of the crust varies from 23.2 to 80.1 Mpa and in conditions of freezing drops up to 8.5 - 51.1 Mpa;

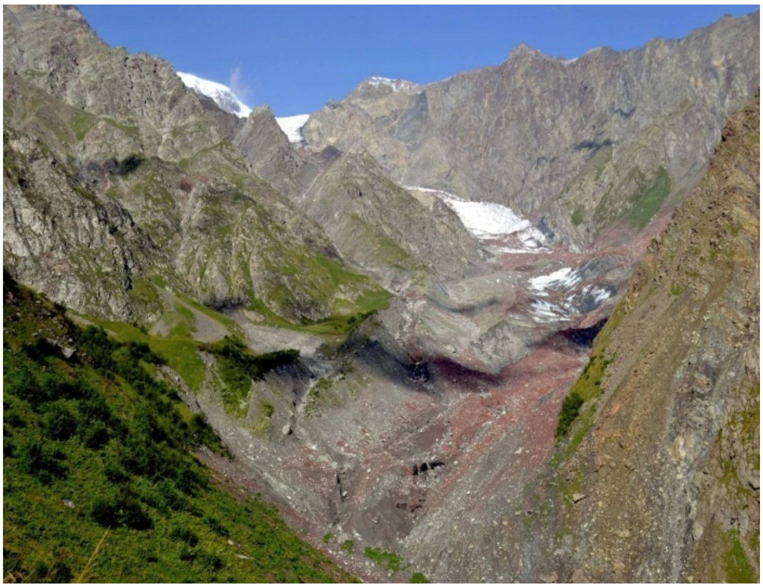

Figure 13. Glacier Devdoraki.

Figure 14. Devdoraki Valley.

Figure 15. Damaged highway.

- Complex climatic conditions—sharp changes in thermal gradient of zero isotherm and associated frosty-mechanical exhaustion and intensive course of solifluction events;
- Active movement of morphostructural blocks separated by tectonic joint fissure, high seismic risk and increase of tension of physical field up to critical level. High 7 - 8 rate earthquakes were observed in the block of seismic activity of Akzbegi were observed in 1878, 1915, 1947, 1951, 1992;
- Diverse attitude of volcanic fallout rocks towards depletion causing agents;
- Development of center of debrisflow formation by rocky-avalanche and erosive-gravitational events in the beginning and bed of the gorge;
- Existence and accumulation of large amount of glacial, fluvio-glacial and moraine formations in the bed of the gorge and on its sides;
- Thaw water formed after intensive thawing of glacial cover and snow by means of pouring rains and ground waters in the beginning of the gorge and excessive dampening of debrisflow forming centers at the bed of the gorge (flooding);
- Impacts, caused by global climate change;
- It also should be noted that catastrophic geologic event, which recently occurred in the gorge f the river Tergi as well as formation of glacial debrisflows in the glacial center of the mountain Mkinvartsveri, are connected only with natural factors and the role of human being is ruled out.

6. Conclusions and Recommendations

- On May 17, 2014 and August 20 of the same year, a catastrophic debrisflow occurred in the junction of the river Tergi and Devdoraki-Amali in Dariali gorge, which paralyzed country's main strategic infrastructural objects. Debrisflows have damaged Georgian military road, "North-South" connecting 700 and 1200 mm gas pipelines, knocked down transmission line, means of transportation, isolated base of border guards, customs point, and residence of Georgian Patriarchate, caused serious problems to employees, and caused death of 10 people (including foreign citizens);
- It is necessary to resume complex hydro-meteorological and geologic-geophysical long-term monitoring, firstly in the sector of Mkinvartsveri-Jamaikhori glaciers, located in central Kavkasioni. It should be noted that out of the glaciers that exist today in Georgia, taking into consideration their complex climatic and landscape condition, dynamics, causes and intervals of reoccurrence of glaciers in this zone is studied least of all. It should be determined which glacier experiences pulsation, its recurrence, and with which natural factors it is connected to. The most important of these issues is studying of geological-morphologic condition of a debrisflow forming basin in a separate nival-glacial zone by means of instrumental technologies, mapping of

morphology of the surface of glaciers, projecting of crevice, their morphometry, determination of glacial, surface and deep lakes and free waters, determination of their scale, evaluation of thermo karst dripping events;

- Evaluation of condition of rocks in the area of wide spreading of glaciers concerning development of rock avalanches and determination of anomalies having inclination towards gravitational events;
- Determination of alive destructions in the area of widespread of glaciers, routing of destructions and studying of thermal regime in the area of destruction and glaciers;
- Determination of durability, capacity of the glacier, also determination of hidden crevices, as one of factors preconditioning rheological nature and pulsation of the glacier;
- Studying of engineering-geologic features of transforming glacial-moraine fallouts of glacial debrisflows and taking into account durability, determination of the amount of mass of glacial and debris flow fallouts will take part the process of forming of debrisflow processes;
- For making long-term and short-term forecasts of debrisflows and corresponding notifications it is necessary to use not only overground monitoring observations but also high quality pictures, received from satellites. Management of database and identification of a pulsating glacier, its ratio and cycles;
- Based on historical information and our observations, the process becomes irreversible in space and time and we can expect development of debrisflows and such events of the same scale;
- Undertaking of any protective measures in the zone of forming and transit of debrisflows in Devdoraki-Amali is practically impossible, as morphologic conditions of the gorge (slopes, shortness of the river, narrowness of the bed, etc.) do not allow building of any engineering building. It also should be mentioned, that over 10.5 km (length of debrisflow), relative height between the wall of abruption and the zone of junction of the river Tergi with the river Amali (the base level of the river Amali) makes up 3160 m. One of the options is to arrange an early warning system in a short period of time.
- Signal of complex early warning system (geological, meteorological, geophysical), located on the observable area shall be given to all bodies, involved in servicing of infrastructural objects and provision of their development.

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