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Analysis of Spontaneous Exodynamic Processes in the Dghviora River Basin Taking into Consideration the Perspectives of the Shovi-Glola (Georgia) Tourist Agglomeration

Merab Gongadze[1,*], George Lominadze[1], George Khomeriki[1]
George Kavlashvili[2]
[1] TSU, Vakhushti Bagrationi Institute of Geography, Tbilisi, Georgia
* Corresponding author: merabgogazde@yahoo.com

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Abstract

River Dghviora originates from the much-modified cirque of the vanished glacier on the northern slope of the Shoda-Kedela mountain range, parallel to the Central Caucasus. The glacial and erosive-glacial relief of the nival zone is developed here, with clearly defined troughs, moraines, individual erratic boulders. At relatively low hypsometric levels, alpine and subalpine landscapes are represented. The building rocks of the valley, along with the slope of its bed and climatic conditions, are the main factors of the formation and development of exodynamic processes. The material coming from Dghviora river, and its parallel valleys flows into the Chanchakhi valley and forms a large withdrawal cone at the confluence, on which the village of Glola is built. From here, destructive mudflows arise during heavy rains, because of which this and other settlements are damaged. In July 2020, because of heavy rains, due to the overflow of Rioni, Chanchakhi, its abovementioned and other tributaries, destructive mudflows were formed, which destroyed the infrastructure, highways and bridges of the villages of region Zemo Racha. The purpose of the article is to analyse the mechanism of occurrence of natural processes and to assess their impact on the tourist agglomeration of Shovi-Glola, as well as to predict the further development of these processes as much as possible and to present preventive measures.

Keywords: Exodynamic processes; rockslides; mudflows; threats to tourism

Introduction

The Racha region covers the upper part of the Rioni River basin, from the Tvishi Narrows to the crest of the Central Caucasus. This includes the entire ethnographic Racha and partly the northwestern section of Samachablo (the headwaters of the Jejora River). The area covers an area 100 km in length and 50 km in width, and the depth of the vertical incision ranges from 500 to 1200 m. Absolute heights vary from 350 m (Tvishi Narrows) to 3780 m (Pasi Mountain). The region is distinguished by a complex and diverse geological and geomorphological structure, as the entire stratigraphic spectrum, starting with Palaeozoic crystalline rocks and ending with Quaternary alluvium, is exposed here, and the complexity of the relief is conditioned by the large amplitudes of the absolute and relative heights of its surrounding ridges and the genesis and morphology of the related relief landforms. Fragmented by Rioni and its tributaries, the cavity is bounded in the northeast by the southern slope of the main Caucasus Range, in the northwest by the Lechkhumi Ridge (Mt. Samertskhle, 3560 m) and its southwestern branches, and in the southeastern border by the Racha Ridge (Mt. Khikhamta, 2240 m). The Dghviora River is also a left tributary of Chanchakhi, the left tributary of the upper waist of Rioni, which originates on the northern slope of the Shoda-Kedela ridge, parallel to the Central Caucasus. The rocks forming the valley-Jurky and Lower Cretaceous shales, clay shales, sandstones, limestones, and Quaternary deluvial, proluvial and partially alluvial layers, together with the slopes of the valley, inclination of its bed and climatic conditions, are the main factors for the creation of exodynamic processes: mountain torrents, rock avalanches, stone falls, and debris cones. The material coming from Dghviora and its parallel valleys flows into the Chanchakhi valley and forms a large debris cone near the estuary. The Dghviora valley originates from the highly deformed cirque of the vanished glacier, where alluvial centers have appeared. From here, destructive mudflows arise during heavy rains, because of which the village of Glola and other settlements are damaged. In July 2020, because of heavy rains, due to the overflow of Rioni, Chanchakhi, its abovementioned and other tributaries, destructive mudflows were formed, which destroyed the infrastructure, highways and bridges of the villages of Zemo (Upper) Racha (Tsereteli, 1965).

Spontaneous Exodynamic Processes in the Dghviora River Basin

The Chanchakhi River basin is located on the southern slope of the Greater Caucasus. The glacial and erosive-glacial relief of the nival belt is developed here, with clearly defined troughs, moraines, and individual erratic blocks. At relatively low hypsometric levels, alpine and subalpine landscapes are represented. The depth of erosive dissection is more than 1000 m in some places, and the inclination of the slopes is 40-600. The absolute height of the highest peak of the Shoda-Kedela range, Shoda, is 3609 m. This high-elevation, deep-valley, erosional-denudation terrain developed on Jurassic and Lower Cretaceous sedimentary rocks. The presence of relatively mild forms of the relief relates to the erosive processes occurring in the Liassic, strongly dislocated micaceous sandstones and with the erosion processes occurring in the shale clays. The shape of the valleys is mostly V-shaped, and where clay shales dominate, the rivers form glacial-carved valleys (Tsereteli, 1965). At relatively low altitudes, denudation relief occurs with the active development of mudflows and landslide events. In the Lower Cretaceous sediments, intense tectonic movements produced folded structures. It is dominated by young and old faults of three latitudinal directions, which are complicated by paraclases and rupture dislocations of different directions, which are well defined in the terrain. The geological formations on the northern wing of the Upper Racha syncline are mainly composed of thick-layered marls of Upper Jurassic age, carbonate shales, and interlayers of limestones. Quaternary eluvial, deluvian, colluvial, alluvial, Proluvian and fluvioglacial layers form relatively young sediments (Fig. 1).

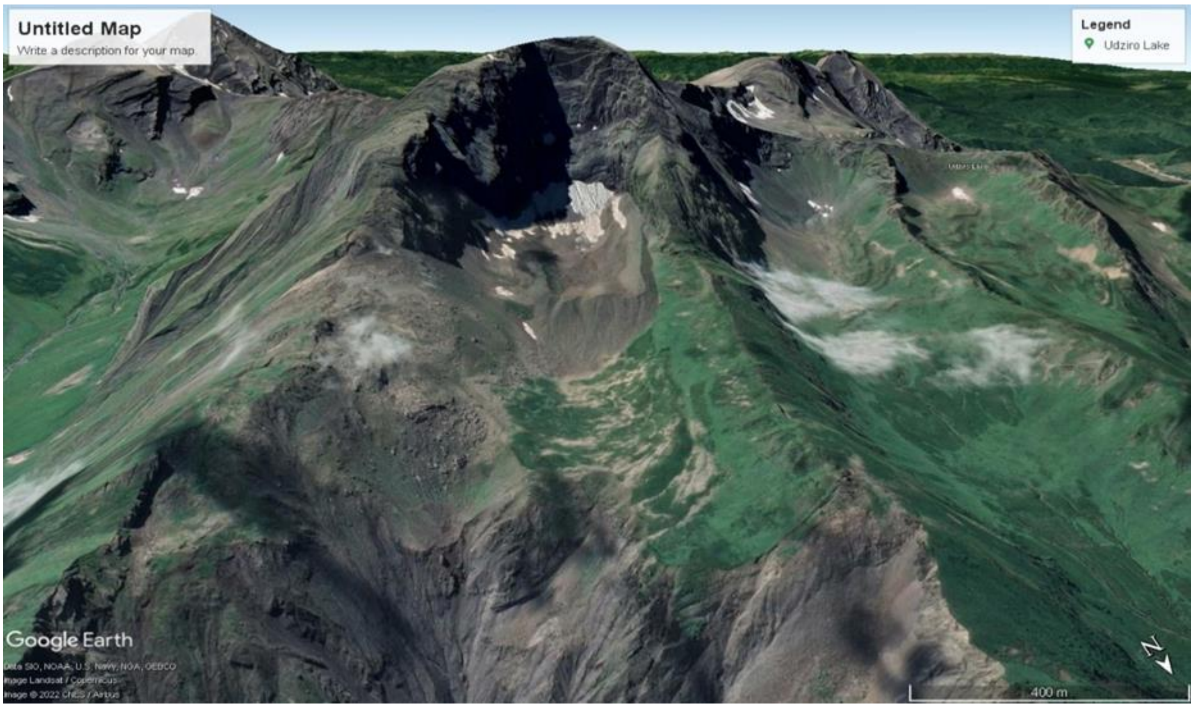

Figure 1. The head section of Dgviora river in the Chanchakhi basin. Source: Google Earth

The upper part of the Chanchakhi River from the left side joins the Dghviora River, whose basin is very peculiar and at the same time typical in terms of the manifestation of natural exodynamic processes in Upper Racha and in the Caucasus (Map oh mudflow hazards in Transcaucasus and Dagestan, 1989; Cernomorets, 2006; Dokukin et al., 2015). There are two channels near the mouth of the Dghviora River—old and new—developed later. The river originates from the northern slope of the Shoda-Kedela ridge near the summit at an altitude of 2640 m above sea level. The head of the river is a bursiform valley bounded by steep (60-700) slopes, which is probably a deformed glacial cirque (Figs. 2 and 3). Tectonic and rock lithology are among the most important factors influencing the relief of a valley (Adamia & Gujabidze, 2004; Tsereteli et al., 1985; Ovsyuchenko et al., 2011; Arefev et al., 2006).

According to the tectonic division into districts of Georgia, Lower Cretaceous clay shales and marly shales are intensively folded here. In the sandstone and limestone distribution zone, the relief is sharply dissected and represented by steep ridge and scarp slopes.

The area of the river basin does not exceed 6 km2, the length is 5 km, and the average slope of the riverbed varies between 15-17^0 in the middle and lower parts (Fig. 3). Fluvioglacial, proluvial and

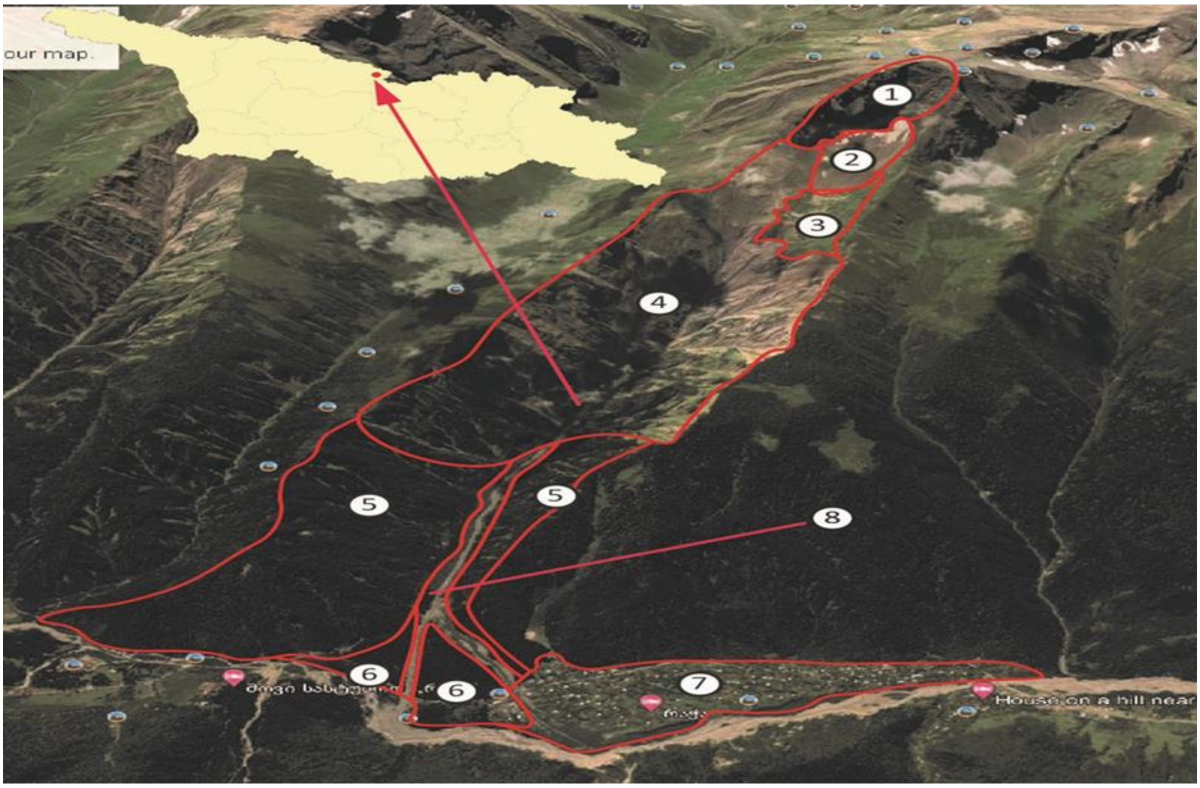

Figure 2. Scheme of the main geomorphological elements of the Chanchakhi river basin (Georgia, south slope of the Greater Caucasus range): 1. Old glacial cirque, 2. Moraine sediments, 3. Fragment of Old Trog 4. Wide erosive area 5. Relatively stable slopes, 6. Alluvial fan (cone), 7. Terrace-step of polygenetic origin 8. False terraces along the right side of the Dghviora river channel. Source: Google Earth

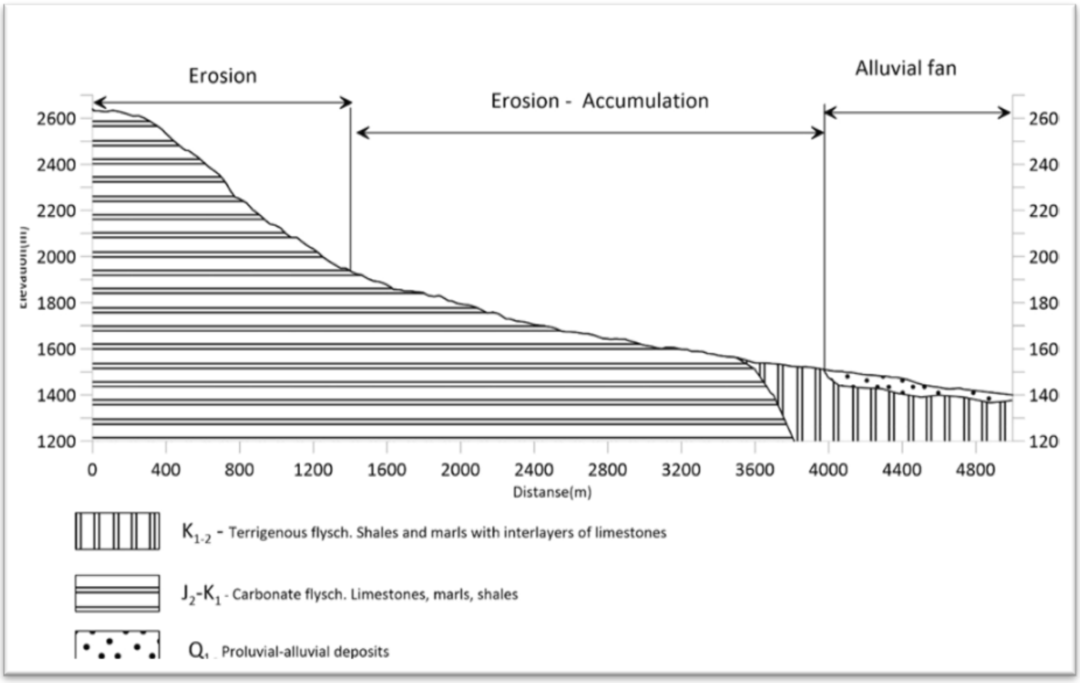

Figure 3. Profile along the Dgviora river gally

partially alluvial sediments accumulate in the riverbed in different layers. As a result, mudslides, landslides, rock avalanches, and snow avalanches are actively occurring here.

Figure 4. The head and bed of the Dghviora river

The Dghviora River basin developed because of a complex combination of erosive-denudational, glacial, tectonic, and climatic factors and lithological features of the basin-forming rocks. At the head of the river, there is a deep fault in the northeastern direction, which is complicated by numerous local faults in different directions, which significantly weakens the strength and stability of the rocky rocks against depletion, denudation and erosion (Abutidze et al., 2010). Additionally, a clearly defined cirque is formed here, which is followed by a small trough of a tub-like shape below. Over time, its area decreases, which is related to the erosive processes of the river, particularly reverse erosion. This process gradually consumes the rest of the trough. It should be noted that the Holocene layers slightly below the cirque moraine layers are probably preserved.

According to the 2010 report of the National Environment Agency of Georgia (Abutidze et al., 2010), fossilized ice masses appear under loose sediments, which weakens the stability of the ground when thawing in warm weather, which becomes a contributing factor to the formation of mud flows. Below the trough, on a 50-60^0 inclined slope made of eroded rocks, large boulders can be found, the mass of which in some cases reaches tens of tons. Interestingly, at the bottom of the abovementioned steep slope, two water streams join and episodically; due to rock avalanches from above, impounded lakes appear in the valley. As a result of their breakthrough by the accumulated water, mud-flow torrents are released. After the confluence of the watercourses, the riverbed is continuously covered with depleted material. In the middle of the river, both slopes of the narrow gorge are erosive-denudational at 1 km and consist of Lower Cretaceous shale clays and marly clays, which are also among the main sources of mud-flow streams (Fig. 2). Further down, in the direction of the flow of the river, almost to the confluence, at 3 km, both. The slopes of the valley are covered with thick dark coniferous forest and are practically free from erosion. The right bank of the river is bordered by a 35-40 m wide pseudoterrace made of colluvial and fluvioglacial material, which consists of several steps. Its height varies from 3-4 m to 8-10 m. It occupies insignificant areas on the left bank of the river (Fig. 3). The thickness of the deposited mass in the bed itself should be at least 12-20 m.

Figure 5. Typical composition sediments on the right bank of river Dghviora

Two streams, which flow from the steep and weathered slopes of the Shoda-Kedela Ridge, join each other in the upper part of the river and form the main stream of the Dghviora River (Fig. 4). Disintegrated material, mainly in large fractions, falls from the head, and slopes accumulate there, periodically blocking the flow of the river and temporarily creating lakes. Over time, this natural dam is breached by excess water, and a torrent is formed. The width of the river floodplain reaches 50-60 m in this section, and the inclination of the bed is 15-200. The accumulated material consists of several fractions: single large boulders of 1.5-2 m in size, small boulders of 20-30%, and small pebbles of up to 70%.

In its new bed, at 1.2 km upstream of the confluence with Chanchakhi, riv. Dghviora has cut its accumulation material in several places. The bottom of one of the trenches (height 1,717 m above sea level, thickness 120 cm, width 250 cm) begins with a sand fraction (less than 0.5 cm), which occupies 15% of the trench volume. Then, a slightly larger fraction of less than 5 cm (12%) was observed. These layers are as follows: 5-10 cm fraction - 9%; 10-20 cm fraction - 12%; 20-35 cm fraction - 20%; and 15 cm layer with 10 cm interlayers of pebbles, sand and clay - 12%, fine gravel coarse material or less processed 35-50 cm - 20% (Figure 5).

In the middle of the river, 120 m above the bridge, a granulometric polygon (20 m²) was set up to record the horizontal distribution of the solid sediment fractions of the river. The polygon consists of the following fractions: 0.5 m thick sand, clay and fine pebbles—25%, 5 cm thick sand fraction—13%, 5-10 cm sand and gravel fraction—11%, 10-20 cm thick sandy-pebble layer with inclusions of 15-20 cm boulders—10%, 20-35 cm thick boulders—8%, 35-50 cm thick boulders—11%, and 70 cm thick boulders—22% (Fig. 6).

At the estuary of the Chanchakhi River, the Dghviora River has created a powerful extraction cone, the length of which reaches 700 m, and the width reaches 60-70 m. As a result of the washing of the alluvial-proluvial layers of the cone by the riv. Chanchakhi, a 6-7 m high bare plateau escarpment was formed, where the structure of the material is clearly visible. Boulders from 0.4 m to 1.0-1.4 m long are clearly visible here. Their amount ranges from 10-15%, and the remaining mass (55-60%) is made up of clayey and marly shale with a sandy filler, as well as a pebble-gravel fraction (20-25%). The surface of the extraction cone is covered with large and medium-sized boulders. While passing the catastrophic floods, the material from the Dghviora River completely or partially blocks the bed of the Chanchakhi

River. As a result, the right bank of the river is intensively washed away, where a 10-12 m high and 50-60 m long exposure was formed. Rough moraine material appears here. The size of the boulders varies from 0.4-0.7 m to 1.8-2.5 m.

Figure 6. Granulometric polygon in the bed of Dghviora river

The Dghviora River, at the confluence of the Chanchakhi River, creates a modern powerful detrital cone. Today, two beds are marked on its surface: one old and the other partially artificially expanded. The new confluence of the Dghviora River has moved at 450 m from the location of the old confluence with the Chanchakhi River. The expansion of the new bed occurred after the event when, in the early 2010s, a catastrophic mud flow with a volume of 2 million m^3 passed through the Dghviora River basin, which damaged residential houses and other buildings. The new riverbed begins 700 m above the old mouth. The bottom of the old bed along its entire length was quite quickly covered by perennial vegetation, a circumstance to be considered for the safety of the village of Glola. With a 2-3% reproducibility, only one branch of the estuary cannot deal with the catastrophic flow when passing extreme runoff. However, the flow may enter the surrounding coniferous forest and lose energy. It is necessary to clear the bottom of the old branch of the river from dense vegetation to a length of 600 m to ensure the maximum permeability of the flood flow. The modern detrital fan of the Dghviora River is joined to a lower 2 km long inclined terrace step of polygenetic origin on which the village of Glola is located. The terrace is Quaternary in age, and the relatively plain areas surrounding Glola are also Quaternary in age, apart from the bedrock outcrops. Therefore, it is not surprising that in highly mountainous, highly fragmented terrain, people choose more comfortable, relatively flat terrain for settlement.

Changes in the Dghviora riverbed have saved the important village of Glola from the ever-increasing threat of mudslides. Before the relocation, the continuously cultivated bed of the Dghviora River passed through its territory.

The village is located on the southern slope of the main watershed of the Caucasus, 25 km from Oni, at an average of 1,275 meters above sea level; it opens to the west to the Rioni valley, and the other three sides are surrounded by mountains covered with coniferous forests. Notably, this area is an important section of the northern border zone of Georgia (Fig. 7).

According to the classification by Jaoshvili (1996), Glola belongs to the seventh type of rural settlement in Georgia, which brings together small settlements scattered on mountain slopes that feature extensive agriculture, mainly based on animal farming. Such settlements often develop into agglomerated layouts, with Glola and Shovi also forming this kind of agglomeration.

Glola is a historical village – sources link an episode of its history with Queen Tamar. Vakhushti Batonishvili also provides a brief description of Glola (Vakhushti, 1973). The past importance of the village was mainly related to its location. For a long time, it represented a crossroad in the Middle Ages where caravan routes from Georgia’s lowland and Lower Racha passed on their way to Upper Racha and Svaneti, as well as to Ossetia through Mamisoni, Notsara and other crossings on the Caucasus. This gave Glola—in particular, its lower roadside part, Saglolo—the role of a traffic distributor.

Starting in the nineteenth century and along with changing trade routes, Glola largely lost its function

Figure 7. Rural agglomeration Glola-Shovi, emerging as a tourism cluster. In the center of the image, you can see the result of the shifting of the bed of river Dghviora to the east, which saved the settled part of village Glola from the danger of a catastrophic mudflow. Source: Google Earth

as a transport hub. Instead, with the development of the Shovi resort, Glola acquired the function of the resort's economic hinterland, along with its traditional agricultural role. Shovi is a climate and balneological resort located adjacent to Glola village at 1,520-1,565 meters above the sea in the Chanchakhi River valley, with a pulmonological, allergic and gastroenterological healing profile, healthy air and picturesque landscape that proved very popular between the 1920s and 1980s. (Sharashenidze, 1940). Since the 1990s, the situation has changed—the Shovi resort has lost its social purpose (healthcare for workers), and the state could no longer finance it, leading to a decline in both the resort and Glola village. The depopulation processes characteristic of Racha villages also developed here. Between the 2002 and 2014 state censuses, the population of Glola decreased by 27.5% to 279 residents.

In recent years, signs of revitalization of Shovi have appeared with its adaptation to the conditions of the market economy, activation of the process of commercialization of resort activities and resulting revival of health tourism, which has also been reflected in Glola - the village reacquired the function of providing accommodation for vacationers in the Shovi area. In addition to private apartments for rent, several family hotels (guesthouses) operate here, and a very comfortable and relatively expensive ($120/night) tourist cottage has opened. Activities serving tourism in the resort area—trade, supply, services, and transportation—have been stimulated. It is important for local prospects that Glola also features its own resources for tourism development – a healthy mountain climate (Gavasheli, 1978), coniferous forests, mountain trails for trekking and horseback riding tours, "Glola boulders" – granite moraine formations included in the “Red Book of Georgia” – as well as mineral waters and remains of cultural heritage.

Some authors writing about problems in rural areas consider the development of new, additional functions—e.g., industry, communications, energy, and tourism—for these locations to be one of the most effective means of stopping their depopulation and ensuring support (Delgado, 2019). In this regard, Glola can improve the services of the Shovi resort (in case of its restoration after the disaster of August 2023) and develop its own recreational activities, especially if we take into account the launch of the Gomi-Oni Road in the near future.

Conclusion

Along with natural factors, human agricultural activity plays an important role in the changes in the environment of Racha, which is manifested in the cultivation of agricultural lands (ploughing the slopes in accordance with the slopes, cutting down forests and growing annual crops in their place, etc.) and, as a result, soil damage (Salukvadze, 2022). Accordingly, agricultural activity in this zone has both extensive and intensive growth prospects. Natural exodynamic processes pose a constant threat to the regional communications and tourist infrastructure of the village of Glola. The prospects for tourism, including international tourism, in this dynamic, natural environment are directly related to ensuring security. Accordingly, for the prediction of environmental threats, regulation and protection measures against natural disasters have become even more important. Thus, to stop the critical decrease in the population in Glola and the surrounding area, it is necessary to activate tourism, which in turn requires ensuring the safety of the environment. Accordingly, for the prediction of environmental threats, regulation and protection measures against natural disasters have become even more important, and a positive and successful example of this is the change in the bed of the Dghviora River. To ensure the high security of the village of Glola and the surrounding area, it is necessary to clear the bottom of the old branch of the river from dense vegetation to a length of 600 m so that the flood flow can pass unhindered. It is also necessary to install an early warning system for natural processes at the headwaters of the Dghviora River (Tsreteli et al., 2018).

The 2023 Shovi disaster revealed high risks of natural hazards in this area and serious consequences for resort businesses, such as the failure to consider them. On August 3, at approximately 4:00 p.m., a glacial mudflow descended on the territory of the Shovi resort, resulting in the destruction of its built-up area and casualties—the tragedy claimed the lives of 32 people. The main area of the resort was covered by sediment, the total volume of which, according to initial calculations, reached one million m3. Cottages built in a manner that neglected natural risks near the banks of the Bubistskali River were destroyed, and the very existence of the resort came under question.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

M.G. and G.L. conceived of the presented idea and wrote the manuscript. G.K. performed the analytic calculations and created the maps and design. G.K. contributed to the analysis and interpretation of the results and the writing of the manuscript. All authors provided critical feedback and helped shape the research, analysis and manuscript.

ORCID iD

Merab Gongadze :https://orcid.org/0009-0006-7905-2525
George Lominadze https://orcid.org/0009-0003-0630-2739
George Khomeriki https://orcid.org/0000-0001-7264-4348
George Kavlashvili https://orcid.org/0009-0004-5171-043X

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