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Assessment of Debris/Mudflow Hazards Developed in Pasanauri Section of Natakhtari-Mleta Highway (Mtskheta-Mtianeti Region, Georgia)

Zurab Varazashvili[1], Zurab Kakulia[1], George Gaprindashvili[1,2,3], Irakli Ramishvili[1], Goga Chakhaia[1], George Tlashadze[1], Dali Chutkerashvili[1], Davit Ratiani[4]

[1]Institute of Hydrogeology and Engineering Geology, Georgian Technical University, Tbilisi, Georgia
[2]Faculty of Exact and Natural Sciences, Ivane Javakhishvili Tbilisi State University, Tbilisi, Georgia
[3]Department of Geology, National Environmental Agency, Tbilisi, Georgia
[4]Faculty of Mining and Geology, Georgian Technical University, Tbilisi, Georgia
Email: gaprindashvili.george@gmail.com

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Abstract

Research presents assessment of debris/mudflow ravine located to riv. Tetri Aragvi gorge in the territory of Pasanauri district. Above mentioned ravine is directly adjacent to the Natakhtari-Mleta road and poses a threat to its safety functioning. Research presents analysis, and assessment of expected risks of the factors shaping the debris/mudflows of this ravine. In addition, the accumulated material will serve as a basis for developing modern methods for modeling and assessment of landslide and debris/mudflow events. It states that the formation of debris/mudflows is largely determined by the landslide massif at the source area of the ravine and the strong erosion processes taking place in it. Numerical indicators of the stability of this landslide body have been calculated, considering the main factors—the moisture content of the bedrocks and seismic activity. The study is based on fieldwork data conducted in 2023-2024. Based on it, estimated values were obtained that determine the risks of mudflows. The material presented in the paper will be used in the future to develop mudflow preventive measures.

Keywords

Mudflow, Debrisflow, Landslide, Georgia, Geology, Hazard, Road

1. Introduction

With the background of global climate change on earth, natural hazards such as landslides, debris/mudflows, floods, erosion, mudflows, landslides are happening more frequent [1]-[9]. There are many such sensitive regions and areas in Georgia. One of the most important of these is riv. Tetri Aragvi gorge and the various dangers emanating from its slopes. River has many large and small tributaries. Under the hazard risk are population and road section of Natakhtari-Mleta of Mtskheta-Stepantsminda-Larsi road [10]-[16].

These valleys are periodically characterized by strong mudflows. Statistics shows that number of debris/mudflow and landslide events increases annually. Therefore, conducting engineering and geological surveys and identifying geodynamic hazards on the Natakhtari-Mleta section of Mtskheta-Stepantsminda-Larsi road is of great importance for the security and sustainable economic development of our country.

2. Data and Methods

Aim of the research was to study geodynamic hazards activated on the right slope of riv. Tetri Aragvi, in the territory of the district Pasanauri, which may pose a danger to traffic on the Natakhtari-Mleta section of the Georgian Military Road (Mtskheta-Stepantsminda-Larsi) (**Figure 1**). In particular, we are talking about mudflows that periodically emerge from the aforementioned ravine. If we consider the problem raised in a historical aspect, we will see that these events are not peaceful and harmless in nature. The overall geomorphological picture of the ravine clearly shows a fairly large extraction cone formed at its base (**Figure 2**), which, at first glance, is much larger than the scale of the ravine, which indicates its very active past (**Figure 3**). This does not give reason for complacency, since in the recent past, several disasters occurred in Georgia. This is also due to the fact that a fairly large landslide body has formed in the headwaters of the ravine we selected for our research, which includes a proluvial massif formed in the ravine bed at an early stage (pQ_{IV}). This massif is experiencing severe erosion and feeds the ravine with solid material to produce mudflows. It is built of gravel and crushed stone material, bound together with clay-loam filler. Its thickness reaches 22.0 meters. It is bordered on three sides by flat forms of vertical arrangement and forms an accumulation-erosion form. It is easy to see that the washing away and collapse of such a formation represents a real threat, being a direct triggering factor for mudflows.

As our study of the data from field-scientific research and familiarization with field data from early years has shown, the factors contributing to the occurrence of mudflows in the above-mentioned valleys, in addition to those mentioned above, are the following: Climate; geological structure and geomorphological features, to which, in this case, consideration of seismic factors must also be added [17]. Study area is characterized by diverse climate conditions, main triggering factor for debris/mudflow activation is daily precipitation [18].

Among the geological factors, the lithological structure of the study area is important. Study area is located in the Mestia-Tianeti tectonic zone and is represented

Figure 1. Study area.

Figure 2. Proluvial deposits.

by carbonate-terrigenous flysch of the Berrian-Valanginian and Hotrivian stages. These floors are built up of clastic limestones and sandstones, turbidites, pelagic marls, limestones, mudstones, and shales. Rocks are easily subject to weathering processes [19] which creates an important prerequisite for the occurrence of modern gravitational phenomena. These phenomena are actively developing in the headwaters of these valleys, where the main mudflows are formed [20] (**Figure 4**).

Among the geomorphological features of the study area, the steepness of the slopes and the high degree of relief fragmentation should be highlighted [19] [20] (**Figures 5-7**).

And finally, the most important thing—all the above-mentioned factors unambiguously serve to generate landslide-gravity events within the mentioned valleys, which serve as the main supplier of solid material for mudflows [19] [20] (**Figures 5-7**). This is clearly illustrated in **Table 1** below.

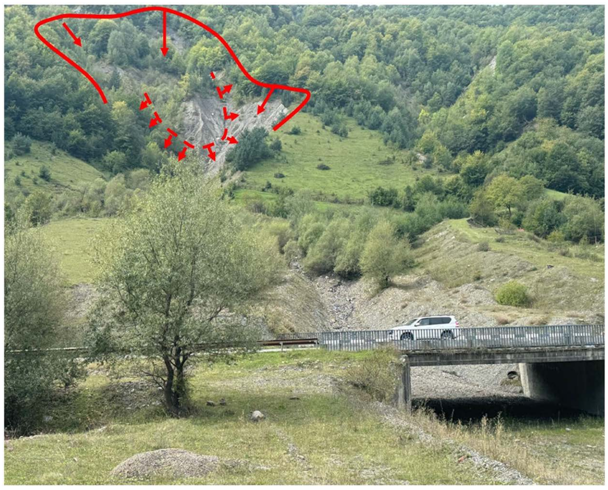


Figure 3. View of the landslide body and its main elements: the main slidu surface the proluvial deposits.

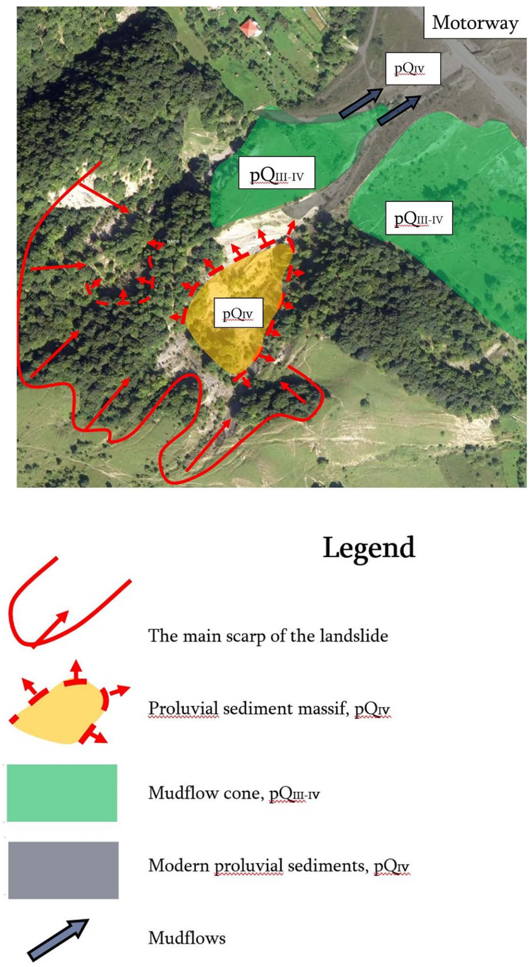


Figure 4. Top view of the study ravine and legend.

Table 1. Characteristics of erosion and landslide-gravitational damage of the ravine in the debris/mudflow formation zone.

Erosion network				Landslide-gravity events	
Catchment area S, km^2	Slope h_1, km/km	Erosion network L, km	Erosion coefficient (L/S)	Area S_1, km^2	Damage coefficient S_1/S
0.12	0.57	0.252	2.1	0.061	0.51

In this regard, rock samples were taken and their physical characteristics were determined. Their mechanical characteristics were selected based on existing normative documents. On the basis of topographic and geological data landslide slide surface was identified and schematic figure was created. Later slope stability K coefficient was calculated, considering various natural factors (seismicity and rock moisture) [19] [20].

Figure 5. Proluvial massif of a landslide body.

Figure 6. Landslide scarp and proluvial deposits.

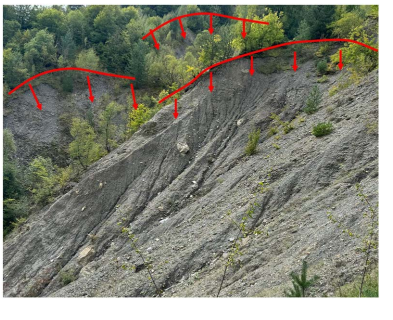
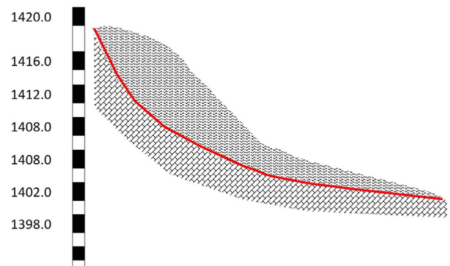


Figure 7. Landslide scarp and proluvial deposits.

3. Results and Discussion

Based on the analyzed data, it can also be noted that the formation of debris/mudflows of various intensity and volume is expected within the study area, which will lead to an increase in ecological risks and, accordingly, the zones of mudflow impact and the vulnerability of various infrastructure facilities (residential buildings, highways, etc.) located in these zones. In the next stage of the research, a digital elevation model (DEM) (Digital Elevation Model—2 × 2 m resolution) will be created using modern technologies of remote sensing and geoinformation systems, which will be used to determine the slope and slope aspect of the study ravine and to construct profiles (Figure 8). The data will be processed using modern software to model landslide and mudflow events and identify their characteristics [12] [21].

In Table 2 are the results of the calculations performed [22]-[24]:



Cut	A-B	
Scale	1:2000	
Block №	I	II
Block weight kg	280.0	88.5
Slide place length m	25	23
Creeping plane sloping, degree	42	8

Legend

Landslide body

Rocky rocks, sandstones and mudstones P_2^2

Landslide creep plane and block rupture line

Figure 8. Cross section.

It should be noted that in future it is planned to use these data for mudflow simulation using software RAMMS (Figure 9, Figure 10). Which was developed to simulate the runout of mudflow and debrisflows in complex terrain [21] [25] [26].

4. Conclusions

- Periodic activation of mudflows is observed in the right tributaries of the Tetri Aragvi River, which creates obstacles for traffic on certain sections of the Georgian Military Road (Mtskheta-Stepantsminda-Larsi road). Debris/mudflow gorge located in the territory of district Pasanauri on the Natakhtari-Mleta section is noteworthy, which, according to general geological and relief data, contains high hazard risk.

Table 2. Slope stability assessment.

Slope stability assessment, Section A-B (rocks in natural conditions, without considering seismicity coefficient)

Block#	Block weight (P)	Slide surface				Resistance to rock movement		Cohesion (C)	Seismicity coefficient	Sustainability coefficient (K)	
						ϕ	tgϕ			Block	Average
	t	degree	sin a	cos a	Length m	degree	tan	t/m²			
I	280.0	38	0.62	0.79	25.0	23	0.42	0.28	0	0.58	**1.8**
II	88.5	9	0.16	0.99	23.0	23	0.42	0.20	0	3.01	

Slope stability assessment, Section A-B (rocks in wet condition, without considering the seismicity coefficient)

Block#	Block weight (P)	Slide surface				Resistance to rock movement		Cohesion (C)	Seismicity coefficient	Sustainability coefficient (K)	
						ϕ	tgϕ			Block	Average
	t	degree	sin a	cos a	Length m	degree	tan	t/m²			
I	300.0	38	0.62	0.79	25.0	19	0.34	0.18	0	0.47	**1.1**
II	100.0	9	0.16	0.99	23.0	14	0.25	0.15	0	1.79	

Slope stability assessment, Section A-B (rocks in natural conditions, considering seismicity coefficient)

Block#	Block weight (P)	Slide surface				Resistance to rock movement		Cohesion (C)	Seismicity coefficient	Sustainability coefficient (K)	
						ϕ	tgϕ			Block	Average
	t	degree	sin a	cos a	Length m	degree	tan	t/m²			
I	280.0	38	0.62	0.79	25.0	23	0.42	0.28	0.05	0.53	**1.4**
II	88.5	9	0.16	0.99	23.0	23	0.42	0.20	0.05	2.27	

Slope stability assessment, section A-B (soils in wet condition, considering seismicity coefficient)

Block#	Block weight (P)	Slide surface				Resistance to rock movement		Cohesion (C)	Seismicity coefficient	Sustainability coefficient (K)	
						ϕ	tgϕ			Block	Average
	t	degree	sin a	cos a	Length m	degree	tan	t/m²			
I	300.0	38	0.62	0.79	25.0	19	0.34	0.18	0.05	0.42	**0.9**
II	100.0	9	0.16	0.99	23.0	14	0.25	0.15	0.05	1.35	

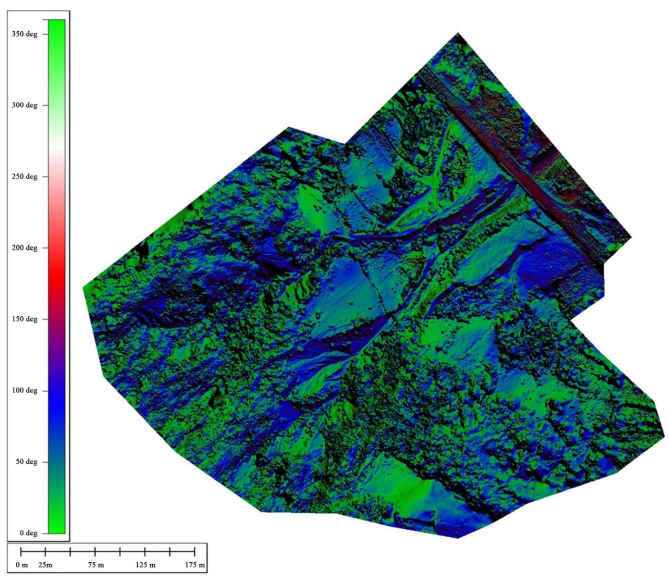


Figure 9. Slope map.

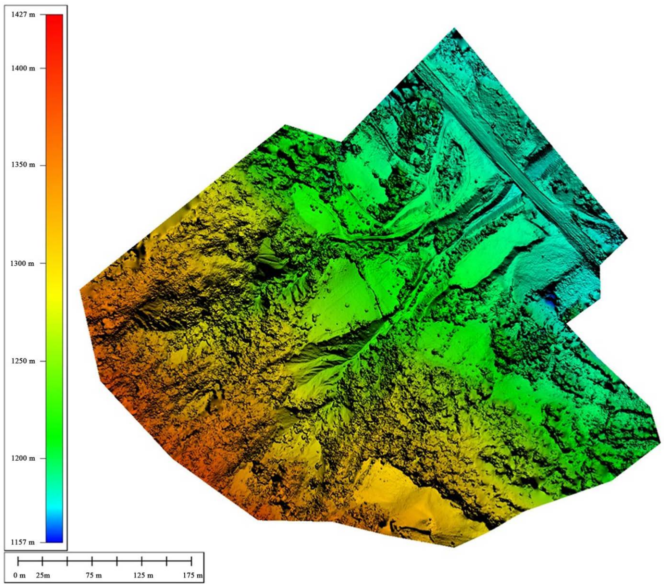


Figure 10. Elevation map.

- Based on the studies conducted in the mentioned ravine, it was possible to determine the main triggering factors of debris/mudflow activation: Geological, tectonic and climate conditions and complicated morphology; Lithological structure of the study area is represented by Cretaceous flysch deposits, which creates an important pre-condition for the activation of modern gravitational phenomena. In addition, it should be noted that during the early stages of the formation of the gorge, thick proluvial sediments accumulated in the riverbed, which are represented by easily washable rocks—gravel-crushed material built with clay-loamy filler. Morphological features, such as slope steepness and slope aspect are one of the main permanently active triggering factors for the formation of debris/mudflows.
- Based on the analyzed data, it can be noted that the existing geodynamic situation of the studied gorge and the unity of the active natural factors create conditions for the formation of mudflows of various capacities, which increases ecological risks and, consequently, the vulnerability of various infrastructure facilities (residential buildings, highways, etc.) located in the mudflow impact zones.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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