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Computer modeling and forecast of expected debris flow in the mletiskhevi

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ABSTRACT

The aim of the research is computer modeling and risk analysis of debris flow of expected erosion and landslide genesis in Mletiskhevi, for which, at the initial stage, the minimum conditions for the resistance of the landslide slope mainly caused by debris flow were determined. In case of both dry and water-saturated ground.

At a later stage for modelling the debris flow we used computer program RAMMS (Rapid mass movement simulation) and for its functioning Mletiskhevi DEM (Digital Elevation Model) was used. Besides the inputs were defined for RAMMS.

As a result by modelling carried out with RAMMS computer program, the forecasting characteristics of the expected debris flow in the Mletiskhevi catchment area were defined: height, speed, pressure and volume of the extracted mass. Accordingly, debris flow risk zones were also identified. There are 3 houses, agricultural land, St. George Church and Motor bridge. Therefore, effective anti-debris flow measures should be taken immediately to minimize the risk of expected debris flow in Mletiskhevi.

Key words*:* Debris flow, erosion, landside, modelling, RAMMS.

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INTRODUCTION

From the natural disasters that occur in Georgia, special attention is paid to erosion and landslide genesis debris flow phenomena. There are 3000 debris flows in Georgia, which is about 29% of the country's territory. The population, strategic values like bridges, transport mains, water and energy objects, churches and other cultural monuments are at risk for being under the threat of debris flow [1].

The debris flows are created with special frequency in the waters of the MletisKhevi watershed (42˚02'09.70»N; 44˚45'38.87»E) basin tributary of river Aragvi (Fig. 1) in the Dusheti municipality (Georgia), where because of intensive exogenous catastrophic debris flow processes are creating. These processes threaten the Mleta village, tourist routes, Mleta St. George Church, motorway and bridge [2-4]. They also prevent the normal function of Tbilisi water supply - Zhinvali water reservoir. The debris flow mass formed in the Mletiskhevi ravine meets the river via the river Tetri Aragvi thus it flows into the Zhinvali water reservoir. The quality of the water reservoir is deteriorating and its useful volume decreases within the short period of time, consequently restricting Tbilisi water supply.

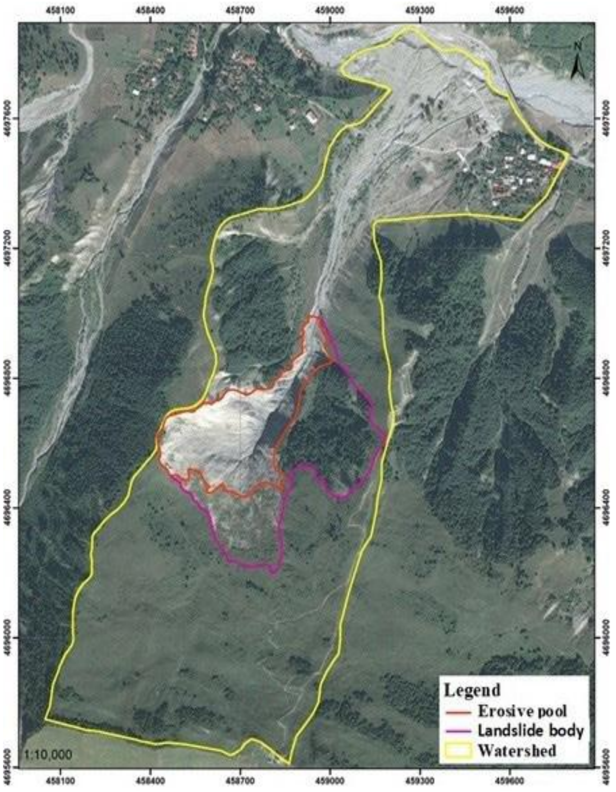

Fig. 1. *Mletiskhevi catchment area*

It should be noted that, in recent years, large-capacity debris flows (1953, 1981, 1982, 1983, 1985, 1987, 1989, 2001, 2003, 2005, 2011) have been observed in the Mleta gorge, as well as an increase in the frequency of debris flows, in particular, from 1897 to 2011, in Mleta, catastrophic debris flow were recorded 150 times, which resulted in the destruction of settlements and various objects. Field research has shown that not only has the frequency of debris flows increased, but also the volume of solid mass emitted by debris flows, the volume of disposable material often exceeding 1 million m^3 [5].

The situation has become especially vulnerable during the last five years, as the debris flow of mullet is becoming more frequent. A prominent example is the tragedy formed on Mletiskhevi on 10th August, 2018 which caused significant damage to 8 populated areas [6].

The average annual rainfall in Mletiskhevi is 1,339 mm. The maximum value of incoming precipitation is recorded in spring and summer: in May, June and July, when 1/3 of the total annual precipitation falls. The maximum average daily precipitation is within 45.6 mm, while the absolute maximum daily precipitation is 125.0 mm [7].

Mleta gorge is presented as a canyon with a slope of 500÷600 m and it decreases to 450÷200 m, the width of the bed bottom increases from 4÷5 m to 10÷15 m from the end of the transit zone. The output cone is presented in the form of an expanded cone up to 600÷800 m, its surface is relatively convex and is represented by sand-gravel and small fractions[8].

The geological structure of Mletiskhevi is composed of the lower valangin black shale (K_{1V1}), which is represented by limestone interlayers (0.5-1.2 m) with black shale marls (3-6 m). The azimuth of the layer direction is southeast 120-125°, the angle of inclination is 54-55°. The main rocks in the lower part of the slope are covered with strong (5-20 m) proluvial (pQ_{IV}) sediments and are represented by 20-25% gravel soil with clay filler, while the upper part is covered with eluvial-deluvial layers, whose power is variable:: reaches 4-8 m in the lower and upper parts of the slope, while 1.0-3.0 m in the main central part. They are represented by loamy soil with up to 30% crushed stone inclusions (edQ_{IV}) [5].

Objectives and Methods

The aim of the research is computer modeling and risk analysis of debris flow of expected erosion and landslide genesis in Mletiskhevi.

Landslide processes are the main provoking factor of debris flows in Mletiskhevi, it is the main supplier of solid material in the ravine, which determines the frequency of debris flows and its destructive force.

Landslide processes are the main provoking factor of debris flows in Mletiskhevi, it is the main supplier of solid material in the ravine, which determines the frequency of debris flows and its destructive force, accordingly, at the initial stage, field, laboratory and theoretical studies were conducted to assess the minimum conditions for the sustainability of the landslide slope in the Mletiskhevi gorge [9].

As a result of field studies in Mletiskhevi, it was found that the above-mentioned landslide is circus-shaped (Fig. 2), length 200-250m, width 250-300m, slope angle 250-500, landslide capacity 4-10 m, the surface is stepped, with open cracks, Alluvial-deluvial rocks float on the main rocks.

Fig. 2. *Landslide areas in Mletiskhevi*

To determine the landslide slope sustainability conditions, ground samples were taken from the landslide slope and the calculation parameters[10] were determined under laboratory conditions (Table 1).

Table 1. *Results of laboratory study of ground samples taken from the landslide slope of Mleta gorge*

Internal friction angle of the ground φ^0	Clutch c (t/m^2)	Porosity N %	Mineral density ρ	Water density ρ
23,0	25,0	0,42	2,72	1,0

The above data were used to determine the critical depth of the soil layer on the study slope (when movement begins) in the case of "dry" ground; The calculation was performed using the following methodology [3,4]:

$$\frac{1}{\bar{z}} \le \frac{c}{\rho g z} = \sin\alpha - \tan\varphi\cos\alpha\,, \qquad (1)$$

where $\bar{z}=\frac{\rho g z}{c}$ -the relative thickness of the ground layer, the increase of which causes the slope to climb; ρ – density g acceleration of the force of gravity, z - thickness of the ground layer, φ- internal friction angle of the ground, α - the angle of inclination of the slope, and in the case of a slope saturated with water we will have:

$$\frac{1}{\bar{z}_1} \le \frac{c}{\rho g z_1} = \left(1-\frac{\rho_w}{\rho_m}\right)\cdot(\sin\alpha - \tan\varphi\cos\alpha) + \frac{\rho_w}{\rho_m}\cdot\sin\alpha\cdot\frac{1}{1-n} \qquad (2)$$

In case of taking into account the results of laboratory research of ground samples taken from the landslide slope of Mleta gorge in the mentioned methodology, we get the following relations:

$$\frac{1}{z_1} = \left(1-\frac{1}{2{,}72}\right)(\sin\alpha - 0{,}42\cos\alpha) + \frac{1}{2{,}72}\sin\alpha\,\frac{1}{1-0{,}43} = 0{,}63\sin\alpha - 0{,}26\cos\alpha + 0{,}64\sin\alpha$$
$$= 1{,}27\sin\alpha - 0{,}26\cos\alpha \qquad (3)$$

Finally we will have:

$$\frac{1}{z} = \sin\alpha - 0.42\cos\alpha \quad (4)$$

$$\frac{1}{z_1} = 1.27\sin\alpha - 0.26\cos\alpha \quad (5)$$

In the above relationships, the relationship between the critical slope relative depths and the slope is given in Fig. 3.

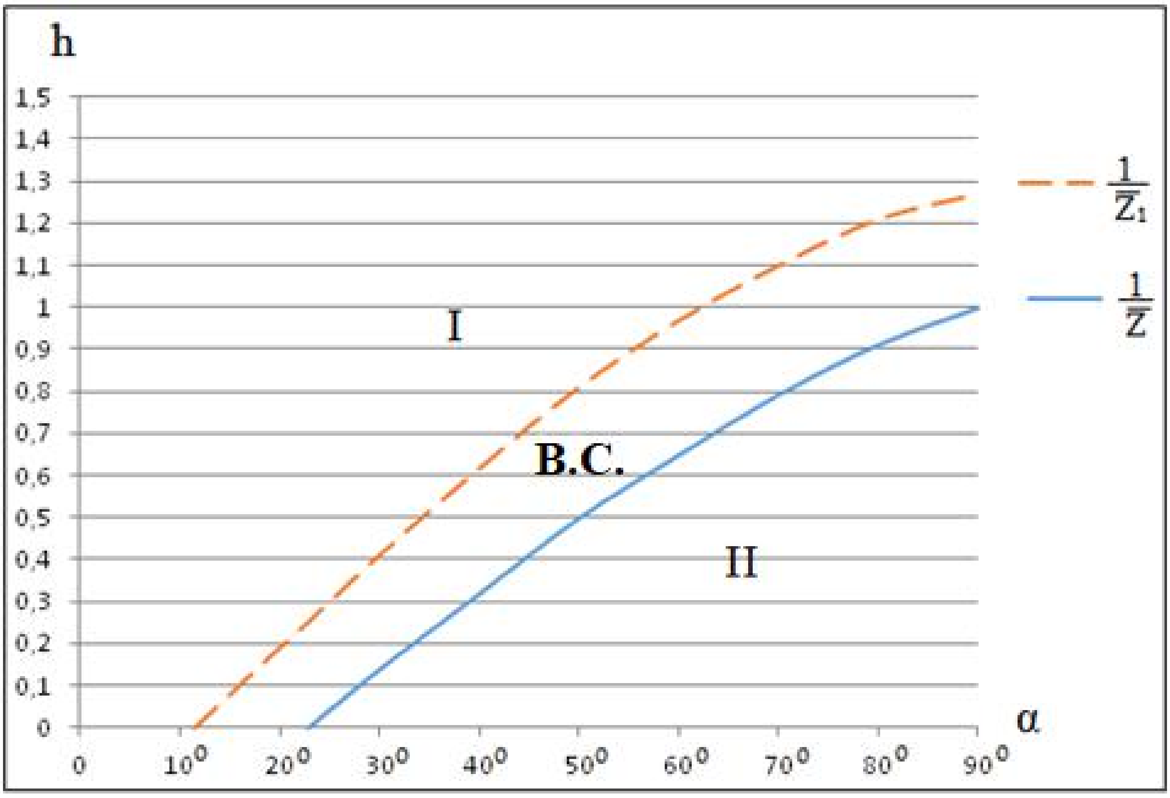

Fig. 3. *The critical ratio of the slope to the depths and slopes graph of the relationship between*

In Fig. 3, **(I)** indicate the steady state of the slope, (**B.C.**) Corresponds to the boundary condition, and **(II)** even beyond the boundary, i.e. when the slope starts to move.

Fig. 3 accordingly, water saturation reduces the critical angle of inclination of the slope (when movement begins) by about $12^0 \div 28^0$.

Get it for “dry” ground $\rho = 1.5t/m^3$, then $\alpha = 30^0$- in the case of $\frac{c}{\rho g z} \le 0.13$, from where $z \ge 1{,}28$ m and start moving. In the case of $\alpha = 40^0$, $\frac{c}{\rho g z} \le 0.32$, from where $z \ge 0{,}52$ m in the case of $\alpha = 50^0$, $\frac{c}{\rho g z} \le 0.5$, from where $z \ge 0.33$ m.

For a water-saturated ground, motion will start at $\alpha = 30^0$ and $z_1 \ge 0{,}61$m, in the case of 40^0, $z_1 \ge 0{,}40$ m, while in the case of 50^0, $z_1 \ge 0{,}31$m.

The results of the report show that the landslide slope is unstable, the formation of large-capacity landslides is expected and provoke debris flow.

Based on the above, it is realistic for catastrophic debris flow to develop again in Mletiskhevi, which makes it necessary to determine the expected magnitudes and zones of influence of the expected debris flow, to assess the impact of debris flow on settlements and infrastructure, for which RAMMS was used [11].

Mletiskhevi DEM (Digital Elevation Model - 2x2 m resolution) was used for modeling and forecasting the expected debris flow in RAMMS (Fig. 4).

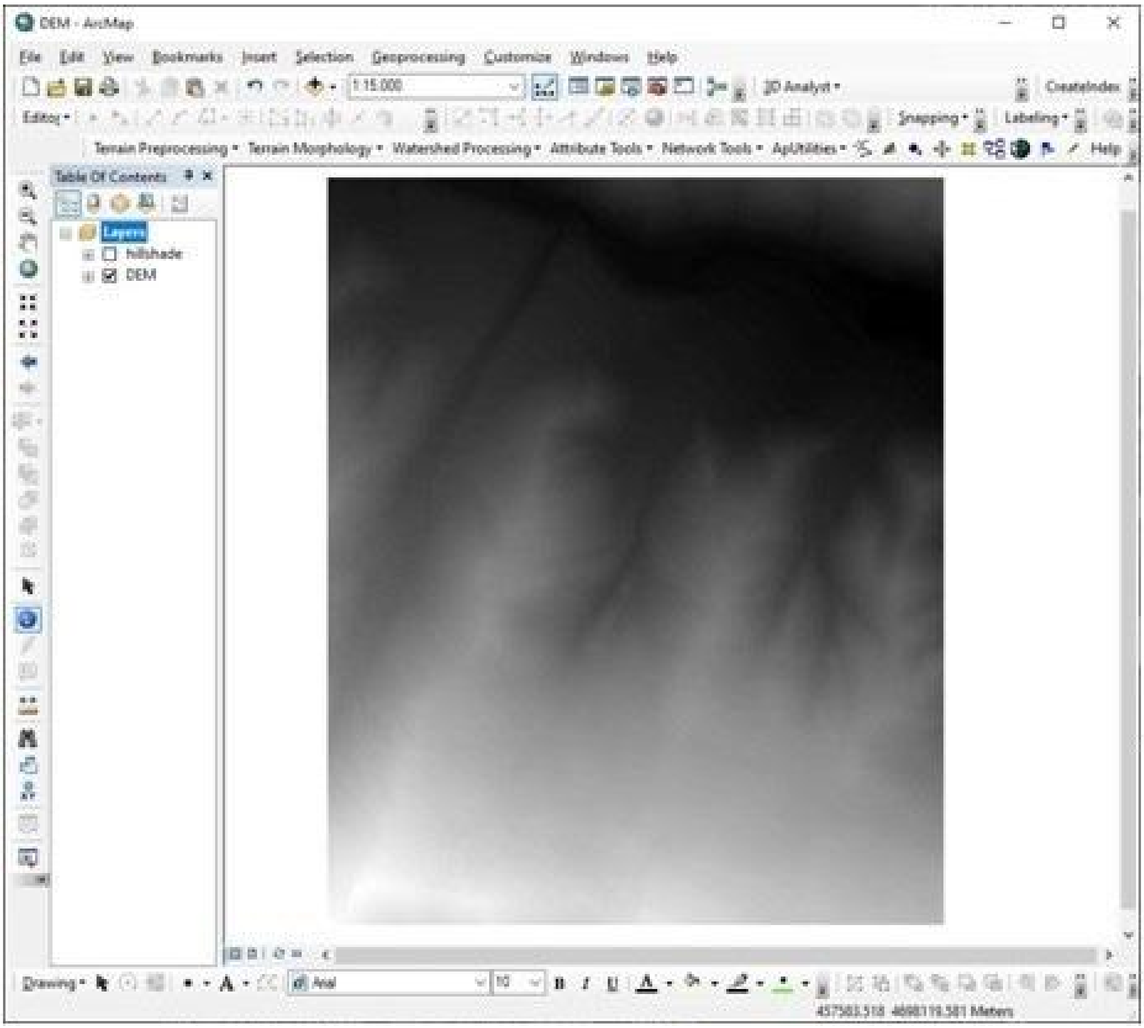

Fig. 4. *DEM (Digital Elevation Model) of Mletiskhevi*

Field surveys in Mletiskhevi revealed average depths and areas of the vulnerable district (landslide slope, eroded slope and bed accumulation zones) causing debris flow.

Due to the lack of previous measurements, the Voellmy friction model calibration took into account the maximum soil-ground volume (more than 1000000 m^3) produced by the debris flow formed in 1987 in Mletiskhevi.

To find the best- fit Voellmy friction coefficients (dry-Coulomb type friction μ and viscous-turbulent friction ξ) recommendations of the authors of ramms [11].

In view of the above, the processed initial data were entered into RAMMS and was modeled the expected catastrophic debris flow in Mletiskhevi (Table 2).

Table 2. *Basic settings to be entered in the computer program RAMMS*

The depth of soil-ground on the erosive slope (m)	The depth of soil-ground accumulated in the debris flow course (m)	The depth of landslide (m)	Debris flows density (kg/m^3)	Coefficient of Coulomb friction μ	Coefficient of turbulent viscosity ξ (m/sec^2)	Earth-pressure coefficient Λ	H cutoff (m)
0,2	2,0	5.8	2000	0,1	120	1	0.0001

Results and discussion

As a result of modeling performed with RAMMS, the maximum height (Fig. 5), velocity (Fig. 6), pressure (Fig. 7).

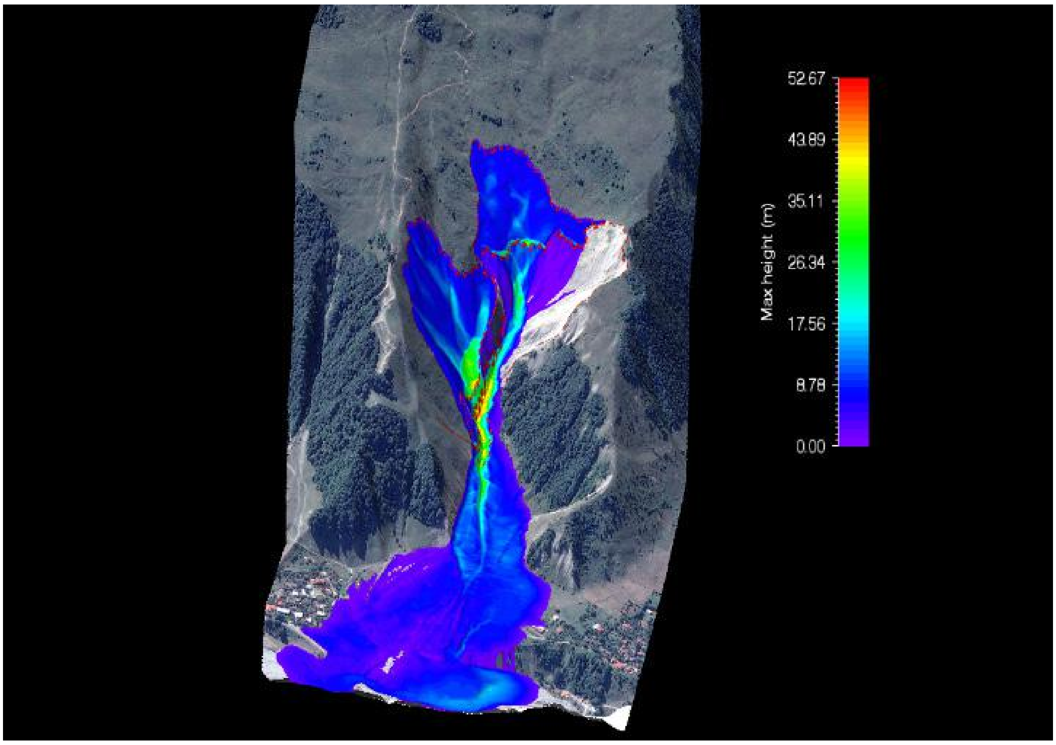

Fig. 5. *Maximum heights of expected debris flow in Mleta gorge*

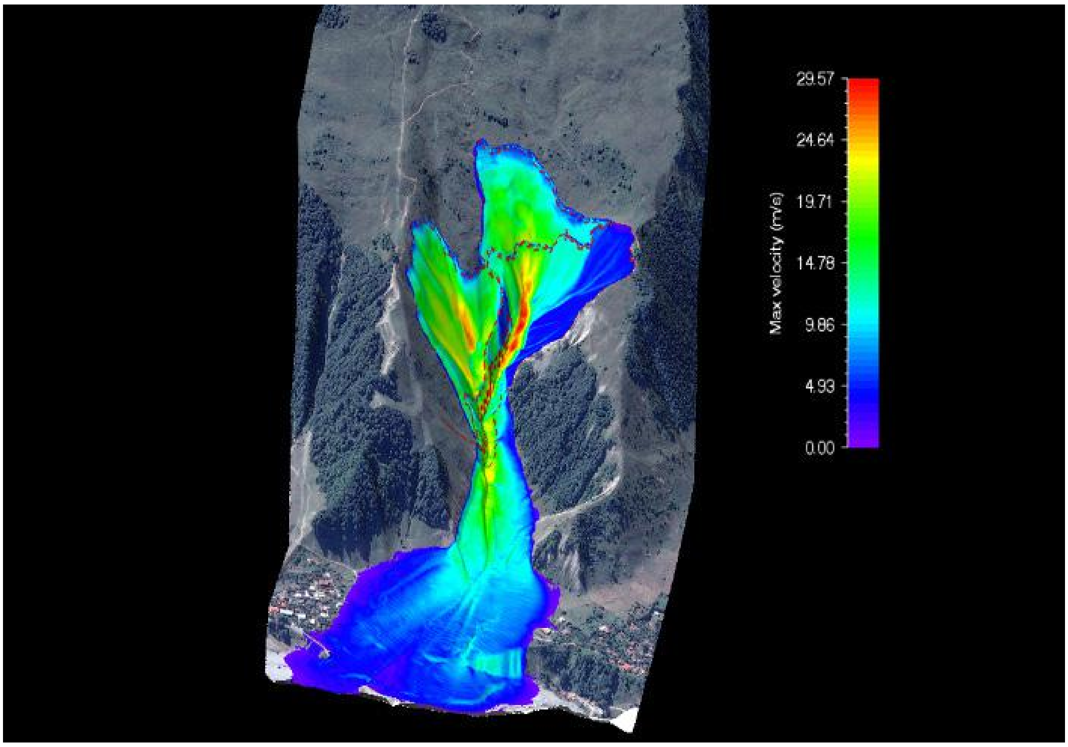

Fig. 6. *Maximum debris flow velocities in Mleta gorge*

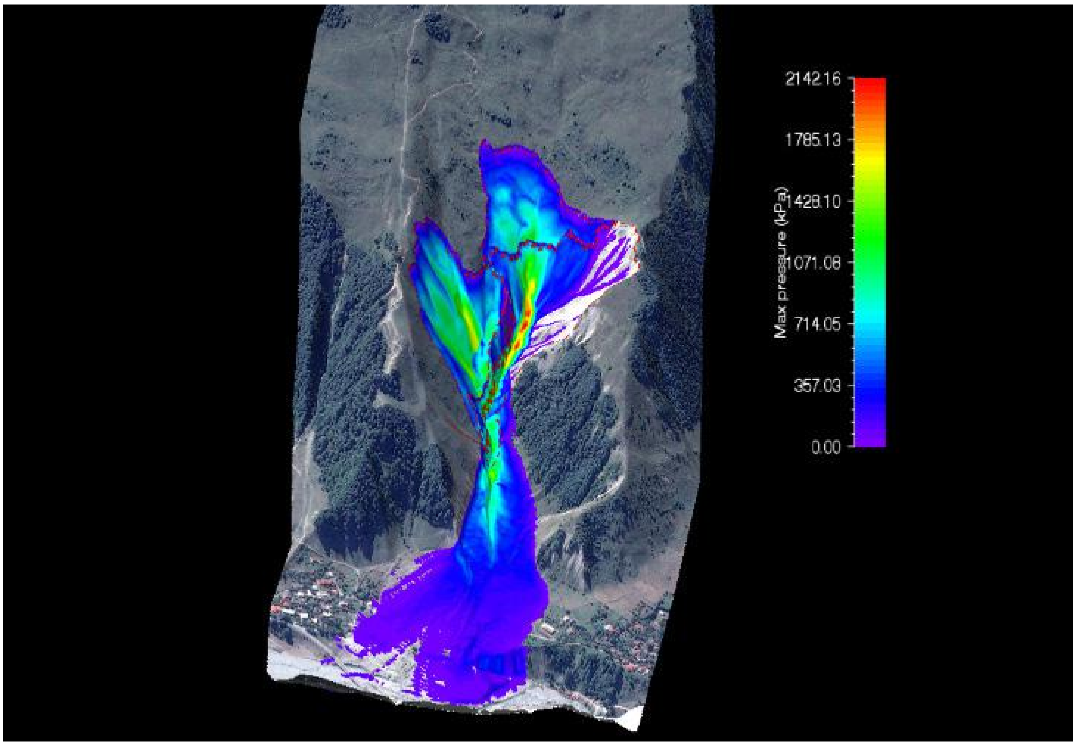

Fig. 7. *Maximum pressures of expected debris flow in Mleta gorge*

After the formation of the flood, the longitudinal profile of river Mletishkevi (Fig. 8) was also determined.

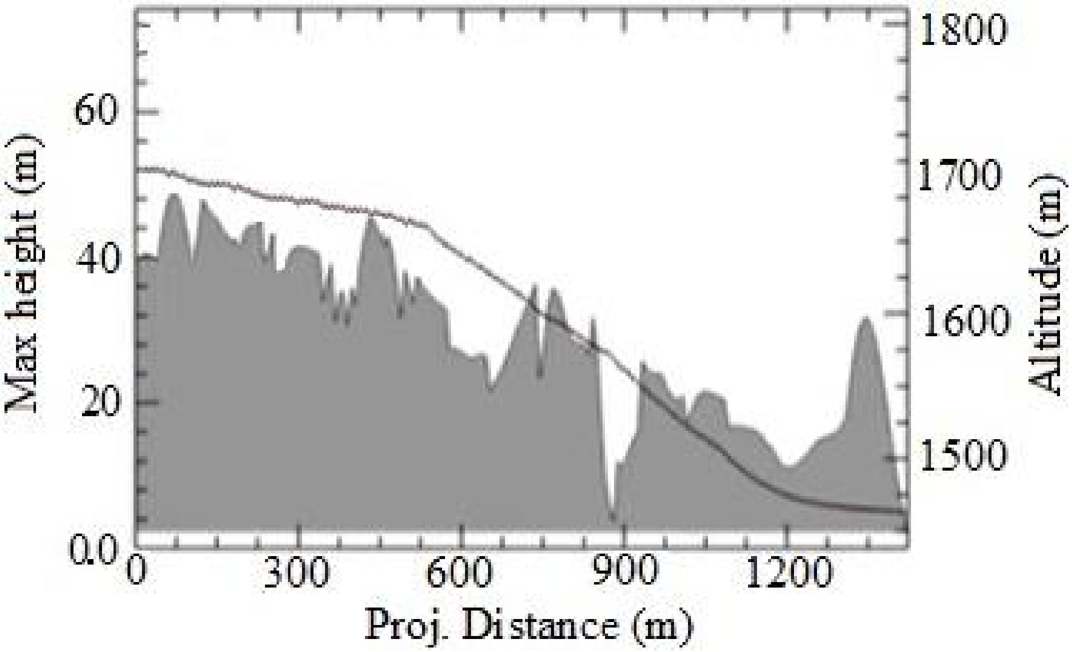

Fig. 8. Longitudinal profile of the river Mletiskhevi after forming the debris flow
Computer modeling also identified the expected debris flow zones in Mletiskhevi and the infrastructure of various destinations in the risk zone (Fig. 9).

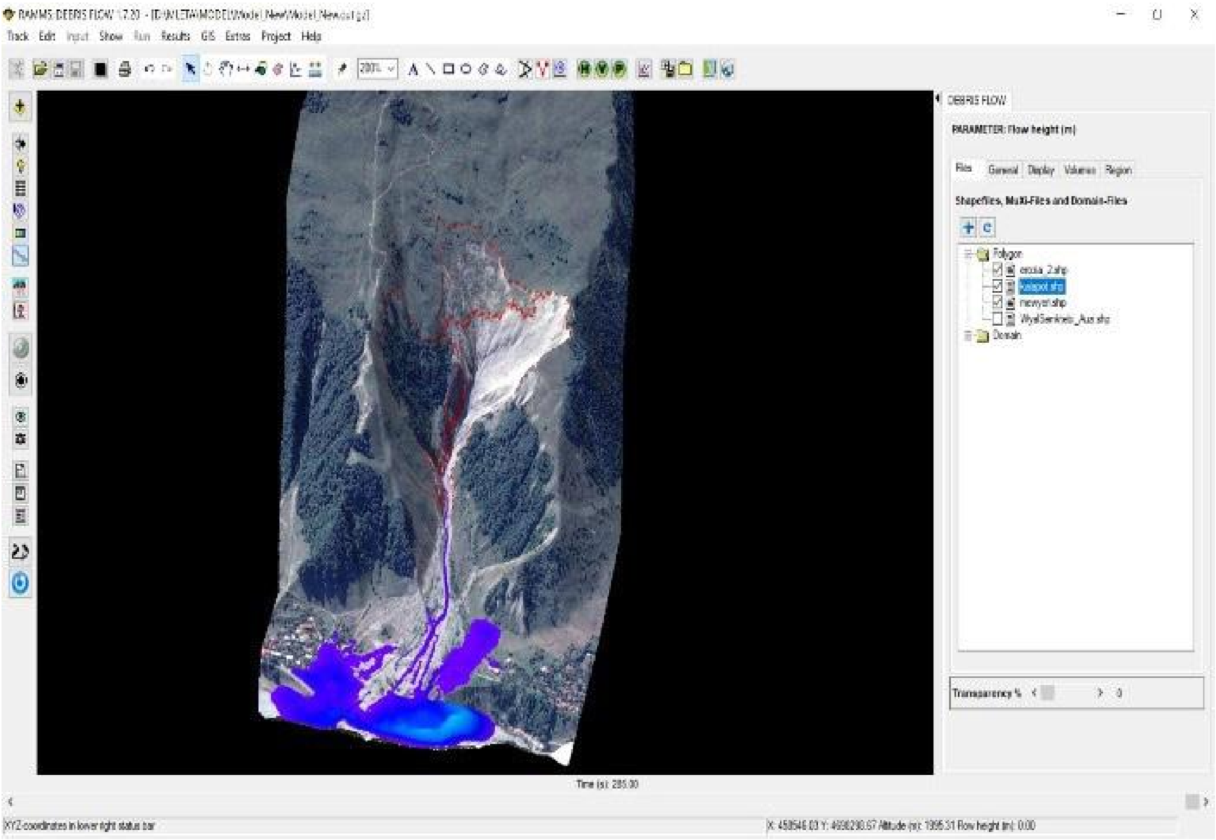

Fig. 9. *The final stage of modeling*

Numerical characteristics of the expected debris flow modeling with RAMMS in Mletiskhevi are given in Table 3.

Table 3. *Data obtained as a result of modeling performed by RAMMS*

The volume of the erosive mass mass on the slope m^3	The accumulated volume of the soil and ground in the debris flow source area m^3	The volume of landslide body m^3	Debris flows volume (m^3)	Debris flows MAX velocity (m/s)	Debris flows MAX flowheight (m)	Debris flows MAX pressure (kPa)
31888.9	6505.8	1063640	1102033.13	29.5694	52.6722	2142.16

Assessing the minimum conditions for the predominantly provocative landslide slope of the expected debris flow in Mletiskhevi, it was found that the study slope is dangerous for landslides, because in the case of an average slope of 30^0, a ground mass of 0.61 m is sufficient to withstand water saturation. Violation, and if we take into account that the depth of the landslide slope is up to 10 meters in most places, the absolute maximum daily precipitation during the peak period is equal to 125.0 mm and the slope angle varies from 200-500, then it can be said that at the head of Mleta gorge The risk of developing debris flow, the main provocative landslide processes, is high.

Also defined, during the modeling of the expected debris flow in Mletiskhevi, the maximum height of the expected debris flow front - 52.6722 m (narrow intersection of the river bed), the maximum speed of the debris flow - 29.5694 m/s, the pressure - 2142.16 kPa and the volume of the mass produced by the debris flow - 1102033.13 m^3, which is almost identical to the solid mass characteristics produced by the debris flow formed in Mletiskhevi in june 2-3, 1987.

Conclusions

The expected flood zones in Mletiskhevi, which includes some settlements, a church, a highway and a bridge, were also identified. The debris flow is likely to block the Tetri Aragvi riverbed and pose a flood risk to the population of Zemo Mleta. It is also expected to enter the Zinvali Reservoir from Mletiskhevi through the Tetri Aragvi riverbed, as the river Tetri Aragvi is the main supply artery for the Zinvali Reservoir. That will cause the limited water supply to Tbilisi, the capital of Georgia.

Based on the performed modeling data, it can be said that the expected ecological threat in Mletikhevi was predicted, which indicates the need for urgent implementation of optimal engineering environmental measures to regulate the expected ecological risks in Mletiskhevi.

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