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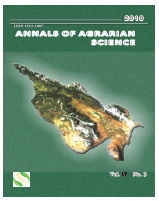

The outcomes of field survey of sensitive areas at Kobi - Gudauri section of the Georgian military road for the purpose of arrangingan innovative snow avalanche construction

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ABSTRACT

The paper presents the sensitive areas of snow avalanches at Kobi - Gudauri section of the Georgian military road in the appropriate GPS coordinates, the areas are marked on a digital map using GIS technologies, based on the field surveys and theoretical studies. The statistical material for snow avalanches formation at Kobi - Gudauri section is assessed and a brief description of the geographical, hydrological and hydraulic parameters of snowpack and avalanche formation is proposed. Using the mentioned material, a geographical location has been selected for the arrangement of the innovative snow avalanche construction, which is located at Kobi-Gudauri section of the Georgian military road, in the vicinity of the so-called Panorama at an average mark of 2500 m above sea level with an average inclination of the slope 24^0.

Keywords: Snow avalanche, Kobi-Gudauri section, Georgian military road, Innovative snow avalanche construction, Anomalies affecting, Slope inclination.

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1. Introduction

Among the anomalies affecting the infrastructure in the mountainous regions of Georgia, snow avalanches are the most dangerous ones, having a particular frequency to the extent of the consequences of the damage incurred and they have been increased geometrically in the last ten years in terms of the climate change in the world.

Mtskheta-Mtianeti region is taken as the survey target, it is located in the northern part of Eastern Georgia and its area constitutes 8.3% of the total country. The region has the most significant strategic purpose for our country.

As scientific studies have shown, the most avalanche-prone regions in Georgia are Racha-Lechkhumi and Kvemo Svaneti (74%), followed by Mtskheta-Mtianeti and Adjara (66-66%). It is interesting that Mtskheta-Mtianeti is the leader in the high-risk avalanching sites, which was probably expectable, taking into consideration great absolute altitudes, slope inclination, forest cover, etc. [1].

According to the data of the National Environment Agency, there are more than 5,000 identified avalanche catchments in Georgia. Updatable data constantly, almost automatically allows the changes in nature to be quickly reflected in the database, processed and thousands of avalanches to be quickly mapped [2].

Due to the natural conditions of Georgia, we believe that it is very important to pay more attention to the study of snow avalanches and the use of modern technologies in the process. Snow avalanche and its danger isolates some municipalities of Georgia for almost ten months, and given that these regions (Tusheti, Khevsureti-Arkhoti, River Arghuni gorge, Mighmakhevi, periodically Kazbegi Municipality) are bordering to the Russian Federation, it becomes

clear that this is the serious problem for safety of the state of Georgia. Figure 1 presents the risk map of snow avalanching sites of Georgia according to the relevant classification [2], and Table # 1 shows the data of the Faculty of Geography of Lomonosov Moscow State University – percentage data of snow avalanche formation on the central range of mountains of Caucasus (including in Georgia) according to absolute altitudes [website].

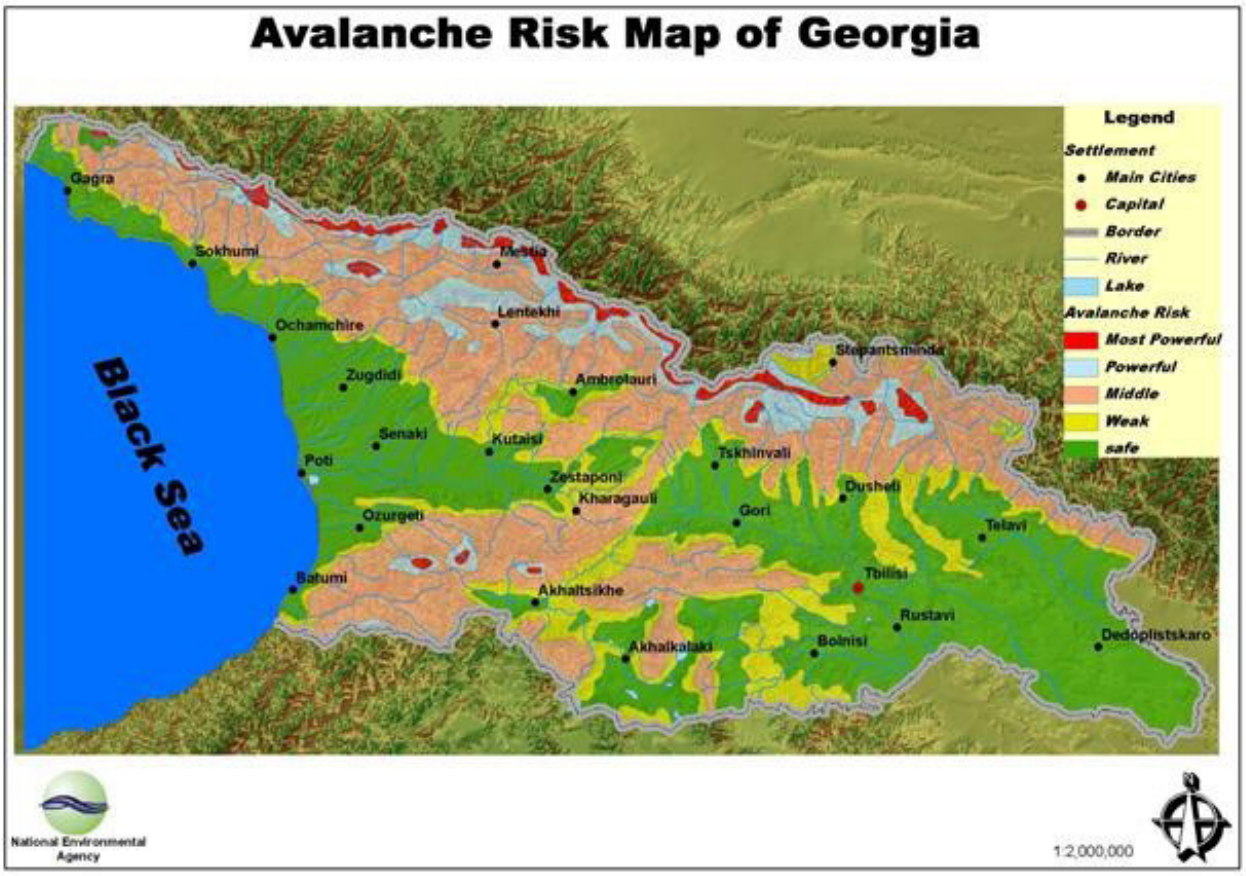

Fig. 1. *Avalanche risk map of Georgia (Scale 1:2000000)*

The study of this natural disaster process is especially important on highways, playing a major role not only within the country but also in transnational movement.

Table 1. Percentage values of snow avalanche formation at the Central Caucasus Mountain Range

№	Absolute marks above sea level (m)	Percentage values of snow avalanche formation (%)
1	From 1000 m - below	2,2
2	1000 - 1500	10,3
3	1500 - 2000	13,9
4	2000 - 2500	19,5
5	2500 - 3000	31,5
6	From 3000 m - above	22,1

Exactly such is the case with the Mtskheta-Mtianeti region highway, known as the Georgian Military Road (Fig. 2). This road has had and still has a transit, trade-economic, cultural, tourist-recreational function both for the Mtskheta-Mtianeti region and for Georgia. This is the road that connects the South Caucasus with the North Caucasus and Russia. The importance of this road is further enhanced by the gas pipeline, which is supplied from Russia to Armenia via a military road. Avalanches are frequent along the mentioned road, especially at Kobi-Gudauri section, which temporarily hinders the traffic during the season [3].

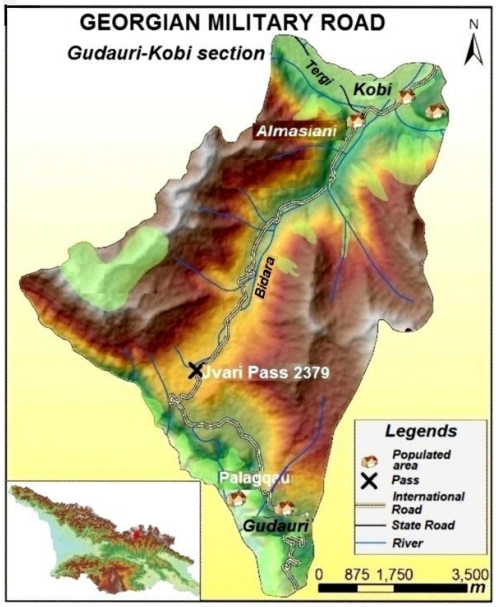

Fig. 2. *Kobi-Gudauri section of the Georgian military road*

Snow avalanches are typical for the medium and high mountain zones of Georgia and its formation and dissemination are mainly preconditioned by the large slope of the relief surface, separation, features of green cover and meteorological elements:

- In 1985-1987, relatively long-term stationary observations of the avalanche regime on the territory of Georgia took place only at Jvari Mountain Pass avalanche research station. According to these data, 18-20 avalanches have been recorded from one and the same avalanche catchment. It should also be noted that a significant proportion of new snow avalanches on the steep slopes of complex avalanche sites stopped at the top of the avalanche catchment so that they could not reach the highway [4];
- In February 1992, 15 avalanches set off at Kobi-Kazbegi motor road section and traffic was interrupted for 4 days and nights. According to the relevant state service data, in 1996, snow-avalanche set off at Gudauri-Kobi section 149 times, as a result of which the motor road was closed for 42 days. In December of the same year, 21 people were lost in an avalanche falling down from the White Mountain (Georgian military road);
- In 1997, a snow-avalanche set off 120 times at Gudauri-Kobi section, killing 5 people, and closing the road for 40 days;
- In 1998, avalanches set off at one and the same section 54 times and traffic was interrupted for 22 days.

The statistics of the loss caused by the snow avalanches at Gudauri-Kobi section in 2020 are as follows:

- In Gudauri, on Stepantsminda-Kobi road, an avalanche set off and carried one car down into the ravine. According to the Emergency Management Service, 3 people were in the car. One was rescued unharmed, one was injured and one citizen was killed (Fig. 3);
- A Russian citizen lady died as a result of a snow avalanche in Gudauri. Two people were rescued, one of whom, a Georgian citizen, had a fracture, and the other, an Armenian citizen, was rescued to a safe place unharmed. Their lives are not in danger (Fig. 4);
- On 15 February 2020 at around 12:00 - 13:00 an avalanche set off on Kobi-Gudauri road on the Sadzele territory - in the ski prohibited zone. There were 4 tourists on the site, three of them managed to leave the territory in time, and one tourist died (Fig. 5). Georgia is a mountainous country and the share of its mountains and foothills is 54%. The infrastructure in these areas is constantly changing due to the events of disturbances of sustainability and ecological balance (Fig. 6).

Among the anomalies affecting the infrastructure in the high mountainous regions of Georgia, snow avalanches are the most dangerous ones, having a particular frequency to the extent of the consequences of the damage incurred and it has been increased geometrically in the last ten years in terms of the climate change in the world [5].

There are three main avalanche-prone sections of the Georgian military road - Zhinvali-Mleta, Gudauri-Kobi and Almasiani-Dariali. The first section (Zhinvali-Mleta) and the third section (Almasiani-Dariali) are weak, while the second section (Gudauri-Kobi) which is our survey target (Fig. 7) is characterized by particularly strong avalanche hazard.

Fig. 3. 2 February 2020

Fig. 4. 10 February 2020

Fig. 5. 15 February 2020

Fig. 6. Gudauri skiing lodge

Fig. 7. Snow avalanche at Kobi-Gudauri section of the Georgian military road

Due to the western air masses, there is humid climate along the Georgian military road, the amount of precipitation in November-April is 1300 mm. The maximum height of snowpack recorded in 1968 was 373 cm. Snow height of more than 100 cm was recorded 16 times in 42 years. Snowpack with the height of 200 cm and more was recorded 23 times and more than 300 cm - 2 times.

There are 52 avalanche catchments at Zhinvali-Mleta section and avalanches are expected during heavy precipitations (more than 70 mm precipitation in 18 hours). Most avalanches cover the road in heavy snowy winters. The exception is three sporadic avalanches of Jinwali-Mleta section, which come out to the road in anomalous winter conditions. The volume of snow taken from avalanches is from 1 to 100 thousand m3. Maximum volume was observed in the extremely snowy winter of 1986/87. At this section, there are 7 avalanche catchments in Pasanauri territory [6, 7].

There are 27 avalanches at Almasiani-Dariali section, which completely block the road during heavy precipitations (50 mm in 18-36 hours), and the volume of snow mass taken on the highroad was 76 thousand m3 in January 1987.

There are 59 avalanche catchments at Gudauri-Kobi section, out of which 41 avalanches come out on the road. The avalanche tunnels and gallery on this section fully or partially protect part of the road from only 17 avalanches.

The annual amount of precipitation on the Georgian military road increases with the increase of the altitude of the place from 739 mm to 1733 mm. Precipitation in the cold period of the year is 27-37% of the annual norm. The number of rainy days ranges from 122 to 183. The snowpack is unevenly distributed. Especially in extremely snowy winters, the maximum height of snowpack at Gudauri and Jvari Mountain Pass is 386-373 cm, respectively. During one snowfall, the height of snowpack increases by 210-270 cm, and the day-night increase is 100-120 cm, the number of snowy days is up to 1300 m, from 50 to 95 days, and at 1900-2400 m it is for 131-218 days. The maximum height and repeatability of snowpack are presented in the table (Table 2).

Table 2. Maximum height and repeatability of snowpack [8]

#	Meteorological station	Max. height (m)/years of observance	Max. height (cm)/ year	Repeatability				
				>50-100	101-200	201-300	301-400	>400
1	Pasanauri	1070/79	148/1939	31	8	-	-	-
2	Mleta	1580/60	360/1991	18	28	1	2	-
3	Stepantsminda	1744/75	112/1974	29	4	-	-	-
4	Kobi	1962/19	176/1956	5	9	-	-	-
5	Gudauri	2194/59	386/1987	-	38	18	3	-
6	Jvari Mountain Pass	2395/42	373/1968	-	16	23	2	-
7	Kazbegi (high mountainous)	3653/48	165/1936	33	8	-	-	-

Most of the avalanche catchments in the vicinity of the Georgian military road - 31 avalanches (45%) cover an area of less than 0.5 ha, while the surface slope is mostly 31-350 (23 avalanches), the maximum speed of 26 avalanches is 31-20 m/s (Table 3).

Table 3. Distribution of avalanche catchments by area, surface slope of avalanche sites and maximum avalanche speed

Area			Slope			Maximum speed		
hec	Amount	%	Degree	Amount	%	m/sec	Amount	%
<0,5	31	45	<25	6	9	<20	12	17
0,5-1,0	16	23	26-30	15	22	21-30	25	36
1,1-10,0	18	26	31-35	23	33	31-40	26	38
>10	4	6	36-40	15	22	>40	6	9
			>40	10	14			

Hazardous avalanche catchments for the Georgian military road are located in all three low- medium- and high mountain zones. The weakest maximum impact force of the existing avalanches is 4 t/m2, and the strongest is 97 t/m2 [9].

2. Outcomes of field survey at Kobi-Gudauri area as of 2020 – 2021

Kobi-Gudauri military road section for the study region is characterized by frequent natural disasters, among which snow avalanches play an important role.

Facts of catastrophically increased snow avalanche intensity and frequency, demographic change, unplanned urbanization, insufficient control over safety requirements protection, socio-economic inequality, environmental degradation, climate change and, in the light of all this, planning the preventive measures, taking into account all possible natural hazards, need an active approach.

Mitigation of the risk of snow avalanche disasters is a multidisciplinary complex issue and requires the support at the political and legislative levels, proper development of appropriate scientific knowledge, planning, selection of innovative regulatory and engineering measures, disaster preparedness, effective response mechanisms and public awareness.

In view of all the above, the grant project leader and project implementers carried out field trips and expeditions to identify the sensitive areas of snow avalanche formation at Kobi-Gudauri section of the Georgian military road in the winter and spring of 2020-2021 for the purpose of conducting field-scientific research.

Sensitive points of snow avalanche were recorded on site using GPS and GIS digital maps, the quantitative indicators of which: absolute height of the point (m), GPS coordinates, point numbers on the Georgian military road and lengths of sections are given in Table # 4 and in parallel marked on the digital map (Fig. 8).

In order to arrange an innovative antiavalanche structure [9], to select a representational place, inJanuary-March 2021 with the involvement of (N)LE Ecocenter for Environmental Protection and thestaff of the Hydrometeorology Department of theNational Environmental Agency, the field recon-naissance surveys were carried out at Kobi-Gudaurisection (Fig. 8). Analysis and evaluation of thesefield surveys revealed two avalanche catchmentsfor the arrangement of an innovative antiavalanche structure, the indicators of which are shown on the map (Fig. 9). The mountain slope inclination of thefirst avalanche catchment is 240, and that of the sec-ond avalanche catchment is 200.

Table 4. Numerical indicators of field - scientific researches

Geographical values of avalanche-prone points at Kobi-Gudauri section of the Georgian Southern Road								
N	**Point numbers**	**Absolute mark**	**Coordinates**		**Road point numbers**	Road coordinates		Distance between point and road
		(H)	**X**	**Y**		**X**	**Y**	**(m)**
1	16	2035	458341	4711074	16.1	458485	4710988	181.27
2	15	2054	458228	4710769	15.1	458331	4710753	110.76
3	1	2122	458099	4710062	1.1	458080	4710083	29.8
4	3	2170	457649	4709686	3.1	457636	4709726	40.74
5	14	2192	456988	4709635	14.1	457093	4709573	127.18
6	5	2220	456872	4709189	5.1	456847	4709212	36.25
7	6	2223	456841	4709142	6.1	456810	4709161	40.01
8	7	2265	456545	4708595	7.1	456466	4708584	81.52
9	8	2274	456545	4708311	8.1	456441	4708348	110.92
10	9	2312	456549	4707951	9.1	456440	4708078	156.98
11	10	2335	456418	4707677	10.1	456255	4707684	179.04

The geological conditions of both avalanche catchments are homogeneous and they are cretaceous marls, limestones and argillaceous slates. Subaerial volcanites of the fourth age with the dacite-andesite composition are also found in the vicinity of the avalanches [10].

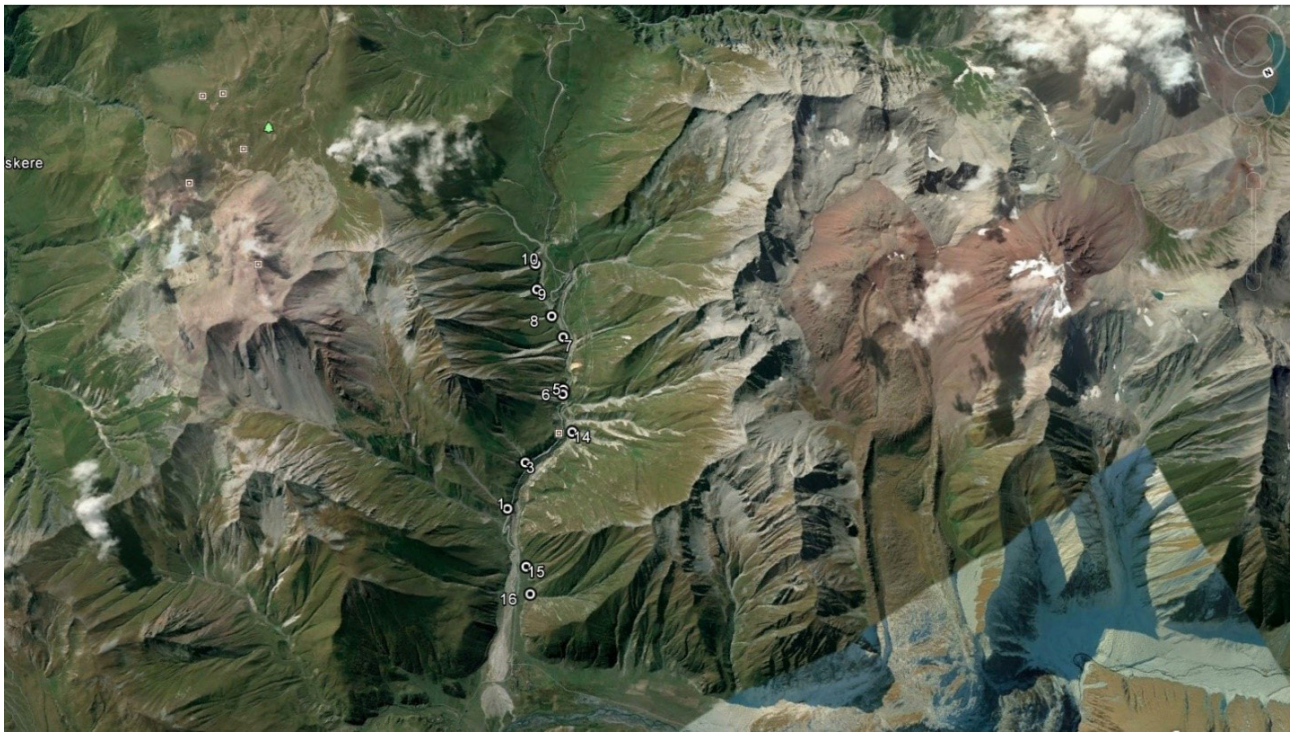

Fig. 8. *Map of the Sensitive Areas of Kobi - Gudauri of the Georgian Military Road (29 October 2020)*

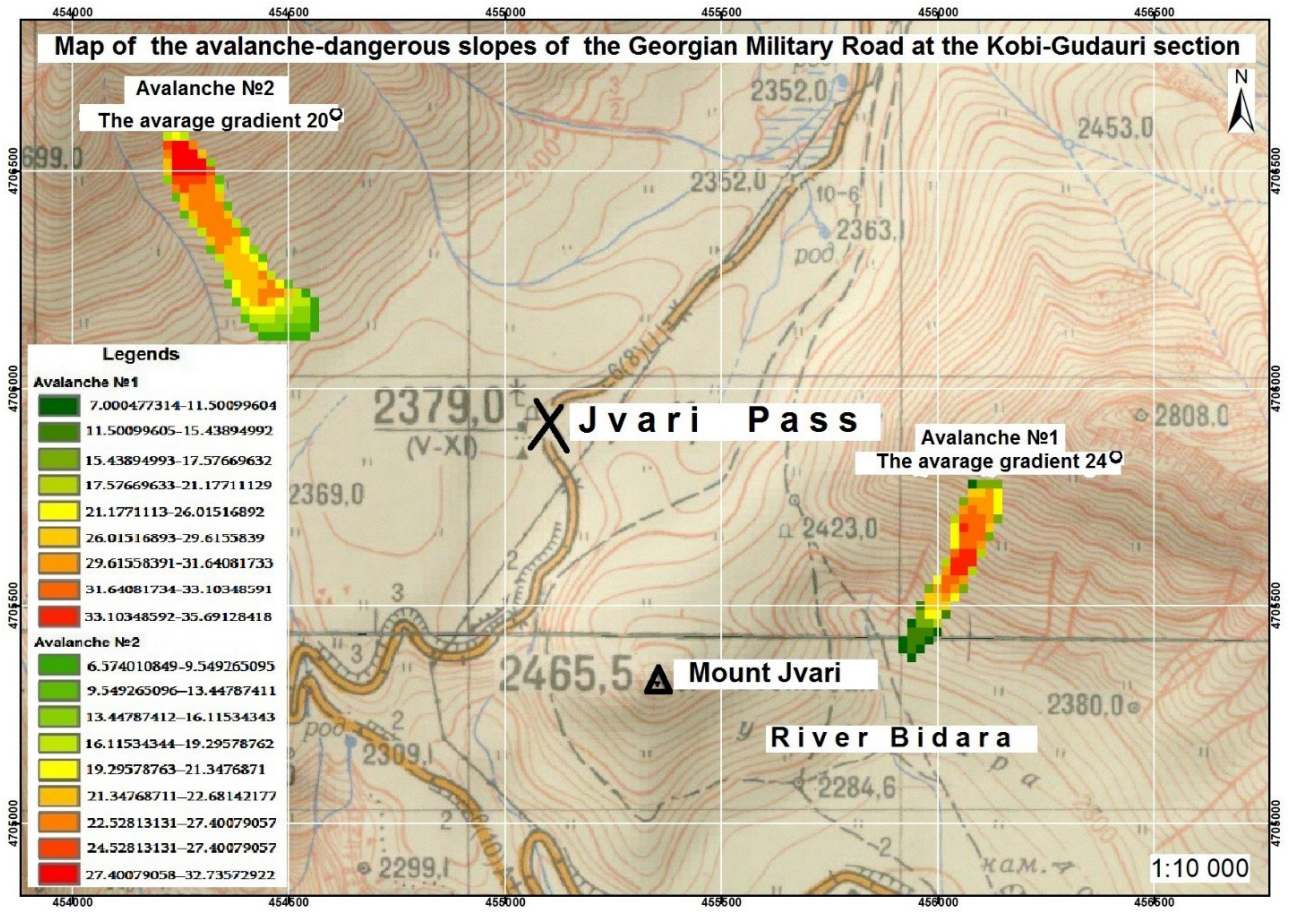

Fig. 9. *Snow-catchment areas for arrangement of antiavalanche structure*

Photo material reflecting the outcomes of the field survey conducted at Kobi-Gudauri area is given at the 10th figures.

a) Snow Avalanche # 2 (Jvari Mountain Pass. Absolute mark 2699 (m) Inclination of the mountain slope 20^0

b) Snow Avalanche #1 (Panorama surrounding territory) Absolute mark 2570 (m)
Inclination of the mountain slope 24^0

Fig. 10. *Field surveys at Kobi - Gudauri section of the Georgian Military Road (16 – 22 March 2021)*

To arrange the innovative snow avalanche construction at Kobi-Gudauri section of the Georgian military road, we selected snow avalanche catchment # 1, with a slope inclination of 240 (see Fig. 9 and Fig. 10 - b), located in the vicinity of Panorama at absolute height 2570 (m), with coordinates X = 4560433; Y = 4705596. Thereafter, based on the conducted scientific field surveys and theoretical studies, it has been established that due to the scale of the avalanches, notwithstanding the existing models and control measures, the catastrophic consequences cannot be avoided. Snow avalanches are a terrifying phenomenon among natural disasters and the creation of an innovative type of the regulatory structures is related to their genesis and dynamics.

Taking into consideration the foregoing, the design of innovative antiavalanche structure [10] has already been developed, the implementation of which is planned for the snow avalanche catchment #1 at the sensitive area of Kobi-Gudauri of the Georgian military road (Fig. 10-b).

Acknowledgement

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