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Avalanche Danger on the Highways of the Samegrelo-Zemo Svaneti Region (Georgia)

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Abstract
The importance of highways in the mountainous regions of Georgia is very great for the socio-economic development of the country. Such natural disasters as snow avalanches significantly damage the road infrastructure, create delays in movement, often cause human casualties. Therefore, in order to implement preventive measures, the study of avalanche hazards on highways is of great importance. Mestia municipality of Samegrelo-Zemo Svaneti region (Zemo Svaneti) is characterized by mountainous and high-mountain terrain, snow avalanches are frequent, including on sections of highways.
Avalanche hazards on highways of Mestia municipality of Samegrelo-Zemo Svaneti region and climatic factors of their occurrence are studied. The data of the Mestia meteorological station on air temperature and solid precipitation covering the years 1961-2021 have been processed. A geo-informational map of the avalanche danger of highways in the Samegrelo-Zemo Svaneti region has been compiled.

Keywords: Snow avalanches, climate, natural disaster, highways, geoinformation map

1. Introduction

In recent years, the government of Georgia has paid special attention to the development of the mountainous regions of the country, which is aimed at solving the social and economic problems of the people living in the mountainous regions. Among them is the promotion of mountain resorts so that our mountain resorts, including mountain-ski resorts (Gudauri, Bakuriani, Goderdzi, Tetnuld, Hatsvali, and Bakhmaro), are available for both local and visiting vacationers in all four seasons. Mountain resorts

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and ski sports are important both for establishing a healthy way of life and for the development of winter tourism.
Most of the winter resorts, including those in Zemo Svaneti of the Samegrelo-Zemo Svaneti region, are located in the avalanche-prone zone; therefore, it is necessary to follow the rules of movement on mountain roads and conduct rescue operations in a timely manner.
During the implementation of infrastructural projects in the mountainous areas of Georgia, as well as during the implementation of anti-avalanche measures, it is necessary to determine the morphometric (beginning and end height, length, area of the avalanche focus, surface slope) and dynamic characteristics of each avalanche (maximum speed of the avalanche, impact force, volume of the cone, and maximum speed of the moving avalanche). calculation.
The aim of the research is to study the avalanche danger of highways in the mountainous regions of Samegrelo-Zemo Svaneti, one of the regions of Georgia. This paper presents a schematic map of avalanche hazards created for each avalanche-prone section of the Upper Svaneti highways, where the area of each avalanche is marked.
The morphometric and dynamic characteristics of each avalanche in the mentioned sections have been studied. Recommendations for avalanche hazard mitigation on these highways are discussed (Kaldani Lado and Salukvadze Manana, 2015; Salukvadze M., 2018; Salukvadze M., 2018; Salukvadze M., 2018).

2. Results

The terrain of the Svaneti area is very difficult. Here lies a significant part of the Central Caucasus, with peaks above 4000-4500 m, the Svaneti ridge, and the deep valleys of the Enguri River and its tributaries: Nakra, Dolra, Nenskra, Mulkhura, Mestiachal, Hadishchal, Khaldechal, Kesleti, Khaishura, and Urashi.
A significant part of the territory is located in the medium and high mountain zones. In the mountainous part of the Enguri river basin, which flows into the river. North of the Magana estuary, the low-mountain zone occupies 12% of the total area. A significant part of the territory of Zemo Svaneti (30%) is located in the medium-mountain zone, and more than half (58%) is located in the high-mountain zone, of which 40% occupies the area between 2000 and 3000 m and 18% above 3000 m.
The area with a slope of less than 150 occupies only 5% of the total area; 33% of the surface is characterized by a slope of 15–250, 49% by a slope of 25–350, and 13% by a slope of more than 350 (Agroclimatic Atlas of Georgia, 2011; Kaldani Lado, Salukvadze Manana, 2001; Kaldani Lado, Salukvadze Manana, 2012).
In the territory of Svaneti, the forest cover extends from sea level to 2200–2400 m, and the higher slopes are characterized by subalpine and alpine vegetation. A large area is occupied by slopes covered with mixed forest, and a significant area is covered with coniferous and deciduous forest. Forest cover is spread over 40–42% of the total area. Deforested slopes are found even below the upper limit of forest extent, which is due to deforestation. Snow avalanches also played an important role in the formation of forested slopes within the natural boundaries of the forest(Table 1.).

Table 1. Avalanche-prone and non-avalanche-prone areas of Upper Svaneti, considering the deforestation factor

№	Avalanche activity	area, %	Before deforestation		In case of deforestation	
			Avalanche danger	Non-avalanche-dangerous	Avalanche danger	Non-avalanche-dangerous
1	0	2	0	4	0	4
2	<20	25	23	21	19	5
3	20-40	20	6	14	16	4
4	40-60	21	10	10	17	4
5	>60	32	2	10	22	10
sum			41	59	74	26

96% of the total area of the territory is located in the avalanche zone, and 41% is completely avalanche-prone.

The annual amount of solid precipitation varies from 300–400 mm to 1100–1200 mm. The maximum height of the snow cover is from 100 to 150 cm to 525 to 575 cm. During one snowfall, the increase in the height of the snow cover in Khaish was 175 cm (21-29 January 1987), in Lakham it was 220 cm (27-29 January 1987), in Nakra it was 290 cm (26.12.1986, 9.01.1987), in Lakhamula it was 246 cm (28-31 January 1987), and in Mestia it was 170 cm (27.01-04.02.1987).

The maximum height and frequency of snow cover are presented in the table (Table 2). Unfortunately, from the meteorological stations and checkpoints presented in the table, only the Mestia weather station continues to observe [8–10]. (Salukvadze Manana, Kobakhidze Natela end etc, 2014; Abdushelishvili K.L., Kaldani L.A., 1997; Indications.., 1973).

Table 2. Maximum height and frequency of snow cover

№	Meteorological station	Height above sea level/m (years of observation)	frequency				
			>50-100	101-200	201-300	301-400	>400
1	Jvari	268 (51)	12	3	1	-	-
2	Khaishi	730 (55)	21	5	2	-	-
3	Lakhami	800 (43)	12	11	1	1	-
4	Dizi	1120 (49)	25	9	2	-	-
5	Naki	1160 (43)	16	19	2	1	-
6	Lakhamula	1200 (48)	23	15	2	-	-
7	Becho	1270 (52)	24	21	2	-	-
8	Mestia	1441 (58)	38	13	1	-	-
9	Murkmeli	2100 (51)	17	18	1	1	-

In addition to populated areas, avalanches also pose a threat to the highway, so we also studied the avalanche danger of the Skormet-Jorkvali section of the Jvari-Mestia highway (Fig. 1).

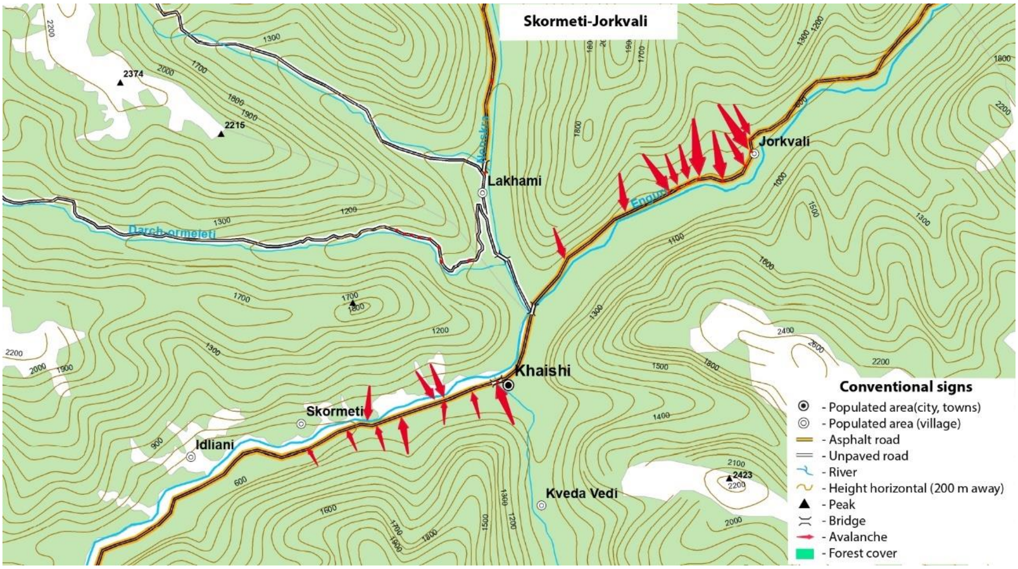

Fig. 1: Avalanches on the section of the Skormet-Jorkvali highway

This road is mainly along the slope of the right bank of Enguri River, and the avalanche centers are located in the medium- and low-mountain region, whose surface is characterized by a large slope. Less than 150 slopes are only a minor part. In most parts of the territory, the slope of the slopes is 25–350. There are more than 350 slopes of only individual peaks, such as some slopes of Mt. Chveri, which are covered with mixed and coniferous forest.

There are 46 avalanche traps on the Skormeti-Jorkvali section, of which 34 avalanches reach the river in the snowless winter. From the right slopes of Enguri, 8 avalanches are expected from the right slope of the Darchi-Ormeleti river, and 6 avalanches are expected from the left slope. Most avalanche foci originate in the 1001–1200, 1201–1400, and 1401–1600 m altitude zones (26%, 24%, and 22%, respectively). Avalanches are especially widespread, and the avalanche centers are characterized by small areas: 81% of the avalanches on this section of the road have an area of up to 1 ha. Only 4% of avalanches have an avalanche center area larger than 5 ha.Avalanches reach their maximum speeds in different sections of the avalanche, which is due to the features of the micro-relief of the avalanches. Relatively small maximum speeds (25 m/s and 25–30 m/s) are characterized by 4% and 20% of the total number of avalanches, respectively. Two avalanches have a particularly high maximum speed (>45 m/s). 33 avalanches have a maximum impact force of 20–80 t/m2, 10 avalanches have an impact force >80 t/m2, and only two avalanches have an impact force greater than 100 t/m2.

The study of 107 avalanches in the Mestia-Choluri section is also important for the territory of Svaneti. At an altitude of 2520 m above sea level, Mt. The source of the Enguri

River is the confluence of streams originating from the glaciers of Namvani (the junction of the main Caucasus range and the Svaneti range). Here, not only in Svaneti but at one of the highest settlements in Europe (at an altitude of 2100–2300 m), the Ushguli community is located, where avalanches descend every heavy snow winter. Especially dangerous are the avalanches formed in the avalanche reservoirs located on the northern slopes of the Svaneti ridge, which caused significant damage to the villages of the Ushguli community (Chazhashi, Murkmeli, Zhibiani, and Chvibiani) in the winter months of 1976 and 1987 (Fig. 2).

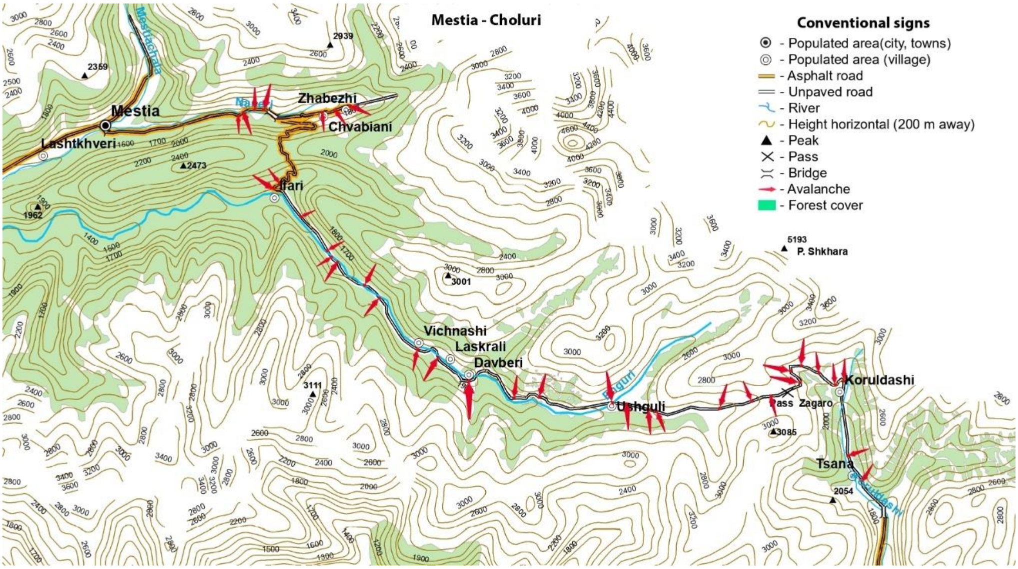

Fig. 2: Avalanches on the Section of Mestia-Cholur Highway

The great fragmentation of the terrain, complex orography, high absolute and relative heights, wide distribution of forested and wooded steep slopes, difficult climatic conditions, and lack of snow conditions lead to the wide spread of avalanches in the Mestia-Choluri section.

The are 107 avalanches on this site, 15 of them are located in the valley of the Mukhra River (right tributary of the Tskhenistskali River), 9 - Guristskali River (left tributary of the Enguri River), 57 - Enguri River, and 26 - in the valley of the Mulkhura River (right tributary of the Enguri River).

4% of the total number of avalanches starts below 1500 m. Up to 1500–2000 m: 36%; up to 2000–2500 m: 50%; up to 2500–3000 m: 7%; and only 3% above 3000 m:

Avalanches with an area of less than 0.5 ha are widespread; their number is 63% of the total number; especially small areas (0.1 ha) are characterized by 12 avalanches, and the area of 5% exceeds 100 ha. The maximum speed of the avalanche varies from 20 m/s to 61 m/s. Avalanches with a maximum speed of 31–35 m/s (28%), and 35–40 m/s (24%), are more frequent (Table. 3).

Table 3. Distribution of avalanches by area, surface slope, and maximum avalanche speed according to 1961-2010.

Area, Ha			slope, degrees			Maximum speed, m/s		
Ha	quantity	%	degrees	quantity	%	m/s	quantity	%
<0,5	51	67	<25	2	2	<20	7	9
0,5-1,0	10	13	26-30	18	24	21-30	38	50
1,1-10	15	20	31-35	39	51	31-40	17	32
>10	-	-	36-40	12	16	>40	14	19
			>40	5	7			
∑	76	100		76	100		76	100

Two avalanches are distinguished by their maximum impact force: 149 t/m2 and 171 t/m2. Avalanches with an impact force of 30–50 t/m2 and 50–70 t/m2 account for 25% and 38%, respectively. Avalanches with a maximum impact force of less than 30 t/m2 (10%) or more than 110 t/m2 (8%) are relatively rare. The snow height of the moving avalanche is, in most cases, 9–10 m (Table. 4).

Table 4. Distribution of avalanches according to the maximum impact force, the volume of the avalanche cone, and the height of the moving avalanche according to 1961-2010.

Impact force, t/m^2			Cone volume, thousand m^3			Height, m		
t/m^2	quantity	%	thousand m^3	quantity	%	m	quantity	%
<20	8	11	<1,0	8	11	<10	-	-
21-40	32	42	1,1-15	49	64	10,1-15	43	4
41-60	9	12	15,1-25	7	9	15,1-20	40	53
61-80	14	18	25,1-100	10	13	20,1-25	22	29
.80	13	17	>100	2	3	>25	11	14
∑	76	100		76	100		76	100

Another valley with avalanche danger is in the territory of Zemo Svaneti, the Nenskra River Chubrula) valley (the main tributary of the Enguri River) stands out. The Nenskra River(Chubrula) begins on the southern slope of the Caucasus mountain range, at an altitude of 2588 m above sea level, and flows into the Enguri River at a height of 566 m. Nine rivers join the Enguri River in the territory of the Chuberi community (Ormeletilitsi, Lakhamlitsi, Tetnashuri, Hokrilashlitsi, Memlura, Darliarlitsi, Titashlitsi, Marghula, and Guashgararislitsi). The role of glaciers in feeding these tributaries is insignificant, and the river Nenskra, as well as the headwaters of the Enguri basin, are covered by glaciers. In ten villages of the Chuberi community (Devra, Zemo Marghi, Larilari, Lakhami, Lekalmaye, Letsferi, Sgurishi, Tita, Kvemo Marghi, and Kari), the massive arrival of catastrophic avalanches turned out to be especially tragic in 1976 and 1987 in January.

There was a lot of material damage: dozens of destroyed residential houses, auxiliary buildings, damaged farms, a goods processing plant, tens of hectares of forest and orchards were destroyed, hundreds of meters of fences were broken, and most importantly, 31 people died as a result of avalanches.

Until 2008, the Khaishi-Chuberi-Sakeni road in this valley was the only connection with the Kodori (Dali) valley; this road gained strategic importance because with its help it was possible to connect the rest of Georgia to the Kodori valley (Fig. 3).

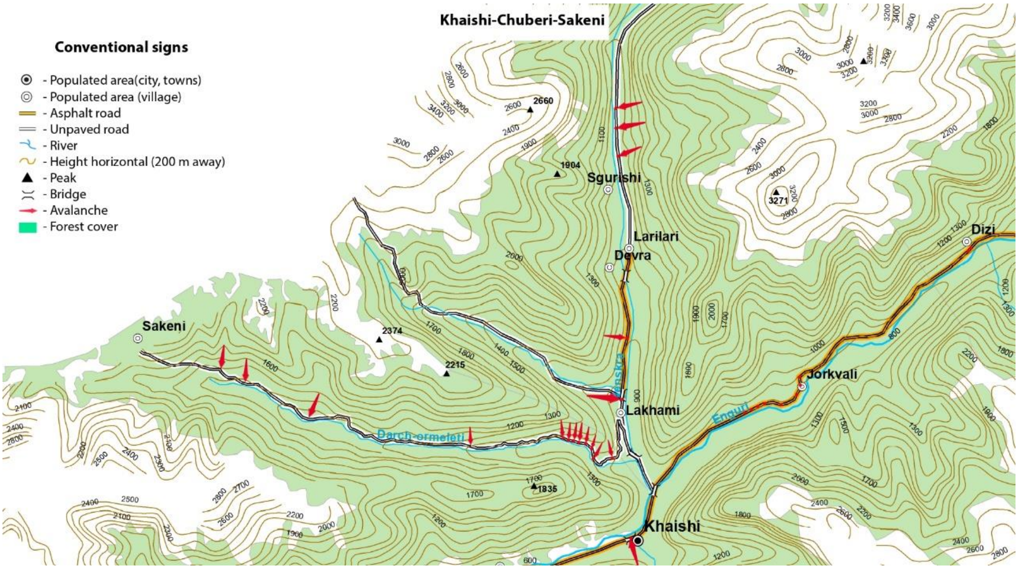

Fig. 3. Avalanches on the Khaishi-Chuberi-Sakeni Highway Section

On the basis of avalanche-generating factors, calculations using theoretical methods, and analysis of field materials, in the Nenskra River basin, 76 avalanches were identified, which are dangerous for the villages in the Chuberi community, as well as for the road entering the valley. Avalanches with a height of 1000–1500 m predominate (72%), and avalanches with a height of 1500–2000 m make up 20%. In only two cases, the absolute height of an avalanche is more than 2000 m. There are widespread (70%) small-area (0.5 ha) glaciers in the valley. The maximum speed of the avalanche varies from 12 m/s to 48 m/s. Most avalanches can develop a speed of 35 m/s (33% respectively). Only 9% of avalanches have a maximum speed of more than 36 m/s. The maximum impact force of avalanches also changes over a large range, from 7 t/m2 to 106 t/m2. For 30% of avalanches, the maximum impact force is less than 30 t/m2 and 30–50 t/m2, and only 10% of avalanches have a maximum impact force greater than 90 t/m2. Four of these avalanches have a maximum impact force of 93 t/m2, three have a maximum impact force of 97 t/m2, and three exceed 100 t/m2. For most of the avalanches (57%), the snow height of the moving avalanche is less than 20 m.

3. Conclusion

A total of 229 avalanche traps are recorded on the examined road sections in the territory of Zemo Svaneti (Skormeti-Jorkvali section of the Jvari-Mestii highway, Mestia-Choluri section, Khaishi-Chuberi-Sakeni section).

There are 46 avalanche traps on the Skormet-Jorkvali highway section. Of these, about 20–25% belong to particularly dangerous avalanches. The number of avalanches in this section, whose area of the avalanche center exceeds 1 ha, is 19%, and the maximum impact force of 12 avalanches exceeds 80 t/m2.
There are 107 avalanche traps on the Mestia-Choluri section. 20% of them are avalanches with an area of more than 1 ha. 20% are also avalanches that can develop a maximum speed of 40 m/s or more. In this section, 50% of avalanches come from an altitude of 2000–2500 m above sea level. And the maximum impact force of 17% of avalanches is 80 t/m2 or more.
There are 76 dangerous avalanches on the Khaishi-Chuberi-Saken section, as well as on the road entering the valley. 10 The maximum impact force of an avalanche exceeds 90 t/m2. 20% of avalanches start between 1500 and 2000 meters above sea level. In this section, most avalanches can develop a speed of 35 m/s, or 33%. Only 9% are avalanches, whose maximum speed is more than 35 m/s.
If the existing forest cover is cut down, the area of avalanches will increase by 33%, and not only in winters without heavy snow but also in winters with average snowfall, 74% of the total area of Upper Svaneti will be affected by avalanches.
The obtained results will help relevant services and municipalities mitigate the negative impact of avalanches. Consideration and practical application of research results in preventive measures will be important in agriculture, construction, the forest and resort sectors, tourism, the economy, and transport operations.

4. Discussion/recommendation

Human casualties and large material losses caused by avalanches necessitate the development of anti-avalanche measures and their implementation. There are: passive, active, temporary, capital and others. Table 5. provides a classification of active and passive anti-avalanche measures(Kaldani Lado, Salukvadze Manana (2003); Abdushelishvili K.L., Kaldani L.A. Salukvadze M.E. (1984)).

Table 5. Classification of anti-avalanche measures

Passive	Active
Examination of the avalanche area, choosing a safe place	Event in the avalanche focus (temporary, permanent, engineering structure, afforestation)
Methods for forecasting avalanches (for certain areas of avalanches, for mountainous areas)	Event in the avalanche channel (avalanche cleaner, launch over the object, Destructive structures)
Avalanche surveillance service, creation of rescue teams	Actions in the avalanche cone (avalanche cleaners, launchers on top of the object, disintegrating braking and locking means)

Passive anti-avalanche measures do not include work in an avalanche zone.

The centuries-old experience of construction in the mountains is of great importance when using avalanche-prone areas. At the same time, it should be taken into account that the arrival of sporadic avalanches causes not only the destruction of individual buildings, but also the complete destruction of settlements, casualties and large material losses.
One of the effective passive measures to combat avalanches is to warn the population about their arrival. A timely avalanche forecast can be more useful than rescue work. It is obvious that it is impossible to protect the building with a timely forecast, but it is possible to evacuate people and save part of the property.
When carrying out active anti-avalanche measures, people actively intervene in the conditions for the formation, movement and spread of avalanches. They are trying to change the surface shape of the center of the avalanche, the existing vegetation, the characteristics of the snow, the direction of the avalanche, the speed and force of the impact. cause preventive avalanches or prevent their formation.
Explosive charges are used to artificially launch avalanches. A grenade, mine or rocket can reach an avalanche slope in a matter of seconds. A helicopter is used to transport explosives, but weather conditions and air travel costs must be taken into account.
An explosion in the avalanche zone is possible in the following cases: a). When an avalanche descends from one slope, it is necessary to check other slopes; b) Sometimes after the explosion snow remains on the slope or a small avalanche is possible.
One of the important measures to combat avalanches is the afforestation of avalanche-prone slopes or reforestation in their tracts. It is advisable to afforest with trees of local species, and under favorable natural conditions - with coniferous trees. Deforestation should be carried out in such a way as to promote the natural regeneration of the forest. It is possible and necessary to renew the forest with artificial plantations. Improper exploitation of forests and fires in forest areas in recent years lead to the emergence of new avalanche centers, which in itself increases the risk of avalanches.
The population of the mountainous regions of Georgia considers the forest cover as an anti-avalanche measure.
A study conducted after the massive occurrence of catastrophic avalanches showed that even in an area of especially high avalanche danger on steep slopes covered with dense, coniferous or mixed forests, not a single avalanche occurred.

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References

Abdushelishvili K.L., Kaldani L.A. (1997), *Maps of the Caucasus - the degree of avalanche activity, factors of avalanche formation, Recurrence and volume of avalanches*, Atlas of snow and ice resources of the World, pp.92-93.
Abdushelishvili K.L., Kaldani L.A. Salukvadze M.E. (1984), *Inventory of avalanches of the USSR*, Volume 9, Transcaucasia and Dagestan, Gidrometeoizdat, pp. 108-197, St. Petersburg.
Agroclimatic Atlas of Georgia, (2011), Georgian Technical University, Tbilisi.
Indications.., (1973), *Instructions on the calculation of avalanche load during design*, Gidrometeoizdat, Moscow.

Kaldani Lado, Salukvadze Manana (2015), *Snow avalanches in Georgia*, monograph, Institute of Hydrometeorology of Georgian Technical University, 159 p., Tbilisi.

Kaldani Lado, Salukvadze Manana (2001), *Frequency of avalanche hazards in the territory of Georgia*, Proceedings of the Institute of Hydrometeorology, Vol. 106. pp. 123-130, Tbilisi.

Kaldani Lado, Salukvadze Manana (2012), *9 maps of the distribution of snow cover and avalanche danger in Georgia*, National Atlas of Georgia, pp. 93-98, Tbilisi.

Kaldani Lado, Salukvadze Manana (2003), *Climate of Georgia. Adjara*, Proceedings of the Institute of Hydrometeorology, vol. 110, pp. 138-147, Tbilisi.

Salukvadze M. (2018), *Cadastre of Snow Avalanches of Georgia*, Institute of Hydrometeorology of Georgian Technical University, 265 pp., Tbilisi.

Salukvadze M. (2018), *Avalanche-prone regions of Georgia*, Proceedings of the Geographical Society of Georgia. New Series I (XIX), Tbilisi, pp. 177-128.

Salukvadze M. (2018), *Avalanche hazard map,* Geographic Atlas of Georgia. Geographical Society of Georgia named after Alexander Javakhirvili and Tbilisi University named after Ivane Javakhirvili, Tbilisi, pp.50.

Salukvadze Manana, Kobakhidze Natela, Jincharadze Gocha (2014.), *Avalanche prevention measures and the possibility of their implementation in Georgia*, collection of works of the Institute of Hydrometeorology of GTU, vol. 120, p. 57-59, Tbilisi.