

A NEW APPROACH TO AVALANCHE RISK ASSESSMENT IN RUSSIA

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ABSTRACT: Snow avalanches pose a challenging problem in many mountain regions of Russia. The expansion of infrastructure and therefore the increased avalanche risk demands the elaboration of risk assessment methods in planning of mitigation measures. The researchers from MSU Laboratory of snow avalanches and debris flows have been developing methods of natural hazard risk assessment in order to estimate the potential social and economic losses at different scales. More precise and accurate calculations are required for risk evaluation in rapidly developing mountain territories. Thus, we have developed a new method, that can be used to estimate snow avalanche risk at large scale. It includes quantification of full social and individual risk values for ski resorts and other types of mountain infrastructure. It also can be used for risk estimations within separate ski pistes and their particular parts.

In this research, we present the results of potential avalanche risk assessment for avalanches with different return periods within Russian ski resorts Rosa Khutor (Caucasus) and Big Wood (Khibiny). We take into account such parameters as the area of avalanche-prone territory, the duration of resort functioning during the year and the day, the number and distribution of visitors within the study area, the configuration of trails etc. Zoning of the territory and allocation of areas with high risk values were performed using data obtained during two separate field observation campaigns in 2016–2017. The area of avalanche-prone territory was calculated using RAMMS model, which was found to fit this task perfectly.

KEYWORDS: snow avalanche, risk assessment, risk zoning, RAMMS, ski resort

1. INTRODUCTION

Risk assessment is supposed to be used to identify and predict hazards, assess the vulnerability of territories and objects, identify possible consequences, determine the possibility and extent of losses (damage and social losses). The requirement of protection from natural hazards is determined by the federal law of Russian Federation (Federal Law...). There are Russian federal guidelines stating the necessity to estimate the snow avalanche danger and to develop the corresponding mitigation measures (SP..., 2012; SP..., 2016). However, the exact procedures are not yet officially approved and the use of numerous formulations of the snow avalanches characteristics required for construction of the protection do not include assessment of the actual quantified risk, varying in space and time. The constant growth of

economic activity in avalanche prone areas of Russia and therefore the increasing avalanche risk encourages development of suitable for operators of such territories avalanche risk assessment methods in Russia.

The methodology of snow avalanche risk assessment was developed at the Laboratory of Snow Avalanches and Debris Flows of the Moscow State University to evaluate risk and potential damage on different scales in order to increase the safety of the local population and tourists, and to protect infrastructure. The result of practical applications of this method was a small-scale risk zoning in terms of quantitative values for individual fatality and full social risk (Seliverstov et al., 2008; Shnyparkov et al., 2012). However, due to economic growth, more profound investigations of particular objects and areas on larger scales have become essential (Komarov et al., 2016).

Thus, we discuss these problems by presenting a new avalanche risk assessment approach on example of Rosa Khutor (Caucasus) and Big Wood (Khibiny) ski resorts. This new methodology is based on the results of previous

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investigations, but is more accurate and designed for risk assessment within local areas such as ski resorts and their particular parts. It also can be applied to other objects of mountain infrastructure as well as off-piste and backcountry areas.

Implementation of the task is greatly facilitated by the capabilities of the RAMMS model. Based on the obtained data, such essential parameters as avalanche runout distance and the area of exposed territory were calculated.

2. METHODOLOGY

Risk can be defined as the product of the probability of an event (i.e. avalanche) and its consequences (vulnerability of the object) (Bohnenblust & Troxler, 1987). The vulnerability is recorded as a conditional probability, under the condition that the avalanche has taken place as well as people were present. Thus, the methodology of full social and individual avalanche risk assessment requires a consecutive calculation of temporal and spatial vulnerability indexes (Komarov et al., 2016). In this case study the calculations are performed for avalanches with 1, 10, 30 and 100-year return periods and for territories characterized by different density of people and duration of their stay in hazardous area. Research includes the collection and statistical analysis of climatic, geomorphological and socio-economic characteristics, such as the height of snow, the area of avalanche prone territory, the distribution of people within resorts, the duration of resorts functioning during the day and the year as well as the configuration of ski slopes.

2.1 Full social risk

Full social avalanche risk (R_s) characterizes the expected average number of people killed in avalanches during the year within the study area. It was calculated as the multiplication of temporal and spatial vulnerability, density of people within selected area and the mortality coefficient (eq. 1):

$$R_s = V_t \times P \times S \times K \quad (1)$$

2.2 Temporal vulnerability

The temporal vulnerability (V_t) characterizes the duration people stay in an avalanche-prone area. This coefficient is calculated as the product of the avalanche return period (V_y), the ratio of the duration of the season to the duration of the avalanche period (V_d) and the ratio of the duration people stay in an area during a day to the duration of a day (V_h) as presented in equation (eq. 2):

$$V_t = V_y \times V_d \times V_h \quad (2)$$

In previous research (Komarov et al., 2016) we have considered only 100-year avalanche return period scenario for risk assessments, while in actual research we use 4 scenarios which are 1, 10, 30 and 100 years. The short return period is not less important for a ski piste area than the extreme but rare avalanches for infrastructure. It is also possible to calculate the risk for avalanches of more frequent occurrence (several times a year), taking into account the frequency of avalanche-hazardous situations related to the slope aspect ratio and weather patterns.

2.3 Spatial vulnerability

The spatial vulnerability (S) is characterized by the exposure of the territory to the impact of snow avalanches of different return periods. It is calculated as the area of the avalanche-prone territory within selected resort or particular slope and defined as the total area of the ski pistes, overlapped by avalanches. The calculation of avalanche outlines was performed using RAMMS model, which was previously verified applying data of direct observations (Turchaniniva, 2013). The spatial vulnerability index was calculated for the zones selected depending on avalanche return period and the spatial distribution of people within the resort.

2.4 People density

On the basis of field observations, zones with high, standard and low people density were identified (Fig. 1). Zones with low density are represented by easily accessible off-piste skiing and forest areas. The zones of standard density are represented by uniform, wide, high-speed sections of the traces and are characterized by mean values for the territory. High-density zones

included sharp turns, intersections, narrowing, pockets and recreation areas, areas around the tourist infrastructure, ski lifts, cafes. At this stage, the boundaries of zones are determined on the basis of visual analysis. Further, for each of the selected zones, the density of people (P) was calculated on the basis of data on the maximum capacity of cableways and the distribution of people between the tracks. It was determined that the density of people in “standard” areas reaches 1500 people per km^2 . In high-density zones, this value may reach up to 15,000 people per km^2 , in areas off-piste skiing – up to 30 people per km^2 (Fig. 1). These values correspond to the calculated and actual values obtained for a number of American and European resorts (von Allmen & Salzmann, 2004).

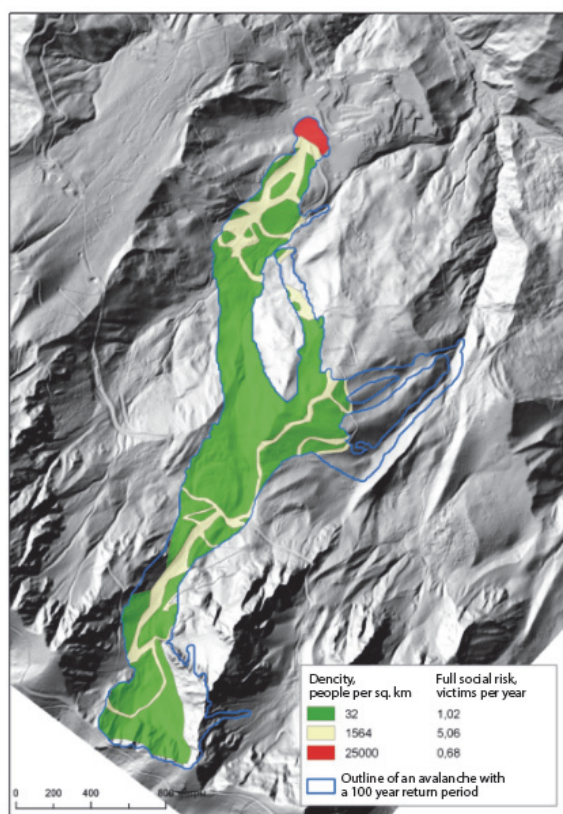


Figure 1. The map of piste (yellow, medium density), recreational (red, high density) and off-piste (green, low density) areas within avalanche-prone territory of Rosa Khutor ski resort.

2.5 Mortality coefficient

In addition, the formula for calculating avalanche risk includes the mortality coefficient (K), which reflects the ratio of deaths and survivors in snow

avalanches. In this research, the constant value of 53% is used for this coefficient (Brugger et al., 2007) that is bound to the 47% probability of surviving an avalanche after being totally buried.

2.6 Individual risk

The obtained values of full social risk can be used to calculate the individual risk (R_i). This index represents the risk situation related to an individual (single person), the probability of premature death of an individual in the study area. This index is calculated as the ratio of the full social risk (R_s) to the total number of people (N) on pistes during the year (Eq. 3):

$$R_i = \frac{R_s}{N} (3)$$

4. RESULTS

Using the new methodology, the values of full social and individual risks have been calculated for Rosa Khutor (Caucasus) and Big Wood (Khibiny) ski resorts. Due to different natural and socio-economic conditions of these regions, the spatial and temporal vulnerability indexes, as well as distribution of people within resorts, differ significantly. However, the final results demonstrate similar values.

At the territory of the Rosa Khutor resort, the full social risk (R_s) was estimated as 6.8 people per year (Table 1, Fig. 1). At the Big Wood resort, it equals 3.8 people per year.

Avalanche return period, years	Full social risk, people/year			
	Off-piste zone	Ski pistes zone	Recreational zone	All zones
1	0,76	2,07	0	6,8
10	0,24	2,63	0	
30	0,02	0,24	0,1	
100	0,01	0,12	0,58	
All	1,02	5,06	0,68	

Table 1. Full social risk values calculated for different zones of Rosa Khutor ski resort.

Despite of these values are of the same order the spatial distribution of risk values show different patterns. In the Caucasus, the areas with highest risk values are located on ski slopes exposed to avalanches of 1 and 10-year return period (about 70% of total risk), while in Khibiny recreation area at the foot of ski pistes is the most dangerous one. It is characterized by highest density of

people and a rare (30, 100 years) recurrence of avalanches (55% of total risk within the resort).

In addition to full social risk, for each zone the number of potential avalanche victims per 1 km² of zone was calculated, which allows to determine the most vulnerable areas. At Rosa Khutor resort the highest value of 193 people per km² was calculated for the area of ski slopes exposed to avalanches of annual frequency (Fig. 2., Table 2). At Big Wood resort the value of 47 people per km² was calculated for recreation area exposed to avalanches of 30-year return period. Based on the obtained results, the maps of the full social risk distribution and the number of potential avalanche victims per square kilometer of zones were constructed for each resort.

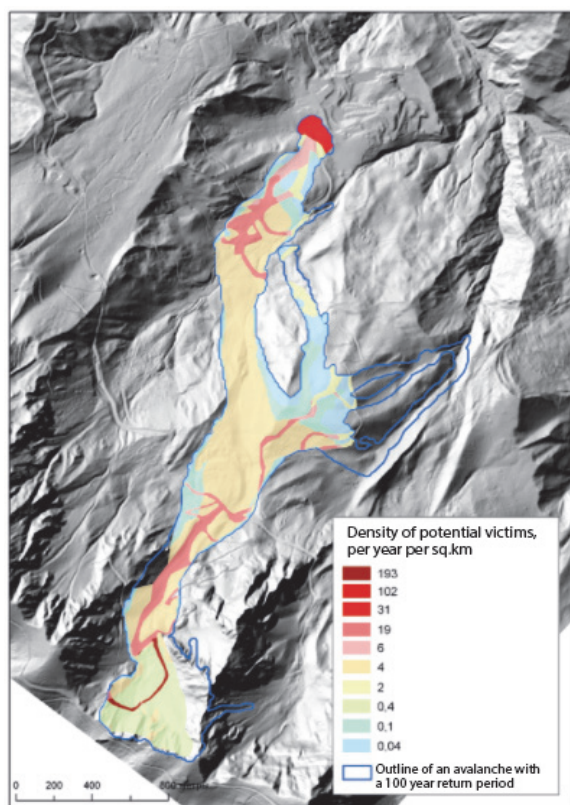


Figure 2 The map, presenting number and distribution of potential avalanche victims per square kilometer of zones in Rosa Khutor ski resort. The red colors represent the most vulnerable areas according to the ratio of the number of victims to the area of zones.

Avalanche return period, years	Density of potential victims, people/km ²		
	Off-piste zone	Ski pistes zone	Recreational zone
1	4	193,4	0
10	0,4	19,3	0
30	0,1	6,4	102
100	0,04	1,9	31
All	1	20	34

Table 2 The density of potential avalanche victims within selected zones of Rosa Khutor ski resort. The highest value of 193 people per km² was calculated for the area of ski slopes exposed to avalanches of annual frequency

The values of individual avalanche risk (R_i) were calculated using the information on the actual attendance of resorts in 2016. The number of visitors was estimated as 180.000 people at Big Wood resort and as 750.000 people at the Rosa Khutor. Individual risk values were 2.1×10^{-5} and 9×10^{-6} , respectively.

5. CONCLUSIONS

The new approach to avalanche risk assessment in Russia was elaborated in The Research Laboratory of Snow Avalanches and Debris Flows, MSU. The new methodology is based on the results of previous investigations (Seliverstov et al., 2008; Shnyparkov et al., 2012; Komarov, 2016), but designed especially for the large-scale risk calculation within specific ski slopes, objects of infrastructure and their particular parts. It takes into account such parameters as the area of avalanche-prone territory, the duration of resort functioning during the year and the day, the number and distribution of visitors and infrastructure facilities within the study area, the configuration of trails etc. It makes possible to estimate the number of victims and the probability of an individual's death in avalanches of a certain return period within a certain territory.

Thus, it can be used to indicate the most vulnerable areas with the largest potential number of victims, and to suggest recommendations on the territory planning and assess the feasibility avalanche mitigation measures. The practical application of the methodology is relevant for research related to

the construction and protection of ski resorts and other facilities exposed to snow avalanches. The methodology can also be used to calculate changes in risk values depending on climatic and economic factors, as well as assess the effectiveness of avalanche mitigation measures and the work of avalanche service.

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