Multi-Hazard Analysis in Natural Risk Assessments

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Abstract

Analysis of natural risks in mountainous regions includes several typical natural processes such as snow avalanches, floods, earthquakes, and different types of landslides. Separate investigations of single processes only might lead to a misjudgement of the general natural risks for this areas. To avoid this trap, natural risk assessments should not focus on a singular process but on multiple processes. Within this study a general methodology is developed to analyse natural risk for multiple processes. The method is applied in Bíldudalur, NW-Iceland. In particular snow avalanches, rock falls and debris flows pose a hazard to the village of 300 inhabitants. The natural risk calculation is a function based on the input parameters hazard, vulnerability, probability of the spatial impact, probability of the temporal impact, probability of the seasonal occurrence and damage potential. First, the risk posed by each process is calculated. Results are presented as individual risk and object risk to life, and as economic risk for each process. Finally, single process risk maps are combined to multi hazard risk maps. In the study area the highest risks throughout all of the analyses (individual risk to life, object risk to life and economic risk) are caused by debris flows, followed by snow avalanches and rock falls. It is demonstrated, that risk varies heavily depending on the process considered. The total risk to life caused by snow avalanches, debris flows, rock fall and multi-hazards is 0.19, 0.63, 0.009 and 0.83 deaths per year, respectively. Multi-hazard approaches are not only valuable to get an overview on the overall risk but have also a high significance for planning effective countermeasures. It can be concluded that the newly developed method is applicable to other natural processes as well as to further catchments in Iceland as well as in other countries with different environmental settings.
Keywords: natural hazards, risk assessment, snow avalanches, debris flows, rock falls, Iceland

1 Introduction

"Society in general and individuals within it all face various risks. These cannot be eliminated, only reduced by applying additional resources. Furthermore, the reduction of risks from one hazard may increase risks from other hazards, and thus not be beneficial overall" [1].

The example of Gondo (Switzerland) demonstrates this very well. To mitigate rock fall hazard a combined wall/fence structure was build to collect falling rocks and prevent to threat the community of Gondo any longer. Unfortunately, on 14 October 2000 extreme precipitation triggered a debris flow, which, first, was caught by the rockfall mitigation structure, but later, the pressure caused by the debris flow material exceeded the withstand-power of the mitigation structure which then failed and released all material at once, taking with it the material of the structure and then moved into the village and destroyed several houses and caused 13 deaths. Without the rock fall mitigation structure the event potentially could have been less severe. This case shows that countermeasures against one hazardous process (here, rockfall) can increase the threat of another process (here, debris flow) [2]. Demands resulting from such a disaster are that multi-hazard risk assessments should be always carried out whenever possible and should include calculation under natural conditions as well as considering counter-measures.

Following these demands, a general methodology is developed to analyse natural risk for mutli hazards within this study. The method is applied in Bíldudalur, NW-Iceland, where in particular snow avalanches, debris flows and rock falls pose a threat to the village of 300 inhabitants.

2 Risk assessment

Usually, when natural disasters occur both environmental and human systems are involved. Natural events do not pose a threat to society or a community if the affected area is not used by people. Thus, holsitic concepts are necessary to analyse the complex interactions between these two systems and to find the "best" solutions for endangered areas adopted to local needs.

Hollenstein developed such a holistic concept to natural risks [3]. The entire risk assessment consists of three equal parts: risk analysis, risk evaluation and risk management. The main focus of each part is demonstrated by the questions given in Figure 1. For more details refer to [3; 9].

For specific risks, such concepts are provided by numerous authors, e.g. for landslide risk by [4 - 8].

Within this study, risk analysis alone is considered.

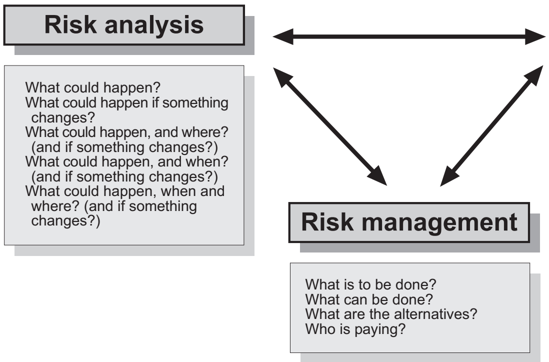

Figure 1: The holistic concept of risk assessment (based on [10; 11; 3; 12])

3 Study area “Bíldudalur”

The village Bíldudalur is located in the Westfjords in NW-Iceland (Figure 2a). Especially snow avalanches, debris flows, rock falls and slush flows pose a threat to the community (see [9] or [13] for more details). Within this study, only the former three could be investigated.

The Westfjords are characterized by a fjord landscape with typical u-shaped valleys. Extensive plateaus can be found on the top of the mountains, which rises up to 460m a.s.l. above Bíldudalur. The mountainside is dissected into two large gullies and several smaller ones in between (Figure 2b), followed by respective debris cones. The mild and maritime climate is characterized by cool summers and mild winters. Mean annual air temperature is 3°C and annual precipitation ammounts to approximately 1250mm. The lithology consists of various basaltic layers, which are nearly horizontal bedded. Periglacial, gravitational and fluvial processes are dominating the study area (for more details refer to [9] or [13]).

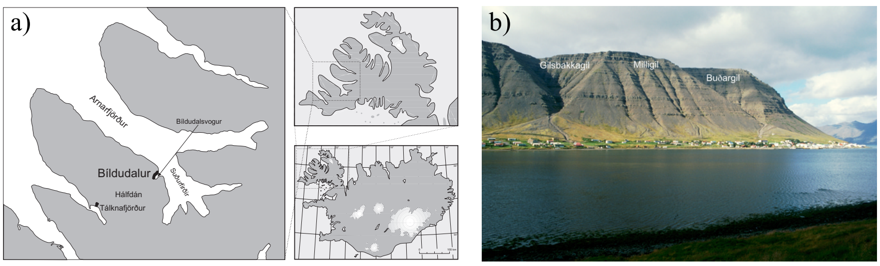

Figure 2: Study area Bíldudalur - a) location, b) photography from opposite Fjord border, view towards the north

4 Methodology

Within this study, a new raster based approach on a regional scale was developed based on recent approaches to risk analysis [14; 11; 6; 15; 16]. The approach consist of the following steps: scope definition, hazard identification, hazard analysis, consequence analysis and risk calculation.

The calculation of the natural risk follows a function of the input parameters hazard (H), vulnerability (of people (V_{pe}), property (V_p), infrastructure (V_{str}) and powerline (V_{po})), probability of the spatial impact (P_s), probability of the temporal impact (P_t), probability of the seasonal occurrence (P_{so}) and damage potential (number of people (E_{pe} or E_{ipe}), economic value (E_p)). First, the risk posed by each process is calculated. Results are presented as individual risk and object risk to life, and as economic risk for each process. Finally, single process risk maps are combined to multi-hazard risk maps. A detailed description of the methodology in general and for debris flows and rock falls in particular is given in [9].

For snow avalanches more information must be provided. Snow avalanche risk analysis is based on a preliminary snow avalanche hazard map created by Siegfried Sauermoser, who applied Austrian guidelines to delineate hazardous areas. Two different hazard zones resulted: a red hazard zone and a yellow zone. The border of the red hazard zone is defined as a snow avalanche with a return period of 150 years exceeding an impact pressure of 10 kN/m² (until recently the threshold was 25 kN/m²) or as a snow avalanche with a return period of 10 years on the average. The border of the yellow hazard zone is defined as a 150 year event exceeding an impact pressure of 1 kN/m² (Sauermoser 2002, personal communication).

Figure 3 shows the methodological concept of multi-hazard analysis including the respective formulas to calculate the individual risk to life, the object risk to life and the economic risk.

5 Results

5.1 Hazard identification and analysis

Snow avalanches, debris flows and rock falls pose threats to people, properties and infrastructure along the whole length of the village. The highest snow avalanche and debris flow hazards exist below the two large gullies (refer to figure 2b). However, also the smaller catchments in between these two large gullies are active. Recently more but smaller debris flow events were triggered from these small gullies. Regarding rock falls field investigations show that the most north-eastern part is most active, while the largest boulder could be found below the gully Gilsbakkagil. More detailed information on debris flows and rock falls is given in [9].

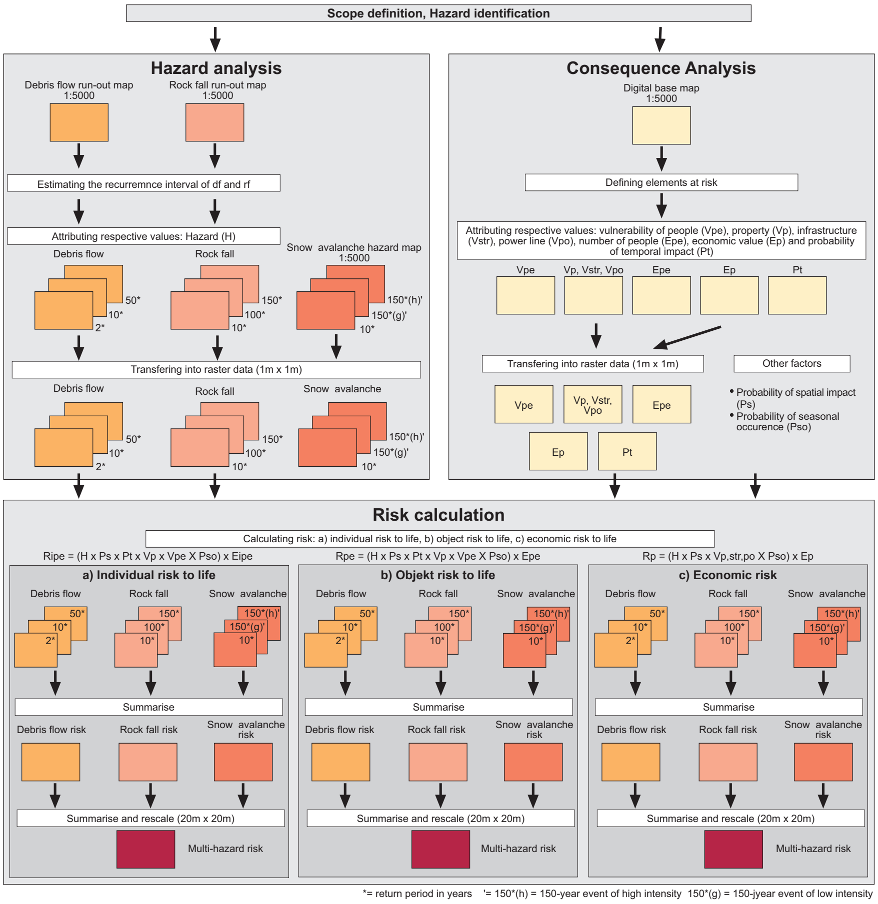

Figure 3: Methodological concept of multi-hazard analysis

5.2 Consequence analysis

The spatial pattern of the economic value of the elements at risk is given in Figure 4. As detailed data is confidential, following four classes were defined: very low (0-36€/m²: 16 buildings and the power line), low (>36-480€/m²: roads, infrastructure and 45 buildings), medium (>480-960€/m²: 72 buildings), high (>960-1440€/m²: 26 buildings) and very high (>1440€/m²: 13 buildings). The spatial pattern of residents and employees is given in [9].

The vulnerability values are determined based on the process and its magnitude (debris flow and rock fall) or hazard (snow avalanches). Values used are presented in table 1.

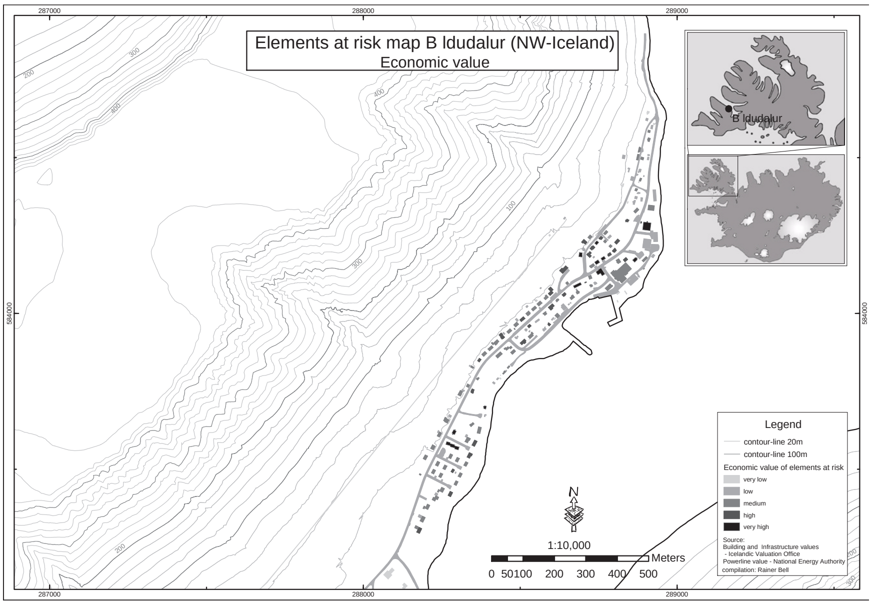

Figure 4: Elements at risk map – economic value

Table 1: Vulnerability values used within this study (Note: V_{po} = vulnerability of the power line, V_{str} = vulnerability of roads and infrastructures, V_p = vulnerability of properties, V_{pe} = vulnerability of people and V_{pep} = vulnerability of people in buildings, high(1) = 10 year event of high hazard class, high(2) = 150 year event of the high hazard class)

Magnitude	*low*					*medium*					*high*				
Process	V_{po}	V_{str}	V_p	V_{pe}	V_{pep}	V_{po}	V_{str}	V_p	V_{pe}	V_{pep}	V_{po}	V_{str}	V_p	V_{pe}	V_{pep}
Debris flow	1.0	0.2	0.1	0.2	0.02	1.0	0.4	0.2	0.3	0.06	1.0	0.6	0.5	0.5	0.25
Rock fall	1.0	0.1	0.1	0.2	0.02	1.0	0.2	0.3	0.4	0.12	1.0	0.4	0.5	0.5	0.25
Hazard	*low*					*high(1)*					*high(2)*				
Process	V_{po}	V_{str}	V_p	V_{pe}	V_{pep}	V_{po}	V_{str}	V_p	V_{pe}	V_{pep}	V_{po}	V_{str}	V_p	V_{pe}	V_{pep}
Snow avalanche	1.0	0.3	0.3	0.5	0.15	1.0	0.1	0.3	0.1	0.03	1.0	0.8	1.0	1.0	1.0

Applied values for the probability of spatial impact are shown in table 2. As the hazards map show, even large debris flows or snow avalanches would not affect the whole settlement. Therefore, low values were estimated.

Regarding the probability of temporal impact (i.e. of the building being occupied given an event), for residential houses 18h a day was chosen, whereas for companies and the school a common value is 9-10h a day.

Since snow avalanches only occur in winter times the probability of seasonal occurrence is set to 0.5. For debris flows and rock falls the factor 1 is chosen due to the fact that both processes can occur during the whole year, as historical records demonstrate.

Table 2: Probability of spatial impact of each process dependant on its magnitude or hazard (Note: within snow avalanches, high(1) refers to the criterion of the event with a return period of 10 years and high(2) is related to the 150 year event. As stated in chapter 4 low hazard refers also to the 150 year event but with a lower impact pressure. Since the 10 year event refering to high(1) hazard is supposed to be smaller than the 150 year event refering to low hazard, the lowest value is chosen for high(1) hazard.)

Magnitude Process	*low*	*medium*	*high*
Debris flow	0.1	0.2	0.3
Rock fall	0.01	0.01	0.02
Hazard Process	*low*	*high(1)*	*high(2)*
Snow avalanche	0.3	0.2	0.5

The final individual risks to life, object risks to life and economic risks due to snow avalanches, debris flows, rock falls and multi-hazards are summarised in Table 3. The total risk to life caused by snow avalanches, debris flows, rock fall and multi-hazards is 0.19, 0.63, 0.009 and 0.83 deaths per year, respectively. Figure 5 presents the economic risks posed by multi-hazards.

Table 3: Individual risk to life, object risk to life and economic risk in Bíldudalur

	Unit	**risk value**		**% per risk class**			
Risk type		min	max	very low	low	medium	high
individual risk to life				*<0,3*10^-4^*	*0,3 - <1,0*10^-4^*	*1,0 - <3,0*10^-4^*	*>3,0*10^-4^*
snow avalanche	r/a	5.6×10^{-5}	1.6×10^{-3}	0.00	33.53	26.47	40.00
debris flow	r/a	5.7×10^{-4}	2.8×10^{-3}	0.00	0.00	0.00	100.00
rock fall	r/a	1.1×10^{-5}	5.6×10^{-5}	7.80	92.20	0.00	0.00
multi-hazard	r/a	5.7×10^{-5}	4.4×10^{-3}	0.00	0.00	7.08	83.63
object risk to life				*<0,3*10^-4^*	*0,3 - <1,0*10^-4^*	*1,0 - <3,0*10^-4^*	*>3,0*10^-4^*
snow avalanche	r/a	6.3×10^{-5}	2.9×10^{-2}	0.00	14.72	21.18	64.12
debris flow	r/a	6.3×10^{-4}	7.8×10^{-2}	0.00	0.00	0.00	100.00
rock fall	r/a	2.1×10^{-5}	1.6×10^{-3}	4.26	26.95	57.45	11.35
multi-hazard	r/a	6.3×10^{-5}	8.2×10^{-2}	0.00	4.42	3.10	92.48
economic risk				*<3.6*	*3.6 - <9*	*9 - <18*	*>=18*
snow avalanche	€/m²/a	0.024	9.84	4.26	26.95	57.45	11.35
debris flow	€/m²/a	0.24	26.52	42.09	46.28	9.77	1.86
rock fall	€/m²/a	0.0036	0.22	100.00	0.00	0.00	0.00
multi-hazard	€/m²/a	0.036	33.84	50.67	24.38	21.69	3.26

6 Discussion

Final results show that snow avalanches, debris flows and rock falls pose partly serious threats to the community of Bíldudalur.

The highest risks by far throughout all of the analyses (individual risk to life, object risk to life, economic risk) are caused by debris flows, followed by snow avalanches and rock falls. The low return periods of 2, 10 and 50 years of the debris flows lead mainly to the high debris flow risks. Further investigations are necessary to improve the reliability of the return periods (e.g. sediment supply rates must be defined in detail, see [9] and [17] for more details). The calculated risk in relation to snow avalanches seems to be more reasonable, since higher recurrence intervals were applied in the hazard map and in the risk calculations. Rock falls are very local phenomena. Thus, the probability of spatial impact is very low, causing relatively low values of rock fall risks. However, this does not mean that rock falls might not cause economic damage or fatalities in the study area.

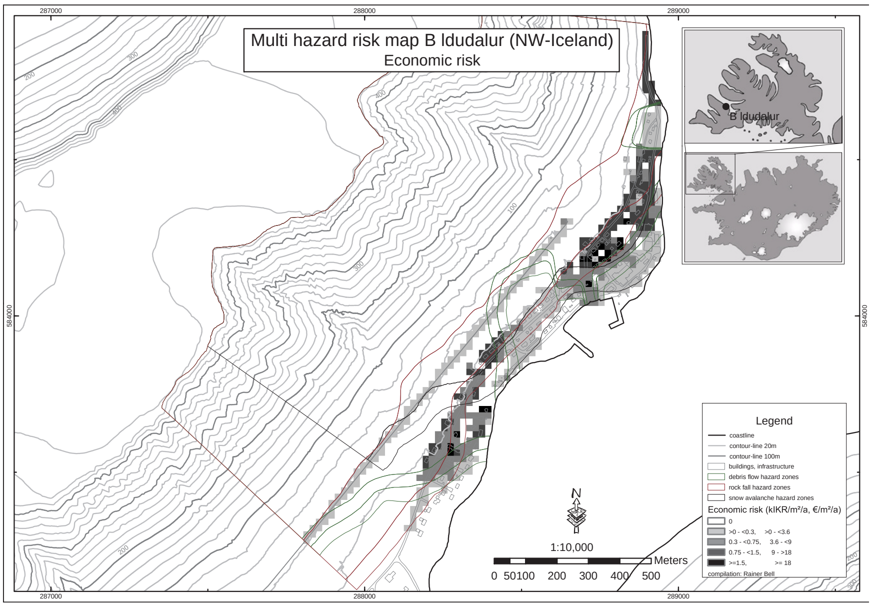

Figure 5: Multi-hazard risk map – economic risk

The multi-hazard risks give an indication of the overall risk posed to the community. Multi-hazard approaches are not only valuable to get an overview on the overall risk but have also a high significance for planning effective countermeasures. To avoid the trap of reducing risks from one hazard, but increasing risks from other hazards, as shown by the example of Gondo, multi-hazard analyses should be more often applied within natural risk assessments.

It can be concluded that the newly developed method is applicable to further processes as well as to further catchments in Iceland, but also to other countries with different environmental settings.

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