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Automated Risk Mapping for Buildings Endangered by Natural Hazards

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INTRODUCTION

Natural hazards can have severe economic and social consequences, cutting off settlements, wiping out entire towns, destroying homes and lives. The past decades have seen an increasing natural disaster cost (Riebeek 2005) and - perhaps as a result of this - a change in attitude concerning natural hazard risk management. Many societies have adopted the mentality that it is generally less costly to prevent a disaster rather than to pick up the pieces afterwards (Grossi and Kunreuther 2005). This is especially the case in more-developed countries, where a strong risk-averse culture has taken root (Smith 2013). Often authorities attempt to manage risk by limiting construction in dangerous areas but the question remains of what to do with already existing, endangered structures. Hazard and risk experts are called upon to identify and assess hazards, to appraise endangered assets and estimate the prevailing risk. Based on this preliminary work, an appropriate course of action such as the erection of mitigation measures may be decided upon. For these tasks, risk maps are very valuable tools, giving visual overviews, helping experts make decisions and communicate information. This is why visualizing and mapping risk has become an indispensable part of risk management (Van Westen 2013).

Today, risk mappers have at their disposal a variety of software products to aid them in their task, starting with universal GIS tools all the way to risk-specific instruments such as the New Zealand project *Regional RiskScape* (Schmidt et al. 2011), the US ArcGIS-based tool HAZUS (Schneider & Schauer 2006) and the Australian natural hazards database PerilAUS (Risk Frontiers n.d.). However, we found that such mapping tools dedicated to visualizing risk are scarce, often tailored to fit hazard and/or country specific situations and are sometimes dependent on commercial GIS products. In particular, we identified the need for a risk mapping tool which can address mountain natural hazards. Mountain areas are inherently subjected to multiple hazards such as avalanches, debris flows, floods and rockfalls. Additionally, mountain areas have limited space suitable for settlements, which often forces expanding towns into hazard-prone terrain.

The SLF-developed program RAMMS presented itself as the ideal framework for this risk mapping project: RAMMS can simulate snow avalanches, debris flows, hillslope debris flows and rockfall events in three-dimensional terrain (Christen et al. 2012), thus giving powerful

support to professionals in natural hazard assessment. In RAMMS we implemented a new module called RAMMS::RISK, which estimates risk quantitatively and automates risk mapping for buildings in an easy and appealing way. RAMMS::RISK resolves risk analysis down to individual buildings and can assess the following hazards: avalanche, rockfall, rock slide, deep-seated and shallow landslides, debris flow, static and dynamic floods.

In this paper we will give a brief outline of RAMMS::RISK's architecture, what functionalities it offers and how it performs in an avalanche case study.

METHOD

RAMMS::RISK

RAMMS::RISK was programmed using IDL (EXELIS 2014) and was built into the already existing framework of RAMMS (Christen, Kowalski & Bartelt 2010). In this module, two main features are new to the otherwise familiar RAMMS interface: A special cursor mode was implemented to query asset attributes directly in the map, while a *Risk* tab contains the entire rest of the risk functionalities specific to this module (see Fig. 1).

The *Risk* tab is the heart of RAMMS::RISK. It envelopes the *Scenario* tab, where the risk calculation results are summarized (as shown under 7 in Fig. 1), as well as the *Classification* and *Selection* tabs, which provide the means to spatially analyze the data.

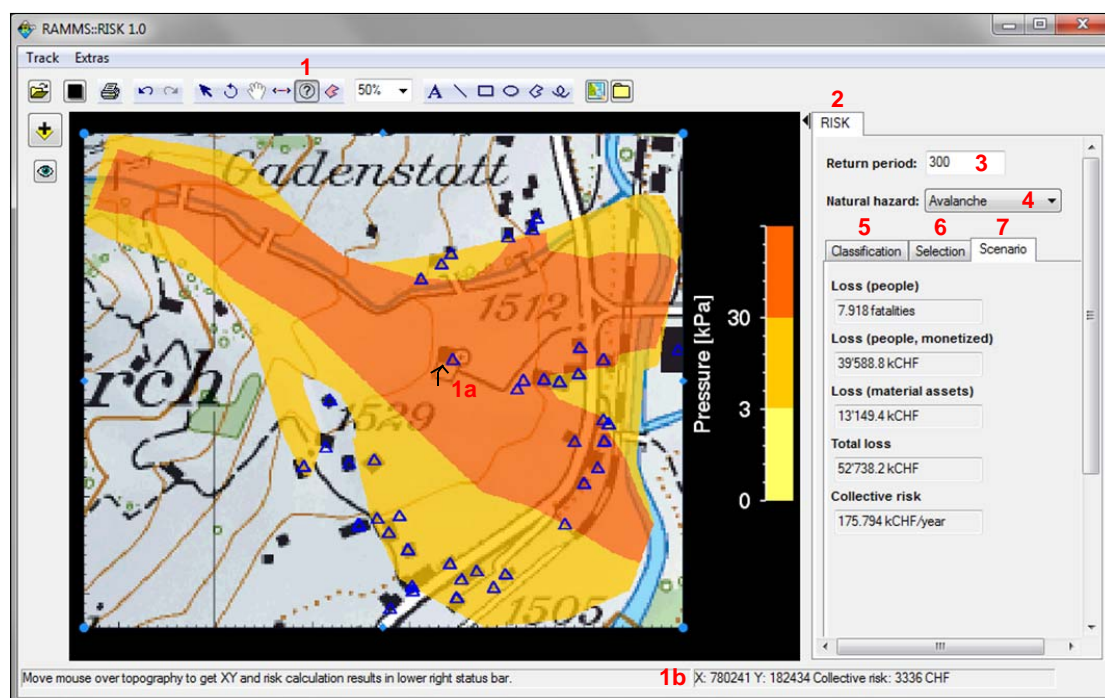


Fig. 1: The RAMMS::RISK user interface: a special cursor mode (1) to query asset attributes directly in the map (1a, 1b) and the Risk tab (2), containing information on the scenario's return period (3), the type of natural hazard (4), the risk calculation results (Scenario tab (7)), and the rest of the risk analysis functionalities (Classification (5) and Selection tabs (6)). Scenario: 300-yearly avalanche prior to mitigation measures, Davos Frauenkirch. Topographical map: pixmaps © 2014 swisstopo (57 04 000 000).

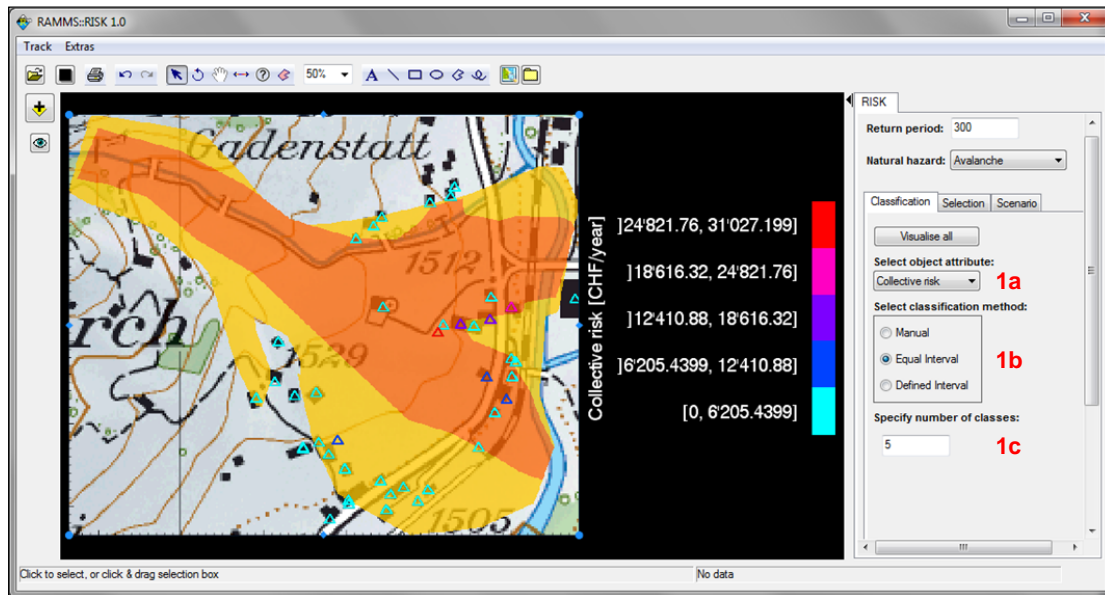


Fig. 2: Demonstration of the classification functionality: The buildings (triangles) are grouped in five classes according to their collective risk (1abc). Only seven buildings fall into the top four risk classes. Scenario: 300-yearly avalanche prior to mitigation measures, Davos Frauenkirch. Topographical map: pixmaps © 2014 swisstopo (57 04 000 000).

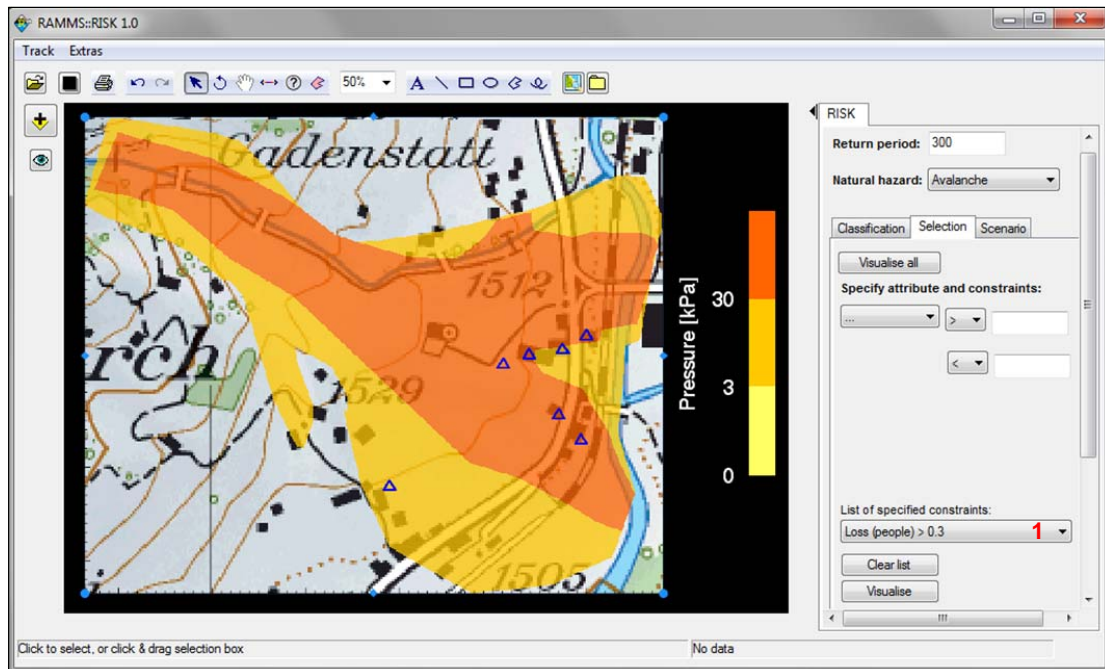


Fig. 3: Demonstration of the selection functionality: All buildings with a loss of lives greater than 0.3 deaths (1) are shown as blue triangles (same buildings with highest overall risk as shown in Fig. 2). Scenario: 300-yearly avalanche prior to mitigation measures, Davos Frauenkirch. Topographical map: pixmaps © 2014 swisstopo (57 04 000 000).

Tbl. 1: An overview of required and optional RAMMS::RISK input files

Input	Importance	Format	Content	See also...
Intensity map	required	georef. ASCII (e.g. RAMMS simulation)	intensity information header with spatial and data-specific information	Appendix Fig. 4
Asset information	required	CSV or SHP	buildings to be considered in the risk analysis <i>required attributes:</i> <ul style="list-style-type: none"> • type of building • coordinates • cost of building <i>optional but risk-relevant attributes:</i> (EconoMe default values used if absent) <ul style="list-style-type: none"> • occupancy (average no. of people present in building) • presence factor (average portion of day which building is occupied) <i>optional attributes:</i> any, e.g. building material, year of construction	Appendix Fig. 5
Topographical map, orthophoto	optional	georef. TIFF	image to aid spatial analysis	-

Classification allows the user to distinguish between groups of buildings according to their attributes (see example in Fig. 2). Quantitative attributes can be split into groups using one of three classification methods: *manual* calls for a manual definition of class boundaries, *equal interval* divides the data range into a specified number of intervals of the same length and *defined interval* creates classes according to a specified interval size. Qualitative attributes are classified by selecting the attribute values which are of interest from a list. In the map the various classes are distinguished by different colors.

As the name suggests, the *Selection* tab is designed to highlight those buildings which fulfill certain selection criteria (see example in Fig. 3). Values and ranges are defined for one or more attributes. Only those buildings which satisfy all the specified conditions are finally displayed in the map.

In order to calculate and display risk, RAMMS::RISK requires several input files, which are described in Tbl. 1. The tool calculates risk adhering to the methodology implemented in EconoMe, an IT tool provided by the Swiss Federal Office for the Environment to evaluate the cost-benefit ratio of natural hazard mitigation measures (FOEN n.d.). The structure of EconoMe, the risk concept behind it and the formulas used to calculate risk are described in detail in Bründl (2012) and Bründl et al. (2009). RAMMS::RISK is programmed to display results in Swiss Francs but any other currency may be used.

Case Study

Although mountains are the stage for various types of natural hazards, winters are generally dominated by only one: avalanches. To demonstrate the layout and functionalities of RAMMS::RISK with a concrete example, a well-documented avalanche case study, assessed by a team of avalanche and risk experts, has been calculated in our risk mapping

tool. The case study is based on an expertise¹ drawn up for the settlement of Davos Frauenkirch following the disastrous winter of early 1999. Also called the avalanche winter of 1999, this season was characterised by heavy snowfalls throughout the alps, resulting in countless avalanches and claiming 17 lives in buildings and on traffic routes in Switzerland alone (Wiesinger & Adams 2007). The Frauenkirch expertise encompasses intensity maps for various scenarios and a complete survey of the endangered assets. Based on this expertise, mitigation measures were later implemented.

Since the intensity maps developed for the Frauenkirch expertise were readily available to us, we used these as the intensity input for our case study instead of reproducing them with RAMMS simulations. In these intensity files, only areas of medium and high intensity were distinguished (see also Fig. 1, Fig. 2 and Fig. 3).

The building insurance of the canton of Grisons kindly supplied a dataset of georeferenced buildings for the municipality of Davos Frauenkirch including building values. Asset information of this dataset was verified by field work. Occupancy and presence factors were estimated for all buildings according to the Frauenkirch expertise.

The Swiss national map 1:25000 no. 1197 Davos was used as a topographical map.

RESULTS AND DISCUSSION

The RAMMS::RISK calculations for the evaluated scenarios are summarized in Tbl. 2 and Tbl. 3. As shown in Tbl. 3, these results are of the same order of magnitude as the calculations made for the Frauenkirch expertise. Discrepancies result mainly from different risk calculation methodologies (expertise: Borter (1999), case study: Bründl et al. (2009)) and the updated asset cadaster used for this case study.

Tbl. 2: RAMMS::RISK calculations for three avalanche scenarios (return periods) in Davos Frauenkirch prior to mitigation measures

<i>Risk and loss calculations</i>	<i>30 yrs</i>	<i>100 yrs</i>	<i>300 yrs</i>
Loss (people) [fatalities]	0.1	7.5	8
Loss (people) [kCHF]	504	37'165	39'589
Loss (assets) [kCHF]	372	12'770	13'149
Total loss [kCHF]	876	49'935	52'738
Collective risk [kCHF/year]	29	499	176

Tbl. 3: Comparison of calculations for the avalanche risk situation in Davos Frauenkirch prior to mitigation measures

<i>Method</i>	<i>Risk of death [fatalities/year]</i>	<i>Collective risk [kCHF/year]</i>
RAMMS: :RISK	0.08	704
Frauenkirch expertise	0.07	500

Although RAMMS::RISK clearly delivers credible results, manual validation of the calculations has shown that the tool makes some classification mistakes because RAMMS::RISK considers assets (buildings) as point objects. If this median point of the

¹ The expertise is not available to the public. For more information on the data drawn from this expertise please contact the corresponding author.

building is located outside an intensity zone, the building is not considered for risk calculations pertaining to this zone, even if the building lies partly within it. A polygon-based approach would, however, be very complex, especially with regards to the required input data.

Two examples of possible spatial risk analyses with RAMMS::RISK are shown in Fig. 2 and Fig. 3. Fig. 2 makes apparent, that the buildings with the highest collective risk (ca. 6'200 CHF/year and higher) are not necessarily affected by high intensity (orange intensity zone). Fig. 3 shows that the high collective risk of these seven buildings is connected with their high loss of human lives. Thanks to the highly specialized nature of RAMMS::RISK, identifying patterns such as these is made possible with little effort or software training.

CONCLUSIONS

RAMMS::RISK is an easy-to use risk mapping tool, which runs independently of commercial GIS products and is designed to be used internationally. The risk module provides the means to assess the risk posed by a multitude of natural hazards. RAMMS::RISK offers different spatial analysis tools to explore and understand the risk situation: attributes can be queried from each building directly in the map, buildings may be grouped into classes by different methods and attributes, and assets fulfilling certain selection criteria specified by the user can be highlighted in the map.

Using a well-documented expertise as an input case study we have been able to show that RAMMS::RISK provides reasonable risk estimations. The user must, however, be aware that the tool cannot reproduce or predict reality, but merely provides an estimate of the natural hazard risk. Also, the results can only ever be as good as the input; an intensity map verified by experts as well as accurate and detailed asset information are key to a sound risk analysis. Finally, interpretation of the results requires expertise and critical thinking, which cannot be provided by the mapping tool itself.

RAMMS::RISK is still at a prototype stage, requiring additional features such as the inclusion of traffic routes as well as rigorous testing. However, we believe that RAMMS::RISK's non-restrictive design and its basic risk analysis functions will be a support to decision-makers in natural hazard risk assessment everywhere.

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APPENDIX

```
ncols      444
nrows     358
xllcorner 779882.4355
yllcorner 182281.6828
cellsize   1
NODATA_value -9999
-9999 -9999 0.518 2.870 6.624 10.768
```

Fig. 4: Header and excerpt from an intensity map ASCII file (fictional). *ncols*, *nrows*: number of columns and rows, *xllcorner*, *yllcorner*: coordinates of the map's lower left corner, given in Swiss grid coordinates (national survey 1903), *cellsize*: size of ASCII grid cells, *NODATA_value*: value used to show that no data is available for a particular cell

```
BUICODE, LONGITUDE, LATITUDE, COST, USE, BUIMAT
87,781500.663,179619.903,1211700.00,residential,mixed
2,781506.474,179641.694,628100.00,barn,wood
4,781519.604,181822.992,50500.00,garage,brick
2,781611.071,179695.445,423800.00,barn,wood
1,781833.314,183196.948,590300.00,residential,brick
```

Fig. 5: Excerpt from a CSV file containing asset information (fictional) with the four mandatory attributes type of building (using the EconoMe buildings code), coordinates and cost of the building as well as two optional attributes (use of the building and building material). Building codes: 1=one-family house, 2=barn, 4=garage, 87=multi-family house