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ORIGINAL PAPER

Monitoring the temporal development of natural hazard risks as a basis indicator for climate change adaptation

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Abstract The potential effects of climatic changes on natural risks are widely discussed. But the formulation of strategies for adapting risk management practice to climate changes requires knowledge of the related risks for people and economic values. The main goals of this work were (1) the development of a method for analysing and comparing risks induced by different natural hazard types, (2) highlighting the most relevant natural hazard processes and related damages, (3) the development of an information system for the monitoring of the temporal development of natural hazard risk and (4) the visualisation of the resulting information for the wider public. A comparative exposure analysis provides the basis for pointing out the hot spots of natural hazard risks in the province of Carinthia, Austria. An analysis of flood risks in all municipalities provides the basis for setting the priorities in the planning of flood protection measures. The methods form the basis for a monitoring system that periodically observes the temporal development of natural hazard risks. This makes it possible firstly to identify situations in which natural hazard risks are rising and secondly to differentiate between the most relevant factors responsible for the increasing risks. The factors that most influence the natural risks could be made evident

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and eventual climate signals could be pointed out. Only with this information can the discussion about potential increases in natural risks due to climate change be separated from other influencing factors and be made at an objective level.

Keywords Integral natural hazards and risk management · Climate change adaptation · Risk analysis

1 Introduction

The management of natural hazards has a long tradition in Austria and in the Alps. For a decade, the former practice of managing floods, debris flows, avalanches, rock falls and landslides has been more or less transformed into a practice of integrated risk management. Integrated risk management is the process of finding the most efficient solutions and combinations of measures for risk reduction throughout all phases of risk management (prevention, intervention and restoration). The focus in natural hazard management has shifted from the construction of protective measures as the principal solution to the defence against natural hazards to a more holistic approach, which views risk management as integrating a variety of individual but coordinated activities from different disciplines and different administrative levels (Zischg 2010). One principle of integrated risk management is the consideration of the results of quantitative risk analysis and therefore risk-based decision-making.

The risk resulting from natural hazards is defined as a quantifying function of the probability of occurrence of a dangerous process and the related degree of damage. The latter is specified by the damage potential and the vulnerability of the endangered object (United Nations 2004).

$$R_{i,j} = p_{Si} \cdot A_{Oj} \cdot p_{Oj,Si} \cdot v_{Oj,Si}$$

According to the United Nations (2004) definition, the specifications for the probability of the defined scenario (p_{Si}), the monetary value of the object affected by this scenario (A_{Oj}), the probability of exposure of object *j* to scenario *i* ($p_{Oj,Si}$) and the vulnerability of object *j* in dependence on scenario *i* ($v_{Oj,Si}$) are required for the quantification of risk ($R_{i,j}$).

The risks induced by natural hazards change over time with the changing environment (Keiler et al. 2006; Fuchs et al. 2005). On the one hand, the probability of occurrence and the magnitudes of natural hazard processes may be altered by the effects of climate change. These effects vary remarkably between process types and between specific local situations (Keiler et al. 2010). Whereas the effects of rising temperatures on natural hazard processes related to glacier and permafrost degradation may be identified and constrained locally, the effects of climate change on precipitation and, therefore, on precipitation-related processes are more difficult to assess. The occurrence probability of natural hazard processes related to precipitation, such as floods, debris flows and avalanches, is expected to increase (Frei et al. 2006; Caspary 2004). Other analyses point out a possible decrease in the occurrence probability of debris flows depending on their type of sediment delivery for transportation (Staffler et al. 2008; Jomelli et al. 2004, 2007). While the direct effects of climate change on natural hazard processes can be assessed and monitored, indirect effects or feedbacks in process chains are less well known (Keiler et al. 2010). In mountainous areas, natural hazard processes are strongly influenced by the topographical, geological and microclimatological conditions and evolve in a downward slope from the headwater catchment area towards the floodplain areas. This means that natural hazard processes in the flood plains are influenced by processes in higher areas. This interrelation depends on the characteristics of transport processes and leads to a high spatial and temporal variability in the domain of natural hazard processes (Keiler et al. 2010; Staffler et al. 2008). The topographical, climatical and geomorphological diversity of the Alps require a locally differentiated view of the potential effects of climatic changes on natural hazards. There will be areas likely to be affected by natural hazards related to climate change, and there will be others without any changes in the actual natural hazard situation (Staffler et al. 2008).

Besides the probability of occurrence and the intensity of potential natural hazards that can be affected by climatic changes, the extent of damage and the vulnerability of endangered objects also affect the level of risks (e.g., Fuchs et al. 2007). In comparison to the potential effects of climate change on natural hazards, the latter parameter of the risk formula affects the resulting risks more significantly. Economic development leads to the spread of settlements and infrastructure towards endangered zones. At the same time, the values of houses and goods and the requirements for mobility are increasing (Keiler 2004; Keiler et al. 2005). The functioning of local economies is based on the functioning of infrastructures for transport, communication, water provision and electricity supply. This leads to an increased dependency of human activities on the continuous functioning of infrastructures and, therefore, to an increase in vulnerability to the effects of natural hazards. Society's demand for absolute safety in the area of natural hazards is increasing while, at the same time, individual responsibility is increasingly denied (Fuchs 2009; Zischg 2010). The increasing demands for higher safety standards will also put greater pressure on public finances.

Due to the dimensionality and the aggregation of these trends in increasing natural hazard risks, the practice of risk management in general has to be adapted to these new situations and the challenges must be faced by the relevant stakeholders (PLANALP 2010). The resulting rapid changes in both the number of exposed people or values of goods and the changing characteristics of natural hazards due to climate change require a new approach to managing this complex system of risk and safety. Although the effects of climate change are only one of several factors influencing natural hazard risks, they should be monitored and evidenced. But this factor has to be considered separately from the others. At the moment, the common agreement in natural hazard risk management practice is to avoid a general consideration of simplified effects of climate change on natural hazards equally over wide areas without any local differentiation. The common agreement of most relevant stakeholders in natural hazard risk management in the Alps is to monitor the further development of natural hazard risks influenced by climate change. And in cases where the effects of climate change on a specific risk situation become evident or can be reliably assessed, these effects are faced by an integrated risk management approach (Greminger and Zischg 2011). A general update of hazard zone maps over large areas on the basis of today's climate projections is not considered.

The monitoring of the long-term development of natural hazard risks requires a monitoring system that is able to differentiate between the main factors influencing the risks. The pre-condition for the monitoring of the effects of climate change on natural hazard risks is the knowledge of the existing risks. The effects of climate change on the existing risk situation can only be quantified if existing risks in the whole study area are known.

The main aim of this work was to elaborate a method for analysing and comparing natural hazard risks induced by different processes in a wider area. The method should meet the following requirements:

- the actual risks induced by floods, debris flows, avalanches, rock falls and landslides should be analysed on the basis of the existing data (hazard maps and land-use maps)
- the procedure should be able to analyse the natural hazard risks on a community level but the risks should be summarisable at the regional level (province)
- the procedure should highlight the communities in the study area with the highest values of natural hazard risks (hot spots)
- the procedure should make it possible distinguish between different factors influencing the risks (hazard-related or vulnerability-related factors)
- the procedure should be made on the basis of the methodological framework of risk analysis for cost-benefit analyses (binding guidelines for cost-benefit analyses in Austria), the damage functions and object-related vulnerability functions should be incorporated as variables that can be adapted to new findings
- the procedures should allow periodic updates and the analysis of the historic development of risks
- the results of the risk analysis should be visualised for the wider public

One aim of this study was to show which hazardous processes (floods, debris flows, avalanches, rock-fall processes and landslides) produce the most relevant exposure of people and property. This comparative analysis should provide the basis for pointing out the hot spots of natural hazard risks in the province of Carinthia (Bundesland Kärnten), Austria. The method should provide the basis for a control system that periodically observes whether the effects of climate change are increasing the risks of flooding.

2 Method

The achievement of the goals set requires a close collaboration between the various responsible institutions in the province of Carinthia. In Carinthia, the authority responsible for flood protection is the Department of Water Resources Management. The authority responsible for protection against torrential hazards and avalanches is the Torrent and Avalanche Control Service. The Department of Geology and Soil Protection is responsible for the management of rock fall and landslide threats. The Department of Land Use Planning is responsible for land use planning.

The first step towards the goals was the definition of a common dataset of object categories to be considered in exposure and risk analysis (elements at risk). The second step was the elaboration and compilation of datasets for the different natural hazard processes. On the basis of a dataset of elements at risk and subsequently compiled damage maps, an exposure analysis for all processes and a risk analysis for flood processes were made. The results of exposure analyses of individual single process types were compared, and the communities with the highest number of elements at risk have been pointed out. Finally, the results of this comparative analysis were prepared for visualisation and for use as a basis for communicating risks.

2.1 Definition of the classes of elements at risk

The European Water Framework Directive and the Guidelines for cost-benefit analyses in hydraulic engineering and in torrent and avalanche control (BMLFUW 2006a, 2008) define the classes of elements at risk that are to be considered in risk analyses. In general, this study followed the definitions for elements at risk in these guidelines with adaptations to local particularities, especially due to classification schemes of existing datasets. A catalogue of elements at risk was prepared for the whole region of Carinthia on the basis of existing datasets and without additional field work. The elaboration of the catalogue of elements at risk was supported by an interdisciplinary working group with people from different administrative units. The result of this work was a jointly accepted catalogue of elements at risk that have to be considered in the exposure and risk analyses of all relevant natural hazard types. The standardisation of the classes of elements at risk was one precondition to make exposure and risk analyses of different natural hazard processes comparable. The following classes of elements at risk were considered in exposure and risk analysis:

Buildings
Buildings with one domicile
Buildings with two or more domiciles
Buildings for apartment-sharing communities
Buildings with tourist functions
Industrial buildings
Public buildings
Schools or hospitals
Others
Infrastructure
Motorways
Main roads with regional function
Municipal roads
Secondary access roads
Bridges
Areas with industrial functions
Airports
Railways
Power stations and electricity substations
Sewage management infrastructure
Water supply infrastructure
Power lines
Gas supply stations and lines
Agriculture and forestry
Grassland
Farmland
Forest

There is a variety of different datasets in the study area that provide the databases to be used within a GIS-based analysis of the elements at risk. The datasets range from land-use maps, information systems for water resource management, roads and railways, to datasets of power- and water-supply companies. The procedure for the compilation of a database of elements at risk from many different datasets was combined into a software package that guarantees a standardisation of the procedure and saves time resources. Most of the existing datasets are suited for the compilation of the dataset of object categories for risk analysis. But in the study area at the moment, there is no specific dataset of buildings with attributes useable directly for risk analysis. The building categories therefore had to be extracted and classified combining two different datasets: (1) the land registry, without any information on the function of the buildings and (2) the dataset of the location of household addresses. These two datasets are not related and were provided from different institutions. The procedure takes the extent and the localisation of the buildings from the land registry, which contains only the surface area of the building itself. The classification of the functionality of the building was derived from the address dataset that is available as a point file. The point datasets of the addresses and of the schools were combined with the polygon datasets of the building layer. The attributes of the point layers were attributed to the polygon layer by means of different rules for spatial relationships. All address points related spatially to a building were used to classify the building itself. If a single address point of a private household falls into a single building or is situated in the vicinity of the building, then the building itself was classified as a domicile for one household. In cases where a building polygon is overlaid by more than one address point, the building was classified as multi-functional depending on the type of use. After classifying the functionality of each building, the next step was to attribute the number of residents or the number of workplaces to each building. The number of people and workplaces for each building were calculated on the basis of the Austrian statistics dataset. This provides information on the type of household and employment within grid cells with a resolution of 125 m. The total sum of workplaces and inhabitants of each grid cell of the statistics dataset was divided by the number of buildings of the respective functions within this raster cell. The resulting value was attributed to the individual buildings of each class of buildings. In cases where the grid cells indicate the number of workplaces, this number could be divided by the number of buildings with industrial functions.

2.2 Compilation of the hazard information

There are different datasets that can be used to describe information on natural hazard processes in the study area. Three different datasets exist for flood processes, and there are different datasets for rock falls, debris flows and landslides. There are hazard zone maps for flood hazards on the major rivers, which were elaborated following the guidelines for the hazard zone maps of the BMLFUW (2006b). The maps drawn up before 2006 show two classes of intensity of a flood event with a return period of 100 years. More recent maps differentiate between flood events with return periods of 30, 100 and 300 years. These maps consist of intensity maps for each of the selected scenarios and return periods. The hazard zone maps do not cover all areas. Hazard maps are being drawn up for the missing areas. Furthermore, a nationwide map of flood events of a return period of 30, 100 and 200 years (HORA, see http://www.wassernet.at/article/articleview/74694/1/13524/) is available. In areas where there are no regional authority hazard zone maps, the HORA flood hazard maps of an event with a return period of 100 years were considered for risk analysis. A simplified modelling procedure was used to map the extent of potential flood areas for a few areas where there are no hazard zone maps of the regional authority or HORA flood hazard maps. This procedure uses a digital elevation model to demarcate any areas that can be flooded due to the topographic condition. This does not consider the quantity of the discharge but defines all areas potentially affected by flooding from the main rivers. It was assumed that all rivers overflow their banks or breach the dams. The resulting map therefore does not contain any information on probability of occurrence or intensity. This map was used only for a small number of river reaches. For the other hazardous processes considered in the comparative exposure analysis, the existing datasets compiled to one harmonised map for each process. The hazard zone maps for torrential hazards were prepared by the Torrent and Avalanche Control Service following the Austrian guidelines (BMLFUW 2011). These hazard zone maps define the areas potentially affected by flood or debris-flow processes from torrential catchments of a return period of 150 years. The hazard zones are classified into two categories of process intensity. The same guidelines also describe the procedure for drawing up hazard zone maps for avalanches. The hazard zone maps of avalanches also consider a return period of 150 years and classify two categories of intensity. The hazard maps for rock fall and landslide processes were compiled and provided by the Department of Geology and Soil Protection. These hazard maps do not consider a certain return period or occurrence probability but classify the evident and potential hazard areas in three categories: potential hazard area, area with identified hazard and area with identified hazard of a high probability or intensity. One hazard map was compiled for each process type.

2.3 Comparative exposure analysis

In a further step, the catalogue of elements at risk was intersected with the hazard maps. The hazard information was attributed to the buildings dataset. The information of the process type, the related intensity class and the return period of the respective scenario were attributed to every single building. If a building was located on the border of two classes of hazard intensity, the intensity class with the higher grade was attributed to it. Afterwards, the number of exposed buildings was summarised at municipality level for each process type and intensity class. The other categories of elements at risk such as streets and infrastructure were intersected with all hazard maps of each process type. The units describing the quantity of the exposed elements were summarised at municipality level. This resulted in a table for each municipality that summarises the number of exposed objects or the length/area of all categories of the catalogue of elements at risk. The results of the exposure analysis for each process type were compared at municipality level.

2.4 Flood risk analysis

The analysis of flood risk was made on the BMLFUW (2006a, 2008) guidelines. These contain functions for the estimation of the damages on endangered objects. The risk analysis was made only for flood processes of the main rivers. The analysis of damage and risks due to torrential processes, avalanches, rock-fall processes and landslides was not made within this study but it is planned for the near future.

The damage to buildings was calculated using the following formula (1):

$$S = S_{\min} + 1000 * B * \sqrt{W} \tag{1}$$

where S is damage in €, $S_{\min}$ minimal damage in € and B factor depending on the functionality of the building. Damage in k€ with an inundation depth of 1 m (without $S_{\min}$), W water depth in m above floor level of the building.

The values of the parameters used for the calculation of the damages are described in Table 1. The water depths were extracted from the hazard zone maps. The transformation

Table 1 Parameters and their values used for the calculation of damages to buildings due to flooding

Functionality of the building	Smin cellar	B cellar	Smin ground floor	B ground floor
Buildings with one domicile	3,250	11.0	13,360	30.0
Buildings with two or more domiciles	2,800	11.0	11,800	29.0
Buildings for apartment-sharing communities	1,000	5.0	8,000	25.0
Buildings with tourist functions	10,000	20.0	20,000	62.5
Industrial buildings	12,000	21.3	26,000	216.0
Public buildings	12,000	21.3	30,000	168.8
Schools or hospitals	12,000	21.3	30,000	168.8
Others	1,000	8.0	7,000	20.0

of inundation water depths to the water depth above floor level of the building was made by using mean values for the factor *W*. The mean values were extracted from a reverse analysis of a detailed study in the catchment of the river Glan. For yellow hazard zones (low and medium intensity), a medium water depth above floor level of 0.15 m was assumed and for red hazard zones (high intensity) 0.77 m. A value of 0.16 m was used for the factor *W* to calculate flood damage on the basis of the HORA flood hazard maps.

We did not use a vulnerability factor to calculate damage on other classes of the catalogue of elements at risk because the existing hazard maps do not make it possible to deduce the required details of process intensity for the assessment of the vulnerability factor of infrastructures. For both intensity classes, we used medium damage values instead of the vulnerability factor. The values are shown in Table 2. The results of the risk analysis were summarised at communal and regional administrative level.

2.5 Visualisation of the results of the comparative exposure analysis and of the risk analysis for decision-makers and the wider public

The results of comparative exposure analysis and the flood risk analysis were summarised at municipal level and subsequently published on a website of the provincial authorities of Carinthia. A fact sheet showing the results of the comparative exposure analyses was prepared for each municipality (see Fig. 1). These fact sheets contain the most relevant information about the municipality with the characteristics of the different process types, the hazard maps, and the number of the exposed objects and the results of the flood risk analyses. The number of elements at risk of each hazard type (flood processes, debris flows, rock-fall processes and landslides) was visualised in tables and in summary charts or diagrams. The diagrams show the number of elements at risk of different categories. The results of the flood risk analysis are summarised in a table. For each category of the catalogue of elements at risk, the potential damage of a flood event with a return period of 100 years is summarised in the table. The comparison between potential damages of different categories of elements at risk is shown in common diagrams (see Fig. 2).

2.6 Combination into an information system for monitoring the temporal development of natural hazard risks

The procedure for the comparative exposure analysis and the flood risk analysis was combined into the information system of the Carinthian provincial authorities. This system

Table 2 Mean values of damage to infrastructure due to flooding

Element at risk	Unit	Value
Motorways	€/m	2575
Main roads with regional function	€/m	527
Secondary access roads	€/m	527
Municipal roads	€/m	527
Bridges	€/m	16000
Railways	€/km	3.51
Power stations and electricity substations	€	10,000.00
Sewage infrastructure management	€	10,000.00
Water supply infrastructure	€	10,000.00
Electricity lines 20 kV	€/m	149
Electricity lines 110 kV	€/m	702
Grassland	€/m^2	2453
Farmland	€/m^2	3271

includes all relevant information for the procedure, either as static maps or periodically updated maps. The hazard zone maps are updated regularly after a period of 10–15 years. If significant system changes that influence either the probability or the intensity of hazard processes occur, the hazard zone maps will be updated, for example, after significant system changes due to the effects of climate change or due to the construction of protection measures.

3 Results

The result of the approach is a database with the information about the numbers of elements at risk for different process types and the potential damages of a flood event with a return period of 100 years. The information can be queried at local level (hazard zone), at a communal or regional level. The database provides an overview of the expected damages or losses. It allows the aggregation of data on different levels and provides the basis for a comparative analysis of the risks in the municipalities of Carinthia. The summarised data are presented in the form of fact sheets on the internet. These fact sheets for each municipality highlight the critical hazards in their territory.

The comparative exposure analysis shows the spatial distribution of the elements at risk exposed to the different process types within Carinthia and highlights the municipalities with the highest number of exposed buildings, people and infrastructure. It shows that the municipalities in the valleys of the study area are mostly affected by flood and debris-flow processes on the alluvial fans. The municipalities with the highest number of elements at risk are located in the wider flood plains potentially affected by flooding. These risks are concentrated within a few municipalities (see Fig. 3). In total, more than 52,000 inhabitants are potentially affected by a flood event with a return period of 100 years in the study area. Almost 50% of the total number of inhabitants affected by flood processes are located in two municipalities. Totally, of 35,455 buildings are potentially exposed by flood processes. This is 14% of the total building stock. The comparison between the number of elements at risk exposed to the different process types shows a high variability (see Fig. 3). In comparison to flood processes, torrential processes (debris flows and flood process of

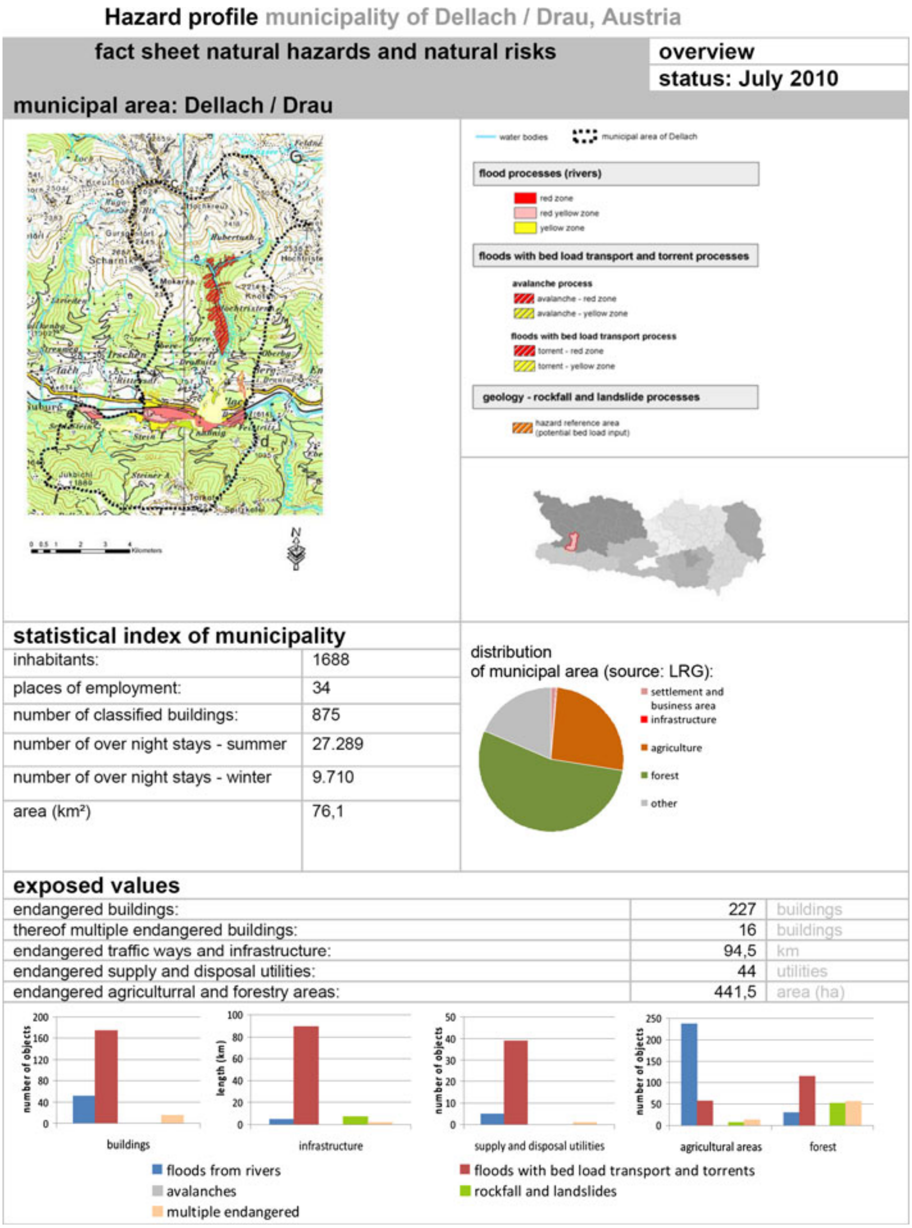

Fig. 1 Example of a factsheet showing the results of the comparative exposure analysis. Example of the municipality of Dellach im Drautal

mountain torrents) potentially affect 39,897 inhabitants and 19,287 buildings. Avalanches potentially affect 1,249 inhabitants and 660 buildings. Figure 4 shows the spatial distribution of potential damages due to flooding. In mountainous regions, the damage to infrastructure is higher than the damage to buildings. This contrasts to the situation in the floodplains, where the potential damage to buildings is higher.

	red hazard zone (high intensity)	red-yellow hazard zone (high intensity)	yellow hazard zone (low and medium intensity)	sum HQ100
damages on buildings	789.000 €	307.000 €	1.377.000 €	2.473.000 €
buildings with residential function	0 €	0 €	575.000 €	575.000 €
public buildings, industrial buildings, schools	789.000 €	307.000 €	802.000 €	1.898.000 €
infrastructure	2.428.000 €	1.002.000 €	6.056.000 €	9.486.000 €
roads	663.000 €	228.000 €	923.000 €	1.814.000 €
bridges	---	---	---	---
railroads	1.765.000 €	774.000 €	5.133.000 €	7.672.000 €
utilities	505.000 €	109.000 €	198.000 €	812.000 €
agriculture	356.000 €	112.000 €	191.000 €	659.000 €
number of exposed persons	**39**			
number of exposed working places	**16**			

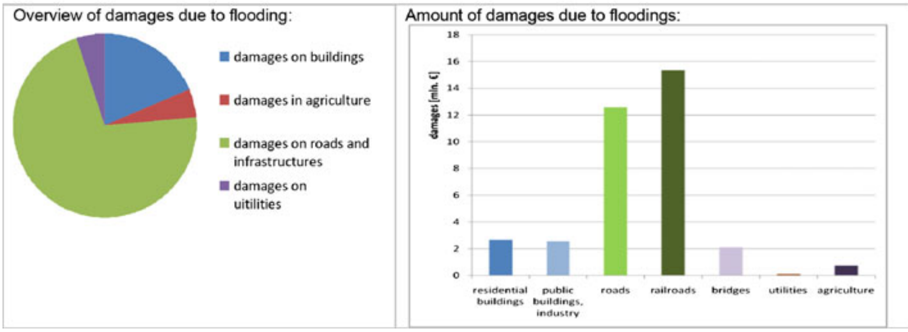

Fig. 2 Example of one part of a fact sheet showing the results of the flood risk analysis. Example of the municipality of Dellach im Drautal

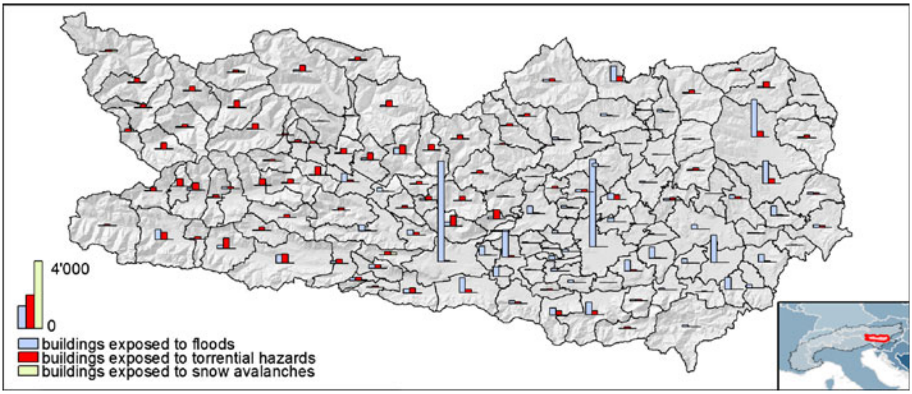

Fig. 3 Number of buildings exposed to floods, torrent hazards and avalanches in the municipalities of Carinthia

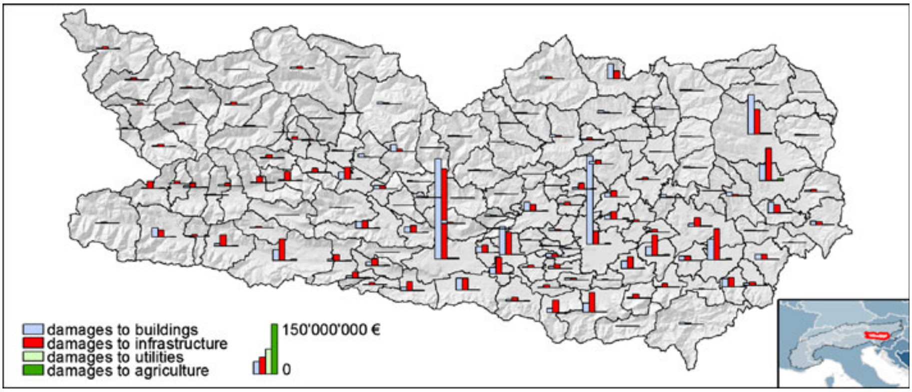

Fig. 4 Potential damage to buildings, infrastructure, utilities and agriculture due to flooding in the municipalities of Carinthia. The damage is calculated for a flood event with a return period of 100 years and is summarised at municipality level

4 Discussion and conclusions

The procedure provides the number of different classes of elements at risk exposed to floods, torrential hazards and avalanches. This comparative exposure analysis highlights the most critical processes in each municipality in Carinthia. The information is published in the form of fact sheets for each municipality, which summarise and visualise the results in a comprehensible form at municipality level. The number and units of exposed categories of elements at risk and the expected damage are values that are used in everyday management tasks and routines. The fact sheets allow a differentiated view of natural hazards at municipality level and a comparison of potential damage between different process types and between different categories of elements at risk. They therefore represent a kind of "risk portfolio" of the municipalities.

But the comparison between the different hazard types is limited, because of (1) different return periods of the hazard scenarios on which the hazard zone maps are based, (2) the spatial probability of occurrence was not considered in the exposure analysis, (3) the vulnerability of the elements at risk was not considered in the exposure analysis and (4) the spatial and temporal coherence of natural hazard events was not considered. Whereas flooding is likely occur in a greater area at the same time, debris-flow processes are in most cases spatially and temporally dispersed. This limits the comparability of the results of exposure analysis. This gap could only be bypassed by analysing the risks for all processes by means of a detailed risk analysis.

Nevertheless, the comparative exposure analysis highlights the order of dimension of elements at risk, and it is therefore suited to highlighting the hot spots in the region and in each municipality. With this, the results could provide indications for investing public funds most efficiently across administrative borders. The differentiation between damage of different categories of elements at risk makes it possible to analyse which type of stakeholder could contribute most to risk reduction. In municipalities in which damage to buildings is potentially the most relevant factor in the total sum of damages, private households can contribute significantly to risk reduction (in addition to flood protection measures). In these municipalities, raising citizens' awareness should be supported and promoted. In this sense, the information basis provides a tool for communicating risks and therefore for improving self-responsibility in a long-term time scale. In municipalities in which only infrastructure or utilities are affected by natural hazards, the public authorities responsible for the maintenance of the affected infrastructure should be involved in risk reduction activities.

The result of the flood risk analysis provides a tool for setting the priorities in the planning and construction of flood reduction measures. The responsible authority therefore becomes an objective decision base for the investment of public funds.

5 Outlook

With the elaborated information system, a point of origin for setting up an indicator system to monitor the effects of climate change on the natural hazard situation has been created. In Carinthia, the potential damage caused by natural hazards and the hot spots are now known. The monitoring system is able to run the procedure for different time steps, and the changes in the values have been archived. On the basis of historic data, the historic development of the damage potential and the resulting risks have been reconstructed. In future, the monitoring system will update the fact sheets once a new version of an information layer is available. If the procedure is repeated regularly after an update of the hazard maps or of the database of elements at risk, the trends in the temporal development of natural hazard risks could be monitored and highlighted. The differentiation between the temporal development of risks and elements at risk allows the extraction of an eventual climate signal. This climate signal could be evidenced in future if the trend in the development of natural hazard risks is remarkably different from the trend of the economic values of elements at risks (see Fig. 5). The factors that influence the temporal development of natural hazard risks have mostly been made evident. This leads to the identification of areas in which an increasing natural hazard risk is influenced by a climate signal and not by the increase in the economic value of elements at risk. Only in these areas, adaptation measures are necessary. With this information, the discussion of potential increases in natural risks due to climate change has been made at an objective level for a whole region. But the comparative analysis of different hazard types should in future be based on a detailed risk analysis rather than on an exposure analysis.

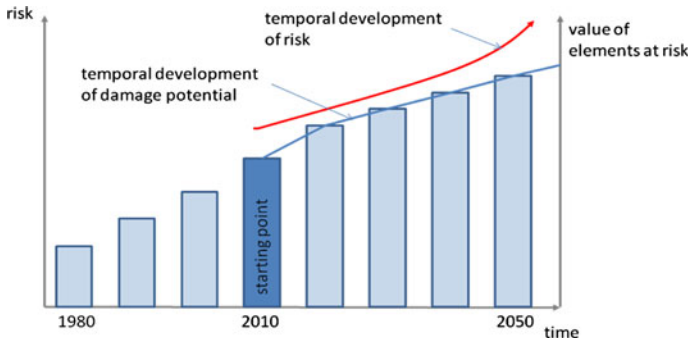

Fig. 5 Simplified concept for monitoring the temporal development of the economic values at risk and the related risks. The *dark bar* shows the situation of 2010, the *light bars* show hypothetical values of future and historic trends

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