Natural hazard risk depending on the variability of damage potential

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Abstract

In recent years, risk analysis has emerged as the appropriate method to assess natural hazards in mountain regions. The methodology is comparatively reliable in determining the hazard potential and the related probability of occurrence of defined design events, even if modelling approaches differ. So far, little attention has been given to the damage potential affected by those design events, especially concerning temporal changes. The damage potential, particularly the tangible asset, is subject to long-term changes due to the socio-economic development of mountain regions since the outgoing 19th century. These long-term changes have led to variations in the resulting risk, dependent on the dimension of the individual hazard impact. Due to seasonal and diurnal variability of intangibles, short-term changes of damage potential interfere with those long-term developments. Since intangibles form an essential part of damage potential, significant differences in the values at risk could be observed. In this study, long-term as well as short-term shifts in the values at risk are presented for different study areas and on different scales. A conceptual framework for the consideration of those changes in risk analyses is developed, and possible explanations for different trends in different study areas are discussed. The spatial sensitivity of the results is highlighted.
Keywords: natural hazards, risk analysis, variability, values at risk.

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1 Introduction

The historical shift of a traditionally agricultural society to a service industry- and leisure-oriented society led to socio-economic development in mountain environments and foreland regions. This shift is reflected by an increasing usage of those areas for settlement, industry, and recreation. Consequently, a conflict between human requirements on the one hand and naturally determined conditions on the other hand results, leading to an increasing concentration of tangible and intangible assets and to an increasing number of persons exposed to natural processes, which in the case of harm to human life or property are considered as natural hazards.

As the European Commission has stated and recently confirmed in a proposal for a directive of the European Parliament on the assessment and management of floods [1], natural hazards are phenomena, which occur periodically and episodically and cannot be prevented. This statement is proven by the development of the worldwide losses due to natural hazards [2], even if the insurance penetration might have increased in the past. Therefore, the responsible authorities in most of the European mountain countries developed methods of integrated risk management, which follow mainly the engineering approach to express risk as a product of hazard and values at risk [3, 4, 5], see eqn. (1).

$$R = p_{Si} \cdot A_{Oj} \cdot p_{Oj,\,Si} \cdot v_{Oj,\,Si} \tag{1}$$

R = risk
p_{Si} = probability of scenario i
A_{Oj} = value at risk of object j
$p_{Oj,\,Si}$ = probability of exposure of object j to scenario i
$v_{Oj,\,Si}$ = vulnerability of object j, dependent on scenario i

Following eqn. (1) it becomes apparent that all parameters have a linear influence on the result of risk analysis. The procedure of hazard assessment is methodologically reliable in determining the hazard potential and the related probability of occurrence (p_{Si}) by studying, modelling, and assessing individual processes and defined design events (e.g. [6, 7]). So far, little attention has been given to the damage potential (A_{Oj}) affected by hazard processes, particularly concerning spatial patterns and temporal shifts. Studies related to the probability of exposure of an object ($p_{Oj,\,Si}$) to a defined scenario and the appropriate vulnerability of the object ($v_{Oj,\,Si}$) have predominantly been carried out so far as proposals to determine the risk of property and human life with the focus on risk within a specific location and a specific point in time [e.g., 3, 6, 8, 9]. However, risk changes over time; thus, the temporal variability of damage potential is a key variable in the consideration of risk. Hence, there is a need for a precautionary, sustainable dealing with natural hazard phenomena, taking into account particularly the values at risk [10, 11]. Recently, conceptual studies related to the temporal variability of damage potential have been carried out, focussing both, the long-term and the short-term temporal development of indicators [12, 13, 14]. Based on these studies, the multi-temporal development of values at risk is presented with respect to snow avalanches in Alpine settlements. This multi-temporal approach aims to demonstrate the different superimposed temporal scales in the development of damage potential complementing each another.

2 Temporal development of values at risk

Case studies have been carried out in Davos (Switzerland) and Galtür (Austria) [12, 13]. Both villages represent typical mountain resorts dependent on winter tourism, thus, the results mirror recent developments of society in alpine destinations. Methodologically, the areas affected by avalanches were deduced using the incident cadastre of former events, the legally valid hazard maps, and the numerical avalanche model AVAL-1D. The values at risk were obtained analysing the zoning plan with respect to location and perimeter of every building. Additional information, such as building type, year of construction and replacement value, as well as the number of residents were provided by the official authorities and joint using a GIS. The number of endangered tourists was derived from tourism statistics of the municipalities.

A general shift in damage potential resulted from the development of mountain areas from traditionally agricultural societies to tourism centres within the 20th century. This development could be evaluated using decadal study periods, and provided a general idea about the development of assets in endangered areas. This approach mainly focused on the development of values in endangered areas, such as the number and value of buildings, or the number of persons inhabiting those buildings.

A second development of damage potential, especially focusing on mobile values and intangible assets, is based on a seasonal and diurnal assessment of variations in damage potential. This approach had also been applied for an application related to the number of tourists staying temporally at a specific endangered location.

2.1 Long-term development of values at risk

Regarding the long-term development in numbers and values of endangered buildings, a significant increase could be proven in both study sites for the period between 1950 and 2000 [12].

In Davos, the total number of buildings has almost tripled, from 161 in 1950 to 462 in 2000 (Fig. 1). This increase was due to the shift from 51 to 256 in the category of residential buildings, while in the other categories the number of buildings was approximately unchanging. A significant increase in number dated back in the 1960s and 1970s before the legally hazard map came into force [15]. The total value of buildings increased by a factor of almost four. In 1950, the total sum of insured buildings was €240 million and in 2000, the total sum was €930 million. In 1950, the proportion of residential buildings was less than 15%, compared to the total amount of endangered buildings. Until 2000, this ratio changed to almost 50%. Regarding the category of hotels and guest houses as well as the category of special risks, nearly no increase in value could be observed. However, those categories showed a higher average value per building than residential buildings. The number of endangered permanent residential population increased slightly. In 1950, a population of 1,098 persons was exposed to avalanche hazards, until 2000 this value increased to 1,137 persons.

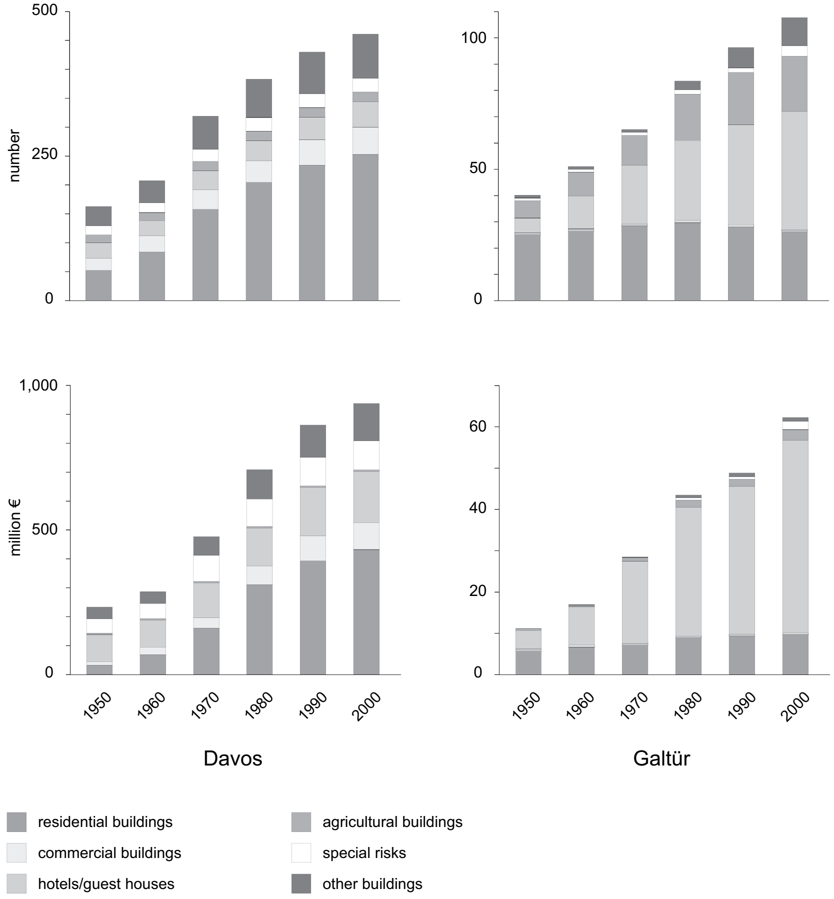

Figure 1: Development of values at risk in Davos (CH) and Galtür (A) related to the respective avalanche-prone areas, subdivided in decades and building categories [12].

This is a relatively moderate increase of 3.6%, compared to the increase in tangible assets. If the classification into different building functions is carried out, this increase turned out to be larger. In residential buildings, 673 persons were concerned in 1950 and 1,116 in 2000, which is an increase of two thirds.

In Galtür, the total number of buildings inside avalanche-prone areas rose by a factor of 2.5 (Fig. 1), from 41 in 1950 to 108 in 2000. This increase is due to the relative development in the category of hotels and guest houses, and – obviously less important – in the category of agricultural buildings. The number of buildings in all other categories stayed nearly constant. The decrease in the number of residential buildings since 1980 resulted from a modification of buildings formerly used for habitation to accommodation facilities subsequently used for tourism. The total value of buildings rose by a factor of almost six. In 1950, the total value of buildings amounted to €12 million and in 2000 to €64 million. Since the 1960s, the category of hotels and guest houses held the highest proportion of the total amount of endangered values per decade and per category. In 1950, the proportion of hotels and guest houses was about 30%, compared to the total value of buildings. In 2000, this ratio changed to approximately 75%. In contrast, the number and value of residential buildings showed nearly no change between 1950 and 2000. Generally, the number of buildings in the community of Galtür has risen above average in comparison to the numbers of the Federal State of Tyrol. In 2000, a quarter of the total value of all buildings in the municipality was found to be located in the avalanche-prone areas. The proportional increase in the value of buildings was significantly higher than the proportional increase in the number of buildings. Buildings inside avalanche-prone areas showed a lower average value as buildings outside those areas. The number of endangered persons increased substantially between 1950 and 2000. In Galtür, in 1950, approximately 850 persons were located inside exposed areas, consisting of 460 residents and 390 tourists. Until the year 2000, this value increased to 4,700 persons, 770 of whom were residents and 3,930 were tourists. The increase in residential population was about 60%, while the increase in temporal population was a factor of ten.

2.2 Short-term development of values at risk

Parallel to the long-term increases described in the previous section, remarkable short-term variations of persons at risk were detectable. Those variations could be determined on seasonal, weekly and hourly resolution.

Results of the community of Davos have shown that subdividing the utilisation of hotels and guest houses into months, peaks arose during the Christmas period and towards the end of February. According to the analysis of the avalanche bulletin of the Swiss Federal Institute of Snow and Avalanche Research SLF, these periods coincided closely with periods when there was an above-average occurrence of days with high avalanche danger. As a result, temporal risk peaks within the time frame of weeks occur.

In the community of Galtür, similar developments have been quantified for the number of endangered persons. Over the whole study period, the total number of endangered persons fluctuated by a factor of almost six. Based on a fluctuation approach outlined in [13], strong variations could be observed during the winter season as well as in daytime (Fig. 2). The seasonal fluctuation was characterised by a strongly increasing number of tourists at Christmas time and the Easter travel season. The end of the winter season was highlighted by a sharp decrease in the number of persons to nearly the amount of the permanent population. Considering the diurnal fluctuation, the weekly structure could be easily followed. From the beginning of the winter season on, these patterns were concealed by general movements of the tourists during daytime. The number of persons varied by a factor of 1.4 between minimum and maximum in the off-season, and by a factor of 3.4 in the period of the main season. These changes could occur extremely rapidly within one or two hours.

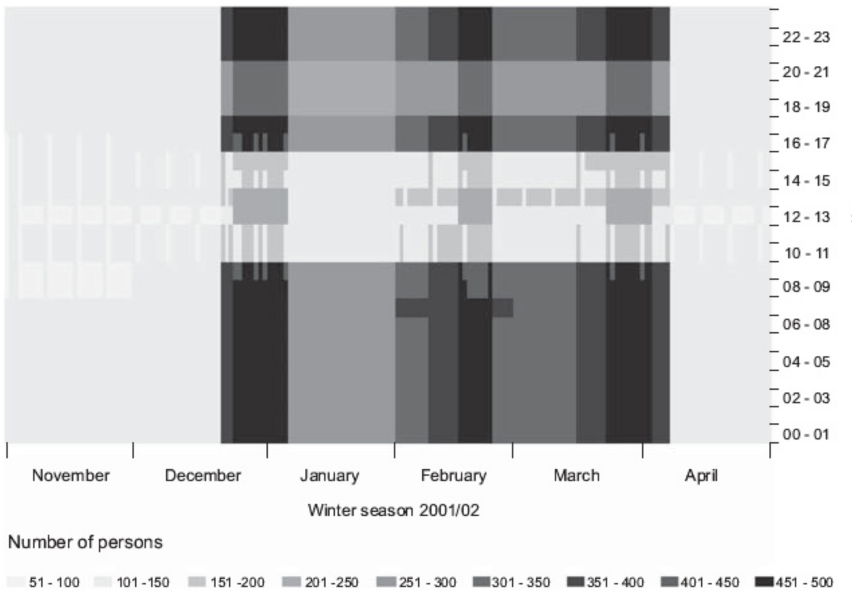

Figure 2: Monthly, weekly, and diurnal fluctuations of the number of exposed persons in the study area of Galtür (A) [13].

3 Multi-temporal approach for an effective risk reduction

As presented in the previous sections, the development of values at risk due to socioeconomic transformation in mountain areas has to be considered when evaluating risk resulting from natural hazards. In doing so, long-term changes and short-term fluctuations have to be considered.

Long-term changes in values at risk could be considered as basic disposition (Fig. 3). To reduce the risk resulting from this basic disposition, permanent constructive mitigation measures could be constructed and land-use regulations implemented. As a consequence, the basic risk could be reduced due to a reduction of the process area. As pointed out in [16] for the study area of Davos, the risk due to snow avalanches decreased fundamentally since the 1950s, even if the values at risk increased in the municipality. This development could be mainly attributed to the construction of permanent mitigation measures, and is strongly related to immobile values. However, extraordinary losses could be estimated if rare events with severe effects occur. Similar results were obtained for the study area Galtür [17]. Furthermore, since the socioeconomic development differs within Alpine regions, studies on the long-term behaviour of values at risk contribute to the ongoing discussion of passive and active developing regions and suburbanisation [15].

Short-term fluctuations in damage potential supplement this continuing development of damage potential within a specific range. Thus, they have to be considered as variable disposition. To mitigate those fluctuations, temporal measures could be applied, such as evacuations or temporary road closures.

However, if a potentially dangerous natural event will occur, it depends on the actual amount of values at risk (basic and variable disposition) within the process area whether or not damage will be triggered.

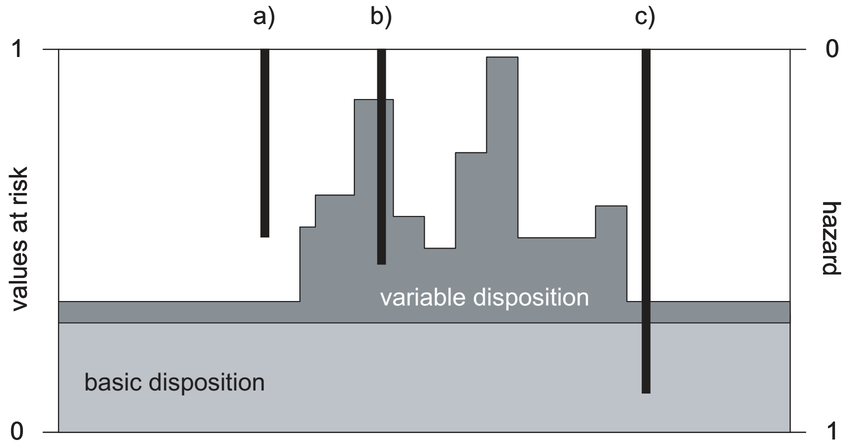

Figure 3: Schematic description of the concept of basic (long-term) and variable (short-term) damage potential and the relation to triggering events.

In Fig. 3, the significance for a consideration of variable as well as basic damage potential is shown. As presented in example a) the event will not hit any values at risk, and thus, the level of risk reduction is sufficient. In example b), due to high amounts of variable values at risk, damage will occur. Thus, temporal mitigation strategies could reduce the variable damage potential until a critical level. In example c), basic and variable values at risk are affected by a process. Thus, temporal measures are no more sufficient enough for an effective risk reduction.

4 Conclusion

Information on the general development of damage potential and seasonal, weekly or diurnal peaks should be implemented in the risk management procedure, since the range of the results is remarkably high, and the values at risk have a key influence on the risk equation. Even if the results suggest – due to the long-term increase in damage potential – a similar shift in risk, in general, the risk decreased fundamentally as a result of the construction of mitigation measures and the introduction of land-use restrictions in endangered areas.

However, the short-term fluctuations in damage potential might lead to a temporal increase in risk, resulting from a modified recreational behaviour within the society. Until now, there is a particular lack in information related to short-term fluctuations of values at risk. In contrast to the immobile damage potential (buildings and infrastructure, etc.), persons and mobile values can either leave or be removed out of hazard-prone areas in case of dangerous situations. For developing efficient and effective evacuation and emergency plans, information on numbers of persons and mobile values as well as their location and movements in the area is needed. In consequence, permanent mitigation structures could be complemented by temporal measures to achieve an efficient and effective risk reduction.

Information on the temporal variability of values at risk both from a long-term as well as from a short-term point of view provide in combination with process knowledge the basis for a dynamic risk visualisation. Such information may help to recognise high risk situations more easily and enables a situation-oriented and risk-based decision-making [14, 18]. Apart from the damage potential, risk analyses are based on the concept of recurrence intervals of hazard processes. If those defined design events would be exceeded, the remarkable increase of values at risk would result in a significant shift in monetary losses (and presumably fatalities). Hence, risk analyses concerning natural hazards should be carried out with respect to a dynamic change of input parameters. This is essential for efficient disaster risk reduction and contributes to the concept of resilience as part of proactive adaptation. Thus, future research is needed to quantify the impact of such modifications on (1) the result of risk analyses, (2) the assessment of risk in the cycle of integrated risk management, (3) the adjustment of coping strategies, and (4) the perception of risk by all parties involved, including policy makers.

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