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ORIGINAL PAPER

Assessment of socioeconomic vulnerability to landslides using an indicator-based approach: methodology and case studies

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Abstract The severity of the impact of a natural hazard on a society depends on, among other factors, the intensity of the hazard and the exposure and resistance ability of the elements at risk (e.g., persons, buildings and infrastructures). Social conditions strongly influence the vulnerability factors for both direct and indirect impact and therefore control the possibility to transform the occurrence of a natural hazard into a natural disaster. This article presents a model to assess the relative socioeconomic vulnerability to landslides at the local to regional scale. The model applies an indicator-based approach. The indicators represent the underlying factors that influence a community's ability to prepare for, deal with, and recover from the damage and loss associated with landslides. The proposed model includes indicators that characterize the demographic, social and economic setting as well as indicators representing the degree of preparedness, effectiveness of the response and capacity to recover. Although this model focuses primarily on the indirect losses, it could easily be extended to include physical indicators accounting for the direct losses. Each indicator is individually ranked from 1 (lowest vulnerability) to 5 (highest vulnerability) and weighted, based on its overall degree of influence. The final vulnerability estimate is formulated as a weighted average of the individual indicator scores. The proposed model is applied for six case studies in Europe. The case studies demonstrate that the method gives a reasonable ranking of the vulnerability. The practical experience achieved through the case studies shows that the model is straightforward for users with knowledge on landslide locations and with access to local census data.

Keywords Socioeconomic vulnerability · Indicator-based vulnerability models · Landslide · Case study

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Introduction

Landslides cannot be avoided, but their impacts can be reduced through hazard mitigation strategies and implementation of legislative and policy frameworks for exposure and vulnerability reduction. In order to minimize the society's vulnerability to landslides, it is necessary to map the vulnerability and identify the indicators that contribute most to its advancement. In the last few decades there has been increasing effort toward the quantification of the landslide physical vulnerability for people, buildings and infrastructures (Uzielli et al. 2008; Papathoma-Köhle et al. 2011; Puissant et al. 2013), but the calculation of the social vulnerability in quantitative terms still remains a complicated issue.

Although there are many existing models that address the issue of social or socioeconomic vulnerability, there is no single model available that provides a landslide vulnerability index for European communities. The majority of existing models focus on only one aspect of vulnerability (i.e., coping capacity), generalize for all natural hazards and/or suggest indicators without defining any sort of weighting scheme. Furthermore, indicator sets and models generally describe a wide range of social or socioeconomic indicators, which restricts their operational applications where transferable models are needed to be applied for different locations. Vulnerability models with semiquantitative key-indicators are useful here. Therefore, the development of a European socioeconomic vulnerability model for landslides is important in order to maximize safety levels and optimize resource usage in European regions susceptible to slope instability.

The objective of this study is to propose a straightforward methodology for the estimation of socioeconomic vulnerability to landslides at the local to regional scale, providing: (1) a selection and ranking of indicators adapted to European conditions; (2) an explicit formulation on how to rank and weight the indicators, such that the method is independent or less dependent on the judgment of the users, and (3) an aggregation method of the indicators to obtain the vulnerability score.

Background

Vulnerability assessment, with respect to natural hazards, is a complex process. The assessment must consider multiple dimensions of vulnerability, including physical and social factors. Physical vulnerability is a function of the intensity and magnitude of the hazard, the degree of physical protection provided by the natural and built environment, and/or the resistance levels of the exposed elements (Corominas et al. 2013; Li et al. 2010). However, social factors such as preparedness, institutional and non-institutional abilities for dealing with natural hazard events (e.g., response and recovery) are also important elements of a society's vulnerability to natural hazards. Social vulnerability refers to the underlying factors leading to the inability of people, organizations and societies to withstand impacts from natural hazards (e.g., Cutter et al. 2003).

Social vulnerability models can be used in combination with physical vulnerability models to estimate direct and indirect losses. Direct losses result from the physical destruction of exposed elements, and indirect losses represent the consequences of that destruction (Committee on Assessing the Costs of Natural Disasters 1999). The direct impacts of a landslide typically include casualties and damages to buildings and infrastructure, while indirect losses may include income losses until the society functions are fully recovered (e.g., stop in production, closure of businesses due to the impact) or losses due to malfunctioning of infrastructures (e.g., due to closed roads or to closed schools). The direct losses are primarily assessed using physical vulnerability indicators (e.g., construction material and dimension of buildings), while indirect losses are mainly assessed by means of socioeconomic indicators (e.g., economical resources). In this article, the socioeconomic vulnerability refers to the potential to be harmed, including both the immediate and long-term consequences (indirect losses). In a wide sense, socioeconomic vulnerability is considered here as the potential degree of loss not only for existing values, but also for future values.

A vulnerability indicator is a variable that is an operational representation of a characteristic or quality of a system able to provide information regarding the susceptibility, coping capacity and resilience of a system to an impact of an albeit ill-defined event (Birkmann 2006). The indicators serve as inputs to an explicit vulnerability model, and the choice of the model and the corresponding indicators depends on the scale, site factors and data availability as well as the overall purpose and target audience/users of the vulnerability assessment. In socioeconomic vulnerability assessments of landslides, the indicators represent the underlying socioeconomic factors pertaining to a community and that influence their ability to deal with, and recover from, the damage associated with landslides. The purpose of the indicators is to set the premises for prioritizing, to serve as a background for action, to raise awareness, to analyze trends and to empower risk management.

Indexing approaches can be characterized as inductive or deductive (Cardona 2003):

- Deductive, when measurement of risk is hazard specific and based on disaster impact data; deductive approaches are based on the modelling of historical patterns of materialized risk.
- Inductive, where measurement of risk is based on underlying factors that influence a community's ability to prepare for, deal with and recover from an impact. Such methods are relatively independent of the type of

hazard. Inductive approaches model risk through weighting and through the combination of different hazard, vulnerability and risk reduction variables.

The model proposed in this article belongs to the group of inductive models.

A short review of relevant indicator-based vulnerability and risk studies

There are several indicator-based methods available in the literature, and these were recently reviewed by Puissant et al. (2013) according to the spatial scale of analysis. Carreño et al. (2007a) developed an international risk management index (RMI) used to measure the capacity of governing bodies at the national, sub-national and urban levels to deal with natural disasters based on their achievements in the following public policy areas:

- Risk identification, represented by RMI_{RI}.
- Risk reduction, represented by RMI_{RR}.
- Disaster management, represented by RMI_{DM}.
- Financial protection, represented by RMI_{FP}.

The risk identification index, RMI_{RI}, is a measure of individual perceptions, of how these perceptions are understood by the society as a whole and of the objective assessment of risk. Risk reduction index, RMI_{RR}, involves prevention and mitigation measures. The disaster management index, RMI_{DM}, involves measures of response and recovery, and governance, and financial protection, RMI_{FP}, measures the degree of institutionalization and risk transfer. Each of these subindices comprises six indicators that are categorized into one of five performance levels, ranging from low (1) to optimal (5). The indicators are denoted with public policy group and number (e.g., RI1 corresponds to risk identification, indicator 1), and the corresponding weights are denoted $w_{\text{public policy area and number}}$ (e.g., w_{RI1}). The weights of the individual indicators are selected based on expert opinion, and each subindex is evaluated by incorporating the indicator weights into a fuzzy analysis. Fuzzy set theory was selected because its gradual phase transitions are applicable to qualitative analyses. The RMI could also be calculated as a weighted sum of integer values, 1–5, assigned to describe the performance levels for each indicator.

Cutter et al. (2003) developed a county-level social vulnerability index (SoVI) for the US based on 11 independent indicator variables (reduced from 42 using a factorial analysis). They performed a statistical analysis on the final 11 indicators to determine the amount of variation explained by each. The result is listed in Table 1. Each of the indicators was assigned a score, and the total SoVI score for each county was calculated as the sum of the indicator scores (no weights were applied). The SoVI levels were categorized relatively to the mean US value—counties with a SoVI score greater than +1 standard deviation from the mean were considered the most vulnerable, and those with greater than −1 standard deviation from the mean were considered the least vulnerable.

Peduzzi et al. (2009) proposed a model of factors influencing levels of human losses from natural hazards at the global scale for the period 1980–2000. This model was designed for the United Nations Development Program as a building stone of the Disaster Risk Index (DRI), which aims to monitor the evolution of risk. Human vulnerability was measured by correlating exposure with selected socioeconomic parameters. Partial correlation analysis was applied to identify the indicators explaining the major part of the casualties. The indicators used differ by hazard type. For tropical cyclones, droughts and floods, physical exposure and GDP were identified as important indicators. In addition, the rural population (percentage of country dedicated to crop land) was considered important for tropical cyclones, and the percentage of arable land was considered important for droughts. For earthquakes, the indicators identified as most important included physical exposure, percentage of urban growth and percentage of forest coverage in the country.

Vulnerability indicators may be expressed at a specific geographical scale (local/site-specific, regional or global), at a specific organizational level (individual, household, community or national) and for different hazard types. Except for smaller countries, typically landslide-prone island nations, a single landslide rarely has socioeconomic consequences at national or global levels. Thus, the most relevant scale for landslides will typically be the local or regional scale. For methods where the organizational levels rather than geographical scales are applied, the focus is on methodologies that deal with vulnerability at the community level. With a focus on models applicable to the local to regional scale or to the community level, the proposed model is adapted to European conditions based on the work of Cutter et al. (2003), Tapsell et al. (2005), Steinführer et al. (2009), King and MacGregor (2000) and Lahidji (2008).

Tapsell et al. (2005) and Steinführer et al. (2009) described socioeconomic vulnerability for floods for European countries. King and MacGregor (2000) discussed the development of social indicators to measure community vulnerability to natural hazards. Lahidji (2008) proposed a model for assessing coping capacity developed for Asia, but applicable globally, for several hazard types. The indicators used in the literature are summarized in Table 1.

Table 1 Indicators used for vulnerability assessment at household and community level

Case study methodology			
Reference	Level	Hazard type	Applied indicators
Cutter et al. (2003)	Community	Environmental hazard	Personal wealth (per capita income) Age (median age) Density of the built environment (no. commercial establishments/mi^2) Single-sector economic dependence (% employed in extractive industries) Housing stock and tenancy (% housing units that are mobile homes) Race (% African American, % Asian) Ethnicity (% Hispanic, % Native American) Occupation (% employed in service) Infrastructure dependence (% employed in transportation, communication and public utilities) The content of the parentheses indicate the dominant variables to describe the indicators
Tapsell et al. (2005)	Community	Flood	Age Gender Employment Occupation Educational level Family/household composition Nationality/ethnicity Type of housing Number of rooms per household Rural/urban Additionally: Level of risk awareness and preparedness Previous flood experience (*can be transferred to landslides or other hazards*) Access to decision-making Trust in authorities Long-term-illness or disability Length of residence (*refers to the experience and knowledge of the area, potential hazards, and possible experience from former events*) Serviced by (flood) warning system (*can be transferred to landslides or other hazards*)
Steinführer et al. (2009)	Household	Flood	The following social groups within communities were considered more likely to need specific targeting and support: Those with no previous flood experience (*can be transferred to landslides or other hazards*) Those who have recently moved to an area Those with lower social status Those living alone without disposing of a social network outside their home Household with long-term ill or disabled members Those living in vulnerable housing (like mobile homes or bungalows) Older people (in particular the oldest and weakest, not living in homes for the aged)
King and MacGregor (2000)	Household	Natural hazards	Significant socioeconomic and demographic characteristics: The very young The very old The disabled Single parents household One person household Newcomers to the community and migrants People lacking communication and language skills Low income earners Required behavior and characteristics to minimize vulnerability: Ability and willingness to evacuate, ability to protect home and property, having insurance, substantial structures, involvement with community and neighbors and family, having good mental and physical health, no dependency and no dependents, an ability to access warnings, instruction and advice, general and local knowledge, common sense and caution and youthfulness

Table 1 continued

Case study methodology			
Reference	Level	Hazard type	Applied indicators
Lahidji (2008)	National and local	Natural hazards	The coping capacity was assessed using the ten components: Hazard evaluation Consequence and vulnerability assessment Awareness-raising activities Sectoral regulations Structural defences Continuity planning Early warning Emergency response Insurance and disaster funds Reconstruction and rehabilitation planning (In the study, the indicators were found through a local government questionnaire)

Proposed model for socioeconomic vulnerability assessment

Vulnerability may be defined either (1) quantitatively as a dimensionless number between 0 and 1 representing the degree of loss within a given time and space frame or as a probability of loss or (2) semiquantitatively if the vulnerability is ranked relatively according to a scale defined within the model. The model proposed in this article is a semiquantitative method, which ranks the vulnerability on the relative scale of 1–5, where 1 corresponds to the lowest vulnerability and 5 to the highest vulnerability.

Choice of indicators

The indicators should be chosen such that they collectively represent several aspects of the society's ability to prepare for, deal with and recover from an impact. Important questions in the selection of indicators are:

1. *Vulnerable elements* What and who are the most vulnerable elements of the society (e.g., vulnerable groups of people, industries, buildings, infrastructures)?
2. *Preparedness and response* Is the population prepared for an emergency (e.g., existence of early warning systems and emergency response procedures, and risk awareness of the population)?
3. *Recovery* Are resources available for recovery (e.g., resources for rebuilding destroyed physical environments, medical facilities, etc.)?

Based on these questions, the indicators chosen in the proposed model were:

1. *Vulnerable elements*

In the proposed model, the most vulnerable groups considered and assessed were:

- Children below 5 years and people above 65 years of age: Young children and senior citizens are more vulnerable to harm (Cutter et al. 2003; Tapsell et al. 2005; Steinführer et al. 2009; King and MacGregor 2000).
- People with language and cultural barriers: Language and cultural barriers could affect the ability to understand warning information and access to post-disaster funding and residential locations in high hazard areas (Cutter et al. 2003). Newcomers to the community and migrants and people lacking communication and language skills are likely to have less involvement with community, neighbors and family, and less ability to access warnings, instructions and advice (King and MacGregor 2000).
- Rural populations who are dependent on the surrounding natural resources for their primary source of income: a singular reliance on one economic sector for income generation creates a form of economic vulnerability (Cutter et al. 2003). Rural residents may also be more vulnerable because of lower incomes (Cutter et al. 2003; Tapsell et al. 2005).
- High-density populations: Urban regions with very dense populations are more difficult to evacuate and care for during emergencies (Cutter et al. 2003).
- People without a post-secondary education: Lower education constrains the ability to understand warning information and access to recovery information (Cutter et al. 2003). Education can indicate to what extent

people have a basic understanding of the processes, are able to understand and judge information material, and how they follow media and information flows. However, it is not necessarily related to risk perception and awareness.

In addition to the vulnerable groups of people, other indicators for describing vulnerable elements such as buildings and critical infrastructures include:

- The indicator 'housing type' was considered very important for the assessment of building vulnerability levels. The value, quality and density of residential construction affect potential losses and recovery (Cutter et al. 2003). Cutter et al. (2003) applied the fraction of housing units that are mobile homes as the indicator for housing type. Mobile homes are easily destroyed and less resilient to hazards. As mobile homes are uncommon in Europe, the corresponding indicator for Europe was chosen to assess the resistance of the buildings in the study. In addition, housing type is an economic indicator directly related to the economic status of individuals, communities and nations. Thus, constructions of weak resistance that are affected by a landslide hazard are typically associated with socially vulnerable communities having an unfavorable influence on the quality of life.
- The indicator 'critical infrastructure' considers vulnerable infrastructure and facilities. Critical infrastructures (Papathoma-Köhle et al. 2007; Taubenböck et al. 2008) summarize critical (care) facilities and lifelines that are important for the functioning of the society and have been shown to contribute to the impacts of natural hazards if located in the affected area. Hospitals and schools hit surprisingly by a landslide are considered particularly vulnerable, because of the number and susceptibility of people allocated to these facilities. Moreover, the destruction of life-supporting infrastructure and infrastructure necessary for the functioning of the society, such as the road network, telecommunication or power supply, increases vulnerability and hampers emergency management as well as the recovery process.

2. *Preparedness and response*

Preparedness levels were ranked based on:

- The risk awareness of the population, which influences peoples' preparedness and behavioral patterns in case of an emergency (Tapsell et al. 2005; Dwyer et al. 2004; Taubenböck et al. 2008). Risk awareness is particularly related to exposure (in terms of proximity) to the hazard, the experience of the population with landslides, the time they have been living in the exposed area, and the information they receive regarding their specific, local risk situation, possible mitigation measures and procedures in case of an emergency. Risk awareness is individual and subjective, and therefore difficult to measure. The indicator 'risk awareness' here includes mainly two factors: the length of residence (Tapsell et al. 2005) and the information status of the exposed people.
- The early warning capacity of the society. This indicator assesses both the evaluation of landslide hazard and the presence of early warning systems in the region. These two were assessed by one indicator to avoid overestimating the role of preparedness in the overall vulnerability analysis. The early warning capacity includes the overall preparedness of a community against the disaster. Landslides might come as very sudden and rapid events, as for example rockfalls. Although in some cases early warning systems can be used for the closure or evacuation of areas after an event (as for example of a road to avoid collision of vehicles with fallen rock blocks), they do not permit quick evacuation before or during the event or other personal preparedness measures. For sudden and rapid events, e.g., rockfalls, a high weight given to preparedness indicators (e.g., presence of an early warning system or hazard maps) would pretend a false safety. The ranking of the indicator is formulated such that landslides for which an early warning is not available (e.g., earthquake-triggered landslides) result in a high vulnerability.
- The stringency of regulation control and the extent of emergency response procedures. If there is a significant amount of control over construction and land-use guidelines, the infrastructure is generally well-built and relatively resilient, and thus the exposure to landslides is avoided.
- The emergency response. The quality of the emergency response depends on a clear definition of roles and responsibilities at the local level, access to equipment and training of the rescue services (Lahidji 2008).

3. *Recovery*

The ability to recover from a landslide was assessed by analyzing the following indicators:

- Personal wealth: As a measure for resources for recovery, the chosen indicator is GDP per capita. Wealth enables communities to absorb and recover from losses more quickly (Cutter et al. 2003).
- Insurance and disaster funds: The existence and quality of insurance and disaster funds is important for the recovery process (Cutter et al. 2003; Lahidji 2008).

- Quality of medical services: The access to hospital beds is important for the population in case of large disasters. However, this indicator was considered less important compared to other indicators as (1) landslides generally cause more infrastructure and natural resource losses than casualties, and this indicator should not be weighted as heavily as in, for instance, an earthquake vulnerability model and (2) the model is on the local to regional scale; thus, the lack of hospital beds might be resolved by transferring patients to other regions within the country.

Aggregation of indicators

A weighting system is introduced to account for the relative importance of each indicator for the total vulnerability level. If all the indicators are believed to be of equal significance, equal weighting should be applied. Techniques to determine weights include expert judgment, the analytical hierarchy process, principal component analysis and factor analysis (CIMNE 2009). In this work, expert judgment is used based on experience and on the verbal description of the importance of each indicator given in the literature.

Once the indicators have been weighted, a method for aggregation is chosen among three main groups:

- additive models, produced by, for example, multi-criteria decision models;
- multiplicative models, produced by, for example, multiple regression models;
- decision rules, produced by, for example, decision trees.

An additive model is to be preferred when the indicators are believed to influence the vulnerability independently of each other. A high vulnerability score on one indicator could be compensated with a low indicator score on another indicator (e.g., a lack of personal wealth could be compensated by an extensive insurance coverage). However, if the influence of one indicator on the vulnerability depends on another indicator, a multiplicative model should be used. For example, if the indicators “regulation of land use in hazardous areas” and “existence of hazard maps” are used, they could not work independently of each other, as strict regulations of land use in hazard areas are valueless if no hazard maps exist.

The proposed model describes the vulnerability semi-quantitatively, with additive aggregation of the indicators, according to Eq. 1. Each indicator is individually ranked from 1 (lowest vulnerability) to 5 (highest vulnerability) and weighted based on its overall degree of influence. The weights are chosen from among the values 1, 2 and 3. The choice of weights is an iterative process. In the first step, all weights were assigned a value of 2, e.g., equal weighting. Then the indicators believed to be of more importance were assigned a value of 3, and those deemed to be of less importance were assigned a value of 1. In addition, the choice of indicators and weighting were modified when experience with the method was gained through the case studies. The weights should still not be considered as rigid and could be modified by the user, but in order to compare socioeconomic vulnerability between different locations, the same weights should be used. The weighting scheme was adapted accordingly:

- Most influential: housing type, early warning capacity and critical infrastructure;
- Moderately influential: age distribution, diversity of income of rural population, personal wealth, insurance and disaster funds, risk awareness, regulation control and emergency response;
- Least influential: population density, vulnerable groups due to language/cultural barriers, education level and quality of medical services.

The indicators are divided into three groups: “demographic and social indicators,” “economic indicators” and “preparedness, response and recovery indicators.” Tables 2, 3 and 4 show the proposed socioeconomic vulnerability model with suggested indicators, their corresponding weights, the source for data collection and the criteria for ranking the indicators.

When all the indicators are assigned a vulnerability score, the score for each indicator is multiplied with its corresponding weight and summed to give a weighted vulnerability score. The final vulnerability estimate is formulated as a weighted average of the individual indicator scores (Eq. 1):

$$\text{Aggregated vulnerability score value} = \sum_{\text{All indicators}} \text{indicator score} \times \text{indicator weight} \Big/ \sum \text{weights} \quad (1)$$

The application of the model is demonstrated in the “Case studies” section.

Application of the method produces vulnerability scores according to Eq. 1 aggregated for each group of indicators and aggregated for all indicators. The obtained vulnerability scores are on a relative scale 1–5, where 1 corresponds to the lowest possible vulnerability score and 5 to the highest possible vulnerability score. Since the scale of the method is relative, it is difficult to interpret a single vulnerability score. For a better interpretation, there are two main possibilities:

- The score could be compared/calibrated against total loss estimations (including direct and indirect loss) after disasters and the difference between direct and

Table 2 Proposed socioeconomic vulnerability model: demographic and social indicators

Demographic and social indicators		
Indicator (weights)	Means of data collection	Criteria for indicator ranking (1: low vulnerability, 5: very high vulnerability)
Age distribution (2) (see note 1)	Census	1: Uniform age distribution—less than 20 % of the population is either between 0 and 5 or over 65 years of age
		2: 20–30 % of the population is either between 0 and 5 or over 65 years of age
		3: 30–40 % of the population is either between 0 and 5 or over 65 years of age
		4: 40–50 % of the population is either between 0 and 5 or over 65 years of age
		5: Over 50 % of the population is either between 0 and 5 or over 65 years of age
Diversity of income of rural population (2) (see note 2)	Census	1: <10 % of the population is dependent on the land for primary source of income
		2: 10–25 % of the population is dependent on the land for the primary source of income
		3: 25–50 % of the population is dependent on the land for the primary source of income
		4: 50–75 % of the population is dependent on the land for the primary source of income
		5: Over 75 % of the population is dependent on the land for the primary source of income
Population density (1) (see note 2)	Census	1: Population density is <50 people/km^2
		2: Population density is between 50 and 100 people/km^2
		3: Population density is between 100 and 250 people/km^2
		4: Population density is between 250 and 500 people/km^2
		5: Population density is >500 people/km^2
Vulnerable groups due to language or cultural barriers (1)	Census	1: <5 % of the population is not familiar with the majority language and culture
		2: 5–10 % of the population is not familiar with the majority language and culture
		3: 10–15 % of the population is not familiar with the majority language and culture
		4: 15–25 % of the population is not familiar with the majority language and culture
		5: >25 % of the population is not familiar with the majority language or culture (indicative of a high percentage of tourists and/or recent immigrants)
Education level (1)	Census	1: >30 % of the eligible population (over 18 years of age) has attended, or is attending, a post-secondary education
		2: 20–30 % of the eligible population has attended, or is attending, a post-secondary education
		3: 10–20 % of the eligible population has attended, or is attending, a post-secondary education
		4: 5–10 % of the eligible population has attended, or is attending, a post-secondary education
		5: <5 % of eligible population has attended, or is attending, a post-secondary education

Note 1: Age distribution

The population of young children and senior citizens more vulnerable to harm in the event of a landslide is estimated by the percentage of people between 0 and 5 or over 65 years of age. Since the average life expectancy in Europe is approximately 75 years, a uniform age distribution would indicate that 20 % of the population is 'vulnerable.' This was used as the basis for the age distribution indicator scale

Note 2: Diversity of income of rural population/population density

Rural populations are highly vulnerable because of their lower incomes (on average) and dependence on the surrounding natural resources (e.g., farming, fishing, extractive industry, tourist industry) for sustenance. However, urban regions with very dense populations are more difficult to evacuate during emergencies (Cutter et al. 2003). Although these two categories are not mutually exclusive, they have been separated. The percentage of rural inhabitants appears to be a slightly more influential measure of vulnerability than the percentage of urban inhabitants; therefore, rural is weighted as '2' and urban as '1'

total loss. Carreño (2007b) calculated the total losses from the direct losses by multiplying with an impact factor or aggravating coefficient based on variables associated with the socioeconomic conditions.

- Several case studies applying the method should be performed, and the results will form a basis for interpretation of the single results.

In this work, interpretation of vulnerability scores is performed by comparing scores obtained by case studies. The next section describes application of the method for six case study locations in Europe.

Case studies

The socioeconomic vulnerability is assessed for two locations in Norway and for one location in Greece, Andorra, France and Romania. The case studies are indicated in Fig. 1.

The purpose of the case studies is to test the applicability of the proposed method and to demonstrate several case studies with different characteristics as application examples. The six study areas are characterized by various landslide types and various levels of exposures to hazards:

Table 3 Proposed socioeconomic model: economic indicators

Economic indicators		
Indicators (weights)	Means of data collection	Criteria for indicator ranking (1: low vulnerability, 5: very high vulnerability)
Personal wealth (2)	Census	1: GDP per capita >50,000 USD 2: GDP per capita 30–50,000 USD 3: GDP per capita 20–30,000 USD 4: GDP per capita 10–20,000 USD 5: GDP per capita <10,000 USD
Housing type (3) (see note 3)	Census/maps/ vulnerability studies	1: The majority of constructions are of strong resistance; there are some or none of medium resistance and none of weak resistance 2: The majority of constructions are of strong resistance; there are some or none of medium resistance and some of weak resistance 3: The majority of constructions are of medium resistance; there are some or none of strong resistance and some or none of weak resistance 4: The majority of constructions are of weak resistance; there are some or none of medium resistance and some of strong resistance 5: The majority of constructions are of weak resistance; there are some or none of medium resistance and none of strong resistance (see note 3 for definition of "strong," "medium" and "weak" resistance)
Insurance and disaster funds (2) (Lahidji 2008)	Local government questionnaire	1: Extensive coverage for private and public buildings, existence of government-sponsored landslide funds 2: Insurance coverage for the majority of private and public buildings, limited government funding 3: Widespread landslide insurance in development phase, but not yet accessible to everyone 4: Incomplete support for victims of past landslide events 5: Little or no insurance provided

Note 3: Housing type

Strong resistance refers to thick brick or stone wall and reinforced concrete constructions, medium resistance to mixed concrete-timber and thin brick-wall constructions, and weak resistance to simple timber and very light constructions (Heinimann 1999). The typology of vulnerable houses depends also on the type of landslide

- Skien (south Norway) is characterized by the occurrence of quick clay slides. Quick clay is a marine clay where the salt content is reduced through flushing of ground water. When collapsing due to loading beyond failure or large movements, a quick clay may turn into a liquid.
- Stranda (west Norway) is characterized by a potential unstable rock slope at Åknes of up to 70-mm^2 volume. A large rockslide at Åknes could generate a tsunami in the fjord (Storfjorden) that would flood the communities in Stranda municipality.
- Grevena (northwest Greece) is characterized by earthquake-triggered landslides. Grevena is a town and municipality surrounded by mountains. Landslide hazard mapping has been performed for the broader area identifying regions with high susceptibility to landsliding. Significant slope angles that range from 0° to 90° are presented even inside the city. The vulnerability assessment of different elements at risk (roads, pipelines) exposed to earthquake-triggered landslides has been investigated in a previous study (Pitilakis et al. 2011). The results reveal that most of the expected damages are attributed to the occurrence of permanent ground deformations due to landsliding and not to the effect of ground shaking.
- Andorra la Vella (Andorra) is characterized by rock fall events. Andorra is a mountainous country located in the Eastern-Central Pyrenean Range between France and Spain, with an average elevation of 1,830 m. The rock fall activity in the area poses a continuous threat for persons and infrastructures (Corominas et al. 2005). The capital of Andorra, Andorra la Vella, and its neighboring urban area, Santa Coloma, are situated right next to the Solà d'Andorra slope for some kilometers. In the last decades, demographic pressures resulted in the construction of buildings on areas reached by rock blocks. In 1985, 1997 and 2008 rock blocks of 7, 25 and 30 m^3, respectively, impacted on buildings, in the second case causing the injury of a person. These events raised the public awareness of the

Table 4 Proposed socioeconomic vulnerability model: preparedness, response and recovery indicators

Preparedness, response and recovery indicators		
Indicators (weights)	Means of data collection	Criteria for indicator ranking (1: low vulnerability, 5: very high vulnerability)
Risk awareness (2) (see note 4)	Local government questionnaire	1: Stringent information campaigns on local risks in the community, in schools and for households; most of the residents have lived in the area for a long time
		2: Sporadic distribution of information material on local risk and risk management to households, information signs in the hazard zone
		3: Information on possible risks in the area are available on a website and on signs in the hazard zone
		4: Information on hazard and risk available for experts; people have to look for information themselves, high fluctuation of population
		5: No information on hazard and risk in the area, high fluctuation of population
Early warning capacity (3) (modified after Lahidji (2008))	Local government questionnaire	1: Detailed hazard maps and advanced early warning systems used in coordination with emergency response procedures available
		2: Basic hazard maps available, hazard mapping research ongoing (with some gaps) and basic early warning systems available for researchers
		3: Hazard is a fast-moving landslide; hazard maps and early warning system available
		4: Incomplete assessment of direct impacts on exposed populations, no early warning system
		5: Hazard is a fast-moving landslide, no hazard maps and early warning system available
Regulation control (2) (Lahidji 2008) (see note 5)	Local government questionnaire	1: Stringent guidelines in place to ensure minimal risk to exposed population
		2: Consistent approach to the regulation of construction and land use on the basis of exposure to landslides
		3: Fairly effective regulations for new developments; however, potential problems with older constructions
		4: Some consideration of risk during construction, but inadequate enforcement of regulations
		5: No consideration of risk in planning and construction
Emergency response (2) (Lahidji 2008)	Local government questionnaire	1: Permanent coordination between responders in communities; specialized equipment and well-trained rescue services available throughout the country
		2: Clear definition of roles and responsibilities at local level; proportionate allocation of resources
		3: Existence of an organization of emergency response, with coordination authority; adequate supplies of medical transport, communications and other specialized equipment in all important cities
		4: Professional search and rescue services, evacuation possibilities and central operation centers available in the most landslide-prone areas
		5: Fragmented organization and scattered resources; predominance of voluntary responders
Quality of medical services (1) (see note 6)	Government data	1: >4 hospital beds per 1,000 people
		2: 3–4 hospital beds per 1,000 people
		3: 2–3 hospital beds per 1,000 people
		4: 1–2 hospital beds per 1,000 people
		5: <1 hospital beds per 1,000 people

Table 4 continued

Preparedness, response and recovery indicators		
Indicators (weights)	Means of data collection	Criteria for indicator ranking (1: low vulnerability, 5: very high vulnerability)
Critical infrastructure (3) (see note 7)	Maps/census	1: No critical care facilities and lifelines in the hazard zone
		2: Only a few critical care facilities and no lifelines in the hazard zone
		3: Several critical facilities and lifelines in the hazard zone
		4: Important care facilities, such as hospitals, and major lifelines in the hazard zone
		5: All major critical care facilities and all lifelines in the hazard zone

Note 4: Risk awareness

Length of residence of the inhabitants in the risk area. Inhabitants who have been living in the area for a long time are expected to be better informed about local hazards and risks. Further, if landslides occur frequently in the area, inhabitants who have been living there for a long time might have experience from a former event. Those people are assumed to be better prepared, better informed about local organizational structures and react adequately in case of an emergency

The indicator also includes the information status on hazard, risk and behavior in case of an emergency provided to households, at schools, via the Internet, information events or signs in the hazard zone. An informed society is assumed to be better prepared

Note 5: Regulation control

This indicator takes into account the quality of infrastructure in the region. If there is a significant amount of control over construction guidelines, the infrastructure is generally well built and relatively resilient to landslides

Note 6: Quality of medical services

This indicator is categorized by the number of hospital beds per 100,000 people. However, since the scale under consideration is usually at the local level, the distance to and accessibility of the nearest medical services are also taken into consideration. The scale used is based on data provided by the European Commission Eurostat (2008)

Note 7: Critical infrastructure

The indicator takes into account:

Critical care facilities: hospitals, schools, fire-fighting and police stations, etc.

Critical facilities: large companies or production facilities where many people are located at the same time; chemical or other hazardous material facilities

Lifelines:

A railway network or station and/or major roads, tunnels and bridges in the hazard zone, which might serve as an evacuation route or provide major access to the community

Power stations (e.g., electric, gas) located in the hazard zone. Destruction would lead to an interruption of the power supply

Major telecommunication stations or cables in the hazard zone. A cable break would lead to an interruption of telecommunication and therefore could hamper early warning and emergency response

Major water pipes or stations (e.g., tanks or pumping stations) in the hazard zone. Destruction of these would lead to an interruption of the water supply

risk and the local authorities were mobilized, to take action against possible future rock falls.

- Barcelonnette (southeast France) is characterized by the occurrence of various types of slope movements (shallow slides, large complex landslides, debris flows, rockfalls) affecting both communities and traffic networks in the valley floor and on the slopes (Malet et al. 2005). In the last 20 years, demographic and touristic pressures resulted in the construction of several buildings on unstable slopes and on torrential fans.
- Slănic (southeast-central Romania) is characterized by complex slope movements (translational and rotational slides overtopping deep-seated landslide bodies, earth and debris flows). The resort town is located in the Prahova Subcarpathians, an area prone to landslides because of its lithological and structural char-acteristics (flysch deposits affected by longitudinal and transversal faults and mollase formations). An additional factor controlling the stability of slopes in Slănic and the surrounding area is the historical salt extraction activity. Recurrent landslides following episodes of heavy rainfall or snow melt result in damages to the built environment and infrastructure (especially, transportation lines), and the evacuation or isolation of affected communities.

The data required to rank the indicators were obtained from census data, interviews with people with local knowledge and/or subjective expert judgment of the authors.

Fig. 1 Locations of case studies

Tables 5, 6 and 7 show the ranking of the indicators (i.e., the indicator scores) for the six case study locations.

The social and demographic indicators in Table 5 were found from census data and ranked according to Table 2 (Data collected in 2009–2012). Sources: Statistics, Norway: http://www.ssb.no/english/, Hellenic Statistical Authority: www.statistics.gr, Department of statistics of the Govern of Andorra: http://www.estadistica.ad/, INSEE (2006), http://www.recensement.insee.fr/home.action and National Institute of Statistics, Romania: http://www.prahova.insse.ro/main.php.

Explanations of the ranking of the economic indicators in Table 6 are given below (data collected in 2009–2012):

Skien and Stranda, Norway

- Gross domestic product (GDP) for Skien = \$87,000, for Stranda = \$96,000.
- For both Standa and Skien, the majority of the buildings are wooden houses with reinforced concrete foundation walls, which would be classified as a medium-resistance housing type.
- Insurance and disaster funds: National funding through Finance Norway (FNO) for natural hazards. The insurance against natural hazards is a mandatory addition to the fire insurance.

Grevena, Greece

- Gross domestic product (GDP) per capita for Greece (2012) = \$18,578 (source: www.tradingeconomics.com).

Table 5 Ranking of the social and demographic indicators for the six case study locations

Social and demographic indicators (weights in parenthesis)	Indicator score					
	Skien, Norway	Stranda, Norway	Grevena, Greece	Andorra la Vella Andorra	Barcelonnette, France	Slănic, Romania
Age distribution (2)	1	2	2	1	2	2
Diversity of income of the rural population (2)	1	3	1	1	1.5	1
Population density (1)	2	1	1	5	1	3
Vulnerable groups due to language and cultural barriers (1)	1	1	2	3	1	1
Education level (1)	2	3	2	No data	3	4

Table 6 Ranking of the economic indicators for the six case study locations

Economic indicators	Indicator score					
	Skien, Norway	Stranda, Norway	Grevena, Greece	Andorra la Vella, Andorra	Barcelonnette, France	Slănic, Romania
Personal wealth (2)	1	1	4	2	3	5
Housing type (3)	3	3	4	1	3	4
Insurance and disaster funds (2)	1	1	3	4	1	4

Table 7 Ranking of the preparedness, response and recovery indicators for the six case study locations

Preparedness, response and recovery indicators	Indicator score					
	Skien, Norway	Stranda, Norway	Grevena, Greece	Andorra la Vella, Andorra	Barcelonnette, France	Slănic, Romania
Risk awareness (2)	3	2	4	3	4	4
Early warning capacity (3)	2	1	4	4	3	3
Regulation control (2)	2	3	3	3	1	4
Emergency response (2)	2	1	3	2	3.5	3
Quality of medical services (1)	2	2	2	3	1	2
Critical infrastructure (3)	3	4	3	2	2	3

- The building stock is governed by old (URM or 'low code' R/C) buildings (in particular, URM: 21 % and R/C: 49 %, 'low code;' 11 %, 'moderate code;' 19 %, 'high code') (source: Kappos et al. 2010).
- Widespread landslide insurance in the development phase, but not yet accessible to everyone (estimation based on general information and experience).

Andorra la Vella, Andorra

- Given that Andorra la Vella is the center of economic activity in Andorra, the GDP per capita is assumed to be 75–95 % of the country average. GDP per capita: $39,492 (source: http://www.tradingeconomics.com/).
- The exposed buildings are reinforced-concrete or masonry structures (from the field survey).
- Incomplete support for victims of past landslide events. (The available information is insufficient, and this ranking was selected as the most unfavorable one.)

Barcelonnette, France

- GDP per capita for Alpes-de-Haute-Provence Department: $29,200 in 2010.
- The municipalities can be clearly divided into two groups with different characteristics: (1) Enchastrayes, Uvernet and Barcelonnette are characterized by large buildings, most of them comprising more than ten dwellings, constructed in the period 1950–1990; (2) Faucon-de-Barcelonnette, Jausiers, Saint-Pons, Méolans, Les Thuiles and La Condamine are characterized by small individual chalets that are either old (built before 1915)

or built in the period 1950–1990. These chalets are expected to be less resistant than the larger constructions of Barcelonnette, Uvernet and Enchastrayes.
- Existence of a natural disaster decree (national funding) and a national insurance system for disasters.

Slănic, Romania

- Gross domestic product (GDP) 91 % of country average (based on census data). GDP for Romania = $9,290 in 2011 (http://www.globalpropertyguide.com/Europe/Norway/gdp-per-capita).
- The majority of constructions (99, 63 %; 2011 census data) are residential buildings; the building stock is generally of weak resistance (adobe or wood structures with low-stiffness walls) for individual units, followed by medium-resistance buildings (multiple or individual masonry structures with well-joined walls or mixed with stone). A limited number are of strong resistance (multi-story apartment buildings out of reinforced concrete; from the field survey).
- Landslide insurance is mandatory by law (Law 260/2008); however, the number of contributors is very limited, and the maximum premium is €20,000 (https://www.paidromania.ro/). The necessary resources to resist and recover from the impact are (in almost all cases) entirely state contributions and generally estimated as insufficient.

Explanations to the ranking of the preparedness, response and recovery indicators in Table 7 are given below (data collected in 2010–2012). List numbers correspond to (1) risk awareness, (2) early warning capacity, (3) regulation control, (4) emergency response, (5) quality of medical services and (6) critical infrastructures.

Skien, Norway

1. Information about landslide risk is provided on the Internet, e.g., skredatlas.nve.no, and reports are available from the authorities online.
2. Basic hazard maps are available.
3. Consistent approach to the regulation of construction and land use on the basis of exposure to landslides.
4. Clear definition of roles and responsibilities at the local level; proportional allocation of resources.
5. In census data, the number of hospital beds is not given; the ranking is based on the number of medical doctors.
6. Infrastructure affected: railway, major roads in Gråten, Borgestad, two schools in Skien, Gråten kindergarden in the city center of Skien, one bigger care facility in Skien.

Stranda, Norway

1. The population is aware of the landslide (and tsunami) risk through Internet and media presence.
2. Basic hazard maps are available; an advanced early warning system is used in coordination with emergency response procedures.
3. Regulation control: Fairly effective regulations for new developments; however, potential problems with older constructions.
4. Permanent coordination between responders in communities; specialized equipment and well-trained rescue services available throughout the country.
5. In census data, the number of hospital beds is not given; the ranking is based on the number of medical doctors.
6. The whole community would be affected if a tsunami is generated by a rockslide from Åknes.

Grevena, Greece

1. Geotechnical, geological and topographic maps as well as hazard and risk assessment studies are available in public organizations and authorities. No information is provided to the population.
2. Basic hazard maps available. Incomplete assessment of direct impacts on exposed populations through preliminary studies; no early warning system in the area.
3. Fairly effective regulations for new developments, especially due to seismic loads. However, there are potential problems with older constructions designed with no or low code provisions.
4. Existence of an organization of emergency response with coordination authority; adequate supplies of medical transport, communications and other specialized equipment in all important cities in Greece. The experience from past events in the area (e.g., the earthquake on 13 May 1995, $M = 6.6$) and the territory of northwest Greece have contributed to the improvement of emergency response.
5. 3.0–3.6 beds per 1,000 people (source: http://www.ygeianet.gov.gr).
6. Several critical facilities and lifelines in the boarder hazard zone such as the Egnatia Motorway (bridges, tunnels and other civil works), the General Hospital of Grevena and other infrastructures (i.e., local road and water supply systems).

Andorra la Vella, Andorra

1. The most important rock fall risk mitigation action carried out was the Rockfall Risk Management Master Plan of the Solà d'Andorra, which was completed in May 1998. The most important achievement is the change in the perception of risk by the stakeholders. The awareness of rock fall hazard has risen with the public audiences, building codes and control works. The Andorran administration is currently engaged in

Table 8 Result of vulnerability assessment for the six case study locations (A score of 1 corresponds to the lowest vulnerability and 5 to the highest vulnerability)

Indicator group	Skien, Norway	Stranda, Norway	Grevena, Greece	Andorra la Vella , Andorra	Barcelonette, France	Slănic, Romania
Demographic and social indicator score	1.3	2.1	1.6	2.0	1.7	2.0
Economic indicator score	1.9	1.9	3.7	2.1	2.4	4.3
Preparedness, response and recovery indicator score	2.4	2.2	3.3	2.8	2.5	3.2
Aggregated vulnerability score	2.0	2.1	3.0	2.5	2.3	3.2

Relative vulnerability colour scale:

Low High

an ambitious program of rock fall risk mitigation with special interest in both the urban areas and main road network.

2. Incomplete assessment of direct impacts to exposed populations, no early warning system.
3. Master plan of the Solà d'Andorra established restriction of development in the most threatened sectors.
4. Clear definition of roles and responsibilities at the local level; proportionate allocation of resources.
5. 2,60 Hospital beds per 1,000 (year: 2006) (source: Instituto Nacional de Estadística, España).
6. Critical infrastructure: high energy dissipative steel fences to protect the exposed areas.

Barcelonnette, France

1. Information on hazard and risk available for experts; people have to look for information themselves.
2. Existence of detailed local hazard maps (PPR—Plan de Prévention des Risques) for eight of the ten municipalities.
3. Good because of the existence of local hazard maps.
4. Existence of preparedness (or local rescue) plans (called Plan Communal de Sauvegarde, PCS) in two out of the ten municipalities; the eight other municipalities have to prepare their PCS within the next 5 years. Rescue service based on civil protection, fireman and volunteers.
5. Local hospital has 64 hospital beds, which represents 943 hospital beds per 100,000 people.
6. Critical infrastructure: main national road for access to Italy and ski resort areas, high voltage electricity lines.

Slănic, Romania

1. Information about landslide risk is mostly available for experts and decision makers. The main instrument of spatial planning at the local level is the General Urbanistic Plan (PUG), where areas affected by landslides and floods are identified and delimited. Risk awareness varies among citizens according to personal experience.
2. No early warning system for landslides or hazard maps is available. There is incomplete assessment of direct impacts to exposed populations and assets. However, geotechnical studies and monitoring of slope stability were performed at specific locations.
3. Inadequate enforcement of building control regulations.
4. Coordinating authority at (1) the regional level: Emergency Situations Inspectorate Prahova; (2) local level: Local Committee for Emergency Situations; adequate emergency services and collaboration with police, firefighters and hospitals.
5. Local hospital has 40 hospital beds (source: www.prahova.insse.ro); the number of beds per 100,000 people is 628.5 in 2010 (source: http://epp.eurostat.ec.europa.eu/).
6. Critical infrastructure: transportation network, electricity powerlines, water supply networks. The site is considered an important touristic attraction in the region; thus,

reception and recreational facilities exposed to hazards are subjected to damage in the case of a landslide event.

Table 8 shows the aggregated vulnerability score within each group of indicators and the aggregated vulnerability score as calculated from the indicator scores in Tables 5, 6 and 7.

The Norwegian locations of Skien and Stranda obtained the lowest vulnerability score in the study (2.0 and 2.1, respectively). Many of the indicators that contributed to the low vulnerability score are similar for the whole of Norway, including age distribution, personal wealth, urban population, insurance and disaster funds, and quality of medical services.

Stranda obtained the lowest score on the preparedness, response and recovery components. In Stranda, the Åknes/Tafjord project was initiated in 2005 by the municipalities to investigate rockslides, establish monitoring systems, and implement a warning and evacuation system to prevent fatalities should a massive, tsunami-genic rockslide take place. On the other hand, Stranda obtains a higher score on the critical infrastructure component (see Table 7) because a large number of critical care facilities, critical facilities and infrastructure is located in the hazard zone.

Barcelonnette in France and Andorra la Vella obtained vulnerability scores of 2.3 and 2.5, respectively, which are slightly higher than those of the Norwegian sites. Compared to the other locations, Andorra la Vella obtained a lower vulnerability score on the economic component, but higher on the demographic and social components. Barcelonette obtained a relatively low vulnerability score on preparedness, response and recovery but higher on the economic component.

Grevena in Greece obtained a higher vulnerability score (3.0) and Slănic in Romania obtained the highest vulnerability score (3.2) among the analyzed locations. Grevena in particular scored high on the economic component as well as rather high on the preparedness, response and recovery components. Slănic had the highest vulnerability scores of all components except the demographic and social components, with particularly high scores on the economic as well as the preparedness response and recovery components.

To interpret the results individually, one could define thresholds for division of the results into vulnerability classes such as 'low,' 'medium' and 'high.' The simplest choice of threshold for vulnerability levels would be a linear scale:

- Low vulnerability: scores 1–2.33
- Medium vulnerability: scores 2.33–3.66
- High vulnerability: scores 3.66–5.

According to such a definition, the socioeconomic vulnerability for the locations in Norway and France would be classified as 'low,' for Andorra la Vella it would be classified as 'medium' (toward "low"), and for Grevena in Greece and Slănic in Romania the socioeconomic vulnerability would be classified as 'medium.' However, since the method is not based on disaster impact data, the above-mentioned division into vulnerability classes is subjective and based on expert judgment. To improve the interpretation of the vulnerability score, the socioeconomic vulnerability for a large number of locations could be assessed. Then it would be possible to analyze the results statistically to generalize and draw conclusions about interpretations of the individual vulnerability scores.

Discussion and conclusion

The proposed model assesses the level of socioeconomic vulnerability by ranking the vulnerability on a relative scale (1–5). Application of this model to map the vulnerability enables the comparison of socioeconomic vulnerability between communities in Europe. The model defines criteria for assigning a score to every indicator, which may be a qualitative, semiquantitative or quantitative parameter. The ranking approach and unambiguous score criteria make the model easy to use. The model is simple and permits the vulnerability evaluation at a local to regional scale. Using Geographical Information Systems (GIS), it is possible to scale up the model and its results, taking into account the spatial variation of the indicator scores.

The proposed method is developed for European conditions and modes of living. The model could also be applied for or adapted to other similar countries.

A logical future step would be to calibrate the model against historical data; comparison of recovery time for communities hit by comparable impacts is one possibility for calibration. It would also be both interesting and useful to gather data for validation purposes in the immediate aftermath of an event. This model may also be transferred to and combined with an existing quantitative vulnerability model (Li et al. 2010). Although presently it is not an intensity-associated model, it might permit the calculation of the vulnerability as a function of the expected event intensity through the proper ranking of indicators for different intensities. Then the absolute estimates of vulnerability in terms of degree of loss within predefined space and time frames could be made, which allows direct calibration against disaster loss data.

The model was applied to assess the socioeconomic vulnerability level of six case studies in Europe by identifying the indicators and indicator groups contributing most to the vulnerability for each location; see Tables 7 and 8. The purpose of the indicators used in this model is to raise awareness and to provoke some action for vulnerability reduction. The natural step to reduce the vulnerability would be to focus on the indicators that contribute most to the risk. Some indicators are difficult to change (e.g., the social and demographic indicators), while others could be changed through government policies (e.g., to improve the regulation control).

The proposed method is flexible, allowing the comparison in terms of total vulnerability scores for several landslide types. The comparison of vulnerability scores is useful in order to interpret a single vulnerability score and to define the most critical areas in terms of vulnerability. Mapping of vulnerability is also useful for preparation of response to impacts from landslides. However, since the study areas are exposed to different types of landslides, it would be more relevant to compare the risk.

When applying the model, low socioeconomic vulnerability does not necessarily imply low risk. The risk depends also on the temporal probability and intensity of the potential impact. Nadim et al. (2006) defined the physical exposure as the annual frequency of a hazard with specified severity multiplied by the number of persons exposed. A relative risk value could be obtained by multiplying the physical exposure with the vulnerability scores obtained with this method. For locations with similar physical exposures, the relative risk values would have a similar ranking as the relative socioeconomic vulnerability values. All the locations selected for the case studies are areas with high landslide susceptibility. By comparing the risk associated with landslides, the priorities for mitigation actions can be defined by the authorities/stakeholders at the national, European or even Pan-European level in order to maximize safety levels and optimize resource usage in European regions susceptible to slope instability.

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