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Socio-economic vulnerability to natural hazards – proposal for an indicator-based model

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ABSTRACT: The severity of a natural hazard impact on a society depends, among others on the intensity of the hazard and vulnerability factors like the number, and resistance of exposed elements (e.g. persons, buildings and infrastructure). Social conditions strongly influence the vulnerability factors both for direct and indirect impact and therefore have the power to transform the occurrence of a natural hazard into a natural disaster.

This paper presents a model, using an indicator-based methodology, to assess relative socio-economic vulnerability to landslides. The indicators represent the underlying factors which influence a community's ability to deal with, and recover from the damage associated with landslides. The proposed model includes indicators which represent demographic, economic and social characteristics as well as indicators representing the degree of preparedness and recovery capacity. Although this model focuses primarily on the indirect losses, it could easily be extended to include more physical indicators which account 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. Application of the proposed model is shown for a Norwegian community.

Keywords: Socio-economic vulnerability, indicator-based vulnerability models

1 INTRODUCTION

Vulnerability assessment, with respect to natural hazards, is a complex process that must consider multiple dimensions of vulnerability, including both 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. However, social factors such as preparedness and institutional and non-institutional abilities for handling natural hazards events are also important elements for 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 the natural hazards.

Social vulnerability models can be used in combination with physical vulnerability models to estimate both direct losses, i.e. losses that occur during and immediately after the impact, as well as indirect losses, i.e. long-term effects of the event. Direct impact of a landslide typically includes casualties and damages to buildings and infrastructure while indirect losses may include business closures or increased levels of homelessness. The direct losses are mainly assessed using physical vulnerability indicators (e.g. construction material and height of buildings) while indirect losses are mainly assessed with social indicators (e.g. economical resources). The 2010 Haiti earthquake caused enormous direct losses (fatalities and collapsed buildings). One year later, long term effects such as diseases, unemployment and homelessness are still prevailing.

2 BACKGROUND

The proposed model uses an indicator-based methodology to assess socio-economic vulnerability to landslides. A vulnerability indicator is a variable which 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 linked with a hazard of natural origin (Birkmann, 2006).The purpose of the indicators is to set priorities, serve as background for action, raise awareness, analyze trends and empower risk management.

Indicator-based risk models may be divided into two main groups: i) deductive, where measurement of risk is hazard specific and based on disaster impact data or ii) inductive, where measurement of risk is based on underlying factors which influence a community's ability to deal with, and recover from an impact. Such methods are less hazard specific or hazard independent. The model proposed in this paper belongs to the inductive models.

Vulnerability indicators may be expressed at a specific geographical scale (local, regional or global), at a specific organizational level (individual, household, community or national) and for different hazard types. As landslides rarely have socio-economic consequences at global or national levels, the most relevant level for landslides would be community level. With focus on the models applicable to community level, the proposed model is adapted to European conditions based on the work of Steinführer et al. (2009), Tapsell et al.(2005), King and MacGregor (2000), Lahidji (2008) and Cutter et al. (2003).

Steinführer et al. (2009) and Tapsell et al.(2005) describes socio-economic vulnerability for floods for European countries, Lahidji (2008) propose a model for assessing coping capacity developed for Asia, but applicable globally for several hazard types, and Cutter et al. (2003) proposed a social vulnerability index for environmental hazard for use in USA, applicable to community level.

2.1 Choice of indicators

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

- What and who is most vulnerable in the society? (e.g. vulnerable groups of people, vulnerable industries, vulnerable buildings)
- Is the population prepared for an emergency? (e.g. emergency response procedures, existence of early warning system, etc.)
- Are there available resources for recovery? (e.g. resources for rebuilding destroyed physical environments, medical facilities)

In the proposed model, the most vulnerable groups considered and assessed were "children and people above 65 years of age", "people with language and cultural barriers" and "rural populations dependent on the land for their primary source of income". Additionally, the "housing type" indicator was considered very important for the assessment of building vulnerability levels.

Preparedness levels were ranked based on the quality of existing hazard evaluations and early warning systems, the stringency of regulation control and the extent of emergency response procedures.

The ability to recover from a landslide was assessed by analyzing insurance and disaster funds and the quality of medical services and finally, the population density was considered, as it is more difficult to evacuate and care for highly dense populations.

2.2 Aggregation of indicators

A weighting system is introduced to account for the relative importance of each indicators on the total vulnerability level. If all the indicators are believed to be of equal significance, equal weighting should be applied. Other techniques to determine weights include expert judgment, analytical hierarchy process, principal component analysis and factor analysis.

The model for aggregation of vulnerability indicators may be quantitative where the vulnerability is a dimensionless number between 0 to 1 representing the degree of loss within a given time- and space-frame, or semi-quantitative where the vulnerability is ranked relatively according to a scale defined within the model. The main groups of models used for the aggregation of indicators are:

- Additive models, produced by e.g. multi-criteria decision approach.
- Multiplicative models, produced by e.g. multiple regression models.
- Definition of vulnerability by decision rules, produced by e.g. use of decision trees.

3 PROPOSED MODEL FOR SOCIO-ECONOMIC VULNERABILITY ASSESSMENT

The proposed model includes indicators which represent demographic, economic and social characteristics as well as indicators representing the degree of preparedness and recovery capacity as outlined in section 2.1. The model describes the vulnerability semi-quantitatively, with additive aggregation of the indicators. 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 among the values 1, 2 and 3, where weight 1 is assigned to the least influential indicators, 2 to the intermediate influential indicators and 3 to the most influential indicators. In the proposed model, the assignment of weights to the indicators is based on literature review and expert judgment. Table 1 shows the proposed socio-economic vulnerability model with suggested indicators, their corresponding weights and criteria for ranking of the indicators.

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

$$\text{Total vulnerability score value} = \sum \text{Weighted vulnerability score} / \sum \text{Weights}$$

Application of the model is shown in section 4.

Table 1. Proposed socio-economic vulnerability model

Indicators	Weights	Criteria for indicator ranking (1: Low vulnerability, 5: very high vulnerability)
Demographic Indicators		
Age distribution (see note 1)	2	1: Uniform age distribution - less than 20% population is either between 0-5 years of age or over 65.
		2: 20-30% population is either between 0-5 years of age or over 65.
		3: 30-40% population is either between 0-5 years of age or over 65.
		4: 40-50% population is either between 0-5 years of age or over 65.
		5: Over 50% population is either between 0-5 years of age or over 65.
Housing type (see note 2)	3	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.
Rural population (see note 3)	2	1: Less than 10% population is dependent on the land for primary source of income.
		2: 10-25% population is dependent on the land for primary source of income.
		3: 25-50% population is dependent on the land for primary source of income.
		4: 50-75% population is dependent on the land for primary source of income.
		5: Over 75% population is dependent on the land for primary source of income.
Urban population (see note 3)	1	1: Population density is < 50 people/km^2
		2: Population density is between 50-100 people/km^2
		3: Population density is between 100-250 people/km^2
		4: Population density is between 250-500 people/km^2
		5: Population density is > 500 people/km^2
Economic Indicators		
Personal wealth	2	1 : GDP per capita > 50 thousand USD
		2 : GDP per capita 30 – 50 thousand USD
		3 : GDP per capita 20 – 30 thousand USD
		4: GDP per capita 10 – 20 thousand USD
		5 : GDP per capita < 10 thousand USD

Social Indicators		
Vulnerable groups due to language or cultural barriers	1	1: < 5% of the population is not familiar with majority language and culture 2: 5-10% of the population is not familiar with majority language and culture 3: 10-15% of the population is not familiar with majority language and culture 4: 15-25% of the population is not familiar with majority language and culture 5: > 25% of the population is not familiar with majority language or culture (indicative of a high percentage of tourists and/or recent immigrants)
Education Level	1	1: > 30% of the eligible population (over 18 years of age) have attended, or are attending, a post-secondary education 2: 20-30% of the eligible population have attended, or are attending, a post-secondary education 3: 10-20% of the eligible population have attended, or are attending, a post-secondary education 4: 5-10% of the eligible population have attended, or are attending, a post-secondary education 5: <5 % of eligible population have attended, or are attending, a post-secondary education
Preparedness indicators		
Hazard evaluation (Lahidji, R., 2008)	3	1: Detailed hazard maps available 2: Basic hazard maps available 3: Hazard mapping research ongoing (with some gaps) 4: Basic assessment of direct impacts to exposed populations completed 5: Incomplete assessment of direct impacts to exposed populations
Regulation control (Lahidji, R., 2008) (see note 4)	3	1: Stringent guidelines(which take into account all landslide triggers) in place for all constructions and land-use activities 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 (Lahidji, R., 2008)	2 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
Early warning system (Lahidji, R., 2008)	2 Local government questionnaire	1: Advanced early warning systems used in coordination with emergency response procedures 2: Adequate early warning system coordinated with media announcements capable of reaching the majority of the population prior to the landslide 3: Basic early warning systems available to the public 4: Basic early warning system available to risk managers 5: No early warning system

Recovery indicators		
Insurance and disaster funds (Lahidji, R., 2008)	2 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
Quality of medical services (see note 5)	1 Government data	1: > 4 hospital beds per 1000 people
		2: 3 - 4 hospital beds per 1000 people
		3: 2 - 3 hospital beds per 1000 people
		4: 1 - 2 hospital beds per 1000 people
		5: < 1 hospital beds per 1000 people

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 0-5 years of age or over 65. 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: 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).

Note 3: Rural/urban population:
Rural populations are highly vulnerable due to their lower incomes (on average) and dependence on the surrounding natural resources (e.g., farming, fishing) for sustenance. However, urban regions with very dense populations are more difficult to evacuate during emergencies (Cutter et al., 2003).

Note 4: 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 5: Quality of medical services:
This indicator is categorized by the number of hospital beds per 100 000 people. The scale used is based on data provided by the European Commission Eurostat (2008).

4 APPLICATION OF THE MODEL

This section shows the application of the model to the Norwegian city Skien. Skien is a city on the Southern coast of Norway with about 50 000 inhabitants. The area is especially prone to clay landslide because of quick clay deposits. Quick clay is marine clay, where the salt content is reduced through flushing of ground water. When quick clay is either exposed to loads or movement, the clay may turn into a liquid.

The data required to rank the indicators was obtained from census data, interviews (with people knowledgeable of Skien) and/or subjective judgment of the authors.

Table 2 shows the result of the indicator ranking and calculation of the socio-economic vulnerability score for Skien.

Table 2. Calculation of vulnerability score for Skien

Indicator	Indicator score	Indicator weight	Weighted vulnerability score
Age distribution	1	2	2
Housing type	3	3	9
Rural population	2	2	4
Urban population	1	1	1
Personal wealth	1	2	2
Vulnerable groups	1	1	1
Education level	2	1	2
Hazard evaluation	2	3	6
Regulation control	2	3	6
Emergency response	2	2	4
Early warning system	5	2	10
Insurance and disaster funds	1	2	2
Quality of medical services	2	1	2
Total, Σ	Weighted average vulnerability score = 51/25 = 2.04	∑ Weights= 25	∑ Weighted vulnerability score= 51

The vulnerability score for Skien is 2.04, where 1 is the lowest possible vulnerability score and 5 is the highest possible vulnerability score.

5 CONCLUSION AND DISCUSSION

The model proposed in this paper assesses the level of socio-economic vulnerability by ranking the vulnerability on a relative scale. Application of this model enables comparison of socio-economic vulnerability between communities within Europe. This model defines criteria for assigning a score to every indicator, which may be a qualitative, semi-quantitative or quantitative parameter. The ranking approach and unambiguous score criteria make the model easy to use.

This model is still under development and the choice and weighting of indicators will be validated and improved by performing more case studies for European communities. The model may also be extended to include more physical indicators to account for the direct losses.

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. This model may also be transferred to, and combined with an existing quantitative vulnerability model (e.g. Li et al. (2010)). 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.

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