

# Elements at risk as a framework for assessing the vulnerability of communities to landslides

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**Abstract.** The assessment of the vulnerability of communities prone to landslide related disasters is a topic that is growing in importance. Few studies discuss this issue and limited research has been carried out on the relationship between types of landslide and their potential impact on buildings and infrastructure. We outline a framework to undertake an assessment of the vulnerability of buildings to landslide utilising a similar framework used for assessing the vulnerability of buildings to tsunami damage. The framework is based on the development of an “elements at risk database” that takes into consideration the characteristics and use of the buildings, their importance for the local economy and the characteristics of the inhabitants (population density, age and so forth). The attributes that affect vulnerability are imported and examined within a GIS database which is used to visualise the physical, human and economic vulnerability. The results may have important implications for disaster management and emergency planning, and the database can be used by various end-users and stakeholders such as insurance companies, local authorities and the emergency services. The approach presented here can be integrated in to a wider more detailed “Framework for Landslide Risk and Vulnerability Assessment for Communities”. We illustrate the potential of this framework and present preliminary results from Lichtenstein, Baden Württemberg, Germany.

## 1 Introduction

Globally, landslides are responsible for significant loss of life and injury to people and their livestock as well as loss of and damage to lifelines, critical infrastructure, agricultural lands, housing and public and private infrastructure and assets (JRC, 2003; Blöchl and Braun, 2005; USGS, 2001;

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UNU, 2006). Landslides are the expression of slope instability and they belong to a wider group of processes called mass movements (Glade and Crozier, 2005). Landslides are often categorised in terms of material (earth, rock, debris) and moving process (fall, slide, topple) (Glade and Crozier, 2005). In this paper, based on the dominant type of landslide in the study area we are focusing on, the prominent form of landslide processes which include translation slides and flows and rotational slides.

The effects of landslides can be very significant and vary according to geographic location. For example, landslides in Europe cause significant economic losses, whereas, in Asia and Latin America, they cause great loss of life. According to the OFDA/CRED International Disaster Database, between 1903 and 2004, 75 landslide events were recorded in Europe resulting in the loss of 16 158 lives (an average of 215 people per event), left 3125 homeless and resulted in damages in excess of US\$1.7 billion (Table 1) (UNU, 2006). It is highly possible that climate change in combination with wide-scale development on steep slopes has increased the impact of landslide events and the disasters they may cause globally (UNU, 2006). Climate change can affect the occurrence of landslides in two ways: increasing rainfall intensity and frequency, and changes in soil temperature which can lead to reduced slope cohesion and stability (UNU, 2006). Other phenomena that can trigger landslides include earthquakes, volcanic eruptions and inappropriate human activities such as mining and poorly planned developments (UNU, 2006).

In Europe (and in our study area in particular), large magnitude landslides have a low probability of generating “catastrophic” events (as defined by a significant loss of human life) but they do have considerable social, economic and ecologic consequences (Blöchl and Braun, 2005; Scavia and Castelli, 2003). The concentration of property on steep slopes, high standard of living and high population density all combine to make society vulnerable to landslide events

**Table 1.** Landslides worldwide: 1903-2004.

	Events	Killed	Injured	Homeless	Affected	Total Affected	Damage USD (000's)
Africa	22	721	56	7,936	11 748	19 740	0
Average per event		33	3	361	534	897	0
Americas	139	20 532	4750	186 752	4 476 441	4 667 943	1 317 927
Average per event		148	34	1344	32 205	33 582	9482
Asia	220	15 754	3464	3 742 596	1 309 796	5 055 856	534 229
Average per event		72	16	17 012	5954	22 981	2428
Europe	75	16 158	743	3125	37 668	41 536	1 705 689
Average per event		215	10	42	502	554	22 743
Oceania	15	528	52	8000	2963	11 015	2466
Average per event		35	4	533	198	734	164

Source: OFDA/CRED International Disaster Database, Universite Catholique de Louvain, Belgium

– even those of small magnitude (Blöchl and Braun, 2005). Landslides may have very significant impacts on buildings and are very expensive in terms of the costs of rehabilitation, securing the structures and ongoing maintenance. Interestingly, the impact of landslide processes is often underestimated and overlooked because they frequently occur in combination with other events such as floods, earthquakes and volcanic eruptions (USGS, 2001; Blöchl and Braun, 2005; JRC, 2003).

Helmer and Hilhorst (2006) have suggested that climate change may be connected to an increase in the number of natural disasters worldwide and the primary message for disaster management should be on the reduction of vulnerability to such extreme natural processes. Consequently, an enhancement of capacity-building and resilience is essential (Helmer and Hilhorst, 2006). Further, any changes in the frequency and intensity of and exposure to landslides requires a vulnerability assessment framework that takes into consideration the natural, built and human environments. This is important since a proper understanding of vulnerability can lead to more effective emergency management and in the development of mitigation and preparedness activities all of which are designed to reduce the loss of life and economic costs.

## 2 Existing methods for vulnerability assessment and the need for a new method

Before a description of our framework is provided we outline the basic concepts of landslide hazard, risk and vulnerability. UNDRO (1979) (cited by Glade, 2003) defined risk around is various elements through the following equation:

$$R = H \times E \times V \quad (1)$$

Where:

*R*: Risk, referring to the expected number of lives lost, persons injured and damage to property or disruption of economic activity due to a particular event.

*H*: Natural hazard, defined as the probability of occurrence of a potentially damaging event within a specified time and given area.

*E*: Elements at risk, including population, buildings and engineering structures, infrastructure areas and lines, public service utilities and economic activities.

*V*: Vulnerability related to the (potential) results from event occurrence expressed with qualitative, semi-quantitative or quantitative methods in terms of loss, disadvantage or gain, damage, injury or loss of life.

In the field of landslide research, most studies have focused on the landslide hazard part of this equation and have resulted in the generation of landslide hazard maps which include “hazard zones”. Few have concentrated on the risk and vulnerability elements. A number of studies have tried to examine both risk and community vulnerability and a very limited number have examined vulnerability specifically.

Hollenstein (2005) conducted a review of existing vulnerability assessment methods associated with different hazard/disaster types and concluded that studies dealing with landslide vulnerability are very limited. Hollenstein (2005) recorded more than 100 related to earthquake vulnerability, more than 100 regarding wind related vulnerability models but less than twenty involving gravitational hazards such as landslides, debris flows, snow avalanches and floods. Hollenstein (2005) suggests that one potential reason for this lack of vulnerability research is that gravitational processes are usually accurately delimited and the most common strategy of the authorities and other stakeholders is to simply avoid areas likely to be affected. A further reason might be that the institutions responsible for the management of these hazards have enough empirical knowledge so that they do not need theoretical models (Hollenstein, 2005).

Bell and Glade (2004) using a Quantitative Risk Analysis framework for landslides in Iceland acknowledged a gap in relation to the assessment of vulnerability of elements at risk.

They used general information about the houses within their “at risk” areas based on the material of the buildings and the existence of large windows on the mountain side. However, no detailed investigation of building types was carried out. The vulnerability of the people in structures was assumed by multiplying the vulnerability of buildings with the vulnerability of people. The vulnerability of buildings and people was determined based upon the landslide processes and their magnitude. As outputs they provided an “elements at risk map” based on number of residents and employees and a *total* risk map. Vulnerability to landslides is also discussed by Glade and Crozier (2005) who determine the vulnerability of people according to their location (open space, vehicle or building). Gomes (2003) included a vulnerability assessment element for landslides within a Quantitative Risk Analysis (QRA) framework based on a weighting of elements at risk that gives the highest weighting to human life. Gomes’ criteria included the presence, frequency and absolute number of human lives, infrastructure (public, residential etc.) and productive function and activities (industry, agriculture, etc.). Although vulnerability was considered in the work of Gomes (2003), its inclusion was the means of producing a risk map so there was no final map demonstrating explicitly the vulnerability pattern.

An interesting study has been carried out by the Department of Hydrology and Meteorology of Nepal (Shrestha, 2005<sup>1</sup>). The study includes both the physical and social vulnerability to landslides and floods. The physical vulnerability was calculated and mapped on the basis of a combination between physical exposure (population, households, agricultural land, road length) and hazard. The social vulnerability assessment considered factors such as telephone lines, hospitals, banks etc., per number of inhabitants and economic diversity. The study points out the significance of vulnerability assessment since it proves that although the hazard has decreased the vulnerability has risen due to higher physical exposure and lower adaptive capabilities (Shrestha, 2005<sup>1</sup>).

Lastly, a QRA undertaken by the Geotechnical Engineering Office (GEO) is also of note. Their QRA was part of “Slope Safety” – a long term program aimed at identifying the quickest possible method to reduce landslide risk to the community of Hong Kong. The QRA includes a “Consequence Analysis” which considers the vulnerability of the elements at risk by assessing the conditional probability of the consequences occurring given the occurrence of a hazard. The result of the application of the QRA technique in Hong Kong was a reduction of the overall landslide risk from sub-standard man-made slopes to less than 5% in 23 years (1977–2000) (<http://hkss.cedd.gov.hk/hkss/eng/studies/qra/>).

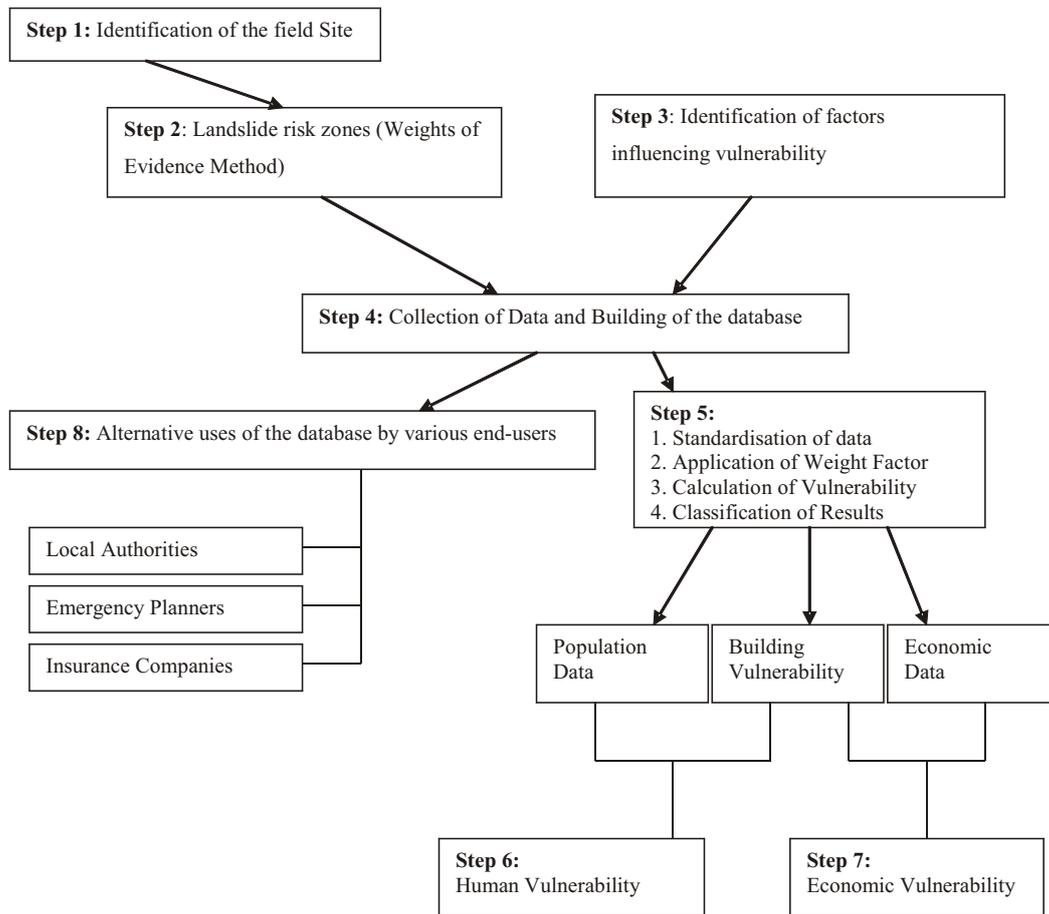
<sup>1</sup>Shrestha, A.: Vulnerability assessment of weather disasters in Syangja District, Nepal: A case study in Putalibazaar Municipality, Advances Institute on Vulnerability to Global Environmental Change, submitted, 2005.

From this short review of the literature related to landslide hazard, risk and vulnerability, it is apparent that there is no common approach used for the assessment of vulnerability for communities prone to landslide related disasters that can be used as a tool for effective emergency and disaster management. Given this lack of conformity and the gap in landslide vulnerability research identified by Hollenstein (2005), we present a framework for assessing the vulnerability of buildings structures to landslides. Our framework utilises a similar framework already developed for tsunami (Papathoma, 2003). For the purposes of demonstration, the framework will be applied to a landslide prone area using preliminary data for the village of Lichtenstein in the Swabian Alb region of Germany, where a previous landslide susceptibility assessment study has been conducted (Neuhäuser, 2005). This assessment indicated the landslide susceptibility zones of a wider area in the Swabian Alb. The aim of the present study is to present a framework that is able to identify the vulnerability of buildings located within the landslide susceptibility zones. Due to difficulties with the availability of data and for ease of demonstration, we only assess the vulnerability of buildings within the “medium” and “high” susceptibility zones of Neuhäuser (2005) rather than a comprehensive “vulnerability map” of the entire Swabian Alb.

Adger (2006) suggests that key parameters affecting vulnerability are the stress to which a system is exposed, its sensitivity and its adaptive capacity. According to Adger (2006), there are two major research traditions in vulnerability: the analysis of vulnerability as lack of entitlements and the analysis of vulnerability to natural hazards. The basis of the second tradition is the physical elements of exposure, probability and impacts of hazards. In the present work we focus on this approach by using a model based on first principles of physical and engineering elements.

Vulnerability is a dynamic element that should be assessed taking into consideration temporal and spatial aspects. Not everything and everyone located within the risk zone is equally vulnerable. By having a detailed spatial pattern of the vulnerability within a community, the priorities for the local authorities in regard to the preparedness phase of the disaster cycle, as well as the priorities of the rescue teams in the response phase, can be effectively established. There are some characteristics of the built and social environment that influence the vulnerability of the community, therefore, the first step of the study is to identify those characteristics by looking at the impact of previous landslide events on inhabitants, buildings and infrastructure. These characteristics will be collected for each building in the area of interest and they will be imported in a GIS database. A weigh factor for each characteristic can then be assigned, given the fact that not all the factors are equally important for the overall vulnerability of the unit, and an overall vulnerability for each unit will be calculated using a *Multi Criteria Evaluation Method* and particular, the *Weighted Linear Combination Method*. According to the *Weighted Linear Combination Method* a weight

## METHODOLOGY



**Fig. 1.** The steps of the vulnerability assessment methodology.

is assigned to every factor that influences the vulnerability and for every building within the study area a vulnerability value is calculated. Subsequently, the human vulnerability can be calculated on the basis of the building vulnerability and the population density. At this point it is important to mention that the calculation of the population density during the day/night and summer/winter is important as it is taking into consideration the temporal dimension of the vulnerability which may be especially important in an area of high tourist activity.

The results are presented in a map that can be used as the basis for emergency management decision-making. The GIS database produced is a useful tool for various stakeholders of the community such as local authorities, rescue teams, individuals and insurance companies. The specific framework was first developed for tsunami related disasters (Papathoma, 2003) and has been applied to two coastal areas in Greece that are susceptible to tsunami flooding (Papathoma et al., 2003; Papathoma and Dominey Howes, 2003). In Fig. 1 the methodological steps are shown. The framework is based on the development of a database (Step 4, Fig. 1) containing the

factors that affect the physical, social and economic vulnerability of a community and they can result either in a building/human/economic vulnerability map (Steps 5, 6, 7) or the utilisation of the database by various end-users (Step 8). Recently, it was evaluated using evidence from the 2004 Indian Ocean tsunami (Dominey-Howes and Papathoma, 2007).

### 3 The proposed framework and the Swabian Alb

In the following paragraphs the method developed by Papathoma (2003) is modified for landslides and is applied to the area of Lichtenstein (Baden Württemberg, South Germany) using some basic data to test its capacity to generate information about vulnerability.

#### 3.1 Identification of the field site

Landslides in the Swabian Alb occur less frequently and with less dramatic consequences than in other places in Europe (Blöchl and Braun, 2005). Although landslides of different type and age are widespread across the region Alb the main

type of landslide affecting the area can be described as slump earth-flow (Bibus and Terhorst, 2001). Generally, the landslides in “Albtrauf” (anticlinal escarpment) belong to one of the following categories:

- Recently active areas that can be recognised by damage to vegetation, the soil and roads. They are mostly classified as translation-slides and flows; and
- Slope terrace, “steps”, and ridges that are created by rotational slips, where high flat areas of the “Alb” that are located next to the cliff have slipped. Nearly all these areas are now stable. Some recent activities can be found only at very steep areas of the slope.

The landslide risk is however, often underestimated in these regions and the need for drastic and expensive landslide measures, such as slope stability structures is not considered necessary. We feel that a large scale vulnerability assessment could help the local authorities concentrate their efforts and resources towards specific buildings/areas and to have a low cost risk/vulnerability assessment of the communities under danger. Lastly, the majority of existing landslide vulnerability assessment studies relate to developing rather than developed countries. The framework presented here is designed for a developed country and does not take into consideration factors such as poverty, high crime rates and so forth. that are not relevant to a study area in a European country like Germany. In the following paragraphs we apply our approach to a village in the Swabian Alb that is threatened by landslides.

In a study by Blöchl and Braun (2005) the houses of the area around Lichtenstein-Unterhausen are classified as mainly semi-detached residential. The risk of landslides is obvious as some of them have already cracks in masonry (Fig. 2), damage to electricity and water supply, subsidence and alike. Interestingly, all the houses are insured following a regulation that was introduced in 1994 that suggested that all the buildings should be privately insured and according to a survey based on questionnaires people seem to be aware of landslides as a hazard capable of affecting them and their property (Blöchl and Braun, 2005). However, owners do not take into consideration the landslide potential when they choose a house location and only 39% of owners have taken preventive measures such as geological engineering consultations, construction of walls and reinforced foundations.

A study undertaken by Neuhäuser (2005) within the framework of the LESSLOSS project used the *Weights of Evidence Method* in order to identify landslide susceptible areas in part of the Swabian Alb region of Germany (Fig. 3). The susceptibility map is the result of the calculation of the probability of landslide occurrence in the future, based on the assumption that future landslides will occur under similar circumstances to the past. From Fig. 3 it can be seen that landslide susceptible areas coincide with inhabited areas and one of them is the village of Lichtenstein where the present case study was carried out.



**Fig. 2.** Residential house in Reutlingen (Swabian Alb) damaged by a landslide (Blöchl and Braun, 2005).

Based on the work of Neuhäuser (2005) a landslide susceptibility map of Lichtenstein-Unterhausen has been produced (Fig. 4). Figure 4 indicates that in the area of Lichtenstein-Unterhausen a significant number of buildings are located within the low, medium and high landslide susceptibility zones. Figure 4 shows that there are some clusters of buildings especially in the centre and south of the village that are included within the high landslide susceptibility zones. The buildings within these zones cannot be considered equally vulnerable since vulnerability is dynamic and it depends on many factors. The pattern of the vulnerability within these zones is what the present study will focus on.

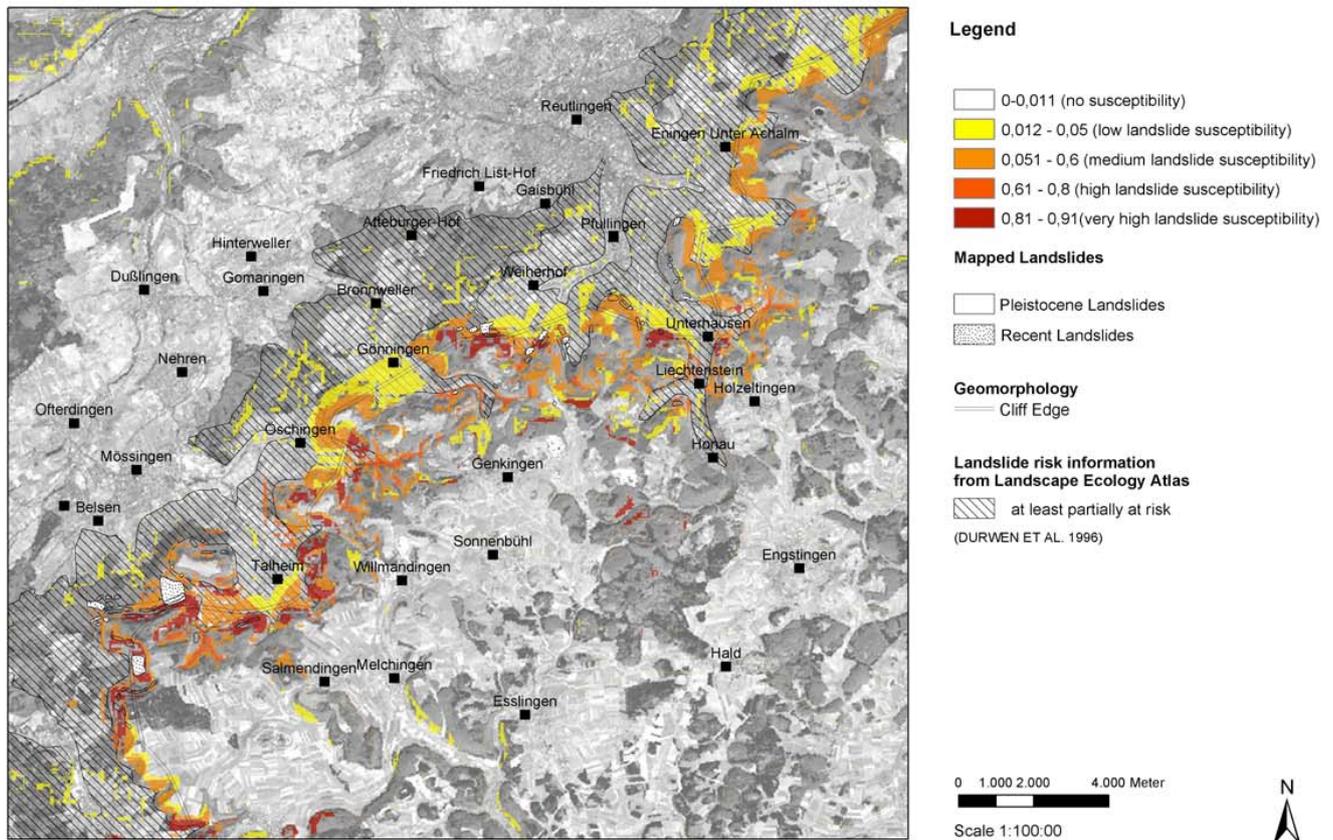
Using Google Earth air photography, at least 1271 buildings were recognised and digitized for the area of Lichtenstein-Unterhausen. The absolute number and the percentage of the buildings that lie within very high, high, medium and low susceptibility areas are shown in Table 2. These numbers concern the exposure within the landslide susceptibility zones. The next step will be to quantify the vulnerability of these structures. It will be possible to see the buildings vulnerability pattern when the database is populated with the required data. The specific data is not always available from the authorities and when they are they are often costly. The alternative is a house-to-house survey which in this case will not be particularly time consuming but as far as the transferability of the framework is concerned this is definitely a negative point.

### 3.2 Identification of parameters that may contribute to vulnerability

At this point the parameters that influence the vulnerability of a building to a landslide have to be identified and the relevant data for each building have to be collected in order to create a GIS database. Not many studies describe in detail the impact of a landslide on a building. Nevertheless, it is understood that a building during the landslide may be

## Landslide Susceptibility Map for Recent Landslides ("Albtrauf") Including Uncertainties

Landslide Susceptibility expressed through Relative Occurrence Probability



**Fig. 3.** Landslide Susceptibility map of part of the Swabian Alb based on the Weights of Evidence Method (Neuhäuser, 2005).

**Table 2.** The buildings of Lichtenstein.

	Absolute number	Percentage
Total buildings	1271	–
Low Landslide Susceptibility Area	155	12%
Medium Landslide Susceptibility Area	10	0.8%
High Landslide Susceptibility Area	98	7.8%
Very High Landslide Susceptibility Area	129	10%
Total number of buildings within landslide susceptibility zones	392	31%

completely destroyed, partially damaged or it can just experience excessive deformation (inclination without damage) (EPFL, 2002). Many factors play a role in this impact such as the material of a building, its age, its height/size and its foundations. A post-event survey after a catastrophic landslide in Italy showed that from all the destroyed buildings none of them were constructed of concrete, 60% were made of stone and 40% of masonry (EPFL, 2002).

Another factor that affects the physical vulnerability of a building during a landslide is its location (<http://www.knowledgenetwork.ca/slide>).

Not only as far as its presence within a high risk zone, but also regarding the characteristics of the neighbouring slope. It is understood that a slope with a steady inclination with heavy uncut forest is safer than a slope with irregular rise (like the ones that are caused due to road construction) or a slope without vegetation (<http://www.knowledgenetwork.ca/slide>).

As it has been previously mentioned, disastrous events have direct and indirect losses. An indirect loss of the landslide can be the loss of the house content. Although this is also dependent on the landslide volume and speed it is also connected to the nature of the wall of the building which is facing the slope. The presence of large glass windows can increase the vulnerability, as far as content loss is concerned, whereas the absolute absence of openings (windows, doors, etc.) will decrease this type of vulnerability. Therefore, data concerning the built environment would be essential. For example:

Data concerning the build environment:

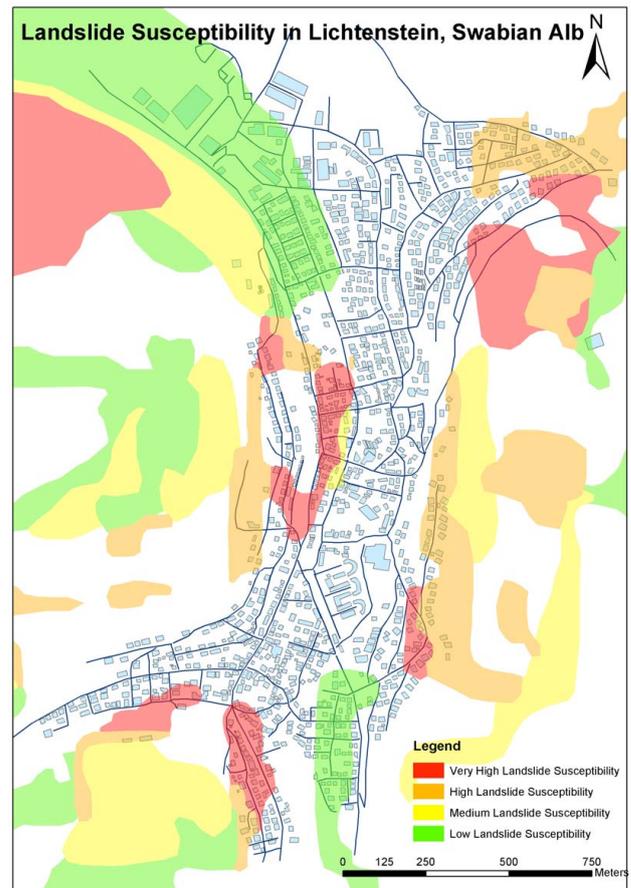
- Material and age of the buildings
- Existence of surrounding wall
- Existence of large windows toward the mountain slope.
- Number of floors
- Roads/railway lines
- Lifelines

Moreover, according to the Federal Emergency Management Agency (FEMA) of the US government, there are some warning signs that the house owners might notice before a landslide occurs such as:

- doors and windows stick or jam;
- new cracks appear in the plaster, tiles, bricks or foundations;
- outside walls/walks/stairs pilling away from the building;
- slow developing widening cracks on the ground/paved areas/streets/driveways;
- underground utility lines break;
- waterbreaks through the ground surface in new locations;
- fences, retaining walls, utility poles, or trees tilt or move; and
- unusual sounds are heard (tree cracking sounds) pavements are collapsing and fallen rocks are found at roadsides ([http://www.fema.gov/hazard/landslide/ls\\_before.shtm](http://www.fema.gov/hazard/landslide/ls_before.shtm)).

Lastly, in order to assess the social vulnerability of the community data concerning the population are very important and include:

- number of households per building;
- land use/building use;



**Fig. 4.** The landslide susceptibility zones in Lichtenstein.

- empty houses (if any);
- temporary high density of population (theatres/ski resorts/tourist buildings etc.); and
- buildings with particularly vulnerable populations (hospitals, elderly nursing homes, kindergartens, schools, jails).

Other data that are of interest and could also play a role in the vulnerability assessment include:

- existence of slope support structures/other mitigation measures;
- buildings of high economic importance; and
- buildings without private insurance.

The exact field description and coding (3 = high vulnerability, 2 = medium vulnerability, 1 = low) is given in Table 2.

### 3.3 The generation of an elements at risk GIS database

The various fields comprising the GIS database are shown in Table 3. Of course, the data collected depend also on data availability and costs.

**Table 3.** The various fields comprising the GIS database.

Field	Description of field	Description of categories	Code
Material	Material of which the building is made	Concrete	1
		Masonry	2
		Other (poor)	3
Surround	Surrounding walls or protection especially on the side of the slope	No/low surrounding wall	3
		Medium wall	2
		Strong high wall	1
Floors		One floor	2
		More than one floor	1
Slope_side	Description of the side of the building facing the slope	Only wall	1
		Small windows	2
		Large windows	3
Eco_imp	Importance for the local economy (factories, main local employers)	High	2
		Low	1
Use		Residential	1
		Commercial	2
		Service	3
households	Number of households	Absolute number	–
Employees	Number of employees	Absolute number	–
Population density during the year	Difference in density for buildings with special use (e.g. winter resorts etc.)	High pop. Density in the summer	1
		High pop. Density in the winter	2
Population density during the day	Difference in population density during day (schools) and night (hotels, theatres).	High pop. Density during the day	1
		High pop. Density during the night	2
Vul_pop		Yes	2
		No	1
Insurance	Private Insurance	Yes	1
		No	2
Warning	Presence of warning signs of landslides	Yes	2
		No	1

The data collected for each building can be divided into three categories:

1. quantitative (population, population density, number of households);
2. qualitative (condition, building surroundings, etc.) and;
3. descriptive (e.g., building use).

The data that will be used in the weighted linear combination are the quantitative ones. Standardisation is the method used in order to rescale the data to a common numerical basis by simple linear transformation (Voogd, 1983). In this study the standardisation method used is the transformation to raw data to scores from 0 to 1 by using the following formula:

Standardized score  $I = \text{raw score } I / \text{maximum raw score}$  (Voogd, 1983)

The standardised data are outlined in Table 4.

### 3.4 The database within a landslide risk and vulnerability framework

As assessing vulnerability is an important part of disaster management, a framework that includes vulnerability and risk assessment taking into consideration the direct and the indirect impacts of a specific natural hazard is necessary for communities at risk. In the present study a framework for community planning for coastal hazards proposed by John Heinz III Center (2000) is used as a base for a landslide risk and vulnerability framework.

In the framework for community planning for coastal hazards by John Heinz III Center (2000) both the insured costs of coastal hazards and the “hidden costs” are taken into

**Table 4.** The standardised scores.

Factor	Categories	Raw Score (Code)	Standardised Score
Material	Concrete	1	0.33
	Masonry	2	0.66
	Other (poor)	3	1
Surround	Strong high wall	1	0.33
	Medium wall	2	0.66
	No/low surrounding wall	3	1
Slope_side	Only wall	1	0.33
	Small windows	2	0.66
	Large widows	3	1
Warning	No	2	0.50
	Yes	1	1
Floors	More than one floor	1	0.50
	One floor	2	1

consideration. According to the John Heinz Center (2000), damage assessments are currently based on insured losses only. However, there are additional costs that affect the community such as business interruption, effects on the local economy (e.g., tourism), social costs, disturbance of natural ecosystems and so on. This framework is recommended to local planners and decision makers in order to help in the strengthening of community mitigation programs. The John Heinz Center framework proposes that risk and vulnerability result from a combination of natural and societal conditions. It also includes an evaluation of the current strategies and makes recommendations for new ones that consider the impact on individual stakeholder groups as well as on society.

The John Heinz Center framework is organised around the following principles:

- in order to characterise potential losses from disasters of different magnitudes, linking risk assessment and vulnerability is essential;
- evaluation of alternative mitigation and preparedness strategies should take into consideration direct and indirect economic, business, social and environmental costs; and
- the alternative strategies and policies have to recognise the relevance of the status quo without being restricted by the current policies.

Although the framework was prepared for coastal weather hazards it has the potential to be applied to a broad range of hazard types.

From the framework it is clear that there is a need for a database containing the information required as far as natural and societal conditions are concerned as well as characteristics of the build environment or the community that could lead to direct or indirect losses following a disastrous event. The database of elements at risk proposed here can

**Table 5.** The weighting of the factors.

Factor	Weight
Material	5
Surround	4
Slope_side	3
Warning	2
Floors	1

be used in order to assess the different types of vulnerability to a community under threat (physical, social and economic vulnerability) and it can be integrated within such a framework. The scale and the unit of the vulnerability assessment study should be in such a scale so that it can be efficiently used by local authorities and other stakeholders. A Landslide Risk and Vulnerability Framework based on the Heinz Center Risk and Vulnerability Framework is presented in the following paragraphs.

### 3.5 Preliminary results

#### 3.5.1 Building vulnerability ( $V_b$ )

The data needed and shown in Table 3 may be provided by the local authorities, the individual property owners by filling in a questionnaire or collected on site by researchers and are entered in to the GIS database. The weighting of the factors can be chosen by each user according to his priorities and the final purpose of his assessment. In our work, we weight the factors as shown in Table 5.

Finally, the vulnerability of each building in the inundation zone is calculated.

$$V_b = (5 \times a) + (4 \times b) + (3 \times c) + (2 \times d) + (1 \times e) \quad (2)$$

Where  $a, b, c, d, e$  the standardised scores that are:

- $a$ : related to the material of the building;
- $b$ : related to the surroundings of the building;
- $c$ : related to the description of the building's side facing the slope;
- $d$ : related to the existence of warning signs;
- $e$ : related to the number of floors of the building;

The lowest vulnerability can be calculated for a building that is concrete, has more than one floor and a high surrounding wall, has no windows on the slope side and has no evidence of landslide warning signs. The vulnerability of this building will be:

$$V_b = 5 \times 0.33 + 4 \times 0.33 + 3 \times 0.33 + 2 \times 0.5 + 1 \times 0.5 = 1.65 + 1.32 + 0.99 + 1 + 0.5 = 4.46 \quad (3)$$

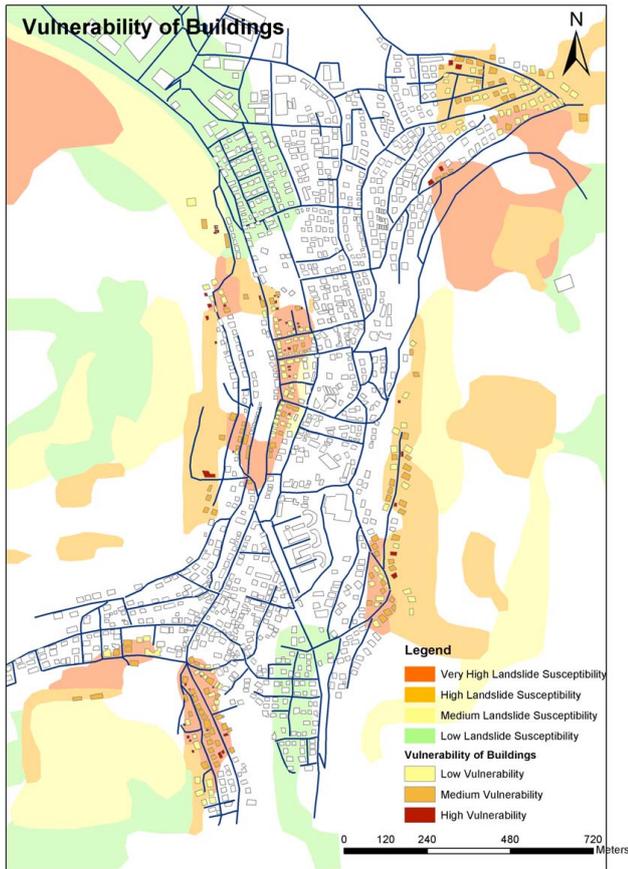


Fig. 5. The spatial pattern of the vulnerability of the buildings.

The highest vulnerability will be calculated for a one-floor building of poor material, with no surrounding wall, large windows on the slope side and landslide warning signs. The vulnerability of this building will be:

$$Vb = 5 \times 1 + 4 \times 1 + 3 \times 1 + 2 \times 1 + 1 \times 1 = 15 \quad (4)$$

The value of the vulnerability of the other buildings will be between these two numbers. By following this framework, it is possible to generate a vulnerability map such as the one shown in Fig. 5. Figure 5 suggests that there are no clusters of vulnerable buildings in Lichtenstein. On the contrary, the high vulnerability buildings are dispersed randomly in the village. Consequently, the local authorities could approach the owners of the specific buildings and make some suggestions regarding mitigation measures.

### 3.5.2 Human vulnerability ( $Vh$ )

Following the calculation and visualisation of the vulnerability of the buildings ( $Vb$ ), the overall human vulnerability can be calculated. This may be done if the population of each house is multiplied by its vulnerability. In this way, a new item named “human vulnerability”  $Vh$  is created in

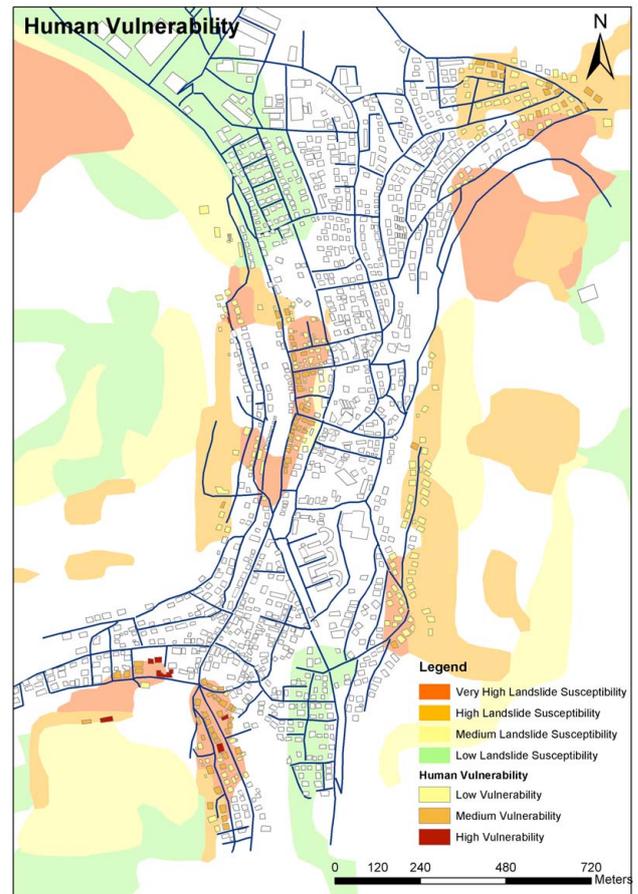


Fig. 6. The spatial pattern of human vulnerability.

the attribute table of the building coverage. For example, two buildings with  $Vb=12$  (high vulnerability) have different numbers of residents. The first has two households (6 people) and the second one has no residents. The human vulnerability ( $Vh$ ) for the buildings is:

For the first building:  $Vh = Vb \times \text{Population} = 12 \times 6 = 72$

Whereas, for the second building:  $Vh = 12 \times 0 = 0$

A pattern of the population density in the landslide susceptibility areas during the day/night and summer/winter can also be shown. Based on the  $Vb$  map and a rough estimation of households in the study area, a Human Vulnerability map is calculated (Fig. 6). As in Fig. 5, Fig. 6 does not show any clusters of high human vulnerability buildings. Due to the high resolution of the map the individual vulnerable buildings can be identified and suggestions regarding public awareness and education may be made.

### 3.5.3 Economic vulnerability

The economic vulnerability is mainly based on the number of buildings of economic importance within the high and

medium susceptibility zones, the highly vulnerable buildings housing businesses or services that are vital for the local economy and the number of employees that work within these structures. It is important to know in advance the main employers of the community and the businesses of high local, regional or even national economic importance. The next step is to check the vulnerability of the buildings (Fig. 5) where important businesses are housed. Then we can have an estimate of the unemployment rates, loss of products and compensation rates following a landslide disaster.

## 4 Discussion

### 4.1 Alternative uses of the database

Apart from the outputs generated by our approach (the building and human vulnerability assessment maps) the database itself may be a valuable tool in the hands of different end-users.

#### *Local authorities:*

The landslide susceptibility map is anyway important for the local authorities since it enables them to identify the high landslide susceptibility areas and prohibit development within these areas through a programme of urban land use planning. However, the proposed database offers information that combined with the landslide susceptibility map can be of great importance for the local authorities.

A database produced during this study may also be useful to the Local Authorities since it provides information concerning the characteristics of individual buildings. Local Authorities can make recommendations to individuals regarding their properties. The Local Authorities can then locate buildings that need reinforcement, alterations of the ground floor, or construction of a surrounding wall. Recommendations for slope stabilisation construction or simply planting of trees in specific locations could then be made. One of the problems that rescue teams often face right after an event is blocked roads from debris. Local Authorities could use the database in order to see which roads are likely to be blocked and which buildings are going to have no access after a landslide event. Figure 7 show the areas of the road network that might be blocked after a landslide event and the rescue teams and emergency services can use this map in order to find alternative routes or to relocate buildings with highly vulnerable populations that have no access to the local road network after a landslide.

#### *Emergency/rescue teams:*

One of the problems that emergency planners and rescue teams face after the occurrence of a disastrous event is poor communication. Telephone lines might not be working prop-

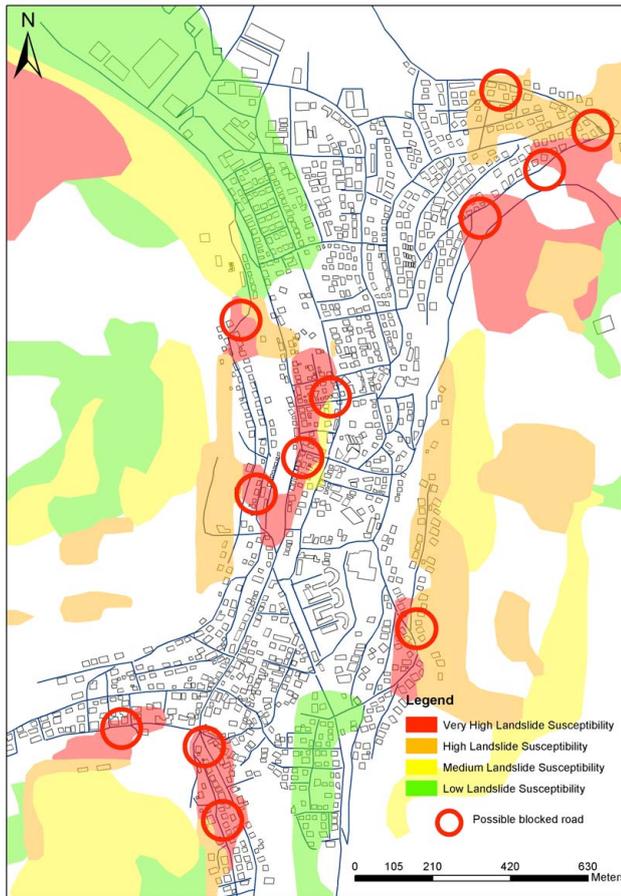
erly and the rescue teams do not know what the impact of the disaster is, how many victims are involved and where trapped people and casualties are located. Bad weather conditions or darkness can make the job of the rescue teams even more difficult. Therefore, the time of the occurrence of a disastrous event affects its impact. By giving a code to each building according to its population density during the night/day or during the summer/winter, the population density of the whole area during different times of the day and during different times of the year can be identified and its spatial distribution investigated. Emergency planners and rescue teams are also interested in evacuation procedures. The database may be used to highlight the buildings that belong to the High Human Vulnerability category and have no access to roads leading away from the high landslide susceptibility areas or their distance to essential services such as fire stations. Figure 8 shows the location of buildings housing vulnerable population (in this case kindergartens and schools) and their distance to essential services such as fire and police stations. In the case of Lichtenstein, there is only one building with a vulnerable population at a considerable distance from emergency support services. Further, none of the buildings containing highly vulnerable population is located within a high landslide susceptibility zone.

Other potential users of the database may include insurance companies (for the creation of catastrophe models), individuals (property owners in the high susceptibility areas), and voluntary rescue groups.

### 4.2 The proposed landslide risk and vulnerability framework

The elements at risk database can be integrated within a Risk and Vulnerability Framework for communities prone to landslides. The proposed framework is based on a similar framework for coastal disasters proposed by John Heinz Center which is described in Sect. 3.4. The framework has been modified here for landslide related disasters (Fig. 9). As it is suggested by J. Heinz Centre, the risk and vulnerability result from a combination of societal and natural conditions. The database proposed in the present study can be integrated in this framework containing all the data regarding the societal (number of households/inhabitants, characteristics of buildings) and natural conditions (landslide susceptibility map) related to landslide disasters.

The integration of our approach and the database constructed to a Landslide Risk and Vulnerability Assessment Model demonstrates the importance of vulnerability assessment and vulnerability mapping to the emergency planning of communities prone to landslides. Our approach ensures that the resources of the local community will be efficiently distributed since vulnerability is not uniform within the landslide susceptibility zones. The framework is taking into consideration direct (e.g. destruction of building and loss of life) and indirect losses (impact on tourism, job losses) and



**Fig. 7.** Locations of possible road blockage.

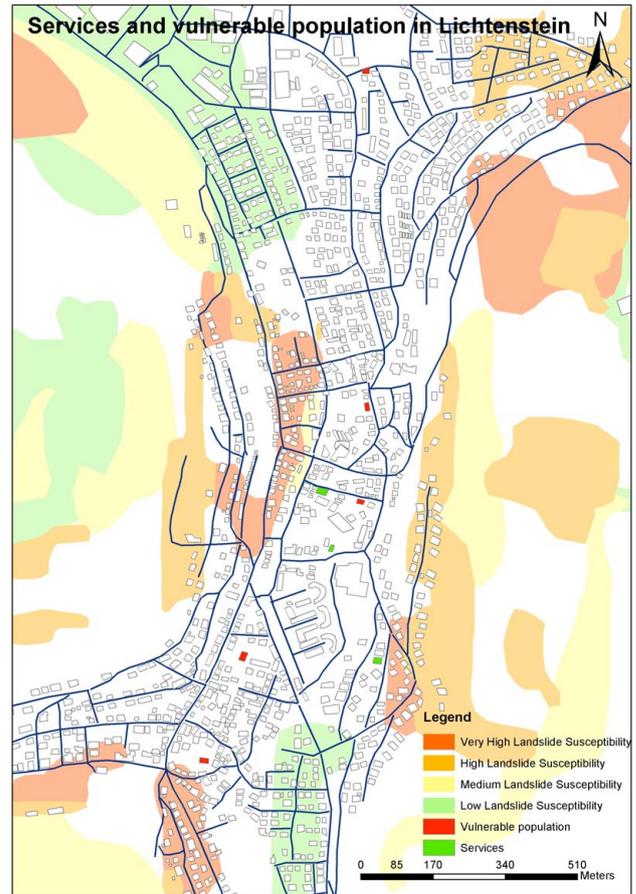
finally, based on the results of the proposed study the existing civil protection and emergency plans can be evaluated and updated (Feedback loop, Fig. 9).

#### 4.3 Limitations of the proposed framework for landslide vulnerability assessment

There are limitations in our preliminary work that will have to be tackled in later stages of research. These include:

*Identification of the area under study:* According to our framework, the area under study has to be identified by a pre-existing landslide susceptibility map. These maps are not always available, especially for areas with medium or low landslide susceptibility. Moreover, the production of such maps requires many sets of data (soil, DEMs, rainfall data) that are also expensive and not always available at the required scale and form.

*Data availability and costs:* the required data for the proposed vulnerability assessment method can be expensive and difficult to acquire. As suggested earlier, this may be overcome by the collection of:

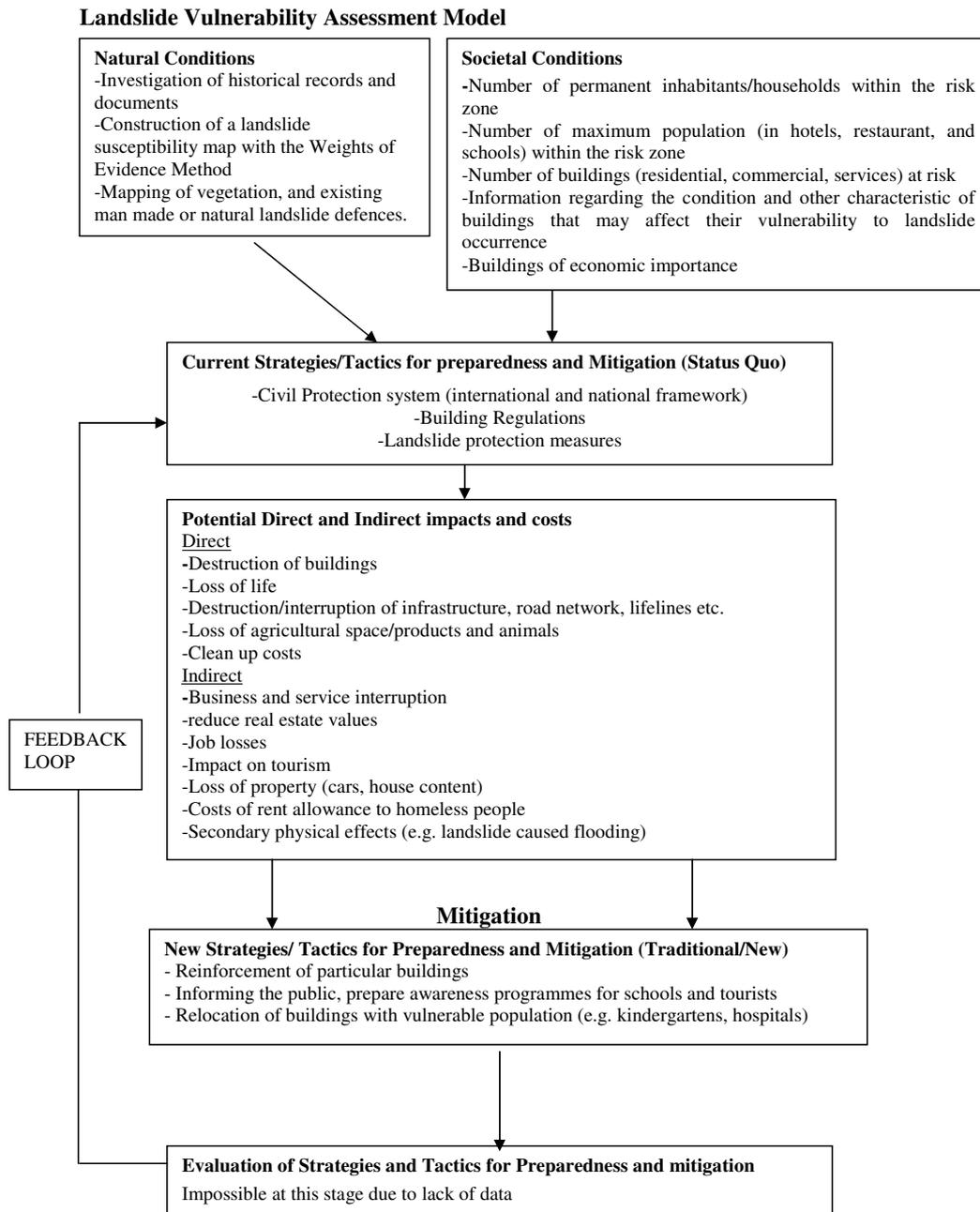


**Fig. 8.** Map showing the location of the buildings where vulnerable population is located (e.g. Kindergartens) and their distance to services (fire brigade, police).

1. Air-photographs and remote sensing data (buildings locations, railway and road network)
2. Local authorities (some of the buildings characteristics, lifelines, utilities)
3. Questionnaires (information regarding the warning signs of landslides, insurance income, household information etc.)
4. Fields survey (characteristics of buildings that are not available from the local authorities)

Some of the data needed are unlikely to be available due to their nature. Data concerning the financial situation of households, disabilities, etc, might be protected or simply non-existent. Data concerning the types of housing and detailed cadastral maps are normally very expensive. Finally, the field survey can be time consuming depending on the size of the area under investigation.

*Weighting of factors:* we do not really know which factor is the most important as the destruction of the building depends



**Fig. 9.** Proposed landslide vulnerability assessment model (Framework).

also on the type of the landslide, the speed of the movement and its size. Also we have not included the protection that can be offered to some buildings from being located behind others. The buildings that are located directly by the slope should be more vulnerable in some types of mass movements (such as debris flows, mud slides, rock falls) than buildings that are located behind them. Other types of landslides given their size and nature can move buildings from their foundations. In this case, the location of the building, as far the

direct proximity to the slope is concerned, does not play an important role.

*Landslide associated and other phenomena:* The study does not take into consideration the vulnerability of the buildings to other phenomena that might follow a landslide (e.g. flood) or to phenomena that caused the landslide (e.g. earthquakes). A vulnerability assessment regarding earthquakes and floods would require data that at the moment are not included in our approach and its database.

*Sensitivity of the results to the variation of the parameters:* The sensitivity of the results of the present study depends very much on the weighting of the parameters. For example, according to the present weighting two buildings with different material type are very likely to belong to different vulnerability categories although the rest of their characteristics might be quite similar. On the contrary, buildings made of similar material although they might differ significantly as far as the surroundings or their side towards the slope is concerned might belong to the same vulnerability class. Although this can be considered as a disadvantage of our approach, it highlights the importance of the fact that in this framework the weighting is flexible and the user can weight the factors according to their priorities. To overcome this difficulty, we recommend that in future work, a non linear regression sensitivity analysis should be undertaken to determine which attribute within the database has the most significant affect on the overall vulnerability of a building.

*Magnitude, Frequency and Run out:* Our work does not take into consideration the magnitude, frequency and run out of potential landslides since it has been based on the susceptibility map developed using the weights of evidence method. This method is based on the assumption that future landslides will occur under the same conditions as past events. In this case we cannot take into consideration the frequency of the phenomenon, as we do not talk about reactivated past landslides but potential first-time events. Consequently, information regarding their run-out and magnitude are also difficult to acquire. Knowledge of the magnitude and frequency of a landslide event is essential for landslide hazard assessment (Crozier and Glade, 1999) but this is not the purpose of our work. We recommend that future work attempt to take account of these factors since they will clearly produce a more effective base scenario (landslide susceptibility map) upon which our framework may be applied.

## 5 Conclusions

In the present paper, after reviewing existing studies regarding landslide risk and vulnerability assessment we found out that not much has been done in the field of landslide vulnerability assessment. We apply here a new framework to a landslide susceptible area based on the development of an “elements at risk database”, in order to assess the vulnerability of the buildings to landslide.

It may be asked why such a detailed study concerning the vulnerability of a community to landslides is necessary. The answer to this question includes the following:

1. The landslide hazard in the area is realistic but not very high, resulting in an underestimation of the real risk.
2. It would be impossible due to high costs to reinforce every building located within the landslide susceptibility zones. It is of vital importance that disaster managers

and emergency planners are provided with detailed information regarding the location of buildings, infrastructural units and groups of people that are vulnerable to landslide events. This leads to cost effective mitigation measures and good prioritisation of resources.

3. Finally, through this study the advantage of using a GIS database of elements at risk and their characteristics as far as a specific disaster type is concerned is demonstrated. The advantage of using a GIS database rather than an inventory containing this information is that the GIS database can be updated easily, it can be used by various stakeholders according to their needs and priorities and that different weight factors can be applied to the data.

Based on the limitations of the framework such as the availability of a reliable landslide hazard or susceptibility map, the availability and costs of required data, alternative weighting of factors and the inclusion of landslide associated phenomena, improvements to our approach could be made. These improvements could focus on the acquisition of better quality data, the identification of more landslide prone areas and the modification of the framework to include landslide-associated phenomena. Moreover, the inclusion of magnitude and frequency of the landslide to the assessment and a non-linear regression sensitivity analysis in order to determine which attribute of the database influences more the overall vulnerability of the building, could improve the outcome of our study significantly. Last but not least, one of the main advantages of the approach presented here is that it can be easily used in the future for multi-hazard risk assessment if the database is populated with data regarding the vulnerability of the elements at risk as far as other types of hazards are concerned.

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