Guide book
Session 5: Vulnerability assessment

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Objectives:

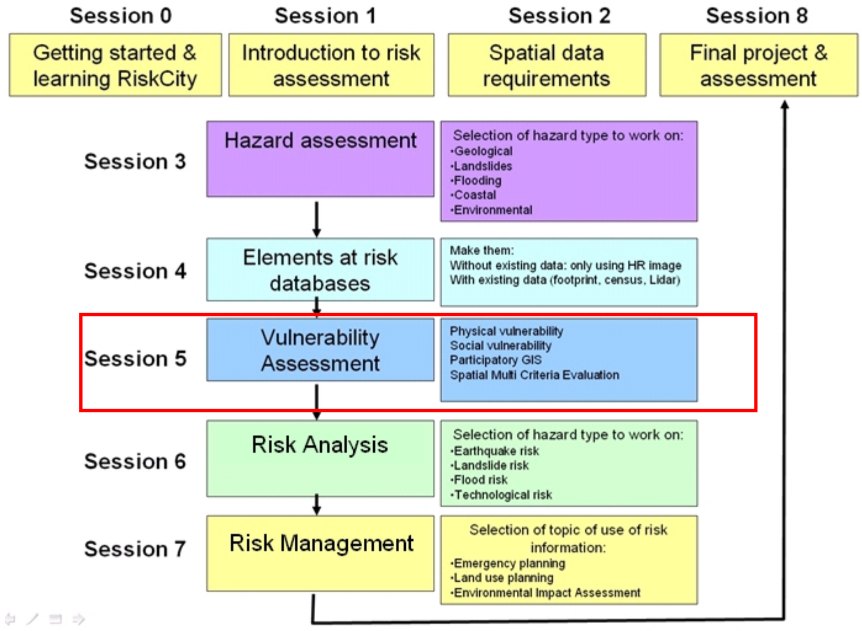
After this session you should be able to:

- Understand the types of vulnerability: physical, social, economic and environmental;
- Understand the complexity in approaches used for vulnerability and the varyibng ways in which it is defined.
- Indicate the ways in which vulnerability can be expressed.
- Outline the main approaches used for flood, earthquake and landslide vulnerability assessment
- Understand the concepts of Spatial Multi Criteria Evaluation for vulnerability assessment;
- Carry out Spatial Multi Criteria Evaluation in GIS

This chapter might be one of the most “fuzzy” ones of the book, as the concept of vulnerability is defined in many different ways. Therefore we will start this chapter by looking at the various definitions and approaches that are used to “capture” vulnerability. Most of the session deals with methods to express and quantify physical vulnerability. We will look at methods for creating vulnerability curves and matrices for flooding, earthquake and landslides. A separate section deals with the analysis of population vulnerability. In the last part of the session we will look at methods that are used to quantify the entire spectrum of vulnerability. This is mostly done with indicators, and Spatial Multi-Criteria Evaluation (SMCE) is one of the main tools used. The session ends therefore with a RiskCity exercise on the use of SMCE.

Section	Topic	Task	Time required		
5.1	Introduction		Day 1	0.5	0.5
5.2	Defining vulnerability			0.35	0.5
		Task 5.1: Vulnerability, coping capacity and resilience		0.15	
5.3	Conceptual frame-works of vulnerability			1.00	1.0
5.4	Types of losses and vulnerability			0.35	0.5
		Task 5.2: Linking loss types with vulnerability		0.15	
5.5	Expressing vulnerability			0.35	0.5
		Task 5.3: Methods for expressing vulnerability	Day 2	0.15	
5.6	Measuring physical vulnerability			1.35	3.5
		Task 5.4: Vulnerability methods		0.15	
		Task 5.5: Vulnerability curves from damage data		1.00	
		Task 5.6: Expert opinion & vulnerability curves		0.25	
		Task 5.7: Watch Shaketable test on Youtube		0.25	
		Task 5.8: European flood vulnerability methods		0.50	
5.7	Comprehensive vuln. assessment		Day 3	0.50	0.5
5.8	Spatial Multi Criteria Evaluation			0.50	4.5
		Task 5.9: RiskCity exercise on the use of SMCE		4.00	
		Total	**3 days**	**11.5 hours**	

5.1 Introduction



This session deals with one of the most complicated components of multi-hazard risk assessment: vulnerability. It is complicated because the concept of vulnerability has a wide range of interpretations. The concept of vulnerability originated from the social sciences in response to the pure hazard oriented perception of disaster risk in the 1970s. Here the vulnerability was mostly related to buildings & structures at risk and how these buildings & structures were damaged by hazards, due to physical forces exterted by ground motion, wind, water, etc. The damage was rated on a scale of 0 (no damage) to 1 total damage. Since that time different discilpines are working with the concept of vulnerabilityand and the concept of vulnerability has broadened (see figure 5.1), by not only looking at buildings and structures but more to human beings. As mentioned in session 1.2.2 the study of disaster and risk has gone through an interesting evolution during the past decades. A set of paradigms has ruled the study of disasters and risk in the past decades.

Paradigms of risk and vulnerability

$R \approx H$

$\downarrow$

$R \approx H \times V$

$\downarrow$

$R \approx H \times V / C$

$\downarrow$

$R \approx H(v, c) \times V(h, c) / C(h, v)$

Technocratic or Behavioral paradigm:
The first approaches to risk were the ones that assimilated it to hazard or focused mainly on it, carried out especially by professionals of the natural sciences (geologists, engineers, meteorologists, etc.). According to Blaikie et al (1994), until the emergence of the idea of vulnerability to explain disasters, there was a range of prevailing views. None of which really dealt with the issue of how society creates the conditions in which people face hazards differently. The first approach was unapologetically naturalist, in which all blame was apportioned to 'the violent forces of nature'. Governments and individuals relied upon physical protection against the hazards.

Physical Vulnerability or Structural paradigm:
The concept of vulnerability entered the risk scene. Protection was defined not only according to the physical protection systems built, but also according to the people's behavior. This inclusion of people's behavior led to the design and use of early warning systems and educational programs about hazards and how to protect against them. This paradigm lasted for a couple of decades and was even used during the Yokohama Strategy and Plan of Action for a Safer World (1994), where all the efforts were aimed towards increasing our scientific knowledge about the causes and consequences of natural hazards and facilitate its wider application to reducing vulnerability of disaster-prone communities. This perspective included overall development, attacking root causes, and capacity building.

Complexity paradigm:
A new understanding of the complex interaction between nature and society has emerged, and as such, a new complex approach to understanding risk has to be undertaken. Vulnerability is not only about groups or individuals, but is also embedded in complex and social relations and processes.

5.2 Defining vulnerability.

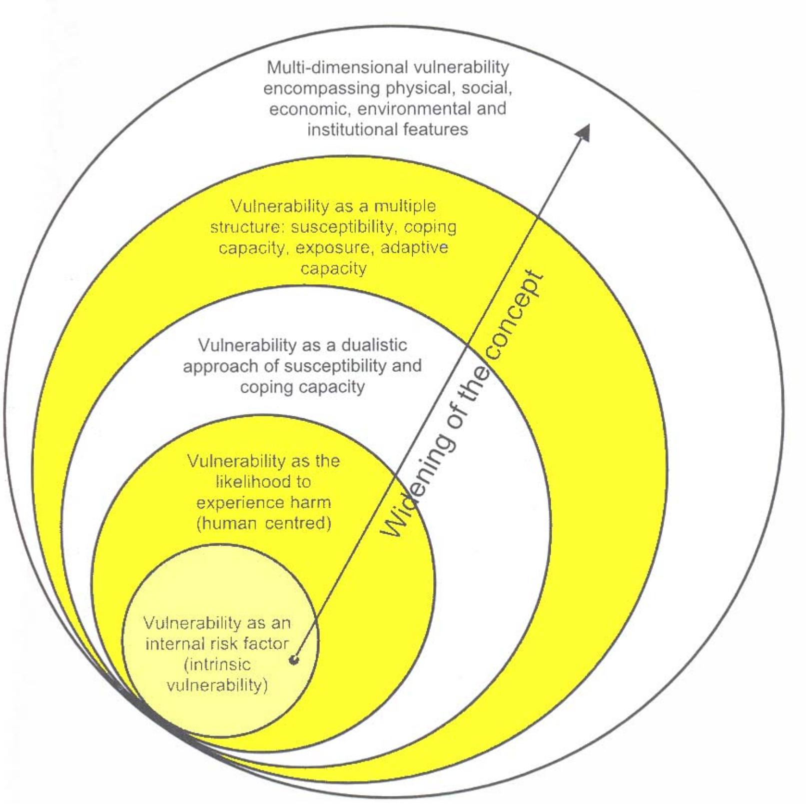


Figure 5.1 Key spheres of the concept of vulnerability. Source: Birkmann, 2006)

Multiple definitions and different conceptual frameworks of vulnerability exist, because several distinct groups have different views on vulnerability. Academic staff from different disciplines, Disaster management agencies, development corporations, climatic change organization etc. An overview is given on the website of the ProVention Consortium (http://www.proventionconsortium.org/) and in the book on Vulnerability edited by Birkmann (2006). Birkmann writes about the paradox of aiming to measure vulnerability if we cannot yet define vulnerability precisely.
Some of the definitions are given in the box below. The first definition is still related only to physical vulnerability while in the other definitions we find that vulnerability is influenced by several factors, mostly mentioned are physical, economic, social and environmental factors.
The definitions of vulnerability of Provention and Blaikie clearly show that besides vulnerability the elements at risk also have capacities. According to the UN, in their report Living with Risk (UN/ISDR , 2004), risk is rooted in conditions of physical, social, economic and environmental vulnerability that need to be assessed and managed on a continuing basis (Figure 5.2).

General definitions of vulnerability:
Vulnerability is:

- "The degree of loss to a given element at risk or set of elements at risk resulting from the occurrence of a natural phenomenon of a given magnitude and expressed on a scale from 0 (no damage) to 1 (total damage)" (UNDRO, 1991)
- "Exposure to risk and an inability to avoid or absorb potential harm (Pelling, 2003). In this context, he defines physical vulnerability as the vulnerability of the physical environment; social vulnerability as experienced by people and their social, economic, and political systems; and human vulnerability as the combination of physical and social vulnerability" (in Vilagrán de León, 2006)
- "The characteristics of a person or group in terms of their capacity to anticipate, cope with, resist and recover from impacts of a hazard" (Blaikie, Cannon et al. 1994).
- "The degree of susceptibility and resilience of the community and environment to hazards" (EMA, 1995).
- "A human condition or process resulting from physical, social, economic and environmental factors, which determine the likelihood and scale of damage from the impact of a given hazard" (UNDP, 2004).

Vulnerability is:

- "The conditions determined by physical, social, economic and environmental factors or processes, which increase the susceptibility of a community to the impact of hazards "(UN-ISDR)

- "The intrinsic and dynamic feature of an element at risk that determines the expected damage/harm resulting from a given hazardous event and is often even affected by the harmful event itself. Vulnerability changes continuously over time and is driven by physical, social, economic and environmental factors" (UNU-EHS, 2006)

- "The potential to suffer harm or loss, related to the capacity to anticipate a hazard, cope with it, resist it and recover from its impact. Both vulnerability and its antithesis, resilience, are determined by physical, environmental, social, economic, political, cultural and institutional factors" (Provention Consortium, 2007)

- "The degree to which a system is susceptible to, or unable to cope with adverse effects of climate change, including climate variability and extremes". Vulnerability is a function of the character, magnitude, and rate of climate variation to which the system is exposed, its sensitivity, and its adaptive capacity" (IPCC,2001:165).

- Vulnerability = (Exposure) + (Resistance) + Resilience

  With: Exposure: at risk property and population;
  Resistance: Measures taken to prevent, avoid or reduce loss;
  Resilience: Ability to recover prior state or achieve desired post-disaster state.

What is common from the definitions is that vulnerability is:

- **Multi-dimensional** (e.g. physical, social, economic, environmental, institutional, and human factors define vulnerability);
- **Dynamic** (vulnerability changes over time);
- **Scale-dependent** (vulnerability can be expressed at different scales from human to household to community to country resolution;
- **Site-specific** (each location might need its own approach).

Below a number of vulnerability types are defined, based also on figure 5.2. These definitions will be used as the working definitions within this chapter and book. In the RiskCity exercises we will concentrate mostly on physical vulnerability and to a lesser extent also on social vulnerability.

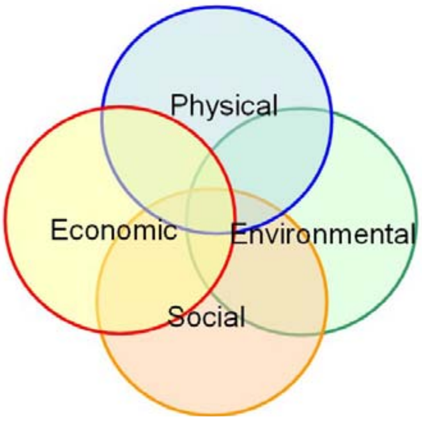


Figure 5.2 Factors, Influencing vulnerability (Source: UN-ISDR).

Vulnerability types:

- **Physical Vulnerability**: meaning the potential for physical impact on the built environment and population. The degree of loss to a given element at risk or set of elements at risk resulting from the occurrence of a natural phenomenon of a given magnitude and expressed on a scale from 0 (no damage) to 1 (total damage)".
  - Vulnerability is analyzed per group of constructions (i.e. structural types) having similar damage performance;
  - It is an intrinsic quality of a structure and it does not depend on location.
- **Economic vulnerability**: the potential impacts of hazards on economic assets and processes (i.e. business interruption, secondary effects such as increased poverty and job loss) Vulnerability of different economic sectors,
- **Social vulnerability**: the potential impacts of events on groups such as the poor, single parent households, pregnant or lactating women, the handicapped, children, and elderly; consider public awareness of risk, ability of groups to self-cope with catastrophes, and status of institutional structures designed to help them cope.
- **Environmental vulnerability**: the potential impacts of events on the environment.

Coping capacity and resilience.

Besides vulnerabilities, elements at risk posses also capacities to cope with hazards. A large variety of definitions exist on capacity, coping and resilience, which are used in the different models of vulnerability and risk.

"**Capacity** is a combination of all strength and resources available within a community or organization that can reduce the level of risk, or the effect of a disaster. It may include physical, institutional, social or economic means as well as skilled personal or collective attributes such as leadership and management. Capacity may also be described as capability" (UN-ISDR, 2004)

In general, this involves managing resources, both in normal times as well as during crises or adverse conditions. Some examples of capacity are:

- Ownership of land;
- Provisions made in advance to pay for potential damages for instance by mobilizing insurance repayments, savings or contingency reserves
- Adequate food and income sources;
- Family and community support in times of crisis;
- Local knowledge;
- Good leadership & management.

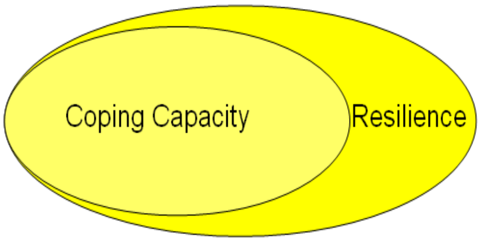


Figure 5.3 Coping capacity and resilience. Source: (Thywissen 2006)

The strengthening of coping capacities usually builds resilience to withstand the effects of natural and human-induced hazards. According to Thywissen (2006) resilience is in general a more encompassing term than coping capacity (See figure 5.3).

Definitions of resilience / resilient

- "Resilience is the capacity of a system, community or society potentially exposed to hazards to adapt, by resisting or changing in order to reach and maintain an acceptable level of functioning and structure. This is determined by the degree to which the social system is capable of organizing itself to increase its capacity for learning from past disasters for better future protection and to improve risk reduction measures".(UN-SDR 2004) See also : http://www.undp.org/cpr/disred/documents/publications/rdr/english/glossary.pdf
- "Not just the absence of vulnerability. Rather it is the capacity, in the first place, to prevent or mitigate losses and then, secondly, if damage occurs to maintain normal living conditions and thirdly, to manage recovery from the impact". (Buckle et al., 2000)
- "Resilience is the flip side of vulnerability – a resilient system or population is not sensitive to climate change and has the capacity to adapt" (IPCC 2001)
- "Resilience to disasters means a locale can withstand an extreme natural event with a tolerable level of losses. It takes mitigations actions consistent with achieving that level of protection" (Mileti 1999) in: K. Thywissen in Birkmann 2006

Task 5.1: Vulnerability, coping capacity and resilience (duration 10 minutes)

After reading the definitions of vulnerability, coping capacity and resilience, determine for yourself what the main differences are.

5.3 Conceptual frameworks of vulnerability

In the last decades different frameworks on vulnerability were developed. In this section we will look at a number of them. A good overview is given by Birkmann, 2006.

5.3.1 The Double Structure of Vulnerability:

Chambers (1989) defined an external and internal side of vulnerability. The external side: related to exposure to external shocks and stresses; and the internal side: associated with defenselessness, incapacity to cope. Shocks relate to often sudden and sometimes unpredictable events like, floods, earthquakes, epidemics, etc. Stresses, in contrast, relate to shortages, declining resources etc. They refer to pressures which are typically continuous, cumulative and more predictable, such as seasonal. At the livelihood level, vulnerability can be related to assets and how people manage them. But assets such as labour and human capital, although vulnerable, are also the key elements in coping with shocks and stresses. Bohle (2001) expanded on the concept of vulnerability of Chambers. Vulnerability is seen as having two sides: an internal side and an external side (see figure 5.4). The external side related to the **exposure to risks** and shocks and is influenced by *Political Economic approaches* (e.g. social inequalities, assets control by upper classes), *Human Ecology Perspectives* (population dynamics and capacities to manage the environment) and the *Entitlement Theory* (relates vulnerability to the incapacity of people to obtain or manage assets via legitimate economic means). The internal side is called **coping** and relates to the capacity to anticipate, cope with, resist and recover from the impact of a hazard and is influenced by the *Crisis and Conflict Theory* (control of assets and resources, capacities to manage crisis situations and resolve conflicts), *Action Theory Approaches* (how people act and react freely or as a result of societal, economical or governmental constraints) and *Models of Access to Assets* (mitigation of vulnerability via access to assets) .

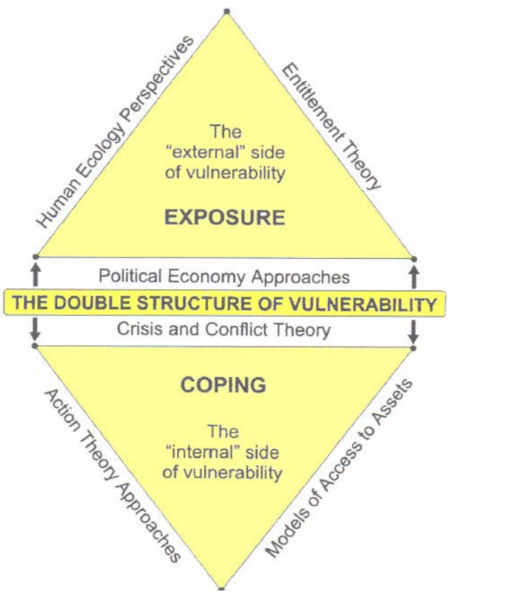


Figure 5.4 Bohle's conceptual Framework for vulnerability analysis. (Source: Bohle, 2001 in Birkmann, 2006)

> The concept indicates that vulnerability cannot adequately be characterized without considering coping and response.

5.3.2 Vulnerability is defined as a component within the context of risk.

In the conceptual framework of Davidson, adopted by Bollin et al 2003, risk is seen as the sum of hazard, exposure, vulnerabilities and capacity measures. Hazard is characterized by probability and severity; exposure elements are structures, population and economy; capacity and measures is concerned with physical planning, management, social- and economic capacity (see figure 5.5).

Figure 5.5: Conceptual framework to identify disaster risk. (Source: Davidson, 1997; Bollin et al.,2003)

5.3.3 The school of climate change.

This school developed the Risk-Hazard (RH) model (Turner, Kasperson et al., 2003). In this model the impact of a hazard is seen as a function of exposure of a system to the hazard event and the response of the system as shown in figure 5.6 where the concept of vulnerability is commonly implicit.

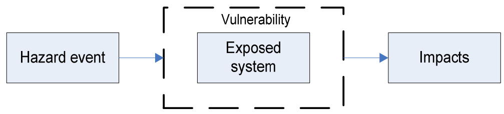


Figure 5.6 RH model (Source: Turner et al., 2003)

A more elaborate model of Turner et al., 2003; is given in figure 5.7. The model / system operates at multiple spatial (the world, region and place), functional and temporal scales, where interactions take place. Vulnerability is registered not by exposure to hazards (perturbations and stresses) alone but also resides in the sensitivity and resilience of the system experiencing such hazards (Turner et al., 2003) (see figure 5.7). The sensitivity to exposure is defined by the human-environmental conditions. The human-environmental conditions e.g. social and biophysical capital, influence the coping mechanisms, when the impact is experienced, also influencing the coping mechanisms adjusted or created because of the experience (Turner et al, 2003). In some cases coping responses lead to adaptation and changes in the human-environmental conditions.

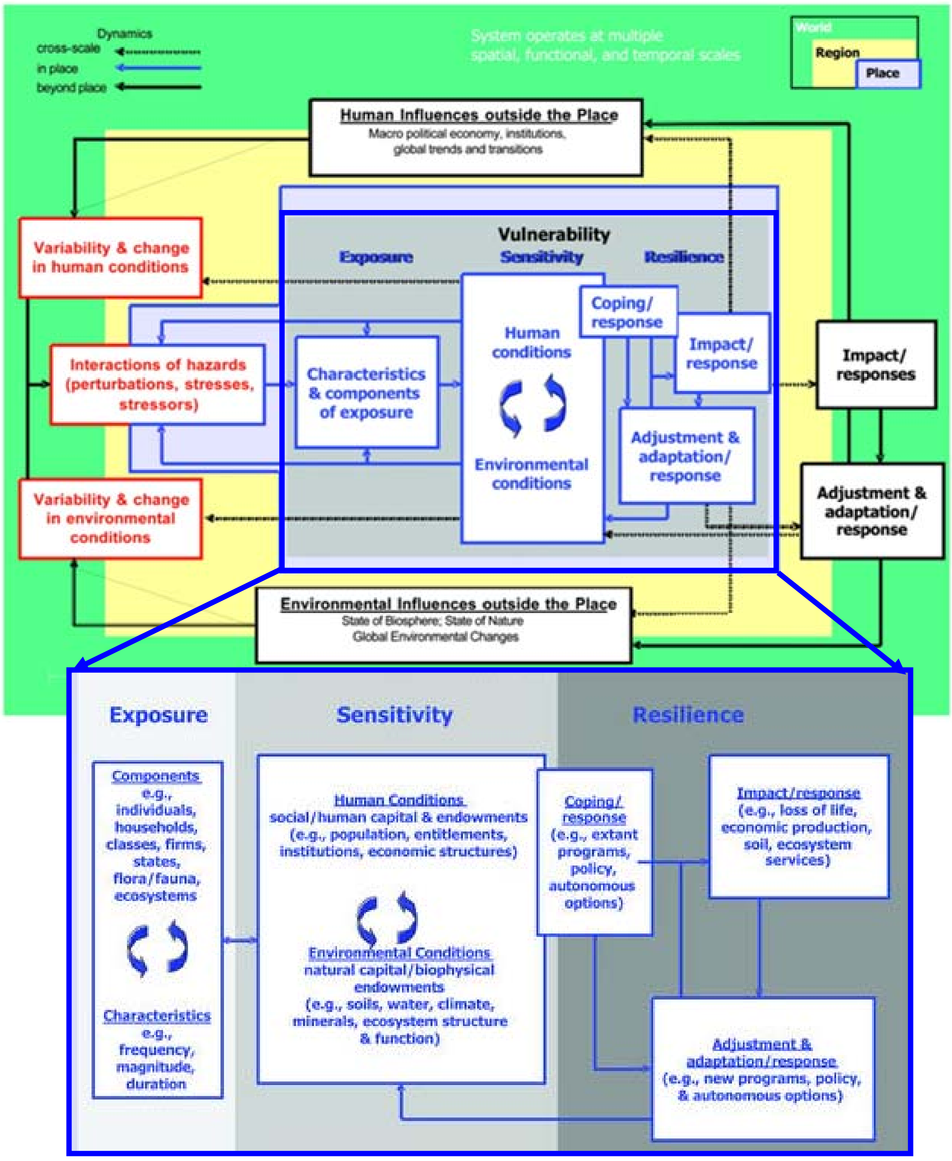


Figure 5.7: Vulnerability framework: multiscale (Source:Turner et al, 2003: http://www.pnas.org/content/100/14/8074.full.pdf+html)

5.3.4 Pressure and Release (PAR) Model:

Blaikie et al (1994) and Wisner et al., 2004 presented the Pressure and Release (PAR) model that shows vulnerability as a social product of a chain of factors. Disasters are caused by opposing forces, on the one hand by a progression of vulnerability, from root causes to dynamic pressures to unsafe conditions and by the hazard event on the other hand (figure 5.8). Vulnerability is defined as the characteristics of a person or group in terms of their capacity to anticipate, cope with, resist and recover from impacts of a hazard.

> **Livelihood** is defined as the command an individual, family or other social group has over an income and/or bundles of resources that can be used or exchanged to satisfy its needs.

The aim is to understand and explain the disasters that people face caused by hazard events, like floods and earthquakes etc. The vulnerability can be caused for instance by limited access to resources or causes of political & social background, not just directly related to the hazard event itself. The release idea, the reduction of disaster: to relieve the pressure, vulnerability has to be reduced and even address the underlying causes.

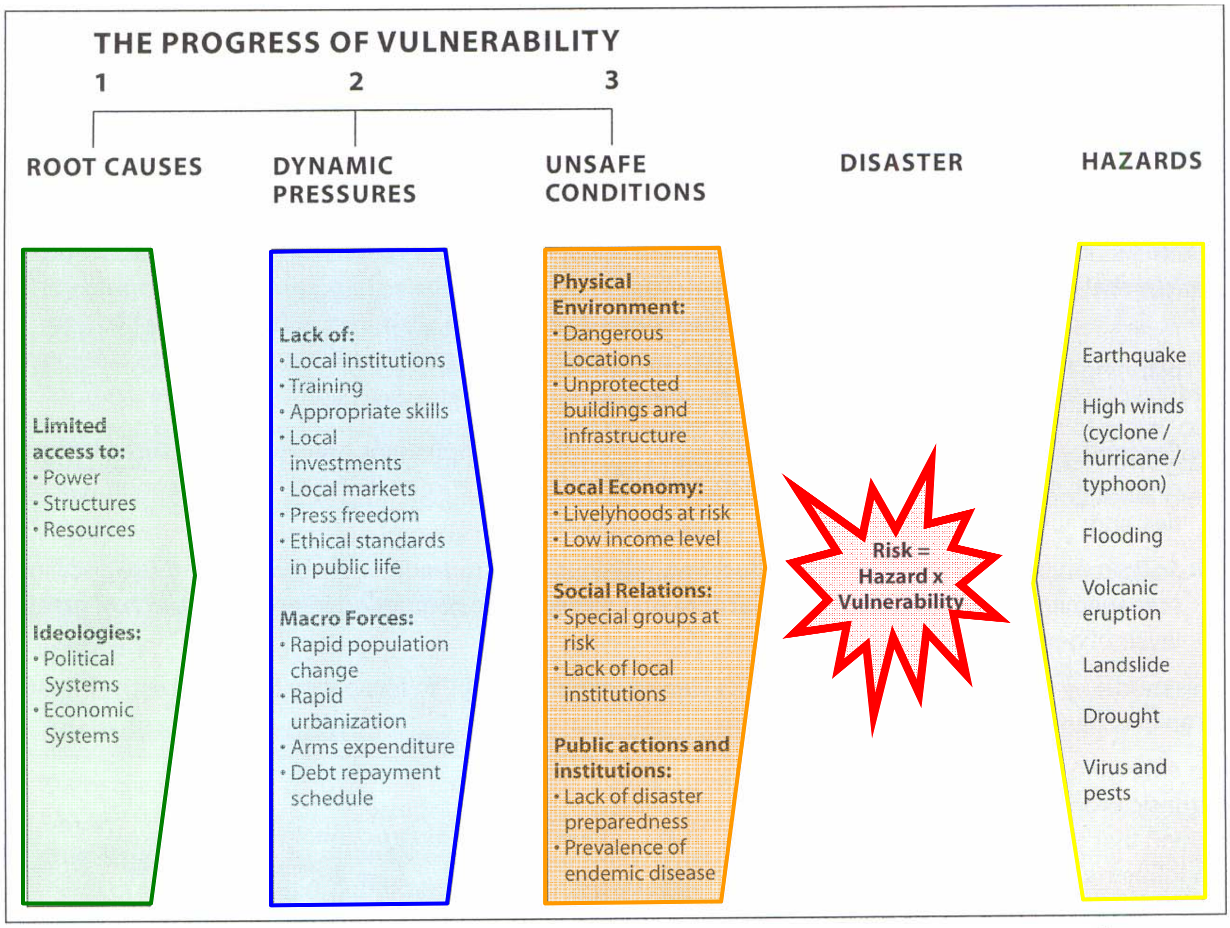


Figure 5.7 The PAR model (Source: Blaikie, Cannon et al, 1994)

Root causes are related to economic, demographic, and political processes as a function of economic structure, legal definitions of rights, gender relations, and other elements of the ideological order and reflect the distribution of power in a society (Blaikie, Cannon et al. 1994). Dynamic pressures are processes and activities that 'translate" the effects of root causes into the vulnerability of unsafe conditions (Blaikie, Cannon et al. 1994). Unsafe conditions: are the specific form in which vulnerability of a population is expressed in time and space in conjunction with a hazard (Blaikie, Cannon et al. 1994). According to Blaikie et al, key characteristics of vulnerable groups in society are socioeconomic group, caste, ethnicity, gender; disability; age and seniority.

5.3.5 Pelling model

In the framework for vulnerability proposed by Pelling (2003) human vulnerability is defined by: exposure, resistance and resilience. Exposure is related to the location and characteristics of the hazard; resistance is related to the economical, psychological, and physical health, as well as the capacity of individuals or communities to withstand the impact of the event and is related with livelihoods; resilience is defined as the ability to cope with or adapt to the hazard stress through preparedness and spontaneous adaptations once the event has manifested itself.

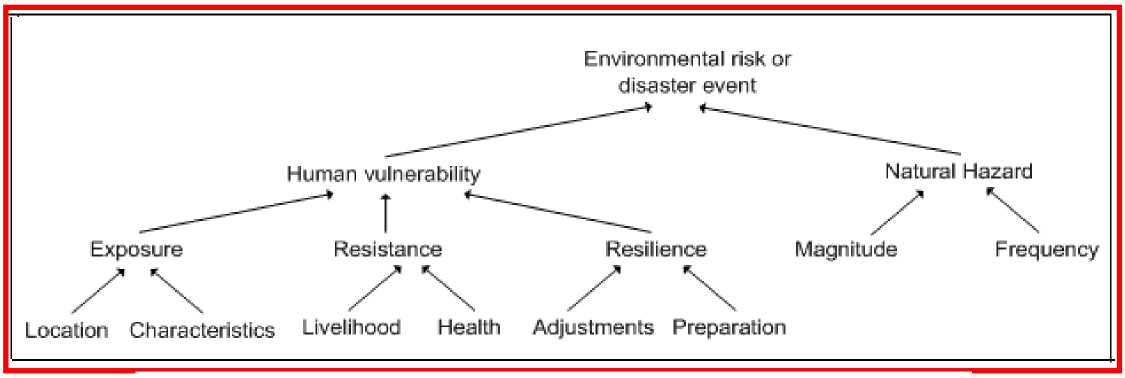


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Figure 5.8: Exposure, resistance, resilience model (Pelling, 2003)

5.3.6 UNU –EHS: BBC framework.

The United Nations University - Institute for Environment ad Human Security (UNU-EHS) developed two frameworks for vulnerability. The onion framework (Bogardi and Birkmann 2004), has a natural event sphere, an economic (monetary) sphere and a social (disutility sphere) crossed by an "opportunity"(or probability) axis and a "reality" axis (certainty). The BBC frame-work (figure 5.9) is a combination of existing models, and is mainly based on the conceptual work of Bogardi and Birkmann (2004) and Cardona (1999). According to the authors it tries to link vulnerability, human security and sustainable development. It underlines the need to view vulnerability as dynamic, focusing on vulnerabilities, coping capacities and potential intervention tools to reduce it (feedback-loop system) (Birkmann, 2006). Environmental, social and economic spheres are considered in defining vulnerability, coping capa-cities, risk and their vulnerability/risk reduction measures.

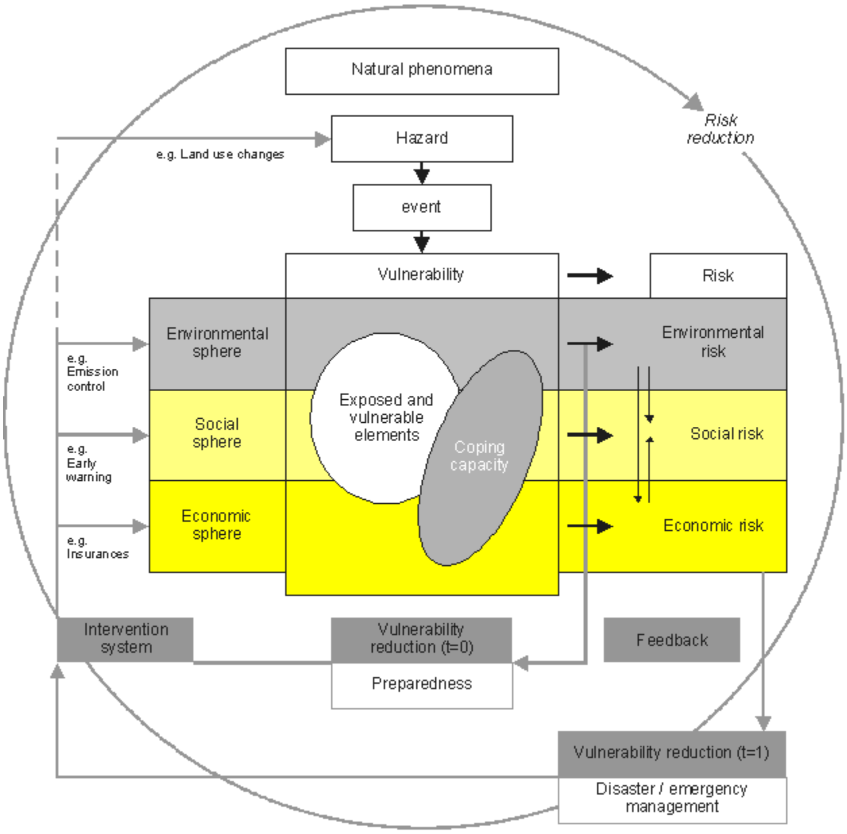


Figure 5.9: The BBC conceptual framework. (Source: Bogardi and Birkmann, 2004)

The conceptual models described above are mainly tools for explaining vulnerability, and for awareness purposes, but have limited use for measuring vulnerability. There exist limited guidelines on how to assess the different components.

5.4 Types of losses and vulnerability

There are many different types of losses that can be evaluated. These can be either direct or indirect, and can be human-social, physical, economic and cultural/environmental. Table 5.1 gives an overview with examples. The ones indicated in red are those that are most frequently evaluated.

	Human - social	Physical	Economic	Cultural Environmental
Direct losses	• Fatalities • Injuries • Loss of income or employment • Homelessness	• Structural damage or collapse to buildings • Non-structural damage and damage to contents • Structural damage infrastructure	• Interruption of business due to damage to buildings and infrastructure • Loss of productive workforce through fatalities, injuries and relief efforts • Capital costs of response and relief	• Sedimentation • Pollution • Endangered species • Destruction of ecological zones • Destruction of cultural heritage
Indirect losses	• Diseases • Permanent disability • Psychological impact • Loss of social cohesion due to disruption of community • Political unrest	• Progressive deterioration of damaged buildings and infrastructure which are not repaired	• Economic losses due to short term disruption of activities • Long term economic losses • insurance losses weaken-ing the insurance market • Less investments • Capital costs of repair • Reduction in tourism	• Loss of biodiversity • Loss of cultural diversity

Table 5.1: Overview of types of losses

Factors to be considered in vulnerability quantification are:

- Different elements at risk with their characteristics:
- Different types of vulnerability: physical, social, economical, environmental.
- Different levels of scale. Different levels of scale require often different methods. E.g. in the analytical models the data requirement increases with more complex methods.
- Different hazard types. Not all methods of vulnerability quantification are used for the different hazard types.
- Different hazard intensities and indicators for hazard intensity. Table 5.2 gives an overview of indicators for 3 hazard types.

Flooding	Landslides	Earthquakes
Water depth Flow velocity Flow duration Wave height Time of onset Water-level ascend rate	Ground movement-displacements Velocity of ground movement Run-out distance Impact forces from rock falls	Mercalli intensity Peak ground acceleration Peak ground velocity Permanent ground displacement Spectral acceleration

Table 5.2: Hazard indicators that can be used in vulnerability assessment

Task 5.2: Linking loss types with vulnerability quantification (15 minutes)

Compare the losses indicated in table 5.1, the vulnerability factors that are in table 5.2, the elements at risk information discussed in session 2.
Is it possible to make vulnerability quantifications for indirect losses? Select one of the loss categories in table 5.1 and think of a way how these could be analyzed using the hazard indicators in table 5.2.

5.5 Expressing vulnerability

Vulnerability can be expressed or presented in various ways.

Vulnerability indices based on indicators of vulnerability; mostly no direct relation with the different hazard intensities. These are mostly used for expressing social, economic and environmental vulnerability. See also 5.5.

Vulnerability curves that are constructed on the basis on the relation between hazard intensities and damage data. They provide a relation in the form of a curve, with an increase in damage for a higher level of hazard intensity. Different types of elements at risk will show different levels of damage given the same intensity of hazard. This is illustrated in figure 5.10, where the red line indicates an element at risk with a lower vulnerability than the green line. This method is mostly applied for physical vulnerability. Vulnerability curves are also named damage functions, or stage-damage curves. Vulnerability curves can be subdivided into two types:

- **Relative curves**: they show the percentage of property value as the damaged share of the total value to hazard intensity.
- **Absolute curves**: show the absolute amount of damage depending on the hazard intensity; i.e. the value of the asset is already integrated in the damage function.

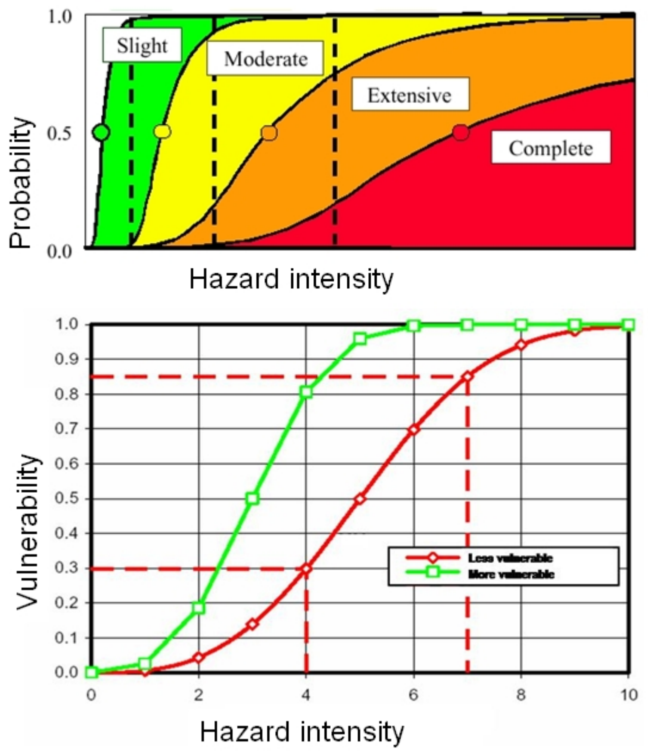


Figure 5.10: Fragility curves (above) and vulnerability curve (below)

Fragility curves provide the probability for a particular group of element at risk to be in or exceeding a certain damage state under a given hazard intensity. In figure 5.10 there are four damage states defined (complete destruction, extensive damage, moderate damage, and slight damage). Given a particular level of hazard intensity, these four stages have different probabilities. For instance the left dotted line has 0 probability to be moderately damaged or worse. The middle dotted line indicated that the chance of being slightly damaged or more is very high, whereas the chance of complete damage is still 0. Fragility curves are used often in earthquake loss estimation, mostly for physical loss estimation.

Vulnerability table: the relation between hazard intensity and degree of damage can also be given in a table. In that case the smooth vulnerability curve is actually divided into a number of hazard intensity classes, and for each class the corresponding degree of damage is given. This is frequently done in earthquake vulnerability when the hazard intensity is expressed as Modified Mercalli Intensity, which is an ordinal scale that doesn't have intermediate values between two intensities.

Task 5.3: Methods for expressing vulnerability (10 minutes)

What are the pro's and cons of relative and absolute damage functions?
Can you think of an example for these for a particular hazard type?

5.6 Measuring physical vulnerability

Measuring physical vulnerability is increasingly seen as an effective step towards risk reduction and the promotion of a culture of disaster resilience (Kasperson et al., 2005). Also the Hyogo Framework for Action stresses the need to develop indicators of vulnerability as a key activity, and underlines the fact that the impacts of disasters on social , economic and environmental conditions must be examined through such indicators (*http://www.unisdr.org/eng/hfa/hfa.htm*). Since vulnerability is, multi-dimensional, dynamic in time, scale-dependent and site-specific, different indicators are selected in the different vulnerability assessments studies. In the text below a number of methods are presented. We will concentrate here on methods used for measuring physical and social vulnerability.

5.6.1 Methods for physical vulnerability assessment

Physical vulnerability refers to the potential for physical impact on the built environment and population. This aspect is relatively "easily" quantified because it depends directly on the physical impact of a hazard event and relates to the characteristics of the element at risk and the intensity and magnitude of the hazard. See also Figure 1.12.

Group	Method	Description
Empirical methods	**Analysis of observed damage**	Based on the collection and analysis of statistics of damage that occurred in recent and historic events. Relating vulnerability to different hazard intensities.
	Expert opinion	Based on asking groups of experts on vulnerability to give their opinion e.g. on the percentage damage they expect for the different structural types having different intensities of hazard. In order to come to a good assessment of the vulnerability, many experts have to be asked and this is time consuming, and subjective in general. Re-assessments of vulnerability after building upgrading or repair are difficult to accommodate.
	Score Assignment	Method using a questionnaire with different parameters to assess the potential damages in relation to different hazard levels. The score assignment method is easier to update e.g. if we think about earthquake vulnerability before and after application of retrofitting.
Analytical models	**Simple Analytical models**	Studying the behavior of buildings and structures based on engineering design criteria, analyzing e.g. seismic load and to derive the likelihood of failure, using computer based methods from geotechnical engineering. Using e.g. shake tables and wind tunnels, as well as computer simulation techniques.
	Detailed Analytical methods	Using complex methods. It is time consuming, needs a lot of detailed data and will be used for assessment of individual structures.

Table 5.3: Overview of methods used for measuring physical vulnerability

Figure 5.11 gives a schematic overview of the methods used for physical vulnerability assessment

Expenditure	**Increasing computational effort** →				
Application	**Building stock**				**Individual buildings**
Methods	**Observed Vulnerability**	**Expert Opinions**	**Simple Analytical Methods**	**Score Assignments**	**Detailed Analysis procedures**

Figure 5.11: Methods for the assessment of vulnerability of elements at risk (Lang 2002. Source: BRGM, 2005)

Task 5.4: Vulnerability methods (duration 10 minutes)

Consider which of the methods would be most appropriate to use for obtaining vulnerability information in the following cases:

- *A national scale flood loss assessment in a situation where no prior flood data is available.*
- *The analysis of the vulnerability of hospitals in an earthquake threatened city.*
- *Landslide vulnerability assessment in an urban area with frequent landslides.*

Direct observations

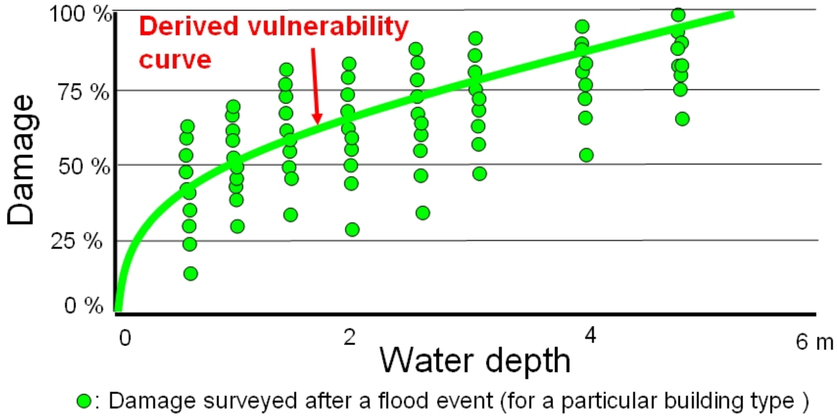


Figure 5.12: Illustration of the use of damage surveys for the generation of vulnerability curves.

For events that are relatively frequent and widespread it is possible to collect information on the degree of physical damage to buildings or infrastructure after the event has occurred. This method is particularly suited for flooding and for earthquakes, which normally affect many buildings that are of the same type, and allow to generate large enough samples in order to make a correlation between the intensity/magnitude of the hazard (e.g. modified mercalli intensity, ground acceleration, water depth etc) in order to make a statistical correlation with the degree of damage and derive a vulnerability curve. Figure 5.12 gives an illustration of the principle. The range of damage results for the same intensity depends on the definition of the building types. If the building types are very similar, also the degree of damage that will be observed is more similar than for buildings that have a large variation within the group.

Damage assessment can be done using different tools:

- Remote Sensing can be useful for mapping the extent of the hazard phenomena, especially in the case of flooding. This, in combination with information from a Digital Elevation Model, and from a flood model (See session 3) allows you to obtain a good idea of the flood extent and the flood parameters (depth especially). Satellite images, aerial photographs, etc taken during the disaster event, or shortly after are important inputs.
- In some cases rapid monitoring using video cameras might be a good tool , especially for the rapid mapping of earthquake damage (see figure 5.13)
- For the assessment of damage Participatory GIS approaches can be a very useful tool, as mentioned in session 4.
- Existing data bases: Munich Re and Swiss Re data bases for natural catastrophes MR NatCat SERVISE

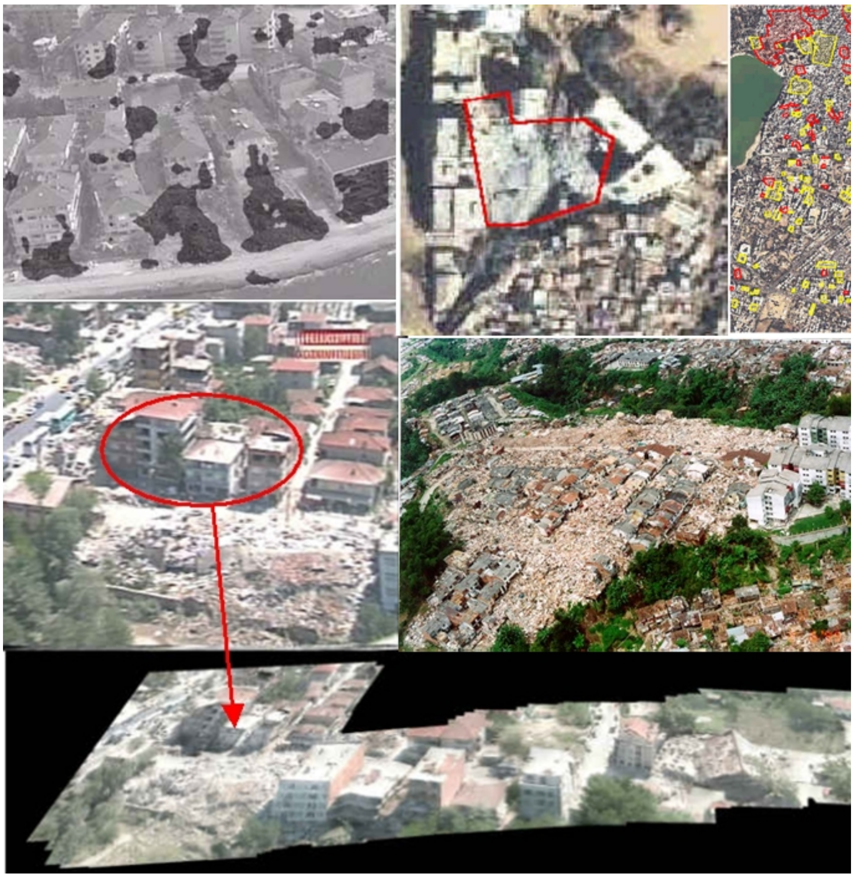


Figure 5.13: different approaches for using Remote Sensing data for rapid damage assessment, such as video images, oblique photographs, and high resolution satellite imagery (Source: Derya Osirik, ITC MSc student)

(NatCat) includes more than 20,000 entries on material and human loss events worldwide (Munich Re,2003)

- In most of the cases however, detailed damage surveys need to be carried out with the help of checklists.

Task 5.5: RiskCity exercise: derivation of vulnerability curves using damage data (duration 2 hours)

In this exercise you will analyze damage data from RiskCity which has been collected using Participatory mapping after a major flood event. The input for the analysis consists of a point map in GIS, which is linked to a table. The table looks like the one below.

X	*Y*	*Building type*	*Flood height*	*Damage*
		Wood		
		Masonry		

The aim of this exercise is to make vulnerability curves for buildings present in the area

Go to the exercise book and follow the instructions there.

Expert Opinion

In many situations expert opinion will be the most feasible option for obtaining vulnerability information, either because there is no prior damage information, not enough funding to apply analytical methods or because building classifications used elsewhere do not reflect the local building stock and a local classification is then deemed more appropriate. This method involves the consultation of a group of experts on vulnerability to give their opinion e.g. on the percentage damage they expect for the different structural types having different intensities of hazard. In order to come to a good assessment of the vulnerability, many experts have to be asked and this is time consuming, and subjective in general. Re-assessments of vulnerability after building upgrading or repair are difficult to accommodate.

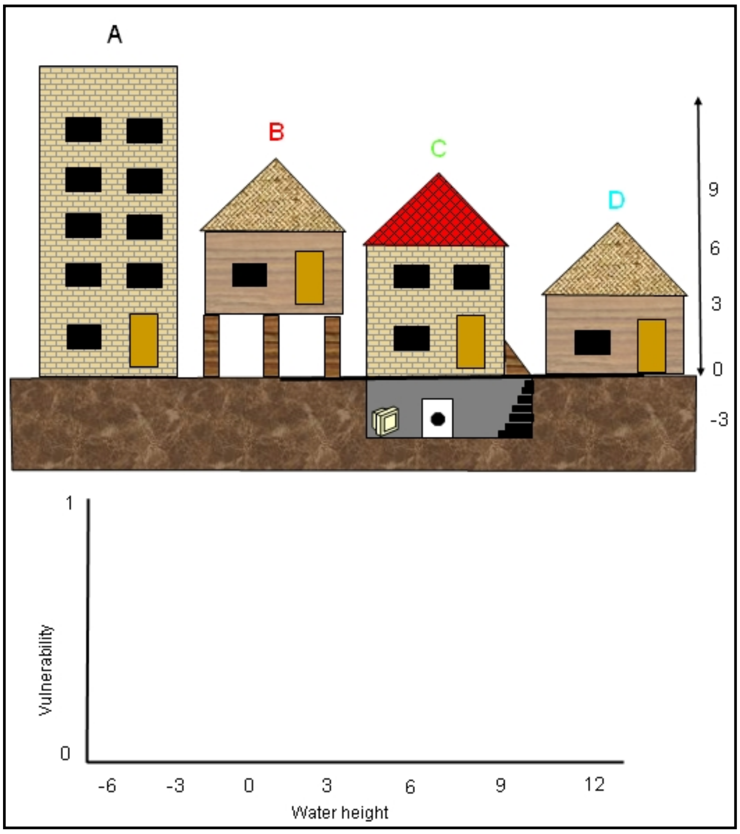


Figure 5.14: It is possible to make a reasonable estimate of the vulnerability of these 4 buildings.

Task 5.6: Expert opinion in generating a vulnerability curve (duration 15 minutes)

In the figure above there are 4 different buildings, each with different characteristics. Imagine the flood will take place in the area, and the waterlevel is rising slowly but constantly. How would the four buildings be affected?
Draw 4 approximate vulnerability curves in the graph.

Analytical methods

Analytical methods study the behavior of buildings and structures based on engineering design criteria, analyzing e.g. seismic load and derive the likelihood of failure, using computer based methods from geotechnical engineering. Analytical methods use for example shake tables and wind tunnels, as well as computer simulation techniques. In the analytical methods the information on the intensity of the hazard should be also more detailed. For instance in the case of earthquake vulnerability analysis of buildings it is important to have geotechnical reports to establish the value of the effective peak acceleration coefficient, the value of the effective peak velocity-related acceleration coefficient and the soil profile type. Also spectral acceleration should be obtained. One of the commonly used tests is done with a shake table. This is a device for shaking structural models or building components with a wide range of simulated ground motions, including reproductions of recorded earthquakes time-histories.

Task 5.7: Watch Shaketable test on Youtube (duration 15 minutes)

There are many examples on the Internet of shaketests with building models on shaketable, to investigate the behaviour of buildings under different earthquake accelerations.
For instance:
The collapse of an adobe building:
http://www.youtube.com/watch?v=AL7Kh31tB2M&NR=1
Collapse of conventional wooden building:
http://www.youtube.com/watch?v=kc652Zp5qWk&feature=related
Woodframe building, very flexible:
http://www.youtube.com/watch?v=otyLaENTkHE&feature=related
See the softstory effect in a 6 floor building:
http://www.youtube.com/watch?v=3z4YLUqOysI&feature=related
Very large simulation with realsize RCC building:
http://www.youtube.com/watch?v=O2XMfOXVOvo

In combination with shake table tests, building behavior is increasingly modelled with the aid of computer simulation programmes, with for instance finite element methods. For example Figure 5.15 shows an example of the modeled collapse of masonry structures during an earthquake which has been analyzed using a three-dimensional distinct element method. This is a numerical analysis technique, in which positions of elements are calculated by solving equations of motion step by step. Both individual and group behavior can be simulated. The structure is modeled as an assembly of distinct elements connected by virtual springs and dashpots, where elements come into contact.

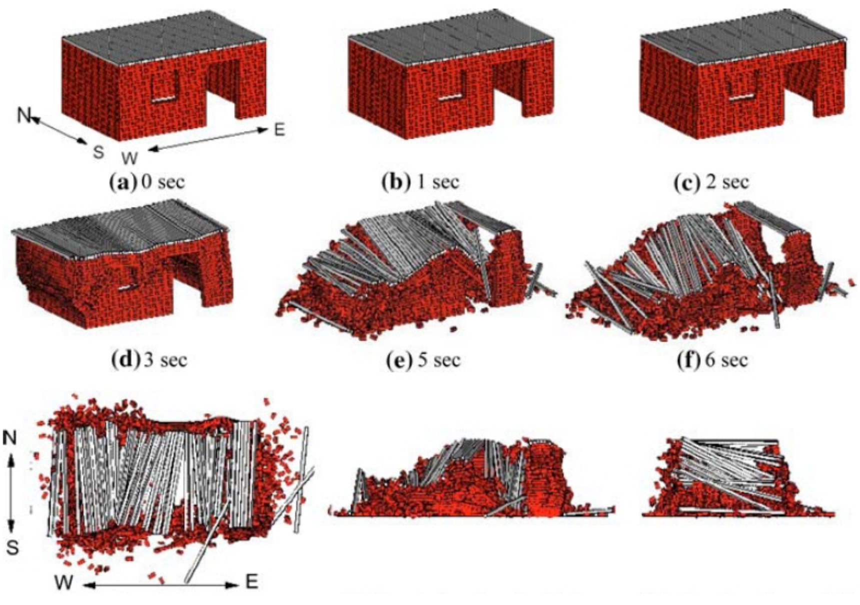


Figure 5.15: Example of a numerical simulation of a masonry building under an earthquake, comparable to the Bam earthquake (Source: Furukawa and Ohta, 2009)

5.6.2 Earthquake vulnerability assessment.

Earthquake vulnerability curves are generated using any of the methods indicated in table 5.3. They differ in terms of the hazard indicator used and the building types. Vulnerability curves have been generated for many parts of the world (See figure 5.16)

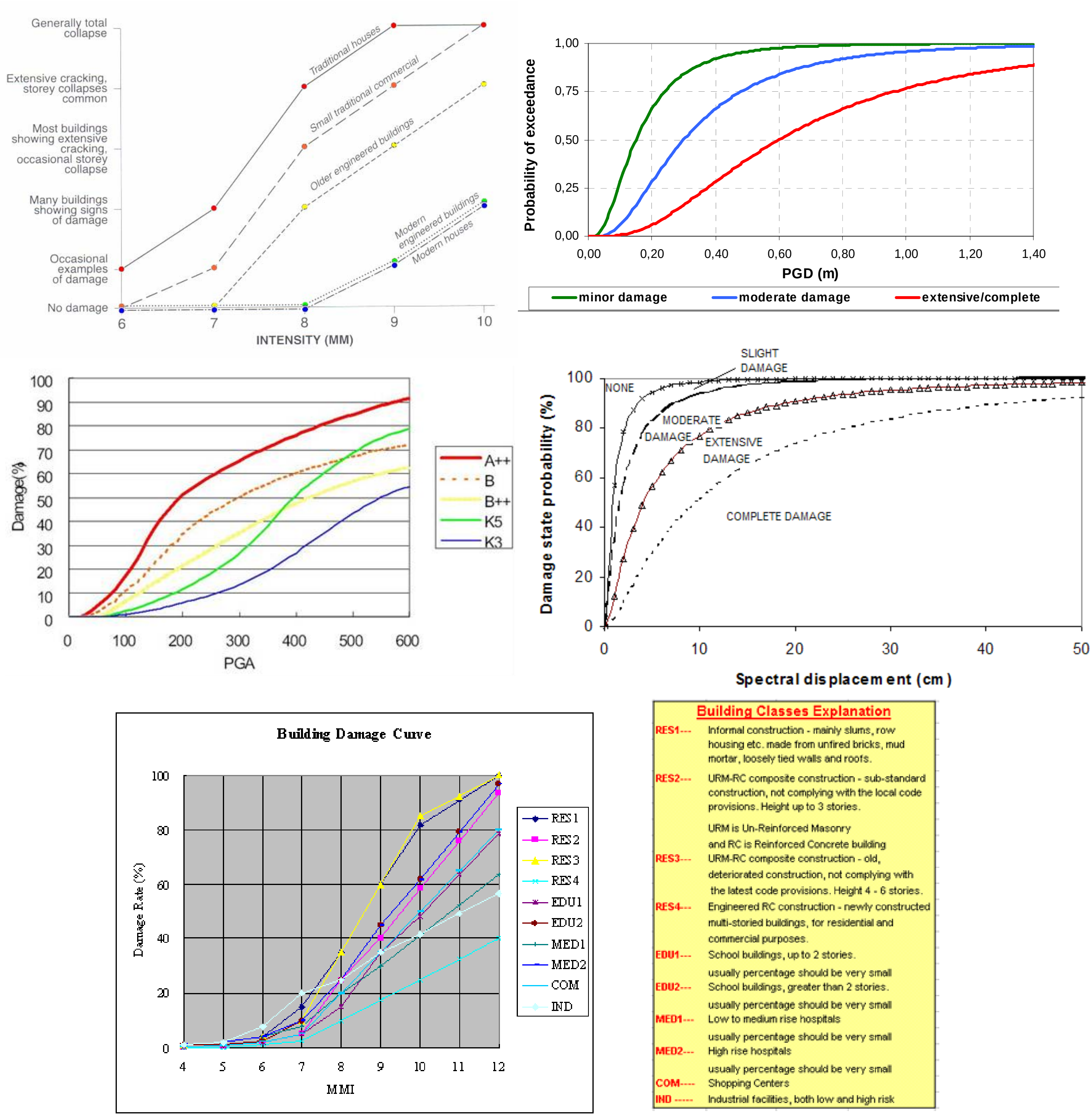


Figure 5.16 Different types of vulnerability and fragility curves for earthquakes. Upper right: general relationships between earthquake intensity on the Modified Mercalli scale and building damage based on the effects of the 1995 Kobe earthquake (Source: Alexander Howden Group Ltd and institution of Civil Engineers 1995). Upper right: fragility curve for roads in Greece (Source: Pitilakis, Greece) Middle left: Relationship between Peak Ground Acceleration and damage for typical building types in Nepal (Source: NSET, Nepal). Middle right: fragility curves for building based on spectral displacement (Source: HAZUS). Below: building damage curves and building classification as used in the Radius method for earthquake loss estimation.

Different buildings can respond in widely differing manners to the same earthquake ground motion. Conversely, a given building will act differently during different earthquakes. This phenomenon highlights the need to concisely represent the building's range of responses to ground motion of different frequency contents. Such a representation is known as a response spectrum. A response spectrum is a graph that plots the maximum response values of acceleration, velocity and displacement against period and frequency (see figure 5.17). Such response spectra are very important in earthquake engineering.

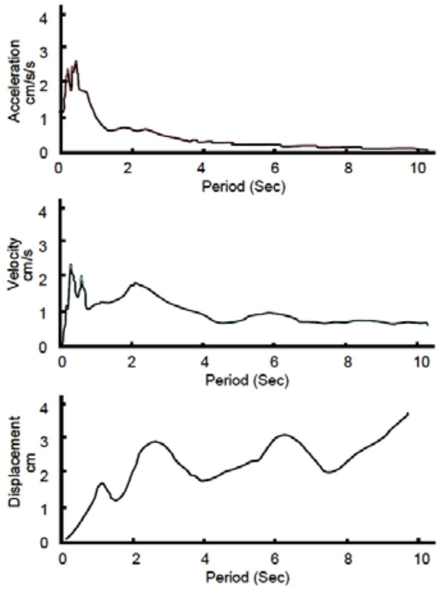


Figure 5.17: Simplified response spectra (Source: Montoya, 2003)

The HAZUS methodology for earthquake loss estimation makes use of the response spectra. The site-dependent response spectrum of the ground motion is employed as a demand spectrum in the method. The methodology uses a technique to estimate inelastic building response as the intersection of the building capacity curve and the response spectrum of shaking demand at the building's location (demand spectrum). It uses a building capacity curve , which is a plot of a building's lateral load resistance as a function of a characteristic lateral displacement (i.e., a force-deflection plot). For each type of building a fragility curve is made. Each fragility curve is defined by a median value of the demand parameter (e.g., spectral displacement) that corresponds to the threshold of that damage state and by the variability associated with that damage state. See figure 5.18.

s

Damage State		Description
	Slight	Small plaster cracks at corners of door and window openings and wall-ceiling intersections; small cracks in masonry chimneys and masonry veneers. Small cracks are assumed to be visible with a maximum width of less than 1/8 inch (cracks wider than 1/8 inch are referred to as "large" cracks).
	Moderate	Large plaster or gypsum-board cracks at corners of door and window openings; small diagonal cracks across shear wall panels exhibited by small cracks in stucco and gypsum wall panels; large cracks in brick chimneys; toppling of tall masonry chimneys.
	Extensive	Large diagonal cracks across shear wall panels or large cracks at plywood joints; permanent lateral movement of floors and roof; toppling of most brick chimneys; cracks in foundations; splitting of wood sill plates and/or slippage of structure over foundations.
	Complete	Structure may have large permanent lateral displacement or be in imminent danger of collapse due to cripple wall failure or failure of the lateral load resisting system; some structures may slip and fall off the foundation; large foundation cracks. Three percent of the total area of buildings with Complete damage is expected to be collapsed, on average.

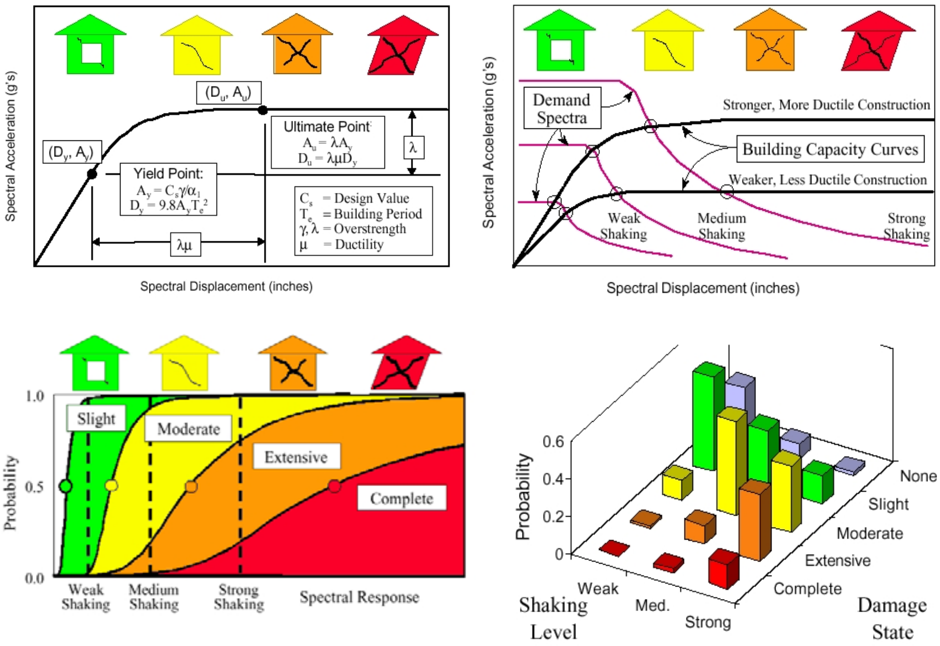


Figure 5.18: HAZUS method for earthquake loss estimation of buildings.

5.6.3 Flood vulnerability assessment

Flood damage functions describe the relationship between hydraulic parameters and the relative damage or damage factor of the element at risk. Three different scale levels are defined micro, meso and macro. Figure 5.19 indicates the relation of the relevant food model with the relavant damage function scale level.

Below 3 examples are given on the use of vulnerability information in flood risk assessment.

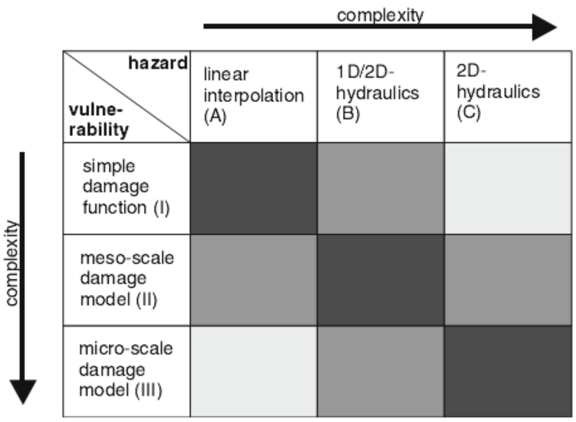


Figure 5.19: The comparative model matrix. Dark colours represent match in complexity, light colours a mismatch. (Source: Apel et al, 2009.)

Flood example 1: United Kingdom Flood data base and damage functions of the Flood Hazard Research Centre (FHRC) from Middlesex University.

This method deals with the derivation of damage curves from synthetic damage data. The main variables used are: depth of flood water within the buildings and the depth and extent of floodwater on the floodplain. Velocity is assumed to cause in rare cases structural failure. The data base has 100 residential and more than ten non residential property types. Costs relate to restoration to pre-flood conditions, but do not always allow for full replacement. Absolute damage functions are used.

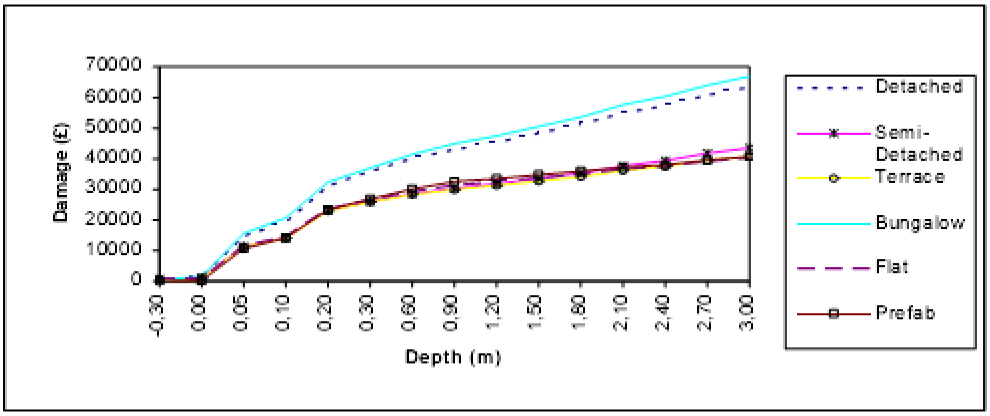


Figure 5.12 Synthetic depth-damage curves for different residential house types (Source: Penning-Rowsell et al. 2003).

Flood example 2: HOWAS data base from Germany and derived damage functions.

This is a typical example of the use of actual (observed) flood damage data. Nine flood events are considered over a period between 1978 and 1994. The assessment of damages was carried out by insurance adjusters and can be interpreted as replacement costs. Howas derived absolute depth-damage functions. An example of a HOWAS damage function is indicated in figure 5.13. With expert knowledge the function can be made suitable for different building structural types. If you can read German it might be worthwhile to visit the website: http://nadine-ws.gfz-potsdam.de:8080/howasPortal/client/start\

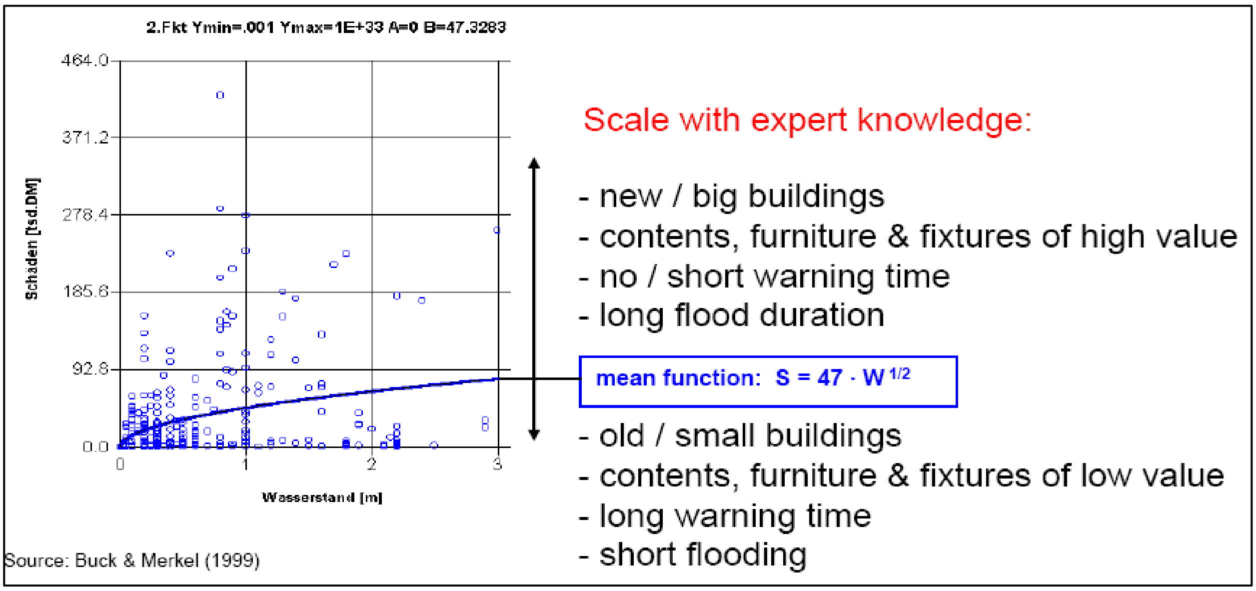


Figure 5.13 Example for a damage function from the HOWAS database.

Flood example 3: Damage functions of the Dutch Standard Method

This method has been developed for the typical type of flooding in the Netherlands: inundation of polder areas.

Flood characteristics are defined by using 1D/2D hydraulic models that require detailed digital elevation models and dike breach scenario's (where the dike breaches, how large is the breach, how fast the water enters). Here the output are time-series maps of water depth and flow velocity. Especially inundation depth is needed for the damage evaluation. In case of residential buildings impacts of velocity and waves are also considered. Regarding casualties, three different inundation characteristics are taken into account: velocity, rise rate and inundation depth. The method uses land use data in a grid of 100 by 100 meter for the entire country, which is made from a mix of different data sources. Official aggregated land use data is supplemented by geomarketing data on buildings and employees in economy, as well as by official data on the street and railway network.

The Dutch standard method (2004) has eleven relative depth-damage functions which are derived synthetically and are based on both damage data and expert judgment. The damage functions are mostly depth-damage functions. Only the damage factor for residential buildings additionally takes into account a critical velocity of inundation and the impact of waves caused by storms (Kok et al. 2004). The method is developed for meso-scale and uses aggregated land use data (See http://www.floodsite.net/) . Damage categories considered are buildings, population, infrastructure, cars and agriculture. Damage is calculated for each grid cell using a dedicated softwate (HIS-SSM) with GIS capabilities. Examples of the damage function are given in figures 5.14, respectively for low- rise dwellings, intermediate dwellings and high rise dwelling.

Task 5.8: Evaluate European flood vulnerability assessment methods (20 minutes)

Read the following material: Floodsite report: Evaluating flood damages: guidance and recommendations on principles and methods. Chapter 3.section3.4.4.2 and section 3.6 Messner F. et al 2007. You can find it in background reading or online:

www.floodsite.net/html/partner_area/project_docs/T09_06_01_Flood_damage_guidelines_D9_1_v2_2_p44.pdf

Define the different scale levels of the methods of the UK, Germany and the Netherlands.
What land use data these methods use?
How are the values of assets determined?

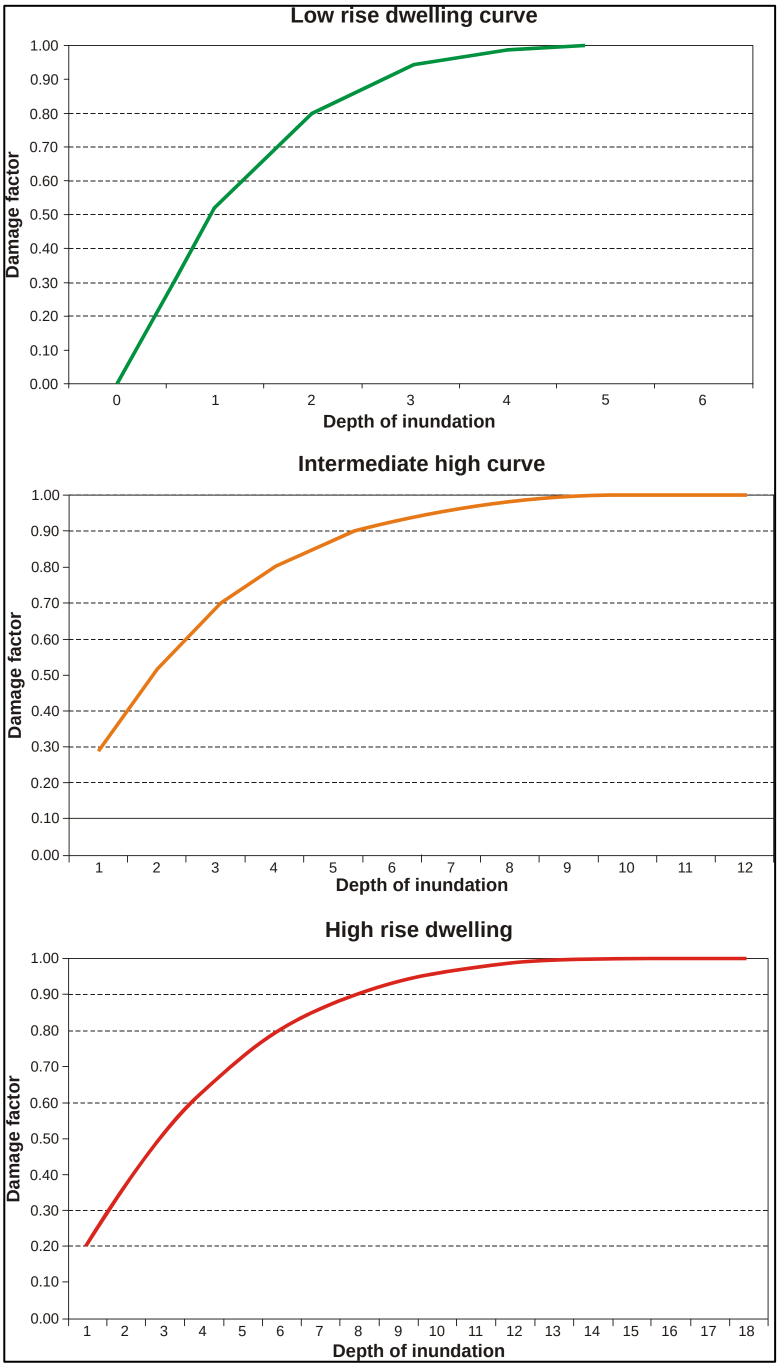


Figure 5.14 Depth-damage function of the Dutch standard method 2004 for low rise, intermediate and high rise dwellings. (Source; Huizinga,et al. , 2004).

5.6.4 Landslide vulnerability assessment

Mass movement vulnerability is much more difficult to analyze than flood or earthquake vulnerability. This has the following reasons:

- **Lack of useful hazard intensity scales**. As shown in session 4.3.3 mass movements are a wide variety of processes (fall, slide, flow, creep, spread) that may occur under different conditions and with different velocities. Therefore it is very difficult to find good scales for expressing the hazard intensity of landslides. Attempts have been made to use velocity, impact (rockfall), depth (debris flow)

Figure 5.15: Landslide vulnerability: being hit by a rockfall while driving

or volume as hazard indicators, but still there is no universal hazard intensity scale that is applicable everywhere.

- **Lack of historical damage databases**. Mass movements generally occur as isolated features that do not cover very large areas, and therefore it is difficult to use direct observations of damage in order to build vulnerability curves. It is not really possible to use aggregated damage data over large areas, because the hazard types are different and the elements at risk are very different.
- **V = 1**. Mass movements very often result in collapse or burial of the buildings that are directly in the path or on top of a fast moving landslide, therefore very often a vulnerability of 1 is used.

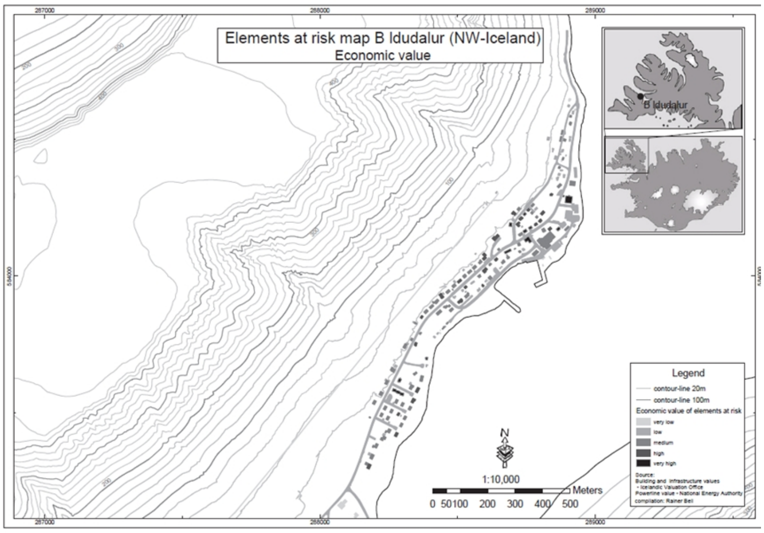
In practice most of the methods for landslide vulnerability assessment use an expert opinion approach. Table 5.4 represents the type of expert-based information that is often used in landslide vulnerability assessment.

Element at risk	Damage Intensity	Type of damage	Vulnerability (0-1)
Buildings	I	Slight non-structural damage, stability not affected, furnishing or fitting damaged	0.01 – 0.1
	II	Cracks in the wall, stability not affected, reparation not urgent	0.2 – 0.3
	III	Strong deformations, huge holes in wall, cracks in supporting structures, stability affected, doors and windows unusable, evacuation necessary	0.4 – 0.6
	IV	Structural breaks, partly destructed, evacuation necessary, reconstruction of destructed parts	0.7 – 0.8
	V	Partly or totally destructed, evacuation necessary, complete reconstruction	0.9 – 1.0
Roads	I	Slight damage of road	0.05 – 0.3
	II	Damage of roadway, reparation using 10 m3 material	0.3 – 0.6
	III	Damage of roadway, reparation using 100 m3 material	0.5 – 0.8
	IV	Destruction of roadway	0.8 – 1.0
Population	I	Moral disadvantage	0.002
	II	Psychological problems	0.003-0.005
	III	Severe physical injury. Invalidity	0.04 – 0.1
	IV	Death	1.0

Table 5.4: Vulnerability of various elements at risk according to the type of damage through landslides (Glade 2003 – modified after Leone et al. 1996)

Figure 5.16 shows an example of a landslide risk study carried out in Iceland, where the vulnerability was evaluated for debris flows, rockfall and snow avalanches, based on expert opinion and supported by historical information and basic run out modeling. The vulnerability is evaluated for all major classes of the elements at risk in the area: buildings, population (outside or in buildings), power lines, and roads. The study also evaluated the values of the elements at risk, and combined them with the vulnerability in order to calculate individual risk.

The vulnerability values obtained in the Iceland study cannot be directly used in other areas, as they are based on the local situation.



Magnitude / Process	low					medium					high				
	V_{po}	V_{str}	V_p	V_{pe}	V_{pep}	V_{po}	V_{str}	V_p	V_{pe}	V_{pep}	V_{po}	V_{str}	V_p	V_{pe}	V_{pep}
Debris flow	1.0	0.2	0.1	0.2	0.02	1.0	0.4	0.2	0.3	0.06	1.0	0.6	0.5	0.5	0.25
Rock fall	1.0	0.1	0.1	0.2	0.02	1.0	0.2	0.3	0.4	0.12	1.0	0.4	0.5	0.5	0.25
Hazard / Process	low					high(1)					high(2)				
	V_{po}	V_{str}	V_p	V_{pe}	V_{pep}	V_{po}	V_{str}	V_p	V_{pe}	V_{pep}	V_{po}	V_{str}	V_p	V_{pe}	V_{pep}
Snow avalanche	1.0	0.3	0.3	0.5	0.15	1.0	0.1	0.3	0.1	0.03	1.0	0.8	1.0	1.0	1.0

Figure 5.16: Vulnerability study in Iceland. Vpo = vulnerability of a power line, Vstr = vulnerability of roads and infrastructures, Vp = vulnerability of properties (buildings), Vpe = vulnerability of people and Vpep = vulnerability of people in buildings. Source: Bell and Glade 2003)

Table 5.5 presents some general vulnerability values for residents, buildings and roads for landslides in three different situations, derived by expert opinion.

Process	Vulnerability of		
	Residents	Buildings	Roads
Landslides on hill slopes	0.05	0.25	0.3
Susceptible to proximal debris flows	0.9	1	1
Susceptible to distal debris flows	0.05	0.1	0.3

Table 5.5: Vulnerability of various elements at risk with respect to landslides including debris flows (Glade 2003 – modified after Michael-Leiba et al. 2000)

There have been attempts to derive vulnerability curves for landslides. Figure 5.16 is an example from Cuba, where the vulnerability of three different building types was evaluated for debris flow. This was done after analyzing a historical debrisflow and evaluation of the thickness of the debrisflow material in relation to the degree of loss. However, this didn't give enough information, so the main input for the vulnerability curves came again from expert opinion.

Figure 5.17 shows results from several studies that are based on observed damages due to debrisflows.

Currently analytical methods are developed for the generation of vulnerability curves for landslides. Particularly for rockfall impact and debrisflows these tools are very promising, and are, apart from the expert derived methods, the best option. For instance for the evaluation of the structural vulnerability of a building due to a rock impact, the probability of collapse can be analyzed by combining the probability of building collapse with the impact probability. The impact of a rock block on the structural components of a building (columns) can be modeled and the stability of the structure after the impact can be analyzed. Landslide vulnerability assessment is still in its infant stages, and needs to obtain more attention in order to be able to produce quantitative assessments of landslide risk.

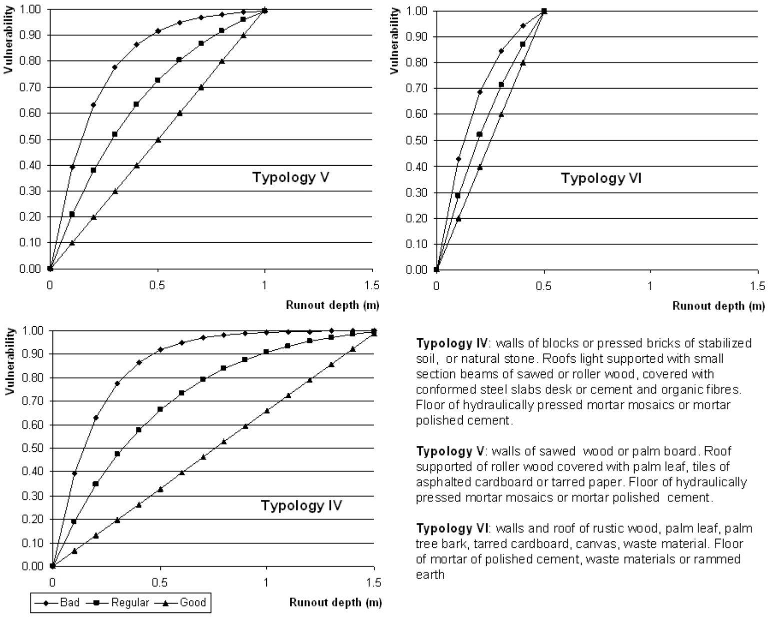


Figure 5.16: Vulnerability curves for debrisflows derived from expert opinion and supported by historical damage data for three building types in Cuba. (Source: Castellanos and Van Westen,

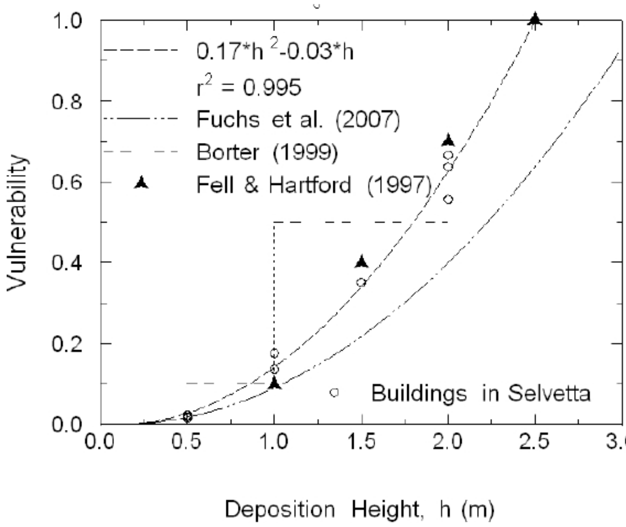


Figure 5.17: Debrisflow vulnerability curves from different studies (Source: Akbas et al, 2009)

Building structure	**Resistance**	**Rockfall magnitude**		
		Low	**Medium**	**High**
Lightest structure (wood)	None	0.2	1	1
Light structure	Very weak	0.15	0.5	0.9
Mixed structure (concrete and wood)	Weak	0.1	0.3	0.8
Brick walls, concrete	Medum	0.08	0.25	0.7
Reinforced concrete	Strong	0.05	0.2	0.5
Reinforced	Very strong	0	0.1	0.3

Table 5.6: Vulnerability of buildings according to the magnitude of rock fall (Glade 2003 – modified from Heinimann 1999).

5.6.5 Population loss estimation.

The vulnerability of population can be subdivided in the direct physical vulnerability of the population (injury, casualties, and homelessness) which will be evaluated here, and the indirect social vulnerability and capacity, which will be dealt with in the next section.
One of the very important next steps after a building vulnerability study is to analyze the effect of the damage of the building on the population inside of the building. For the evaluation of population losses, a first step is to define population injury severity classes. Table 5.7 gives the classification which is used in the HAZUS methodology.

Injury Severity Level	Description Of Injury
Severity 1	Requiring basic medical aid without requiring hospitalization
Severity 2	Requiring a greater degree of medical care and hospitalization, but not expected to progress to a life threatening status
Severity 3	Pose an immediate life threatening condition if not treated adequately and expeditiously. The majority of these injuries are the result of structural collapse and subsequent entrapment or impairment of the occupants.
Severity 4	Instantaneously killed or mortally injured

Table 5.7: Injury severity levels as indicated in the HAZUS methodology.

Several methods exist for linking of building damage to these severity levels. Table 5.8 gives the information used in HAZUS for earthquake vulnerability of people. HAZUS doesn't make similar estimates for flooding and hurricanes due to lack of data.

Structural damage	Structural type	Affected people (values are in percentage)			
		Severity 1	Severity 2	Severity 3	Severity 4
Complete (collapse)	Most structural types	40	20	3-5	5-10
	Masonry	40	20	5	10
Complete (no collapse)	Most structural types	5	1	0.01	0.01
	Masonry	10	2	0.02	0.02
Extensive	Most structural types	1	0.1	0.001	0.001
	Masonry	2	0.2	0.002	0.002
Moderate	Most structural types	0.20 – 0.25	0.025 – 0.03	0	0
	Masonry	0.35	0.4	0.001	0.001
Slight	Most structural types	0.05	0	0	0
	Masonry	0.05	0	0	0

Table 5.8: Population vulnerability used in the HAZUS method for earthquake losses.

Table 5.9 give the estimate used in Canada by the NHEMATIS method for loss estimation. Here the data is linked to the percentage of building damage.

Percentage of building damage	Fraction of population affected		
	Minor injuries	Major injuries	Dead
0.00	0	0	0
0.50	3/100,000	1/250,000	1/1,000,000
5.00	3/10,000	1/25,000	1/100,000
20.00	3/1,000	1/2.500	1/10,000
45.00	3/100	1/250	1/1,000
80.00	3/10	1/25	1/100
100.00	2/5	2/5	1/5

Table 5.9: Population vulnerability values used in the Nhematis method.

The severity levels and the percentages of affected people should be combined with the temporal distribution patterns of the population, which were discussed in session 4.4. This allows then to model in a GIS the distribution of people indoors and outdoors in different periods of the day, and to use this as input in loss estimation scenarios, where the percentage of damaged buildings (following table 5.7) or the percentage of buildings per structural damage class (following table 5.8) will determine the population affected. Figure 5.18 gives an example of this for the city of Lalitpur in Nepal, related to earthquake losses.

Also for landslides population vunerability curves have been made based on expert opinion. Table 5.10 Presents results on population vulnerability for the Hong Kong area for landslides, which are based on an extensive database of slope failures and associated injuries and casualties.

Location	Description	Population vulnerability (individuals)		
		Data range	Recommended	Comments
Open Space	Struck by rock fall	0.1 -0.7	0.5	May be injured but unlikely to cause death
	Buried by debris	0.8 – 1.0	1	Death by asphyxia
	Not buried but hit by debris	0.1 – 0.5	0.1	High chance of survival
Vehicle	Vehicle is buried/crushed	0.9 – 1.0	1	Death almost certain
	Vehicle damaged only	0.0 – 0.3	0.3	High chance of survival
Building	Building collapse	0.9 – 1.0	1	Death almost certain
	Inundated building with debris	0.8 – 1.0	1	Death is highly likely
	Inundated building with debris but person is not buried	0.0 – 0.5	0.2	High chance of survival
	Debris strikes building only	0.0 – 0.1	0.05	Virtually no danger

Table 5.10: Vulnerability of a person being affected by a landslide in open space, in a vehicle and in a building (Table 2, Glade 2003 – modified after Wong et al. 1997)

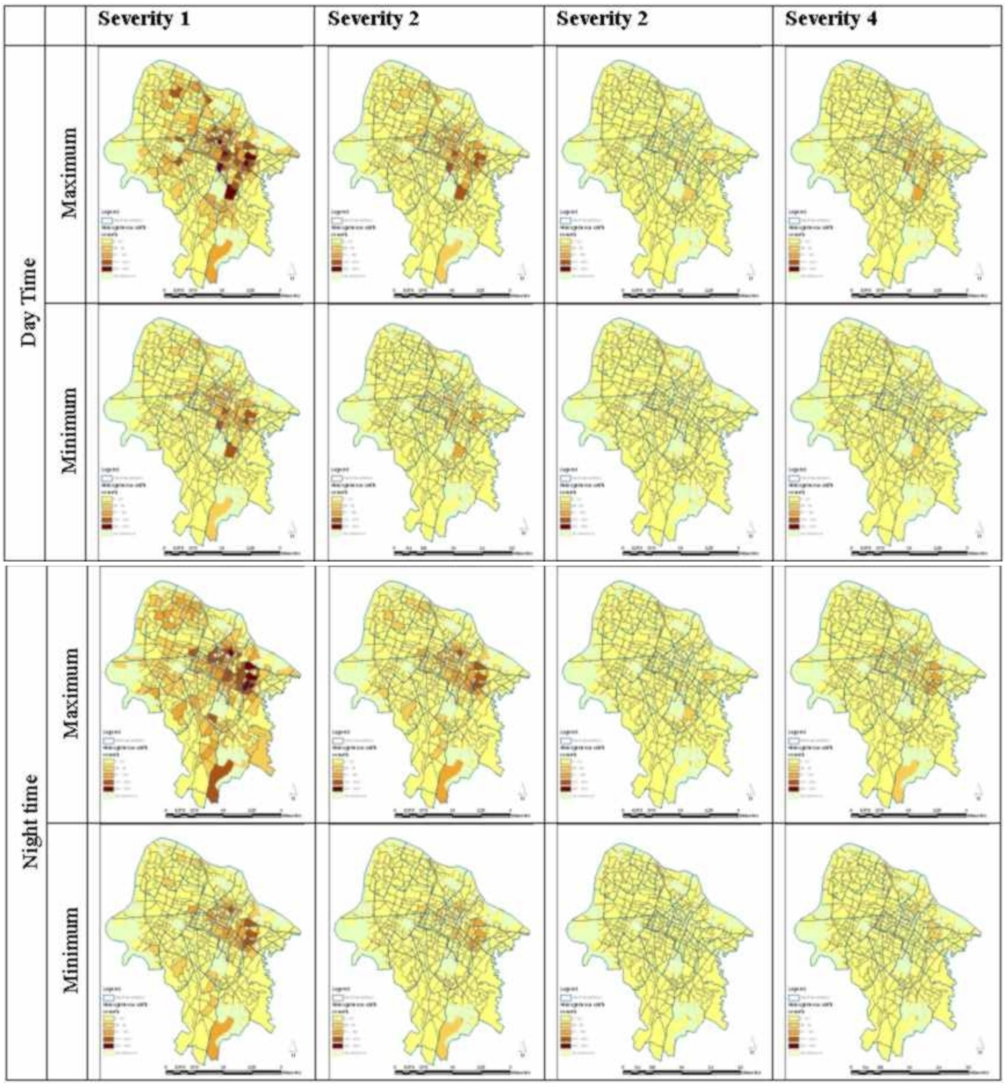


Figure 5.18: Population loss estimation for Lalitpur, Nepal, for two temporal scenarios (daytime and nighttime) and for the four severity levels defined in table 5.6 (Source: Islam MSc ITC, 2004)

5.7 Comprehensive vulnerability assessment

In the previous section we have concentrated mainly on the methods used for assessing physical vulnerability, mostly using vulnerability curves or tables that relate the expected damage with the hazard intensity. As we have seen in the introduction of this session, vulnerability encompasses much more than that (see section 5.2). In this section we will look at methods that have a much wider scope in defining vulnerability. These methods mostly use indicators, based on expert opinion. We will do this by showing some examples.

Example 1: Villagrán de León (2006): " sectoral approach"; Expert opinion method working with vulnerability indices.

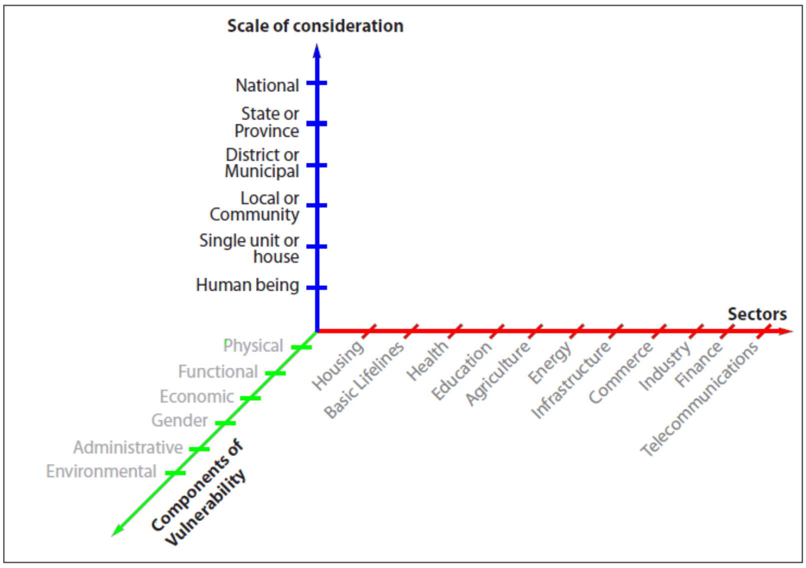


Figure 5.19: Framework for vulnerability. (Source: Villagrán de León, 2006).

Villagrán de León (2006) developed a framework for decomposing vulnerabilities (figure 5.19). He distinguishes 3 dimensions of vulnerability; the scale or geographical level (from human being to national level), the various sectors of society ("elements at risk "), and 6 components of vulnerability ("types of vulnerability"). Hazard intensity is not further specified, the method is based on a very high magnitude event. This sectoral approach, proposed from a policy point of view, seems useful since it promotes assigning responsibilities for reducing vulnerabilities to those private or public institutions in charge of the sector (Villagrán de Leon 2006). The method uses matrices to calculate a vulnerability index, which is grouped in 3 classes (high, medium and low). The example shown in figure 5.20 considers the housing as elements at risk, and looks at physical vulnerability at the scale of a single building for a high hazard level of volcanic eruptions.
The indicators do not show how vulnerability depends on magnitude of the hazard. As can be seen in figure 5.20 the vulnerability is defined by 6 characteristics / parameters of the house that are rated based on their construction material, method, and design into 3 classes. (See also Session 4: Elements at Risk). Per characteristic a weight is given with respect to the other characteristics. Here the wall material is defined as most important parameter contributing to the vulnerability of the house. The 3 subclasses are based on historic research of volcanic impacts on housing in Central America.

		LOW	MEDIUM	HIGH
	WEIGHT	1	3	5
Walls	15	block, brick metallic structure	adobe	cardboard, light wood, plastic, bamboo
Roof, materials	10	concrete slab	galvanized sheeting, cement tiles	straw, plastic brick tiles
Roof, inclination	5	very inclined	modetately inclined	low inclination
Roof, support material	5	steel structure new, treated wood	old, non-treated wood	weights, stones
Doors	1	metal, wood	small windows	large windows
Windows	1	metal, wood	small glass	large glass

$$V_{estruct} = 15 \times 5 + 10 \times 5 + 5 \times 5 + 5 \times 3 + 1 \times 1 + 1 \times 1 = 167$$

Figure 5.20: Matrix to asses the structural vulnerability index of a house in regarding volcanic eruptions. (Source: Villagran de Leon)

Degree of structural vulnerability	Numerical range
Low	37–80 points
Medium	81–130 points
High	131–185 points

Example 2. Framework of the German Technical Cooperation Agency – GTZ (2004): for defining vulnerability at Local Level.

The GTZ framework is an expert-opinion index method, for defining physical, social, economic and environmental vulnerability at local level (Community scale). It uses the conceptual framework of Davidson, adopted by Bollin et al (in: Birkmann 2006)(see figure 5.5). Each type of vulnerability is characterized by a number of indicators, as indicated in table 5.11). The main aim is to define a Community-Based Risk Index by identifying and quantifying the main risk characteristics (exposure, vulnerability, management capacities) within a community. It has the function of comparing risk between different communities, as well as the goal of identifying whether the level of risk is primarily an outcome of the hazard, the exposure, the vulnerability or the capacity component (see Bollin and Hidajat, 2006).

Physical/demographic	Social	Economic	Environmental
Population density Demographic pressure Insecure settlements Access to basic services	Level of poverty Degree of illiteracy Attitude Decentralization Community participation	Local resource base Diversification Small enterprises Accessibility	Forest area Degraded area Over-used area

Table 5.11: Indicators proposed by H. Hahn to assess vulnerability. Source:(Hahn, Villagrán De León et al. 2003)

The model assigns 3 possible values (low=1, medium=2 or high=3) to the each of the indicators, and uses weights for the vulnerability index when calculating it for each type of hazard. The different indicators were weighted according to their importance for the specific hazard. The final index is representative for the community as a whole. An example is given below for the calculation of an earthquake vulnerability index the municipality of Villa Canales in Guatemala.

Indicator		Weight	Value	Product
V1	Population density	3	1	3
V2	Demographic pressure	3	3	9
V3	Insecure settlements	1	1	1
V4	Access to basic services	1	2	2
V5	Poverty level	2	2	4
V6	Illiteracy rate	2	2	4
V7	Attitude	3	2	6
V8	Decentralization	1	2	2
V9	Community participation	2	2	4
V10	Local resource base	3	3	9
V11	Diversification	2	3	6
V12	Small enterprises	2	2	4
V13	Accessibility	2	2	4
V14	Forest area	2	2	4
		33	29	62

Table 5.11 Indicators for the city of Villa Canales in Guatemala Source:(Hahn, Villagrán De León et al. 2003)

Table 5.12 gives an overview of the whole concept of the community based disaster risk index including the index of vulnerability. The 37 indicators are scored and weighted (as indicated above) and one final risk index is produced (see figure 5.21). Depending on the scaled indicator values, the factor indices vary between 0 and 100. This was achieved by distributing a total of 33 weighting points according to the assumed importance of the indicators for each factor (Bollin and Hidajat, 2006). The aim is to compare risk with other communities and to analyze risk within the community. (See Bollin and Hidajat, 2006). Furthermore, it highlights the determining factors of risk, for example whether risk originates primarily from the hazard or whether the vulnerability or the lack of capacity is the major concern.

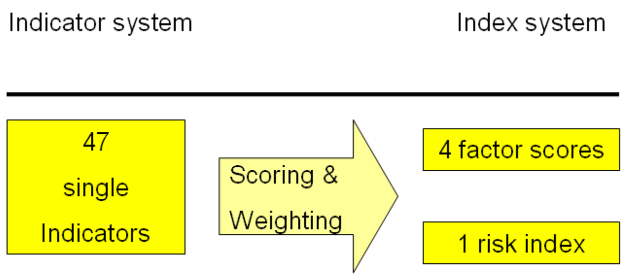


Figure 5.21 defining the final risk index.

Main factor	Indicator name	Indicator
EXPOSURE		
Structures	(E1) Number of housing units (E2) Lifelines	Number of housing units (living quarters) % of homes with piped drinking water
Population	(E3)Total resident population	Total resident population
Economy	(E4) Local gross domestic product (GDP)	Total locally generated GDP in constant currency
VULNERABILITY		
Physical/ demographic	(V1) Population Density (V2) Demographic pressure (V3) Unsafe settlements (V4) Access to basic services	People per km2 Population growth rate Homes in hazard prone areas (ravines, river banks, etc) % of homes with piped drinking water
Social	(V5) Poverty level (V6) Literacy rate (V7) Attitude (V8) Decentralization (V9) Community participation	% of population below poverty level % of adult population that can read and write Priority of population to protect against a hazard Portion of self-generated revenues of the total budget % voter turn out at last communal elections
Economic	(V10) Local resource base (V11) Diversification (V12) Small businesses (V13)Accessibility	Total available local budget in US$ Economic sector mix for employment % of businesses with fewer than 20 employees Number of interruption of road access in last 30 years
Environmental	(V14) Area under forest (V15) Degraded land (V16) Overused land	% of area of the commune covered with forest % of area that is degraded/eroded/desertified % of agricultural land that is overused
CAPACITY MEASURES		
Physical planning and engineering	C1) Land use planning (C2) Building codes (C3) Retrofitting/ Maintenance (C4) Preventive structures (C5) Environmental management	Enforced land use or zoning regulations Applied building codes Applied retrofitting and regular maintenance Expected effect on impact-limiting structures Measures that promote and enforce nature conservation
Societal capacity	(C6)Public awareness programs (C7) School curricula (C8) Emergency response drills (C9) Public participation (C10)Local risk management/ emergency groups	Frequency of public awareness programmes Scope of relevant topics taught at school Ongoing emergency committee with public representatives Grade of organization of local groups
Economic capacity	(C11) Local emergency funds (C12) Access to national emergency funds (C13) Access to intl. emergency funds (C14) Insurance market (C15) Mitigation loans (C16) Reconstruction loans (C17) Public works	Local emergency funds as % of local budget Release period of national emergency funds Access to international emergency funds Availability of insurance for buildings Availability of loans for disaster risk reduction measures Availability of reconstruction credits Magnitude of local public works programmes
Management and institutional capacity	(C18) Risk management/emergency committee (C19) Risk map (C20) Emergency plan (C21) Early warning system (C22) Institutional capacity building (C23) Communication	

Table 5.12: Community based disaster risk indicators. (Source: Bollin/Hidajat 2006)

The vulnerability indicators, defining the physical, economic, social and environmental vulnerability can be aggregated and combined into an overall vulnerability value (see figure 5.22). One very suitable tool for combining and weighing the different vulnerability factors is Spatial Multi Criteria Evaluation. SMCE can also be used for hazard assessment, using an expert based approach as was mentioned in session 3.

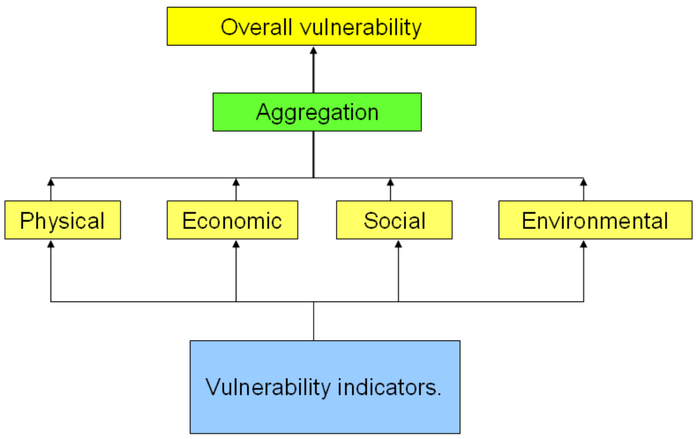


Figure 5.22: A model to integrate the vulnerability components into an overall vulnerability.

5.8 Spatial Multi Criteria Evaluation for vulnerability assessment.

The theoretical background for the multi-criteria evaluation is based on the Analytical Hierarchical Process (AHP) developed by Saaty (1980). The AHP has been extensively applied on decision-making problems (Saaty and Vargas 2001), and extensive research has been carried out to apply AHP to risk assessment. For implementing the semi-quantitative model, the SMCE module of ILWIS-GIS can be used. The SMCE application assists and guides users when performing multi-criteria evaluation in a spatial manner (ITC 2001).The input is a set of maps that are the spatial representation of the criteria, which are grouped, standardised and weighted in a 'criteria tree.' The output is one or more 'composite index map(s),' which indicates the realisation of the model implemented.

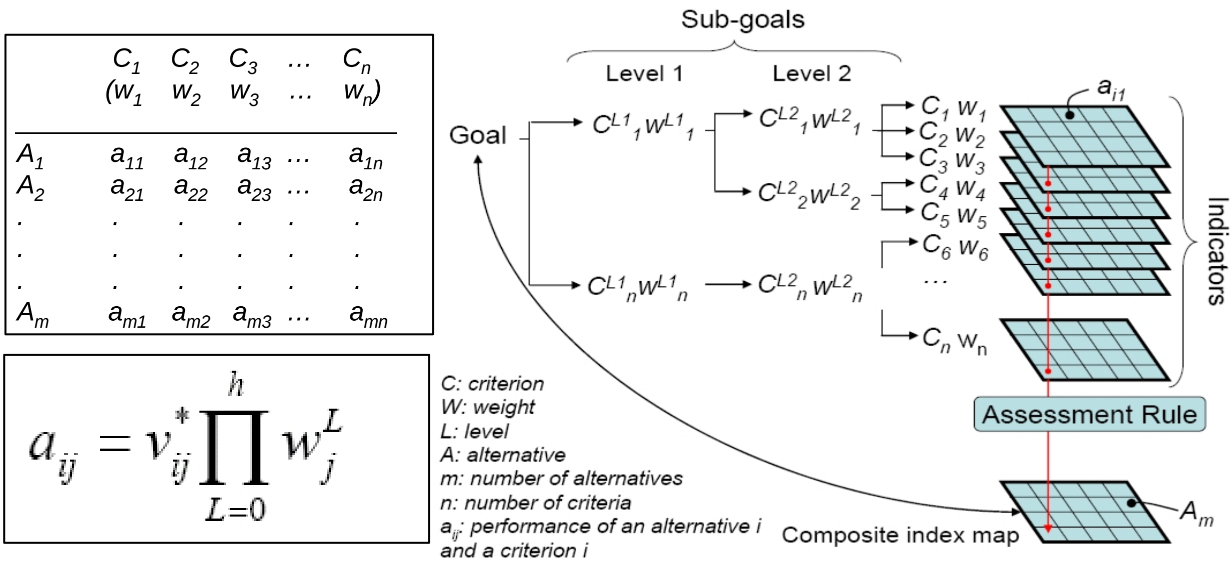


Figure 5.23. Schematic procedure for spatial multi-criteria evaluation based on the analytical hierarchical process

From a decision-making perspective, multi-criteria evaluation can be expressed in a matrix as shown in Figure 6.8. The matrix A contains the criteria in one axis (C_1 to C_n), and a list of possible alternatives, from which a decision has to be taken on the other axis (A_1 to A_m). Each cell in the matrix (a_{ij}) indicates the performance of a particular alternative in terms of a particular criterion. The value of each cell in the matrix is composed of the multiplication of the standardised value (between 0 and 1) of the criterion for the particular alternative, multiplied by the weight (W_1 to W_n) related to the criterion. Once the matrix has been filled, the final value can be obtained by adding up all cell values of the different criteria for the particular alternative (e.g. a_{11} to a_{1n} for alternative A_1).

For implementing this matrix according to the AHP, three principles steps need to be considered. The first one decomposes the problem (and the weights) into a hierarchical structure. The second one considers the weighting process, employing the pairwise comparisons of the criteria, and the synthesis is related to the multiplications among the hierarchical levels. Additionally, in the spatial implementation of this procedure, every criterion (C_j) becomes a raster layer, and every pixel (or set of pixels) of the final composite index map eventually becomes an alternative Aj. The goal (risk index) has been decomposed into criteria levels C_{L1} and C_{L2}. The intermediate levels are often indicated as sub-goals or objectives (e.g. in level 1, the sub-goals are a 'hazard index' and a 'vulnerability index'). Each criterion of each level will also have an assigned weight. Therefore, the values for the layers of the intermediate levels are obtained through the summation of the performance for the alternative at lower levels. As the criteria consist of raster maps, their spatial performance (a_{ij}) and the alternative (A_i) will be identified for particular raster cells.

The composite risk index map is obtained by an assessment rule (sometimes also called decision rule), which is calculated by adding up the performance of all cell values of the different criteria (a_{ij}) for the particular alternative. However, the performance of every element in the matrix (a_{ij}), is obtained in a different way:

In this equation, v_{ij} refers to the standardised value of criterion (C_j) for alternative (A_i), and weight w^L_j refers to the weight of criterion (C_j) for level L (0–h levels). During the analysis, it could be desirable (and sometimes necessary for a better definition of the weights w^L_j) to produce the intermediate criteria maps. In this case, Eq. 1 should not be applied because weights need to be multiplied with the standardised values only up to the specific level of the intermediate maps. The intermediate maps might also be combined using different methods. When designing vulnerability indicators, it is necessary to take into account the socio-economic conditions, which may vary from country to country. In general, vulnerability can be divided in four different types, such as physical, social, economic and environmental (UNPD 2004), which can be combined in order to derive a qualitative index.

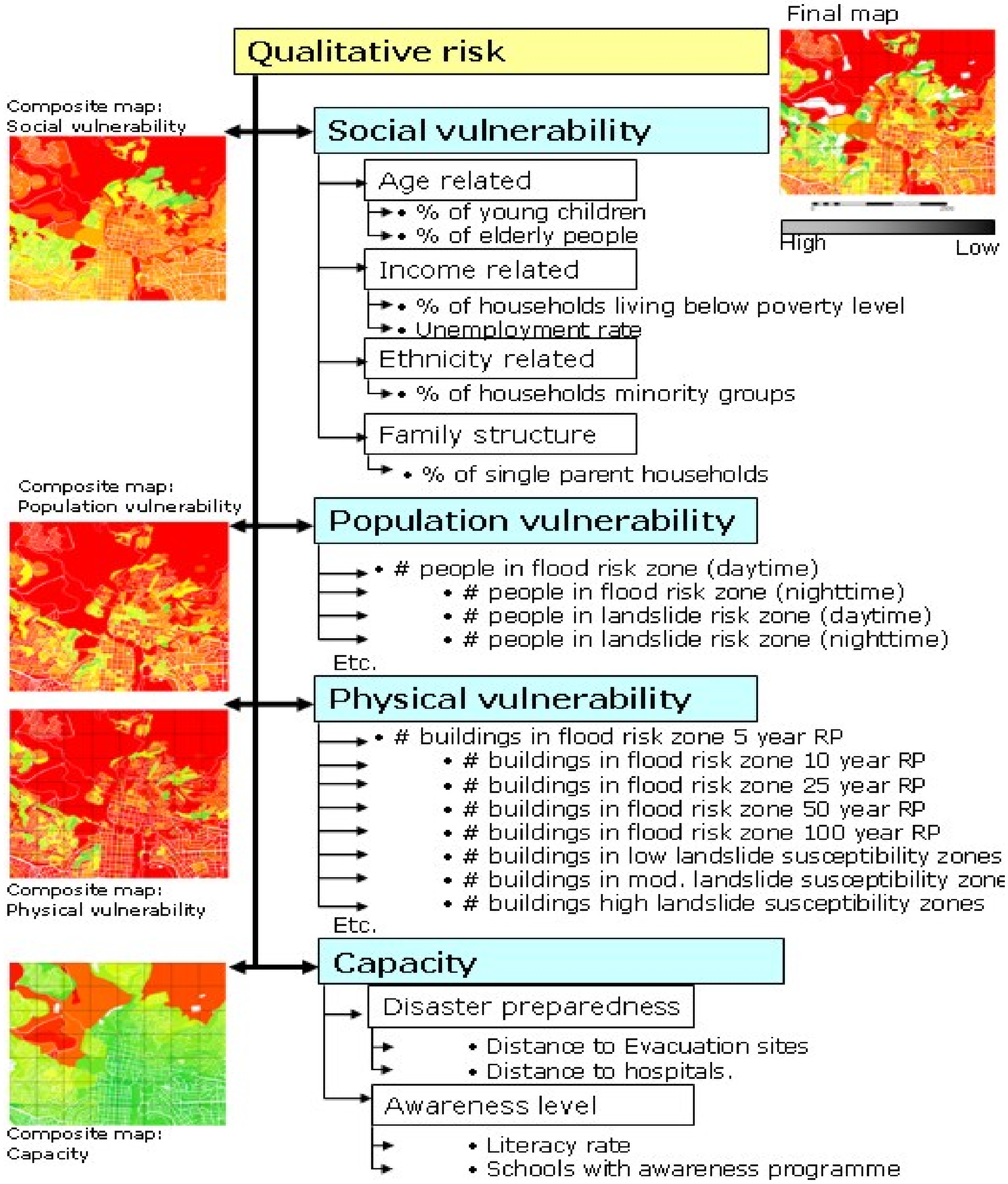


Figure 5.24: Example of a criteria tree used for spatial multi-criteria evaluation for qualitative risk assessment which will be used in the RiskCity exercises.

Task 5.9: RiskCity exercise on the use of Spatial Multi Criteria Evaluation (duration 3 hours)

To illustrate the use of Spatial Multi Criteria Evaluation in vulnerability/ capacity assessment and quantitative risk assessment, we have made an exercise on the evaluation of indicators for RiskCity. Go to this RiskCity exercise and follow the instructions there.

Selftest

In order to evaluate whether you have understood the concepts that were presented in this session. Please make the following test, and check the answers in Blackboard.

Question: Vulnerability
Which indicators could be used to measure social vulnerability?
A) Age, gender, literacy rate
B) Age, building type, number of floors
C) Biodiversity, species, ecological indicators
D) Production, import, export

Question: Vulnerability curve
A vulnerability curve:
A) Displays the probability that one single building (with a particular design, construction types, and number of floors) might be damaged, given a particular magnitude/intensity of the hazard event.
B) Displays the duration that a particular element at risk cannot be used after the occurrence of a hazardous event
C) Display the relation between the percentage of damage, to a group of elements at risk with the same characteristics, and the magnitude/intensity of the hazard event.
D) Display the probability of a potentially damaging phenomenon within a given period of time and a given area.

Question: Secondary losses
Losses due to disasters can be subdivided in primary and secondary losses, and can be of social, physical and economic nature. An example of secondary human/social losses of disasters is:
A) Injuries and fatalities
B) Increase of social tension and crime rate in a society
C) Financial losses that have to be paid by insurance companies
D) Capital costs of response and relief.

Question: Spatial Multi Criteria Evaluation
What are the main advantages and disadvantages of using Spatial Multi-Criteria Evaluation (SMCE) in Risk Assessment?
A) With SMCE you can calculate physical vulnerability and quantitative risk, but you cannot include social vulnerability or capacity.
B) With SMCE you can incorporate social vulnerability and capacity into a qualitative risk assessment; however, it does not allow quantifying the actual risk in losses and probability.
C) With SMCE you can analyze costs and benefits, based on quantitative risk assessment, but it does not allow the evaluation of different alternatives.
D) With SMCE you can evaluate different alternatives, but you cannot include expert-based weight values.

Question: losses.
Losses due to disasters can be subdivided in primary and secondary losses, and can be of social, physical and economic nature. Give an example of losses in the following categories and briefly explain how these losses could be evaluated:
A. Secondary human/social losses due to earthquakes

B. Secondary economic losses to landslides

Further reading and references:

Some of the key publications on vulnerability are:

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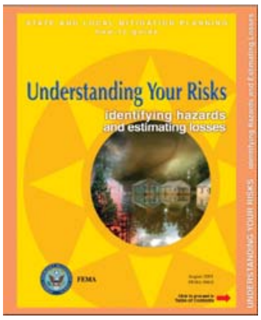

FEMA guide

There is a very useful guide prepared by FEMA called “Understanding your risks” that guides you through the various phases of a risk assessment. This guide is not ment for the use of GIS, but it is a very useful background reading document. The guide is also in the background materials of the course. You can also access it on: http://www.fema.gov/plan/mitplanning/howto2.shtm

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