Guide Book
Session 6:
Risk Analysis

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Objectives

After this session you should be able to:

- Understand the procedures for loss estimation
- Carry out a qualitative risk assessment combining susceptibility and vulnerability
- Carry out a quantitative risk assessment using risk curves
- Use GIS for risk assessment for two different hazard types
- Use GIS for multi-hazard risk assessment for buildings and population
- Use ILWIS for exploring the dataset and evaluating the risk situation in RiskCity

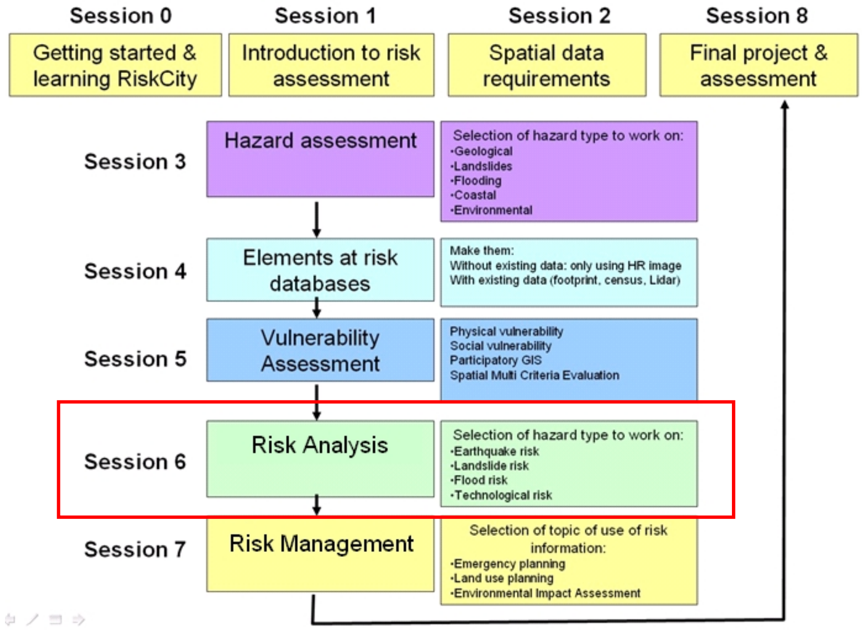
In this session you will look at the various methods that can be used for risk assessment. We will look first at the concepts of risk assessment and the different ways in which risk can be expressed. Then we will look at three different types of approaches for risk assessment: qualitative methods using risk matrices, semi-quantitative methods using indices and spatial multi-criteria evaluation, and quantitative methods using a probabilistic approach.
In this chapter there are also a number of exercises using Excel for learning the method, and there are several RiskCity exercises:

- Exercise 6a: Qualitative risk assessment
- Exercise 6b: Flood risk assessment
- Exercise 6c: Landslide risk assessment
- Exercise 6d: Earthquake risk assessment
- Exercise 6e: Technological risk assessment
- Exercise 6f: Multi-hazard risk assessment

You can make a choice regarding which of the hazard types you would like to work on. In any case 6a and 6f are for everyone, but you can choose two topics from 6b to 6e depending on your interest. At the end of the session we will give a short self test, in which the main concepts are tested.

Part	**Topic**	**Task**	**Time required**		
6.1	Basic concept of risk analysis	Reading text	Day 1	0.75	1 h
		Task 6.1: Basic risk calculation		0.25	
6.2	Types of risk	Reading text		0.90	2 h
		Task 6.2: Types of losses		0.25	
		Task 6.3: Population risk calculation		0.25	
		Task 6.4: Calculate F-N curves		0.50	
		Task 6.5: Calculate relative risk		0.10	
6.3	Qualitative risk assessment	Reading text	Day 2	0.50	1.5 h
		Task 6.6: RiskCity exercise: qualitative risk assessment		1.00	
6.4	Semi-quantitative risk assessment	Reading text		0.75	1.5 h
		Task 6.7: DRI Index		0.25	
		Task 6.8: Evaluating Global hotspots data with GIS		0.5	
6.5	Quantitative risk assessment	Reading text	Day 3	2.00	10 h
		Task 6.9: Calculation of a risk curve		0.50	
		Task 6.10: Calculate seismic risk		0.50	
			Day 4		
		Task 6.11: RiskCity exercise on quantitative risk assessment: choice option: Flood, Landslide, Earthquake or Technological risk.		2.00	
		Task 6.12: RiskCity exercise on Multi hazard risk assessment		3.00	
		Total	**4 days**		**16 h**

6.1 Basic concept of risk analysis



This session deals with the central theme of this course: risk analysis. This is the next in line of the chain of previous steps related to the identification of the hazards, the hazard assessment, generation of elements at risk data bases, and the vulnerability assessment. The risk assessment consists of two components: risk analysis and risk evaluation. In this session we will look specifically at the risk analysis part. Risk evaluation will be dealt with in the next session.

To start with some working definitions:

Risk Assessment is the process of making a decision or recommendation on whether existing risks are tolerable and present risk control measures are adequate, and if not, whether alternative risk control measures are justified or will be implemented. Risk assessment incorporates the risk analysis and risk evaluation phases

Risk Analysis deals with the use of available information to estimate the risk caused by hazards to individuals or populations, property or the environment, from hazards. Risk analyses generally contain the following steps: definition of scope, danger (threat) identification, estimation of probability of occurrence to estimate hazard, evaluation of the vulnerability of the element(s) at risk, consequence identification, and risk estimation.

Risk evaluation is the stage at which values and judgment enter the decision process, explicitly or implicitly, by including consideration of the importance of the estimated risks and the associated social, environmental, and economic consequences, in order to

There are many ways in which risk, and the individual components of risk, has been defined in literature. In session 1 we have used two equations that represent risk. The first equation represents risk in a qualitative manner:

Risk = Hazard * Vulnerability / Capacity [6.1]

This equation is only conceptual, but allows to incorporate the multi-dimensional aspects of vulnerability, and capacity. In this approach indicators are used to characterize vulnerability and capacity, for instance by relating it with population characteristics as we have seen in the section on vulnerability. These indicators are often integrated with hazard indicators using Spatial Multi-Criteria Evaluation. The result of the equations will show risk only as relative qualitative classes, and allows to compare risk levels between different communities, neighborhoods, cities or even countries. In section 6.2 the techniques for qualitative risk assessment will be treated.
The other approach is called the quantitative one, which tries to quantify the risk according to the risk definition given in session 1. As explained in session 1 this equation has the basic form:

Risk = Hazard * Vulnerability * Amount of elements-at-risk [6.2]

The equation given above is not only a conceptual one, but can also be actually calculated with spatial data in a GIS to quantify risk from hazards. The way in which the amount of elements-at-risk are characterized (e.g. as number of buildings, number of people, economic value or the area of qualitative classes of importance) also defines the way in which the risk is presented. The hazard component in the equation actually refers to the probability of occurrence of a hazardous phenomenon with a given intensity within a specified period of time (e.g. annual probability).
For calculating risk quantitatively using equation 1 the vulnerability is limited to physical vulnerability of the elements-at-risk considered, determined by the intensity of the hazard event and the characteristics of the elements-at-risk (e.g. building type). Table 1 gives a more in-depth explanation of the various components involved.
In order to calculate the specific risk (see table 6.1) equation 6.2 can be modified in the following way:

$$R_S = P_T * P_L * V * A \qquad [6.3]$$

in which:

- $\mathbf{P_T}$ is the temporal (e.g. annual) probability of occurrence of a specific hazard scenario (H_s) with a given return period in an area;
- $\mathbf{P_L}$ is the locational or spatial probability of occurrence of a specific hazard scenario with a given return period in an area impacting the elements-at-risk. ;
- **V** is the physical vulnerability, specified as the degree of damage to a specific element-at-risk E_s given the local intensity caused due to the occurrence of hazard scenario H_S
- **A** is the quantification of the specific type of element at risk evaluated. It is important to indicate here that the amount can be quantified in different ways, and that the way in which the amount is quantified also the risk is quantified. For instance the amount can be given in numbers, such as the number of buildings (e.g. number of buildings that might suffer damage), number of people (e.g. injuries/ casualties/affected), the number of pipeline breaks per kilometre network, etc. The elements at risk can also be quantified in economic terms.

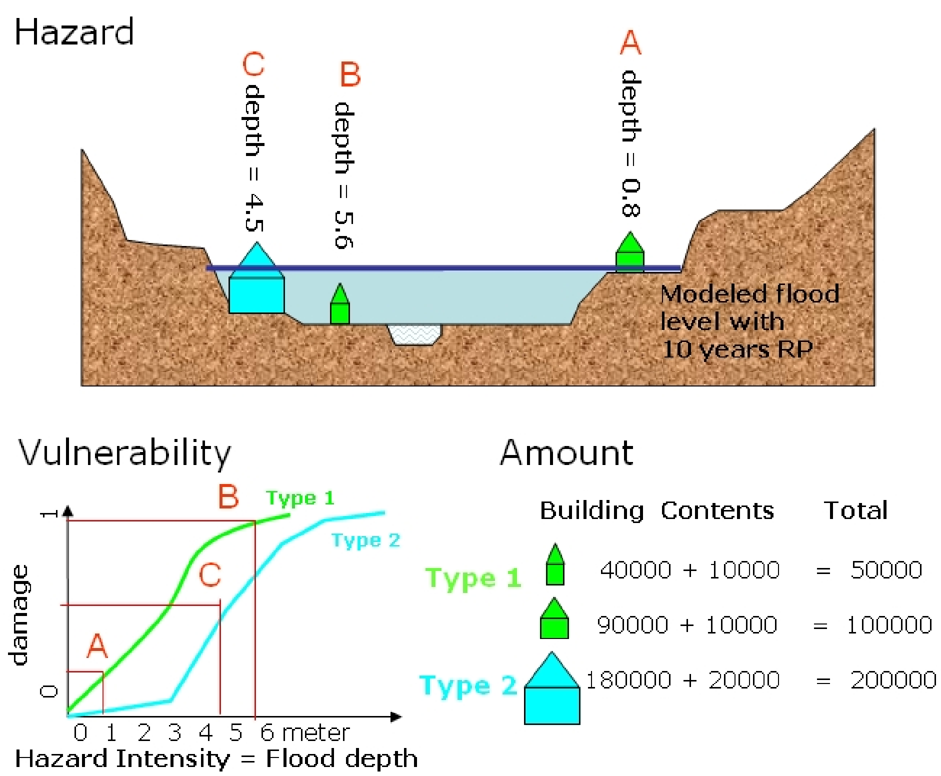
In order to evaluate these components we need to have spatial information as all components of equation [6.3] vary spatially, as well as temporally. The temporal probability of occurrence of the hazard scenario (P_T) has also a spatial component. For example a flood with a given return period has a certain extension, and spatial variation of intensity. The equation [6.3] also contains a term (P_T) indicating the spatial probability of occurrence and impact. This is not relevant for all types of hazards, and in many cases this probability can be indicated as 1, given a specific hazard scenario (e.g. the area that will be flooded given a return period of 50 years). However, for other types of hazards, such as landslides, the location of future events cannot be identified exactly, because the areal unit used in assessing hazard is not always identical to the area specifically impacted by the hazard. For instance, the chance of occurrence of landslides within the high susceptibility zone can be calculated as the ratio of the landslide area to the high susceptible area, multiplied by the ratio of the area of the element of interest to the high susceptible area. The intensity of the hazard varies from place to place (e.g. flood depth, or landslide volume), and the exposure of the elements-at-risk varies. Note that in many risk approaches the term 'exposure of elements-at-risk' is included in the risk equation. When using a GIS approach this is actually redundant information, as a GIS overlay of the hazard footprint with the elements-at-risks will immediate include only the exposed elements-at-risk in the risk equation. The procedure is illustrated in figure 6.2, which shows an example of a floodplain with 3 different buildings (elements at risk) of two different construction types. As discussed in Session 5, these two types of buildings will have a different degree of vulnerability, given the same level of flooding.

Table 6.1: List of terms and definitions used in the GIS-based risk assessment presented in this chapter (based on IUGS, 1997; UN-ISDR, 2004).

Term	Definition	Equations & explanation
Natural hazard (H)	A potentially damaging physical event, phenomenon or human activity that may cause the loss of life or injury, property damage, social and economic disruption or environmental degradation. This event has a probability of occurrence within a specified period of time and within a given area, and has a given intensity.	**P_T** is the temporal (e.g. annual) probability of occurrence of a specific hazard scenario (H_s) with a given return period in an area; **P_L** is the locational or spatial probability of occurrence of a specific hazard scenario with a given return period in an area impacting the elements-at-risk
Elements-at-risk (E)	Population, properties, economic activities, including public services, or any other defined values exposed to hazards in a given area". Also referred to as "assets".	**E_s** is a specific type of elements-at-risk (e.g. masonry buildings of 2 floors)
Vulnerability (V)	The conditions determined by physical, social, economic and environmental factors or processes, which increase the susceptibility of a community to the impact of hazards. Can be subdivided in physical, social, economical, and environmental vulnerability.	**V** is the physical vulnerability, specified as the degrees of damage to E_S given the local intensity caused due to the occurrence of hazard scenario H_S It is expressed on a scale from 0 (no damage) to 1 (total loss)
Amount of elements-at-risk (A_E)	Quantification of the elements-at-risk either in numbers (of buildings, people etc), in monetary value (replacement costs etc), area or perception (importance of elements-at-risk).	**A** is the quantification of the specific type of element at risk evaluated (e.g. number of buildings)
Consequence (C)	The expected losses (of which the quantification type is determined by A_E) in a given area as a result of a given hazard scenario.	**C** is the "specific consequence", or expected losses of the specific hazard scenario which is the multiplication of $V_S * A_{ES}$
Specific risk (R_S)	The expected losses in a given area and period of time (e.g. annual) for a specific set of elements-at-risk as a consequence of a specific hazard scenario with a specific return period.	$R_S = H * V * A$ $R_S = H * C$ $R_S = P_T * P_L * V * A$
Total risk (R_T)	The probability of harmful consequences, or expected losses (deaths, injuries, property, livelihoods, economic activity disrupted or environment damaged) resulting from interactions between natural or human-induced hazards and vulnerable conditions in a given area and time period. It is calculated by first analyzing all specific risks. It is the integration of all specific consequences over all probabilities.	$R_T \approx \sum (R_T) = \sum(H_S * V * A)$ Or better: $R_T = \int (V_S * A_{ES})$ - For all hazard types - For all return periods - For all types of elements-at-risk. It is normally obtained by plotting consequences against probabilities, and constructing a risk curve. The area below the curve is the total risk.

Based on the analysis of historic flood damage for buildings with the same characteristics, flood vulnerability curves have been made, which reflect the relation between the flooddepth and the degree of damage. For this particular section of the flood plain a critical flood depth has been defined, based on inundation modeling as described in session 4. Given the historical discharge information, a flood with the level indicated in figure 6.2 is expected to occur on average every 10 years (the Return period is given as 10 years.). Therefore the annual probability is 0.1 (1/return period). The three elements at risk not only differ in type, but also in their economic value (Amount). For the flood risk estimation both the building value as well as the content value is used.

The approach indicated in table 6.1 is related to the estimation of physical vulnerability, and its use in quantitative risk assessment. It can also be used as the basis for estimating population losses and economic losses. Later on in this session we will see how we can use this approach for probabilistic risk assessment, which calculates the probable losses for many scenarios with different return periods. However, the principle is the same. Hazard information is combined with vulnerability information to produce estimated losses.



Element at risk		Temporal Probability	Amount (economic value)	Vulnerability	**Specific risk**
A		0.1	100000	0.1	1000
B		0.1	50000	1	5000
C		0.1	200000	0.5	10000
					16000

Figure 6.2: Example of a risk estimation for a floodplain with 3 elements at risk of two different types.

Task 6.1: Risk calculation (duration 15 minutes)

A. What would be the annual risk of the buildings in the example in figure 6.2 if all buildings were of type 1?

B. What would be the annual risk of the buildings in the example in figure 6.2 if the return period of the event was 25 years?

C. What would be the annual risk of the buildings in the example in figure 6.2 if the return period of the event was 25 years, after 10 year with an increase in house prices of 10 % per year?

Risk assessments should be (ADPC, 2005):

- **Multi-hazard**: the same area may be threatened by different types of hazards. In the RiskCity exercises we look at four different types: landslides, flooding, earthquakes and technological hazards. Each of these hazard types has different areas that might be impacted by hazard scenarios. Each of the hazard scenarios also might have different magnitudes (see session 3 for a description of the methods used to estimate hazards). For instance water depth and velocity in the case of flooding, acceleration and ground displacement in the case of earthquakes. These hazard magnitudes would also have different impacts on the various elements at risk, and require therefore different vulnerability curves (as discussed in session 5). The scenarios will also have different probabilities of occurrence. Therefore it is important to identify the range of hazards and the impact of these hazards on current and planned investments, on different groups of people, and their ability to resist and cope with the impact of hazards.
- **Multi-sectoral**: hazards will impact different types of elements at risk (See session 4), and it is therefore important to calculate the total effect on them including rural areas and urban areas. In rural areas the impact on agriculture will be very important, but also on the rural population, the transportation network, tourism, mining sector and on the natural environment (protected areas, forests, wetlands etc). In urban areas it is most important to consider the building types, transportation and communication networks, economic activities, people's livelihood, health and education systems, and people's awareness and commitment to protecting themselves. In both situations the risk of current landuse can be estimated, but it is also important to estimate the effect of future planning scenarios. We will look at this aspect later in the RiskCity exercise in session 7.
- **Multi-level**: risk assessment can be carried out at different levels. In session 3 the various levels of hazard assessment were identified. Depending on the objectives of the risk study it is possible to differentiate between national, provincial and local policies, plans and activities to see how they have contributed to increased or reduced risk, their strengths and weaknesses in dealing with risks, and what resources are available at different levels to reduce risks.
- **Multi-stakeholder**: risk assessment should involve the relevant stakeholders, which can be individuals, businesses, organizations, and authorities.
- **Multi-phase**: risk assessment should consider actions for response, recovery, mitigation, and preparedness

Types of risk assessment.

Risk assessments can be carried out with a range of methods, that can be broadly classified into:

- **Qualitative methods**: this results in qualitative descriptions of risk in terms of high, moderate and low. These are used when the hazard cannot be expressed in quantitative terms (the hazard information does not allow to express the probability of occurrence, or it is not possible to estimate the magnitude), and/or when the vulnerability cannot be expressed quantitatively.
- **Semi-quantitative methods**: semi-quantitative techniques express risk in terms of risk indices. These are numerical values, often ranging between 0 and 1, but these do not have a direct meaning of expected losses, but are merely relative indications of risk. Also in this case risk is expressed in a relative sense. These two types of risk are estimated using qualitative risk assessment methods, which will be further explained in section 6.3.
- **Quantitative methods**: they express the risk in quantitative terms either as probabilities, or expected losses. They can be deterministic/scenario-based (looking at a particular scenario) or probabilistic (taking into account the effect of all possible scenarios).

In the next section we will first look at the types of risk before dealing with these three methods of risk assessment.

6.2 Types of risk

Risk is the product of probability and expected losses. Expected losses can be subdivided in many different ways. One of the first and most relevant subdivisions is between direct and indirect losses.

- **Risk for direct losses**: risk assessment that includes those losses resulting directly from the impact of the hazard, for instance buildings that are flooded, or that collapse due to an earthquake, wind damage to infrastructure
- **Risk for indirect losses**: risk assessment that also includes the losses that result due to the event but not by a direct impact, but due to loss of function, for example, disruption of transport, business losses or clean up costs

In both these loss categories, it is possible to make another subdivision:

- **Tangible losses**: loss of things that have a monetary (replacement) value, for example, buildings, livestock, infrastructure etc.
- **Intangible losses**: Loss of things that cannot be bought and sold, for example, lives and injuries, cultural heritage, environmental quality, biodiversity etc.

Yet another subdivision of losses is possible between:

- **Private losses**: losses that affect elements at risk that are privately owned, such as residential buildings and their contents, or businesses. These losses impact private people or companies and their should have them covered by insurance or cope with them by themselves.
- **Public losses**: losses that affect public elements at risk, such as educational sector, institutional sector, lifelines, infrastructure, etc. These losses should be borne by the entire community. In case of large disasters, the community will also take the burden of private losses to homeowners, depending on the government policy.

Task 6.2: Types of losses (duration 15 minutes)
Give an example of the following types of losses:

A. *Tangible, direct, private losses due to an earthquake*
B. *Intangible, indirect, public losses due to a wildfire*
C. *Tangible, indirect losses due a flood in an agricultural area*
D. *Intangible, direct losses due a hurricane.*

Since losses are very diverse, also risk can be expressed in many different ways. The first main differentiation is between qualitative, semi quantitative and quantitative risk (see table 6.2). Risk can be expressed quantitatively, if there is enough information on the individual components of hazard, vulnerability and elements at risk. This can be expressed as a probability value, for a given loss outcome. For instance, the probability of being hit by a rockfall while driving on the road. The Amount part of the risk equation can be expressed in different ways, for instance as:

- **Property risk**: indicating the number of buildings that might be partially damaged / severely damaged or collapsed.
- **Economic risk**: indicating the amount of money that is likely to be lost as a consequence of hazardous phenomena
- **Population risk**: indicating the risk fatality or injury to an individual (individual risk) or to a group of individuals (societal risk)

Table 6.2 Different ways of expressing risk

<table>
<tr><th>General</th><th>Type</th><th colspan="2">Principle</th></tr>
<tr><td rowspan="2">Qualitative</td><td>Qualitative</td><td colspan="2">Based on relative risk classes categorized by expert judgment. Risk classes: High, Moderate and Low</td></tr>
<tr><td>Semi-quantitative</td><td colspan="2">Based on relative ranking and weights assignments by a given criteria. Risk index: ranked values (0-1, 0-10 or 0-100). (dimensionless)</td></tr>
<tr><td rowspan="9">Quantitative</td><td>Probability</td><td colspan="2">Probabilistic values (0-1) for having a predefined loss over a particular time period</td></tr>
<tr><td rowspan="4">Economic risk</td><td colspan="2">Quantification of the expected losses in monetary values over a specific period of time</td></tr>
<tr><td>Probable Maximum Loss (PML)</td><td>Probable Maximum Loss (PML) The largest loss believed to be possible in a defined return period, such as 1 in 100 years, or 1 in 250 years.</td></tr>
<tr><td>Average Annual Loss (AAL)</td><td>Expected loss per year when averaged over a very long period (e.g., 1,000 years). Computationally, AAL is the summation of products of event losses and event occurrence probabilities for all stochastic events in a loss model.</td></tr>
<tr><td>Loss Exceedance curve (LEC)</td><td>Risk curve plotting the consequences (losses) against the probability for many different events with different return periods.</td></tr>
<tr><td rowspan="3">Population risk</td><td colspan="2">Quantification of the risk to population</td></tr>
<tr><td>Individual risk</td><td>The risk of fatality or injury to any identifiable (named) individual who live within the zone impacted by a hazard; or follows a particular pattern of life that might subject him or her to the consequences of a hazard.</td></tr>
<tr><td>Societal risk</td><td>The risk of multiple fatalities or injuries in society as a whole: one where society would have to carry the burden of a hazard causing a number of deaths, injury, financial, environmental, and other losses.</td></tr>
</table>

6.2.1 Population risk

Population risk can be expressed as individual risk or societal risk. Individual risk is the risk of fatality or injury to any identifiable (named) individual who lives within the zone impacted by a hazard, or follows a particular pattern of life that might subject him or her to the consequences of a hazard. Table 6.3 gives an example of individual risk for different causes. Individual risk can be calculated as the total risk divided by the population at risk. For example, if a region with a population of one million people experiences on average 5 deaths from flooding per year, the individual risk of being killed by a flood in that region is 5/1,000,000, usually expressed in orders of magnitude as $5\times10-6$.

Table 6.3:Individual risk

Cause	Probability / year	Cause	Probability / year
All causes (illness)	1.19E-02	Rock climbing	8.00E-03
Cancer	2.80E-03	Canoeing	2.00E-03
Road accidents	1.00E-04	Hang-gliding	1.50E-03
Accidents at home	9.30E-05	Motor cycling	2.40E-04
Fire	1.50E-05	Mining	9.00E-04
Drowning	6.00E-06	Fire fighting	8.00E-04
Excessive cold	8.00E-06	Police	2.00E-04
Lightning	1.00E-07	Accidents at offices	4.50E-06

Societal risk is the risk of multiple fatalities or injuries in the society as a whole, and where society would have to carry the burden of a hazard causing a number of deaths, injury, financial, environmental, and other losses.

Task 6.3: Population risk calculation (duration 15 minutes)
What is the risk of being killed by a rock fall while driving on the road from A to B?
- There are 500,000 cars driving on the road per year, there are 100 accidents due to rockfall on the road each year, 1 in 10 results in death, the average number of persons per car is 2.

A. The number of deaths per year is:
B. The individual risk of having an accident is
C. The individual risk of being killed is:
D. The societal risk is:

Societal risk is generally expressed by f-N or F-N curves (See figure 6.4). When the frequency of events which causes at least N fatalities is plotted against the number N on log log scales, the result is called an F-N curve. The difference between the frequency of events with N or more fatalities, F(N), and that with N+1 or more, F(N+1), is the frequency of events with exactly N fatalities, usually represented by f(N), with lower-case f. Because f(N) must be non-negative, it follows that F(N) ≥ F(N+1) for all N, so that FN-curves never rise from left to right, but are always falling or flat. The lower an FN-curve is located on the FN-graph, the safer is the system it represents, because lower FN-curves represent lower frequencies of fatal events than higher curves. The value F(1) is the frequency of accidents with 1 or more fatalities, or in other words the overall frequency of fatal accidents. This is the left-hand point on FN-curves, where the curve meets the vertical axis (usually located at N = 1 with logarithmic scales).
If the frequency scale is replaced by annual probability, then the resultant curve is called f-N curve. F-N curves can be constructed based on historical data in the form of number of events (floods, landslides, etc) and related fatalities. They can also be based on different future risk scenarios, in which for a number of events with different magnitudes the number of casualties is estimated using the methods that will be explained in this chapter. Then the F-N curve displays the future risk. The curves can be constructed for different spatial units. These can be country, province, municipality, but also a community or even a building block within a neighborhood. F-N curves are very important because they form the basis for developing societal acceptability and tolerability levels. This will be treated in session 7, in the section dealing with risk evaluation.

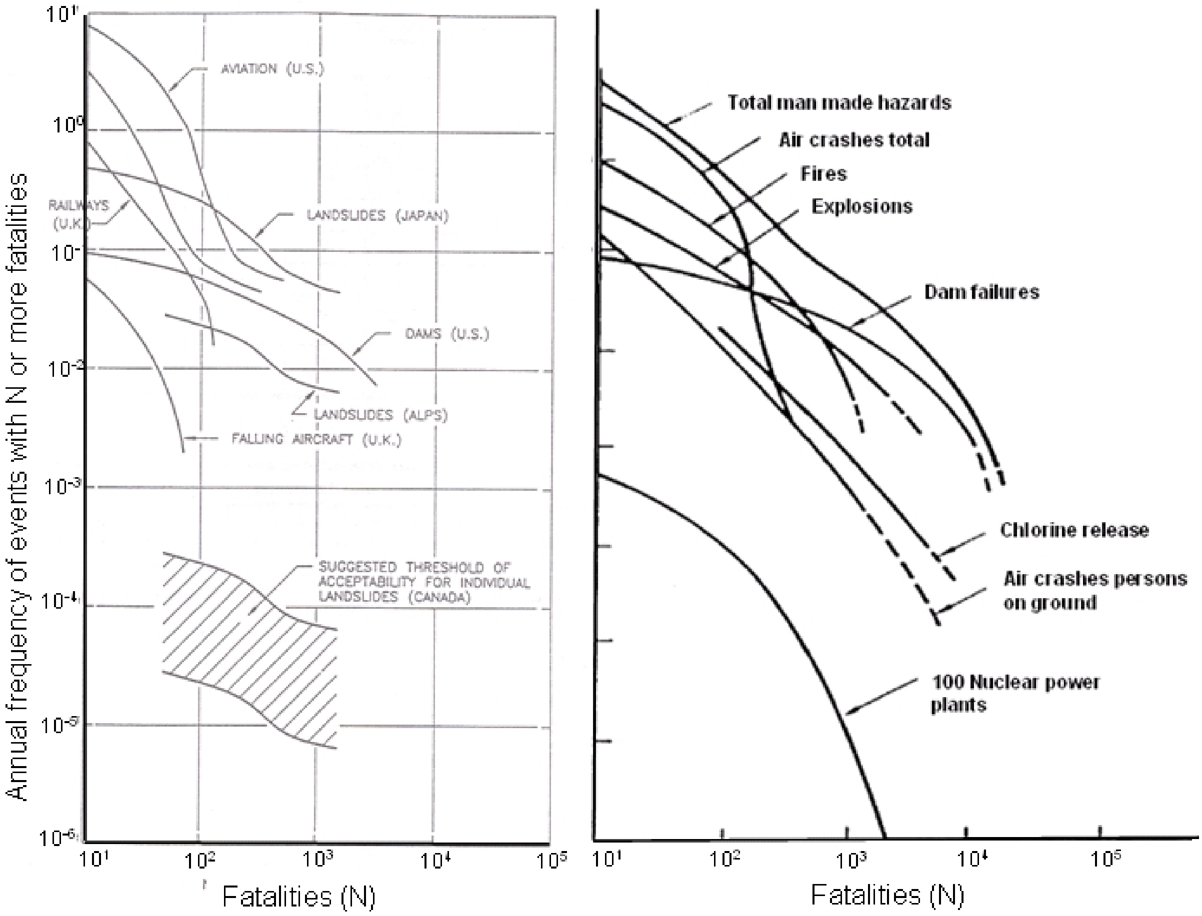


Figure 6.4: Left: F-N curves showing the number of fatalities against annual frequency. For natural and man-made hazards

Task 6.4: Calculate F-N curves (duration 30 minutes)

In this exercise you will calculate F-N curves for accidents that have occurred in Europe in the period 1967 to 2001. Three different types of accident data area available: for roads, railroad and aviation. The analysis is based on empirical data, collected from historical accidents records. In the excel file task 6.4 you can find the data, and the general schedule for generating the F-N curve. The figure below shows the structure of the Excel file.

To calculate the F-N curve take the following steps:

1. First calculate the total number of fatalities for road, railroad and aviation accidents by multiplying the number of events with the fatality class. Also calculate the average number of fatalities per year..
2. The calculate the cumulative number of events, starting with the lowest one in the table (related to 146 fatalities) and summing them up upwards.
3. Then calculate the cumulative frequency of events per year, by dividing the cumulative number by the number of years.
4. Plot these values in the graph indicated at the bottom of the spreadsheet in a log-log manner, with Fatalities (N) or the X-axis, and the cumulative frequency per year on the Y-Axis.
5. Compare the results. What can you conclude on the:
   - Severity of the accident type
   - Frequency of the accident type

What are the shortcomings of such a way of representation?

This example was taken from the following source:
http://www.hse.gov.uk/research/rrpdf/rr073.pdf

	Road	Rail	Aviation
From	1969	1967	1967
To	2001	2001	2001
Period	33	35	35

	Number of events			Fatalities			Cumulative number of events			Cumulative frequency per year		
Fatalities	Road	Rail	Aviation	Road	Rail	Aviation	Road	Rail	Aviation	Road	Rail	Aviation
1	151,722	2,284	330									
2	9,350	78	178									
3	1,612	16	50									
4	443	9	46									
5	138	6	7									
6	39	3	10									
7	9	3	1									
8	5	0	2									
9	6	2	0									
10	5	2	1									
11	0	1	2									
12	0	1	1									
13	5	1	1									
17	0	0	1									
20	1	0	1									
31	0	2	0									
32	1	0	0									
35	0	1	0									
43	0	1	0									
45	0	0	1									
47	0	0	1									
48	0	0	1									
49	0	1	0									
55	0	0	1									
63	0	0	2									
66	0	0	1									
72	0	0	1									
88	0	0	1									
104	0	0	1									
112	0	0	1									
118	0	0	1									
146	0	0	1									
Total	163,336	2,411	644	0	0	0						
per year	4949.6	68.9	18.4	0.0	0.0	0.0						

Relative risk is a term used originally in epidemiology to indicate the ratio between the probability of the event occurring in an exposed group versus a non-exposed group. This would be the case for example of people developing a certain disease which are exposed to a certain chemical during an industrial accident.

$$RR = \frac{p_{\text{exposed}}}{p_{\text{non-exposed}}} \qquad [6.5]$$

In table 6.4 this would be indicated as:

Relative Risk = (E+ / (E+ + E-)) / (N+ / (N+ + N-)) [6.6]

Table 6.4: Relative risk calculation

	Exposed group	Non-exposed group
Cases with positive outcome	E+ = 300	N+ = 3
Cases with negative outcome	E- = 1000	N- = 1000

Related to that is the so-called **Odds ratio**:

Odds ratio = (E+ + N+) / (E- + N-) [6.7]

Task 6.5: Calculate relative risk and odds ratio (duration 5 minutes)
Calculate the relative risk and the odds ratio for the values from table 6.3
Relative risk = 300/1100 / 10/1010 =
Odds ratio =

6.2.2 Economic losses

There are several ways to express economic losses. The Probable Maximum Losses (PML) is the largest loss believed to be possible in a defined return period, such as 1 in 100 years, or 1 in 250 years. In figure 6.5 (left) the PML for 1 in 1000 years is 1400. The risk can also be represented as a curve, in which all scenarios are plotted with their return periods or probability and associated losses. Such a risk curve is also called the Loss Exceedance Curve (LEC). Figure 6.5 shows two ways to represent such a curve. The left one has the advantage that it is better visible which return periods have the largest contribution to losses. The right curve can be used directly to calculated the Average Annual Losses (AAL). This is done by calculating the area under the curve (See also section 6.5.5).

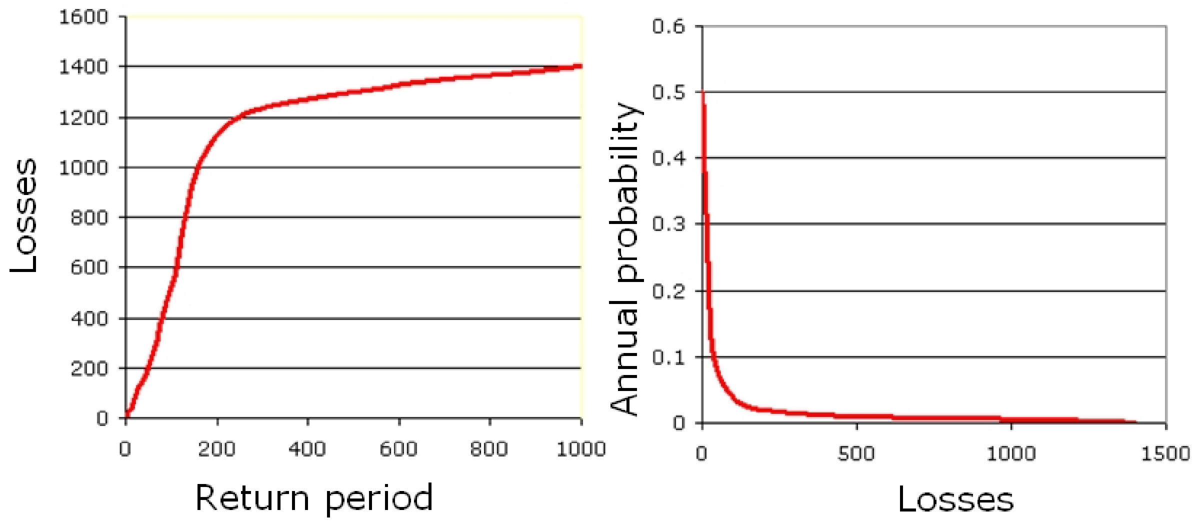


Figure 6.5: Two ways to represent a risk curve. Left: Plotting losses against return period. Right: plotting losses against annual probability. Losses are in 10^6

6.3 Qualitative risk assessment

The qualitative approach is based on the experience of the experts and the risk areas are categorized with terms as 'very high', 'high', 'moderate', 'low' and 'very low' risk. The number of qualitative classes varies but generally three or five classes are accepted which should have a direct line with practical indications (e.g. in very high risk areas: 'immediate physical and no-physical remedial measures are required and no more infrastructure development must be allowed in this area'). Fell (1994) proposed terminology definitions for qualitative risk assessment considering classes for magnitude, probability, hazard, vulnerability and specific risk. A terminology proposal guideline for assessing risk to property was developed by the Australian Geomechanics Society and the Sub-committee on Landslide Risk Management (AGS, 2000) considering a combination of likelihood and the possible consequences as shown in Table 6.5. This method is applicable for spatial analysis using GIS. These approaches are usually applied at national or regional levels as in these scales the quantitative variables are not available or they need to be generalized.

Table 6.5: Qualitative risk analysis matrix – level of risk to property (AGS, 2000). VH: Very High, H: High, M: Moderate, L: Low and VL: Very Low risk.

Likelihood	Consequences				
	Catastrophic	Major	Medium	Minor	Insignificant
Almost certain	VH	VH	H	H	M
Likely	VH	H	H	M	L-M
Possible	H	H	M	L-M	VL-L
Unlikely	M-H	M	L-M	VL-L	VL
Rare	M-L	L-M	VL-L	VL	VL
Not credible	VL	VL	VL	VL	VL

Such as method can be used for situations where an inexpensive and fast method is required for risk assessment. The methods use a scoring and weighting approach emphasising on quantifying the subjective components involved in the risk assessment procedure as much as possible, defining terms as precisely and clearly possible and development of categories of hazard, consequence and risk that may be presented in a quantitative format. Once the hazard has been qualitatively estimated, the consequence is assessed for different elements at risk like railway lines, roads, etc. For each type the consequences are rated into the levels (e.g. VH, H, M, L, VL). See for example table 6.6 from Ko Ko et al. (2004).

Table 6.6: Qualitative assessment (Ko Ko et al., 2004).

Score	Description	Annual probability	Hazard level
>100	The event is expected and may be triggered by conditions expected over a 5 year period	> 0.2 (within 5 years)	Very High (VH)
80 - <100	The event may be triggered by conditions expected over a 5-50 year period	0.2 – 0.02 (within 5 to 50 years)	High (H)
60 - <80	The event may be triggered by conditions expected over a 50-500 year period	0.02 - 0.002	Medium (M)
40 - <60	The event may be triggered by conditions expected over a 500-5000 year period	0.002 – 0.0002 (within 500 to 5000 years)	Low (L)
<40	The event is possible and may be triggered by exceptional circumstances over a period exceeding 5000 year	> 0.0002 (> 5000 years)	Very Low (VL)

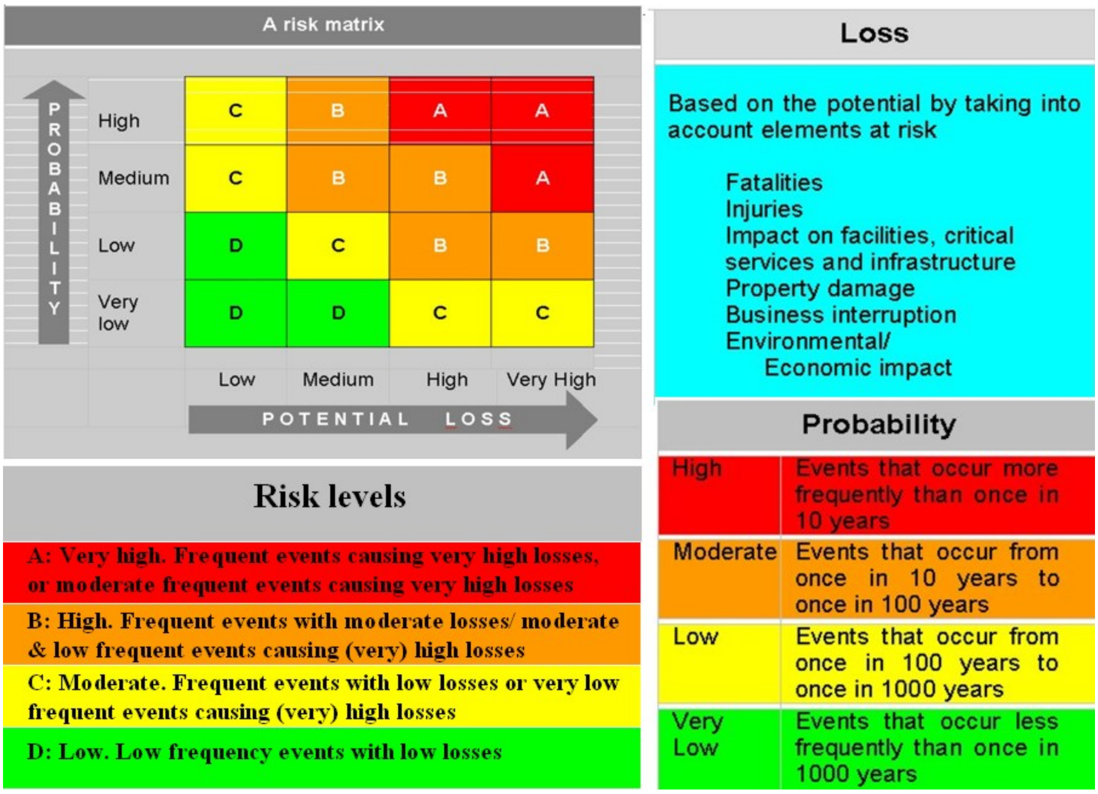


Figure 6.6: Example of a qualitative risk matrix, combining probability of the event with the potential losses.

		Site: level of stake (-) → (+)			
Position of site (Distance from the phenomenon) (far) ↓ (close)		Null (0)	Low (10)	Moderate (30)	High (100)
	Far (0.2)	0	2	6	20
	Moderatly far (0.5)	0	5	15	50
	Close (0.9)	0	9	27	90
	Very close (1)	0	10	30	100

Final stake
- Null
- Low
- Moderate
- High

Figure 6.7: Example of a qualitative risk matrix relating the distance of the stake (=element at risk) and the importance level of the stake to risk classes, as used in France.

Task 6.6: RiskCity exercise for qualitative risk assessment (duration 1 hour)

Go to the RiskCity exercise 6 dealing with qualitative landslide risk assessment, which is an example of the use of a risk matrix, combining qualitatively vulnerability with hazards.

6.4 Semi quantitative landslide risk assessment

The main difference between qualitative and semi-quantitative approaches is the assignment of weights under certain criteria which provide numbers as outcome instead of qualitative classes. The semi quantitative estimation for risk assessment is found useful in the following situations i) as an initial screening process to identify hazards and risks; ii) when the level of risk (pre-assumed) does not justify the time and effort and iii) where the possibility of obtaining numerical data is limited. Semi-quantitative approaches consider a number of factors that have an influence on the risk. A range of scores and settings for each factor may be used to assess the extent to which that factor is favourable or unfavourable to the occurrence of instability (hazard) and the occurrence of loss or damage (consequence). The matrix of hazards and consequences is used to obtain a ranked risk value. This is made by combining a set of hazard categories with a set of consequence categories. The final risk values can also be categorised and ranked with qualitative implications. The risk estimation can be done separately for loss of life and economic loss.

The semi-quantitative approach could be adapted to cover larger areas (spatial or GIS-based). In any case, there will always be the dilemma of adapting the scoring system to each particular region. This approach may be applicable at any scale or level of analysis, but more reasonably used in medium scales. Nowadays, such a semi-quantitative approach can efficiently use spatial multi-criteria techniques implemented in GIS that facilitate standardization, weighting and data integration in a single set of tools. In this section on semi-quantitative methods we will look at two different approaches:

- Risk indices
- Spatial Multi Criteria Evaluation

6.4.1 Spatial Multi-Criteria Evaluation

In session 5 the concept of Spatial Multi Criteria Evaluation (SMCE) was presented. SMCE is a very important tool for both vulnerability as well as hazard assessment. Figure 6.8 gives an example of the use of SMCE for the generation of a risk index for landslides for the country of Cuba (Castellanos and Van Westen, 2007). In this example a risk index is generated by combining a hazard index and a vulnerability index. The hazard index is made using indicator maps related to triggering factors (earthquakes and rainfall) and environmental factors. The vulnerability index is made using four groups of indicators. Initially a total of 43 vulnerability indicators were considered to be used in this study at the national level, and the Cuban National Statistical Office was asked to provide information on these. However, due to the fact that not all information could be obtained, and the high correlation between several of the initially selected indicators, the total number was reduced to five key indicators: housing condition and transportation (physical

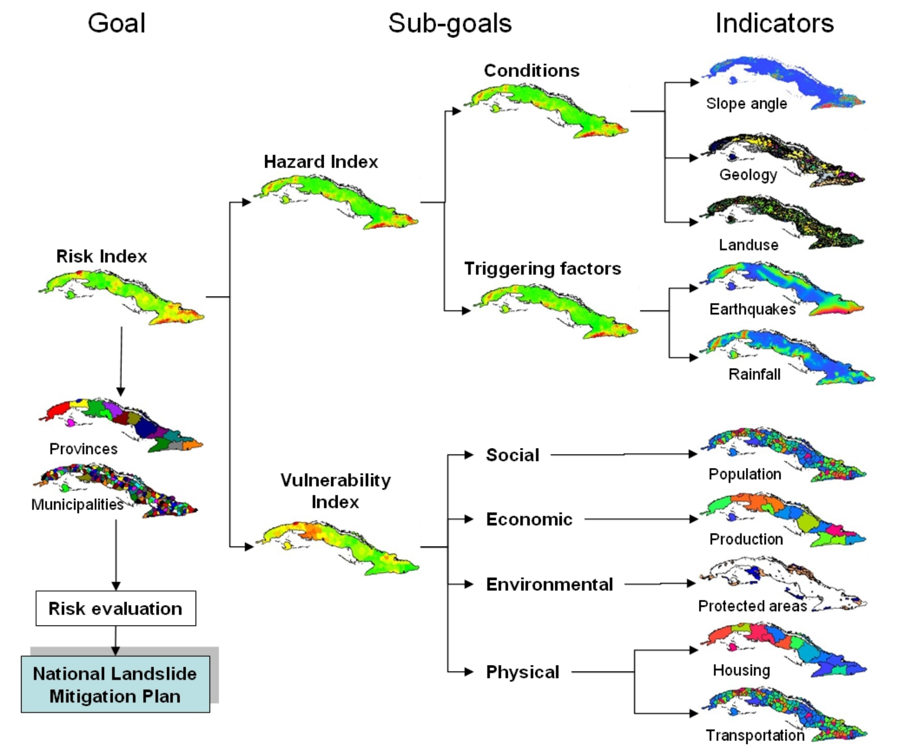


Figure 6.8: Schematic flowchart for the assessment of a national risk index for landslides in Cuba, using spatial multi criteria evaluation (source: Castellanos and Van Westen, 2007)

vulnerability indicators), population (social vulnerability indicator), production (economic vulnerability indicator) and protected areas (environmental vulnerability indicator). The indicators are based on polygons related to political-administrative areas, which are mostly at municipal level. Each indicator was processed, analysed and standardized according to its contribution to hazard and vulnerability. The indicators were weighted using direct, pairwise comparison and rank ordering weighting methods and weights were combined to obtain the final landslide risk index map. The results were analysed per physiographic region and administrative units at provincial and municipal levels. The final risk map is presented in Figure 6.9.

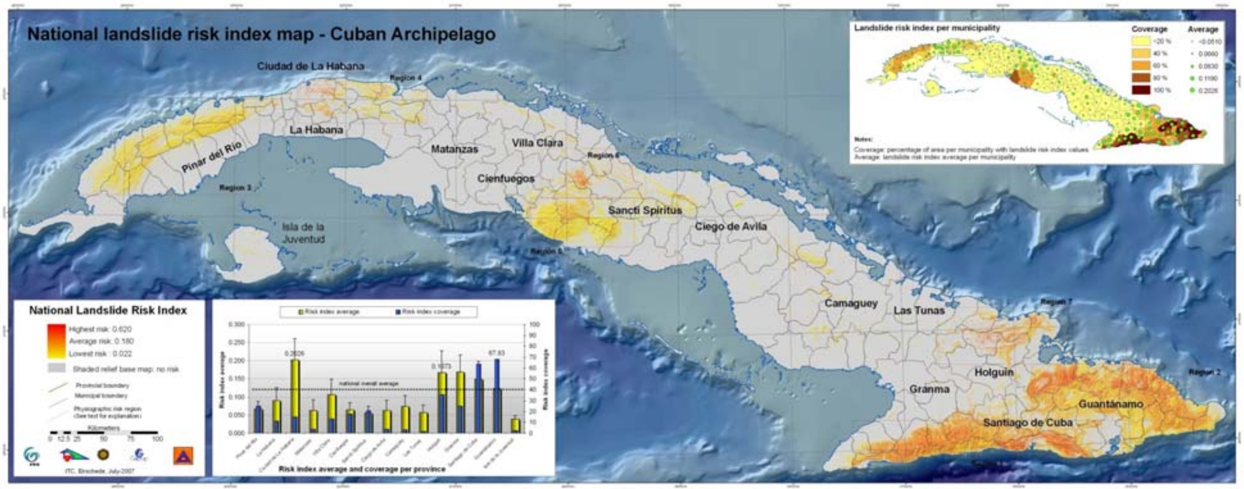


Figure 6.9: Final landslide risk index map for Cuba made using spatial multi criteria evaluation.

6.4.2 Risk indices

There are many methods in which such risk indices have been used in combination with SMCE. This section will present some examples.

Disaster Risk Index (DRI):
This measures the physical exposure and relative vulnerability of a country. The DRI enables the calculation of the average risk of death per country in large- and medium-scale disasters associated with earthquakes, tropical cyclones, and floods based on data from 1980 to 2000. It also enables the identification of a number of socio-economic and environmental variables that are correlated with risk of death and which may point to causal processes of disaster risk. In the DRI, countries are indexed for each hazard type according to their degree of physical exposure, their degree of relative vulnerability, and their degree of risk (UNDP, 2004a; UNDP, 2004b).

Task 6.7: DRI index (duration 15 minutes)
The DRI index can also be consulted as an interactive tool on internet
Go to the following website: http://gridca.grid.unep.ch/undp/
Select your own country and view the risk profile. Compare your country with another one.

IDB Indicator System: this method uses a set of indicators for benchmarking countries in different periods (e.g. from 1980 to 2000) to make cross-national comparisons in a systematic and quantitative fashion. Each index has a number of variables that are associated with it and empirically measured. The choice of variables is driven by a consideration of a number of factors including: country coverage, the soundness of the data, direct relevance to the phenomenon that the indicators are intended to measure, and quality. Four components or composite indicators reflect the principal elements that represent vulnerability and show the advances of different countries in risk management: Disaster Deficit Index, Local Disaster Index, Prevalent Vulnerability Index and Risk Management Index. See also: http://idea.unalmzl.edu.co . The following boxes explain the four indicators that are used.

The following description of the IDB system of indicators developed by A.D. Cardona can be found in: http://www.unisdr.org/HFdialogue/download/tp3-paper-system-indicators.pdf

The **Disaster Deficit Index** measures country risk from a macroeconomic and financial perspective according to possible catastrophic events. It requires the estimation of critical impacts during a given period of exposure, as well as the country's financial ability to cope with the situation.

$$DDI = \frac{MCE\ loss}{Economic\ Resilience}$$

The losses occurring in a Maximum Considered Event (MCE) represent the maximum direct economic impact in probabilistic terms on public and private stocks that are governments' responsibility. This is a fraction of the total loss LR which is estimated as :

$$L_R = E\,V(I_R F_S)\,K$$

where, E is the economic value of all the property exposed; V( ) is the vulnerability function, which relates the intensity of the event with the fraction of the value that is lost if an event of such intensity takes place; I_R is the intensity of the event associated to the selected return period; F_S is a factor that corrects intensities to account for local site effects; and K is a factor that corrects for uncertainty in the vulnerability function.
Economic resilience is a composite index which is made by combining 5 indicators:

- Insurance and reassurance payments (F1p)
- Reserve funds for disasters (F2p)
- Aid and donations (F3p)
- New taxes (F4p)
- Budgetary reallocations (F5p)
- External credit (F6p)
- Internal credit (F7p)

A DDI greater than 1.0 reflects the country's inability to cope with extreme disasters even by going into as much debt as possible. The greater the DDI, the greater the gap between losses and the country's ability to face them.

The **Local Disaster Index** identifies the social and environmental risks resulting from more recurrent lower level events (which are often chronic at the local and subnational levels). These events have a disproportionate impact on more socially and economically vulnerable populations, and have highly damaging impacts on national development. The LDI is equal to the sum of three local disaster subindices that are calculated based on data from the DesInventar database (made by the Network of Social Studies in Disaster Prevention of Latin America, La RED in Spanish) for number of deaths K, number of people affected A, and losses L in each municipality, taking into account four wide groups of events: landslides and debris flows, seismo-tectonic, floods and storms, and other events.

$$LDI = LDI_K + LDI_A + LDI_L$$

The LDI captures simultaneously the incidence and uniformity of the distribution of local effects. That is, it accounts for the relative weight and persistence of the effects attributable to phenomena that give risk to municipal scale disasters. The higher the relative value of the index, the more uniform the magnitude and distribution of the effects of various hazards among municipalities. A low LDI value means low spatial distribution of the effects among the municipalities where events have occurred.

The **Prevalent Vulnerability Index** is made up of a series of indicators that characterize prevalent vulnerability conditions reflected in exposure in prone areas, socioeconomic weaknesses and lack of social resilience in general.

$$PVI = PVI_{ES} + PVI_{SF} + PVI_{LR}$$

The weighting technique used to obtain the PVI was the Analytic Hierarchy Process (AHP); a widely used technique for multi attribute decision making proposed by Saaty (1980, 1987). This is also further explained in the next section.
An overview of indicators to determine PVI is shown below.

Description	Indicator	Weight
Population growth, average annual rate (%)	ES1	$w1$
Urban growth, avg. annual rate (%)	ES2	$w2$
Population density, people/5 Km²	ES3	$w3$
Poverty-population below US$ 1 per day PPP	ES4	$w4$
Capital stock, million US$ dollar/1000 km²	ES5	$w5$
Imports and exports of goods and services, % GDP	ES6	$w6$
Gross domestic fixed investment, % of GDP	ES7	$w7$
Arable land and permanent crops, % land area	ES8	$w8$

PVI_{ES}

Description	Indicator	Weight
Human Poverty Index, HPI-1	SF1	$w1$
Dependents as proportion of working age population	SF2	$w2$
Social disparity, concentration of income measured using Gini index	SF3	$w3$
Unemployment, as % of total labor force	SF4	$w4$
Inflation, food prices, annual %	SF5	$w5$
Dependency of GDP growth of agriculture, annual %	SF6	$w6$
Debt servicing, % of GDP	SF7	$w7$
Human-induced Soil Degradation (GLASOD)	SF8	$w8$

PVI_{SF}

Description	Indicator	Weight
Human Development Index, HDI [Inv]	LR1	$w1$
Gender-related Development Index, GDI [Inv]	LR2	$w2$
Social expenditure; on pensions, health, and education, % of GDP [Inv]	LR3	$w3$
Governance Index (Kaufmann) [Inv]	LR4	$w4$
Insurance of infrastructure and housing, % of GD [Inv]	LR5	$w5$
Television sets per 1000 people [Inv]	LR6	$w6$
Hospital beds per 1000 people [Inv]	LR7	$w7$
Environmental Sustainability Index, ESI [Inv]	LR8	$w8$

PVI_{LR}

PVI

The **Risk Management Index** brings together a group of indicators that measure a country's risk management performance. These indicators reflect the organizational, development, capacity and institutional actions taken to reduce vulnerability and losses, to prepare for crisis and to recover efficiently from disasters.

The RMI was constructed by quantifying four public policies, each of which has six indicators. The policies include the identification of risk, risk reduction, disaster management, and governance and financial protection. Risk identification (RI) is a measure of individual perceptions, how those perceptions are understood by society as a whole, and the objective assessment of risk. Risk reduction (RR) involves prevention and mitigation measures. Disaster management (DM) involves measures of response and recovery. And, finally, governance and financial protection (FP) measures the degree of institutionalization and risk transfer.

$$RMI = (RMI_{RI} + RMI_{RR} + RMI_{DM} + RMI_{FP}) / 4$$

Also this index is made using a set of indicators:

Indicator	Description	Weight
RI1	Systematic disaster and loss inventory	w_{RI1}
RI2	Hazard monitoring and forecasting	w_{RI2}
RI3	Hazard evaluation and mapping	w_{RI3}
RI4	Vulnerability and risk assessment	w_{RI4}
RI5	Public information and community participation	w_{RI5}
RI6	Training and education on risk management	w_{RI6}

RMI_{RI}

Indicator	Description	Weight
RR1	Risk consideration in land use and urban planning	w_{RR1}
RR2	Hydrographical basin intervention and environmental protection	w_{RR2}
RR3	Implementation of hazard-event control and protection techniques	w_{RR3}
RR4	Housing improvement and human settlement relocation from prone-areas	w_{RR4}
RR5	Updating and enforcement of safety standards and construction codes	w_{RR5}
RR6	Reinforcement and retrofitting of public and private assets	w_{RR6}

RMI_{RR}

Indicator	Description	Weight
DM1	Organization and coordination of emergency operations	w_{DM1}
DM2	Emergency response planning and implementation of warning systems	w_{DM2}
DM3	Endowment of equipments, tools and infrastructure	w_{DM3}
DM4	Simulation, updating and test of inter institutional response	w_{DM4}
DM5	Community preparedness and training	w_{DM5}
DM6	Rehabilitation and reconstruction planning	w_{DM6}

RMI_{DM}

Indicator	Description	Weight
FP1	Interinstitutional, multisectoral and decentralizing organization	w_{FP1}
FP2	Reserve funds for institutional strengthening	w_{FP2}
FP3	Budget allocation and mobilization	w_{FP3}
FP4	Implementation of social safety nets and funds response	w_{FP4}
FP5	Insurance coverage and loss transfer strategies of public assets	w_{FP5}
FP6	Housing and private sector insurance and reinsurance coverage	w_{FP6}

RMI_{FP}

RMI

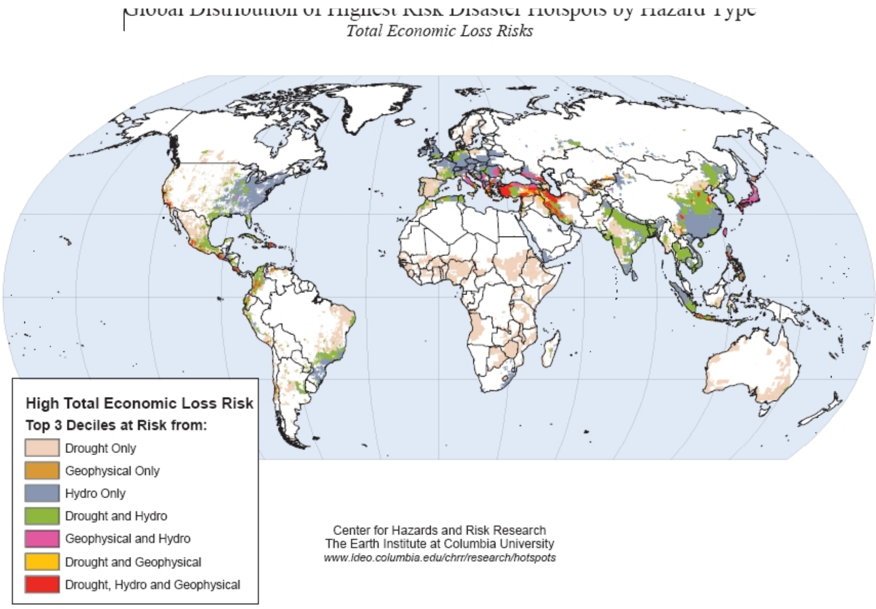
The IDB indicator system was designed to measure indicators at national level using existing information from existing national and international databases. Although it can be used at local level, it was primarily designed for national and sub-national comparisons. It gives a complete idea of how vulnerable a country is, according to the hazards that affect it.

Seismic Risk Index (SRI): Is a composite index that measures risk to earthquakes within cities. First, the model defines the physical seismic risk index (also called hard) based on descriptors obtained from estimating potential urban losses due to future earthquakes. Second, it defines the context seismic risk index (also called soft) obtained as the scaled product of the seismic hazard and context vulnerability descriptors. Both the physical seismic risk index and the context seismic risk index are combined using weights (Cardona, 2001a).
The DRI measures risks for country indexation purposes; therefore, it uses national indicators such as GDP (Gross Domestic Product) or HDI (Human Development Index). On the other hand, the EDRI measures risk at city level, but as a general index for comparison with other cities worldwide. None of the results of these indices can be used at the local level for risk reduction practices. In the case of the SRI, the measurement of risk can be performed within cities, allowing for comparison at different aggregation levels. No matter how the different authors group the vulnerability factors in all three indices, the information used for the assessment is basically the same, except when the SRI is used to assess risk within a city, where more detailed information is needed

Global Hotspots Project

The Hotspots project generated a global disaster risk assessment and a set of more localized or hazard-specific case studies. The method is based on the EM-DAT database (see session 1). (http://www.cred.be). The study assessed the global risk for mortality and economic losses, by combining hazard exposure with historical vulnerability for two indicators of elements at risk—gridded population and Gross Domestic Product (GDP) per unit area and for six major natural hazards: earthquakes, volcanoes, landslides, floods, drought, and cyclones. By calculating qualitative risks for each grid cell rather than for countries as a whole, we are able to estimate risk levels at sub-national scales.

Figure 6.10: Example of a map of the Global Disaster Hotspots project



Task 6.8: Evaluating Global hotspots data with GIS (duration 30 minutes)

The data for the Global hotspots project can be downloaded from the following website:
http://www.ldeo.columbia.edu/chrr/research/hotspots/
We have downloaded a few of the data layers for you, and have also converted them into ILWIS, and added a vector map of the world: global multi-hazard economic risk and global multi-hazard mortality.
Open the maps with ILWIS and add the vector map of the world to it. Evaluate how the risk information is for your own country.
You can also download and import more specific information from the website. Make sure to import the .ASC files into ILWIS.

6.5 Quantitative risk assessment

Quantitative risk assessment aims at quantifying the risk according to equation 6.3. In this method the combined effects in terms of losses for all possible scenarios that might occur are calculated. There are several approaches. Although there are certain similarities, some differences appear between the approaches. They include either the way to calculate the hazard or to calculate vulnerability and consequence. Commonly agreement was found among the methods in combining hazard as probability of the hazard and vulnerability as consequences. For a number of different hazard scenarios the consequences are plotted against the temporal probability of occurrence of the hazard events in a graph. Through these points a curve is fitted, the so-called risk curve, and the area below the curve presents the total risk. In a multi-hazard risk assessment this procedure is carried out for all individual hazard types, and care should be taken to evaluate also interrelations between hazards (e.g. domino effects, such as a landslide damming a river and causing a flood). Since the risk is normalized into annual risk, it is then possible to evaluate the multi-hazard risk, and use the risk curves as the basis for disaster risk reduction.

6.5.1 Flood risk

In this section examples are given of the use of probabilistic risk assessment for flooding, landslides and earthquakes.

Figure 6.11 gives an example of a probabilistic risk assessment for building that are threatened to flooding. Whereas is figure 6.2 only one flooding scenario was given, we now have three different scenarios, each with a different probability of occurrence (2 years, 10 years and 50 years). These scenarios are derived from the hazard modeling approaches presented in session 3. In this simple example there are 3 elements at risk only (buildings) that are of two types. Type-1 buildings are weaker in construction than type-2 buildings. Based on past occurrences of flooding a relation has been made between the water depth and the degree of damage using vulnerability curves (explained in chapter 5). This means that with the same water depth type-1 buildings will suffer more damage than type-2 buildings. The vulnerability curves presented in figure 6.11 are hypothetical ones, but are the crucial component in the risk assessment. The three hazard scenarios will affect the three buildings in a different way. The small table in figure 6.11 indicates the water depth that can be expected for the three houses related to the three scenarios.
In the risk calculation presented in the lower table of figure 6.11, the following types of information are determined for each element at risk:

- PT = annual probability of occurrence of the scenarios (this was treated in session 3.1). The annual probability is calculated as the reciprocal of the return period.
- A = the quantification of the elements at risk. In this case the quantification is done in monetary values, including both the structure and the contents of the buildings.
- V = the vulnerability of the building for the specific flood scenario. This is done by relating the flood depth with the damage amount according to the vulnerability curve.
- V * A = the consequences. The expected losses per building for a given flood scenario is calculated by multiplying the vulnerability with the amount of elements at risk.
- ∑ V * A = the total consequences of a flood scenario for all elements at risk exposed to the scenario.

The values of the total consequences per scenario(∑ V * A) are plotted against the temporal probability (PT) in a graph. Each scenario represents on point, and the location depends on the probability of occurrence and the total consequences. If you have at least three scenarios it is possible to plot a curve through the points, which is called the risk curve, or the Loss Exceedance Curve (LEC).

The total area under the curve represents the total annual risk for flooding.

The definition of an accurate Loss Exceedance Curve requires information on many hazard scenarios.

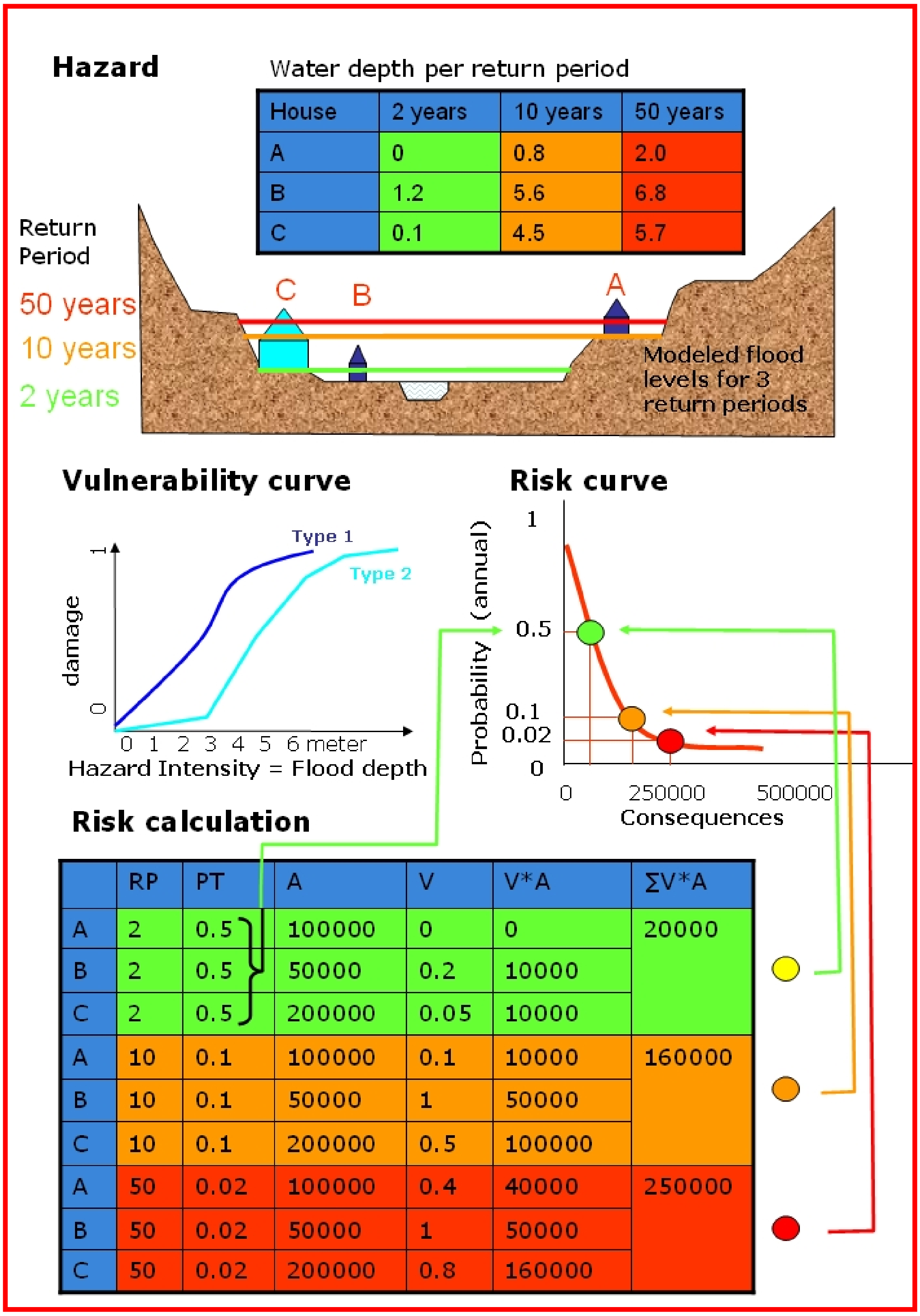


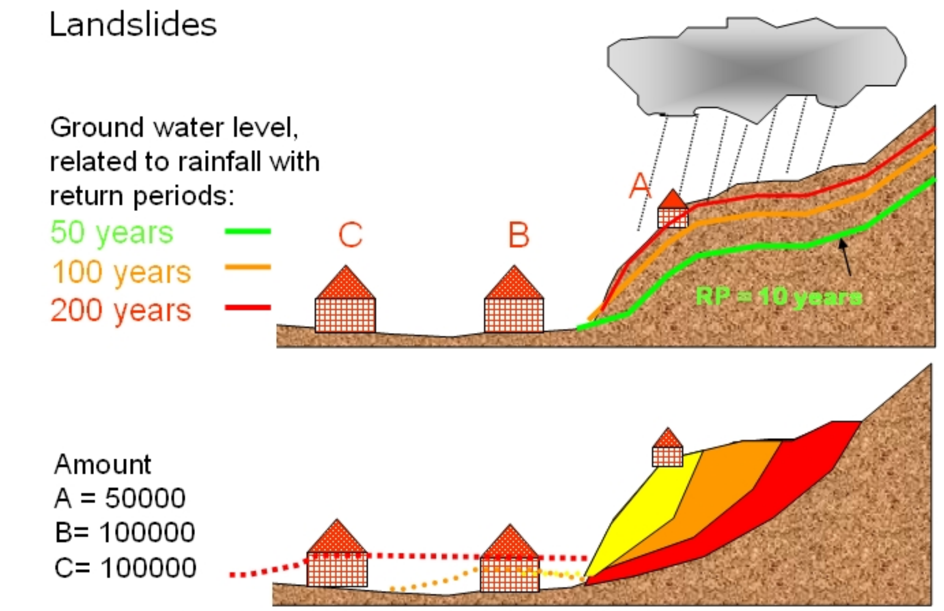
Figure 6.11: Simple example of a probabilistic risk assessment, resulting in the calculation of a risk curve, or loss exceedance curve (LEC).

For each scenario we need to know: the probability of occurrence, the spatial extent, and the magnitude of the event that varies spatially. We also need to know the distribution of the elements at risk, their classification and characterisation in aspects that are relevant for estimating the degree of damage. And we need to know the relation between the magnitude and the expected damage in the form of vulnerability curves.

6.5.2 Landslide risk

Figure 6.12 presents the same concept but now for landslides. The hazard assessment starts with the modelling of groundwater depths, based on a slope hydrology model, where daily rainfall and the soil characteristics form the main sources of input. Based on the rainfall records and the modelling it is theoretically possible to estimate groundwater levels related to a particular return period.

Based on the groundwater modelling a second analysis is carried out using a physically based slope stability model to calculate the factor of safety for each particular return period. This results in three landslide scenarios, in which different volumes of landslides can be identified. The next step would be to carry out a run out analysis, to estimate the length of runout, the velocity and the depth of the landslide materials. These parameters would form the input in a vulnerability assessment.



Risk calculation

	RP	PT	A	V	V*A	ΣV*A
A	50					
B	50					
C	50					
A	100					
B	100					
C	100					
A	200					
B	200					
C	200					

Risk curve

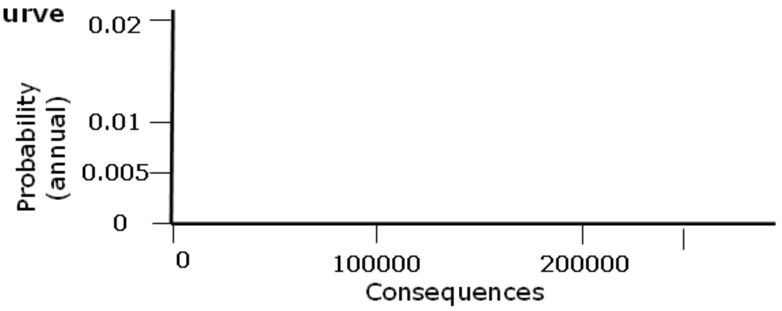
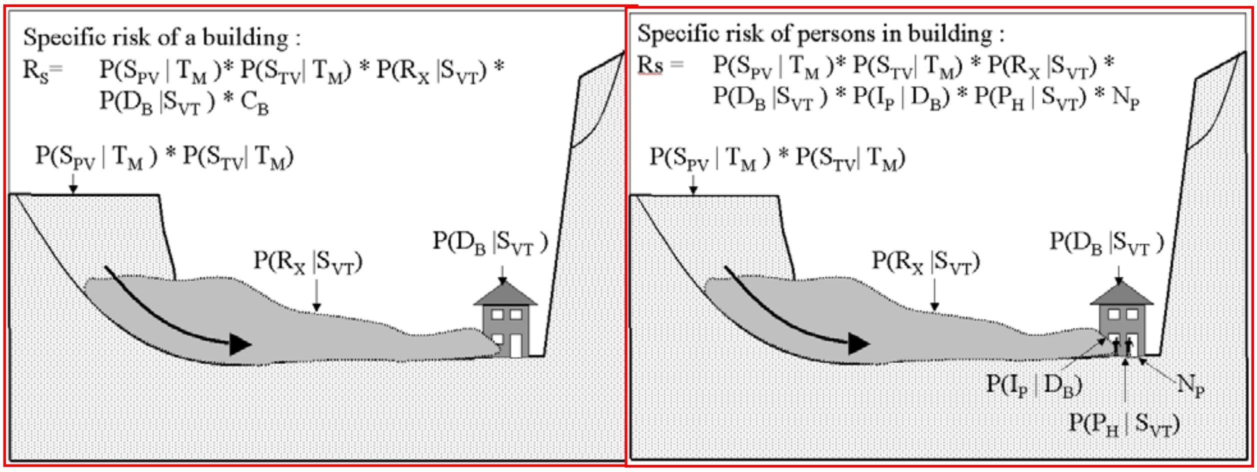


Figure 6.12: Example of quantitative landslide risk assessment, similar to the approach presented in figure 6.11

Task 6.9: Calculation of a risk curve (duration 30 minutes)
*Calculate the specific risks for the individual risk scenarios for 50, 100 and 200 years, using the temporal probability (PT), the amount (A), and the vulnerability (V). In this case make an estimate of the expected degree of loss given the particular scenario. Calculate the consequences (V*A) and the sum of the consequences (ΣV*A). Plot the Temporal probability against the total consequences and create the risk curve.*

Figure 6.13 gives another example of calculation risk for a landslide situation, in which the specific risk is consisting of a number of individual probabilities (see also section 3.3.L).



In which:

$P(S_{PV} | T_M)$ =**Spatial probability**. This is the conditional probability of initiating a landslide with a specific volume and type at a specific location, given a certain triggering event (e.g. rainfall, earthquake) with a certain magnitude/intensity.

$P(S_{VT} | T_M)$ = **Temporal probability**. Conditional probability of initiating a landslide with a specific volume and type , given a certain triggering event (e.g. rainfall, earthquake) with a certain magnitude/intensity, within a certain time period.

$P(R_X | S_{VT})$ =**Conditional probability of runout**. The chance that a run out zone with distance X to the building will be covered, given the occurrence of the landslide with a particular volume and type.

$P(D_B | S_{VT})$ = **Conditional probability of damage to the building** of a particular construction type, given the occurrence of the landslide with a particular volume and type.

C_B = **Replacement costs** of the particular building.

$P(I_P | D_B)$ = **Conditional probability of injuries or death** for a person present in the house, given the degree of damage to the building by a landslide of a given volume and type

$P(P_H | S_{VT})$ = Conditional probability of persons being present in the building, given then time of the day that the landslide might occur (or percentage of persons in the building given time of the day)

N_P = **Number of persons** in the building

Figure 6.13: Example of landslide risk estimation for a building (upper left) and people in a building (upper right).

The estimation of landslide risk as indicated above is conceptual. In practice there are a number of aspects that make landslide risk assessment a particularly difficult procedure. Figure 6.14 illustrates some of these difficulties involved in calculating landslide risk. In this figure, the two schematically represented buildings (elements at risk) present different vulnerabilities as they are geographical located in diverse positions, and might be affected by different types of landslides and in different ways (undercutting

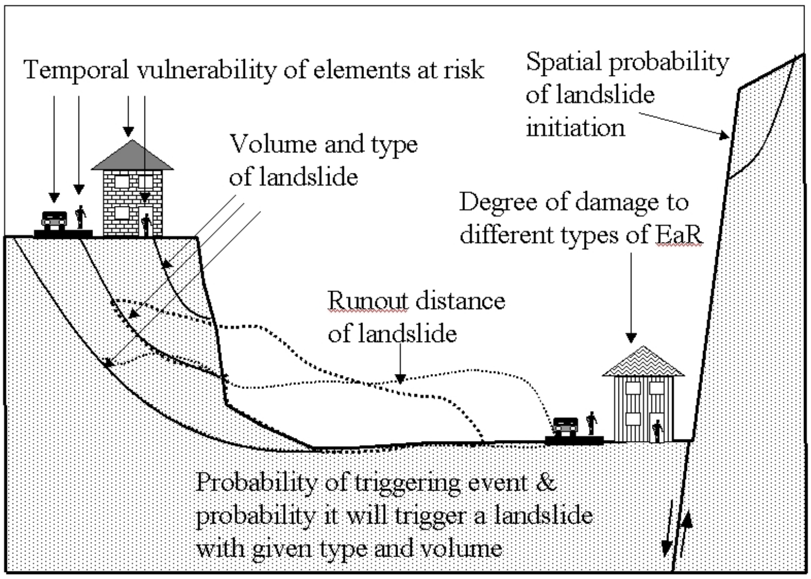


Figure 6.14: Illustration of some of the most problematic aspects of landslide risk assessment

/ impact). Vulnerability is also determined by construction types, (e.g. building materials, foundation types) which determine the strength of the building to withstand impact/erosion. Besides, due to the use, structure and size, the value or cost of these buildings will also be different. In the consequence calculation each building will get a different value and for the same hazard (e.g. a 10 years return period landslide) the risk will be also different. Furthermore, when calculating risk to persons the temporal changes in vulnerability also play a major role, both for persons that are in buildings, or that or in risky locations outside (e.g. in traffic). Although the determination of the (temporal) vulnerability of the elements at risk might be problematic, the elements at risk themselves can be mapped and classified without many conceptual problems, although the process may be quite time consuming. Out of the three risk determining factors as indicated in equation 1, the hazard component is by far the most complex to establish for landslides. Figure 6.14 illustrates several of the problems associated with determining the temporal and spatial probability of occurrence, the volume of the expected landslide, and the extent to where the landslide might be moving (run-out zone).

Therefore, quantitative risk assessment for landslides can be done in different ways:

- Using **physically based models**. In a large scale analysis, or at site investigation scale, based on physical modelling and/or expert opinion. The stability of the slope is calculated as well as the runout and the variability of the input factors is combined with the probability of occurrence of the triggering factors into a probabilistic analysis.
- In the case of a **complete landslide inventory**: this is for instance possible along a transportation route. Landslide probability and vulnerability can be obtained from the historical landslide records.
- **Event-based landslide maps**. In a medium scale analysis event-based landslide inventory maps can be made, displaying landslides that have been triggered by the same event for which the temporal probability is known. They are used in a statistical analysis which results in a landslide susceptibility map, that can be classified in classes (e.g. high, moderate and low). For each return period and each class the following aspects are calculated (See also equation 6.3):
    - P_T = temporal probability, which is related to the return period of the triggering event responsible for the event-based landslide inventory;
    - P_L = locational or spatial probability that a certain area will be impacted by a landslide. This is calculated as the landslide density (of the particular event-based landslide inventory) within the susceptibility class.
    - V is the physical vulnerability,for landslides this is very often taken as 1.
    - A is the quantification of the specific type of element at risk evaluated.

6.5.3 Earthquake risk

The examples given in figure 6.11 and 6.12 refer to simple examples based on profiles. However, in practice risk assessment is done for an entire area, and the input data is spatial. Figure 6.15 gives an example of a spatial risk assessment, in this case for earthquakes. The upper right part of the figure shows the seismic microzonation map, resulting from the hazard assessment as described in session 3). There are three zones, each characterized by a different ground acceleration, and seismic intensity (in Modified Mercalli Intensity), indicated in the table on seismic hazard. The upper left map shows the buildings (elements at risk) classified into 3 building types. For each of the building types a vulnerability curve is available. The figure also shows the joint frequency table (cross table) resulting from the overlaying of the seismic microzonation map with the elements at risk map. Based on the joint frequency table, the hazard table and the vulnerability curve it is possible to calculate the vulnerability, amount (this time expressed as the number of buildings) and the loss/consequence (V*A) for each combination of the zone, building type, and earthquake scenario. Then the losses can be summed up by zone and scenario, and eventually by scenario for the whole map. The losses per scenario are plotted against the annual probability and a risk curve can be constructed.

In the case of earthquake hazard assessment, there may by many different scenarios to consider, as there are many different potential earthquake locations that would lead to a different degree of ground shaking for the same area. Therefore a probabilistic risk assessment for earthquakes required the incorporation of many individual scenarios

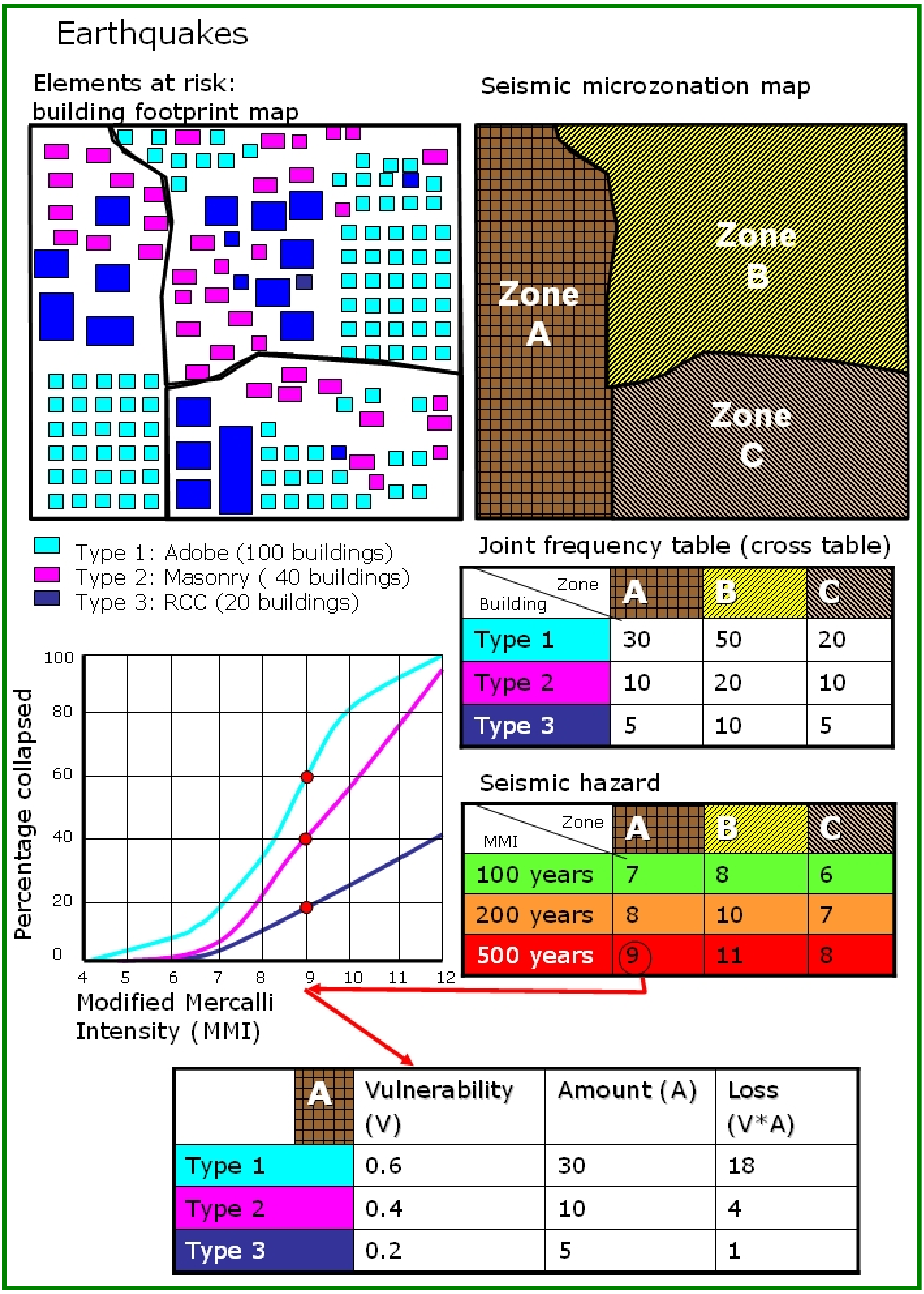


Figure 6.15: Schematic representation of spatial earthquake loss estimation. See text for explanation.

Task 6.10: Calculate seismic risk (duration 30 minutes)
*From the figure above calculate the specific risks for the individual risk scenarios for 100, 200 and 500 years, using the temporal probability (PT), the amount (A), and the vulnerability (V). In this case make an estimate of the expected degree of loss given the particular scenario. Calculate the consequences (V*A) and the sum of the consequences (ΣV*A). Plot the Temporal probability against the total consequences and create the risk curve. Do the calculation in an Excel file.*

A complete risk assessment also includes many more aspects than the direct physical damage to the building stock. Figure 6.16 shows an example of the earthquake loss estimation modules of the HAZUS method, used in the US.

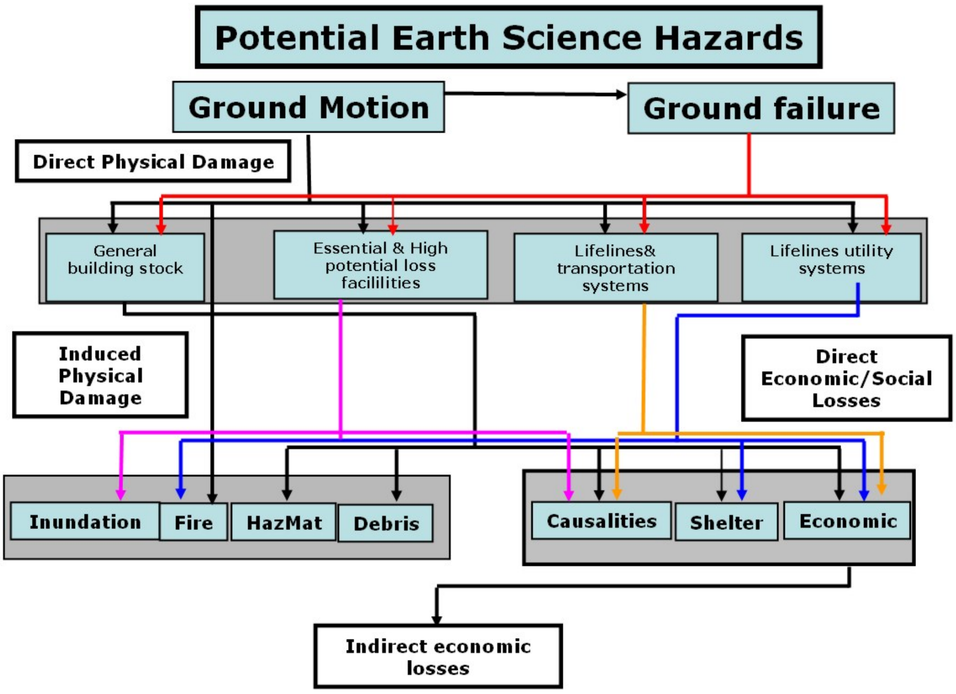


Figure 6.16: Overview of the various modules of the HAZUS method for earthquake loss estimation (Source: www.fema.gov/plan/prevent/hazus)

The generation of a complete earthquake risk assessment is very challenging. Even a methodology like HAZUS is often not complete, as it is difficult to incorporate all secondary effects and domino effects due to earthquakes. Figure 6.17 gives an example of that, showing some of the many hazard types that might be related to a tsunami, which is caused by an earthquake. In such cases the calculation of the return period, and the inundation depth is very difficult to carry out probabilistically.

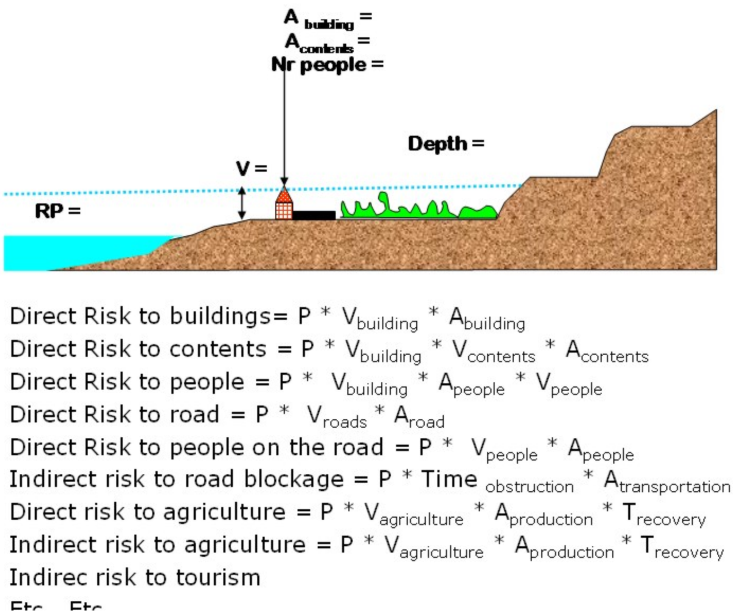


Figure 6.17: Example of the complexity of risk assessment when taking into account direct and indirect losses and different types of elements at risk. The example is for tsunami.

Task 6.11: RiskCity exercise on quantitative risk assessment (duration 3 hours)

Now you can select here if you want to do one of the following topics: ***Flood risk assessment, landslide risk assessment, earthquake risk assessment, Technological risk assessment****. Each has its own exercise description. Go to the exercise book and make your selection. Then follow the instruction there.*

6.5.4 Technological risk

Technological risk assessment is rather different from the risk assessment related to geological or hydro meteorological hazards, discussed before. Technological hazards such as accidents in industrial facilities, or accidents involving hazardous materials depend on the occurrence of failure in a system. There are a range of techniques developed to analyze the risk of such events, which could sometimes also be used to analyze natural events. Some of these techniques are mentioned below.

Use of historical information. This is based on an evaluation of the probability of an accident in a given industrial site, based on statistical information from comparable installations elsewhere. There should be enough historical information in order to be able to make such an analysis. For very rare events it will not be possible to make such a probability estimate (e.g. in the case of a major industrial accident). In other situations it might be more easier to use (e.g. the frequency of road accidents involving vehicles with explosive or flammable substances).

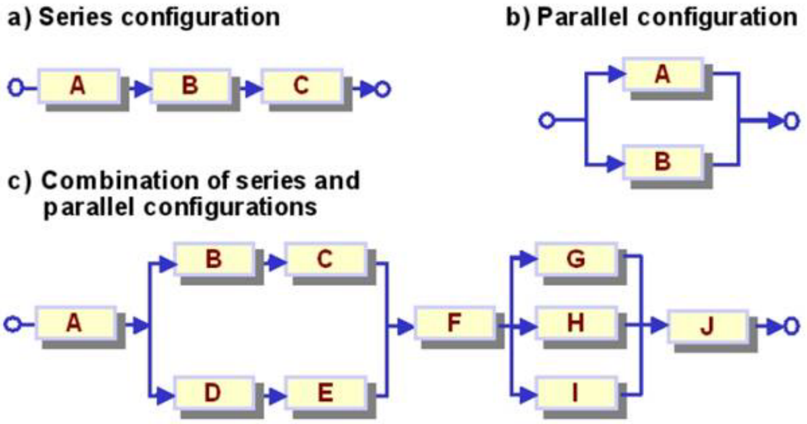


Figure 6.18: Example of configurations that can be used in a Success Path Analysis (SPA). Source: Nahris

Success path analysis
The success path method is a drawing and calculation tool used to model relatively complex systems. In this method, the different components of a system are symbolized as individual graphic and functional elements, called "reliability blocks" (for this reason, in its industrial applications this method is also known under the name of "Reliability Block Diagram", or RBD, method). These blocks are reliability-wise arranged and related, often, but not necessarily, in the same way that the corresponding components are physically connected. Once the blocks are properly configured, and reliability data for these blocks is provided, calculations can be performed in order to calculate the failure rate, the "mean time between failure" (MTBF), reliability and availability of the system. The simplest and most elementary types of reliability blocks configurations are the series and active-parallel configurations. Items connected in series must all work for the system to fulfill its function ("success path"). In the example of figure 6.18 a, the system will fail if either A, B or C fails. Items placed in parallel are considered to be redundant, because the good working of only one of them is enough for the system to function. In the example of figure 6.18 b, either A or B (but not A and B simultaneously) can fail and the system will continue to function.
The reliability of a system of N independent components, all in series or all in active-parallel, can respectively be calculated from the following mathematical expressions (Ri: reliability of component i, assumed to be known) [McCormick, 1981]:

$$R_{sys}(t)=\prod_{i=1}^{N} R_i(t) \qquad \text{(series)}$$

$$1-R_{sys}(t)=\prod_{i=1}^{N}\left[1-R_i(t)\right] \qquad \text{(active-parallel)}$$

These two elementary configurations form the basis of the reliability block diagram construct and success path analysis. The above construction and calculation scheme can be expanded further, as shown in figure 6.18 c, with various combinations of series and parallel configurations in the same diagram.

Event tree analysis.
Event tree analysis is based on binary logic, in which there are always two options: an event happens or does not happen, or a component of a technical system either works or fails. In a fault tree analysis each of the possibilities has a certain probability. An event tree starts with an initiating event, such as a fire or a failure of a component of a system. The consequence of the event is followed through a series of possible paths. Each path is assigned a probability of occurrence and the probability of the various possible outcomes can be calculated.

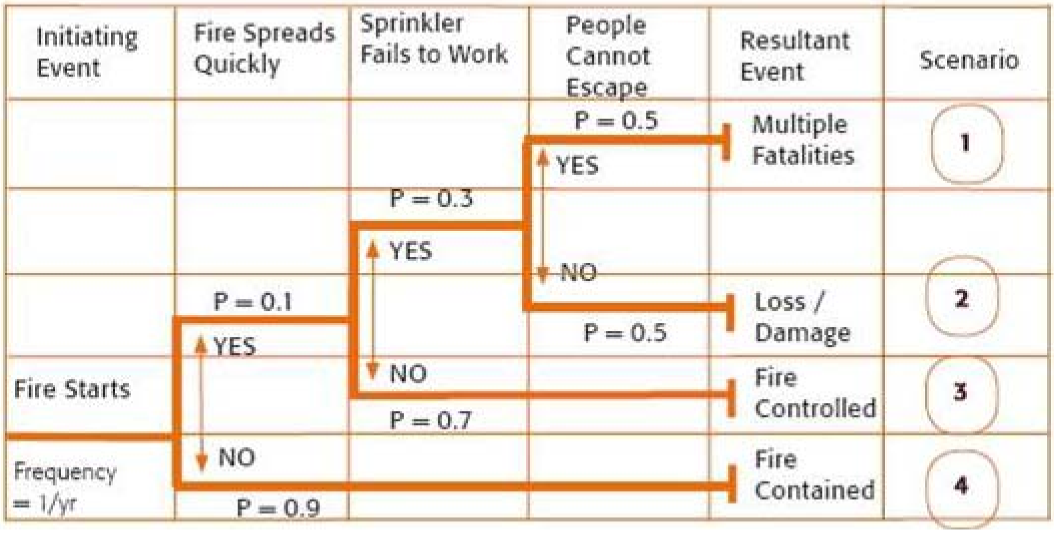


Figure 6.19: Simple example of an event tree analysis for a case of fire. Source: [*http://www.theiet.org/factfiles/health/index.cfm*](http://www.theiet.org/factfiles/health/index.cfm)

Fault-tree analysis
A fault tree is a graphical representation that provides a systematic description of possible occurrences in a system, which can result in an undesirable outcome. The most serious outcome such as a landslide, explosion etc. is selected as the Top Event. A fault tree is then constructed by relating the sequence of events, which individually or in combination, could lead to the Top Event. This may be illustrated by considering the probability of a crash at a road junction and constructing a tree with AND or OR logical operators. The tree is constructed by deducing in turn the preconditions for the top event and then successively for the next levels of events, until the basic causes are identified.

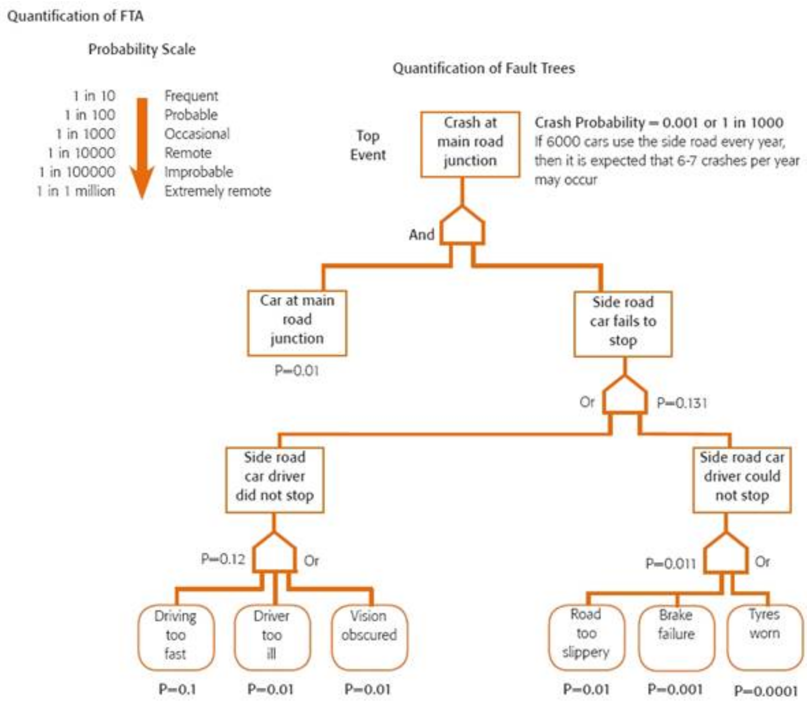


Figure 6.20: Example of a fault-tree analysis. Source: [*http://www.theiet.org/factfiles/health/index.cfm*](http://www.theiet.org/factfiles/health/index.cfm)

6.5.5. Converting risk curves to annualized risk

Once we have calculated a risk curve for any of the hazard types discussed in the previous sections, it is important to convert the information into Averaged Annualized Loss (AAL), which is the Expected loss per year when averaged over a very long period (e.g., 1,000 years). Computationally, AAL is the summation of products of event losses and event occurrence probabilities for all stochastic events in a loss model.
The total annual risk is the total area under the risk curve, of which the X-axis display losses (in monetary values) and the Y-axis displays the annual probability of occurrence. The points in the curve represent the losses associated with the return periods for which an analysis was done (e.g. the return periods listed in the table above). There are two "graphical" methods to calculate the total area under the curve. We will first briefly look at those.

Method 1: Triangles and rectangles method
The area under the curve is divided into trangles, which connect the straight lines between two points in the curve and have X-axis difference as difference between the losses of the two scenarios. Y-axis of the triangles is the difference in probability between two scenarios. The remaining part under the curve is then filled up with rectangles, as illustrated in figure 6.21.

Method 2: Simplified rectangles method.
In this method we simplify the graph into a number of rectangles, which have as Y-axis the difference between two successive scenarios, and as X-axis the average losses between two successive loss events. See figure 6.21.

It is also possible to represent the graph as a function and use this in the calculation of the area under the curve.

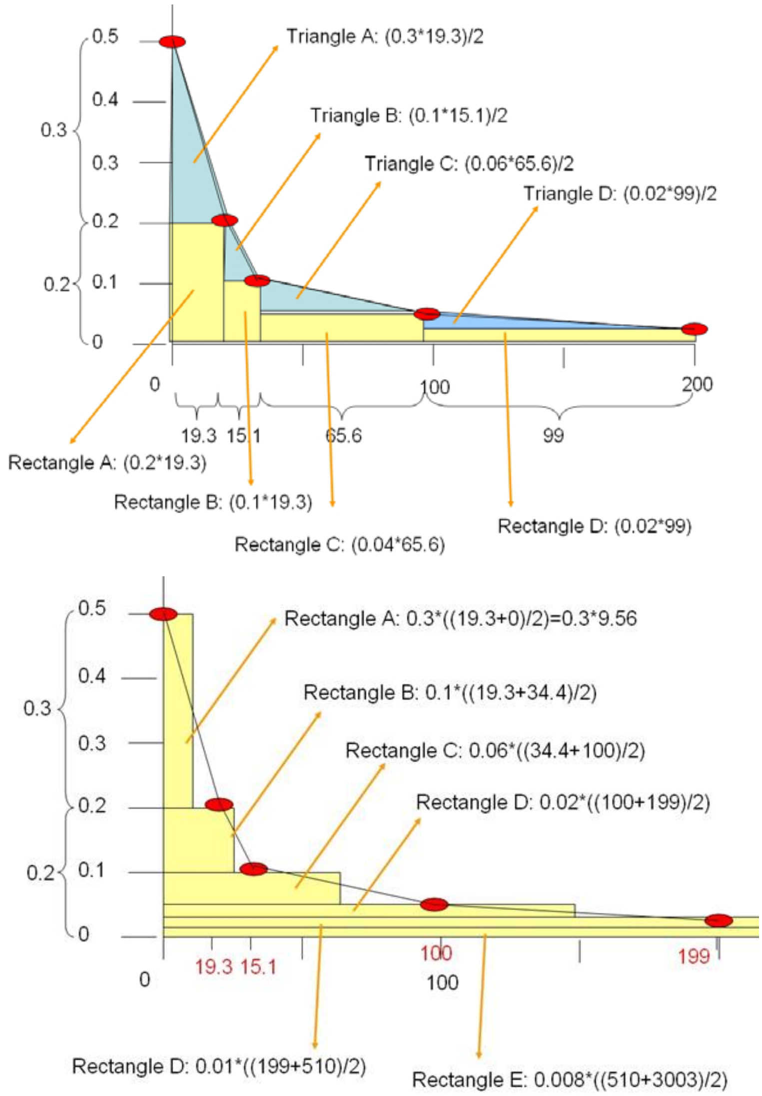


Figure 6.21: Two methods for calculating the area under the risk curve. Left: triangles method; right: simplified rectangles method.

Task 6.12: RiskCity exercise on Multi-hazard risk assessment (duration 3 hours)

In the RiskCity exercise on multi-hazard risk assessment we will evaluate the risk of the 4 hazard types (flooding, landslides, earthquakes and technological hazards, and we will compare the results). Please go to the exercise description and follow the instructions.

6.6 Multi-hazard risk assessment

The risk assessment procedures explained in the previous sections result in risk curves which can be compared, as they are all showing the annualized risk. In figure 6.22 a summary is given of the multihazard risk assessment as applied in the RiskCity case study, illustrated for two hazard types: flooding and landslides. Multi-hazard risk assessment was carried out in the RiskCity case study for buildings. First attribute maps were generated that contain the number of buildings affected for each hazard type and hazard class (A in equation 6.3) for each of the 1306 mapping units in the urban area. Then the values were multiplied with values for vulnerability (V) and with the temporal and spatial probability (P_T and P_L) to convert them into annual risk values. The consequences are plotted against the annual probability and risk curves were generated. For each hazard type, separate scenarios were made for each return period. In the case of flooding this was done for return periods of 5, 10, 25, 50 and 100 years, based on the results of the HEC-RAS and SOBEK modeling. For landslides scenarios were made with return periods of 50, 100, 200, 300 and 400 years, based on the landslide inventory which included a considerable subjective component in defining the age of many of the large landslides in the area. For flooding the spatial probability (P_L in equation 6.3) was taken as 1 since the individual hazard scenarios indicate the areas that will be flooded. For the landslide risk assessment the return period of the triggering event (P_T) was multiplied with the spatial probability of landslides occurring in the high, moderate, and low susceptibility classes (P_L in equation 6.3), the vulnerability per land use type and the number of buildings located in each of the three zones. The resulting risk curves were

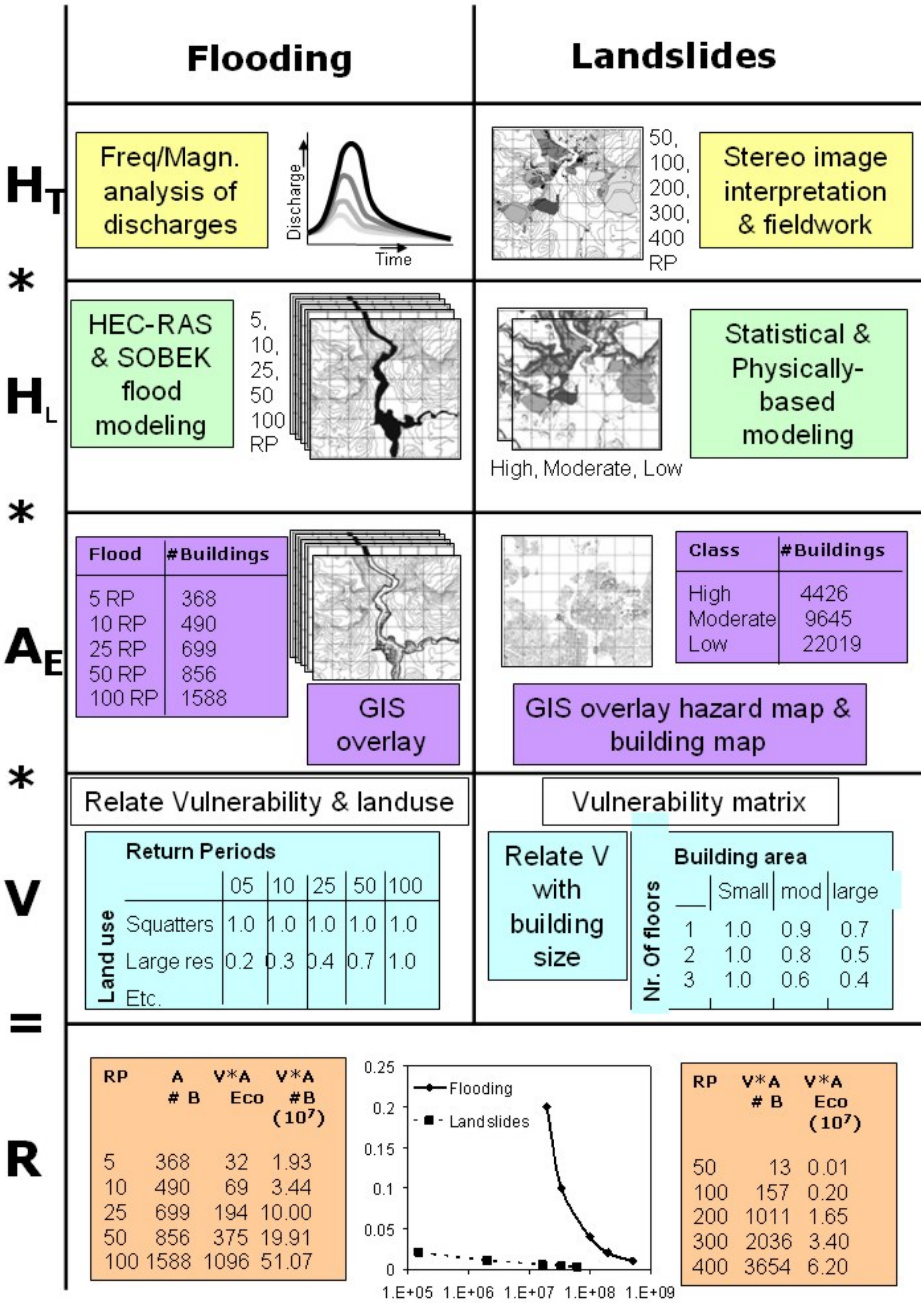


Figure 6.22: Procedure to produce the risk curves for flooding and landslide. The individual components of the risk equation are given on the left hand side. For each component some schematic analysis results are presented.

plotted and the annual risk was calculated by integrating the area under the curve, and by using a simply graphical area calculating in Excel.

Population losses were estimated on the basis of building losses, based on the population vulnerability estimates for different injury levels indicated by HAZUS (FEMA, 2008). HAZUS uses four severity levels ranging from minor injuries (level 1) to deaths (level 4). For each of these four injury levels a relation is made with the building damage level. In a table linked to the mapping units the percentage of the population with a particular severity level was calculated. This calculation was done for the three temporal population scenarios indicated before. The population values were plotted using F-N curves to serve as a basis for defining the risk acceptability levels.

The calculation of direct economic losses due to flooding and landslides was restricted to building losses. The degree of loss to buildings was taken as input for this assessment. In order to valuate the buildings in terms of unit replacement costs, standard values were linked to the urban land use types, and the floorspace for individual buildings. Unit costs (per square meter), based on literature review and evaluation of real estate values, were then applied per mapping unit for buildings and for contents of buildings. These were multiplied with the floorspace to obtain the total costs per mapping units. After this attribute maps were generated that contain the costs of buildings affected for each hazard type and hazard class, which were then used as the A_{ES} parameter in equation 2, and combined with the vulnerability and probability information to generate risk curves with economic losses

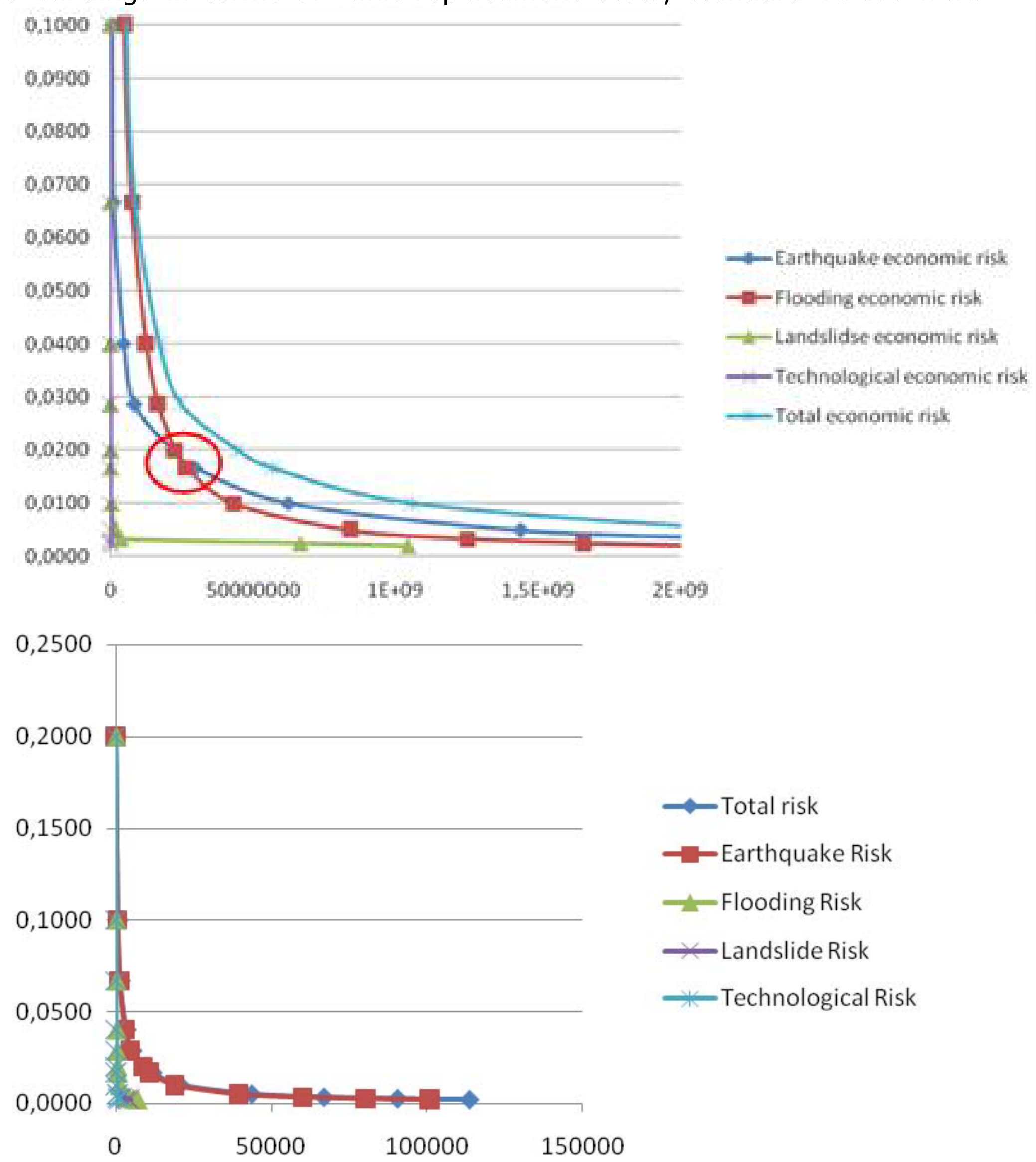


Figure 6.23: Risk Curves for the RiskCity case study for economic building losses (above) and number of buildings (below)

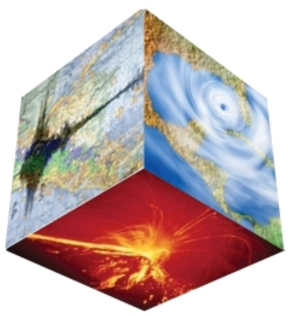
6.7 Loss estimation methods

Computer applications have been developed by different companies and institutions to perform loss estimations for different natural hazards. There are many commercial or non-free applications, such as NHEMATIS (Nobility-Environmental-Software-Systems-Inc., 1999), MRQuake, MRStorm and MRFlood (MunichRe, 2000), RiskLink-ALM, RiskLink-DLM, RiskBrowser and RMS-DataWizard (RMS, 2004), and CLASIC/2, CATRADER, CATMAP/2, AIRProfiler, ALERT (AIR, 2004). These will not be considered in the analysis due to their commercial nature, and that they are basically aimed at supporting insurance company's analyses.

RADIUS (Risk Assessment Tools for Diagnosis of Urban Areas against Seismic Disasters): The amount of information needed by RADIUS enables users to perform an aggregated loss estimation using a gridded mesh, that, depending on the information available, weights each mesh unit assigning it a degree of loss in terms of number of buildings damaged, length of lifelines damaged, and as a number of casualties and injured people. The accuracy of the estimation depends on the detail of the information provided; nevertheless, the algorithms are based on broad assumptions, for instance, soil characteristics and fragility curves (developed for settings different from the one where the methodology is applied). Radius provides a rapid assessment of possible damages according to the detail of the information provided. Although all the categories and weights can be changed, Radius only gives a rough estimate of damage due to the few categories considered and the "raster-like" unit distribution that doesn't account for the typical political administrative boundaries used for decision making and policies.

HAZUS-MH: allows a very detailed analysis of losses based on an enormous amount of information. The information collection can be especially difficult in developing countries due to the poor or inexistent databases and the costs and time needed to update the information necessary for this method. However, after a thorough campaign of information acquisition and preparation, information must be adapted to the requirements of HAZUS-MH. Special attention should be drawn to the issue of the classifications used by HAZUS; since they were designed for the United States of America; other classifications have to be adapted, introducing other sources of error and uncertainty in the loss estimation.
Although these loss estimation methods can give local authorities a loss scenario for a specific hazard, they provide limited insight on how to use that information for the relief and recovery process. They also lack information about the capacities of the community to withstand, cope, and recover from a disaster. Loss estimations can only be considered part of a vulnerability analysis when used as complete inventories of exposed infrastructure and population. In Annex II a summary of the factors considered to perform the loss estimation for the RADIUS and HAZUS initiatives are presented. More information on HAZUS can be obtained from: www.fema.gov/plan/prevent/hazus

CAPRA
CAPRA is an abbreviation for Central American Probabilistic Risk Assessment.
The objectives of CAPRA are: to develop a Disaster Risk Information Platform for decision making using a common methodology and tools for evaluating and expressing disaster risk, and to analyze a regional strategy, that is local, versatile and effective, to advance risk evaluation and risk management decision making. More information on CAPRA and the methods used can be obtained from: http://www.ecapra.org/es/



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 6.1: risk curve

It is **impossible** to generate a risk curve in the following case:

A) When there is no information available on costs, but only on the number of elements at risk
B) When there is no information available on the vulnerability of the elements at risk, but only on the number of elements at risk affected
C) When there is no information available on hazard scenarios with different return periods
D) When there is no quantitative information available on the amount of all the individual elements at risk.

Question 6.2: Dynamic risk

Risk is not static but dynamic, because:

A) Vulnerability changes over time
B) The number of elements at risk changes over time
C) Hazard changes over time
D) All of the above

Question 6.3: Quantitative risk assessment

Which of the components of the "risk formula" can be evaluated based on historical events?

A) Probability of flooding
B) Vulnerability to flooding
C) Number of elements affected by flooding
D) All of the above

Question 6.4 Risk assessment

Consider an area where you have the following hazards and risk:

Flooding:

Return period	Buildings affected	Vulnerability
10	100	0.6
100	500	0.7
200	1000	0.8

Earthquakes

Return period	Buildings destroyed
10	500
100	1000
200	5000

The average building cost is considered to be 100.000 Euro

A) Calculate the contributions of flooding and earthquake to the annual risk.
B) Generate risk curves for the two events.
C) Which of the hazard types will give the highest risk.
D) What is the annual risk of flooding and earthquake combined

Question 6.5: Best methods for risk assessment

Which method for risk assessment would you recommend in the following situations (briefly explain why)

A) In case we would like to indicated the areas with the highest social vulnerability, using a hazard footprint map (without having information on return periods) and a database containing the characteristics of the population (age, gender, literacy rate etc.)
B) In case we would have three flood hazard footprints, each one with information on the return period and the water depth/flow velocity of the event, and an element at risk database with building information containing different building types.

Further reading

In order to know more about the approaches for quantitative loss estimation usnig the HAZUS methodology we refer you to three technical manuals that are included in the further reading part:

- Building loss estimation for earthquakes
- Building loss estimation for floods
- Builidng loss estimation for hurricanes

These manuals are available on the Further Reading directory of this session

ADPC 2005. Knowledge Development, education, public awareness training and information sharing. A Primer of Disaster Risk Management in Asia. Asian Disaster Preparedness Center. URL: http://www.adpc.net

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