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# MULTI-HAZARD RISK ASSESSMENT AND DECISION MAKING

**Abstract:** This section discusses the analysis of multi-hazards risk assessment and decision making. Although the term 'multi-hazards' has been used extensively in literature there are still very limited approaches to analyze the effects of more than one hazard in the same area, especially related to their interaction. The section starts with an overview of the problem of multi-hazard risk assessment, and indicates the various types of multi-hazard interactions, such as independent events, coupled events, concatenated events, and events changing the predisposing factors for other ones**.** The second part of this section discusses three methods for risk mapping: Quantitative risk assessment (QRA), Event-Tree Analysis (ETA), Risk matrix approach (RMA). Last, a case study on disaster risk preparedness and management is illustrated: Disaster risk management of cultural heritage site of Berat.

**Key words:** Multi-hazard, disaster, risk, assessment.

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# 1. PUTTING RISK INTO PERSPECTIVE

## Introduction

The earth is shaped by endogenic processes, caused by forces from within the earth, resulting in hazardous events like earthquakes or volcanic eruptions, and endogenic processes, caused by forces related to the earth's atmosphere, hydrosphere, geosphere, biosphere and cryosphere and their interactions. Anthropogenic activities have had a very important influence on a number of these processes, especially in the last two hundred years, for instance through the increase of greenhouse gasses, leading to global warming, but also through dramatic changes in the land cover and land use, and overexploitation of scarce resources. The above-mentioned processes from endogenic, exogenic and anthropogenic nature may lead to potentially catastrophic events, even in locations that may be far away. For instance, earthquakes might trigger landslides which may lead to landslide-dammed lakes that may break out and cause flooding downstream. Or the dams of large reservoirs in mountains, constructed for hydropower, irrigation or drinking water, may fail under an earthquake or extreme rainfall event and cause a similar flood wave.

These potentially harmful events are called hazards. They pose a level of threat to life, health, property, or environment. They may be classified in different ways, for instance according to the main origin of the hazard in geophysical, meteorological, hydrological, climatological, biological, extra-terrestrial and technological (See Table 1, from Guha-Sapir et al. 2016). Such classifications are always a bit arbitrary, and several hazard types could be grouped in different categories, e.g. landslides could be caused by earthquakes, extreme precipitation and human interventions.

Hazards have a number of characteristics that should be understood in order to be able to assess and subsequently reduce their potential damage. Hazards with certain magnitudes may occur with certain frequencies, as small events may occur often, and large events seldom. In order to be able to establish a magnitude-frequency relationship for hazard events, it is generally necessary to collect historical data (e.g. from seismographs, meteo-stations, stream gauges, historical archives, remote sensing, field investigations etc.) and carry out statistical analysis. The magnitude of the hazard gives an indication of the size of the event, or the energy released, whereas the intensity of a hazard refers to the spatially varying effects. For example, earthquake magnitude refers to the energy released by the ruptured fault (e.g. measured on the Richter scale) whereas the intensity refers to the amount of ground shaking which varies with the distance to the epicenter (e.g. measured on Modified Mercalli scale). The magnitude of floods may be measured as the discharge in the main channel at the outlet of a watershed before leaving the mountainous area, whereas the intensity may be measured as the water height or velocity which is spatially distributed, and depends on the local terrain.

These events may be potentially harmful to people, property, infrastructure, economy and activities, but also to the environment, which are all grouped together under the term Elements-at-risk or assets. Also, the term exposure is used to indicate those elements-at-risk that are subject to potential losses. Important elements-at-risk that should be considered in analyzing potential damage of hazards are population, building stock, essential facilities and critical infrastructure. Critical infrastructure consists of the primary physical structures, technical facilities and systems, which are socially, economically or operationally essential to the functioning of a society or community, both in routine circumstances and in the extreme circumstances of an emergency (UN-ISDR, 2009). Elements-at-risk have a certain level of vulnerability, which can be defined in a number of different ways. The general definition is that vulnerability describes the characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard (UN-ISDR, 2009). There are many aspects of vulnerability, related to physical, social, economic, and environmental conditions (see for example Birkmann, 2006). When considering physical vulnerability only, it can be defined as the degree of damage to an object (e.g. building) exposed to a given level of hazard intensity (e.g. water height, ground shaking, and impact pressure).

**Risk**

Risk is defined as 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 (UN-ISDR, 2009; EC, 2011). Risk can be presented conceptually with the following basic equation, indicated in Figure 1.

Risk = Hazard × Vulnerability × Amount of elements-at-risk

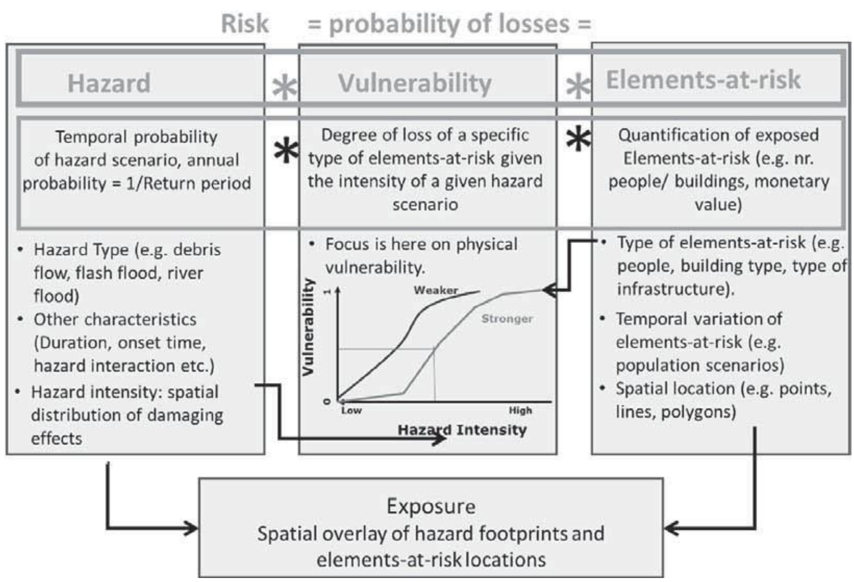



*Figure 1 – Schematic representation of risk as the multiplication of hazard, vulnerability and quantification of the exposed elements-at-risk. The various aspects of hazards, vulnerability and elements-at-risk and their interactions are also indicated. This framework focuses on the analysis of physical losses, using physical vulnerability data.*

*Table 1 – Classification of hazard types as used by the International Disaster Database EM-DAT (Guha-Sapir et al. 2016), which is based on and adapted from the he IRDR Peril Classification and hazard Glossary (IRDR, 2014).*

| Main Group | Main Sub-group | Main Type | Sub-Type |
|---|---|---|---|
| Natural | Geophysical: A hazard originating from solid earth. This term is used interchangeably with the term geological hazard. | Earthquake | Ground shaking, tsunami |
| | | Mass movement | |
| | | Volcanic | Ash fall, lahar, pyroclastic flow, lava flow |
| | Meteorological: A hazard caused by short-lived, micro- to meso-scale extreme weather and atmospheric conditions that last from minutes to days. | Storm | Extra-tropical storm, tropical storm, convective storm |
| | | Extreme temperature | Cold wave, heat wave, severe winter conditions |
| | | Fog | |
| | Hydrological: A hazard caused by the occurrence, movement, and distribution of surface and subsurface freshwater and saltwater. | Flood | Coastal flood, riverine flood, flash flood, ice jam flood. |
| | | Landslide | Avalanche (snow, debris), mudflow, rockfall |
| | | Wave action | Rogue wave, seiche |
| | Climatological: A hazard caused by long-lived, meso- to macro-scale atmospheric processes ranging from intra-seasonal to multi-decadal climate variability. | Drought | |
| | | Glacial Lake outburst | |
| | | Wildfire | Forest Fire, land fire (bush, pasture) |

| | | | |
|---|---|---|---|
| | Biological: A hazard caused by the exposure to living organisms and their toxic substances or vector-borne diseases that they may carry. Examples are venomous wildlife and insects, poisonous plants, and mosquitoes carrying disease-causing agents such as parasites, bacteria, or viruses (e.g. malaria). | Epidemic | Viral , bacterial, parasitic, fungal, prion disease |
| | | Insect infestation | Grasshopper, locust |
| | | Animal accident | |
| | Extraterrestrial: A hazard caused by asteroids, meteoroids, and comets as they pass near-earth, enter the Earth's atmosphere, and/or strike the Earth, and by changes in interplanetary conditions that effect the Earth's magnetosphere, ionosphere, and thermosphere. | Impact | |
| | | Space weather | Energetic particles, geomagnetic storm |
| Technological | Industrial accident | | Chemical spills, collapse, explosion, fire, gas-leak, poisoning, radiation, other |
| | Transport accident | | Air, road, rail, water |
| | Miscellaneous accident | | Collapse, explosion, fire, other. |

Table 2 gives a more in-depth explanation of the various components involved.

*Table 2 – Components of risk with respective definitions*

| Term | Definition |
|---|---|
| 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. |
| 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". |
| 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. |

The term risk mapping is often used as being synonymous with risk analysis in the overall framework of risk management. Risk assessments (and associated risk mapping) include: a review of the technical characteristics of hazards such as their location, intensity, frequency and probability; the analysis of exposure and vulnerability including the physical social, health, economic and environmental dimensions; and the evaluation of the effectiveness of prevailing and alternative coping capacities in respect to likely risk scenarios (UN-ISDR, 2009; EC, 2011; ISO 31000). In the framework of natural hazards risk assessment, the term risk mapping also indicates the importance of the spatial aspects of risk assessment. All components of the risk equation (Figure 1) are spatially varying and the risk assessment is carried out in order to express the risk within certain areas. To be able to evaluate these components there is a need to have spatially distributed information. Computerized systems for the collection, management, analysis and dissemination of spatial information, so-called Geographic Information Systems (GIS) are used to generate the data on the various risk components, and to analyze the risk.

Risk can be expressed in absolute or relative terms. Absolute population risk can be expressed as individual risk (the annual probability of a single exposed person to be killed) or as societal risk (the relation between the annual probability and the number of people that could be killed). Absolute economic risk can be expressed in terms of Average Annual Loss, Maximum Probable Loss, or other indices that are calculated from a series of loss scenarios, each with a relation between frequency and expected monetary losses (Jonkman et al. 2002). It is also possible to differentiate between direct risk (which is the risk directly resulting from the impact of the hazard) and indirect risk (which may occur later as a consequence of the direct impact). Some examples of direct risk are the destruction of physical objects (e.g. buildings, transportation infrastructure), and examples of indirect losses are loss of revenues and economic production, disruption of transportation networks leading to longer travel time etc. A significant component of the losses is intangible (difficult or impossible to quantify), for example the societal or psychological impact of disaster events.

**Multi-hazard risks**

One of the difficult issues in natural hazards risk assessment is how to analyze the risk for more than one hazard in the same area, and the way they interact. Figure 2 shows an illustration of how different sets- of triggering factors can cause a number of different hazards.

A generally accepted definition of multi-hazard still does not exist. In practice, this term is often used to indicate all relevant hazards that are present in a specific area, while in the scientific context it frequently refers to “more than one hazard”. Likewise, the terminology that is used to indicate the relations between hazards is unclear. Many authors speak of interactions, while others call them chains, cascades, domino effects, compound hazards or coupled events. Compared to single processes, standard approaches and methodological frameworks for multi-hazard risk assessment are less common in the literature, which is related to the complex nature of the interaction between the hazards, and the difficulty to quantify these.

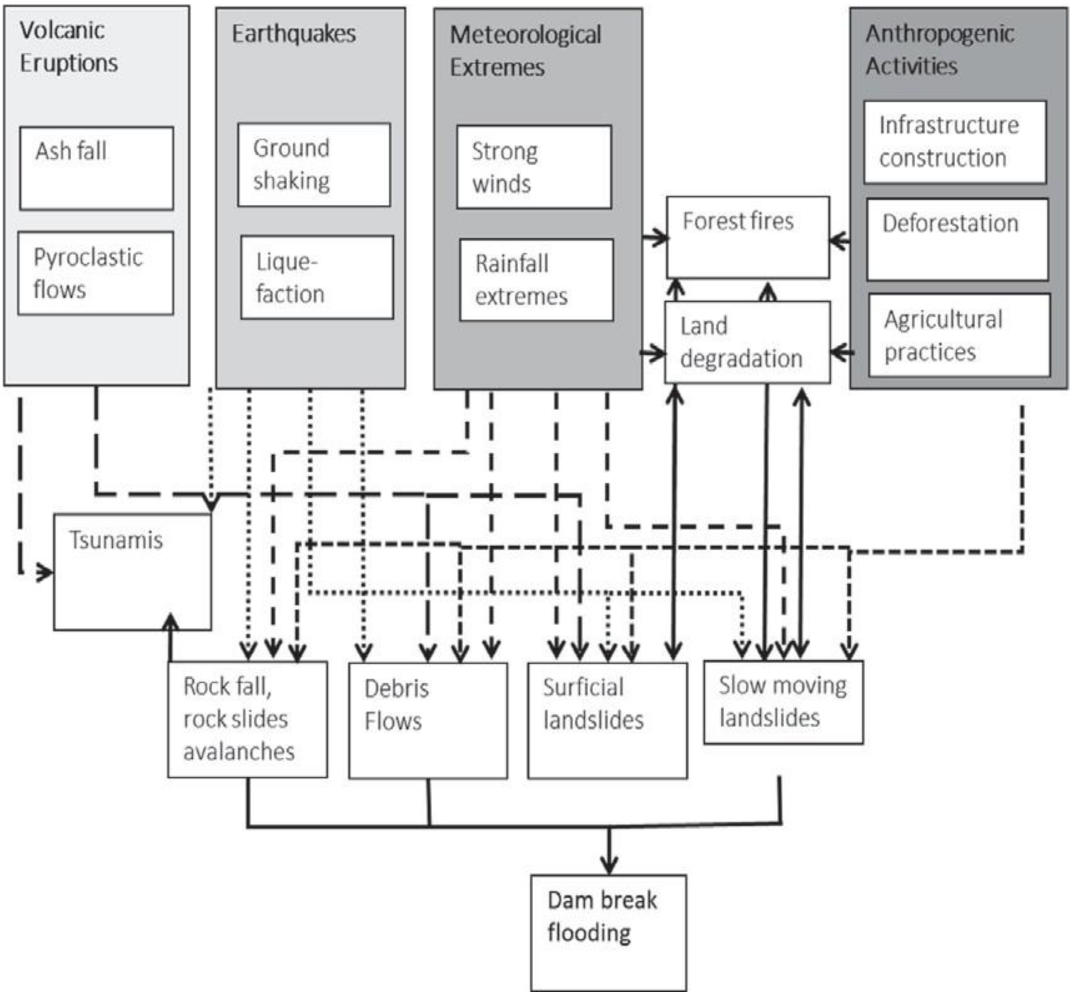



*Figure 2 – Schematic representation of multi-hazards interactions between the main triggering events (volcanic eruptions, Earthquakes, Meteorological extremes, and anthropogenic activities) and secondary hazards.*

## Independent Events

The simplest approach is to consider that the hazards are independent and caused by different triggers. This means that the expected losses from one hazard type are independent from the losses expected from the other hazard type. If that is the case, the risk can be calculated by adding the average annual losses for the different types of hazard. This would be the case for example for earthquake hazard and flood hazard. They have different triggering mechanisms, which do not directly interact. Therefore, earthquake hazard is independent of flood hazard and may be analyzed separately. Also, the risk may be analyzed separately, and the resulting losses could be added. Other examples of independent hazard are for instance technological hazards and flood hazards. Many of the existing tools for multi-hazard risk assessment deal with these hazard independently, and sum up the losses. However, when these apparent independences are examined in detail, the relation may be more complicated.

For instance, an earthquake may trigger landslides that may block a river leading to flooding, which makes that the earthquake and flood risk cannot be considered entirely independent.

**Coupled Events**

The second multi-hazard relationship is between different hazard types that are triggered by the same triggering event. These are what we would call coupled events (Marzocchi et al. 2009). The temporal probability of occurrence of such coupled events is the same as it is linked to the probability of occurrence of the triggering mechanism. For analyzing the spatial extent of the hazard, one should take into account that when such coupled events occur in the same area and the hazard footprints overlap, the processes will interact, and therefore the hazard modelling for these events should be done simultaneously, which is still very complicated.

When the hazard analyses are carried out separately, the consequences of the modelled scenarios cannot be simply added up, as the intensity of combined hazards may be higher than the sum of both or the same areas might be affected by both hazard types, leading to overrepresentation of the losses, and double counting. Examples of such types of coupled events is the effect of an earthquake on a snow-covered building (Lee & Rosowsky, 2006) and the triggering of landslides by earthquakes occurring simultaneously with ground shaking and liquefaction (Delmonaco et al. 2006b; Marzocchi et al. 2009). Within multi-hazard risk assessment, the best way to treat coupled risk is to take the maximum of the risks that are coupled. For example, during the same tropical storm a village may be hit by flash floods or debris flows. Once it is hit by one type there is damage, and buildings cannot be destroyed twice during the same event.

**One hazard changes conditions for the next**

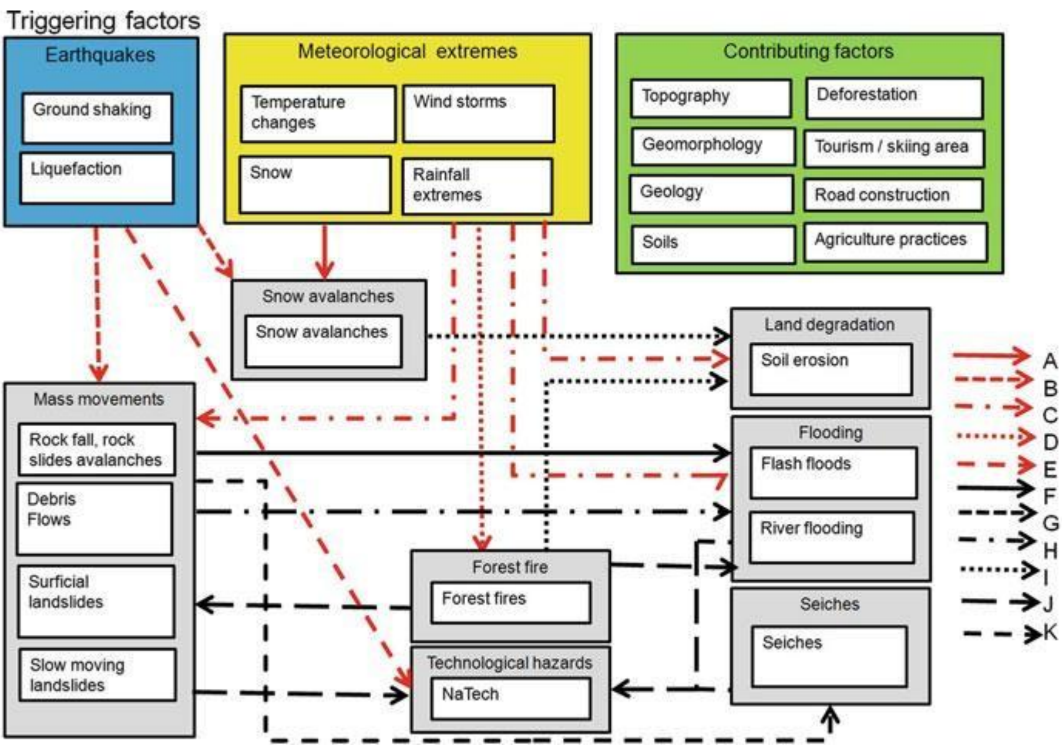
A third type of interrelations is the influence one hazard exerts on the disposition of a second hazard, though without triggering it (Kappes et al. 2010). An example is the “fire-flood cycle” (Cannon & De Graff, 2009): forest fires alter the susceptibility to debris flows and flash floods due to their effect on the vegetation and soil properties.

For instance, volcanic eruptions may lead to the deposition of volcanic ash, which will increase the susceptibility to landslides and flooding. Earthquakes may trigger landslides, and the landslide scars that are unvegetated may lead to increased erosion and debris flows. It is very difficult to take this type of relationship into account before one particular hazard has changed the conditions that make the terrain more susceptible to the second hazard. The practice is to update a multi-hazard risk assessment each time after the occurrence of a major hazard event (like a volcanic eruption, major earthquake or hurricane).

## Domino or cascading hazards

The fourth type of hazard relationships consists of those that occur in chains: one hazard causes the next. These are also called domino effects, concatenated, or cascading hazards. These are the most problematic types to analyze in a multihazard risk assessment. Hazard may occur in sequence, where one hazard may trigger the next. These hazard chains or domino effects are extremely difficult to quantify over certain areas, although good results have been obtained at a local level (e.g. Peila & Guardini, 2008). The best approach for analyzing such hazard chains is to use so-called event-trees (See section 2.2). However, it is often very difficult to apply such event-trees in a spatial manner, where in fact different parts of an area may require different event-trees. Table 3 shows the multi-hazard in a mountainous environment, and their interrelationships.

*Table 3 – Multi-hazard in a mountainous environment, and their interrelationships. Above the triggering factors are indicated (earthquakes, meteorological extremes), and the contributing factors. The red arrows indicate the hazards triggered simultaneously (coupled hazards). The black arrows indicate the concatenated hazards: one hazard causing another hazard over time.* ***(a)*** *Snow accumulation causing snow avalanches,* ***(b)*** *Earthquakes triggering landslides and snow avalanches simultaneously,* ***(c)*** *extreme precipitation causing landslides, debris flows, flooding and soil erosion,* ***(d)*** *drought and/or lightning causing forest fires,* ***(e)*** *earthquakes causing technological hazards,* ***(f)*** *landslides and debris flows damming rivers and causing dam break floods,* ***(g)*** *large rapid landslides or rockfalls in reservoirs causing water floods,* ***(h)*** *debris flows turning into floods in the downstream torrent section;* ***(i)*** *snow avalanches or forest fires leading to soil erosion,* ***(j)*** *forest fires leading to surficial landslides, debris flows and flash floods,* ***(k)*** *landslides, debris flows or floods leading to technological hazards.*



## 2. RISK ANALYSIS APPROACHES

Risk assessment is a process to determine the probability of losses by analyzing potential hazards and evaluating existing conditions of vulnerability that could pose a threat or harm to property, people, livelihoods and the environment on which they depend (UN-ISDR, 2009). ISO 31000 (2009) defines risk assessment as a process made up of three processes: risk identification, risk analysis, and risk evaluation.

Risk identification is the process that is used to find, recognize, and describe the risks that could affect the achievement of objectives. Risk analysis is the process that is used to understand the nature, sources, and causes of the risks that have been identified and to estimate the level of risk. It is also used to study impacts and consequences and to examine the controls that currently exist. Risk evaluation is the process that is used to compare risk analysis results with risk criteria in order to determine whether or not a specified level of risk is acceptable or tolerable.

Risk mapping for natural hazard risk can be carried out at a number of scales and for different purposes. Table.4 and Figure 3 give a summary. In the following sections four methods of risk mapping will be discussed: Quantitative risk assessment (QRA), Event-Tree Analysis (ETA), Risk matrix approach (RMA) and Indicator-based approach (IBA).

*Table 4- Indication of scales of analysis with associated objectives and data characteristics.*

| Scale of Analysis | Scale | Possible Objectives | Possible Approaches |
|---|---|---|---|
| International, Global | <1:1 million | Prioritization of countries/ regions; Early warning | Simplified RMA & IBA |
| Small: provincial to national scale | <1:100,000 | Prioritization of regions; Analysis of triggering events; Implementation of national programs; Strategic environmental assessment; Insurance | Simplified EVA, RMA & IBA |
| Medium: municipality to provincial level | 1:100000 to 1:25000 | Analyzing the effect of changes; Analysis of triggering events; Regional development plans | RMA/IBA |
| Local: community to municipality | 1:25000 to 1:5000 | Land use zoning; Analyzing the effect of changes; Environmental Impact Assessments; Design of risk reduction measures | QRA/EVA/ RMA IBA |
| Site-specific | 1:5000 or larger | Design of risk reduction measures; Early warning systems; detailed land use zoning | QRA/EVA/ RMA |

*Approaches:* QRA = Quantitative risk assessment, EVA = Event-Tree Analysis, RMA = Risk matrix approach, IBA = Indicator-based approach.

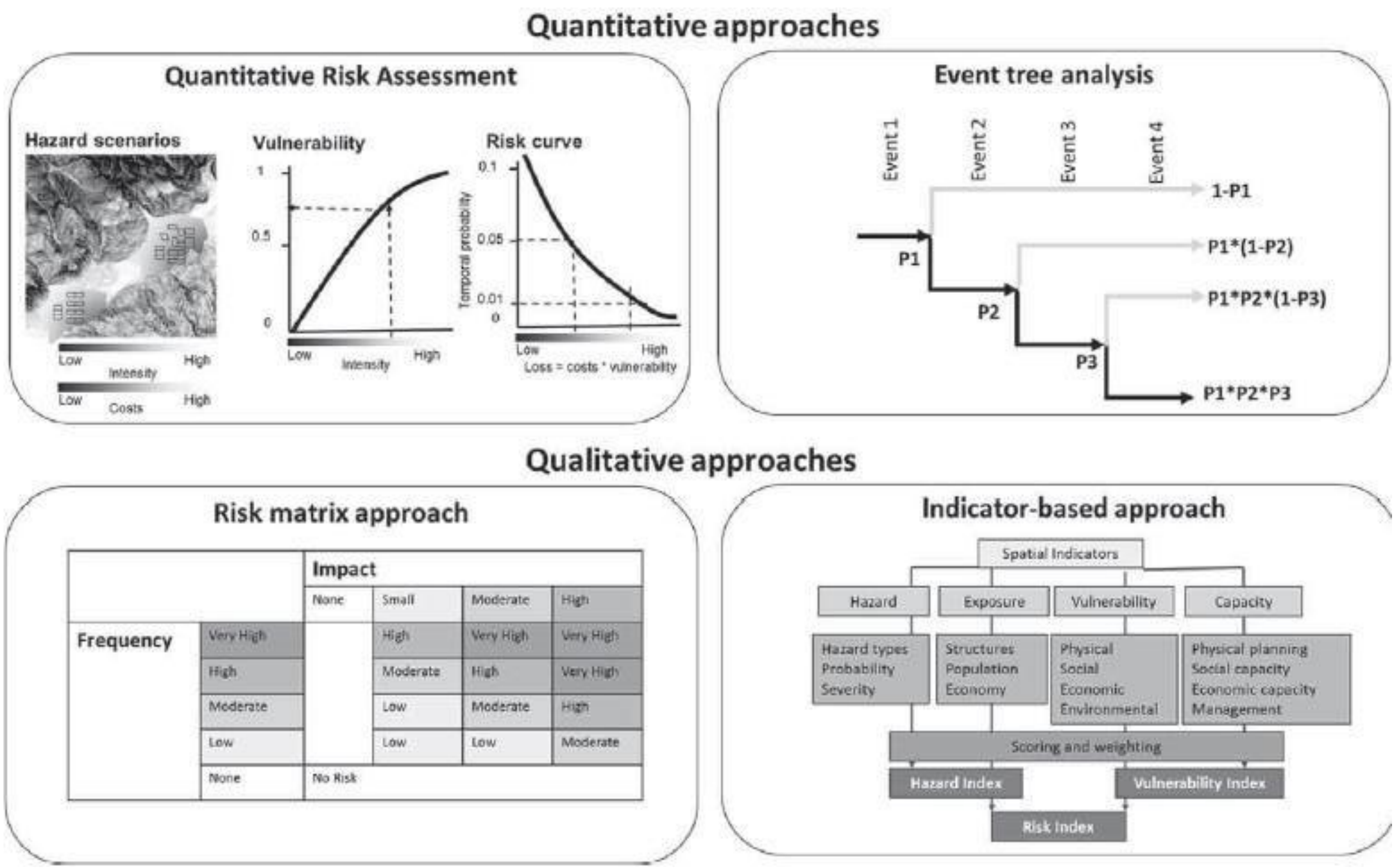



*Figure 3 – Components relevant for risk assessment, and the four major types of risk mapping that are presented in this section*

### Quantitative risk assessment

If the various components of the risk equation can be spatially quantified for a given set of hazard scenarios and elements-at-risk, the risk can be analyzed using the following equation:

$$\text{Risk} = \sum_{\text{All hazards}} \left( \int_{P_T=0}^{P_T=1} P_{(T|HS)} \times \left( \sum_{\text{All EaR}} \left( P_{(S|HS)} \times \left( A_{(ER|HS)} \times V_{(ER|HS)} \right) \right) \right) \right)$$

In which:

P(T/HS) = the temporal probability of a certain hazard scenario (HS). A hazard scenario is a hazard event of a certain type (e.g. flooding) with a certain magnitude and frequency;

P(S/HS) = the spatial probability that a particular location is affected given a certain hazard scenario;

A(ER/HS) = the quantification of the amount of exposed elements-at-risk, given a certain hazard scenario (e.g. number of people, number of buildings, monetary values, hectares of land) and

V(ER/HS) = the vulnerability of elements at risk given the hazard intensity under the specific hazard scenario (as a value between 0 and 1).

The method is schematically indicated in Figure 4. GIS operations are used to analyze the exposure as the intersection between the elements-at-risk and the hazard footprint area for each hazard scenario. For each element-at-risk also the level of intensity is recorded through a GIS-overlay operation. These intensity values are used in combination with the element-at-risk type to find the corresponding vulnerability curve, which is then used as a lookup table to find the vulnerability value. The way in which the amount of elements-at-risk are characterized (e.g. as number of buildings, number of people, economic value) also defines the way in which the risk is calculated. The multiplication of exposed amounts and vulnerability should be done for all elements-at-risk for the same hazard scenario.

The results are multiplied with the spatial probability that the hazard footprint actually intersects with the element-at-risk for the given hazard scenario P(S/HS) to account for uncertainties in the hazard modelling. The resulting value represents the losses, which are plotted against the temporal probability of occurrence for the same hazard scenario in a so-called risk curve. This is repeated for all available hazard scenarios. At least three individual scenarios should be used, although it is preferred to use at least 6 events with different return periods (FEMA, 2004) to better represent the risk curve. The area under the curve is then calculated by integrating all losses with their respective annual probabilities. It is possible to create risk curves for the entire study area, or for different spatial units, such as administrative units, census tracks, road or railway sections etc.

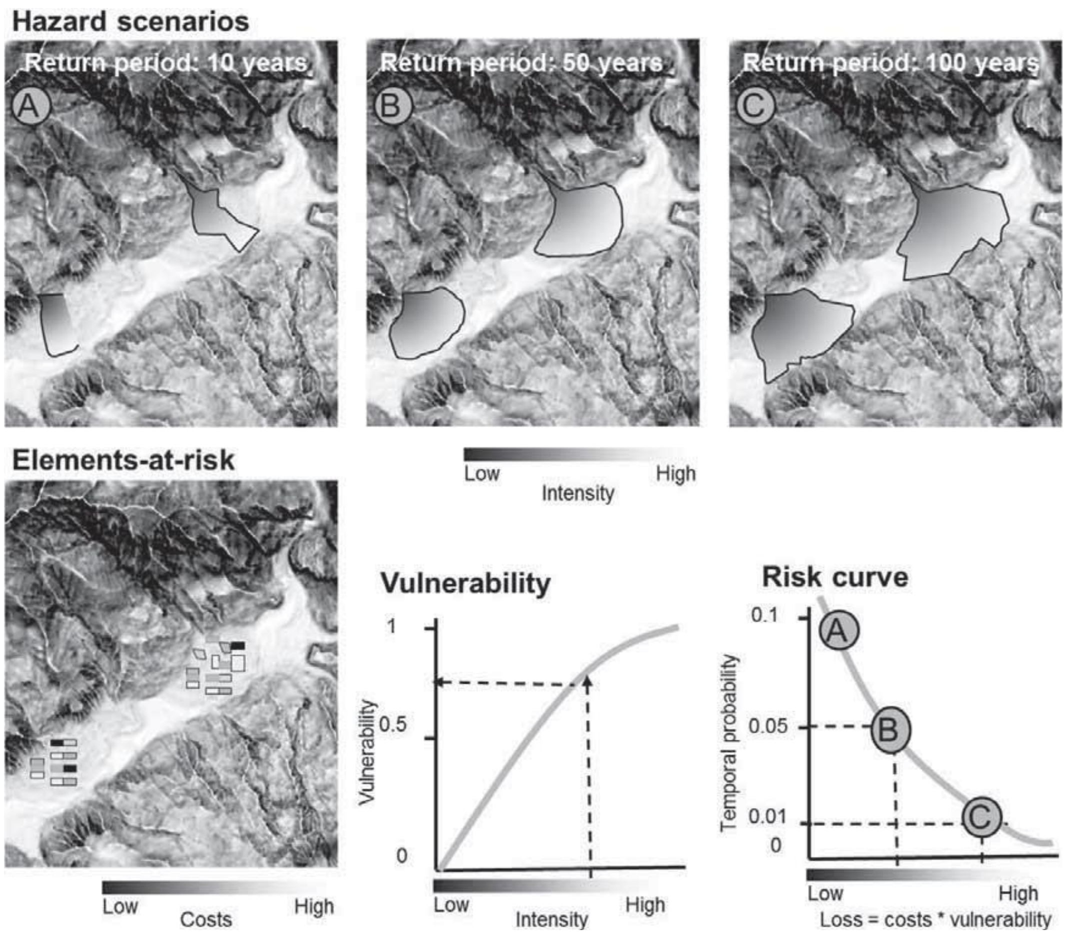



*Figure 4 – Schematic representation of Quantitative Risk Assessment.*

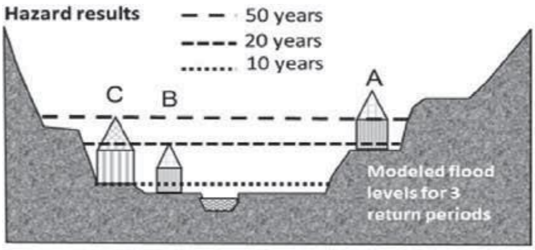
Figure 5 gives an example of a quantitative risk assessment. In this simple example we are taking a flood situation. The figure shows a cross section through a flood plain. There are three hazard scenarios, which have been modelled using a flood model. They have different return periods (10 years, 20 years and 50 years).

In this simple example there are 3 elements at risk only (buildings) that are of two types. Building A and building B are wooden and relatively weak buildings. They have also lower replacement values. They are located in different elevations. Building C is a concrete building, which is stronger. It is also located at a higher elevation than building B. It is also larger and more expensive. In the exposure analysis, there is overlaying the flood heights with the building heights and the water height is calculated for each hazard scenario and for each building. For the 10 years return period, building A is not flooded, and building C only 0.1 meter. For the 20-year return period, all buildings are flooded, but with different degrees. For the 50-year return period, all buildings are flooded, building B and C very much. For the vulnerability analysis, there is a need for vulnerability curves, which are related for each type of building the degree of loss to a building with a given water height.

These curves are generated from past event damage assessment, by correlating the water height with damage. For example: building B has an exposed intensity of 5.6 for the scenario of 20 years return period. And it is a wooden building, so we take the value of 5.6 on the X-axis of the vulnerability curve, representing the flood depth. Because it is a wooden building, the curve for the wooden buildings is looked up, and then the damage value on the y-axis is read. This is done for all buildings and for all return periods. The replacement values (amount) are filled in, and the replacement values (amount) are multiplied with the vulnerability to calculate losses. The losses for the buildings are summed up for the same hazard scenario (return period). The annual probability is calculated: 1 divided by the return period. The probability is plotted for each scenario against the losses, and fit a curve through the points, which links all probabilities with all losses. The area below the curve represents the Average Annual Losses. It is the integration of all losses over all probabilities.

**Event tree Approach**

As mentioned in previously a number of hazards may occur in chains: these are also called domino effects, or concatenated hazards. These are the most problematic types to analyze in a multi-hazard risk assessment. The best approach for analyzing such hazard chains is to use so-called event-trees. An event tree is a system, which is applied to analyze all the combinations (and the associated probability of occurrence) of the parameters that affect the system under analysis. All the analyzed events are linked to each other by means of nodes (See Figure 3) all possible states of the system are considered at each node and each state (branch of the event tree) is characterized by a defined value of probability of occurrence. Figure 6 gives an example of an event tree for a situation where a rockfall in a lake may trigger a flood wave that would impact a village (from Lacasse et al. 2008).



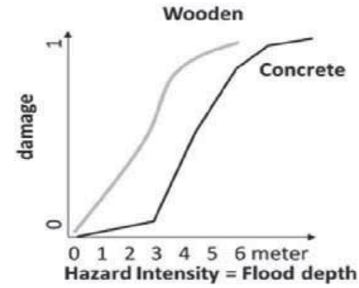

**Exposure results**

| House | 10 years | 20 years | 50 years |
|---|---|---|---|
| A (wood) | 0 | 0.8 | 2.0 |
| B (wood) | 1.2 | 5.6 | 6.8 |
| C (concrete) | 0.1 | 4.5 | 5.7 |

**Vulnerability results**

| | Return Period | Vulnerability |
|---|---|---|
| A | 10 | 0 |
| B | 10 | 0.2 |
| C | 10 | 0.05 |
| A | 20 | 0.1 |
| B | 20 | 1 |
| C | 20 | 0.5 |
| A | 50 | 0.4 |
| B | 50 | 1 |
| C | 50 | 0.8 |

**Vulnerability curves**

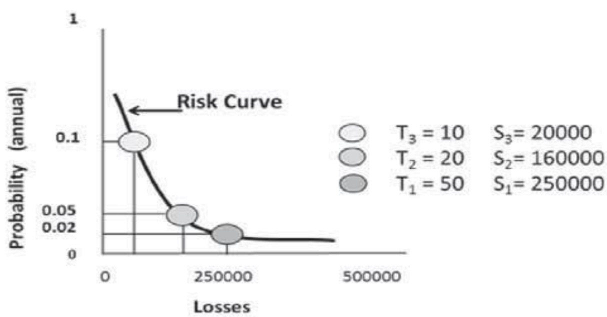



**Loss calculation results**

| | Return Period | Vulnerability | Amount | V*A (loss) | Aggregate loss | Probability |
|---|---|---|---|---|---|---|
| A | 10 | 0 | 100000 | 0 | 20000 | 0.1 |
| B | 10 | 0.2 | 50000 | 10000 | | |
| C | 10 | 0.05 | 200000 | 10000 | | |
| A | 20 | 0.1 | 100000 | 10000 | 160000 | 0.05 |
| B | 20 | 1 | 50000 | 50000 | | |
| C | 20 | 0.5 | 200000 | 100000 | | |
| A | 50 | 0.4 | 100000 | 40000 | 250000 | 0.02 |
| B | 50 | 1 | 50000 | 50000 | | |
| C | 50 | 0.8 | 200000 | 160000 | | |

**Risk curve**

| | Aggregate loss | Probability |
|---|---|---|
| A | 20000 | 0.1 |
| B | | |
| C | | |
| A | 160000 | 0.05 |
| B | | |
| C | | |
| A | 250000 | 0.02 |
| B | | |
| C | | |




**Average Annual Risk: Area under curve**

$$\text{Average Annual Risk} = \frac{1}{T_1}\cdot S_1 + \left(\frac{1}{T_2}-\frac{1}{T_1}\right)\cdot\frac{S_1+S_2}{2} + \left(\frac{1}{T_3}-\frac{1}{T_2}\right)\cdot\frac{S_2+S_3}{2}.$$

*Figure 5 – Schematic presentation of the steps involved in quantitative risk analysis. See text for explanation.*

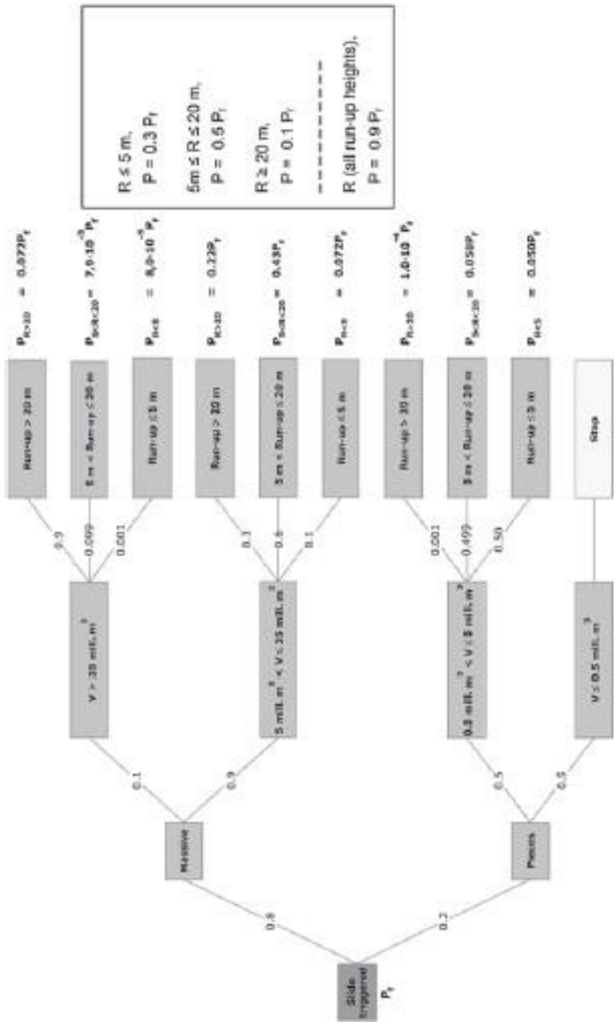



*Figure 6 – Bayesian Event tree for tsunami propagation, given that rock slide in Åknes has occurred (V = rockslide volume, R = run-up height). From Lacasse et al. (2008).*

### Risk matrix approach

Risk assessments are often complex and do not allow to develop a full numerical approach, since many aspects are not fully quantifiable or have a very large degree of uncertainty. This may be related to the difficulty to define hazard scenarios, map and characterize the elements-at-risk, or define the vulnerability using vulnerability curves. In order to overcome these problems, the risk is often assessed using the so-called risk matrices or consequences-frequency matrices (CFM), which are diagrams with consequence and frequency classes on the axes (See Figure 3).

They permit to classify risks based on expert knowledge with limited quantitative data. The risk matrix is made of classes of frequency of the hazardous events on one axis, and the consequences (or expected losses) on the other axis. Instead of using fixed values, the use of classes allows for more flexibility and incorporation of expert opinion. Such methods have been applied extensively in natural hazard risk assessment, e.g. in Switzerland (Figure 7 from Jaboyedoff et al. 2014). This approach also permits to visualize the effects and consequences of risk reduction measures and to give a framework to understand risk assessment (See Figure 7). The system depends on the quality of the group of experts that are formed to identify the hazard scenarios, and that carry out the hazard filtering and ranking in several sub-stages characterized by frequency (probability) and impact classes and their corresponding limits (Haimes, 2008).

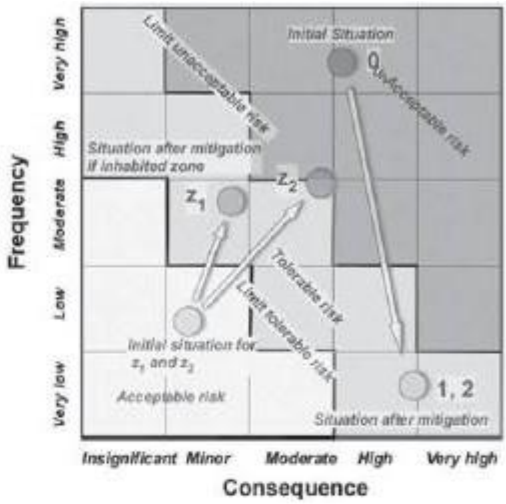



*Figure 7 – The approach permits to visualize the effects and consequences of risk reduction measures and to give a framework to understand risk assessment*

### Which Method to Choose?

The four methods for risk assessment that were treated in the previous sections all have certain advantages and disadvantages, which are summarized in Table 4. The Quantitative Risk Assessment method is the best for evaluating several alternatives for risk reduction, through a comparative analysis of the risk before and after the implementation followed by a cost-benefit analysis. The event-tree analysis is the best approach for analyzing complex chains of events and the associated probabilities.

Qualitative methods for risk assessment are useful as an initial screening process to identify hazards and risks. They are also used when the assumed level of risk does not justify the time and effort of collecting the vast amount of data needed for a quantitative risk assessment, and where the possibility of obtaining numerical data is limited. The risk matrix approach is often the most practical approach as basis for spatial planning, where the effect of risk reduction methods can be seen as changes in the classes within the risk matrix. The decision depends among other factors in particular from the spatial scale of the project, plan or program, the risk assessment was done for (see Table 4). In this context, the subsidiarity principle plays a considerable role. Art. 5 § 2 of the Strategic Environmental Assessment Directive (2001/42/EC) lays down: “The environmental report […] shall include […] the level of detail in the plan or programme, its stage in the decision-making process and the extent to which certain matters are more appropriately assessed at different levels in that process in order to avoid duplication of the assessment.”

## 3. CASE STUDY: DISASTER RISK PREPAREDNESS AND MANAGEMENT OF BERAT

### Brief history of Berat; Attributes and Values as a cultural heritage site

Berat is inscribed as a rare example of an architectural character typical of the Ottoman period. Located in center Albania, Berat bears witness to the coexistence of varies religious and cultural communities down the centuries. It features a castle, locally known as the Kala, most of which was built in the 13th century, although its origins date back to the 4th century BC. The citadel area numbers many Byzantine churches, mainly from the 13th century, as well as several mosques built under Ottoman era which began in 1417.

Attributes and Values:

1. *Architecture*: **a)** Byzantine Churches (architectural, artistic, Christian and spiritual tradition preserved, historic, education value); **b)** Mosques build under the Ottoman era (architectural, spiritual tradition, historic); c) Fortifications (archaeological, architectural, historic); **d)** Vernacular buildings (ottoman architecture, social, functional values, continuously inhabited, economic)
2. *Coexistence* (combination of various religious and cultural traditions)
3. *Artisan tradition* (artistic, craft values)
4. *Urban heritage* (diversity of urban societies, landscape, lifestyle)
5. Landscape (environment values, geological value).

### Stakeholder involvement in DRM plan

The stakeholders involved in DRM plan are:

- Municipality of Berat
- Regional Directorate of national Culture
- Institute of Culture Monuments
- CEZ
- Ministry of Tourism, Culture, Youth and Sports

*Table 4 – Advantages and disadvantages of the four risk assessment methods discussed*

| Method | Advantages | Disadvantages | Suitability for Specific Spatial Scales |
|---|---|---|---|
| Quantitative risk assessment (QRA) | Provides quantitative risk information that can be used in Cost-benefit analysis of risk reduction measures. | Very data demanding. Difficult to quantify temporal probability, hazard intensity and vulnerability. | Normally used as basis for investments in structural mitigation measures on project level |
| Event-tree analysis | Allow modelling of a sequence of events, and works well for domino effects | The probabilities for the different nodes are difficult to assess, and spatial implementation is very difficult due to lack of data. | Normally used as basis for plan approval procedures of dangerous facilities (e.g. nuclear power plants, chemical establishments) on project level |
| Risk matrix approach | Allows to express risk using classes instead of exact values, and is a good basis for discussing risk reduction measures. | The method doesn't give quantitative values that can be used in cost-benefit analysis of risk reduction measures. The assessment of impacts and frequencies is difficult, and one area might have different combinations of impacts and frequencies. | Basis for hazard zoning in many countries like Austria France, Italy and Switzerland. Good fit for regional and local spatial planning as basis for keeping hazard prone areas free of further development |

- Police of Fire Protection and Rescue
- Ministry of Interior Affairs
- Directorate of Museums
- Directorate of Water Supply
- Prefecture of Berat (Emergency Unit)
- Regional District of Berat
- Drainage Board
- Directorate of Forests
- Red Cross
- Citizens Forum
- Chamber of Commerce
- Directorate of Public Health
- Military Division of Berat
- Police Station
- ASHA
- Agency of Environment
- UNESCO office

## Analysis

### Hazard and Vulnerability Identification

*Immediate hazards:*

- **Fire**:

Vulnerabilities to cope immediately:

- Lack of improper functioning of the existing hydrants;
- On air electric lines and worn out electric installations inside the houses;
- Narrow streets and alleys that make it difficult for fire suppression vehicles to pass through;
- Lack of 24 hours water supply;
- Lack of electric and fire projects for the houses;
- Lack of fire suppressions equipment installed in the neighborhood;
- Abandonment and lack of maintenance;
- Lack of awareness.

Other Vulnerabilities:

- Lack of smoke detectors, manual and automatic fire suppression equipment inside the houses;
- Materials, wood constructions, carpets;
- Vegetation growth;
- Scattered garbage;

- Nearness of trees;
- Lack of water collecting areas;
- Lack of evacuation exits;
- Alarms not connected to the fire departments;
- Lack of awareness;
- Lack of fire management plans during restoration;
- Lack of drills;
- Lack of citizen training;
- Water cisterns inside traditional houses not in use;
- Abandoned houses;
- Lack of space for immediate interventions;
- Lack of storage for works of art, etc.;
- Improper measures for visitors;
- Poor security.

- **Rock Fall**
  - Poor drainage system;
  - Unstable hilly rocks;
  - Unconsolidated hilly slopes;
  - No protection against the falling rocks;
  - Soft composition of rocks;
  - Not a thorough seismic and geological research;
  - Lack of funds;
  - Civilian houses are near;
  - The site overlooks the main road;
  - Scarceness of trees spread on the hill.
- Land Slide
  - Lack of drainage system;
  - Poor wall construction;
  - Unstable construction;
  - Unconsolidated hilly slopes;
  - Nearness of houses, people living near or on the slopes;
  - Scarceness of trees spread on the hill;
  - Lack of sewage system for the houses build recently.
- **Floods/Rainfall**
  - Level of discharging pipes is not high enough in the river;
  - Lack of collector;
  - Poor drainage system;
  - Poor condition of the houses;
  - Lack of river embankments;
  - Lack of dams;
  - Lack of maintenance for the river bed;

- Lack of maintenance for heritage assets such as buildings;
- Lack of training;
- Exposed electric cables;
- Nearness of trees;
- Difficult terrain.

- **Earthquakes**

  - Lack of seismic micro zonation
  - Unconsolidated buildings and fortification walls
  - Materials (for example different stages of restorations)
  - Nearness of houses
  - Electrical and telephonic lines are exposed
  - Unstable hilly rocks
  - Lack of space for immediate interventions
  - Abandoned houses
  - Location related to mountains (geographic positioning)
  - Lack of signage for evacuation
  - Lack of river embankments
  - Illegal building interventions
  - Nearness of trees to the walls

*Other hazards:*

- Progressive deterioration
- Abandonment
- Improper restauration
- Little control on buffer zone

**Scenario: a monument house in fire**

Gorica quartier; a museum house of category II near the Saint Church of Saint Spiridon which is a Category I (Figure 8). This house is divided between two owners: one belongs to Scott Logan and the other belongs to Vali Prifti. Vali Prifti doesn't live in the building for years, while Scott Logan does.

Vali Prifti's part has undergone these damages due to abandonment:

- Roof has fallen in;
- Moisture;
- Damaged wall structure (Cracks);
- Weakened foundations;
- Floor has given in.

These have damaged the other part of the house:

- Damaged roof;
- Moisture

- Damaged wall;
- Foundations weakened.

The situation makes the house vulnerable to hazards. The house is vulnerable to fires, earthquake and heavy rain. There is a hole in the roof of the abandoned house through which water flows in freely. There is heavy rain and large amount of water gets through the wall. The water penetrates in the other house and reaches the electric spine causing immediate fire (Figure 9). There are not fire detection and fire suppression equipment. The inhabitants notice the fire late because the disaster is taking place in the bedrooms. The fire spreads rapidly through the wooden structures of the second floor and spreads in the source house as well as in the surrounding area which has high vegetation. The house is a hostel, and tourists might have endangered with a high economic impact. The houses have little compartmentation and the fire has little chance of being suppressed. There is a high possibility that the fire might reach the power pole and the other houses which are very close (Figure 10).

The Firemen are notified late and there is already some damage done when they arrive. The terrain makes it difficult for officials to arrive with a vehicle at the place. Because the houses are very close to each other, the firemen have difficulty in limiting the fire only within the damaged area. There are no hydrants near.

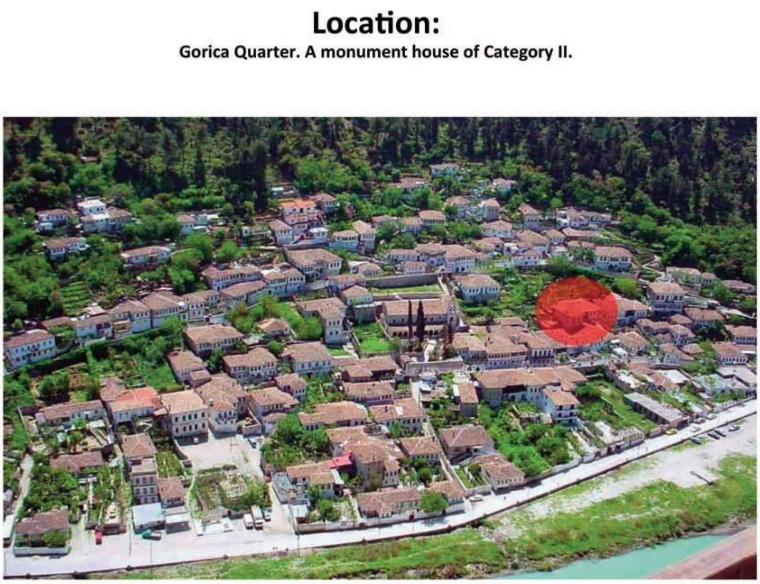
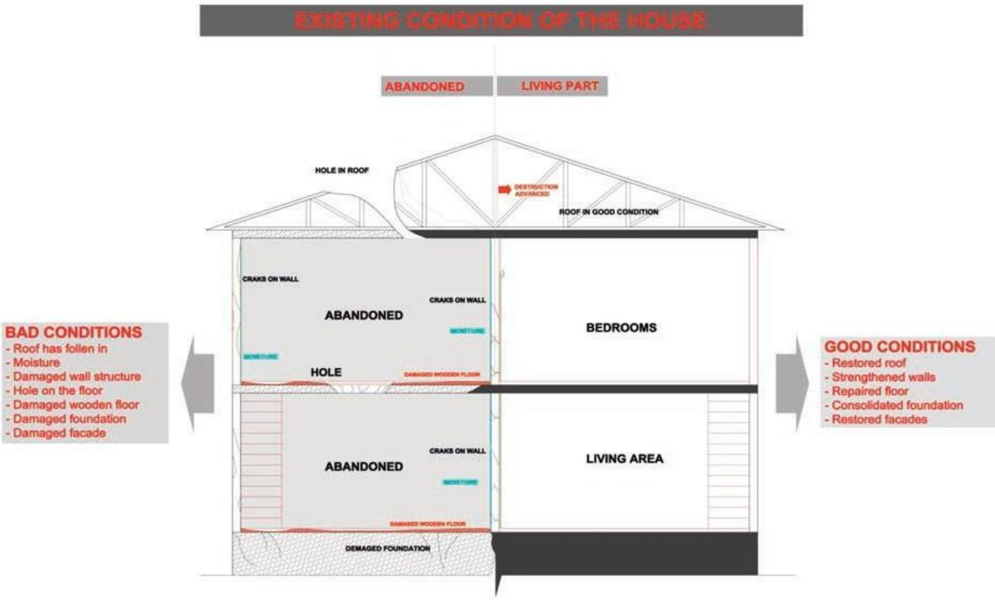
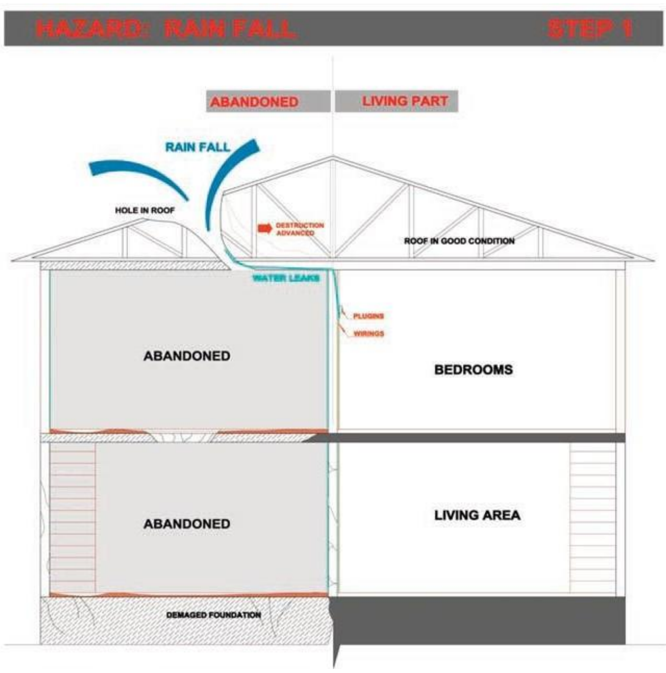
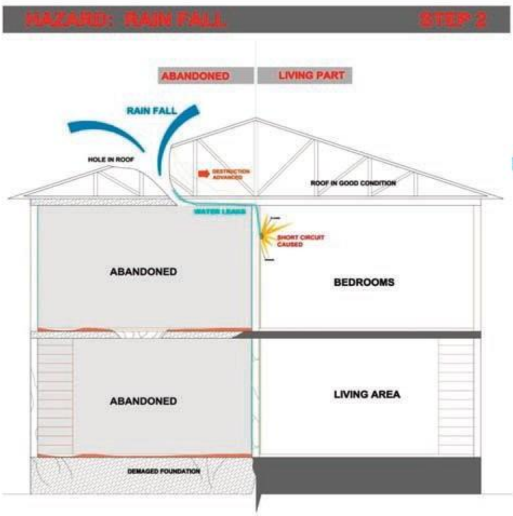


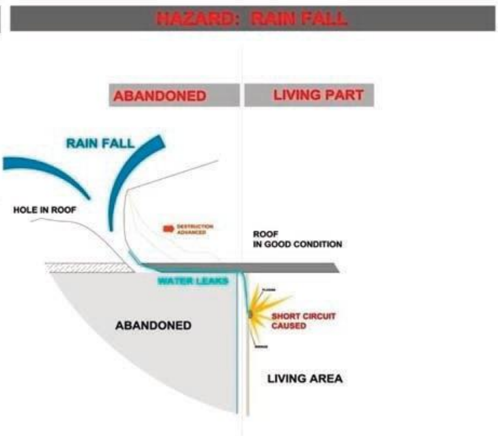

*Figure 8 – Location of the monument house*

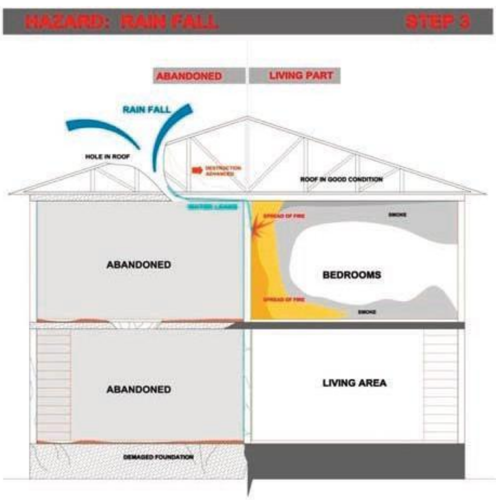
## Scheme of Scenario

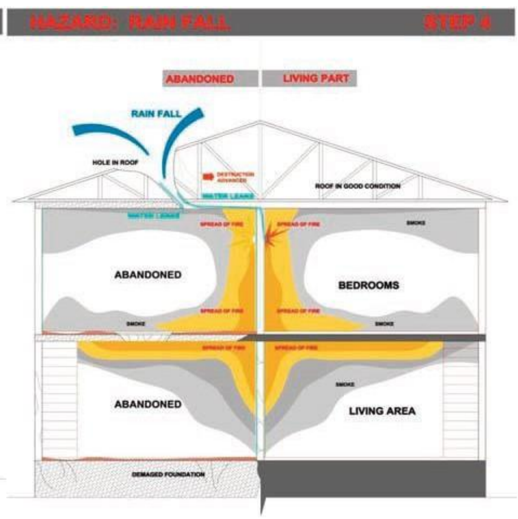



HAZARD: RAIN FALL
STEP 2
ABANDONED
LIVING PART
RAIN FALL
HOLE IN ROOF
ROOF IN GOOD CONDITION
WATER LEAKS
SHORT CIRCUIT CAUSED
ABANDONED
BEDROOMS
ABANDONED
LIVING AREA
DEMAGED FOUNDATION


HAZARD: RAIN FALL
ABANDONED
LIVING PART
RAIN FALL
HOLE IN ROOF
DESTRUCTION ADVANCED
ROOF
IN GOOD CONDITION
WATER LEAKS
SHORT CIRCUIT
CAUSED
ABANDONED
LIVING AREA


HAZARD: RAIN FALL
STEP 3
ABANDONED
LIVING PART
RAIN FALL
HOLE IN ROOF
ROOF IN GOOD CONDITION
ABANDONED
BEDROOMS
ABANDONED
LIVING AREA
DEMAGED FOUNDATION


HAZARD: RAIN FALL
STEP 4
ABANDONED
LIVING PART
RAIN FALL
HOLE IN ROOF
ROOF IN GOOD CONDITION
ABANDONED
BEDROOMS
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LIVING AREA
DEMAGED FOUNDATION

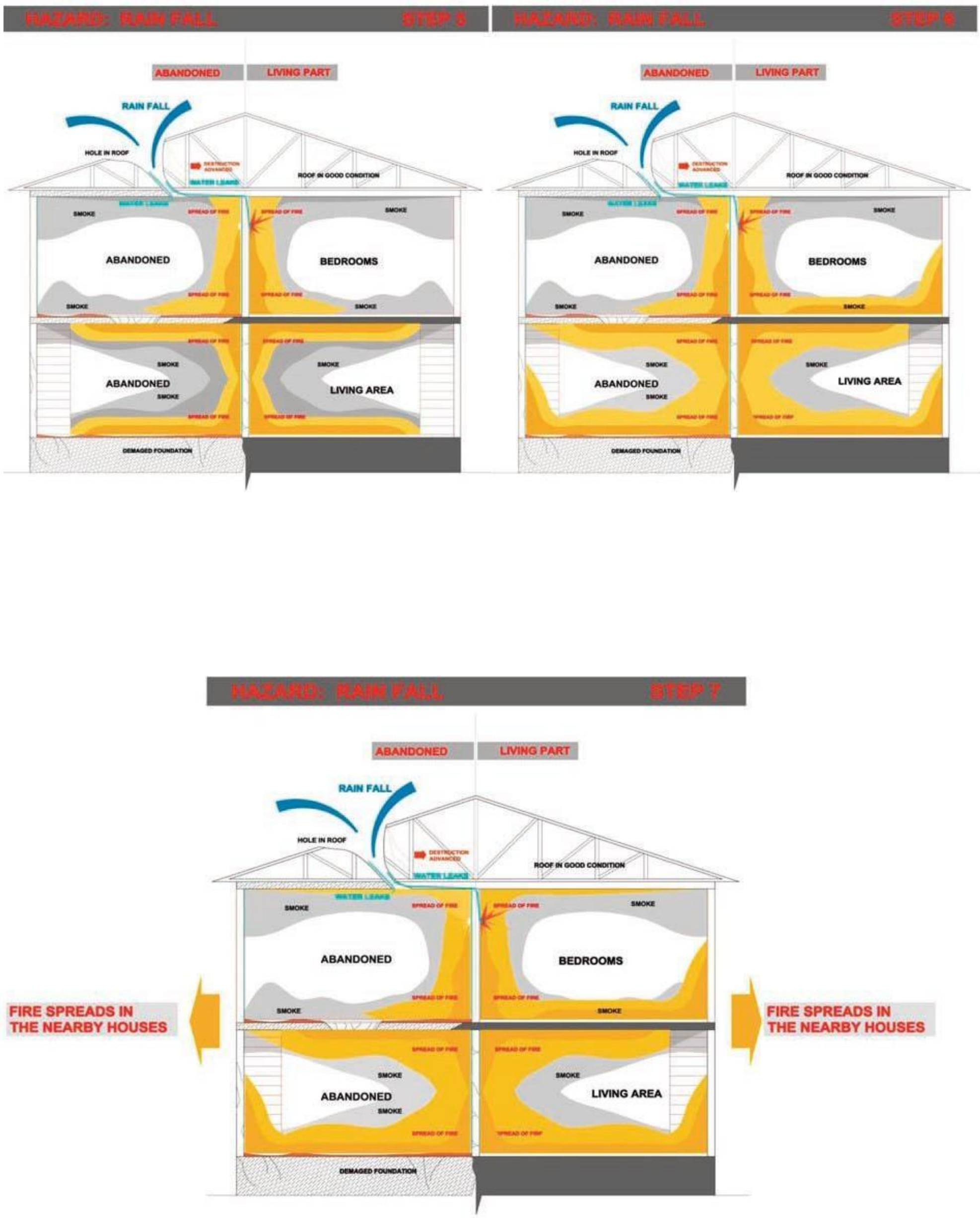


*Figure 9 – Scheme of Scenario*

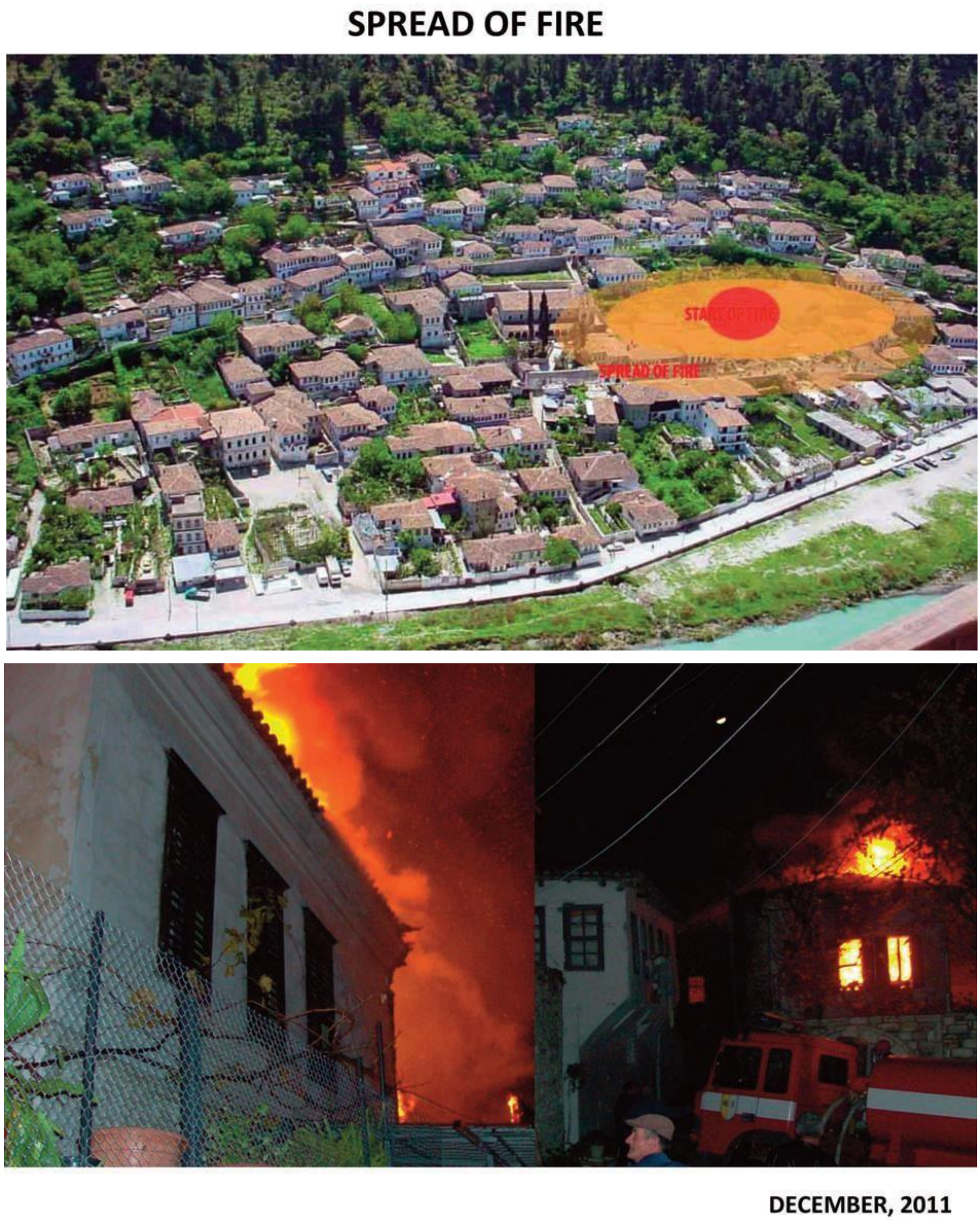


*Figure 10 – Spread of Fire*

**Prevention and mitigation**

Mitigation and preparedness measures can help reducing disaster risk from hazards and vulnerability on the site.

- Documentations and inventory of each monument in the site in details will help in preparing the evacuation plan.
- Improvement of the Electrical System on site
- Systems of Hydrants
- Alarm Systems
- Strong and clear legislation that protects from any improper intervention
- Maintenance of the green areas; Vegetation
- The regular collection of garbage
- Evacuation plan

**Emergency preparedness and response**

*Emergency equipment*

- Extinguishers will be placed near the areas that are dense with houses and that are easily accessed by people in case of emergency
- Smoke alarms will be placed inside the houses
- CCTV-s will be placed on the roof of the church and on Tabaya tower (risk of theft)
- Water from the pipes will be in the form of rain and will not have high pressure to damage the heritage structure
- The hoses will be connected to hydrant positioned on the lower and upper roads

*Evacuation plan*

- The house has two doors and a garden that can be easily crossed. People will exit from the door on the back and will be gathered on the school in the southeastern part of the quarter;
- The shortest way for pedestrian and transport of the heritage assets is to the back for the house;
- The emergency vehicles will take the road on the west
- Team members will protect the three doors from theft and one guard will stay on the garden
- The fireman will provide many barrels to transport the injured people.

**Recovery and Rehabilitation**

- Short term
  - Damage Assessment
  - Inspect the structural stability, material damage, loss of authenticity or integrity, environmental setting;
  - The tools include pictures, drawings, technical reports

  - Institute of Cultural monuments, Directorate of Monuments, Municipality of Berat will inspect the affected area;
  - Recovery activities:
    - The area will be isolated
    - Transport will be prohibited
    - Electricity supply will be disconnected
    - The burnt houses will be temporarily covered for not being further damaged by climate conditions
    - The walls in danger of falling will be temporarily supported with appropriate structures
    - People and heritage assets will be rescued to the school of the neighborhood.
- Long term
  - Restauration and reconstruction of the property in accordance with the integrity and authenticity
  - Rehabilitation of the environment
  - Review of the environment
  - Review of cultural heritage legislation
  - Review of Disaster Management
  - Assessment of human and economic resources
  - Stakeholder involvement and community participation
  - Educational and awareness raising activities
  - Introduction of monitoring system.

**ACKNOWLEDGEMENTS**

The material was adopted from "*Multi-hazard risk assessment and decision making*", Cees J. van Westen and Stefan Greiving, and "*Disaster Risk Management of Cultural Heritage Sites in Albania*", UN Albania.

## 4. QUESTIONS

1. Describe the relationship that exists between the terms hazard, risk, vulnerability, and disaster.

2. At what point can a hazard risk be considered "safe"?

3. Which of the following is defined as "the propensity to incur loss"?

   a. Exposure

   b. Risk

   c. Vulnerability

   d. Resilience

4. Which of the following is a consequence based analysis that begins by considering an initiating event and follows the consequences through a series of possible paths?

   a. Event-tree approach

   b. Quantitative approach

   c. Risk Matrix approach

5. What is the relation between the hazards in the case study scenario?

   a. Independent events

   b. Coupled events

   c. One hazards changes the conditions for the next

   d. Domino events

6. Which of the explained risk assessment methods is most appropriate to be used when:

   a. A cost-benefit analysis of risk reduction measures will follow -

   b. It is needed to visualize the effects and consequences of risk reduction measures -

   c. Several hazards may occur in chain -

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