



## **D.4.2 Handbook of Vulnerability Assessment in Europe**

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# 1 Holistic Evaluation of Seismic Risk in Barcelona

Martha Liliana Carreño, Alex Barbat and Mabel Cristina Marulanda.

## 1.1 Description

The city of Barcelona, capital of Catalonia and second city of Spain, has a total of 1,621,537 inhabitants (2009), is located on the northeast coast of Spain (see figure 2.1). Bounded by the Collserola ridge and rivers Besós and Llobregat, the city has an area of almost 100 km<sup>2</sup>.



Figure 2.1 Location of the city of Barcelona.

The city of Barcelona was founded by the Romans during the Punic Wars. At the end of the Roman period, the city had almost 12000 inhabitants. By the end of the 4th century, Barcelona was a fortified walled town, covering about 10.5 Ha. The Barcelona's evolution into a big city began in 1868 when adjacent towns were added to the city becoming its actual districts. Between 1910 and 1930, the population grew from 587411 to 1005565 inhabitants. This population explosion was accompanied by a highly productive construction period.

Nowadays, Barcelona is divided into ten administrative districts: Ciutat Vella, Eixample, Sants-Montjuïc, Les Corts, Sarrià-Sant Gervasi, Gràcia, Horta-Guinardó, Nou Barris, Sant Andreu and Sant Martí. This division of the city has its roots based on the history of the city. Ciutat Vella is the old centre of the city and the Eixample is where the city expanded after the city walls were knocked down. The other districts correspond to municipal areas that were around the old city, outside the walls, and which became part of Barcelona during the 19th and 20th centuries. The districts are subdivided into 73 neighbourhoods, and 235 AEBs (basic statistic areas in Spanish), according to the cadastral information 70,655 buildings conform the city.

## 1.2 Natural hazards involved

### 1.2.1 Seismic hazard

The seismicity of the Catalonia region is moderate when it is compared to other regions in the Mediterranean Sea. Various earthquakes shook Barcelona - and Catalonia - in the latter third of the 14th century and the first half of the 15th, but these had an even greater effect on a collective imagination that was already quite shaken. More recently small earthquakes have felt by the population of Barcelona (i.e. Mw:4.6 on May 15<sup>th</sup> of 1995 and MI: 4.0 on September 21<sup>st</sup> of 2004), but without causing damage to people and buildings.

The seismic hazard has been simulated, by using the system CRISIS 2007 (Ordaz et al. 2007) which is part of the platform ERN-CAPRA. CRISIS 2007 allows calculating the seismic hazard associated with all feasible events that could occur, a group of selected events, or even a single relevant event.

## 1.2.2 Flood hazard

Barcelona has a Mediterranean weather with low annual rainfall, but with isolated episodes of high intensity rain. Average annual rainfall in Barcelona, according to data of 2007 is 465.3 mm, with monthly averages ranging between 0.5 (June) and 157.9 mm (October). The average annual rainy days is 93. (Adjuntament de Barcelona 2008a). Around thirty rainfall events have originated incidents (without personal injury and / or considerable damages) in the last fifteen years.

In general, in Barcelona, the floods can be originated by two main sources, the overflow of surrounding rivers and the exceedence of the capacity of the sewer system. The overflow of the rivers Llobregat and Besos can punctually affect the city. The flood hazard has been studied for a long time and as result the city has been highly intervenced with flood protection measures.

## 1.3 Risk assessment

### 1.3.1 Seismic risk

Due to the high population growth, the most part of the city's building stock was constructed when no seismic-resistant construction codes were available. The combination of very old buildings constructed without seismic conscience and a highly populated and active city can be extremely risky under the effects of even a moderate earthquake.

In this case study, a probabilistic evaluation of the seismic risk has been done. The risk evaluation includes the probabilistic analysis of the seismic hazard which can affect Barcelona, and of the seismic physical vulnerability of the buildings in the city.

Parameters such as the occurrence frequency of a given earthquake, the probability that it will occur at a specific place, probabilities of exceedence of seismic intensities, etc, are included in the calculation models, to perform a probabilistic seismic hazard analysis.

The seismic hazard has been simulated by using the system CRISIS 2007. This study takes into account the seismic sources for the Catalonia region identified by Secanell et al. (2004) and the attenuation model of Ambraseys (1996). The seismic hazard is quantified in terms of return periods (or exceedence rates) of the relevant seismic intensities for the behaviour of the structures. The exceedence rate of a seismic intensity is defined as the average number of times, per unit of time in which the value of the seismic intensity is exceeded.

The probabilistic calculation method evaluates the desired risk parameters such as percentages of damage, economic losses, effects on people and other effects, for each of the hazard scenarios and then these results are probabilistically integrated by using the occurrence frequencies of each earthquake scenario. For Barcelona, 2058 seismic hazard scenarios have been generated.

Site effects, are included to consider the amplification of seismic hazard parameters according to the geological characterization of Barcelona (Cid et al 2001). Each zone is characterized by a transfer function and an amplification factor for the acceleration level on the rock.

The exposure is mainly related to the infrastructure components or exposed population which can be affected by a particular event. To characterize the exposure is necessary to identify the individual components, including its location, its main physical, geometric and engineering characteristics, their vulnerability to hazardous events, their economic value and the level of human occupation can have in a given analysis scenario. The exposure value of assets at risk is usually estimated from secondary sources such as available databases (see figure 2.2).

This study uses information of Barcelona compiled by Lantada (2007), the economic value of the exposed elements was supplied by the Cadastral Office of Barcelona, and 70655 buildings were taking into account. For each one the geographic situation, economic value, year of construction, number of levels, structural type and human occupation were defined.

The vulnerability of the buildings in the city has been defined by vulnerability functions using the Vulnerability Module of the ERN-CAPRA platform. These functions are defined for each building typology; the most common structural system used in Barcelona is the unreinforced masonry, followed by the reinforced concrete, whose construction has increased rapidly in recent decades. Wood and steel structures are less used and these buildings are not usually for residential use but for industrial



or other uses such as markets, sports areas, among others. The used typologies were defined in ICC/CIMNE (2004).

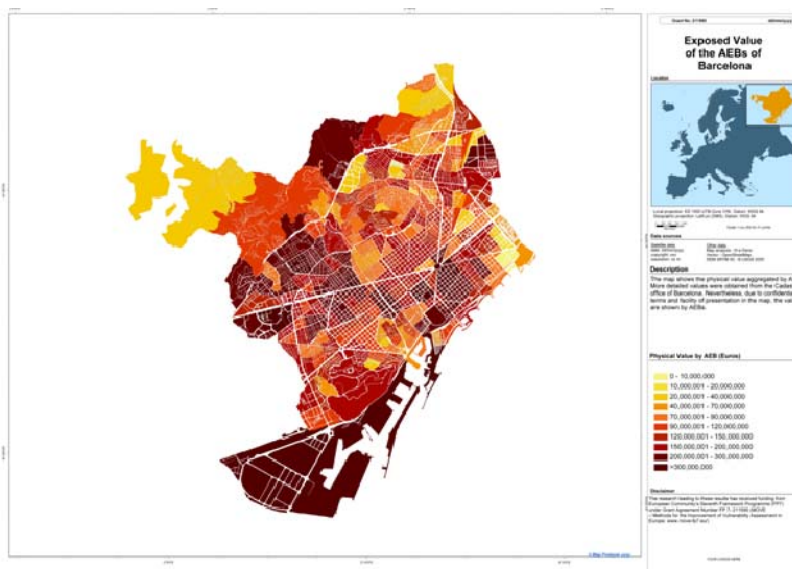


Figure 2.2 Exposed value of the AEBs of Barcelona.

Figure 2.3 shows the vulnerability functions used for the unreinforced masonry buildings; and Figure 4 shows the functions for other building typologies, for low (L), medium (M) and high (H) height. These functions relate the severity of the event, represented by the spectral acceleration with the average damage in the building.

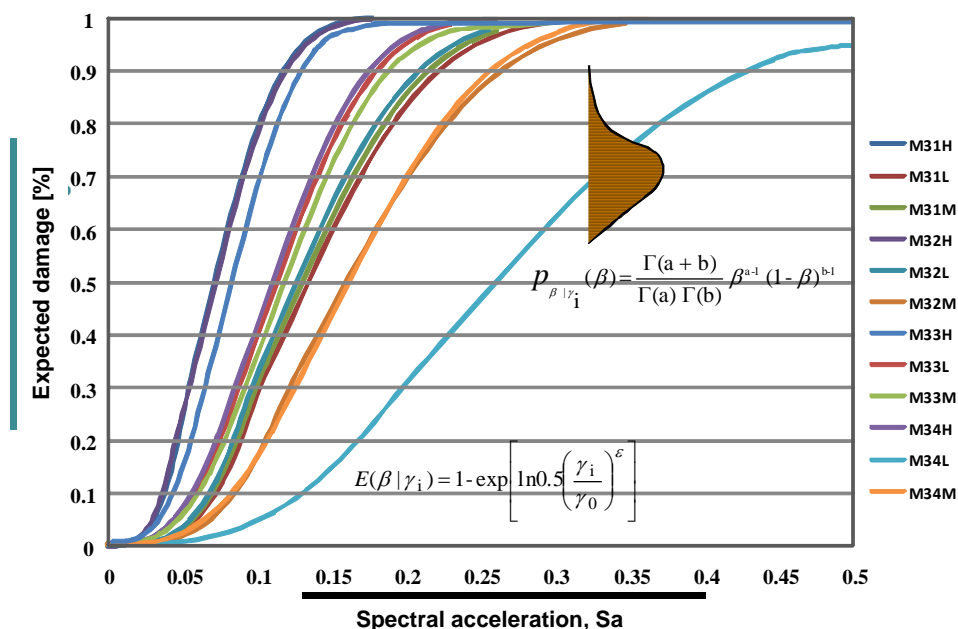


Figure 2.3 Vulnerability functions for unreinforced masonry buildings.

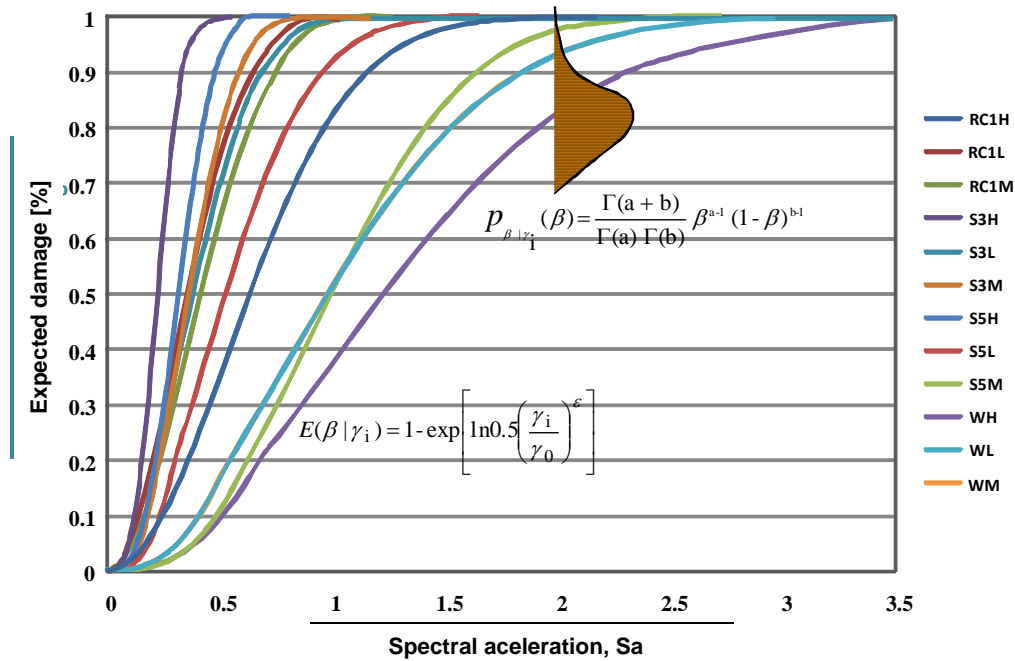


Figure 2.4 Vulnerability functions for reinforce concrete, steel and wood buildings.

The physical seismic risk is evaluated by means of the convolution of the hazard with the vulnerability of the exposed elements, the result are the potential effects or consequences. Risk can be expressed in terms of damage or physical effects, absolute or relative economic loss and/or effects on the population. Once the expected physical damage has been estimated (average potential value and its dispersion) as a percentage for each of the assets or infrastructure components included in the analysis, several parameters can be defined as the result of obtaining the Loss Exceedance Curve (LEC).

The Average Annual Loss for physical assets, fatalities and injuries are calculated for each building in the city. The probabilistic results for the city of Barcelona are shown in the tables 2.1, 2.2 and 2.3. Figure 2.5 shows the PML curve obtained for Barcelona. Figure 2.6 shows the expected annual loss for each AEB of Barcelona. As it was previous mentioned, the expected annual loss was originally calculated building by building, Figure 2.7 shows the obtained results at this resolution.

PHYSICAL EXPOSURE		
Exposed value	€ x106	31,522.80
Average Annual Loss	€ x106	72.14
	‰	2.29‰
PML		
Return period	Loss	
Years	€x106	%
50	729.35	2.31%
100	1,770.16	5.62%
250	3,699.35	11.74%

500	5,172.26	16.41%
1,000	6,510.67	20.65%
1,500	7,021.14	22.27%

Table 2.1 Obtained results for physical exposure.

DEAD PEOPLE		
Exposed value	Inhab	1,639,880.00
Average Annual Loss	Inhab	28.27
	‰	0.017‰
PML		
Return period	Loss	
Years	Inhab	%
50	101.41	0.01%
100	654.30	0.04%
250	2,069.97	0.13%
500	3,380.29	0.21%
1,000	4,898.39	0.30%
1,500	5,799.44	0.35%

Table 2 Obtained results for dead people.

INJURED PEOPLE		
Exposed value	Inhab	1,639,880.00
Average Annual Loss	Inhab	113.55
	‰	0.07‰
PML		
Return period	Loss	
Years	Inhab	%
50	756.92	0.05%
100	3,420.18	0.21%
250	9,028.50	0.55%
500	12,590.98	0.77%
1,000	15,803.45	0.96%
1,500	16,903.45	1.03%

Table 2.3 Obtained results for injured people

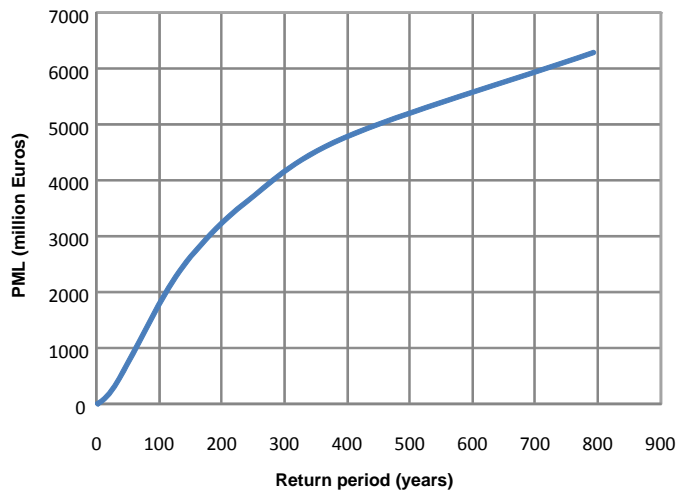


Figure 2.5 PML curve for Barcelona.

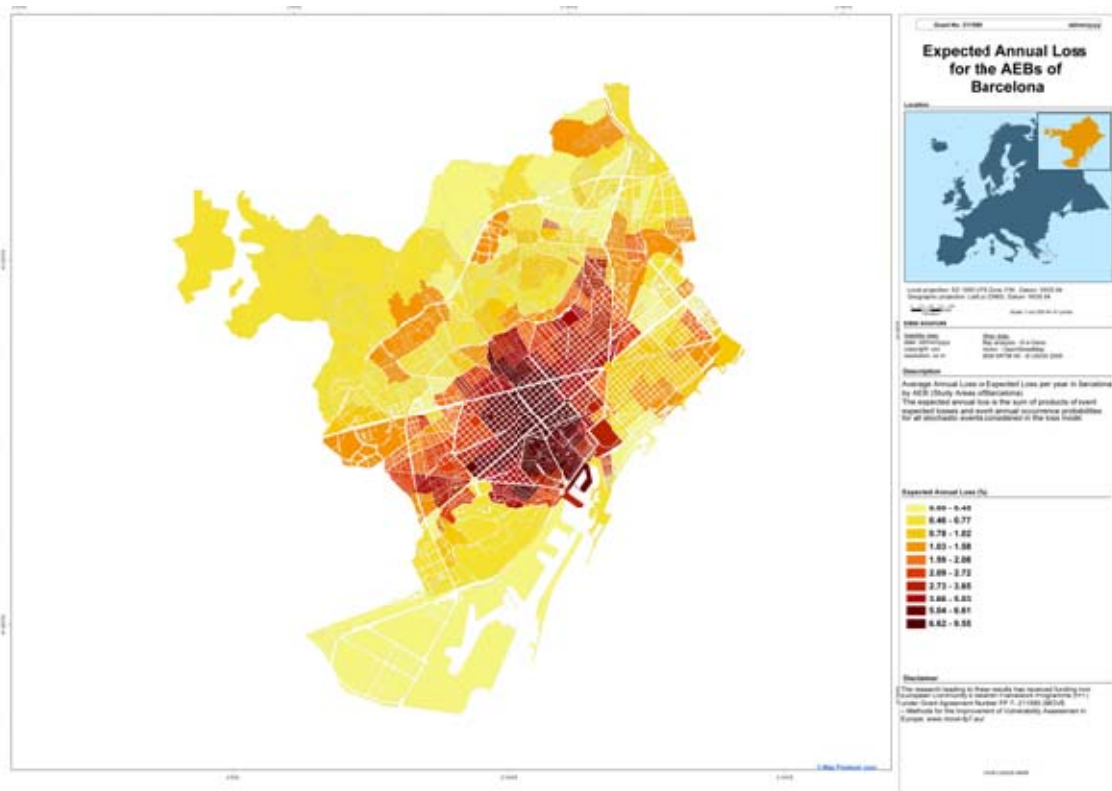


Figure 2.6 Expected annual loss for the AEBs of Barcelona.

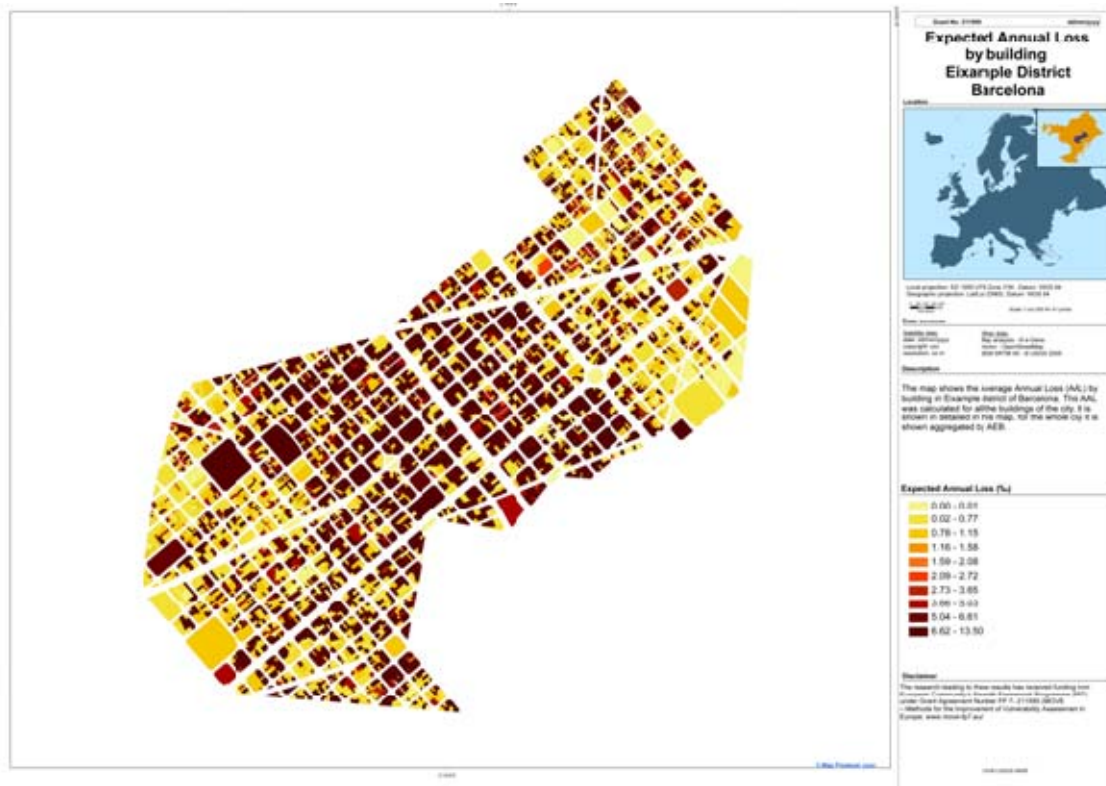


Figure 2.7 Expected annual loss for each building in the Example District of Barcelona.

### 1.3.2 Flooding risk

Barcelona has several characteristics which make difficult the evacuation of rainwater, such as: the strong ground waterproofing due to its urbanization; the topography of the city; conditions that favour convective precipitation processes; and the Mediterranean weather with episodes of isolated high intensity rain. (Adjuntament de Barcelona 2008b). These factors produce, at peak times, flows concentration in some areas of the drain system. This concentration requires the construction of large collectors to conduct the water to the sea.

The city of Barcelona is limited by the rivers Llobregat and Besos. The flooding areas of these rivers, for a return period of 500 years, have been involved in the emergency plans of Catalonia (INUNCAT) and Barcelona (PAEM). According to ACA (2005), the Llobregat river can punctually affect the city. In the case of the Besos River, the estimated damage is very small and limited only to the District of Sant Andreu (a small area of 3 blocks). Both rivers have been intervened for canalization in the lower basin area, now there are two riverside parks for recreation. A hydrological warning system was installed in order to protect the population and to ensure there are no people inside the park during periods of hazardous weather.

The history of the Barcelona sewer is closely linked to the city. Since its founding by the Romans, Barcelona has a sewerage system, but it is from the nineteenth century that begins the modern history of sewage in Barcelona, with the first Sanitation Plan of Pere Garcia Fària in 1891 (CLABSA 2010). The urban expansion, in the mid-nineteenth century, brings changes as the sewer system and the destruction of the walls, which change the effects that certain rainfall events have occurred in previous centuries (Llasat et al 1999). Over the next 200 years, have been developed various plans of reorganization until the PECLAB (Special Sewerage Plan of Barcelona) in 1997 where actions were proposed for the period 1997 to 2019, this Plan has been updated in 2000. As consequence, Barcelona is a city highly intervened to manage the flood risk.

Barcelona has study the problem of floods from a long time ago; as consequence of the growing and historical change and floods of the city, the local government has invested resources in the construction of a complex drainage system, which has been improved over the history. Nowadays, this complex system consists of sewer pipes, scuppers, collector, anti flood retention tanks, sluices, pumping stations and valves. Figures 2.8 and 2.9 show elements of the sewer system of Barcelona.

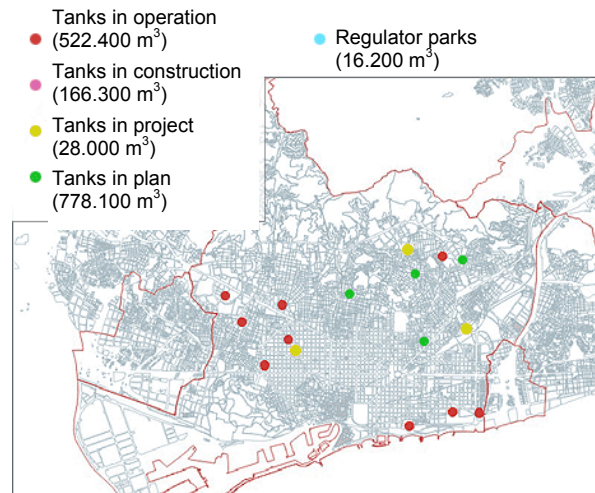


Figure 2.8 Tanks of the Special Sewerage Plan of Barcelona (PECLAB) (CLABSA 2010).



Figure 2.9 Elements of the sewer system (tanks and sluices) (CLABSA 2010).

In the case of floods derived from insufficiency of the drain system, Barcelona has studies of the system capacity. These diagnosis studies are currently being updated by CLABSA, the company which manage the planning, development and operation of the sewerage system of Barcelona. For this case study, CLABSA suggest focusing in an area of the city which has not been intervened for flood protection, these area corresponds to the Tapioles basin (Figure 2.10).



Figure 2.10 Geographic situation of the Tapioles basin in Barcelona.

To study this basin, an elevation model of 1m of resolution was used (ICC 2005), as also the Intensity-Duration-Frequency (IDF) curves (CLAPSA 2010). With this information a catalogue of scenarios with 600 rain storms was generated by using the module ERN–LluviaNH of the CAPRA platform. The flood depth has been evaluated for each one of these storms by using the module ERN–Inundation of the CAPRA platform. The results for rain storms of 1000 years of return period can be seen in figure 2.11, where the maximum depth is 3.61 m in the mouth of the river. This flooding depth do not exceed the height of the control structures, this means that according to the information from CLABSA there is not risk due to rain in the Tapioles basin.

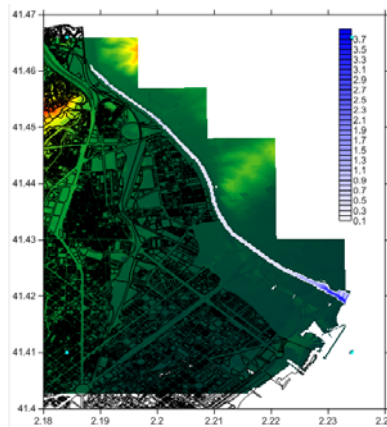


Figure 2.11 Uniform hazard map for an event of 1000 years return period.

### 1.3.3 Holistic risk evaluation

A holistic evaluation of the disaster risk has been performed by means of the adaptation of the methodology proposed by Carreño (2006) and Carreño et al (2007a). In this methodology, risk requires a multidisciplinary evaluation that takes into account not only the expected physical damage, the number and type of casualties or economic losses (first order impact), but also the conditions related to social fragility and lack of resilience conditions, which favour the second order effects (indirect impact) when a hazard event strikes an urban centre (Carreño et al 2007a).

In the holistic evaluation of risk using indices risk results are achieved aggravating the physical risk by means of the contextual conditions, such as the socio-economic fragility and the lack of resilience.

The socio-economic fragility and the lack of resilience are described by a set of indicators that aggravate the physical risk. Thus, the total risk depends on the direct effect, or physical risk, and the indirect effects expressed as a factor of the direct effects. Therefore, the total risk is expressed as

$$R_T = R_F(1 + F) \quad (1)$$

equation known as the Moncho's Equation in the field of disaster risk indicators, where RT is the total risk index, RF is the physical risk index and F is the aggravating coefficient. This coefficient depends on the weighted sum of a set of aggravating factors related to the socio-economic fragility, FFSi, and the lack of resilience of the exposed context, FFRj

$$F = \sum_{i=1}^m w_{FSi} F_{FSi} + \sum_{j=1}^m w_{FRj} F_{FRj} \quad (2)$$

where wFSi and wFRj are the weights or influences of each i and j factors and m and n are the total number of descriptors for social fragility and lack of resilience, respectively. The aggravating factors FFSi and FFRj are calculated using transformation functions, which are discussed in the following.

The descriptors used in this evaluation have different nature and units, the transformation functions standardize the gross values of the descriptors, transforming them into commensurable factors. Figure 12 shows a model for the transformation functions used by the methodology in order to calculate the risk and aggravating factors. They are membership functions for high level of risk and high aggravating level for each. In the Figure 2.12, the x-axis are values of the descriptors while the value of the factor (physical risk or aggravation) is in the y-axis, taking values between 0 and 1, were 0 is the non membership and 1 is the total membership. The limit values, X<sub>min</sub> and X<sub>max</sub>, are defined taking into account the expert opinions and information about past disasters. In the case of the descriptors of lack of resilience, the function has the inverse shape; the higher value of the indicator gives lower value of aggravation. The weights wFSi and wFRj represent the relative importance of each factor and are calculated by means of the Analytic Hierarchy Process, AHP, (Saaty 1991; Carreño et al. 2007; Carreño 2006).

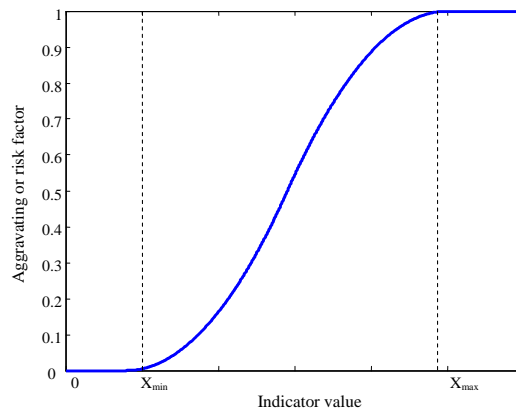


Figure 2.12 Model of the transformation functions.

The physical risk, RF, is evaluated in the same way, by using the following equation:

$$R_F = \sum_{i=1}^p w_{RFi} F_{RFi} \quad (3)$$

This case study will focus in the holistic evaluation of the seismic risk due to not risk was find in the case of floods in section 1.3.2.. The descriptors of physical risk correspond to the obtained results of the probabilistic evaluation of seismic risk (section 1.3.1. of this document). The descriptors of social fragility and lack of resilience correspond to available information of the city.

The robustness of this methodology has been also studied assessing the uncertainty of values and sensitivity to change of values, weights and transformation functions (Marulanda et al. 2009). Detailed information about this evaluation method can be find in references (Carreño et al. 2007a; Carreño 2006; Barbat et al 2011).



### 1.3.4 Evaluation of the risk management performance

The evaluation of the risk management performance has been done by using the methodology proposed by IDEA (2005), Carreño (2006) and Carreño et al (2007b). This methodology calculates the Risk Management Index, RMI, which brings together a group of indicators that measure risk management performance and effectiveness. These indicators reflect the organizational, development, capacity and institutional actions taken to reduce vulnerability and losses in a given area, to prepare for crisis and to recover efficiently from disasters. It provides a quantitative measure of management based on predefined qualitative targets or benchmarks that risk management efforts should aim to achieve.

This index was constructed by quantifying four public policies. Risk identification index,  $RMI_{RI}$ , is a measure of individual perceptions, of how those perceptions are understood by society as a whole, and the objective assessment of risk. Risk reduction index,  $RMI_{RR}$ , involves prevention and mitigation measures. Disaster management index,  $RMI_{DM}$ , involves measures of response and recovery, and governance and financial protection,  $RMI_{FP}$ , measures the degree of institutionalization and risk transfer. The four public policies and their indicators were defined after an agreement with several stakeholders and evaluators. The RMI is defined as the average of the four composite indicators

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

Six indicators are proposed for each public policy. Together, these serve to characterize the risk management performance of a country, region or city. Following the performance evaluation of risk management method proposed by Carreño et al. (2007a), the valuation of each indicator is based on five performance levels (low, incipient, significant, outstanding, and optimal) that correspond to a range from 1 (low) to 5 (optimal). Examples of these performance levels can be seen as follows.

#### RR1. Risk consideration in land use and urban planning

Consideration of some means for identifying risk, and environmental protection in physical planning.

Promulgation of national legislation and some local regulations that consider some hazards as a factor in territorial organization and development planning.

Progressive formulation of land use regulations in various cities that take into account hazards and risks; obligatory design and construction norms based on microzonations.

Wide ranging formulation and updating of territorial organization plans with a preventive approach in the majority of municipalities. Use of microzonations with security ends. Risk management incorporation into sectorial plans.

Approval and control of implementation of territorial organization and development plans that include risk as a major factor and the respective urban security regulations.

This methodological approach permits the use of each reference level simultaneously as a performance target and allows for comparison and identification of results or achievements. Government efforts at formulating, implementing, and evaluating policies should bear these performance targets in mind.

## 1.4 Indicators

Table 2.4 summarize the list of the indicators and their related matter used in this case study.

Seismic hazard	Exposure	Physical susceptibility	Physical risk	Social fragility	Resilience «Lack of»	Composite indicators
Spectral acceleration	Number exposed	of Economic value	Expected annual Economic	Low-income people neighbourhood	Hospital beds	Urban Disaster Risk

Seismic hazard	Exposure	Physical susceptibility	Physical risk	Social fragility	Resilience «Lack of»	Composite indicators
	buildings		Loss	d area		Index, UDRi
spectral displacement	Number of exposed people	Year of construction	Expected annual dead people	Mortality rate	Health human resources	Risk Management Index (RMI)
		Number of levels	Expected annual injuries people	Social disparity	Public space	
		Structural type	Expected jobless	Population density	Development level	
		Human occupation	Expected homeless	Population with fair or poor health	Emergency planning	

Table 2.4 Indicators used by the case study of Barcelona.

## 1.5 Results

### 1.5.1 Holistic risk evaluation

The holistic evaluation of risk has been done following the methodology of [section 1.3.3](#). Figure 2.13 shows the ranking of the average values for the districts of the city; Figure 14 shows the obtained results of the physical risk index,  $R_F$ , for the AEB's of Barcelona. These results give the highest values of physical risk in the districts of Ciutat Vella and Eixample; these areas correspond to the older areas in the city. The smaller values are in the districts of Nou Barris and Horta-Guinardo.

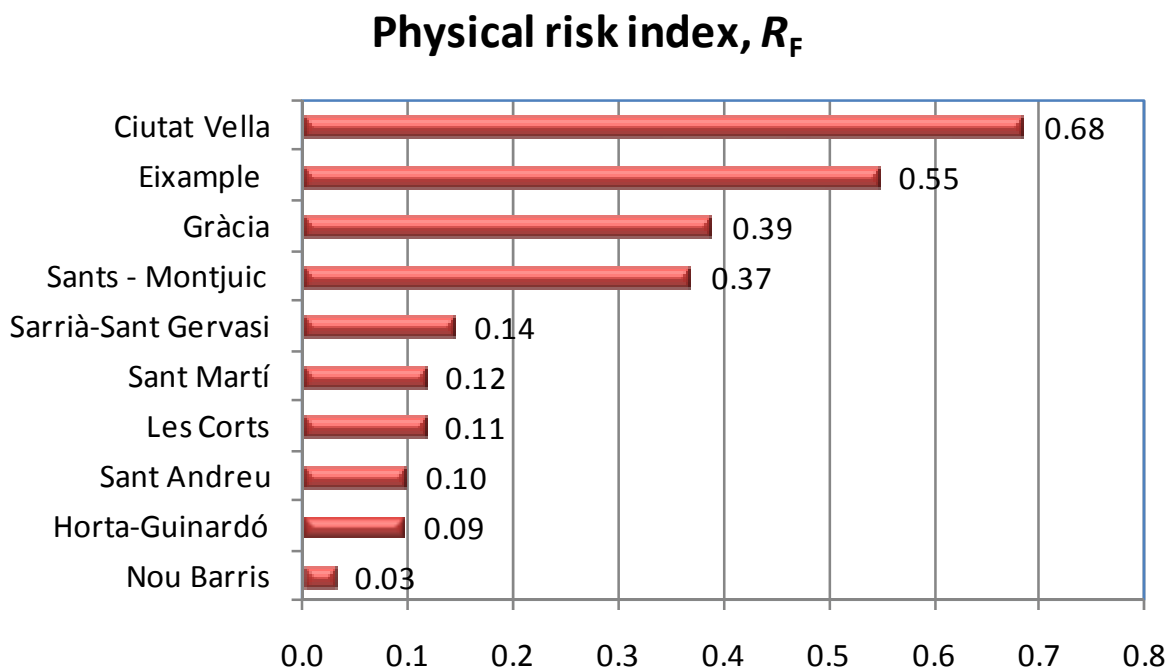


Figure 2.13 Ranking of the average physical risk index for the districts of Barcelona.

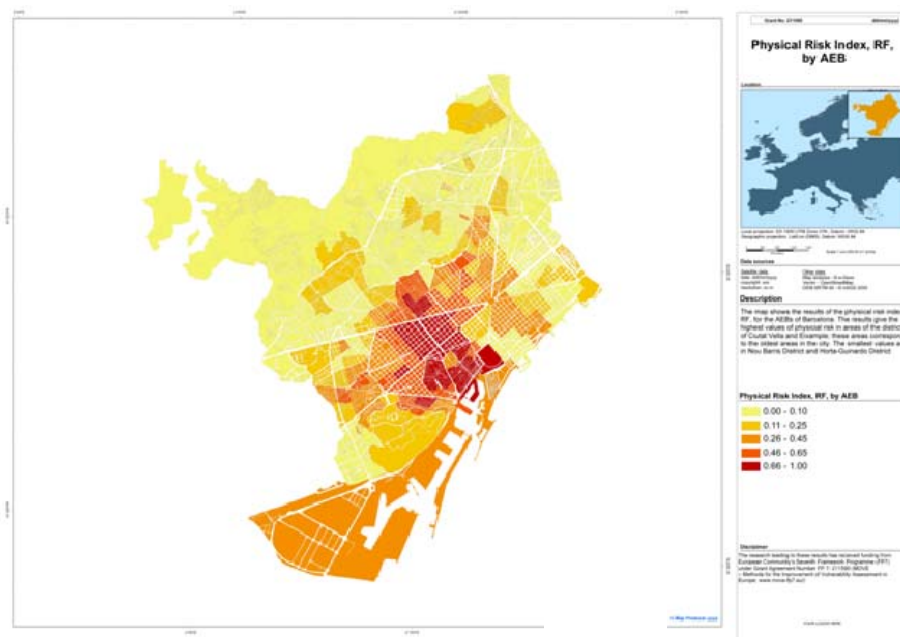


Figure 2.14 Physical risk index.

The ranking of the results of the aggravating coefficient is shown in figure 2.15 for the districts of the city; figure 2.16 shows the map of these results. The district of Ciutat Vella has the worst aggravating situation according to the characteristics of social fragility and lack of resilience, the best situation is for the Sarrià-Sant Gervasi and Les Corts districts.

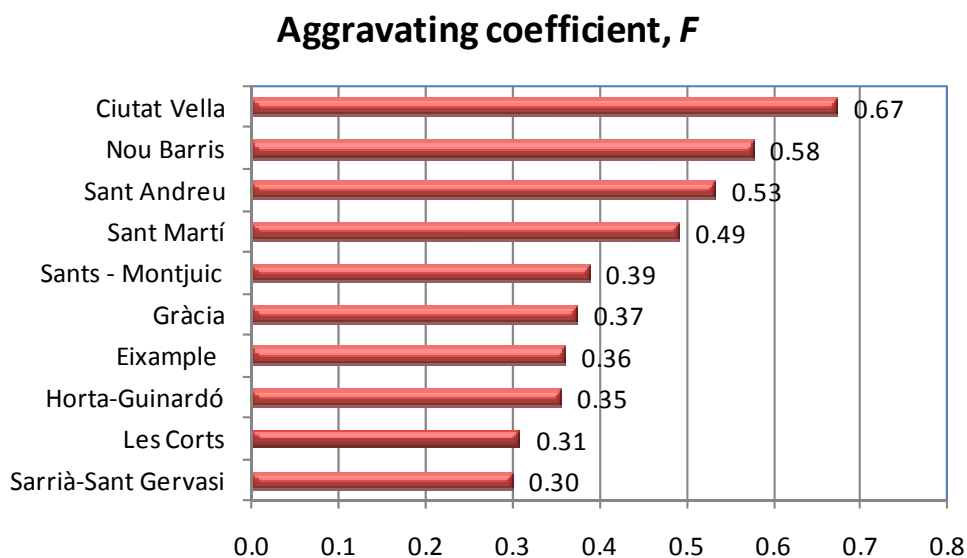


Figure 2.15 Ranking of the aggravating coefficient of the districts of Barcelona.

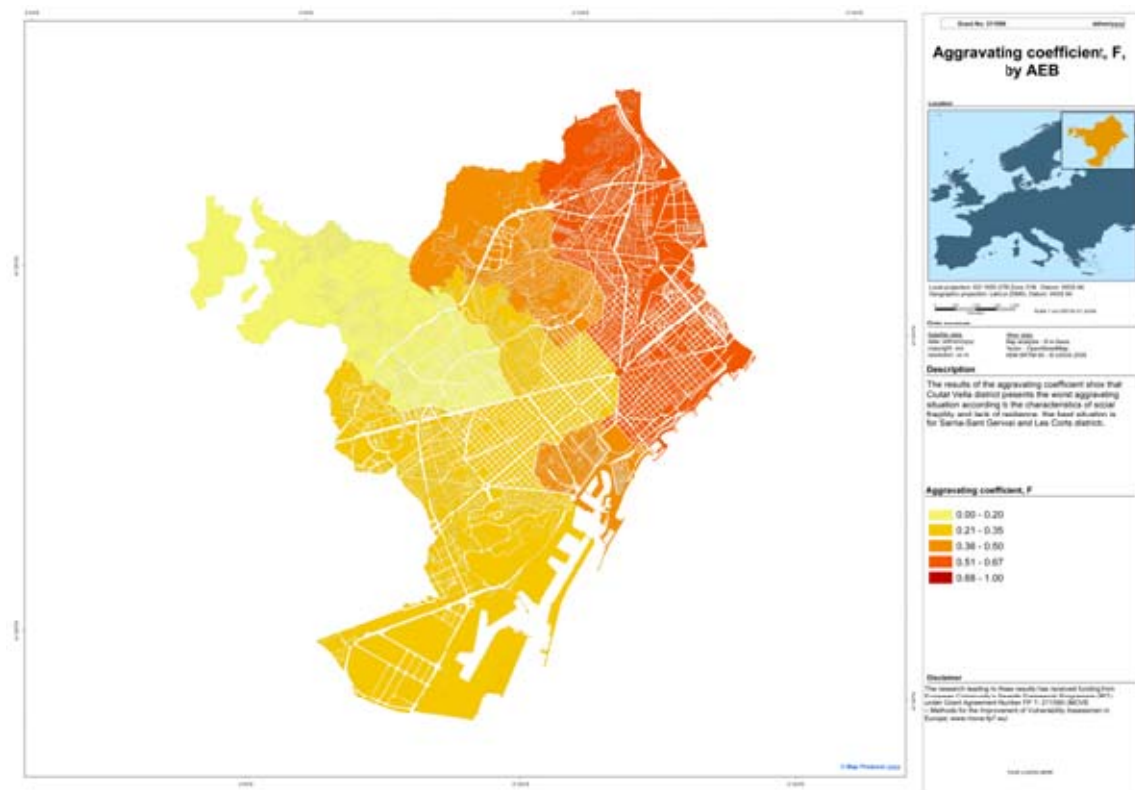


Figure 2.16 Aggravating coefficient for the Barcelona districts.

Figure 2.17 shows the ranking of the average values of  $R_T$  for the district of Barcelona. Figure 2.18 shows the results of the total risk index,  $R_T$ , for the AEB's of Barcelona, and Figure 2.18 shows a detail of the results for the AEB's in the Example district.

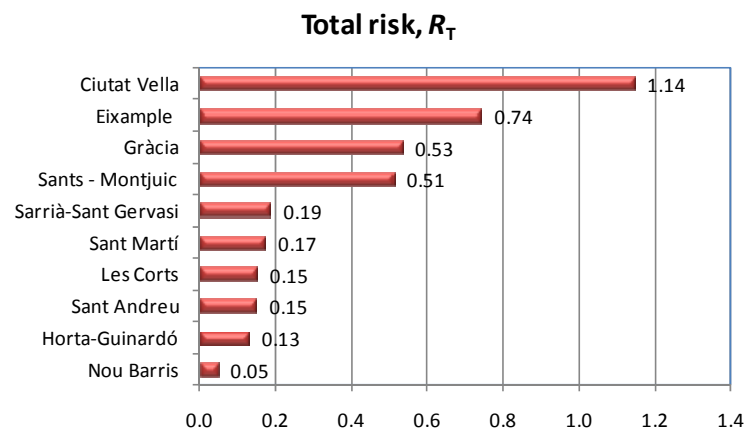


Figure 2.17 Ranking of the average total risk index for the districts of Barcelona.

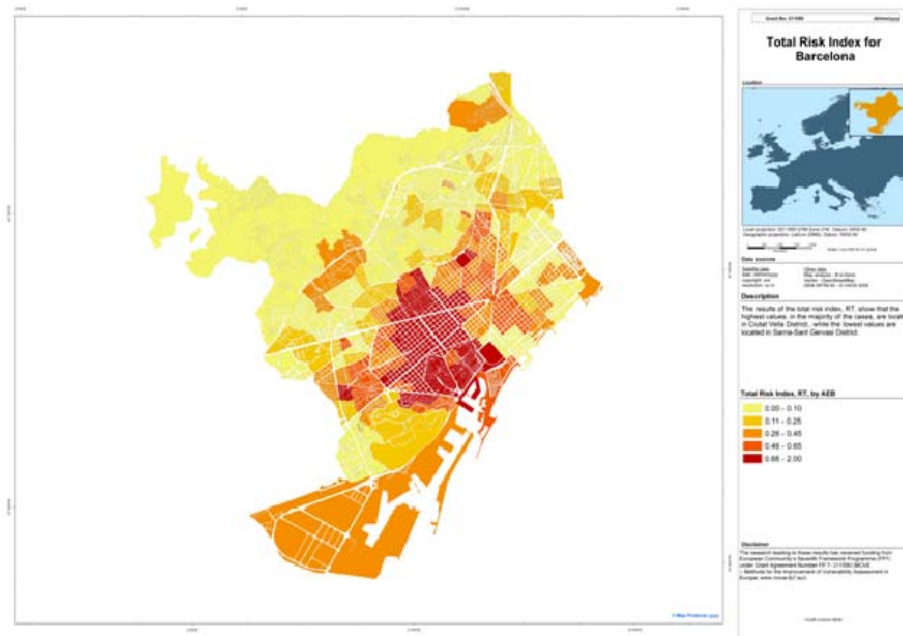


Figure 2.18 Total risk index for Barcelona.

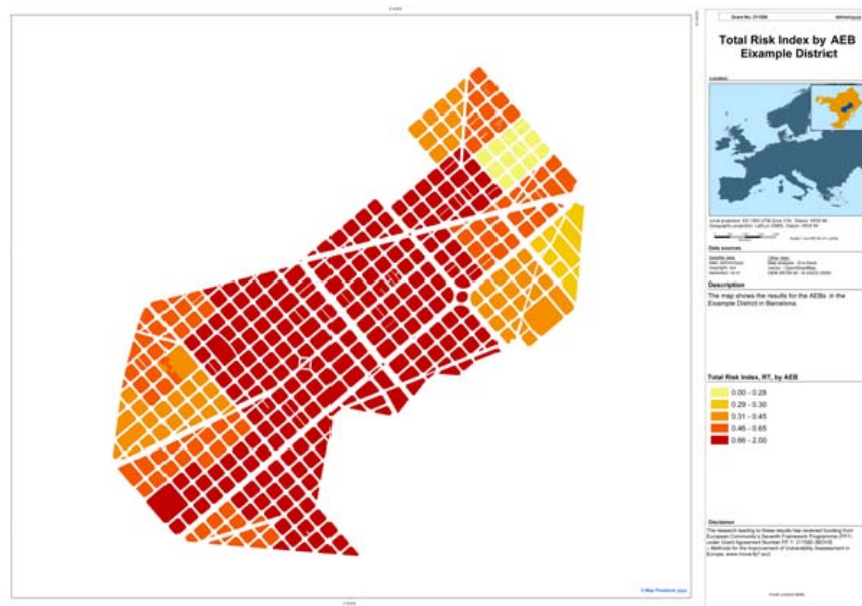


Figure 2.19 Detail of the total risk for the Example district.

### 1.5.2 Evaluation of the risk management performance

In the case of Barcelona, the indicators have been evaluated by local experts from different disciplines; the obtained results presented as follows are calculated taking the average of the evaluations done. Figures 2.20 and 2.21 show the obtained results.

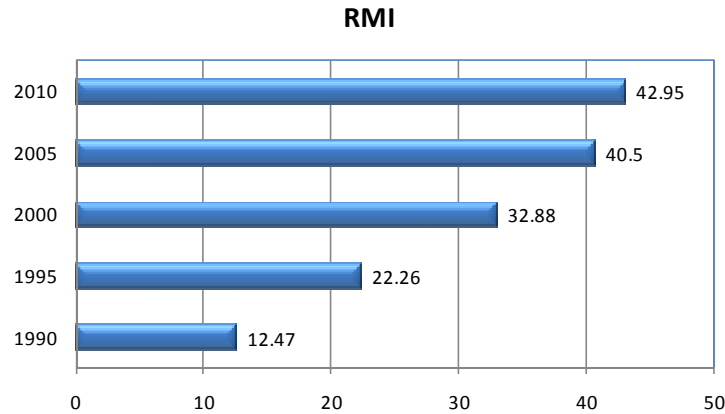


Figure 2.20 Results of the RMI for 1990, 1995, 2000, 2005 and 2010.

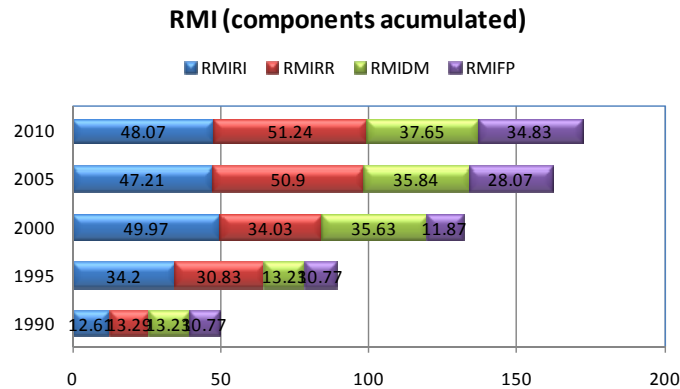


Figure 2.21 Results of the components  $RMI_{RI}$ ,  $RMI_{RR}$ ,  $RMI_{DM}$ ,  $RMI_{FP}$ .

## 1.6 Discussion

For management purposes, the risk assessment should to improve the decision-making process in order to contribute to the effectiveness of risk management, identifying the weaknesses of the exposed elements and their evolution over time. This case study involves several elements that try to capture the different aspects of the city, physical, social and institutional issues.

This study identifies the district of Ciutat Vella as a problematic area due to the potential damage due to the seismic hazard and its social fragility and lack of resilience conditions. It also shows how the districts of Nou Barris and San Andreu are problematic areas due to their social conditions, though the expected damage is comparatively lower than in other districts of the city.

## 1.7 Conclusions and recommendations

The risk in the city of Barcelona has been studied from a holistic approach involving the seismic and flooding hazards from a holistic approach. Indicators related to the physical susceptibility, social fragility and lack of resilience of the city have been involved.

It is expected the obtained results of this case study will be useful for the risk reduction and emergency preparedness plans in the city.

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## 2 Holistic Approach to Assess Vulnerability to Floods at Two Different Scales in the Salzach River Basin, Austria

Stefan Kienberger, Diana Contreras and Peter Zeil.

### 2.1 Case Study Description

#### 2.1.1 General background

The research embraces the Austrian part of the Salzach river catchment, being the Salzach one of the main tributaries of the Inn River (sub-catchment of the Danube Basin). Along 225 km, the Salzach drains a large part of the Eastern Alps in Austria and collects waters from a catchment area of 6.649 km<sup>2</sup> within an altitude range of almost 3000 m as it is depicted in figure 2.1 (Kienberger, Lang, & Zeil, 2009).



Figure 2.1 Location of the Austrian Salzach River case study area within the Upper Danube River Basin and Central Europe. Source: S. Kienberger et al., 2009.

The alpine regime at the headwaters and the middle reaches, and pre-alpine at its lower course characterises the catchment.

The most of the people live in the city of Salzburg (approx. 150 000 inhabitants) and its surroundings, but the study area has a total population of approximately 454 000 inhabitants based on census data from 2001. The climate zones consist of high mountain regimes in the upstream areas, and moderate continental conditions in the lowlands. The northern areas, in which the City of Salzburg is located, receive a large amount of precipitation (around 1120 mm) due to the blocking effect of the Alps, which reaches up to 1400 mm in the inner-alpine Salzach valley and up to 1600 mm at the Sonnblick observatory (Kienberger et al., 2009).

### **2.1.2 Assessment at two policy relevant scales**

The assessment of vulnerability with its underlying components was carried out at the catchment scale which refers to the subnational scale as identified in the MOVE framework. The assessment has been targeted at the social, economic, physical and environmental dimension. The choice of the catchment scale levels is associated to the different policies implemented at this scale level (such as the WFD) and should therefore support decision makers at this specific level within their assessment of vulnerability. Next to the catchment case study, an assessment has been carried out at the local scale level (village; 'Gemeinde'), which is in charge of implementing disaster risk reduction regulations, especially through spatial planning activities.

### **2.1.3 Stakeholder workshops and integration of expert knowledge**

A workshop was carried out to present the framework to the different involved stakeholder groups on July 29<sup>th</sup>, 2010 which comprised representatives from the flood protection, early warning, climate change adaptation and spatial planning departments of the Government of Salzburg, as well as representatives of the Meteorological service of Austria. The feedback from the stakeholders regarding the generic framework was positive, where they could identify themselves and their activities within the framework. The social and economic dimension was seen as the most important one, to be assessed within a vulnerability assessment.

Within the applied methodology an expert bases approach has been chosen where several experts have been asked to allocate scores to the single indicators according to their contribution to the vulnerability for floods in the Salzach case study area (see details below).(Kienberger et al., 2009). In total 5 experts have been interviewed and provided their scoring.

### **2.1.4 Evaluation of the local preparedness**

To achieve the objective to protect people against floods, Austria has developed flood hazards maps, river regulations and technical constructions and flood warning systems, which despite they do not prevent floods, they allow having enough time to evacuate people, minimizing loss of human lives.

The floods in August 2002 demonstrated the need to have longer lead times in Salzburg's flood forecasts. Also it was considered necessary to have methods to incorporate precipitation forecasts, and monitoring soil conditions; all these data will enable hydrologist to develop risk scenarios and make predictions in a window time of 24 hours.

As a consequence of the August floods 2002, the Government of the Province of Salzburg formulated a 10 point program, where among other points it was concluded that building regulations have to be reviewed and adapted, awareness activities must be undertaken between people living on flood prone areas; it was necessary to know the capacity of flood protection measurements, as well as develop emergency plans which include communication protocols and search and rescue (SAR) units (Wiesenecker, 2003).

## 2.2 Hazards

Major hazards found in the case study area include floods, landslides, avalanches, debris flow, flash floods, torrential rainfall and severe storms. The vulnerability assessment in the context of the MOVE project is focused only on river flood hazard.

Since many centuries, the Salzach river has been exposed to floods, causing widespread damage not only to the city, but also the province. The worst flood referred occurred on 1571, and the other events in 1789, 1899, 1920 (Roithmayr, Friembichler, Eder, & Mandl, 2011) and the most recent floods took place in 2002 (with 2300m<sup>3</sup>/s water flow in the city of Salzburg;HQ100),and 2005.

Extreme precipitation amount and widespread thunderstorm activity with several variations in rainfall intensity were observed from northern Germany to Austria in the beginning of August 2002, exceeding monthly average values in the area. Particularly, two events from August 6th to 7th and from 12th to 13th causing severe floods mainly in Lower Austria and Erz Mountains (Ulbrich et al., 2006).

Salzburg was declared a disaster zone, and even Vienna was considered under threat. The Danube was closed to all shipping as the river swelled to a near 100-year high. According to the Emergency services, 8.000 workers and volunteers were available to support evacuation activities.

### 2.2.1 Secondary effects

An isolated case was studied by Schmid et al. (2005) with respect to an outbreak of gastrointestinal illness due to norovirus infection among a group of American tourist; they were exposed to contaminated water in a hotel where they stayed, which was flooded on their arrival day to Salzburg; according to their testimony, they helped the hotel staff to clean up. Later, also the firefighters who pumped the water from the affected hotel fell ill with vomiting or diarrhoea.

Nevertheless, despite floods are usually associated with an increased risk of infection, the risk remain low, unless there are population displacement or water sources contaminated; however, any of this situation took place in Salzburg and mainly the infection were contracted through direct contact with water polluted (Schmid et al., 2005).

The last case is a specific case of secondary event in the study area of the Salzach, however in the most of the cases the increase in precipitation and the flood itself can trigger landslides, as secondary effect.

### 2.2.2 Damages in the past

In 2002, news agencies reported that floods have claimed three lives in Austria in towns near to Salzburg, after the Salzach river burst its banks, according to the declaration made by Franz Schausberger, governor of central Salzburg province, at that time ("Torrential rains - floods leave Europe in Chaos," 2002).

In Salzburg, 1.000 buildings resulted totally or partially under water and the touristic boat Amadeus were sunk after being dragged by the flood. Three-quarters of the region in Upper Austria were also affected by flooding.

The total damage was estimated between 48 mill EUR (Stalzer, 2003;Kienberger et al., 2009), and 3 billion (Ulbrich et al., 2006)only in Austria, in 2002.

## 2.3 Vulnerability assessment methods

### 2.3.1 Assessment:

In the present case study, the part of the framework related with vulnerability was assessed. The indicator provided focused on the assessment of the causal factors of vulnerability: susceptibility/fragility and lack of resilience. The dimensions considered include physical, ecological, social and economic at the scale levels of a local assessment (village scale) and sub-national (catchment scale), as it can be appreciated on figure 2.2.

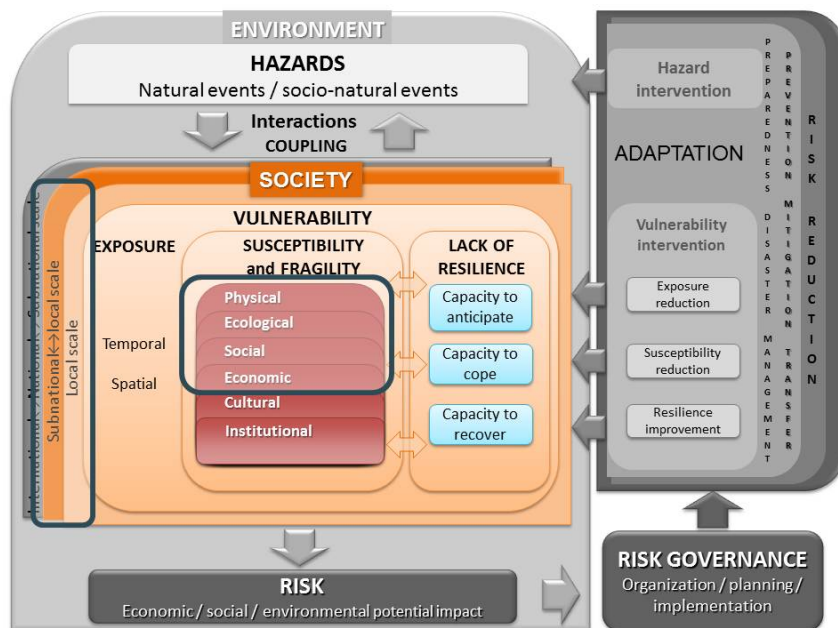


Figure 2.2 MOVE conceptual framework – Causal factors of vulnerability assessed in the Salzach case study area (highlighted).

A specific aim of the developed methodology is to derive spatial homogenous units of vulnerability as a specific case of a geon set (2008;Kienberger et al., 2009). Geons are defined as generic spatial

objects, homogenous and partly controlled by policy intervention (Lang, Zeil, Kienberger, & Tiede, 2008).

An expert-based approach has been chosen considering the fact that vulnerability is not directly measurable, due to its complex dimension and social construction. In order to model the spatial distribution of a complex phenomenon, established methodologies such as Multicriteria Decision Analysis, Delphi exercises and new approaches were integrated (Kienberger et al., 2009).

Appropriate indicator datasets have been selected with the help of expert knowledge, as initial step. The success of this step depends on data availability and coverage. For the study area, these data were mainly provided by the Government of Salzburg through its public GIS database. Data used, range from infrastructure, administrative boundaries, to different socio-economic parameters such as the size of companies, means of subsistence, age distribution and workforce in economy sectors, origin and education level of the population. They originate from the census survey in 2001 and are not only provided on the basis of different administrative units, but additionally in a standardized grid format (e.g. 100m grid cell size; Wonka, 2006) (Kienberger et al., 2009).

To integrate the different indicator data and to aggregate them on a sub-domain level, Multi Criteria Analysis (MCA), Multi Criteria Evaluation or Analytical Hierarchy Process (AHP) were applied. Multi Criteria Evaluation combines information from several criteria to create a single index (Kienberger et al., 2009).

It is proposed to use common methodologies for group decision making such as scoring, ranking, pairwise comparison or Delphi exercises to identify possible functions for the normalization of the values and weights for the different data layers (Kienberger et al., 2009).

## 2.4 Indicators

Following the framework, the Salzach case study undertook a vulnerability assessment, looking at the causal factors of susceptibility and fragility and lack of resilience. The dimensions assessed were: physical, social, economic and ecological for the causal factor of susceptibility and fragility and capacity to anticipate and to recover for the causal factor of lack of resilience. There are composite indicators made up by several single indicators.

As a first step, vulnerability indicators were identified in the scientific publications reviewed, during the first phase of the project. In the second step, each single and composite indicator for the causal factors and the dimensions and capacities mentioned above, were discussed through several sessions in order to refine the list, combining expert and local knowledge. The main criteria to select the indicators were: relevancy for the case study area and the particular hazard, and data availability, as it is depicted in figure number 2.3.

After having a refined list, the last step was to allocate weights to each single and composite indicator, also using expert knowledge.

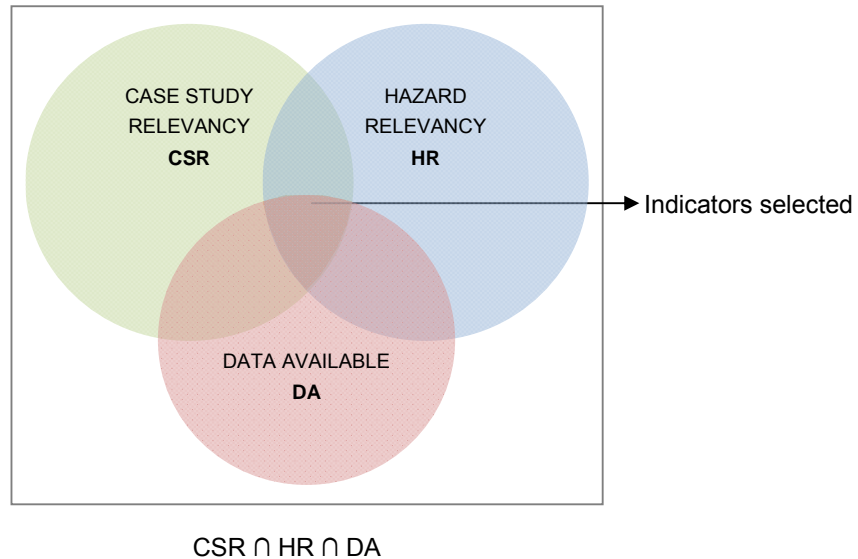


Figure 2.3 Selection of indicators. From the universal set of vulnerability indicators, the indicators considered in the Salzach case study, will be the result of the intersection between the criteria: relevancy for the case study area and the particular hazard, and data available.

### 2.4.1 Physical Dimension

Hydrometeorological events in the past, such as Katrina and Ivan hurricane in USA have demonstrated that highways, primary roads, secondary roads and railways are necessary infrastructure to evacuate people, besides of transport media and traffic conditions. In the relief or early recovery, roads will allow bringing humanitarian aid into the affected areas; and in the prevention and mitigation phase, they will facilitate to carry out risk reduction measures in the areas where it is required.

The level of susceptibility of infrastructures is correlated with potential of damage and the possibility of secondary effects which could make worse the event. Secondary effects must be considered always in relation to critical facilities.

The European Economic and Social Committee and the Committee of the Regions 'Flood risk management — Flood prevention, protection and mitigation' sets out its analysis and approach to managing flood risks at Community level, and states that concerted and coordinated action at Community level would bring considerable added value and improve the overall level of flood protection, and hence will reduce the vulnerability. Reduce population vulnerability is the most important element in disaster risk reduction policies.

Tourism relevant buildings are important not only because of the income that this activity represents, but also because they are part of the identity of the city (Lynch, 1960). In the case of Salzburg, this is a very important indicator due to the city was recognized as a UNESCO World Heritage Site in 1997 on account on its splendid baroque, one of the best preserved of Europe. Reduce the vulnerability of tourism relevant buildings is a key issue in disaster risk reduction policies; they are key elements to be included in the business continuity plan of a city after a disastrous event, because they can support recovery efforts in a later stage.

The number of office buildings is an indicator of the economic activity and development level of the city. Reduce the vulnerability of office buildings is essential to ensure the governability, the implementation of a business continuity plan after a disastrous event, and to formulate and undertake a recovery plan. Susceptibility of commercial buildings is correlated with economic and social susceptibility and with the resilience condition of a community. The number of industries is an indicator of the economic activity in the city and the level of investment attraction. The density of industrial buildings can be a proxy indicator of the economic health of a community, their potential losses and issues to be solved in a recovery phase (Cutter et al., 2003).

Besides other critical facilities, hospitals or the number of beds in a hospital are essential indicators of the capacity to cope with disastrous events in a society. Their location and construction must follow urban and structural laws enacted by the government. Cutter et al. (2003) in her study to examine social vulnerability collected 250 indicators like the number of physicians per 100.000 population; per capita number of community hospitals, and distance measure of each house to the closest health facility. Fekete, A. (2009) in his validation of a social vulnerability index in context to river-floods in Germany includes as indicators: residents per doctor, hospital beds and medical care centres. Hahn, M. B. et al. (2009) in their proposed livelihood vulnerability index in relation with health, considers: average time to health facility (minutes), per cent of households with family member with chronic illness, per cent of households where a family member had to miss work or school in the last 2 weeks due to illness and average malaria exposure\*Prevention Index (range: 0–12). Hospitals are critical facilities in emergency response time, because they must be able to assist the affected population.

Communications is an essential item in the emergency response, included in all the emergency plans over the world. Communication infrastructure is critical in the moment to face an emergency, and reduce its vulnerability is essential in the prevention and mitigation phases in the disaster cycle management. The final list of indicators can be appreciated in table 2.1.

Physical Dimension		
Susceptibility	Composite indicators	Single Indicators
	<b>Transport Infrastructure</b>	Highways
		Primary Roads
		Secondary Roads
		Railway
	<b>Critical Infrastructure</b>	Sewage plant
		Waste deposit
		Gas stations
	<b>Buildings</b>	1-2 households
		>3 households per building
		Tourism relevant buildings
		Offices
		Commercial buildings
		Industry
	<b>Critical Buildings</b>	Transport and communication

Physical Dimension		
		infrastructure
		Hospital
		kindergarten
		Nursing homes
		Primary schools/kindergarten
Lack of Resilience	<b>Early warning system</b>	
	<b>Proximity to roads/Access</b>	
	<b>Proximity to emergency services</b>	

Table 2.1 Composite and single indicators selected in the physical dimension

### 2.4.2 Social Dimension

The social dimension is considered by the MOVE project as the fragility of the community related to the level of human welfare including its social integration, mental and physical health, both at an individual and collective level. This dimension considers special groups of population, who are differentiated on accounts of their age, employment conditions, education level, gender, or origin.

Nowadays, there is a special attention to some specific groups of more vulnerable people such as elders and children, due to the weakness of their physical and sometimes mental conditions. Fekete, A. (2009) in its validation of a social vulnerability index in context to river-floods in Germany includes the variable: residents age 65 and older. Furthermore, the history have several cases in which address the situation of elders have been a big issue: heat wave in Chicago (1999), Kobe earthquake (1995), L'Aquila earthquake (2009), hurricane Katrina (2005) and floods in Mozambique (1999-2000), in which elders had to struggle for food and resources from relief agencies, and they faced sometimes physical violence because of the lack of coordination with authorities in the provisional accommodation centers (Matsimbe, 2003). Extremes of the age spectrum increase the social vulnerability; it makes necessary to evaluate the vulnerability of these groups, in order to formulate policies to improve their condition. They must be also included as a special group in a pre-impact recovery plan, to ensure the suitable management of their requirements.

According to save the children, half of those affected by natural disasters are children. In the response or relief period, elderly and children are considered as multipriority group (MPG) (Chiu, 2007; Contreras, 2009), low mobility groups or potential evacuees without vehicles (Urbina & Wolshon, 2003) and special needs population (Cutter et al., 2003); conditions to be taken into account as the capacity to cope.

The Millennium Development Goals from United Nations in its Goal 1: "Eradicate extreme poverty and hungers" has as a target 1b: "Achieve full and productive employment and decent work for all, including women and young people". Employment is an indicator considered in several vulnerability and recovery index. Employment groups are one of the variables between the socio-economic factors considered by Feckete (2009) in the validation of social vulnerability index in context to river-floods in Germany. According to Cannon, T (2000) poor people have less job security after a flood, and usually few savings to buffer them against the event; employment is included in the livelihood resilience, one of the five components of the vulnerability levels proposed by him. Mileti (1999; Cutter et al., 2003) claims that disasters exacerbates the potential loss of employment, and hence the capacity to recover



in a community. In the recovery phase indicators as: new job applicants ratio per month (Karatani, Y., & Hayashi, H., 2004); effective Job opening ratio per month (Karatani, Y., & Hayashi, H., 2007) and effective Job opening ratio per month per vulnerable population (Noi Abruzzo No.1, 2010) are also considered.

Employment is a source of income which allows people to deal with the normal expenses, also to have some savings, and later improve their living conditions. Employment and income are correlated with less vulnerable conditions because people will have enough resources to avoid living in hazard prone areas or to mitigate the risk; or they will have enough resilience to anticipate to some event, to cope with it, and later to recover from it.

The agricultural sector is usually the economic sector most affected by floods. Cannon, T (2000) states that floods reduce the demand for labour in the agriculture sector because they destroy the crops on which people work. The agriculture sector was considered an essential sector in the recovery process after the earthquake in Chile (2010), therefore measures has been implemented by the state such as subsidy, bonuses, tax alleviation and working capital support in order to repair irrigation infrastructure. This indicator is important not only because agriculture is a source of employment and income for the country or the region, but also because the provision of food for population depends on it.

Mining and production are economic sector that could be affected in an indirect form by a flood event; however, these sectors must be included in the business continuity plan of a city after a disastrous event, because they can support recovery efforts in the post-disaster phase.

Several authors in the topic of social vulnerability have discussed about the topic of immigrants. Cutter et al. (2003) includes the language and cultural barriers in their social vulnerability index because it affects the access that immigrants have to some services in the pre-disaster phase and funding in the post-disaster phase. Jones, B. and Andrey, J. (2007) consider variables such as: people without canadian citizenship, people with no knowledge of English, people new to the area (< 5 years) and number of non-white residents in the Vancouver vulnerability indices. Fekete, A. (2009) in its validation of a social vulnerability index in context to river-floods in Germany includes also new residents and he makes a gender consideration when he includes foreign females as one of the variables. There are special groups of vulnerable population such as immigrants who are more susceptible due to ethnic issues, income-earning capacity and prejudice, which might reduce their capacity to afford to live in safe buildings or safe areas Cannon, T. (2000). A flood can affects everyone in different degrees; and it is important to assess the number of people that can be affected, in order to formulate the prevention, mitigation and pre-impact recovery plans before the disastrous event.

Vulnerability level also changes according to the level of literacy rates. The Millennium Development Goals from United Nations in its Goal 2:"Achieve universal primary education" has as a target 2a:"Ensure that all boys and girls complete a full course of primary schooling". Several authors in the topic of social vulnerability have discussed about the topic of education level or literacy rates Cutter et al. (2003) include people with only a high-school education in their social vulnerability index. Fekete, A. (2009) considers three variables in relation with education: graduates without basic education, graduates with high school graduation, population with no high-school education. Indicators of sustainable development (2000) propose to take into account: adult secondary education achievement level. Cutter et al. (2003) state that a low level of education reduces the comprehension ability to understand warning information and the information in the recovery time. Educated population have more access to information, rather than people without it. Education gives them the opportunity to reduce their risk before the event, and increase all the resilience capacities. The final list of indicators can be appreciated in table 2.2.

Social Dimension			
Susceptibility	Composite indicators	Single Indicators	
	Age	Population under 20 years	
		Population 20 to 64 years	
		Population over 64 years	
	Employment	Employment in agriculture sector	
		Employment in mining sector	
		Employment in Production and construction sector	
		Employment in Service sector	
	Lack of Resilience	Origin	Origin Austria
			Origin EU
Origin other countries			
Education level		Academics	
		Non-Academics	
Mean of subsistence		Full time employment / male	
		Full time employment / female	
		Part- time employment / male	
		Part- time employment / female	
		Precarious employment / male	
		Precarious employment / female	
Early warning system			
Proximity to roads / access			
Accessibility to medical services			
Proximity to emergency services			

Table 2.2 Composite and single indicators selected in social dimension.

### 2.4.3 Economic Dimension

The economic dimension deals with the potential financial damage and/or disruption of the productive capacity. Cutter et al. (2003) include transportation infrastructure in their social vulnerability index taking into account that the loss of this infrastructure is a difficult financial burden on communities with scarce financial resources to rebuild. Ebert, A. et.al. (2009) develop an urban social vulnerability assessment with physical proxies and spatial metrics derived from air- and spaceborne imagery and

GIS data, and one of the variables taken into account was road condition defined as the proportion of paved road of all roads in the neighbourhood.

Cannon, T. (2000) in his paper "vulnerability analysis and disaster" lists as a variable the number of jobs generated in the industries located in the hazard areas and the per cent of the population participating in the labour force (specific year) and Cutter et al. (2003) also includes a gender variable: per cent females participating in civilian labour force (specific year).

The density of industrial buildings can be a proxy indicator of the economic health of a community, their potential losses and issues to be solved in a recovery phase (Cutter et al. ,2003).

The density of raw materials productive areas can be a proxy indicator of the economic health of a community, their potential losses and issues to be solved in a recovery phase (Cutter et al., 2003). Crop areas is an indicator of the susceptibility and resilience, because it allows to measure the level of prevention of the area; at the same time, it is possible to measure the capacity to anticipate, cope and recover after an event, which will affect agricultural land, and hence food production. The final list of indicators can be appreciated in table 2.3.

<b>Economic Dimension</b>		
<b>Lack of Resilience</b>	<b>Composite indicators</b>	Single Indicators
	<b>Transport network</b>	Highways
		Primary Roads
		Secondary Roads
		Railway
	<b>Employment by sectors</b>	Employment in agriculture sector
		Employment in mining sector
		Employment in Production and construction sector
		Employment in Service sector
	<b>Ecosystem Services</b>	Food production
		Raw materials
	<b>Land use</b>	Crop
		Pasture
		Woodland
	<b>Size of Companies</b>	Size of companies < 49
Size of companies 50–200		
Size of companies >200 employees		

Table 2.3 Composite and single indicators selected in the economic dimension.

## 2.4.4 Ecological Dimension

The ecological dimension deals with the fragility of ecological and bio-physical systems, and their different functions, under a hazardous condition, to suffer damage and deterioration. The indicators selected follow the Millennium Development Goal number 7: Ensure environmental sustainability and the targets: Integrate the principles of sustainable development into country policies and programmes; reverse loss of environmental resources and reduce biodiversity loss. The MDG's considers as indicators: proportion of land area covered by forest and proportion of total water resources used.

Rivers, lakes and wetlands denominated fresh water ecosystems are extremely rich in species; however, they are also the most altered and threatened ecosystems in the world. Essential characteristics as the natural flow regime, and the longitudinal and lateral connectivity of rivers, to sustain the biophysical and ecological processes required for life in fresh waters, are disrupted by dams and their reservoirs in fragmented rivers. The fragmentation, and hence the loss of ecosystems processes not only affect ecosystem and species but also humans. The loss of floodplain inundation patterns affect human communities dependent on floodplain fisheries and flood recession agriculture (Nilsson et al. 2005; UNEP, 2002).

Climate change projections show the possibility to have greater droughts in some areas, with consequences as reduction in summertime soil moisture; while in other areas the rainfall will increase, besides the off-site impacts of soil erosion. Soil moisture constitutes a major buffer against flooding, and water capacity in subsoil is a significant factor for plant growth (EEA, 2011).

Water regulation means the influence that ecosystems have on the timing and magnitude of water runoff, flooding, and aquifer recharge, mainly related with water storage potential of the ecosystem or landscape. Water regulation, besides of water purification, pollination and climate regulation are regulation service indicators (WRI, 2011).

The hemeroby indicator is the measure of the effects of the past and present human activities on the current site conditions or vegetation (Kowarik, 1990; Rahman, M. 2010). The hemeroby approach is an essential tool for the ecological analysis. The levels of hemeroby are measured based on the proportion of neophytic and therophytic species, soil characteristics and land use patterns. The hemeroby scale relies on the vegetation coverage and the properties of habitats. Human activities are contrary to nature, the anthropogenic behaviour that harms nature create unnatural conditions, which later make some areas prone to disasters.

In the discussions, besides the indicators selected several interesting indicators were mentioned, mainly in the resilience extreme: social networks, internet access, average distance to health facilities, number of first responders per grid cell, and so on; however, it is difficult to have data to allow us to assess vulnerability based on them. The selection of indicators may have to be very place specific as the characteristics of vulnerability may differ. The final list of indicators can be appreciated in table 2.4.

Environmental Dimension		
Susceptibility	Composite indicators	Single Indicators
	<b>Degradations process</b>	River Fragmentation
		Forest damage
	<b>Hemeroby (Natural distance)</b>	

Lack of Resilience	<b>Ecosystem Services</b>	Regulation of interference
		Soil retention
		Water regulation

Table 2.4 Composite and single indicators selected in the environmental dimension.

## 2.5 Results & Validation

For the causal factors of susceptibility and fragility in the physical, ecological, social and economic dimension the result of the modelling with the expert weights are shown in maps for each dimension. The results for the vulnerability assessment in the physical dimension are depicted in figure 2.4; it shows that the highest level of vulnerability was found around the city of Salzburg where there is a high density of built up area, besides of a big concentration of historic buildings and infrastructure; it is possible to observe three isolated points with a high degree of vulnerability, one of them relatively near to Salzburg and the others at the South, located also along the Salzach river and its tributaries; these points belong to the location of other settlements where within a very short distance different infrastructures are located and therefore increase here the vulnerability.

In the vulnerability assessment with regard to the environmental dimension, the highest level is concentrated around the city of Salzburg and north and south of it, (figure 2.5); this zone is followed by an area with a high-medium degree of vulnerability in the North which is due to strong river fragmentation, which is currently being rehabilitated; and some other areas with a medium degree of vulnerability located mainly along some of the tributaries of the Salzach\_ impacted by different environmental degradation processes.

The results showed in the map in the case of the social dimension are similar to the findings in the physical dimension, due to people are located in the built-up areas, it can be observed in figure 2.6; however, in spite that the high degree of vulnerability still appears mainly concentrated on the city of Salzburg, this time the distribution of the zones with high and high-medium vulnerability has changed. In the social dimension, instead of isolated points with a high degree of vulnerability, there are some zones with a medium level spread out in the study area, mainly located along the tributaries of the Salzach, where some settlements are located.

The results displayed in the map of the vulnerability assessment with respect to the economic dimension depicted in figure 2.7, they shows several areas with a high degree of vulnerability along some of the Salzach river stretches and some of its tributaries; these zones are surrounded by other areas with a medium degree of vulnerability along all the tributaries of the Salzach river and the rest of the area is considered with a low degree of vulnerability. The point with the highest vulnerability degree is the city of Salzburg account for the presence of employment sources, and be an important node in the transport network in the country.

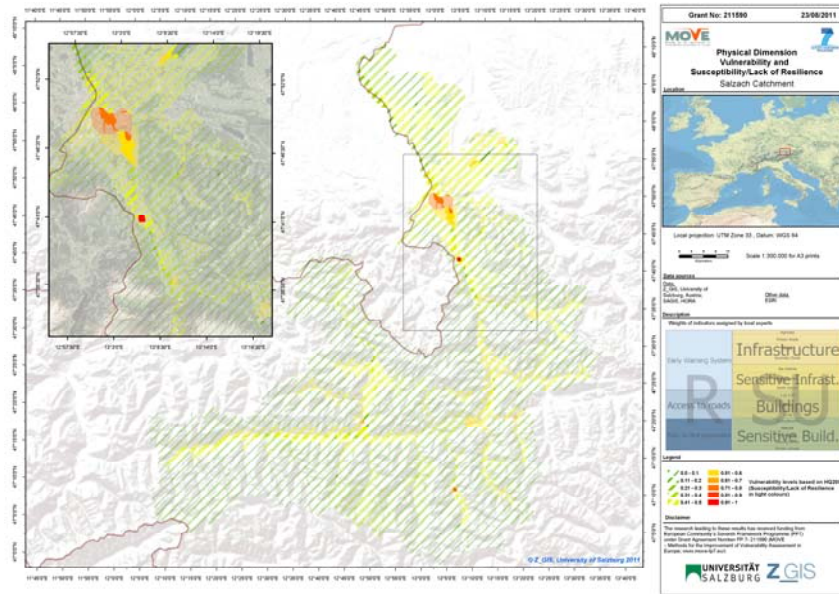


Figure 2.4 Degree of vulnerability in the physical dimension in the Salzach case study.

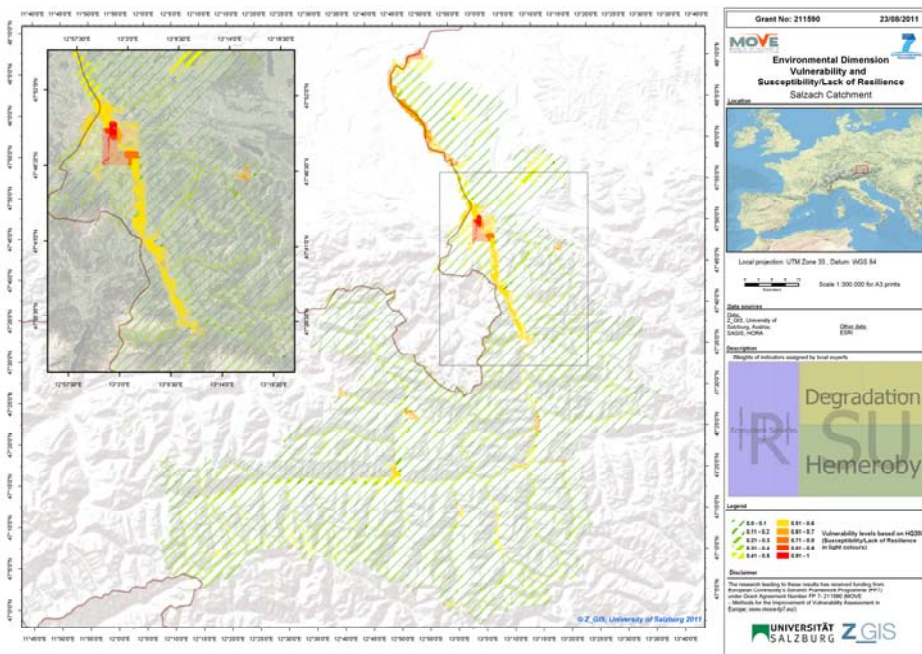


Figure 2.5 Degree of vulnerability in the ecological dimension in the Salzach case study.

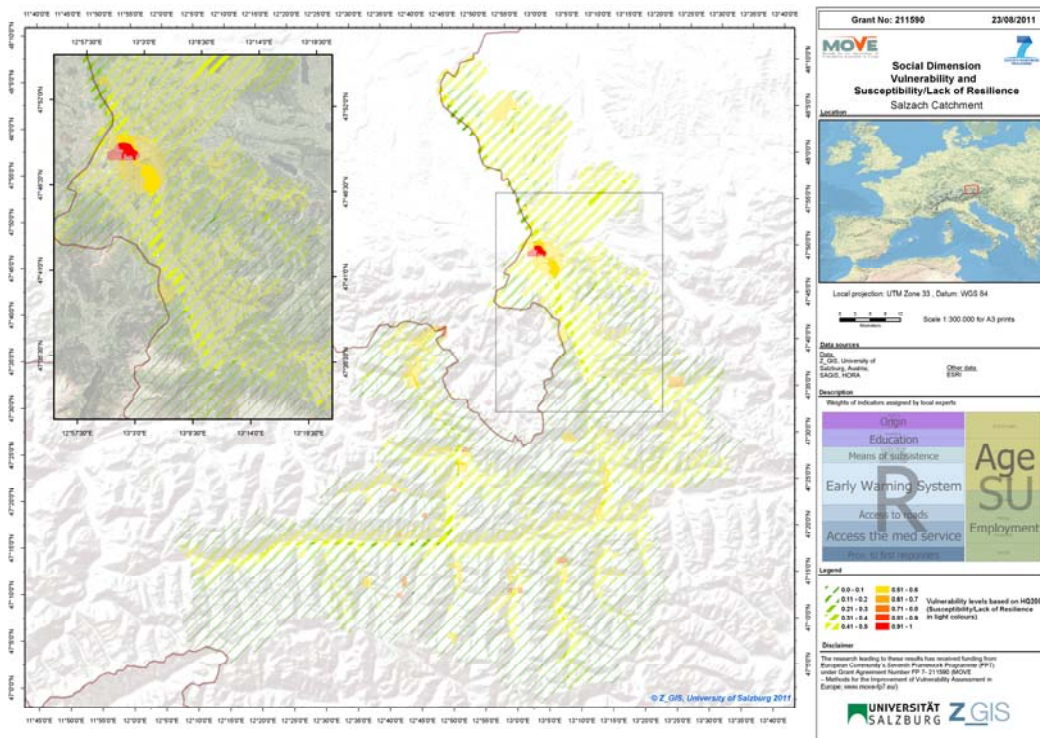


Figure 2.6 Degree of vulnerability in the social dimension in the Salzach case study.

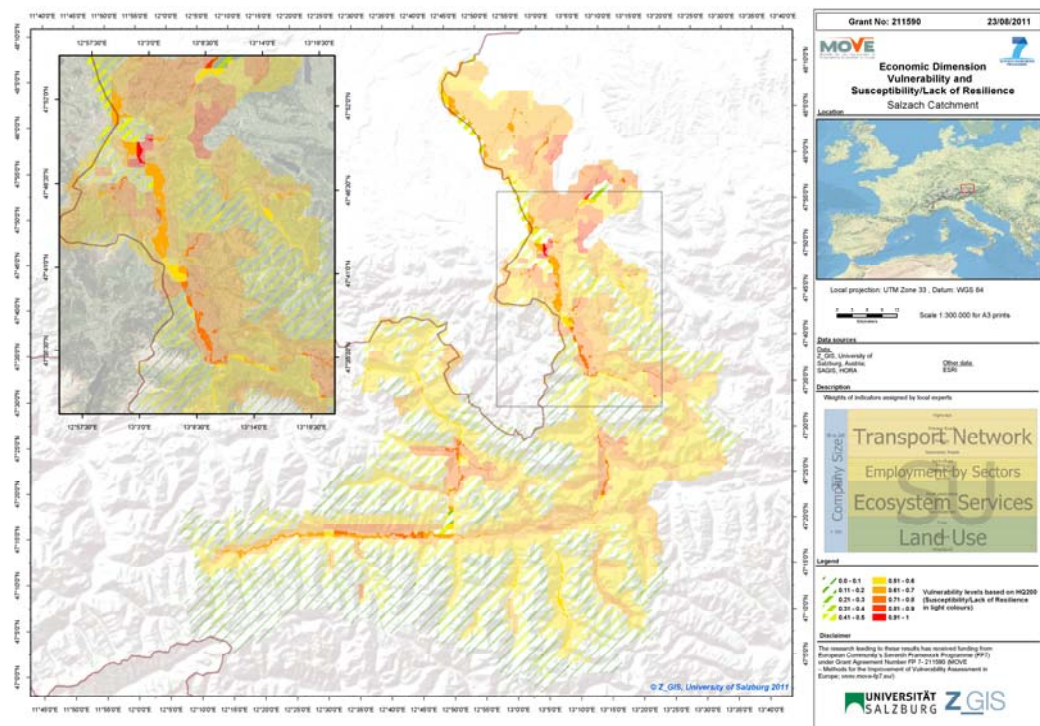


Figure 2.7 Degree of vulnerability in the economic dimension in the Salzach case study.

The validation processes has not been done and it is in fact one of the key challenges.

## 2.6 Discussion

One added value of the results obtained relies on the possibility to use the geon concept and vulnerability units to assess vulnerability combined with mixed methods of stakeholder's involvement (Delphi exercise), multi criteria assessment and regionalization. The applied method based on the geon concept (Lang et al., 2008) and the vulnerability units (Kienberger et al., 2009) as a framework, aims to represent vulnerability independent from administrative units and therefore reduce unit-related biases as modifiable areal unit problem (MAUP) and related effect of "ecological fallacy". The methodology proposed was implemented in the Salzach River; nevertheless, vulnerability units (Kienberger et al., 2009) built upon the geon concept (Lang et al., 2008) allows to transforming continuous spatial information into discrete objects, in order to monitor changes according to different hazards and in whatever area. Changes in the algorithms for interpolation, segmentation, regionalization and generalization must be done according to data requirements to study a specific hazard, and availability of that data.

One achievement was to be able to carry out a complete vulnerability assessment within different dimensions at different scale levels.

The possibility to improve the methodology to assess vulnerability in Europe has the added value of being applied in other hazard areas in Europe and in general in other places in the world. Actually, it can be also integrated to methodologies for risk estimation or it can be applied in further research more focused on some specific causal factors or dimensions of vulnerability. In the specific case of flood hazards, the methodology proposed is an attempt to generate results that support the EC flood directive requirements in relation to water policies for developing river basin management plans and flood risk management plants; empower community actions; have informed technical, financial and political decisions; encourage solidarity principle in the context of flood risk management; prevent duplication of work; incorporate updates from the influence of climate changes on the occurrence of floods, and develop prevention, protection and preparedness measures.

There are several challenges and difficulties related with data availability on the local level, integration of exposure, susceptibility and lack of resilience towards vulnerability, and difficulty to identify 'lack of resilience' indicators.

## 2.7 Conclusions and recommendations

The most vulnerable zones in all the dimensions are located along the Salzach river and its tributaries because its spatial exposure; however, the most vulnerable area through the vulnerability assessment in all the dimensions is mainly the city of Salzburg and its surroundings. This results are due to the density of its built up area, besides of a big concentration of historic buildings and infrastructure; therefore, also the highest vulnerability degree in regard with the social dimension will be concentrated in the city of Salzburg on accounts that is one of the largest settlement located along the Salzach river; also in the economical dimension is the highest point of vulnerability on account for the presence of employment sources, and be an important node in the transport network in the country. The environmental dimension shows the highest degree of vulnerability in the stretch of the Salzach river from the city to the north, associated to river fragmentation.

It is also interesting to compare the results of the vulnerability assessment between the different dimensions; while the results of the vulnerability assessment are similar between the physical and social dimension; the results of the environmental and economic dimension are almost the opposite on account for that the vulnerability in the economical dimension seems between high and medium in an



important part of the study area, the vulnerability in the environmental dimension is low in the most of the case study area mainly concentrated in the North part.

In all the vulnerability assessment exercises is required to be strongly focused on the framework.

Rather than find problems to understand a specific part of the framework, problems were found to understand the relationship between the components and the operationalization to assess the vulnerability based on the framework.

Stakeholder attended the detailed explanation of the MOVE framework carried out; however, in spite that they found it difficult to be understood, they considered that it should be a useful tool.

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## 3 Vulnerability to Earthquakes and Floods of the Healthcare System in Florence, Italy

Roberto Miniati, Christian Iasio and David Alexander.

### 3.1 Case Study Description

The Tuscany cases study is composed of two main studies: a vulnerability assessment of the health system response to earthquakes and floods; and the impact of extreme heat waves on the health of the general population. Seismic risk in Tuscany is moderately high, especially for the Apennine mountain area north to Florence (the Mugello) and Lucca (the Garfagnana). Floods affect many cities and also wide areas of rural land. In 1966 major flooding occurred in Florence, while in 2010 Lucca and Massa Carrara were badly affected by inundation. Finally, the presence of the Tyrrhenian Sea, the Apennine Mountains and other highland areas provides Tuscany with a wide variety of weather conditions during the year.

The evaluation of health system responses to natural hazards and disasters covered the entire hospital system of the Province of Florence, including four hospitals in the municipality and one in the surrounding area. The study of extreme temperatures and heat waves focused on comparisons between Florence and the coastal areas around the cities of Pisa and Livorno.

As the study focused on the local level (the province, its municipalities and some individual buildings), the stakeholders who were asked to participate were local institutional decision-makers, officials responsible for aspects of the health system and functionaries of the local civil protection department.

### 3.2 Hazards

#### 3.2.1 Earthquakes

As noted above, Tuscany is a seismic area. According to the Italian Institute of Geophysics and Volcanology (INGV), in the first four months of 2011 alone, nineteen low-power seismic events (magnitudes 1.9-3.3) have been already registered across a large extend of territory that includes the Mugello, Chianti and Garfagnana areas. The last major seismic disaster in Tuscany was the earthquake of 29 June 1919, whose epicentre was close to the town of Vicchio in the Mugello (the mountains about 30 km north of Florence). The estimated magnitude was 6.2 and damage reached level X on the version of the Mercalli scale used at the time. Seventy towns were significantly affected and approximately 100 people were killed and 400 were injured. At Borgo San Lorenzo, close to the epicentre, damage made three quarters of homes uninhabitable. It was the worst earthquake to have occurred in the Mugello since 1542 (Castenetto and Sebastiano 2004).

Much has changed in the Mugello since 1919. Although the population has remained broadly the same, standards of living have risen, new buildings have been constructed in reinforced concrete, and some older masonry buildings have been retrofitted, apparently decreasing their vulnerability. However, the area is still critically vulnerable, especially in terms of the recent accumulation of new infrastructure, including a trunk motorway and a high-speed railway line. Economic resources include a national significant Formula One racetrack, and there are substantial basic resources, that include a large reservoir with a massive earth-dam and a 130-bed hospital.

### 3.2.2 Floods

The floods that occurred in Tuscany during 2010 caused damage valued at €200 million, while the biggest flood in Florence since 1844, that of 3 November 1966, caused 34 deaths.

Figure 3.1 shows the geographical exposure of the health system at the levels reached in Florence by the 1966 floodwaters (in intervals of 0-2 m, 0-4 m, 4-5 m). The headquarters of the emergency ambulance service and one 90-bed hospital would be well inside the flooded area.

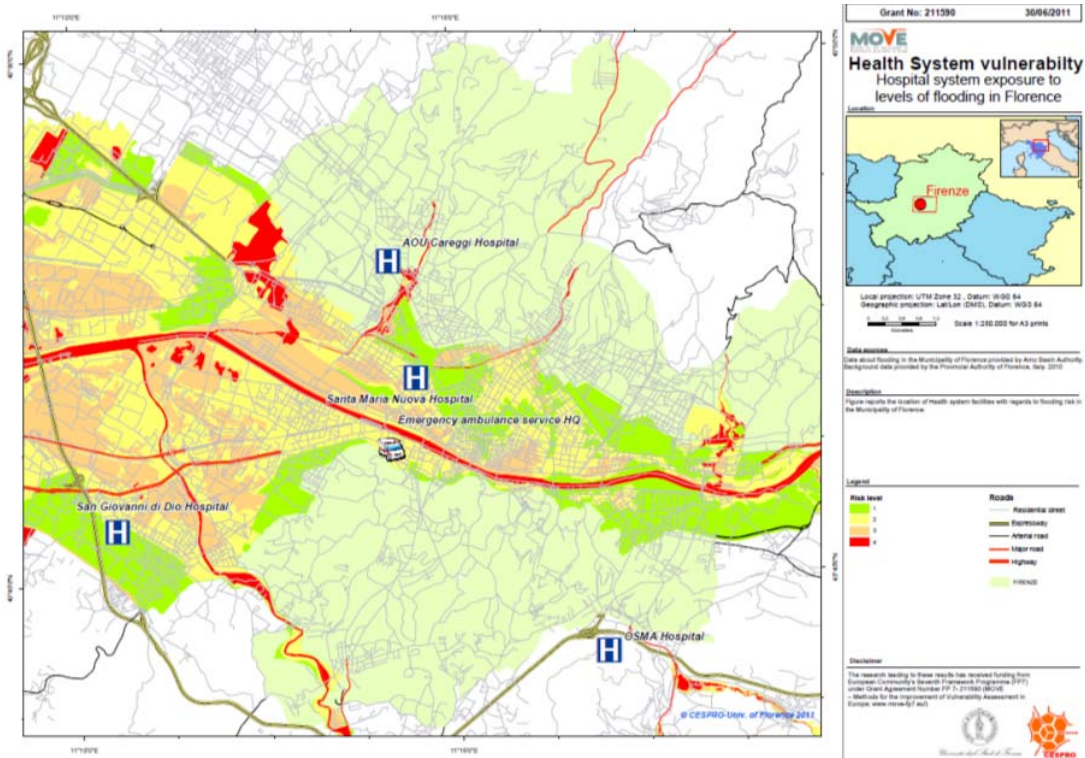


Figure 3.1 Hospital system exposure to levels of flooding in Florence.

### 3.2.3 Extreme heat waves

Unusually high ambient temperatures have long been associated with increased mortality across the world. This effect is now well known and clearly described in two reviews published in the first decade of 21st century (Basu and Samet 2002, Basu 2009). In these studies a full revision of the literature concerning this topic was carried out and studies with accurate modern statistical supports, such as time-series analysis and case-crossover approaches, reported the effect of heat on mortality in different continents. Most of studies showed that the effect of high ambient temperature on mortality is often connected with a specific kind of "heat wave". No universally accepted definition of a heat wave exists (Rikkert et al., 2009), however, this phenomenon can be considered as a period of abnormally and uncomfortably hot and usually humid weather (Glickman 2000). The effects of heat waves on human health may vary depending on the time of the year, the intensity and duration of the heat wave, individual characteristics (age, sex and pre-existing medical condition of people) and other factors (such as living alone, lack of access to transportation or living on the higher floors of multi-storey buildings). In the summer of 2003 a heat wave that was exceptional in term of duration, intensity and geographical extent occurred across most of Western Europe. As a consequence, excess mortality was attributed to the 2003 episode in many European countries. Significant effects were observed in Italy and specifically in the region of Tuscany, where a significant increase of mortality of elderly people was observed (Conti et al. 2007).

### 3.3 Vulnerability assessment methods

#### 3.3.1 Hazard scenario: Earthquakes and floods

##### General framework

One of the aims of the case study is to assess the vulnerability to earthquakes and floods of the Florence health system which is composed of five hospitals and one ambulance dispatch service. Figure 3.2 shows the MOVE general framework with an indication of which parts were evaluated in this case study.

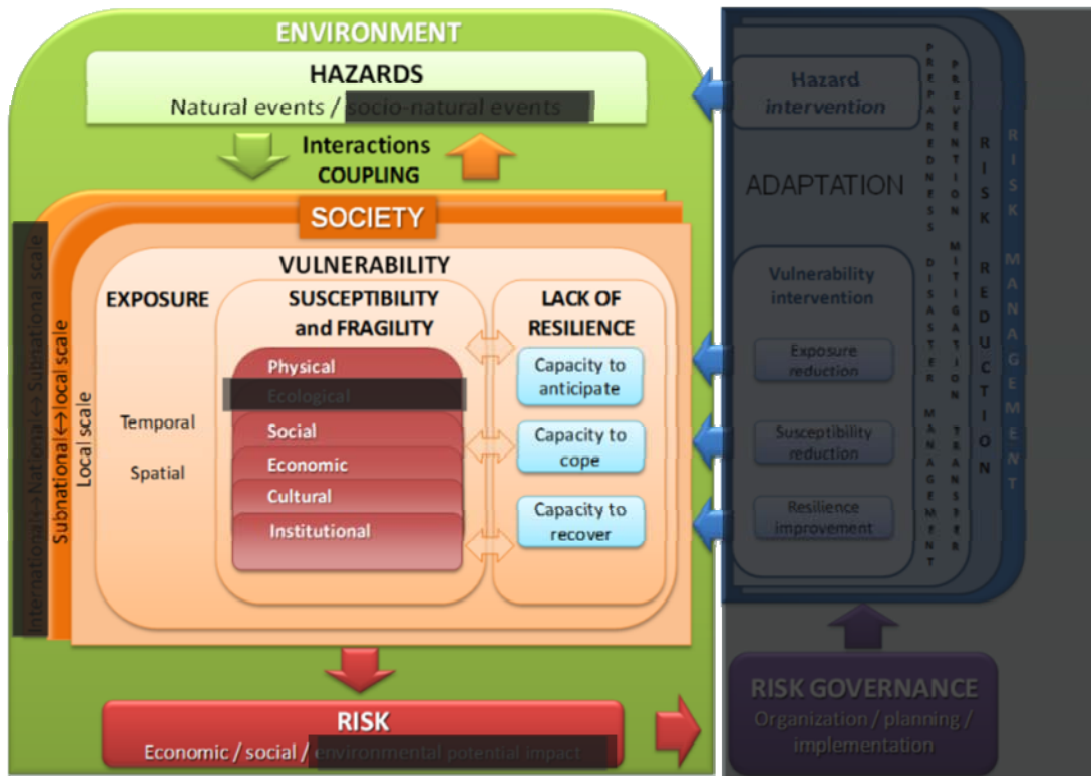


Figure 3.2 Tuscany case study (earthquake and floods hazards) within the MOVE general framework.

As the local health system is made up of different interconnected systems, the assessment utilised a bottom-up analysis from the evaluation of individual hospitals at the building scale to the general system, the provincial scale. The hospital vulnerability included consideration of the geographical and temporal exposure through the development of two scenarios representing a night-time and holiday and a day time-working day situation. The assessment included the evaluation of susceptibility and fragility and estimation of lack of resilience, as the hospital is a complex system where performance levels depend on different factors that require a multi-dimensional analysis. These include the availability of staff, organisational procedures, developmental factors and physical and architectural elements. The assessment was designed to provide a final estimation of economic vulnerability to floods and social risk in the case of both earthquake and floods.

##### Description of workflow

The methodology consisted of the following three steps:

1. Development of scenarios for floods and earthquakes.
2. Application of the Leontieff model.
3. Estimation of the performance of hospitals in crisis situations.

The scenario developed for the seismic hazard used the 1919 Mugello earthquake as a reference event and began with a bibliographic review of the event in order to acquire all available information on the geological aspects (epicentre, magnitude, geographical extent, etc.): Field work was conducted in the affected area with the aim of adapting and updating the seismic impact to the current social and environmental conditions of the area. A numerical simulation was used in order to obtain a first estimation of the expected casualties and damage levels.

The Leontieff model belongs to the world of complex systems analysis and its application to the description of complex realities such as hospitals aims to simulate their behaviour in the event of an external crisis or internal problem by carrying out a vulnerability assessment that takes into consideration how a specific failure can influence the functionality of the whole system. It takes into consideration the elements that make up the system together with their mutual interdependencies, and it quantifies the subsequent inoperability of the infrastructure, where 'inoperability of the system' is defined as its inability to perform completely its intended functions. Three elements are necessary for the application of the Leontieff model: (1) definition of the elements that compose the system; (2) definition of their connections; and (3) estimation of the inoperability vector resulting from the event. The list of hospital elements was obtained by considering the functional areas needed in the aftermath of an earthquake, as listed by the World Health Organization (see Table 3.1).

Clinical and support services	Importance in the event of an emergency
Trauma and Orthopedics	5
Intensive Care Unit / Intensive Treatment Unit	5
Urology	5
Emergency Care	5
Sterilization	5
Diagnostic Imaging	5
Pharmacy	5
Nutrition	5
Transport	5
Recovery	5
Blood Bank	5
Outpatient Consultation/Admissions	4
Pediatric Surgery	4
Pediatrics	4
Laboratory	4
Laundry Services	4
Hemodialysis	4
Internal Medicine	3
Gynecology and Obstetrics	3
Administration	3
Neonatology	3
Respiratory Medicine	2
Neurology	2
Ophthalmology	2
Filing and Case Management	2
Dermatology	1
Psychiatry	1
Oncology	1
Otorhinolaryngology	1
Dental Services	1
Therapy and Rehabilitation	1

Scale of importance:  
 5:Indispensable 4:Very necessary 3:Necessary 2:Preferable 1:Dispensable

Table 3.1. Priority definition of hospital functional areas during disasters (Source: PAHO 2000. Principles of Disaster mitigation in Health Facilities).

The definition of the connectivity of these elements involved interviews with experts such as hospital engineers and medical doctors, with the use of a fuzzy logic model based on semi-structured interviews which takes into consideration the expertise of respondents and confidence levels placed in their answers. Finally, damage estimation depends on definition of the inoperability vector, which is

based on a field survey at each hospital. In order to obtain all the multi-dimensional information about susceptibility and fragility, the vulnerability evaluation was conducted using custom-designed forms.

The evaluation of logistics and intervention capacity in the Mugello area involved fieldwork in the ten municipalities of this sub-region and observation at emergency exercises. The study commissioned an earthquake scenario, which was computed by the National Department of Civil Protection's Seismic Service and which gave data on potential damage, homelessness and distributed geographical effects of a reference earthquake in the Mugello. The damage functions and casualties were based on pre-existing surveys of the seismic performance (in fact, the vulnerability) of building stock in the area, in relation to ground response as derived from geological maps. As a reference event we used the parameters of the 1919 earthquake, as something very similar could easily occur in the Mugello area at any time, especially in the triangle bounded by the towns of Scarperia, Borgo San Lorenzo and Vicchio.

Visual analysis of townscapes revealed a number of situations of high seismic vulnerability related primarily to the following:-

- Complex building forms.
- Poor state of maintenance, especially of historical or old buildings constructed in stone masonry.
- Violations of the building codes leading to enhanced risk of collapse or battering of adjacent buildings.
- Probable loss of architectural details such as poorly secured façade mouldings and perched bell-cotes.
- Mutual battering of adjacent buildings with different fundamental periods.
- High vulnerability to collapse of the sub-regional hospital in Borgo San Lorenzo, the principal town of the Mugello.
- Blockage of access roads by the collapse of buildings that flank them, or as a result of mountain landslides, especially seismically-induced slumping and debris flows.

These are the factors that would lead to significant numbers of casualties, which in a magnitude 6.2 earthquake could well exceed 100 deaths and 300 significant injuries for the ten municipalities of the Mugello area (population 68,700 in 1,185 km<sup>2</sup>).

Analysis of response capability revealed the following problems:

- Lack of a plan and training for site management in search and rescue activities.
- Variable coordination between emergency services.
- Lack of capacity in the accident and emergency department of the local hospital.
- Possible route blockages between Mugello towns and health care facilities in Prato and Florence, just outside the area.

The analysis of deficiencies in emergency response to a seismic event was conducted in the full knowledge of civil protection and hospital emergency management authorities in Florence and Borgo San Lorenzo, who were very interested in the results. They also facilitated the study.

In the case of floods, the inoperability vector is based on the spatial exposure to water damage of essential elements. In order to assess all the elements exposed to flooding within the structure of the health system, additional evaluation forms were developed for health functions, health systems and medical devices. Table 3.2 lists the functions dealt with in the form for healthcare functions and health system elements.

HEALTH FUNCTIONS	Underground	Ground level	First level and upper
ICU		X	
EMERGENCY DEPT.		X	
DIAGNOSTIC		X	
SURGERY			X
UROLOGY			X
PHARMACY		X	
STERILIZATION			X
IN-PATIENT			X
LABORATORY		X	
BLOOD BANK		X	
<b>SYSTEMS</b>			
MEDICAL GAS CENTRAL		X	
POWER CENTRAL	X		
UPS AND BACK UP GENERATORS	X		
DATA AND SERVERS		X	

Table 3.2. Evaluation form for vulnerability to floods of health functions and systems in hospitals.

The estimation of hospital performance took into consideration both the capacity to treat casualties and intrinsic security. Hospital treatment capacity (HTC) was calculated as shown in Equation 1, where  $\alpha$  (0-1) is the organisational operability,  $\beta$  (0-1) represents the staff operability,  $\gamma_1$  is the number of surgical tables,  $\gamma_2$  (0-1) is the performance level of the surgical area, and  $t_m$  is the standardised time required to carry out a general surgical operation.

$$(1) \quad \text{HTC} = \alpha \times \beta \times (\gamma_1 \times \gamma_2) / t_m \quad [\text{n}^\circ \text{ treated patients/h}]$$

Intrinsic security (IS) was estimated as shown in Equation 2. It evaluated the security of “regular” inpatients ( $\gamma_3$ ) in relation to structural resilience ( $\Gamma_2$ ) and intensive care unit (ICU) patients ( $\gamma_4$ ) according to the ICU performance of this sector ( $\rho_2$ ).

$$(2) \quad \text{IS} = \alpha \times \beta \times [(\gamma_3 \times \Gamma_2) + (\gamma_4 \times \rho_2)] / (\gamma_3 + \gamma_4)$$

Finally, the hospital performance index (HPI) is the linear combination of the IS and the hospital treatment capacity index (HTCI), which is the HTC normalized with the expected average surgical demand per hour (as obtained by numerical simulation). The definition of the weights “ $\eta$ ” and “ $\theta$ ” depended on the type of hospital: city hospital ( $\eta = 3, \theta = 2$ ), rural hospital ( $\eta = 2, \theta = 3$ ), or small city hospital ( $\eta = 2, \theta = 2$ ).

$$\text{HPI} = [\eta \times \text{HTCI} + \theta \times \text{IS}] / (\eta + \theta)$$

### 3.3.2 Hazard scenario: Extreme heat waves

#### General framework

The aim of the present work was to detect the temporal modification of the heat-related mortality of older adults ( $\geq 65$  years) living in the Florence area of Tuscany, comparing the four previous and subsequent years with the summer of 2003 (i.e., 1999-2002 and 2004-2007 vs 2003). These dates respectively cover the periods before and after the setting up of a regional heat warning system. It is plausible that, as a consequence of the marked increase interest in the problem as a result of the 2003 heat wave in Europe, heat-related mortality risk may have been reduced thanks to the increased awareness of risks related to extreme high temperatures, the institution of preventative measures and, in particular, the setting up of a local heat waves warning system.

#### Description of workflow

##### Mortality data

Mortality data in the Florence area of central Italy was provided by the Registry of Deaths of the Region of Tuscany. The geographical reference area (Lat.  $43^{\circ}50'$  N, Long.  $11^{\circ}05'$  E) is homogeneous from the climatic point of view in that it has a Mediterranean climate. It includes the municipalities of Calenzano, Campi Bisenzio, Fiesole, Lastra a Signa, Scandicci, Sesto Fiorentino, Signa, Firenze, Agliana, Montale, Pistoia, Serravalle Pistoiese, Quarrata, Carmignano, Montemurlo, Poggio a Caiano, Prato and Vaiano.

Criteria for inclusion criteria were the selection of older adults ( $\geq 65$  years) who were resident in the municipalities considered in this study and who died in this geographical area from a non-violent cause (ICD9<800).

Mortality data were collected during the warmest period of the year (from May until September) from 1999 to 2007 ( $n=21,092$ ).

The choice of the Florence area for the case study was governed mainly by the availability of mortality and weather data for two different time periods (four years before and after 2003) characterised respectively by the absence and presence of a heat warning system set up as a preventative measure after the disastrous 2003 heat wave.

#### Weather data and biometeorological index assessment.

Two different sources of weather data were used: a) daily average data on air temperature and relative humidity obtained from the National Centres for Environmental Prediction (NCEP) - Department of Energy (DOE) Reanalysis 2 (Kanamitsu et al. 2002), a set of gridded data on weather observations that is freely available online (<http://www.esrl.noaa.gov/psd/>); b) hourly data on air temperature and relative humidity provided by four meteorological stations located in urban environments in the geographical reference area.

The sources of weather data from reanalysis and meteorological stations were used to assess daily average values of apparent temperatures for the whole study area. In addition, daily maximum and minimum apparent temperatures were also calculated using hourly data from the local meteorological stations. For these purposes we used the apparent temperature (AT) index (Steadman 1984), which combines air temperature and relative humidity to evaluate human discomfort due to hot weather conditions. The formula was as follows:-

$$AT = -1.3 + (0.92 \cdot Ta) + (2.2 \cdot e)$$

where  $T_a$  is the air temperature ( $^{\circ}\text{C}$ ) and  $e$  is the vapour pressure (hPa).

New time series of daily average, maximum and minimum apparent temperatures ( $AT_{ave}$ ,  $AT_{max}$  and  $AT_{min}$  respectively) were calculated by averaging the assessed AT on a specific day with the value calculated for the previous day ( $lag_{0-1}$ ).



## Statistical analysis

The analyses were conducted for the 9-year period (1999-2007) covering the entire warm period that for this study geographical area is generally considered to extend from 15 May to 15 September. First, descriptive statistical analyses were carried out to describe the mortality trend and the apparent temperature distribution over the period under study. For this purpose, the degree of variation in mortality and apparent temperatures among sub-periods was investigated by non-parametric (Kruskal-Wallis) and parametric (ANOVA) tests respectively. Multiple comparisons between subgroups were tested with the Wilcoxon and the Bonferroni tests.

The time-series approach was employed by using the generalized additive model (GAM) framework (Hastie and Tibshirani 1990) with a Poisson link assumption for the dependent variable that in our case was represented by mortality. GAM functions were systematically used over the whole period to estimate the smoothed shape of exposure-response curves between mortality and the set of independent biometeorological variables:  $AT_{ave}$  obtained from reanalysis (rea) or meteorological station (met),  $AT_{max}$  and  $AT_{min}$ . All independent biometeorological variables were added to the regression equation as a penalised spline (Wood 2000). Breakpoints were then identified corresponding to critical thresholds of AT where the linear relation changes and where the mortality variable starts to increase. These analyses were performed using two statistical packages of R software version 2.8.1 (The R Foundation for Statistical Computing, 2008): “mgcv” (Wood 2006) for GAM procedure and the “segmented” approach (Muggeo 2003) for the evaluation of breakpoints.

Breakpoints detection (i.e., critical thresholds) was then used in the following analyses designed to investigate variations in the heat-related mortality risk through a case-crossover design. Critical thresholds were used for case/control identification. A case-crossover design was individually applied during 2003 and in three sub-periods: 1) 1999-2002 (before 2003); 2) 2004-5 (immediately after 2003); 3) 2006-7 (some years after 2003). The reason why the four-year sub-period after 2003 was divided in further two two-year sub-periods is because immediately after 2003 (2004-5) the heat warning system was only used in an experimental way for the city of Florence, while the other municipalities considered in this study were completely excluded. On the other hand, some years after 2003 (2006-7), the heat warning system was officially working and extended to all municipalities in the Florence area (and eventually to all of Tuscany).

All these analyses were stratified by age and were carried out in the total sample of people  $\geq 65$ , in subjects aged 65-74 and in elderly people aged  $\geq 75$ . In addition, because it is well known that the effect of excessive heat on mortality is not limited to same-day exposure but extends to several subsequent days, further analyses were carried out in order to account for the prolonged effects of high apparent temperature on time series of mortality, “the distributed lag effects” and the possible “harvesting” effect. For this reason, a new approach was applied. Named the “constrained segmented distributed lag model”, it involved a multi-lag segmented approximation in order to account for the non-linear effect of apparent temperature and the use of two different penalised spline bases to model the distributed lag of heat exposure (Muggeo and Hajat 2009).

The general hypothesis was that the variation in heat-related mortality risk suffered a change after 2003, because of the establishment of the local heat warning system.

## 3.4 Indicators

### 3.4.1 Earthquakes and floods

Regarding earthquakes, every indicator belongs to the vulnerability level and can be more precisely classified as indicator for:-

- Exposure
- susceptibility and fragility
- capacity to cope
- capacity to anticipate.

The list referring to the first group of indicators is reported in Figure 3.3 and is divided into three sub-classes according to their main dimension: structural, non-structural or organizational. The exposure indicators refer to geological aspects, such as:-

- soil conditions [EC 8]
- expected seismic intensity
- local seismicity.

The capacity to cope is estimated by the HTC, and HTCI while the capacity to anticipate is evaluated by IS.

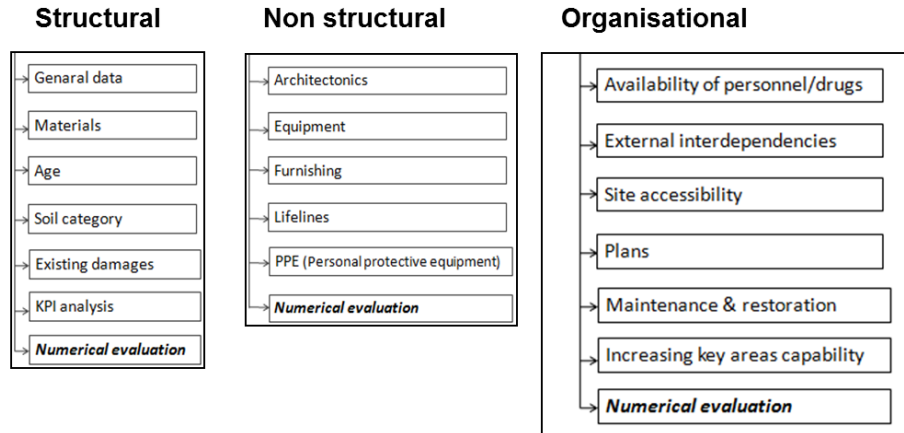


Figure 3.3 Seismic susceptibility and fragility indicators.

Regarding floods, every indicator belongs to the vulnerability level and can be more precisely classified as an indication of:-

- susceptibility and fragility
- exposure
- capacity to cope
- capacity to anticipate
- capacity to recover.

Susceptibility and fragility indicators only take into consideration economic aspects such as the economic loss due of technology due to floods. Exposure is evaluated by the following indicators:-

- number of floodable systems
- number of floodable hospitals
- number of floodable medical devices.

As well as earthquakes, evaluation of capacity to cope in the case of floods is based on HTC and HTCI. Capacity to anticipate considers IS while capacity to recovery is related to the total economic losses, as non-structural elements represent 90 per cent of the hospital costs and values.

### 3.4.2 Extreme heat waves

The indicators developed and applied in this study are:

1. Temporal series of apparent temperature (AT) during the warmest period of the year (15 May to 15 September) through the 9-year period in the Florentine area;

2. Mortality data for not violent causes during the warmest period of the year (15 May to 15 September) stratified by age, through the 9-year period in the Florentine area;
3. Specific critical thresholds of AT where mortality significantly started to increase.

The choices of these indicators are prevalently based on the pre-existing literature and on the base of available data.

### 3.5 Results & Validation

#### 3.5.1 Earthquakes and floods

Figure 3.4 reports the seismic degradation levels assessed for single hospital in terms of performance loss by comparing pre- and post-event conditions during working day time. The provincial health response degradation is about – 33.39%.

The holiday and night scenario brings to a -63.17% health response degradation. The higher level is due to organisational reasons such as presence of staff and number of hospital and ICU beds to care.

The lower presence of staff within the structure depends on organizational and decision which make the most of medical personnel only available on call.

Even if it is a rational choice, the availability on call is a really vulnerable element in case of earthquake, since it depends on road viability conditions.

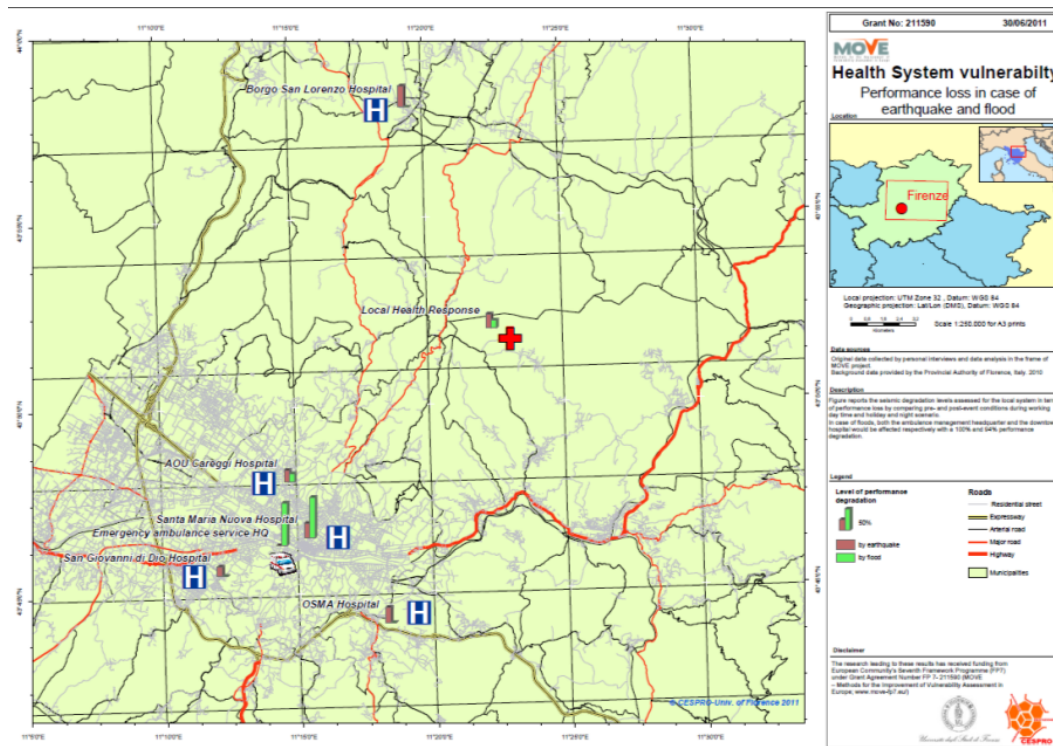


Figure 3.4 Results for Florence health system performance degradations.

In case of floods, both the ambulance management headquarter and the downtown hospital would be affected respectively with a 100% and 94% performance degradation.

The estimated loss of technology consisted of 692 medical devices on a total of 1486 resulting in economic loss of around 3.110.000,00 €.

No scientific validation was carried out but only a users' confirmation of the results. It consisted in periodic meeting with the following stakeholder formally involved: ASF- Florence Health System, AOUC – main Florence Hospital, the Provincial Civil Protection Office of Florence and the Municipal Civil Protection Office of Florence.

### 3.5.2 Extreme heat waves

The main findings of this study are:

A general decrease of heat-related mortality OR starting from the four years before 2003 (when the heat warning system was absent) to the four years afterwards (characterized by the setting up of the heat warning system) was only observed when the  $AT_{max}$  was considered.

This trend was particularly evident when the mortality of elderly people aged  $\geq 75$  was considered. On the other hand, no relationships were found when mortality of subjects aged 65-74 was considered.

The change in mortality for a 1°C increase in  $AT_{max}$  was significantly higher and the heat effect was sustained for more days (until lag 9) during the four-year period without a heat warning system (1999-2002) than during the period 2004-7. In addition a clear harvesting effect was only observed in the four-year period before 2003.

The opportunity arises to use gridded weather data (reanalysis) in environmental epidemiology and in this case for heat-related mortality analyses.

In particular the decrease of the heat-related mortality OR evidenced in this study might also be explained as a consequence of all the preventative public health measures and interventions developed in Italy, and obviously in the Tuscany region, after the notorious European heat wave of 2003. This pattern was especially evident for elderly people ( $\geq 75$  years old), who are at greater risk of mortality than the younger population ( $< 75$ ).

## 3.6 Discussion

The methodology described in this section was useful to stakeholders, with the creation of worst-case scenarios for vulnerability, risk and impact, and their validation and checking through focus-group meetings with stakeholders. The results provide important information for real-time evaluation during normal civil protection and risk management work and during emergency situations, especially considering the single hospital and local health system response to crises and natural disasters.

The system-wide response of health structures is fundamental in planning for a better distribution of resources in order to increase the capacity to cope with and anticipate crises. Economic evaluation was also valuable, as it represents one of the main elements on which institutional decision makers found their planning activities. Finally, the development of a more complete index for the evaluation of hospital performance represented one of the main scientific success of this case study research.

## 3.7 Conclusions and recommendations

For the case of earthquakes and floods, the results showed that health system responses strongly depend on temporal as well as geographical exposure, as the staffing and organisational aspects strongly depend on the time and the day of occurrence of the event. Furthermore, although the analysis focused on the capacity to cope in aftermath of an incident or disaster, in the case of floods, the huge loss of technology and systems predicted by this investigation is equivalent to a large economic and functional loss of the healthcare structure with possible descent to zero treatment capacity, not merely immediately during an impact, also in the longer term.

The study highlighted the lack of a systematic approach the culture of disaster management planning, where, especially for vulnerability assessment of healthcare responses, which is a complex problem, a systemic approach is necessary at both the hospital and local scales. Even though the study showed a lack of communication and co-operation among institutions, these showed a high level of interest in improving their co-operation levels and manifestly support the ideas produced by this study.

For the extreme heat waves, the study clearly shows the impact of excessively hot weather on mortality between periods characterised by the lack and the institution of a heat warning system. People at highest risk are prevalently elderly and aged at least 75 years. The reduction of the heat effect on mortality and the decline in its distributed lag effect in the years after the summer 2003 can reasonably be attributed to the institution of specific preventative measures put into action by the Tuscan Regional Government, in particular the setting up of a reliable heat wave warning system with specific programmed activities that involve healthcare workers in safeguarding the lives of the so-called “frail elderly”.

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## 4 Vulnerability to Heatwaves, Floods and Earthquakes in an Urban Area: Test Case in Cologne, Germany

Torsten Welle, Marjory Angignard, Yaella Depietri and Jörn Birkmann.

### 4.1 The Cologne Urban area

The study area is the Cologne urban area situated in central-western Germany at 50°52' northerly width and 7°05' easterly length in the state of North Rhine Westphalia (NRW) Federal State along the river Rhine (figure 4.1). Cologne is located within the Cologne Bight which is an orographic depression between the Central German uplands and the North German lowlands. The Cologne Bight forms a plain geomorphic delta which expands to North West and slopes towards the Lower Rhine Lowlands and which is localized by the Bergisches Land in the East and the Siebengebirge in the South. The study area has a temperate-oceanic climate with relatively mild winters and warm summers. The average annual temperature ranges between 9,5 – 10,5 °C and the average annual precipitation ranges between 750-900 mm (Kuttler et al. 1997). Cologne is the largest city both in NRW and within the Rhine-Ruhr Metropolitan Area, with around 1 million inhabitants and is the 4th largest city in Germany. The urban area, ranges from industrial sites, inner harbours, historic city centres, residential areas from different periods and with different vegetation portion, mixed residential and industrial areas to parks and fallow land. In the environs of the Cologne and along the river Rhine, the land use pattern composes mainly of agricultural land with corn, sugar beet and forests as well as several artificial lakes (Braun and Herold, 2003). The city is divided into 85 city districts which are again divided into 370 city quarters. From the socio-economic point of view, the vast majority of the lowest status neighbourhoods are clustered in two parts of the city: larger one is located east of the river Rhine and the second one is located northwest of the city (Wolf 2002). The city districts with the highest social status are more dispersed, though most of them are located at the border of the city (Wolf 2002).

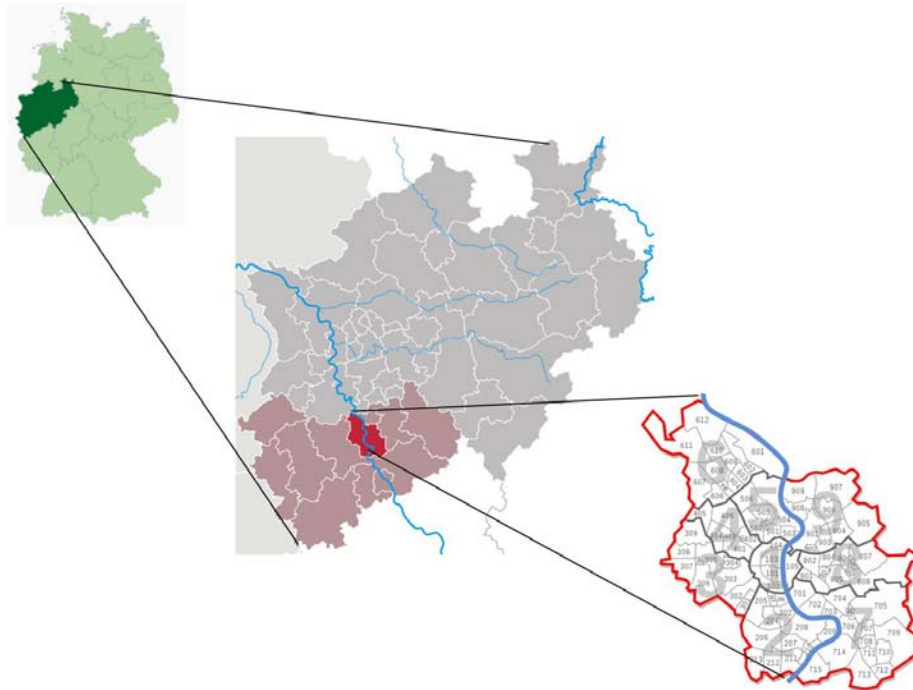


Figure 4.1 The state of North Rhine Westphalia situated in Germany and the state of North Rhine Westphalia and the Cologne urban area highlighted in red (Source: Wikipedia 2008)

In this case study the operationalisation of the MOVE framework for vulnerability assessment of an urban area is performed considering the social, ecological and institutional dimension of vulnerability to floods, heat waves and earthquakes. The assessment of the social dimension of vulnerability to heat waves and floods was carried out on city quarter level (local scale). For the ecological assessment we assume that urban ecosystems are those in which people live at high densities, or where the built infrastructure covers a large portion of the land surface (Pickett et al., 2001). Urban ecosystems can be composed of a series of single ecosystems: street trees, lawns/parks, urban forests, cultivated land, wetlands lakes/sea, and streams (Bolund and Hunhammar, 1999). The assessment was done on district level.

The institutional dimension of vulnerability is mainly related to various institutions that deal with risk management focusing especially on earthquakes. Finally, the coupling between the social and ecological dimension were also taken into account in our assessment.

Several stakeholders of the City of Cologne were contacted and interviewed in order to gather information and data, discuss the methodology and the outcomes of the study. Close Cooperation was taking place with following departments: environmental department, statistical department and city development, Parks and open space department, the Flood protection center and the geological survey of North Rhine Westphalia.

## 4.2 The Hazards

The following chapter focuses on three hazards that can occur in the city of Cologne. The first one is heat waves that can lead to major threats in future especially due to Climate Change. Floods are the second hazard that has a long history in Cologne since the largest river of Germany – the Rhine – flows through the city. Cologne is also at risk of earthquakes due to the fact that the Cologne Bight is a part of the rhenish earthquake zone which range from Basel in Switzerland to the BENELUX countries (see figure earthquake 4.2).

### 4.2.1 Heat waves

Heat waves are extreme events associated with particularly hot sustained temperatures able to produce notable impacts on human mortality and morbidity, regional economies, and ecosystems (Meehl and Tebaldi, 2004, Koppe et al., 2004). There exist no common definition of heat waves but they can be defined as occurring when temperatures exceed both daytime high and night-time low thresholds (Vescovi et al., 2005). Drouin et al. (2005) defined an operational definition based on daytime high of 30 °C (Tmax) and nighttime low of 22°C (Tmin) for three consecutive days. More than half of the world's population lives in cities, where the combination of extreme heat events and the urban heat island (UHI) effect, produce negative health outcomes (Wilhelmi & Hayden, 2010) such as skin eruptions, heat fatigue, heat cramps, heat syncope, heat exhaustion and heat stroke (Koppe et al. 2004). The UHI effect is an important human impact on the local climate of cities reflecting the temperature difference between an urban area and the rural surroundings which is due to heat storage in buildings and sealed roads (Gabriel & Endlicher, 2011).

Alteration of the land surface and atmosphere by urban development leads to the creation of distinct urban climates (Grimmond et al., 2004). The abundance of vegetation cover is important in urban areas. Healthy green vegetation absorbs up to 90 % of the photosynthetically active radiation (visible red) while reflecting 40 to 50 % of near infrared radiation. Built up and impervious surfaces are stronger absorbers and the radiation is then slowly re-emitted as long-wave radiation that is responsible of warming up the boundary layer of the atmosphere within the urban canopy layer (Oke, 1988).

Two main well documented examples of the past are the Chicago 1995 heat wave, which led to at least 700 excess deaths most of which were classified as heat-related (Semenza et al., 1996), and the



European 2003 heat wave, which caused the death of 15.000 persons only in France (Fouillet et al., 2006). All over Europe approx. 50000 excess deaths are attributed to the extreme temperatures, with mortality rates highest in older age groups (see eg. Brückner, 2005; Vescovi et al, 2005). Besides age also other factors are relevant to contribute to above normal mortality rates, such as the duration and intensity of a period with heat stress (Gabriel & Endlicher 2011, Huynen et al, 2001) or the urban structure with its degree of sealed area (Elliasson & Upmanis, 2000). The reason for the 2003 heat wave could be seen in a large precipitation deficit together with early vegetation green-up due to springtime warmth and strong positive radiative anomalies in the months preceding the extreme summer event in 2003 contributed to an early and rapid loss of soil moisture (Fischer et al., 2007, Zaitchik et al., 2006, Ciais et al., 2005). Lower water table levels were also measured in urban areas (Scalenghe & Marsan, 2009). The summer 2003 in Europe was by far the hottest since 1500 AD (Luterbacher et al., 2004) and it seems that heat waves will become more intense, longer lasting, and or more frequent in future warmer climates (Luber & McGeehin, 2008, Meehl & Tebaldi, 2004).

In the summer 2003, in much of Europe reduced crop yields and shortages in green fodder supply caused major financial losses to farmers (Fink et al., 2004), Reichstein et al. 2007). No shortages in drinking water supplies occurred in Germany due to a sufficient replenishment of groundwater resources and reservoirs in the previous period (Fink et al 2004). Another impact affected the power trade market. Several power plants had to reduce outputs due to lack of cooling water. In the eastern border of the Netherlands where the Rhine reached the temperature of 23 °C (Fink et al 2004). In August the lowest discharges at Cologne since 1930 were observed: the minimum water level at Cologne in September 2003 was 81 cm, the lowest gauge height on record (Fink et al 2004). Importantly, glacier melt prevented even lower water level in the Rhine. However this gauge height hampered shipping and caused therefore economic losses.

#### 4.2.2 Floods

Until the 19th century, flooding was frequent in the Rhine but affecting a little human population (Pinter et al., 2006). Regulation of the river in the 19th and 20th century rendered large scale inundation of the Rhine floodplain less frequent but it simultaneously encouraged human encroachment, which has made recent floods much more hazardous.

According to Frijters & Leentvaar (2003), since the Rhine has become a navigable waterway and flood control measures have been taken, such as the construction of dikes along the Upper and Lower Rhine, large stretches of floodplains have been lost. Along the Upper Rhine, the loss of alluvial areas has reached dangerous proportions. Between 1955 and 1977, more than half of the former flooding zones along the Upper Rhine were protected against inundation and are now inhabited and used for farming. Consequently, the habitats of animal and plant species depending on the alluvial areas have been reduced drastically. These radical measures increased the sensitivity of the Rhine ecosystem to disturbances.

Cologne is considered the most flood prone area in Europe. Between 1900 and 2000 Rhine floods at Cologne occurred almost exclusively during winter (Pinter et al., 2006). Peak flows at this station and for the century documented an upward trend with an average increase of about 25%. One of the main drivers of this change, which led to the magnification of flooding in the area, seems to be anthropogenic or otherwise due to climate change.

Fink et al. (1996) analysed the 1995 flood event, in particular describe the snowmelt and precipitation that occurred between the 20th and 30th of January. On 30 January the water level at Cologne rose to 10.69m. This was the value reached during the great New Year flood of 1926 and 6 cm more than the third worst flood since 1780, which occurred at Christmas 1993 (Fink et al., 1996). Factors which contributed to the extreme flood were of 1995: record-rainfall events partly augmented by snowmelt, many tributaries reached flooding levels due to precipitations, the extreme duration of the flood levels of the Mosel which interfered with surges coming down the Rhine, the rainfall event on the Sauerland and the small additional inflow of the river Sieg, which drains into the Rhine a few kilometres upstream of Cologne. In Cologne the ancient city and some low lying suburbs were flooded. Regarding economic losses, preliminary estimates were put at 65 million German Marks (circa 37.5 million Euro). Four people lost their life. Economic losses were about half those of December 1993 (110 million

German Marks circa 55 million Euro) as the population was better prepared and the warning were made much earlier.

Already after 1977, extensive retention measures along the main stream have been planned and partially implemented in the Rhine (Petrow & Merz, 2009). Averaged across many flood events, the river training works have increased the flood peaks at Cologne and the retention measures have decreased the peaks, however to a smaller extent (Petrow & Merz, 2009). After the 1993 and 1995 floods, at the beginning of the 1996 an agenda was established: “the flood protection concept for Cologne”. Already after the 1993 flood some measure were taken which largely reduced the damages and losses caused by the impacts of the 1995 flood. The flood protection concept emphasised the importance of retention measures and strengthened them through the reconstruction of embankments in the hinterland, reshaping brooks in a natural way, unsealing areas of increasing seepage and structural flood mitigations like mobile walls, dikes or flood detention constructions, Until 2008 altogether 400 million Euro were invested in order to protect Cologne up to 11.30 m level and the more endangered parts will be protected up to 11.90m.

### 4.2.3 Earthquake

The region of Cologne is crossed by the Lower Rhine Graben. In this area, earthquakes are very frequent: between 1976 and 2002 the Bensberg station measured more than 1300 quakes in the area. However, most of them are too light to be felt by humans or cause damages. In recent history, only the 1992 Roermond quake reminded inhabitants of the Cologne area that they live under a seismic threat. Although the even killed only one person, and injured 25, 7200 buildings were damaged, and the total amount of losses reached €150 million.

Seismologists reckon that quakes with a magnitude of 6,7 happened in the past, and could still hit the region. This would obviously cause severe damages. A large part of the building stock in Cologne was erected in the 1950s, after the destructions of World War II. If recent constructions have to comply to building codes (among which paraseismic rules), the older stock is not designed to resist earthquakes. The infrastructure could also suffer major damages. In addition, the presence of industrial sites near Cologne could lead to severe secondary effects.

Earthquakes cannot be predicted; however a dense network of stations (operated by different institutions such as the University of Cologne or the geological Survey of North Rhine Westphalia) is constantly monitoring the region. Following map shows the different earthquake zones in Germany Grünthal et al. (2004).

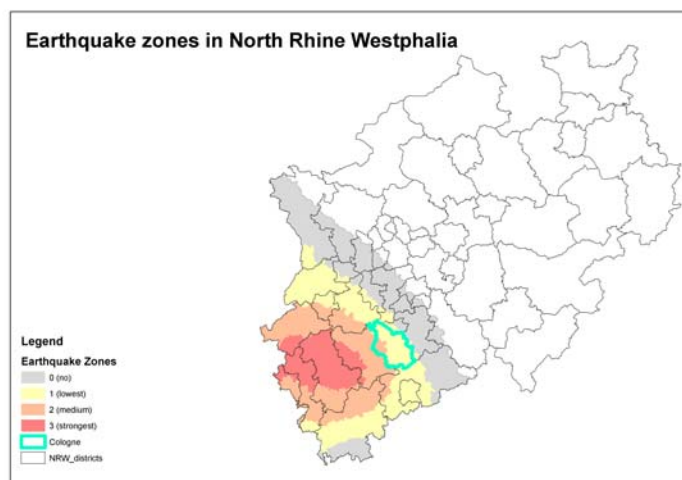


Figure 4.2 Different earthquake zones in North Rhine Westphalia and highlighted in cyan the district of Cologne (Source: UNU-EHS).

### 4.3 Vulnerability assessment

In order to conduct a vulnerability assessment one would need a theoretical background on which any vulnerability assessment methods are based on. This theoretical background was developed within the EU funded project MOVE (Methods for the improvement of vulnerability assessment in Europe). The MOVE Generic Framework addresses vulnerability and disaster risk to natural hazards from a holistic and multidimensional point of view. (see figure 4.3). The diagram of the MOVE framework aims to make an initial identification of elements of coupled social-ecological systems that shape vulnerability outcomes.

The method presented in this study foresees to assess vulnerability taking into account the following terms in the MOVE framework: hazards, coupling, exposure, susceptibility and lack of resilience encompassing the following dimensions: ecological, social and institutional; including the interactions between the different concepts.

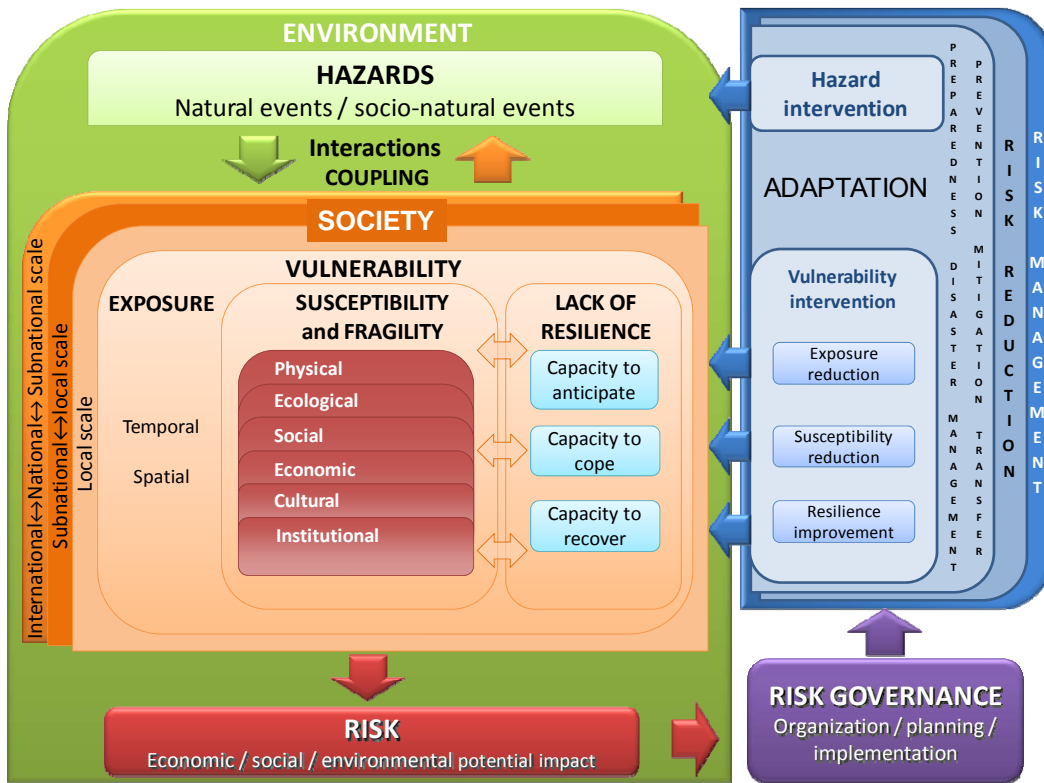


Figure 4.3 The MOVE Generic Framework (Source: MOVE Consortium).

#### 4.3.1 Social dimension

Vulnerability assessment in general focuses on the likelihood of injury, loss, disruption of livelihood and other harm in an extreme event and /or the unusual difficulties in recovering (Wisner et al. 2004, p. 13; Wisner 2002, p. 12/7). Therefore the focus of the vulnerability assessment should lie on the identification of the variables that cause the vulnerability of people and that represent major differences in the (potential and revealed) susceptibility of the population. With respect to the MOVE project the social dimension refers to human welfare including social integration, mental and physical health, both at an individual and collective level.

In the following several vulnerability assessment steps were presented:

The framework was translated into following equation:

$$\text{Vulnerability} = \text{Exposure} \times \left( \frac{\text{Susceptibility} + \text{Lack of resilience}}{2} \right)$$

Equation 1: Aggregation of components of vulnerability

Selection of adequate indicators and methods used:

The identification of adequate indicators and methods for each component of vulnerability such as exposure, susceptibility and lack of resilience is shown in figure 4.4. While the exposure component clearly aims to identify the number of people exposed to selected hazards (i.e. heat waves and floods), the susceptibility and coping capacity focus more in depth on factors that causes the vulnerability of people and their response capacities. The exposure with respect to heat waves was derived by using thermal remote sensing data in order to detect warm surfaces within cities which represent the urban heat island effect, since surface characteristics of the UHI appear to be the main contributor to heat load rather than population density itself (Johnsons & Wilson, 2009). Socio demographic and socio-economic data were used to derive the susceptibility and lack of resilience for the city of Cologne. All components of vulnerability have been normalized and weighted in order to aggregate them to one vulnerability index. The weighting was mainly done by expert judgments and the aggregation according to equation 1.

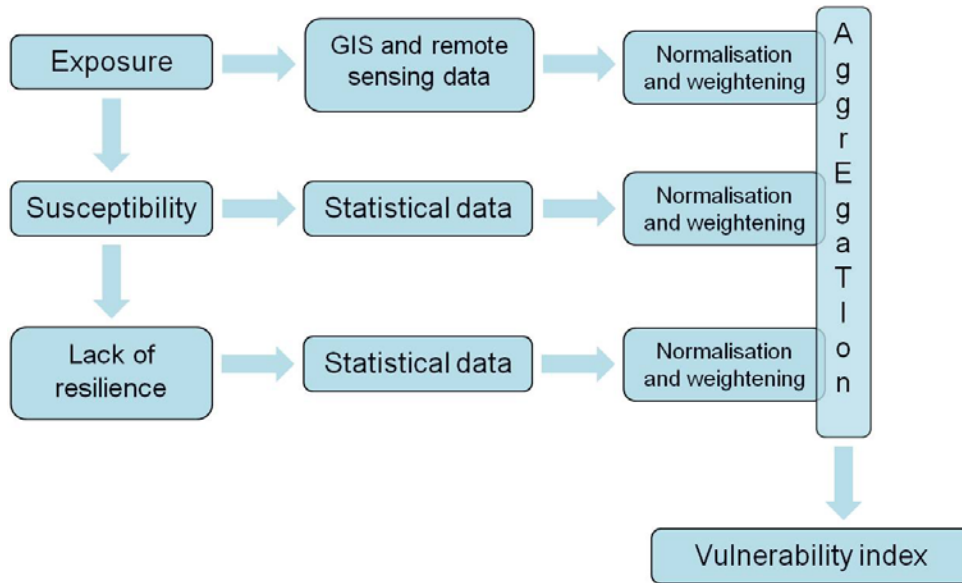


Figure 4.4 Workflow for the vulnerability assessment (socio-ecological dimension) in Cologne (source: UNU-EHS).

### 4.3.2 The ecological dimension

The ecological dimension refers to all ecological and bio-physical systems and their different functions. According to Fisher et al. (2009) such ecological functions and processes become services if there are humans that benefit from them: without human beneficiaries there are no services. In this sense the environment, its landscape and biodiversity is valued for the social and economic services it provides. Such ecosystem services include provisioning services for instance food and water; regulating services such as regulation of floods, droughts, land degradation, and disease; supporting services such as soil formation and nutrient cycling, and cultural services for example recreational, spiritual, religious and other non-material benefits” (MA 2005).

To assess ecosystem services and manage them, one must know what they are, their location, abundance, rate of renewal and resilience. Various evaluation approaches of ecosystem services exist: economic evaluations, ecological function analysis or value-based social assessments. The supply of ecosystem services is related to natural conditions (e.g. land cover, hydrology, soil conditions, fauna and climate). Using land cover information (e.g. remote sensing, simulation models, GIS and statistics), the state of ecosystems and their capacities to supply ecosystem services can be assessed and transferred to maps.

For heat waves we considered two ecosystem services: air quality regulation and climate regulation. According to various authors air pollution, due to higher concentrations during heat waves, can lead to an increase of excess deaths, while the UHI effect contributes to the increase of the impacts of heat waves in urban areas. In this respect green areas have both the capacity to strip pollutants from the air and to lower the temperatures in cities at least at the local scale.

### **4.3.3 Coupled social-ecological dimension**

For heat waves we calculated the vulnerability of the coupled social ecological system. We considered that the impact of heat waves on the population is not only the result of socio-economic factors but it also mediated by the characteristics of the urban ecosystem. As mentioned above, the presence of ecosystems, such as green areas can provide important services (i.e. climate and air quality regulation) to cope with the adverse impacts of heat waves. For the calculation of the vulnerability of the social ecological system, the calculations of the social dimension were recalculated at the district level to be integrated with the indicators of the ecological dimension.

### **4.3.4 Institutional dimension**

Institutional dimension refers to the organizational form and function as well as guiding legal and cultural rules.

For the assessment of the institutional dimension, the above mentioned stakeholders were interviewed in order to receive an understanding of how processes and structures are perceived within institutions. Figure 4.5 shows the workflow for the assessment of the institutional dimension of vulnerability.

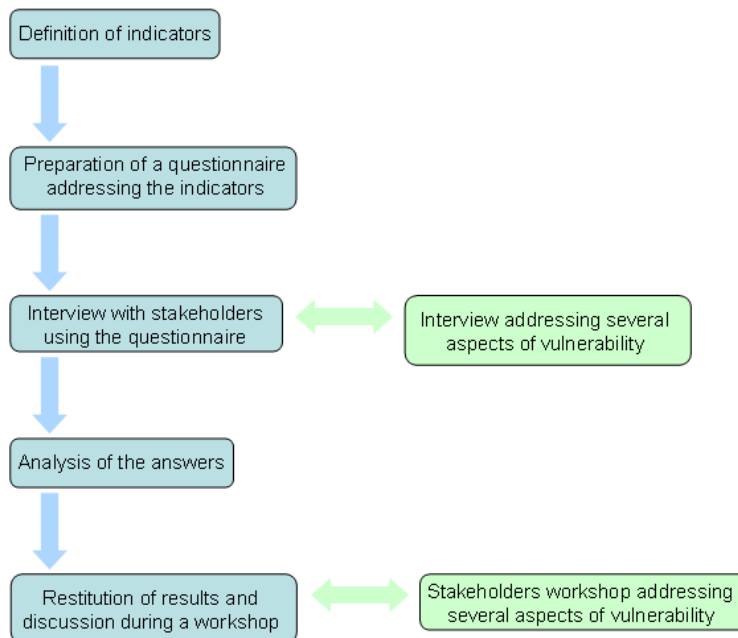


Figure 4.5 Workflow to assess the institutional dimension of vulnerability.

The indicators chosen were semi quantitative: the information is clearly qualitative, and is assessed on a 5 level scale. The indicators were not weighed but all represented on a graph (see results).

## 4.4 Indicators

According to Figure 4.4 relevant indicators for the respective components of vulnerability as well as for the different dimensions are identified. First we describe the indicators for the social dimension of vulnerability towards heat waves and afterwards for the hazard flood. Furthermore the indicators for the ecological dimension and the coupling process through relevant indicators of social and ecological dimensions are presented. Concluding the institutional dimensions and their relevant indicators are outlined.

### 4.4.1 Indicators used for the social dimension of vulnerability towards heat waves

Exposure indicators are defined in time and space as the number of people that are exposed to heat waves related to the administrative units within the city of Cologne. This was calculated using the number of inhabitants per city districts (370 city districts in Cologne) multiplied by the normalized mean surface temperature per city district in Cologne which was derived from thermal infrared satellite imagery. The thermal scan was conducted on 30th June, 1993 for the night image at 9 pm and 1st July, 1993 at 4 am for the day image.

Susceptibility indicators measure the predisposition of a society and ecosystems to suffer harm resulting from the levels of susceptibilities or fragilities of settlements and disadvantageous conditions and relative weaknesses related ecological issues. For the case study Cologne the susceptibility indicators were derived from statistical data. Based on literature review (e.g. Semenza et al. 1996; Brücker, 2005; Brown & Walker, 2008; Ebi, 2008; Fouillet et al., 2006; Klinenberg, 2001; Wilhelm & Hayden, 2010) and experience from major heat events in Chicago 1995 and Europe 2003 it was

shown that especially age and health conditions, socio-economic and socio-cultural factors are main drivers that shape people's vulnerability. In this context and based on discussions during expert workshops following indicators for susceptibility were chosen for Cologne:

- Indicator 1: agegroups (AG) 0-5 years + AG >65 years, (% of susceptible population/city district).
- Indicator 2: unemployment rate/city district [%], (Proxy: low income).
- Indicator 3: foreigner/city district [%] (Proxy: problems in understanding of warning messages).
- Indicator 4: elderly households/city district [%].

Due to expert judgements following weights were chosen: 0.6 for indicator 1, 0.1 for indicator 2, 0.1 for indicator 3 and 0.2 for indicator 4.

Lack of resilience indicators measure the limitations in access to and mobilization of the resources of the social-ecological system, and the incapacity to respond in absorbing the impact. This factor of vulnerability includes the capacity to anticipate, cope and recover in the short term. The selection of indicators that emphasize capacities to strengthen the resilience of people move beyond quantitative aggregate demographic data toward understanding knowledge, attitudes and practices of individuals (Wilhelmi & Hayden, 2010). This information is not available on city district level because it needs to be gained through qualitative research. Therefore based on the knowledge of understanding safety nets in the form of social networks following assumption was made: the bigger one household (HH) is the more HH-member are available and could take care of elderly, invalids and children. This indicator should serve as a proxy for social networks and it is available on city district level and related to the MOVE-framework we would assign it to coping capacity. The HH-sizes were weightened according to equation (2a) and (2b).

$$\text{Coping Capacity} = (1 \cdot 5\text{HH} + 0,8 \cdot 4\text{HH} + 0,6 \cdot 3\text{HH} + 0,4 \cdot 2\text{HH} + 0,2 \cdot 1\text{HH}) / \text{number HH} \quad (2a)$$

$$\text{Lack of Coping Capacity} = 1 - \text{Coping Capacity} \quad (2b)$$

#### 4.4.2 Indicators used for the social dimension of vulnerability towards floods

The Exposure indicator for floods was derived by calculating the number of people that are affected by an extreme flooding event (EHQ 500). For this reason relevant data is needed such as the flooding hazard layer which is a product of a hydrological model showing the inundated areas and inundation depth within the city of Cologne and demographic data. The flooding hazard layer was combined with the population data taken into account the population distribution in order to calculate the potential number of exposed people affected by an extreme flooding event (HQ 500).

Susceptibility indicators were once again derived from statistical data taken into account the experience and knowledge of previous studies. Fekete (2010) provides a table of indicators that shows characteristics of higher vulnerability related to those studies where e.g. old people suffer physical and health consequences (Steinführer & Kuhlicke, 2007) and are less capable of performing emergency measures effectively (Thieken et al., 2007). Also very young people, who need more time to evacuate (Birkmann et al., 2008) and lower income which has shown a lesser degree of insurance are relevant indicators to describe the susceptibility (Steinführer & Kuhlicke, 2007). Additionally education and household size were identified as adequate indicators, since low educated people receive less support and are less capable of performing emergency measures effectively (Steinführer & Kuhlicke, 2007, Thieken et al., 2007). Birkmann (2007) and Kreibich et al. (2005) found out that one person households consider themselves dependent on others in case of an evacuation and that they spend the least amount of money for flood protection. Based on available data provided by the statistical department of Cologne following indicators were chosen:

- Indicator 1: agegroups (AG) 0-5 years + AG >65 years, (% of susceptible population/city district).
- Indicator 2: unemployment rate/city district [%], (Proxy: low income).

- Indicator 3: foreigner/city district [%] (Proxy: problems in understanding of warning messages).
- Indicator 4: elderly households/city district [%].
- Indicator 5: recipient of social benefit/city district [%], (Proxy: low income).

Characteristics that strengthen the resilience of people are according to studies from Steinführer & Kuhlicke (2007), Birkmann et al. (2008) and Thieken et al. (2007) higher income and higher education as well as household size was taken into account since it correlates with effective emergency measures (Thieken et al., 2007). According to Birkmann et al. (2010) the building height is also a relevant indicator since buildings with more than one level allow in general for vertical evacuation in the event of a flood. Due to data limitations only data related to building height of each building within Cologne could be obtained. This information is based on a lidar data set which was converted into a vector data set representing specific characteristics of each building within Cologne. Hence the building height was chosen to characterize the ability to cope during a flooding event. It was calculated by taking the ratio of exposed buildings and exposed buildings higher than 4 m.

$$\text{Coping Capacity} = \frac{\text{exposed buildings per city district}}{\text{exposed buildings} > 4 \text{ m per city district}} \quad (3a)$$

$$\text{Lack of Coping Capacity} = 1 - \text{Coping Capacity} \quad (3b)$$

#### 4.4.3 Indicators used for the ecological dimension of vulnerability towards heat waves

The ecological dimension was integrated in the calculation as a contribution to the Lack of resilience and subsequently used for the assessment of the coupled social-ecological vulnerability. The Lack of Resilience indicator measures the limitations in access and mobilization of resources in the system, and the incapacity to respond in absorbing the impact. It was assumed that different land cover types have different capacities to provide ecosystem services.

The lack of resilience component was computed using following equation:

$$\text{Climate indicator} = 1 - (\text{percentage of green and water areas per district} * \text{climate regulation}) \quad (4a)$$

$$\text{Air quality indicator} = 1 - (\text{percentage of green area} * \text{air quality regulation}) \quad (4b)$$

The green areas include the grassland, coniferous forest, deciduous forest, mixed forest and acre classes. Burkhard et al. (2009) analysed existing landscape data to evaluate the capacities to provide ecosystem services in spatial manner. As a first step they linked expert judgement to the different land cover types' capacities to provide various ecosystem services. In Table 4.1 we reported the capacity expressed as coefficients of the different land cover types taken into account to provide the two ecosystem services considered: climate regulation and air quality regulation.

Ecosystem services Land cover / use classes	Climate regulation	Air quality regulation
Continuous urban fabric (= other sealed areas / sealed high)	0	0
Discontinuous urban fabric (= sealing low / middle)	0	0
Complex cultivation patterns (=acre)	2	1



Ecosystem services Land cover / use classes	Climate regulation	Air quality regulation
Broad leaved forest (=deciduous forest)	5	5
Coniferous forest (=coniferous forest)	5	5
Mixed forest (=mixed forest)	5	5
Natural grassland (=grassland)	2	0
Water bodies (=water bodies)	2	0

Table 4.1. Matrix for the assessment of different land cover types capacity to provide the selected ecosystems services (derived from Burkhard et al. (2009)).

The coefficient of the different land cover types were assigned according to Table 4.1. The “Lack of resilience” indicator was also normalized using the above- mentioned normalization method.

#### 4.4.4 Indicators used for the calculation of the vulnerability of the social ecological system

The exposure was calculated by multiplying the population data in Cologne with the mean temperature for each district. The susceptibility was calculated applying the same susceptibility indicators used for the social dimension (see above) but at the district level. The lack of resilience was calculated by aggregating the social indicator (i.e. the household size) with the indicators for the lack of resilience according to the following formula:

$$\text{Lack of resilience} = 0,6 * \text{social indicator} + 0,2 * \text{climate indicator} + 0,2 * \text{air quality indicator}$$

The different weights have been attributed taking into consideration that the social dimension plays a major role with respect to ecosystem services in providing coping strategies. This needs adequate verification through expert judgment.

#### 4.4.5 Indicators used for the institutional dimension of vulnerability towards earthquakes, floods and heat waves

Concerning institutional vulnerability, following 15 indicators were used which cover several aspects of institutional vulnerability: principles, aim, trust, internal accountability, external accountability, justification, representation, access to information, tolerance towards the process, dialogue, financial resources, staff resources, role of experts, coordination, cooperation. These indicators were derived from past projects, in which they had been tested and validated. Each indicator was applied to the three hazards considered in this case study (earthquakes, floods, heat waves).

### 4.5 Results

The results of the three components of vulnerability such as exposure, susceptibility and coping capacity are derived individually and are displayed in separate maps (figure 5.6–5.15) for all

dimensions besides the institutional dimension. The aggregation of the components is done according to equation 1 in order to obtain one vulnerability index and displayed in figure 9. For the spatial analysis and mapping, the values of the calculated indices were separated into five classes using the quantile classification method, which is integrated within ArcGIS 9.3.

### 4.5.1 Results for the social vulnerability towards heat waves

Each component for vulnerability as it is defined in the MOVE framework could be displayed. Thus figure 4.6 shows the result for the exposure. The exposure in this study was dependent on the surface properties and their heat capacity for each city quarter in combination with the respective population. Hence, the different city quarters could be identified with the highest and lowest number of exposed people. In general a heterogeneous pattern of exposure could be identified where the city quarters east of the river Rhine show a lower degree of exposed people than the quarters west of the river Rhine.

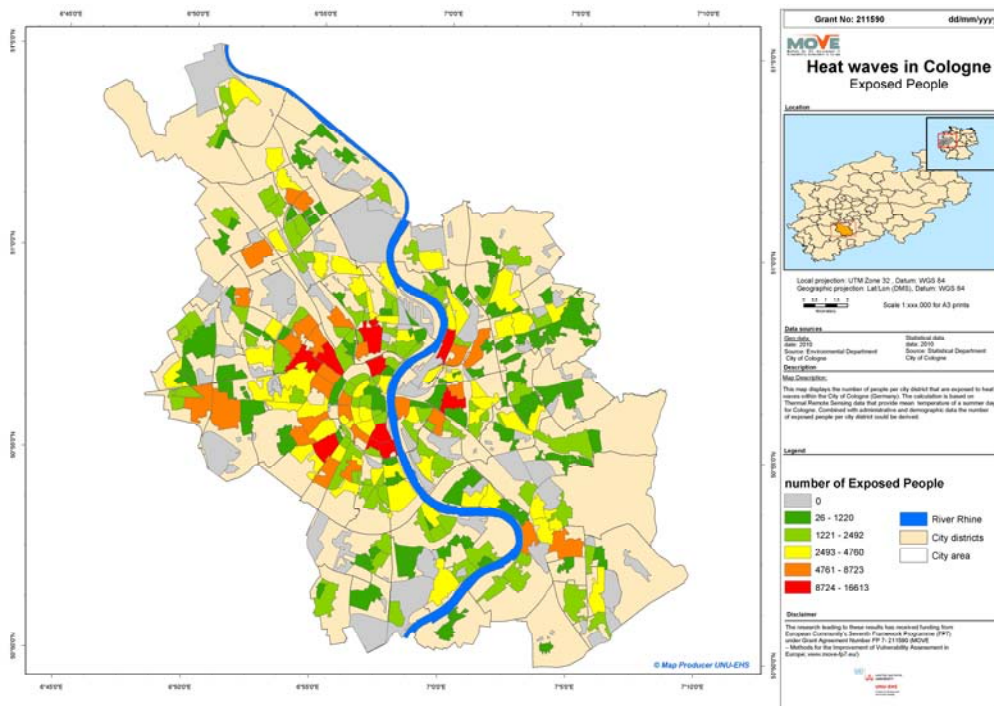


Figure 4.6 Exposure map of Cologne related to heat waves.

The result for the susceptibility to heat waves within the city of Cologne is represented in figure 4.7. The four indicators for susceptibility are mainly based on socio-economic information obtained from the statistical department of the City of Cologne. It is clear that the city centre of Cologne besides two city quarters (Villen Viertel und Andreas Viertel) ranks in the second lowest susceptibility class since these quarters are preferred by single and younger households such as students. The more susceptible city quarters are located in the outskirts of Cologne.

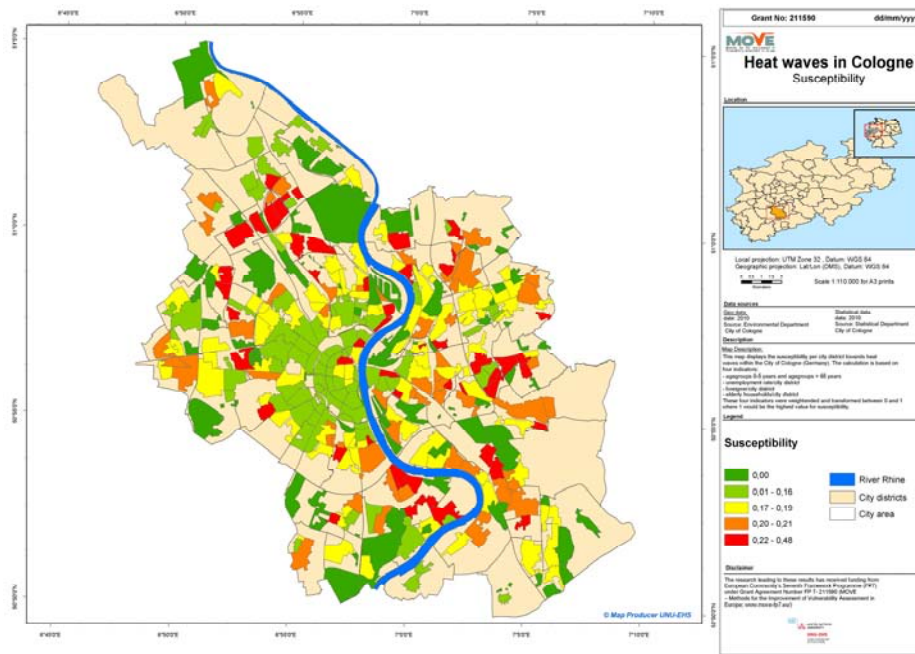


Figure 4.7 Susceptibility map of Cologne related to heat waves.

The lack of resilience, in detail the lack of coping capacity is shown in figure 4.8. Since this indicator is mainly focusing on household size an inverse picture compared to the susceptibility map is noticeable. It could be seen that the city centre has a high lack of coping capacity since mainly single households are located in the city centre.

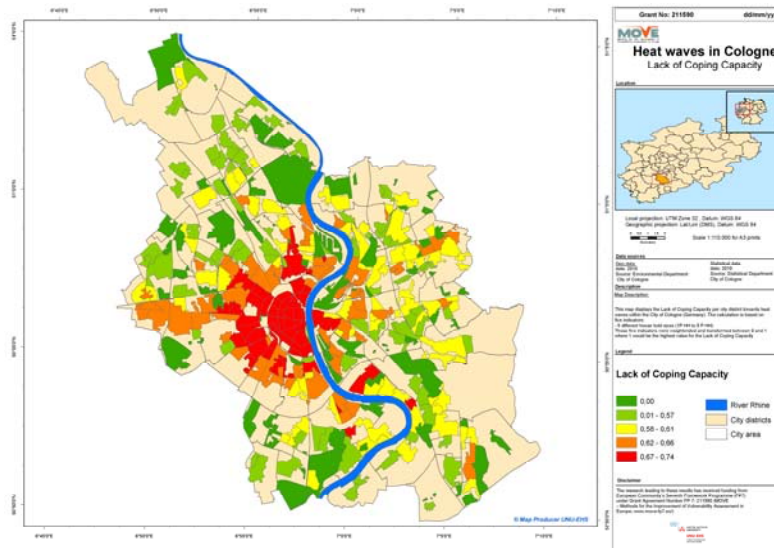


Figure 4.8 Lack of coping capacity map of Cologne related to heat waves.

According to Equation 1 all components of vulnerability are aggregated to one vulnerability index. Figure 4.9 illustrates the different vulnerability pattern towards heat waves in Cologne. The most vulnerable city quarters are located close to the City Centre whereas the outskirts are in general less

vulnerable. Again the western part of Cologne shows more vulnerable city quarters than city quarters east of the Rhine.

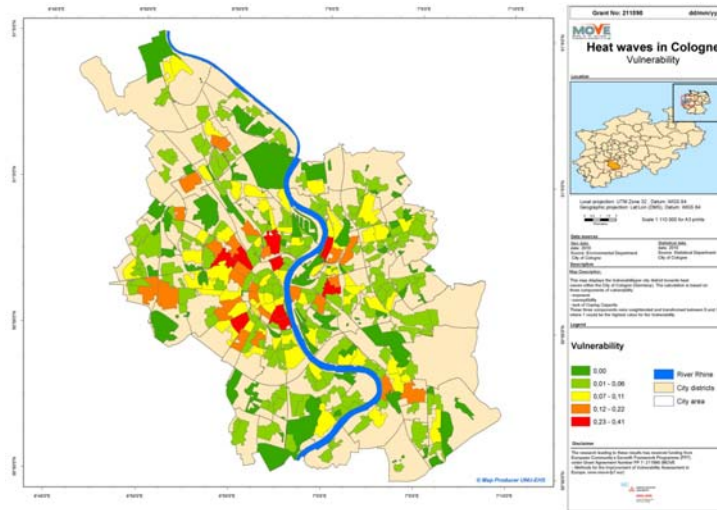


Figure 4.9 Vulnerability map of Cologne related to heat waves.

#### 4.5.2 Results for the social vulnerability towards floods

Figure 4.10 shows the results for the flood (EHQ) exposure within Cologne. Compared to the exposure to heat waves the calculation or detection of exposed areas and exposed people is more explicit since the hazard and its extent could be clearly identified based on the modelled hazard layer. Thus the most exposed people are within the city quarters that are located along the Rhine.

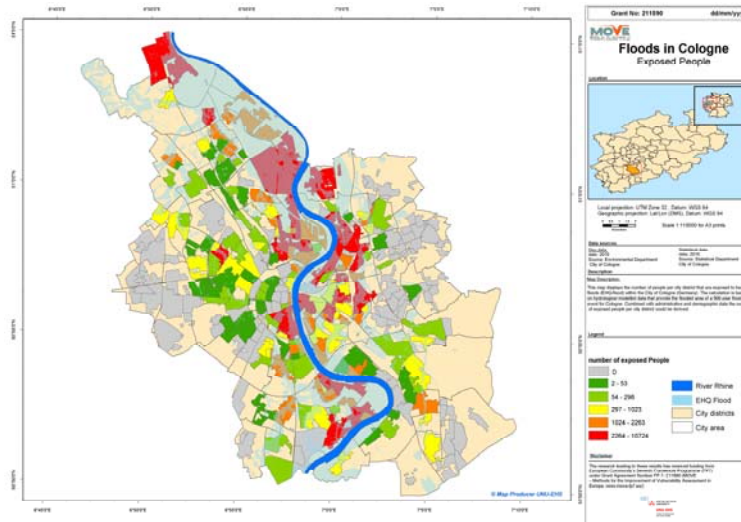


Figure 4.3 Exposure map of Cologne related to floods.

The susceptibility was calculated only for the exposed city quarters. Based on the calculation the most susceptible city quarters are east of the Rhine as well as in the north western part of Cologne. Less susceptible quarters could be identified around the city centre (figure 4.11).

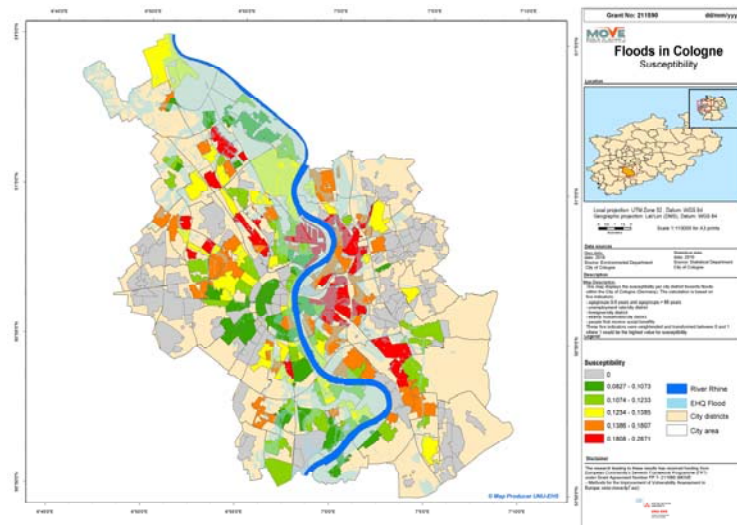


Figure 4.11 Susceptibility map for Cologne related to floods.

Figure 5.12 shows the results for the calculation of the lack of coping capacity towards floods in Cologne. Since this indicator reflects mainly the building heights for each city quarter the highest coping capacity is within as well as close to the city centre. City quarters with a high percentage of one family houses have a potentially higher lack of coping capacity which could be seen for instance in Raderberg, Lindweiler and the Sechzigviertel.

The overall vulnerability map with respect to floods is displayed in figure 4.13. The hot spots of vulnerability are located along the river and in the northern part of the City. In the western part of Cologne low vulnerability values could be identified since these city quarters are less exposed, less susceptible and offer a higher degree of coping capacities as compared to those quarters located along the river Rhine.

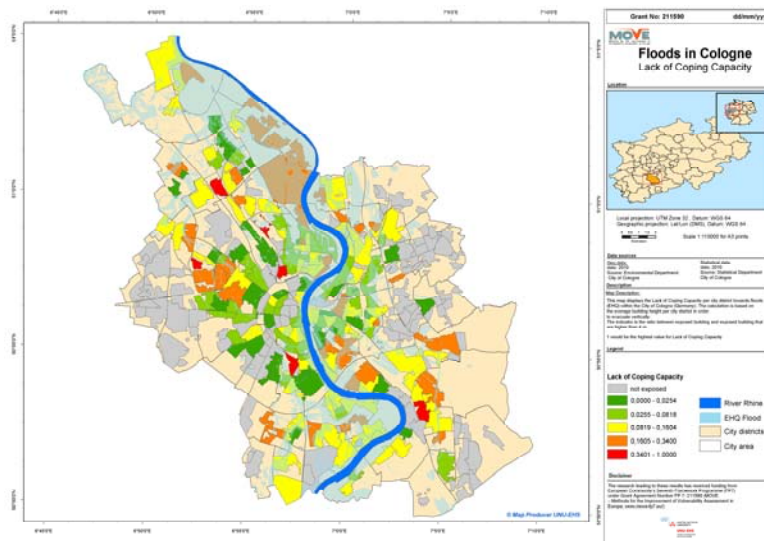


Figure 4.12 Lack of coping capacity map of Cologne related to heat waves.

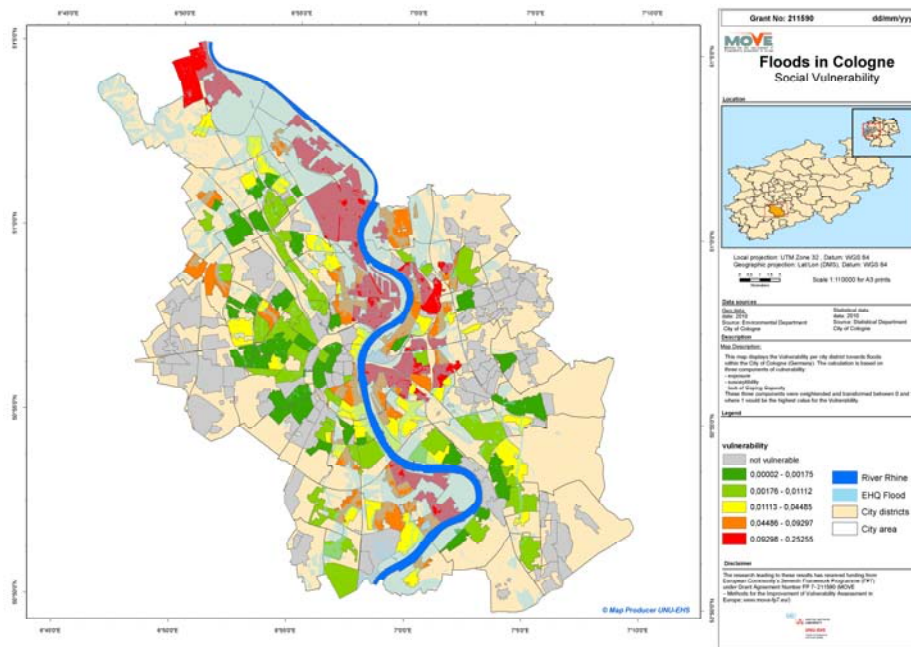


Figure 4.4 Vulnerability map of Cologne related to floods.

### 4.5.3 Results for the assessment of the vulnerability of the social ecological system

The maps obtained for the three components are reported in the figure 4.14.

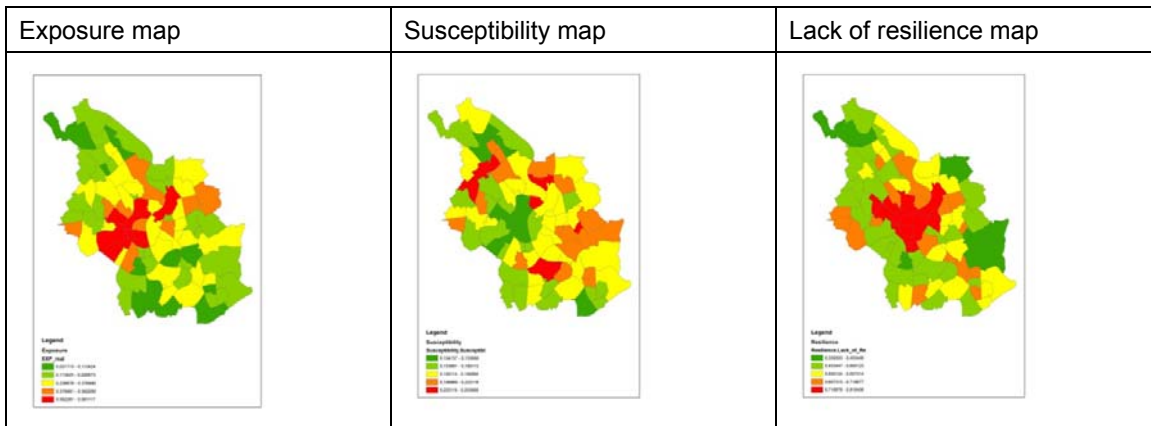


Figure 4.5 Three components of vulnerability of the social ecological system.

As shown the maps the most exposed districts are the ones in the city centre where the UHI effect is higher due to higher concentration of buildings. As already described for the social dimension the most susceptible districts are the ones at the outskirts of the city. While for the lack of resilience it is clear that the district located in the city centre are the ones which present fewer green areas and in which are concentrated single households. The vulnerability map (figure 4.15) was obtained by applying equation 1 also used for the social dimension.

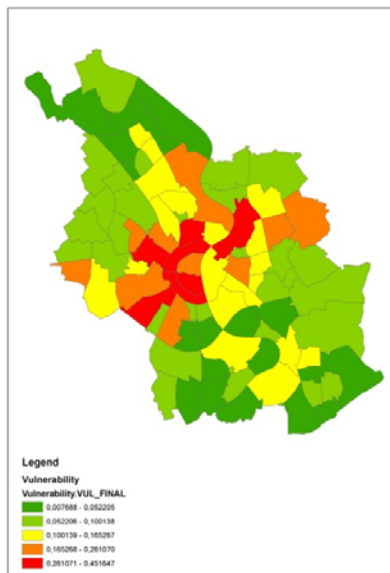
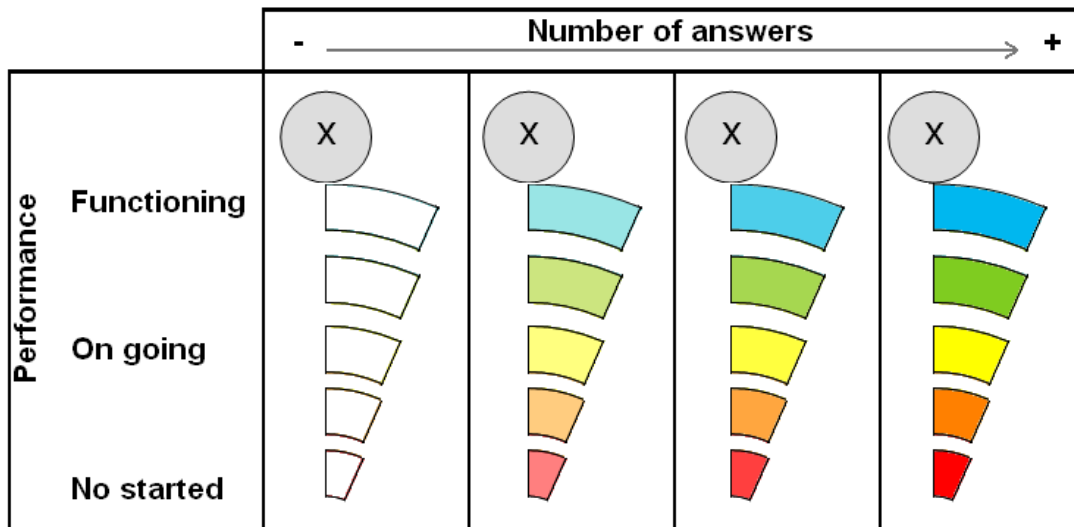


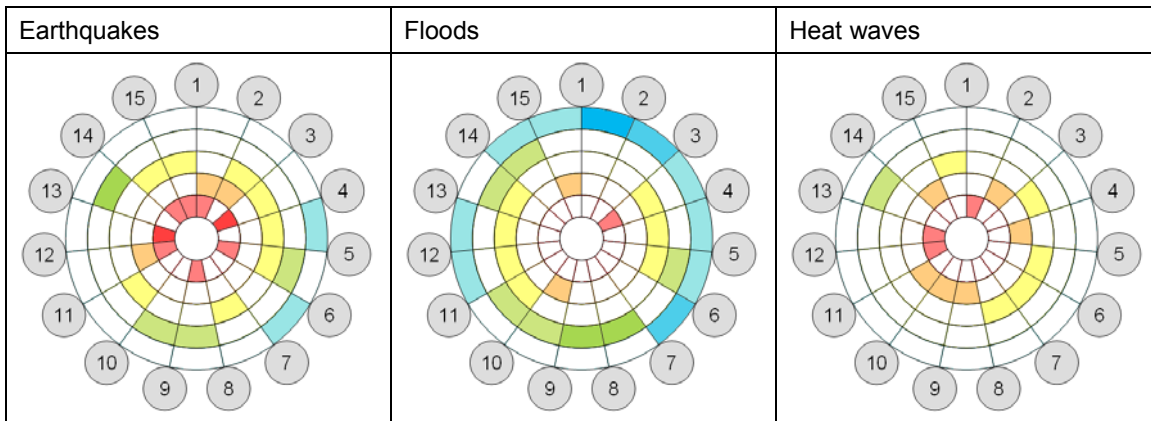
Figure 4.6 Vulnerability map of Cologne related to the social ecological system.

The vulnerability map related to the social ecological system indicates that the most vulnerable districts are the ones concentrated in the city centre. The most vulnerable population to heat waves reside mostly alone and at the core of the urban area of Cologne which presents fewer green spaces. This information can provide urban planners with indication about hotspots.

#### 4.5.4 Results the institutional dimension of vulnerability towards earthquakes, floods and heat waves

The answers of the stakeholders are represented in the graphs below





- |                           |                                 |                        |
|---------------------------|---------------------------------|------------------------|
| 1 Principles              | 6 Justification                 | 11 Financial resources |
| 2 Aim                     | 7 Representation                | 12 Staff resources     |
| 3 Trust                   | 8 Access to information         | 13 Role of experts     |
| 4 Internal accountability | 9 Tolerance towards the process | 14 Coordination        |
| 5 External accountability | 10 Dialogue                     | 15 Cooperation         |

Figure 4.7 Results of the stakeholders regarding institutional vulnerability.

The performance of risk governance processes is hazard dependant. It can be clearly seen that floods are already well addressed, as the performances of the associated risk governance process are seen as good in most domains. Earthquakes, although the risk is known of the authorities and stakeholders, does not benefit of the same attention. If scientists and experts have a clear role, the lack of risk management policy appears as a major problem. Heat waves have a specific status in Cologne: attention on the question was raised recently (e.g. summer of 2003), and the willingness to address it was immediately expressed. However, the risk management policies are still being defined, and it is too soon to give an opinion on their performance. Uncertainties still have to be waived, and regular repetition of a similar study would be of interest to monitor the evolution.

## 4.6 Discussion

In general it could be stated that the methods used allow the assessment of vulnerability towards different hazards in an urban areas such as Cologne. Besides the known fact that working with indicators and indices never give a perfect account of a theoretical concept and finally the development of indices is a systematic and creative process, in which representative data and variables must be identified, gathered, obtained or calculated and evaluated to solve certain problems. However the advantage of an aggregated vulnerability index is to reduce a complex situation to one single value, which allows grasping the current situation at one glance. The individual components also the aggregated vulnerability index could be used for communication and public relations and can serve as first basis for decision-making. The validity of the indicators has been validated by external stakeholders but still there are a lot of uncertainties with respect to the evaluation and validation as well as limitations such as data availability and the matter of scale. The results for each dimension and component of vulnerability are dependent on the availability and the accuracy of the indicators obtained. Also the weights of the individual indicators that are presented here could change e.g. through another stakeholders opinion which on the other hand leads to another spatial pattern of the considered component such as susceptibility.



## 4.7 Conclusions and recommendations

It was shown that the theoretical MOVE framework could be applied to different hazards (heat waves and floods) to different dimensions (social, ecological, coupled social-ecological and institutional) as well as to different scales within a city (city quarters and city districts). The presented methods are related to the resources that stakeholders in Cologne were also using therefore a transferability of these methods is guaranteed. During stakeholder workshops, bilateral cooperation and not least through the results of the assessment of the institutional vulnerability it should be mentioned that the perception and the importance of the studied hazards is completely unbalanced for Cologne. Thus the awareness within the city and its authorities with respect to other hazards than flood should be raised.

The presented results especially with respect to heat waves could be used for spatial planning considering climate change adaptation issues.

Ecosystem services such as climate regulation and air quality regulation play an important role in the assessment of the vulnerability to heat waves in urban areas and should be taken into account. Ecosystem services can buffer the effect of hazards in urban areas and the role of ecosystems should be taken into account by the urban planners, especially in the context of future climatic change.

Further steps include the collection of relevant data to draw the spatial distribution of air pollution which also contributes in determining the exposure of the urban population to heat waves.

In general the theoretical concept of the MOVE framework and the presented results should serve as a communication tool through several authorities within Cologne in order to strengthen the resilience of Cologne against natural hazards such as floods, earthquakes and heat waves.

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## 5 Vulnerability to Drought and Heatwave in London: Revealing Institutionally Configured Risk

Rukhe Zehra Zaidi and Mark Pelling.

### 5.1 Case study description

The case study conducted by King's College London examined two hazard types for the city of London: Drought and Heat waves. For both hazards, risk management structures at the city and local level were examined as an indication of the level of vulnerability existing in the system.

#### Heat wave

For the heat wave hazard, a city-wide approach was adopted to understand risk management in London since the procedures and management structures in place to deal with heat waves hazards are enforced uniformly across the city. This also involved incorporating elements of national risk management since the national Heatwave Plan is implemented by the National Health Service (NHS). Stakeholders and study participants included representatives from the Met Office, national and city level government officers, academics, and emergency management experts. The study established the procedures present for heat wave risk management and explored their impact and robustness in conjunction with practitioners and managers of heat wave risk in London.

The adaptive capacity for heat waves risk at the local level was examined by using Tanja Wolf's doctoral research on heat wave vulnerability mapping to identify groups that are most at risk to heat wave hazards in London – i.e. elderly and disabled individuals requiring care – and investigating the incorporation of heat wave risk management in care practices. Given the complexity of care provision in London, two local councils of Waltham Forest and Hackney were selected for field research, featuring four types of care provision: nursing homes, care homes, sheltered housing, and in-community care. The results were combined to provide a qualitative assessment of preparedness, risk management, and vulnerability to heat waves in London.

#### 5.1.1 Drought

For the drought hazard, a cross-city sample was taken for both the risk management and local adaptive capacity elements of the study. This is due to the fact that water provision across the capital is fairly equitable and well-regulated, offering a uniform level of service delivery across all local councils. In order to assess the management of drought risk at the city level, water providers, regulating authorities, local government officials, and corporate documentation on drought management procedures were consulted for data collection. Using this data, the structure of drought management practices was established and its robustness explored. The adaptive capacity to drought risk at the local level was conducted by identifying ecological, economic, social, cultural and institutional aspects of drought risk for local level organizations directly affected by water shortages. Using interviews and expert analysis the risk management practices of these organizations were explored, and their degree of preparedness and disaster planning and awareness assessed as an indicator of local adaptive capacity to drought risk in London.

### 5.2 Hazards

## 5.2.1 Heat wave

The irregular nature of heat waves, including variations manifested in frequency, magnitude, severity, duration, areal extent and onset speed, had led to a lack of consistency in their definition. In general, Meehl et al (2004) associate such extreme events with particularly hot sustained temperatures that produce notable impacts on human mortality, regional economies, and ecosystems. Similarly, McGregor et al. (2007) consider heat waves to be ‘periods of “anomalous” heat that generate a societal response’. The World Meteorological Society describes heat waves as periods of warm weather lasting for more than five consecutive days, with temperatures that are five degrees in excess of the average maximum temperature for that region. This criterion for heat waves is applied in the UK by the Met Office, with the daytime temperature threshold for most regions in the country set at 30°C. However, taking into account the urban island effect and meteorological conditions across the south east of the country, this average is 2°C higher for the city of London.

Exposure to extreme heat can cause death if the human body is no longer able to maintain its required temperature through circulation. The ambient temperature at which a body is at risk for heat-related health problems varies with the climatic conditions to which an individual is acclimatized. High levels of humidity and air pollution can compound the effects of heat waves by hindering respiratory function or the cooling processes of the body through perspiration. Heat wave mortality is predominantly caused by underlying cardiovascular, respiratory and cerebrovascular conditions (Basu and Samet 2002).

Vulnerability studies indicate that certain subgroups of the population are more susceptible to extreme heat events. Epidemiological studies examining the relation between heat and health indicate that ‘people at highest risk of death following heat waves are over 60, or work in jobs requiring heavy labour, or live in the inner city and/or low-income districts and thus are exposed either to low economic status or higher temperatures or both’ (McGregor et al 2007). Oftentimes, people over the age of 65 years are made more vulnerable to heat stress due to weak thermoregulatory mechanisms, compounded by chronic dehydration, the side effects of medication, and illnesses affecting functions that regulate body temperature (Worfolk 2000). A positive correlation has also been observed between those that are elderly and living in a care home, and increased vulnerability to heat-related illness and death (Faunt et al. 1995). This may be a result of high indoor temperatures in institutions such as hospitals and care homes, as demonstrated during the 2003 heat wave in London (Newton 2005).

The impact of heat waves is generally measured using mortality and morbidity numbers, although this is not necessarily a good indicator of heat wave vulnerability in society. As McGregor et al (2007) indicate, ‘systems for life support (energy, drinking water and sanitation, food distribution), social development (health, education, community development and social support), innovation (cultural and intellectual services including the media), communication (transport, telephone and IT networks), social control (policing and regulatory functions) and the economy (private markets and financial services)’, all play a role in determining the severity of the impact of a heat wave. Therefore, infrastructure and institutional response play an important role in mediating the risk and impact of extreme heat hazards, as do the social determinants of vulnerability.

London was one of the worst affected European cities in terms of mortality numbers for the 2003 heat wave. The Met Office predicts a rise in the incidence of extreme hot weather periods over the coming years.

## 5.2.2 Drought

Most conceptions of drought are relative and vary in scope due to the diverging intensity, duration and spatial extent of the phenomenon. In general, scarcity of moisture - whether it is in the form of rainfall, soil moisture, or groundwater - is evaluated in relation to the demand for that moisture in a particular system. At their simplest droughts can be viewed as a simple equation of water demand outstripping supply. From a social perspective, a drought is seen to occur when such a shortfall between supply and demand causes human hardship (Heathcote 1991). According to the Environment Agency UK, a drought takes place when ‘a period of low rainfall leads to a shortage of water’ (EA website 2009).

In the examination of droughts, precipitation is considered as the primary factor controlling the creation and persistence of drought conditions, but evapotranspiration is also an important variable. However, most research into the general effects of drought relies on the most readily available data – rainfall statistics, and suggests that there is a strong correlation between meteorological droughts (annual

rainfall falling in the lowest 10 percent of values on record) and the occurrence of agricultural, socio-economic or urban droughts (Bond et al 2008, Mpelasoka et al 2008).

The use of a meteorological framework for understanding of droughts reveals itself as problematic when it becomes apparent that human management of resources can either reduce or enhance the risk of drought occurring by reducing or increasing the provision and demand for water. Different thresholds of water need and different management systems create different potentials for drought occurrence. Both are a product of social and technological variables.

Hewitt (1997) reports that throughout the world, drought ranks first among natural disasters in numbers of persons directly affected. In an urban context, rising standards of living and increasing populations mean that water demand in cities is rocketing (Fitzhugh and Richter 2004). According to the UK Environment Agency, London is the driest capital city in all of Europe (GLA 2007). In cities the impact of drought depends largely on societal vulnerability at the time when the drought occurs. Rising population and water demand in London, combined with an aging supply system have led to pressures on the water cycle and recent climatic changes have resulted in an increase in the incidence of droughts in the capital (GLA 2006). The Environment Agency believes that there is a high probability that coming summers in London are hot and dry, which might result in the most severe drought in 100 years.

### 5.3 Vulnerability assessment methods

This section provides an overview of the structure of heat wave and drought risk management practices in London that shaped the criteria for selection of the conceptual framework and methodology of the London case study. Following this contextual background, an account of the derivational process involved in index development is outlined.

#### 5.3.1 Heat wave

Following the large number of deaths in the heat wave of 2003, the Department of Health introduced a national Heatwave Plan for the UK in 2004. The plan sets out the arrangements that will apply and the actions required in advance of, and during a heat wave. It is revised on an annual basis and disseminated by the Department of Health to strategic health authorities and local health authorities for implementation. At the local level, health provision associations, primary care trusts, GPs, lead nurses, directors of social services, directors of housing and planning, professional bodies and care associations are some of the organizations and individuals involved in the implementation of the guidelines set in the Heatwave Plan.

Heat waves are short term and relatively infrequent events in London. This makes it challenging to evaluate management preparedness and response to them. They also affect a diverse group of individuals, and impact differently across geographical, social, and economic scales. In the UK, heat wave impacts are primarily measured in terms of additional morbidity and mortality, with impacts seen as a consequence of hazard and vulnerability together with the limits or failures in risk management. A reliance on only mortality rates and socio-economic data as the primary measure of vulnerability can discount the capacity of social behaviour and institutional change in shaping risk, leading to vulnerability appearing as a static measure rather than a continuously changing social and physical capacity to withstand extreme heat. For example, Hajat et al (2003) and Bell et al (2008) differentiate vulnerability to heat-related mortality along the lines of gender, age, and economic access etc., but in neither case are key data on the behaviour of the vulnerable and their care providers, their use of internal space, and the performance of organisations and institutions that regulate their access to information and support considered in the assessment. This is a critical gap for the MOVE project to examine.

In London, efforts have been made to map vulnerability to heat waves, most notably by Wolf (2009). Similar to efforts in other countries, this study incorporates GIS and socio-economic data to present areas and groups most at risk in London. However, although the Wolf (2009) study provided a pre-existing 'measure' of vulnerability for the MOVE London case study, it also served to highlight the methodological and conceptual limitations of vulnerability studies that fail to incorporate the effect of social practices and institutional risk management. When addressing the issue of vulnerability, nearly all the reviewed theoretical literature acknowledges that human behaviour can/does lead to adaptation

in both the long and short term, and that this process of social adaptation can be facilitated by better health warning systems, heat wave preparedness or action plans, and better information on who is most affected (Hajat et al 2006; Conti 2003; Stafoggia et al 2006). The sets of vulnerability identified in the Wolf study were temporally static and did not reflect the role of adaptive practices, both at the public policy and individual level, in constantly shifting vulnerability.

This critique is reinforced by research undertaken by Abrahamson et al (2008), who found that elderly people's perceptions and knowledge of heat-related health risks, and protective behaviour patterns were central in shaping vulnerability in two UK cities. In order to construct a more dynamic and accurate assessment of vulnerability in London, the concept of adaptive capacity was incorporated into a calculation of vulnerability in the KCL study.

Similarly, it is important to note that few studies have thus far incorporated institutional capacity and infrastructural vulnerability in overall assessments of vulnerability to heat waves. There is also a lack of systematic studies into the relationships between key service providers and their public sector risk regulators. Abrahamson and Raine (2009) explore the perceptions of frontline staff in state medical care facilities, social services and volunteer groups on the feasibility of implementing the UK Heatwave Plan for the elderly. As observed in their research, most health care workers and voluntary staff servicing the elderly in London had never heard of the Heatwave Plan prior to the study. These findings highlight the mutually constitutive role played by policy and action plans, and the importance of behaviour and practices of implementing agencies, actors, and those at risk in shaping overall vulnerability to heat waves.

In addition, heat wave management requires coordination across policy sectors and between individual service providers in particular locations. Evaluating the risk management component of vulnerability therefore relies on a subset of indicators that can encompass a wide range of organizational and social factors. This is needed to allow the capture of the full range of potential policy mixes and associated actors from government to civil society and the private sector in the provision of risk management. The relationship between key service providers, public sector regulators, and those most vulnerable to heat waves needs to be examined in greater detail in order to strengthen institutional capacity, and support greater relevance between policy measures and social adaptive behaviour in the context of heat waves. The ways in which different care provision contexts shape delivery of the London Heatwave Plan from the perspective of different stakeholders including the vulnerable elderly is a critical gap for the MOVE project to examine.

### 5.3.2 Drought

The water provision industry in London has a complex history, which is complicated by the juxtaposed roles played by the public and private sectors in regulation and distribution services. Currently, the primary water supply company in the London metropolitan area is Thames Water Utilities Ltd. Its water supply and sewage operations are supplemented by three other supply-only companies, namely Sutton and East Surrey, Three Valleys Water and Essex and Suffolk Water. These companies represent the public face of the water industry in London. It is their duty to develop and maintain efficient and economical systems of water service provision. In turn, customers have a statutory right that guarantees the appointed water company will connect them to the network and provide them with a constant water service.

In addition, the responsibility for the development of policy and legislative frameworks, control of pollution and environmental regulation, and other regulatory enforcement is shared by the Environment Agency, Department for Environment (DEFRA), Office of Water Services (OFWAT), District Health Authorities, local authorities, and other public institutions. The boundaries between the respective responsibilities of each agency and department listed above are, at times, vague. Over the years, changes to the roles of the different bodies have diminished the public understanding of who is responsible for what task. Likewise, the different interpretations of responsibility have led to reluctance towards incurring costs in the absence of clear funding procedures, particularly for storm water and urban drainage. This has impacted the management and regulation of drought adaptation to a certain degree (GLA 2007).

The Environment Agency has recently published a Consultation on Identifying Areas of Water Stress that highlights London as an area of serious water stress. During most summers, there is sufficient water in the rivers Thames and Lee to meet London's demand for water. It is periods of low rainfall that threaten the security of supply. Low rainfall over the winter months limits the refill of groundwater

stores, which in turn leads to low river flows in the following spring and summer. Typically it takes two winters of below average rainfall to precipitate drought actions.

The Water Act 2003 requires all water companies to have sound drought plans in place so that they can continue to supply water to their customers in times of drought or when sources are depleted. Drought plans are an important element of effective water resources management in London and detail the operational steps that must be taken as a drought progresses. The different stages of the plan and the measures that are to be implemented need to be linked to specific drought 'triggers' during the escalation and de-escalation of a drought. Triggers should be identified in advance, and the crossing of a trigger should prompt a company to initiate pre-determined actions or move to the next stage of drought management. By planning these actions in advance, there is time to consider potential impacts and mitigation measures. As part of such measures, companies can implement actions to manage demand, such as introducing customer restrictions, or to temporarily increase supplies, for example by applying for drought permits or drought orders.

Efforts towards ensuring that all residents in the Greater London area enjoy equal and reliable access to water during periods of water scarcity have minimized the potential social impact of drought in the city. Over the long term, the brunt of water management improvement efforts remain focused on providing engineering solutions to prevent loss through leakages and expand supply sources since institutional practice and learning is generally well developed. Critics argue that the privatized nature of the water sector in London means that there is little incentive for companies to encourage demand management.

However, one reason for this emphasis on supply management and engineering is the large quantity of water loss experienced in the capital. Large parts of London's water supply network date back to a Victorian legacy; over 60 per cent of the network are pre-1900. It is the aged infrastructure that leads to most parts of London having the highest levels of mains leakage in the United Kingdom. While only 70 per cent of Thames Water's customers reside in London, 85 per cent of Thames Water's distribution losses occurred in London. Alternatively, Thames Water accounts for 92 per cent of all distribution losses in London, yet only serves 76 per cent of London's population. Leakage in London ranges from 85 to 260 litres per property per day. Yet having a system with very low leakage levels would prove too costly. Thus, there is some tolerated level of leakage. The Government, regulators and water companies accept the economic level of leakage as the preferred tolerated level of leakage. The economic level of leakage (ELL) is the point at which any further effort to reduce leakage would not be cost-effective; or in other words, the point at which it would cost more to reduce leakage further than it would be to produce water from an alternative source.

As a result of such economic and physical constraints, and the relative lack of drought experience in London, water management and drought risk reduction remains focused on engineering led supply management rather than a transformation of social practices or demand management. The construction of additional reservoirs, storage, and desalination plants is the primary means of reducing drought risk in London. This has resulted in drought management being restricted to public and corporate guidelines at the service delivery level, with very little impact on local level practices within the city.

### 5.3.3 Index development

After an examination of the overall context of vulnerability for heat wave and drought hazards, a common index was considered to be sufficient for capturing both sets of vulnerability in London. Measuring vulnerability to heat waves and drought requires the assessment of several discrete properties. These are identified in the MOVE conceptual framework. The KCL index seeks only to capture that part of the vulnerability dynamic that is affected by the capacity and character of hazard risk reduction and response. These are highlighted in the Risk Governance and Adaptation sections of MOVE framework. Clearly governance and adaptation do not stand alone and the KCL index also includes capacity for risk management systems to obtain information about Hazard and Vulnerability both in anticipation of and as a measure of management fit and feedback from management decisions and actions on risk.

The KCL index is based on the RMI (Cardona et al.) but oriented towards the non-structural impacts of hazards and operating at the scale of a mega-city. As with the RMI, this is a composite indicator. Greater emphasis is placed on adaptive management than in the original RMI. It measures disaster risk management in terms of the perceived performance of public policy and local adaptive capacity



for four fields: risk identification, risk reduction, disaster management, and adaptive governance. Each policy field is evaluated based on the benchmarking of a set of subindicators that reflect performance targets associated with the effectiveness of disaster management activities. The participation of external experts as well as disaster managers is incorporated to minimise bias.

In order to capture the layers of risk management operating within the city scale, the index is applied at two sub-dimensions in the form of the Risk Management Index (RMI) and the Local Capacity Index (LAC). The RMI evaluates hazard risk reduction and response at the level of public policy and risk management practitioners. The RMI is complemented by the LAC, a composite indicator that measures adaptive capacity at the level of individual organisations from small businesses to local authorities. Emphasis in the LAC is on the capacity to act as framed by overarching public institutions as well as the capacity of individual organisations. Similar to the RMI, the LAC index is composed of indicators for risk identification, risk reduction, disaster management, and adaptive governance. Both indexes are intended for generic use across any area at risk from heatwaves or drought.

The RMI and LAC are a participatory risk index. This means that the methodology used to derive the index was itself an opportunity for respondents to reflect on their own practice. The outcome is an index based on generic themes but refined through interviews with London based respondents to emphasise aspects of risk management most germane to London. The index was built in three steps. First a basic structure for the index was derived deductively. At this first stage, the deductively generated KCL index had a simple structure with five component indicators, each populated with input variables, but with no weightings attributed. Stage I was taken from the generic RMI index developed by Cardona et al with one additional field ‘Adaptive management’ added to highlight its importance. No input variables were pre-defined for this component indicator. The Stage I index was offered to respondents for refinement and to gauge their appropriateness. Interviews with key individuals involved in managing and evaluating risk to drought and heat waves in London were used in conjunction with a literature review to provide a basis for assessing the validity of the indicators presented in the index. Table 6.1 and 6.2 provide a sample of the areas of practice from which respondents were recruited and the specific roles of individual respondents with respect to heat wave and drought management respectively. This table also serves to identify any gaps that might bias the re-modelling of the generic RMI to measure heat wave risk. Respondents were asked both to:

Reflect on the suitability of the generic index structure or component indexes, and input variables for heat wave risk; and

Provide background information on the management of heat wave risk in London.

The latter information was not used to structure the index, but was useful in preparing for the Stage III assessment and in helping to identify participants for the Stage III assessment.

<b>Respondent Group</b>	<b>Individual Respondent Roles</b>
Hazard science community	Met Office climate modeller
Heat wave policy practitioners	NHS Heatwave Plan coordinator
Heat wave policy practitioners	Heatwave Plan regulator in Health Protection Agency
Local government risk management	London local council emergency planner
Local government risk management	London Resilience Team
Academic expert	Epidemiological advisor to Heatwave Plan (UK)
Academic expert	Researcher on impact of Heatwave Plan (UK)
Academic expert	Gerontology and older people in London expert
Voluntary social care expert	Director of ‘Help the Aged’ London

Table 6.5 Heat wave respondent groups and individual roles (RMI).

<b>Respondent Group</b>	<b>Individual Respondent Roles</b>
Parks and conservation managers	Species and Estate manager, Royal Kew Gardens
Garden centres and plant stockists	Managers of various Garden centres
Garden allotment holders	Head of London Allotments Association
Local government managers	Waltham Forest Tree manager
Health and policy practitioners	Health Protection Agency (Drought impact officer)
Voluntary organization	Member of 'The Tree Service' in London

Table 6.6 Drought respondent groups and individual roles (LAC).

The index structure was broadly supported. The only change in structure was to remove financial protection and governance, and replace it with adaptive governance as a standalone category. Rather, the financial aspect of management capacity is better reflected integrated across all other component indicators and will appear at the level of input variables.

Finally a small group of experts were invited to provide relative values for individual input variables in the index as part of the validation process. The advantage of a compound index at this stage is that it allows relative assessment across a range of risk management activities for any one place. This made it easier for respondents to place values on input variables. Ideally the index methodology can also be applied to other places so that comparative assessment can be provided. At a minimum the third stage of analysis can be applied in this way. The intended final outputs of the indexing methodology involved increased sensitisation amongst key respondents that were provided a space for reflection on practice, as well as the derivation of an index value and values for index components and input variables.

The following section will assess the relevance of each input variable in light of the experience of heat wave and drought risk management in London.

## 5.4 Indicators

This section provides a description of the indicators and sub indicators used in the common index framework for both drought and vulnerability hazards at the local and risk management level. Each sub indicator has a set of attached input variables that differ across hazard types and reflect the specific characteristics of each case study at both scales of application. A detailed list of the developed and applied indicators, sub indicators, and input variables for each sub-category can be found here ([ADD link to extractable online tool](#))

### 5.4.1 Discussion of the indicators

#### **Risk Identification:**

Risk identification is an important component of hazard management. Prior knowledge of the frequency, duration and impact of the hazard is essential to effective risk management and vulnerability reduction. The response time for mobilizing disaster response initiatives and procedures needs to be quick in order to manage and limit the impact of extreme weather events such as heat waves and drought. The availability of risk identification mechanisms and early warning systems is therefore an integral part of an effective heat wave management system. The following sub indicators were considered to be essential in capturing all the dimensions of risk identification for both hazard types:

1. Systematic inventory of disasters and losses:

The existence of data on the historical frequency of hazards and their impact forms the basis of a robust disaster management system. Meteorological records of daily ambient temperatures or precipitation provide a record of weather and climatic patterns, and assist in their classification as

a potential risk to the population. Losses during a hot weather or drought event are generally calculated in terms of their impact on human mortality and morbidity, although environmental and ecological losses are also important in calculating drought vulnerability. Observed trends in mortality and morbidity rates during heat waves can be compared with data from preceding years to present an overview of the impact on human health during a heat wave.

#### 2. Risk monitoring and forecasting:

The presence of scientific mechanisms for predicting and monitoring the meteorological occurrence of extreme heat or drought events is an important aspect of effective risk management. Also important is the existence of a formal and pre-defined system of risk communication, with both climate scientists and policy makers clear on a common framework of risk classification for hazard events.

#### 3. Vulnerability and risk assessment:

The identification and measurement of vulnerable individuals and groups in a particular setting is key to an effective risk management system. Vulnerability to hazards can be dynamic, and is seen to vary across social groups, physical space, and different scales. An on-going review of vulnerable populations is necessary for an effective risk management system; however, general trends observed in historical data provide an overall picture of those most at risk to hazards.

#### 4. Dissemination of information on risk and response measures to risk managers, at risk groups, and care providers

Discussions with experts and practitioners of risk management in London highlighted the importance of disseminating public information before and during an extreme heat or drought event. In most cases, risk to such hazards can be reduced through increased alertness and taking simple 'common sense' measures. Since drought and heat wave vulnerability is mainly measured by its human impact, providing basic information on risk identification can make it relatively easy to alleviate risk and exposure to such hazards through encouraging minor behavioural changes, and makes public information and community awareness critical in hazard risk management. This input variable is important because it affects the degree of preparedness and risk identification that exists at the local level.

### **Risk reduction:**

Risk reduction measures are pre-event management activities designed to either directly enforce or empower local actors to contain local human vulnerability and hazard, and enhance adaptive capacity and actions in the long and short term. Several steps can be taken to address heat wave risk and the following input variables are assessed for their relevance in evaluating such risk management systems.

#### 1. Hazard and vulnerability considered in land use and urban planning

Hazard and vulnerability consideration in the urban planning and the construction of new infrastructure can greatly reduce vulnerability resulting from the built environment. Although such actions have limited impact in mitigating hazard related risk in the context of cities such as London where changes in existing land use and urban design are financially untenable, management of land use and urban planning can be a key input variable for assessing long term risk reduction in other contexts.

#### 2. Policy and financial support for alleviating risk or retrofitting buildings in high risk areas

The infrastructure of public buildings and assets such as community spaces and transport networks are often not easily adapted to an increasing risk of climate related hazards. This includes the network of hospitals and residential care buildings in which those that are already vulnerable reside, thereby amplifying the risk posed by hot weather. The provision of financial support or policy initiatives to undertake adaptation measures to make public infrastructure more resilient to heat waves or drought events can be critical in reducing vulnerability.

#### 3. Public education on risk

The predominantly human impact of heat waves and drought hazards makes behavioural changes important in reducing vulnerability. Widespread dissemination of information on drought and hazard risk is needed to influence the diverse range of social, financial, ecological, cultural and institutional activities affected. Public guidelines on adopting alternative practices and updating infrastructure can assist in the long term resilience to hazard events. Early warning systems are a potent component of public information since heat waves and drought are both preceded by days of hot or dry weather. This allows time for issuing health warnings and information before the possible onset of extreme temperatures and water scarcity.

#### 4. Regulation of safety measures

Monitoring and regulation of safety processes and procedures in place to mitigate and reduce vulnerability to climate change hazards such as drought and heat waves need to be carried out in order to ensure relevant and robust risk management.

### **Disaster response:**

#### 1. Emergency response plan or procedures

The creation of a formal emergency plan to deal with extreme weather events can greatly improve the risk management capacity of a particular society. Such plans can exist at the national or sub-national level, and outline the procedures and protocol to be followed by a number of different agencies in order to effectively manage risk during hazard events. A heat wave or drought plan should identify individuals and groups most at risk and set out a method for communicating risk both between emergency planners and practitioners, and to the public at large.

#### 2. Availability of disaster response equipment, facilities and skills

Adequate emergency medical facilities and staff need to be present in a system in order to effectively manage health risks during a hazard event. In addition to this, a network of social care workers and staff looking after vulnerable population groups can assist in the provision of assistance and advice to individuals at risk during such periods. In most cases, the presence of a functioning health care system is sufficient infrastructure for the management of heat waves. In the case of drought, facilities can include reserve supplies and storage of water. Overall, this is a useful input variable for assessing risk management capacity.

#### 3. Community and private sector preparedness and training

Community and private sector preparedness serve to complement disaster response efforts by addressing vulnerability in households, work spaces, and in communities.

#### 4. Disaster response training

Similar to community awareness, but perhaps of greater consequence, is the need for practitioners and frontline staff responsible for dealing with people vulnerable to climate hazards to gain adequate training and education regarding risk management procedures and processes for an effective heat wave management system.

### **Adaptive governance:**

Adaptive governance measures the degree to which the existing system has inbuilt mechanisms for adaptive flexibility (change within existing limits of practice) and adaptive reform (a timely changing of the limits). Not only is it necessary to assess the current status of the risk management system, it is also important to appraise room for change within the current institutional framework, and the ability to reform the current institutional framework should it prove wanting. The following sub-indicators gauge adaptive capacity by examining the technical and also some element of the political systems influencing risk management.

#### 1. Horizon scanning for unexpected risks

The ability of risk management systems to continually assess and re-examine the conditions of vulnerability and risk is an important indicator for a flexible regime with a capacity to absorb and predict disaster risk.

#### 2. Ability of policy and implementing agencies to reflect on practice outcomes

This input variable highlights the adaptive behaviour and institutional learning capacity present in a risk management system. It is important to continuously update and improve the practices and

techniques involved in monitoring and managing heat waves due to their dynamic impact and shifting vulnerability in society. Also, risk management of heat waves relies largely on human actions and modification of institutional practices and individual behaviour rather than alterations in infrastructural or environmental management. This makes the testing and alteration of inter-institutional response and practice an important factor in improving and adapting heat wave management systems to better address vulnerability and risk.

### 3. Support for experiments in risk reduction and response

This indicator measures the degree of flexibility within a management system to support adaptive learning and experimentation in its practice and policy.

### 4. Availability of funds for flexible vulnerability management

Budget allocation and mobilization is required for creating and revising risk management systems, and to strengthen coordination and training between different departments involved in its implementation.

## 5.5 Results and Validation

### 5.5.1 Heat waves (RMI)

The application of the RMI index to heat wave risk management at the national, city and sub-city level returned consistent results from a variety of management practitioners and expert commentators. Overall, the index revealed a strong structure for heat wave risk identification in London. A positive result for the sub indicators 'systematic inventory of past events' and 'risk monitoring and forecasting' was in part due to the high level of climatic monitoring and forecasting practiced by the Meteorological Office at the national scale, and its proactive role in disseminating information regarding extreme weather events. The system also performed well in the vulnerability and risk assessment category, although vulnerability was measured within the national framework solely as an outcome of medical factors without taking into account social variables. A new system for categorizing cause of death at hospitals had also allowed for greater accuracy in calculating heat wave mortality. Procedures for the dissemination of information on heat wave risk were well organized and clearly outlined, although their organization within the Health Department meant that the dissemination mechanisms were deployed through the national health service and did not involve social services.

In the risk reduction category the existence of old infrastructure and building stock in London, the high costs associated with renovating and retrofitting, and the relatively small scope for new construction in the city meant that the sub-indicators for hazard and vulnerability considered in land use and planning, policy and financial support for alleviating risk or retrofitting residential and working space in high risk areas, public education on risk reduction, and regulation of safety measures had a low level of applicability to London. It is important to note that existing building codes and regulations for new construction put more stress on insulating buildings against cold weather, which often has the inverse effect of making infrastructure more vulnerable to extreme hot weather. On a city level, the Mayor of London's office has recently conducted studies into the urban heat island effect in London and has acknowledged the need to incorporate land use strategies and urban planning that offset the impact of this urban phenomenon.

The existence of the National Heat wave Plan ensures well developed procedures for heat wave disaster response in London. However, the failure to involve agencies and departments other than the health and emergency services has resulted in limited awareness of the plan outside of the health management system. In addition, although there is a good availability of disaster response equipment, facilities and medical skills to manage heat wave disaster response, limited outreach and information on heat wave risk within the community and private sector means that at risk groups and carers are often unprepared and untrained to identify and respond to emergencies resulting from extreme hot weather. This gap in disaster response is reflected in the persisting proportion of heat related mortality and morbidity in elderly groups living in the community or in care homes across London (and was also validated by the results of the heat wave LAC).

Currently, the national Heat wave Plan is revised on an annual basis and its effectiveness is independently reviewed by the Health Protection Agency every two years or immediately after an episode of extreme hot weather. The presence of such mechanisms results in a high degree of adaptive governance by providing platforms for policy makers and implementing agencies to reflect on practice outcomes. However, although the Department of Health is supporting research for the incorporation of social indicators in framing heat wave vulnerability, the continued understanding of heat wave disaster management as a medically driven response rather than both a medical and social issue has resulted in the exclusion of social service practitioners and care workers from having a role in the formulation and implementation of the plan.

### **5.5.2 Heat waves (LAC)**

The application of the index to assess local adaptive capacity revealed varied results. This was in part due to the inconsistent standards of care provision across private, public, and voluntary organizations, as well as the consideration of four different levels of care provision ranging from nursing homes to in community care. Most care providers had an awareness of heat waves posing a potentially serious risk for elderly and disabled people. Informal records and recollections of hot weather events and their impacts were found in all organizations but only a few private homes had facilities to monitor and record daily indoor temperatures. Risk monitoring and forecasting was generally strong due to the dissemination of health warnings by local PCTs to care providers via email. However, this trend weakened out towards the sheltered housing and in community care sections since information usually disseminated during weekly or biweekly meeting with local council care manager, which were too far apart to effectively inform on risk of hot weather events that occur for short periods of time. In such cases, awareness depended on a carer's access to internet and personal habits of checking email or other advisory sites. Therefore, more needs to be done to ensure an effective chain of communication between health workers, PCTs and care providers.

Risk reduction practices were limited in scope across all organizations. Most care institutions existed in old infrastructure. Even where the buildings were relatively new or brand new, there had been no consideration for hot weather resistance during design and construction. In fact, safety measures and cold weather proofing meant most homes had windows that could not be opened and suffered from poor ventilation. There was also little financial support for alleviating risk or retrofitting residential and working space in high risk areas, with funds often limited to the provision of fans. Public education on risk reduction, and regulation of safety measures was also low. Only one organization had an evacuation procedure in place for hot weather and public information campaigns only took place during summers and were more about response rather than risk reduction. The risk reduction practices of in community carers were limited to informing residents on basic precautions against hot weather during such events.

Most care practitioners were not formally aware of the national heat wave plan. However, they were aware of an advisory information service by the PCT that would warn them of such events. Where there was a good flow of information down from the PCTs to carers, an effort was made by carers to print and disseminate leaflets issued by the health department within their organization. However, those with limited access to NHS information or internet access relied largely on information from watching local news on TV. Also, the dissemination of information by the PCT did not guarantee adequate response. Some care managers, mostly in public and voluntary institutions, did not appear to have adequate knowledge of treating heat wave vulnerability, with most focused on hydrating patients rather than the need to regulate fluids and temperature. Although NHS directives pin pointed those with respiratory and heart illnesses as more vulnerable, most care managers did not appear to be aware of how the two were linked to high ambient temperatures.

Although there was no disaster response training specifically for heat waves in care homes, the daily monitoring of patients and the ongoing assessment of their medical conditions that formed a part of everyday management practices in nursing and care homes ensured daily care interventions and monitoring responses for dealing with heat related problems. For these types of organizations, the quality of preparedness and response to heat wave risk was directly linked with the quality of overall care in the organization itself. In contrast, risk management was relatively weak in sheltered housing and in-community care, irrespective of the quality of staff or care, since these types of care provision did not involve daily contact with residents or the proactive medical monitoring of elderly or disabled patients. The relatively quick onset of heat waves, shifting conditions of vulnerability, and weaker

levels of communication and individual contact meant that unless residents had strong social networks of support, vulnerability was higher in these groups.

There was little indication of adaptive governance at the local level, and most organizations and individual carers were not involved in any reflective or learning activities. However, most were open to following advice and instructions issued by the local PCT on adapting practices and routines, thus highlighting the importance of adaptive learning at the level of risk management in the health department.

### 5.5.3 Drought (RMI)

As mentioned in the methodology section, the application of the RMI to drought management in London was applied using extensive literature reviews due to the unavailability of drought managers as well as the detailed information available in the plans and literature of the water companies and other drought management agencies. In all the categories of risk identification- ie, systematic inventory of past impacts, risk monitoring and forecasting, vulnerability and risk assessment, and dissemination of information on risk and response measures to at risk groups, providers, responders- the index revealed positive results with the exception of the last sub indicator, where targeted public information campaigns for businesses and affected individuals was a little weak.

Practices for risk reduction were primarily focused on supply side solutions. This reflected the engineering focused approach of the water companies, which are interested in expanding supply mechanisms rather than limiting demand. However, strong regulations by government require the metering of all new properties and the consideration of water supply in future land use and planning. In addition, financial support for free retrofitting residential and businesses with meters has also encouraged regulation of demand, though with limited effect. Public education on risk reduction and reduction of water usage remains very low with little effort made to curb water consumption.

Water companies are legally bound to produce emergency response plans and procedures for drought management. These plans rely on restricting usage and demand only as a last resort and instead focus on expansion of supply through engineering solutions and limiting leakages. This has affected the availability and type of disaster response equipment, facilities and skills used to manage drought, with the construction of desalination plants and creation of storage reservoirs given primary precedence. Limited to no community and private sector preparedness and training exists for drought management, as is the case with disaster response training.

The legal requirements imposed on water companies require them to annually revise their drought plans to reflect changing conditions in water supply and demand. However, this exercise is aimed at improving supply and limiting leakages. Therefore although a strong level of adaptive governance- including horizon scanning for unexpected risks, ability of policy and implementing agencies to reflect on practice outcomes, support for experiments in risk reduction and response, and availability of funds for flexible vulnerability management- exists, it is limited to the engineering sphere.

### 5.5.4 Drought LAC

The application of the LAC index to drought risk management in London revealed consistent trends, although variation existed across the different groups of practitioners interviewed.

There was little evidence of formal risk identification practices across any of the respondents involved in the study. No systematic inventory of past events was maintained in any organization except for Kew Gardens, which had in house facilities for monitoring precipitation and recording weather patterns. However, experiential memories in staff served to provide informal records of such events. Risk monitoring and forecasting was provided by the Met Office and gardening information resources, however these were not monitored as part of management practices except for allotment holders since they were the group with least access to unlimited water supplies and hence more reliant on rainfall for water provision. Every group demonstrated the existence of vulnerability and risk assessment procedures, with an acute awareness of stock vulnerability and potential loss. There was also a good network for communication and dissemination of information on drought risk and response measures, but this was provided by other local level practitioners and gardening enthusiasts rather than water companies or the environment agency.

There was a mixed result for risk reduction practices. Gardening centres were acutely aware of changing climatic conditions and the need for water conservation and had responded by changing

their stock to more hardy and drought resistant varieties. Small infrastructural changes to assist in water collection and limit water wastage had also been carried out by garden centres. However, there was relatively little effort to reduce risk by allotment holders since most engaged in gardening as a hobby and did not mind losing stock due to a drought event. In some instances, individual allotment holders or organizations had made provisions for small scale water storage, but this was due to an interest in reducing conflict over sharing common water supply rather than as a drought prevention mechanism. In the case of the royal Parks such as Kew gardens, no effort had been made to reduce risk to drought since a steady supply of water was guaranteed to the organization even in times of drought and the cost of retrofitting buildings with more efficient water usage systems was too high in contrast to just paying for the water supply.

There were no disaster response strategies or procedures in place on a formal level. This was because garden centres, parks, and tree services are exempt from drought orders. Even in the case of extreme events, the availability of water tankers from private suppliers would be used to fill the gap. The only group directly impacted by drought conditions would be allotment holders but as mentioned above, since there was no financial or ecological loss associated with loss of crops and plants, not many were too concerned since plants could be replaced or re-grown. Individual water stores provided some potential relief measures.

Low levels of disaster management practices meant that there were correspondingly low levels of adaptive governance or learning at the local level. Although horizon scanning for unexpected risks formed a part of most gardening practitioners, it was limited to short term fluctuations in weather rather than a concern with climatic conditions or trends. In the case of Kew and garden centres, there was some effort to reflect on practice outcomes (usually spearheaded by motivated individuals), but low levels of organizational support for experiments in risk reduction and response, and limited availability of funds for flexible vulnerability management resulted in little impact of such practices.

Overall, a high level of awareness of drought risk was demonstrated among respondents at the local level but this resulted in little action to change practices unless there were financial incentives or consequences (as for garden centres) to such adaptive measures. Some evidence of long term adaptation and learning (stock change, water conservation) was found, but this was of limited scope and was not relevant during disaster management periods since most organizations were not affected by drought orders.

The process and results of the index were validated through the involvement of participants and expert commentators that were involved in the revision and outcomes of the research.

## 5.6 Discussion

### 5.6.1 Heat wave

Overall, the data revealed that heat waves are not considered to be a high priority threat for London. Both at the risk management and local level, there was more emphasis placed on preparedness and adaptation to cold weather and other hazards such as flooding. This was exacerbated by a variation and lack of consistency in care provision standards at the local level. While certain institutions seemed well prepared for heat wave risk, poor training of non-medical staff and carers in recognizing and addressing heat wave risk appeared to be a problem. Overall, the level of risk management was largely determined by quality of staff and training, individual initiative by manager or council, or financial assistance available to an organization.

At the macro level, the application of the RMI and LAC index to heat wave vulnerability in London revealed fractures in risk management practices that exacerbate existing vulnerabilities across the city. Despite the existence of a coherent and well-revised Heat wave Plan, risk reduction guidance and disaster management procedures do not always filter down to the local level. Also, the perception of heat wave vulnerability as a medical issue has led to risk management efforts focused on preventative measures within the health sector. However, as the LAC data reveals, vulnerable individuals (especially those living in the community) are often already exposed to the risk by the time they come into contact health services. In order to alleviate and reduce risk, social workers, carers, and community members need to have a greater role in preventing and reducing exposure to heat wave risk for those most vulnerable. Therefore, a potential gap in risk identification and management



practices is the understanding of heat wave vulnerability solely as a medical issue. The inclusion of social indicators as contributing factors to heat wave vulnerability (such as consideration of individuals living alone, etc) points to the need for social services to be involved in the risk management structure. This point is reinforced by Tanja Wolf's work (Wolf 2009) which successfully maps vulnerability as a composite of both social and physical indicators but nonetheless fails to capture the dynamic nature of this vulnerability which shifts according to changing social circumstances. In terms of the MOVE framework, this demonstrates that although vulnerability mapping using demographic and physical data provides a good starting point for assessing existing vulnerability in a system, it is nonetheless a static snapshot of vulnerability, which is generally (but especially in the case of heat waves) a dynamic phenomenon.

The role of adaptive governance and institutional learning is an important way of dealing with shifting vulnerability. However, as seen in the London case study, even though formal procedures for revision and learning were explicitly built in to the Heat wave management Plan, the presence of such mechanisms did not in itself guarantee true learning. This appears to be because of the unwillingness on the part of practitioners to involve new actors (and the existing tensions and lack of coordination between social and health departments in the UK).

The application and use of framework proved useful for highlighting areas of weakness in the overall structure of risk management for heat waves in London. At the local level, most of the organizations and individuals involved in data collection found the index to be a useful tool in providing an overall assessment of their risk management practices. In some cases, organizations expressed an interest in the comparative management practices of other organizations and the need for knowledge sharing across care providers. The use of a common index led to exchange of information between respondents, reflection on practice and policies, and increased focus on heat wave management in the local organizations involved in the data collection.

However, it must be noted that recent funding cuts, government restructuring, and the dissolution of PCTs and organizations such as the HPA that played a very important role in the risk management process will have a severe impact of heat wave risk management in London.

## 5.6.2 Drought

The lack of any immediate historical experiences of drought in London limits an assessment of existing emergency drought measures. Overall, an equitable supply and water provision system means low levels of differentiation or social vulnerability at the local level. However, persistently high levels of leakages specific to London's aging infrastructure have resulted in a drought management approach focused on engineering solutions and supply management. Efforts remain focused on preventing loss through updating infrastructure and investments in expanding supplies through construction of reservoirs and desalination plants. This has not been accompanied by a major push to limit demand through reduction of consumption by end users. The narrow measures taken to limit demand have been based on pricing disincentives and the installation of meters in new builds following legislative requirements.

This has resulted in a situation where drought management systems are strong at the corporate and public policy levels but bear little relevance at the local level. This is reflected in the findings of the Drought LAC index. Water reliant businesses (often the most intensive users of water) are metered but completely exempt from hose pipe bans or any drought measures during times of water scarcity. This has led to little incentive for private and corporate water users to reduce water consumption or evolve drought resistant practices. Interviews revealed an awareness of increasing drought risk and changing climate conditions amongst local practitioners, but little action at an organizational level to deal with such potential hazards. There was also minimal collaboration between water companies and end users (whether household consumers or big businesses) to implement risk reduction or adaptation practices. To some degree this was attributed to the closed and engineering focused management attitudes of water companies, which were seen as unapproachable or uninterested in local level collaborations.

In addition, past experiences of drought in other regions revealed little consideration of social and health risks posed by drought orders, which were not considered in drought planning processes since brunt of management efforts focused on drought prevention rather than drought management. This was due to an assumption on the part of water companies that moving beyond a hose pipe ban would be avoided through a manipulation of supplies rather than managing demand. This aversion to

imposing constraints on public demand can be seen as an indirect consequence of the privatisation of water provision.

Overall the index, both at the risk management and local level, proved very useful in providing an assessment of latent vulnerability to heat waves and drought in London. It provided a picture of management robustness not only for the purpose of the study but also for study participants and practitioners to apply to their own context. The application of the index was also a simultaneous validation exercise since respondents participated in its development and ultimately utilized it to reflect on and improve their own practices.

Although specific physical, geographical and social determinants affect the relevance of some indicators over others, the index is a useful tool for a contextualized assessment of what is strong, what is weak, and what is needed for a robust risk management system that alleviates vulnerability to drought and heat wave hazards. The combination of a structured index with open ended interviews allowed for a comprehensive qualitative assessment of risk management processes, circumstances and needs, while anchoring discussion in the index structure to provide comparative and measurable outcomes and data. It offers an interesting methodology for use in vulnerability assessments for the MOVE project.

## 6.7 Conclusions and recommendations

The RMI and LAC indexes in conjunction with semi-structured interviews with risk management practitioners, vulnerable groups, and experts have proved to be a quick and effective method of assessing vulnerability in a particular system through an examination of the strengths and weaknesses of its risk management structure. Although this methodology does not provide a quantitative measure of existing vulnerability, it provides qualitative and actionable assessments that allow for policy and practical improvements to strengthen the overall risk management and disaster response mechanisms. Through its application to heat waves and drought hazards in London, the following observations and recommendations are made with regards to risk management and vulnerability assessment:

Vulnerability to climate change hazards is a dynamic function of both physical as well as social factors. Both types of indicators need to be taken into account when measuring vulnerability.

Disaster risk management directly impacts vulnerability and requires multi-agency coordination from organizations involved not only in disaster response but also risk reduction (such as social services).

Disaster management plans need built-in mechanisms to ensure that they move beyond their role as risk management regimes to best-practice guidelines for local actors.

Climate change hazards need greater prioritization and given further policy and financial support by governments in order to decrease vulnerability and risk.

# 6 Comprehensive Vulnerability Assessment of Forest Fires and Coastal Erosion: Evidence from Case-Study Analysis in Portugal

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## 6.1 Case Study Description

The NW Portugal case-study is focused on three natural hazards: coastal erosion, forest fires and landslides. The last one is not considered in this publication. To validate the vulnerability framework two test sites were selected (figure 6.1). The first one related with coastal erosion, Esposende, is located in the NW Portugal, 50 km north of Porto. Esposende municipality covers a surface of 95 Km<sup>2</sup>

with a coastline length of 16 km fringed by the Atlantic Ocean and is one of the most erosive coasts of Portugal. This administrative unit has 35,761 permanent inhabitants (INE, 2011). However, this area has numerous second houses and touristic infrastructures and the population can hugely increase during touristic season.

For forest fire test case six municipalities from a mountain area were selected. On the 2,200 km<sup>2</sup> covered by the six municipalities lived, in 2010, 88,326 inhabitants. These municipalities are characterized by low population density and small urban areas. Depopulation and aging have been increasing in most of the 167 parishes. In the considered area wild lands represent 80% of the total surface and agriculture 14 % of total surface (Cos 2007). This land use makes the area susceptible to forest fires. The fire hazard has a tendency to increase due to climate change and, mainly, with changes in land cover.

The selection of the local scale to support the vulnerability analyse is justified by the increasing responsibilities of the municipalities in the assessment and management of natural risks. Local scale analysis is important to set priorities in risk prevention and management.

In Portugal risk assessment has been, up to date, developed without considering vulnerability. In 2009, the National Forestry Authority and the National Civil Protection Authority published two manuals with guidelines to support the production of risk maps at the municipal scale. The generic framework presented by both agencies is very similar as is the adopted concept of vulnerability (i.e. the level of loss of the exposed elements) and consider in parallel the economic value of the elements at risk. Although, considering the vulnerability concept, applied to all kind of hazards, the National Civil Protection Authority only defined the elaboration of two maps: hazard susceptibility and exposed elements. The risk map is a result of the overlapping of the previous two maps. In this case vulnerability analysis is absent. On contrary, the National Forestry Authority defined for forest fires the construction of a hazard map (susceptibility vs. probability) and a map of the potential damages (i.e. vulnerability varying between 0 and 1 multiplied by the monetary value of the exposed elements). This last approach presents a partial snapshot of vulnerability.

The application of the Move framework in Portuguese context has the objective of improving this fragility. This is as important as the risk map elaborated at municipal scale that has been influencing landscape management planning and regulation.

In our work we gave particular emphasis on identifying and using indicators which are relevant to identify the vulnerability of people, ecosystems, activities, structures and lifelines. In the coastal erosion test area the purpose was to identify the vulnerability of exposed elements in three different scenarios. Concerning forest fires the selection of indicators made is the base for the elaboration of a vulnerability map to be integrated with the hazard map in order to produce a risk map. However, these indicators can also be used to elaborate a vulnerability profile for each municipality or parish.

The stakeholders were aggregated in three groups: the operational level - responsible for the implementation of the risk management policies (e.g. Municipal Civil Protection Service of each municipality, North Littoral Natural Park, Peneda-Gerês National Park, Fire-fighters brigade); the policy level - responsible for the definition of procedures (e.g. INAG – Water Institute, Polis Litoral Norte, National Forest Authority, National Civil Protection Authority); the civil society which is the target of the policies (e.g. Local Communities: 2<sup>nd</sup> residences landowners, fisherman community, farmers, touristic companies). The first group of stakeholders was the most involved on the validation of Move conceptual framework. The last was not considered yet.

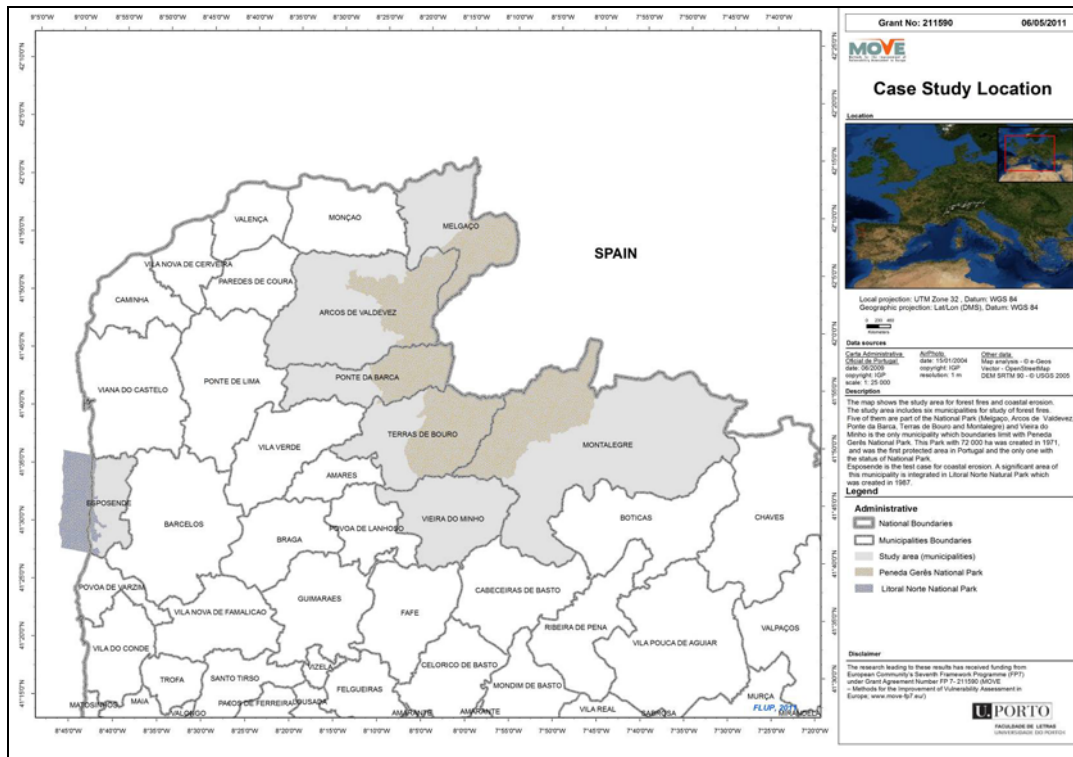


Figure 7.1 Location of the two test sites of the NW Portugal case study.

## 6.2 Hazards

### 6.2.1 Coastal erosion

Esposende municipality is affected by severe coastal erosion. Erosion is highly variable along the coast of this municipality in relation with the morphology, the geological and hydrological context and the lithology of each coastal stretches. The main observed effects of this erosion are a retreat of coast line, changes in beaches profiles, destruction of sandy beaches and dunes, land losses, damages and destruction of buildings and infrastructures and indirectly an increase of the marine submersion hazard. The forcing factors of local erosion are the littoral drift and waves (erosive crisis during storms) but the main cause of erosion is due to a regional negative sedimentary budget and a weak physical resilience due to lack of sediment storage offshore.

The sandy beaches are generally affected by seasonal phases of erosion during winter (due to wave action during storms) and aggradation during summer. The existence of littoral drift can lead to a long shore transport of sediment along the coast. In some coastal stretches, the sedimentary budget (at the pluri-annual scale) is globally positive inducing aggradation, on other coastal stretches; the sedimentary budget is null inducing stability. In the case of negative sedimentary budget which is the most common, the coast is in erosion.

Thus, at the annual scale, erosion can be described as an oscillatory process around an average position of the coastline, with erosional events which can be "crisis erosional event" followed by a relaxation phase with sedimentary aggradations which tend to restore position of the coastline which prevails before erosion crisis. The space of oscillations can be presented as an uncertainty strip around a medium coastline position. This uncertainty strip can represent at a short time scale the area

exposed to the erosion hazard (Crisis event: short term erosional event with coastline retreat during a storm).

At longer time scale (pluri-annual), the spatial evolution of the coastline is dependent on the sedimentary budget of the concerned coastline whatever the processes responsible of this budget (littoral drift, trapping of sediment by defensive work, deficit of sedimentary transport by river linked to river damming...). Thus, "long term" coastal erosion can be characterized by a pluri-annual average rate (Long term erosion: coastline erosion rate (average) based on multi decadal evolution).

Coastal erosion, in itself, is a reversible process at some timescales; the accretion phase can occur after erosion phase and lead to a coastline recovery. The physical resilience of a coastal strip is linked to the stock of sand and to the availability of this sand offshore and backshore for same conditions. Thus, the role of the dunes in the resilience capacity is of a primary importance.

However, even if coastal erosion is reversible, the effect of coastal erosion on assets is irreversible. The buildings, roads, other infrastructures, natural habitats, etc. located on eroded lands are irremediably destroyed, land and soils are definitively loss.

Hence, in this approach, the fragility of assets to coastal erosion is assumed Boolean: an asset which is affected by the coastal erosion is definitively destroyed and damaged and unusable. Thus, we can consider that the fragility of assets (e.g. buildings, networks, roads) is a Boolean function with only two damage states: Not Affected or Affected. For this specific hazard, the fragility is directly linked to the exposure to the hazard.

Therefore, the return period is a concept not adapted to the coastal erosion hazard. Instead, for a specific location we propose the concept of "life expectancy". For the application to the Esposende site, we chose a 30 years life expectancy equivalent to the duration of a planning landscape project (as a reference). We have evaluated for the Esposende coast where this line is located. Noteworthy, in the frame of the MOVE project we have not taken into account the climate change (sea level rise, storm surge) which is an important component potentially acting on erosion processes.

In order to locate the position of the 30 years life expectancy line, we have determined the erosion rates for each homogeneous coastal segment using data from Loureiro (2006). The observations of the cross shore profiles show that the rate at each point can vary in time. The duration of recorded data concerning the evolution of the coastline due to erosion is too short to determine an average accurate and reliable rate.

Hence, to compensate the lack of observations, we adopted a scenario-based approach relying on the combination of the available data from Loureiro (2006), the observations carried out on field and the knowledge of experts of the physical processes involved. Thus three hypotheses of Coastal Erosion Rate (CER) are determined for this duration, the likelihood of occurrence of each of them being qualified (i.e., associated with a qualitative uncertainty level): 1) A "Very likely" coastal erosion rate, 2) a "Likely" coastal erosion rate, 3) a "Possible" coastal erosion rate.

Using GIS, we quantify the areas which will be affected by erosion in the next 30 years for each of the three categories of uncertainties: Very Likely, Likely, Possible (figura 6.2).

## Forest fires

Forest fires are the main threat to productivity and sustainability of forests. Currently, in Portugal, there are two models to produce a hazard map for each municipality (scale 1:25000). The Instituto Geográfico Português calculates the hazard using a model of physical variables that are more relevant to explain the spatial variability of forest fire risk. These variables are: land cover, slope, roads, aspect and population density. Each one of these variables has a different weight and final aggregation results from a linear addition of those components. The model used by the National Forest Authority calculates the hazard as the product of the fire probability (using the historic data) and susceptibility (using slope and land cover). Using the quantile method, the values obtained are reclassified in five hazard classes. For all the analysed area forest fire hazard is very significant. In Terras de Bouro, Melgaço and Arcos de Valdevez the high and very high hazard categories are the most representative (>70%). In the other municipalities considered (Ponte da Barca, Montalegre and Vieira do Minho) this value is lower although it surpasses 60%.

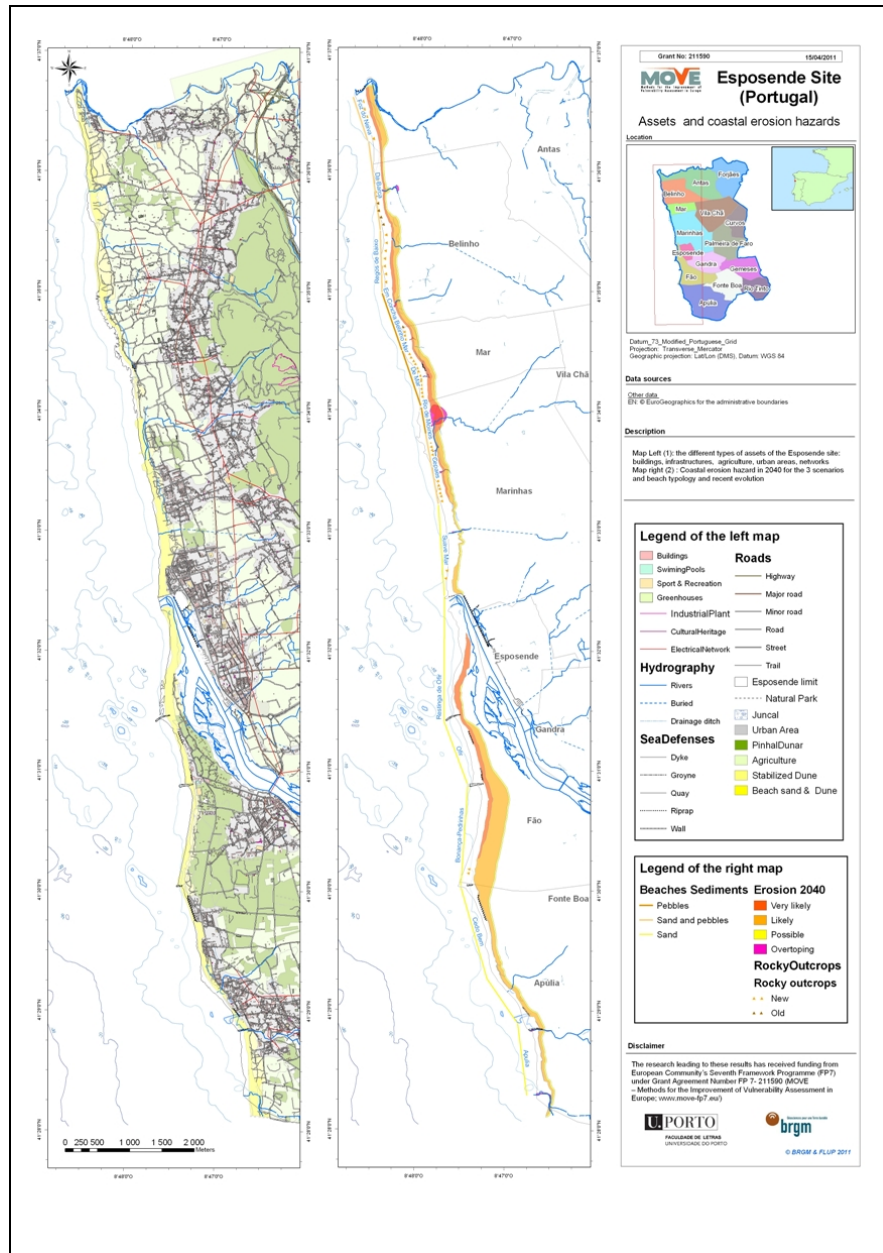


Figure 6.2 Land use, assets and coastal erosion hazard for the Esposende municipality.

There is an open access to forest fire database (<http://www.afn.min-agricultura.pt/>) managed by the National Forestry Authority with data collected since 1980. This national database has two components: i) statistical tables and ii) cartographic data. There is no consistency between the two database components (Tedim & Carvalho, 2011). Between 1975 and 2009, 3,258 fires were registered burning 252,885 ha, according to the cartographic database. During this period the number of events and the burned area showed an increase. After the adoption of the National Fire Plan in 2006 the improvements in prevention and suppression (i.e. better organization and a more availability of means) contributed, in last years, to a small decrease of the frequency of fires and burned area.

Most of the surface of the six municipalities was affected by fires in last 35 years (Fig 6.3). The percentage of burned area in function of the municipality surface is a useful indicator to measure the

hazard incidence. In fact, only in Terras de Bouro the burned area is inferior to the municipality surface (80 % of the municipality surface). On the others administrative units the percentage of burned areas is much higher (e.g. 162 % for Vieira do Minho). These values can be explained by the fact that some areas burned more than once. Between 1975 and 2009 only 24% of the surface was affect by a fire only one time. The other 76% of the burned area was affected more than twice by a fire and 15% burned between 5 and 10 times. The periodicity of fire for the area that burned 10 times was of a fire each 2 to 3 years (Fig. 6.4). Between 1975 and 2009 the municipality of Montalegre has the highest number of occurrences (1,177) and the highest value of burned area (98,257 ha). On the other hand the municipality of Terras de Bouro has the lowest number of occurrences (350) as well as the lowest burned area (23,166 ha).

Usually, the severity of a fire is seen through the size of burned area. About 82% of the fires have a burned area of less than 100 ha accounting for only 28 % of total area affected. Large fires (>1,000 ha) represented less than 1 % of the total of occurrences and 15 % of the burned area. In last decade the incidence of large fires was higher than in the previous ones. The social, economic and environmental consequences of the forest fires are practically unknown. Fire fighting priority is protecting people and the settlements which explain the low social consequences.

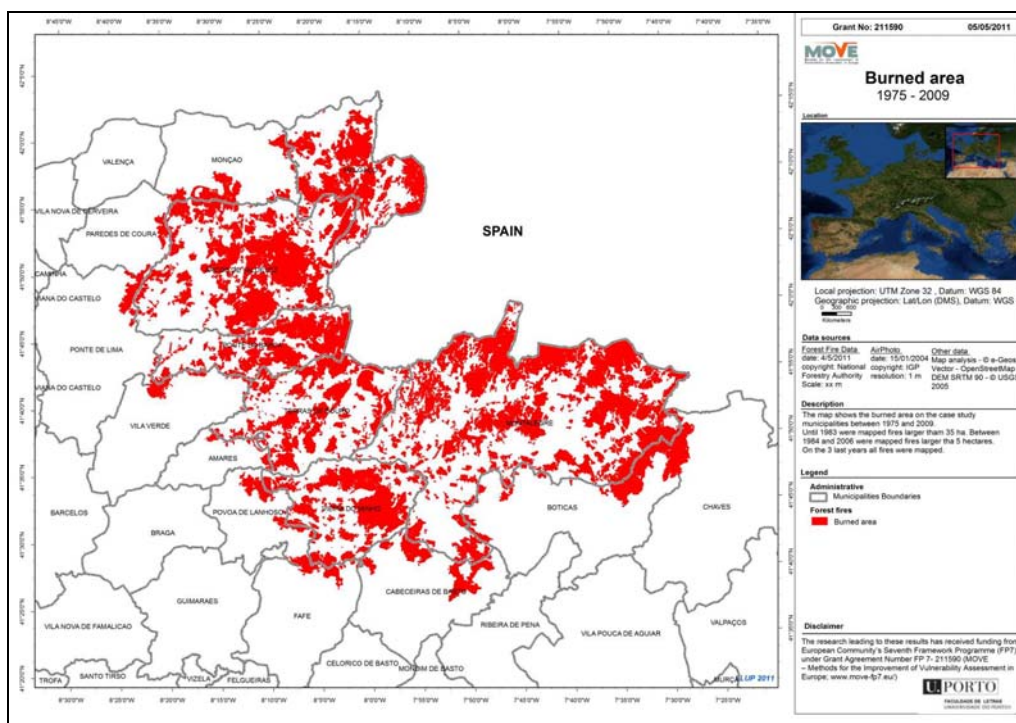


Figure 6.3 - Burned areas (1975-2009).

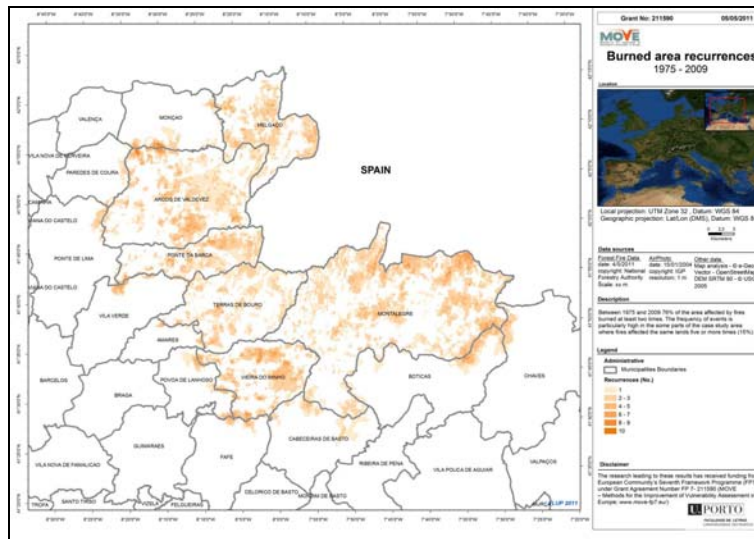


Figure 6.4 - Burned area recurrence (1975-2009).

### 6.3 Vulnerability assessment methods

In NW of Portugal case-study were tested the three components of vulnerability (i.e. the exposure, the fragility and resilience) defined by MOVE framework which proved to be adequate to assess coastal erosion and forest fire vulnerability (figure 6.5).

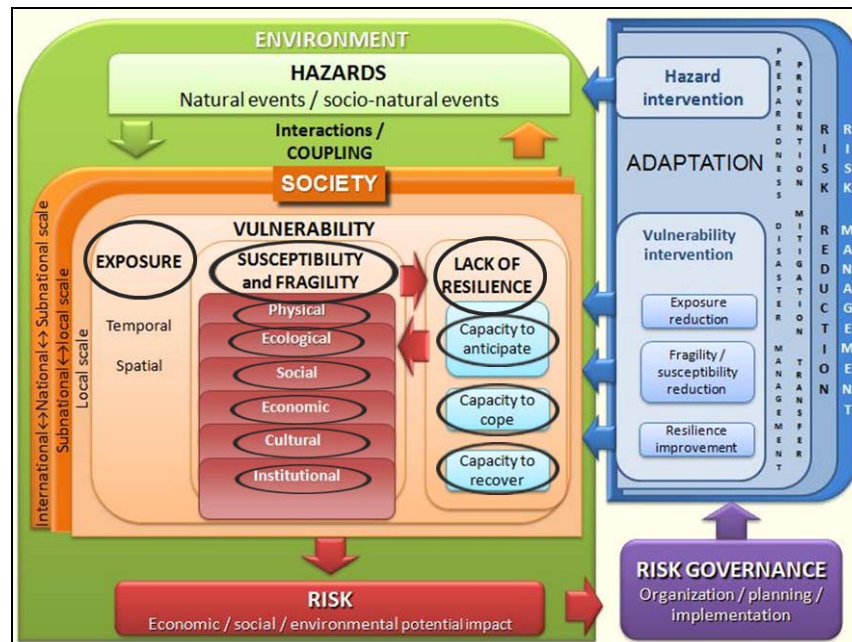


Figure 6.5 - Move framework considered in NW Portugal test case. The blackcircle identify the components and dimensions that have been consider in the Portuguese case-study.



### 6.3.1 Coastal erosion

The life expectancy approach is applicable to the exposed lands, to the ecosystems and also to the human assets (e.g. buildings, roads, infrastructure, population etc.). In order to evaluate the exposure of assets to coastal erosion hazard, we have used the three sets of zoning giving us the assets exposed at erosion hazard in 2040 associated with the uncertainty level (very likely, likely, possible). The exposure of different types of assets has been evaluated in order to quantify the number of affected assets for each parish (**Error! Reference source not found.**). The results can be presented on maps or on graphs and sorted by their uncertainty levels. It's then possible to compare the exposure of coastal erosion for each type of assets and for each parish.

Instead of using single indicator with a numerical value attached to each individual asset, it is possible to have a vulnerability assessment using the surface of specific land use potentially eroded. Each land use class is in fact an aggregating indicator at which the dominant function of the land is affected. The erosion of a surface of a specific land use has in consequence direct effect on the linked function within the community and within the society. For example, environmental vulnerability for each parish ("freguesia") can be expressed as the percentage of "natural" land potentially destroyed by erosion in relation with total "natural" surface for each parish ("freguesia"). The "natural" surfaces are defined as active dune, vegetalized dune and forest. The vulnerability of agriculture can be expressed as a percentage of potentially destroyed agricultural land in relation with the total surface of agricultural land for each parish ("freguesia"). The urban infrastructure vulnerability can be expressed as the percentage of urban areas potentially destroyed by the total of urban areas.

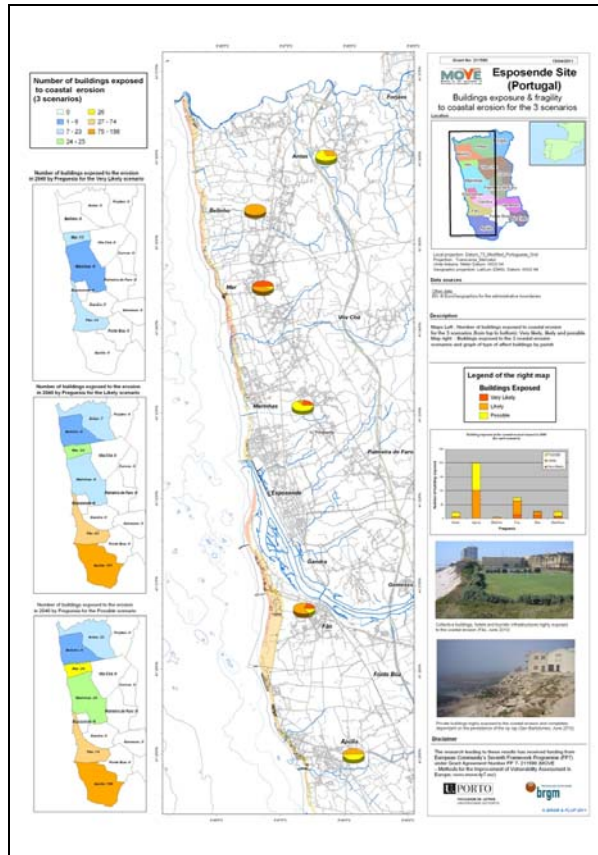


Figure 6.6 Number of buildings exposed to coastal erosion in 2040.

## 6.3.2 Forest fires

The approach used to define and interpret the vulnerability factors was based on the selection and aggregation of indicators even though they cannot completely capture the complexity of social-environmental systems. It was our purpose to develop indicators that could be at the same time scientifically sound and policy relevant as well as easy to operationalize. Each indicator can be considered on its own or could be aggregated by dimensions and components. The final product is a proposal of a vulnerability map aggregating all the indicators or the ones considered relevant to explain vulnerability in a municipality. Using the same list of indicators is also possible to establish a vulnerability profile for each administrative unit without a cartographic representation.

The lack of data was one of the main constraints in the development of the indicators and in the elaboration of a more comprehensive vulnerability assessment. One of the first assumptions was not limiting the vulnerability assessment to the existing data. All the analysis done showed that for a better risk management is necessary to improve data quality and availability. The acquisition of data using primary sources is of course a possibility but, it is only feasible at the local level and it requires a lot of resources and is time consuming. However, it is necessary to do it if we want to have a good vulnerability assessment.

Spatial analysis using GIS was the main tool used to map the vulnerability indicators. The validation of the results is supported on the forest fires occurred last year and through a questionnaire to stakeholders (e.g. fire brigades, civil protection municipal services). It is still in progress. It is our intention to validate the vulnerability framework in other European countries. Several institutions related with fire management from Greece, Spain, Italy, and Bulgaria have already been contacted and will answer a questionnaire.

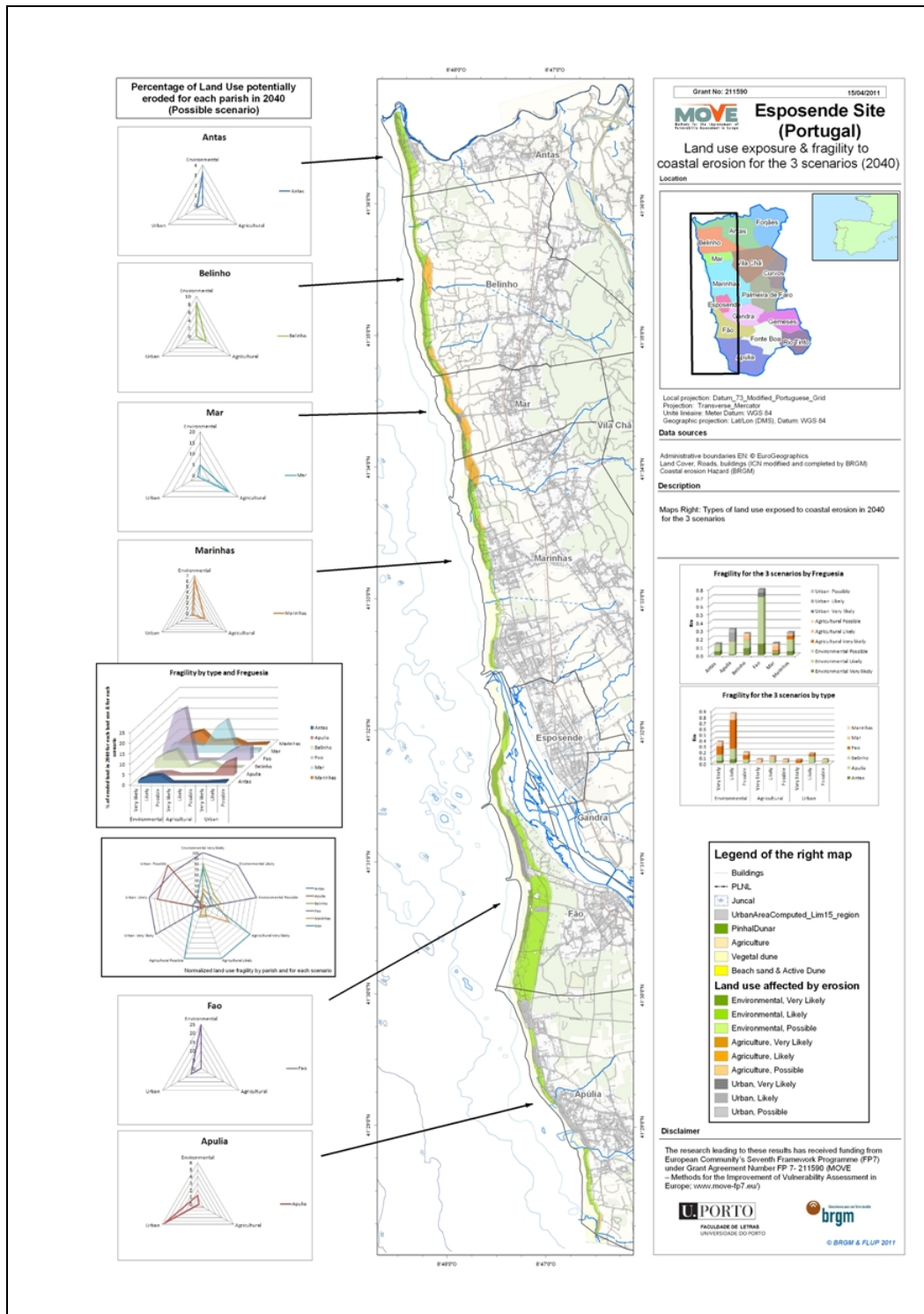
## 6.4 Indicators

### 6.4.1 Coastal erosion

There is a great variability of the different families of vulnerabilities for each parish. Thus, Fão seems to be the largely more vulnerable (exposed and fragile) to the coastal erosion specially regarding environmental and urban infrastructures assets. On other hand, Antas seems to be the less vulnerable (fragile) being, in this municipality the environmental assets especially vulnerable (exposed). One of the more interesting aspect of this approach is to identify the variability both quantitatively and qualitatively of the fragility.

The graphical presentation of radar (figure 6.7) can be used in order to have an overview of the characteristics of the vulnerability of the parishes. The graphical representation is an radar with three axes each one corresponding to one family of vulnerability assets i.e Environmental, Agriculture and Urban infrastructure. The axes are graduated in percentage, the shape of the radar indicates the main characteristics of the vulnerability (dominance of one of the factor for example), the total surface indicating the “intensity” of the vulnerability.

The parishes show great variability of the vulnerability and the dominant family of the type of assets vulnerability (urban infrastructure for Apulia, Agriculture for Mar, Environmental for Belinho and Marinhas). It is interesting to notice that for the majority of parishes vulnerability is due to two sets of components (Urban-Environmental, Environmental-Agriculture).



Figures 6.7 Land use exposure and fragility of parishes to coastal erosion.

## 6.4.2 Forest fires

The primary ecological and social effects of forest fires are physical: houses and other kinds of human structures as well as wild vegetation burn, people may be injured or may die (Bovio et al., 2006). The selection of exposed elements depends on what society considers as relevant in each area or region. In this test case the purpose was to adopt an integrated approach of the socio-environmental system. The exposed elements considered were: population, settlements, forest and ecosystems and for each of them indicators were identified to capture exposure, fragility and resilience.

The identification of indicators to translate and measure the vulnerability drivers was made using deductive, inductive and normative procedures (Hinkel, 2011). Although indicators reduce complexity, they are useful to communicate complex issues from science to policy makers or the general public.

Firstly, we looked for indicators useful to assess forest fire vulnerability in Portugal but soon we realized that concerning the goal of the Move project it could be useful to consider different geographical and cultural contexts and propose indicators that could be applied in others European countries. A list of indicators had been created without considering any restrictions from data availability. Afterward it was submitted to the evaluation of the stakeholders. During three workshops the stakeholders had the opportunity to give their opinions about the conceptual framework as well as collaborate on the selection, the weighting and development of vulnerability indicators.

The final list of indicators identified (Table 6.1) contains some that is not possible to apply in Portugal, not only due to the lack of data but also due to the fact that some of the variables are not significant to explain forest fire vulnerability in Portugal.

Each indicator selected by the stakeholders has been mapped for the test area in order to evaluate its soundness and operationalization. Each indicator can be used individually or aggregated with others to give a measure for each component and finally a general value of vulnerability.

The indicators developed are mainly quantitative but in the process of mapping them we used preferentially a qualitative approach and most of the variables are ordinal. In the process of indicators development we tried to use simple procedures that could be used by stakeholders in decision-making process.

Using the proposed methodology in the process of forest fire vulnerability assessment it is possible to choose the indicators more adequate to the geographical context.

The number of indicators is not an important issue. However, it should be considered that few parameters will lead to large gap between observed facts and expected figures (Bovio et al., 2006). At the same time in the case of a large amount of inputs, the difficulty of the model implementation (by lack of data or by too fuzzy data) is a possibility (Bovio et al., 2006). The fundamental purpose is to capture the different dimensions of vulnerability at local scale to build a vulnerability map.

The indicators selected have analytical soundness, are reliable, easy to interpret, understandable, and effective in the translation of vulnerability. The existence of reliable data at appropriate scale is fundamental and some limitations were found in Portugal. It is evident the lack of information to implement some of the proposed indicators.

In the Portuguese test case the indicators of exposure used were: the distance of each settlement to the forest, wild land-urban interface characteristics, distance to extensive grazing areas, and population density. The coexistence of buildings and dense vegetation increases the conditions favourable to fire spread specially in a situation of houses with high ignitibility. The proximity to forest increases the intrinsic susceptibility of the assets because forest could favourable fire spread. Nowadays, there is an expansion of wild land-urban interface (WUI).

COMPONENT 1. EXPOSURE	COMPONENT 2. SUSCEPTIBILITY/FRAGILITY	COMPONENT 3. LACK OF RESILIENCE
Variable: Proximity to the forest and extensive grazing	1. PHYSICAL DIMENSION Variable: Forest defensibility ▪ <i>Forest areas slope (HI)</i> ▪ <i>Species flammability (HD)</i>	1. CAPACITY TO ANTICIPATE Variable: Fire surveillance ▪ <i>Visibility from surveillance</i>

COMPONENT 1. EXPOSURE	COMPONENT 2. SUSCEPTIBILITY/FRAGILITY	COMPONENT 3. LACK OF RESILIENCE
<p><b>areas</b></p> <ul style="list-style-type: none"> <li>▪ <u>Wildland Urban Interface characteristics (HD)</u></li> <li>▪ <u>Distance of each settlement to the forest (HD)</u></li> <li>▪ <u>Distance to Extensive Grazing areas (HD)</u></li> </ul> <p><b>Variable: Exposed Population and buildings</b></p> <ul style="list-style-type: none"> <li>▪ <u>Population density (HI)</u></li> <li>- Number of persons per household (HI)</li> <li>- Number of households (HI)</li> <li>- Number of buildings (HI)</li> </ul>	<ul style="list-style-type: none"> <li>▪ <u>Forest accesses and fuel breaks (HD)</u></li> </ul> <p><b>Variable: Buildings susceptibility</b></p> <ul style="list-style-type: none"> <li>- Ignitibility of buildings materials (HD)</li> <li>- Housing security (HI)</li> </ul> <p><b>2. SOCIAL DIMENSION</b></p> <p><b>Variable: Population characteristics</b></p> <ul style="list-style-type: none"> <li>▪ <u>Elderly (People over age 75) (HI)</u></li> <li>- Functional age (HI)</li> <li>- People disability (HI)</li> <li>- One person household (HI)</li> </ul> <p><b>Variable: Social inequalities</b></p> <ul style="list-style-type: none"> <li>- Deprivation index (HI)</li> <li>- Multidimensional Poverty Index (HI)</li> </ul> <p><b>Variable: Integration in communities</b></p> <ul style="list-style-type: none"> <li>- Temporary residents and holidaymakers (HI)</li> <li>- No or low level of ethnic minorities integration (HI)</li> <li>- Migrants in country for less than 2 years (HI)</li> </ul> <p><b>Variable: Chronic Health conditions</b></p> <ul style="list-style-type: none"> <li>- Respiratory diseases (HI)</li> <li>- People with mental disorders (HI)</li> </ul> <p><b>Variable: Absence or lack of motivation/ opportunity</b></p> <ul style="list-style-type: none"> <li>▪ <u>Dwellings used as first residence (HI)</u></li> <li>- Absentee homeowners (HI)</li> <li>- Absentee landowners (HI)</li> <li>- Renter houses (HI)</li> </ul> <p><b>Variable: Community fragmentation</b></p> <ul style="list-style-type: none"> <li>- Existence of conflicts inside community (HI)</li> </ul> <p><i>(Existence of Internal conflicts; Existence of conflicts with organized groups; Existence of conflicts with government agencies)</i></p> <p><b>3. ECONOMIC DIMENSION</b></p> <p><b>Variable: Loss of production</b></p> <ul style="list-style-type: none"> <li>- Forest productive areas (HI)</li> </ul> <p><i>( Loss of production; Loss of jobs)</i></p> <ul style="list-style-type: none"> <li>- Agriculture productive areas (HI)</li> </ul> <p><i>(Loss of production; Loss of jobs)</i></p> <ul style="list-style-type: none"> <li>- Industrial and service activities(HI)</li> </ul> <p><i>(Loss of production; Loss of jobs)</i></p> <p><b>Variable: Disruption of livelihoods</b></p> <ul style="list-style-type: none"> <li>- Loss of livelihoods (HI)</li> </ul> <p><i>(Permanent; Long duration; Short duration)</i></p> <ul style="list-style-type: none"> <li>- Families income dependence from forest (HI)</li> </ul>	<p><u>lookout towers (HD)</u></p> <ul style="list-style-type: none"> <li>- Mobile surveillance coverage (HD)</li> </ul> <p><b>Variable: Fuel management effectiveness</b></p> <ul style="list-style-type: none"> <li>- Defensible space around settlements (HD)</li> <li>- Defensible space around buildings (HD)</li> <li>- Use of prescribed burning (HD)</li> <li>- Strategic plan to manage fuels (HD)</li> <li>- Controlled grazing (HD)</li> </ul> <p><b>Variable: Community engagement</b></p> <ul style="list-style-type: none"> <li>- Coordination between communities and civic agencies (HI)</li> <li>- Collective efficacy (HI)</li> <li>- Community participation (HI)</li> <li>- Social networks (HI)</li> <li>- Increase of local volunteers (HI)</li> <li>- Participating planning (HI)</li> <li>- Sense of community (HI)</li> <li>- Place attachment (HI)</li> </ul> <p><b>Variable: Community response preparedness</b></p> <ul style="list-style-type: none"> <li>- Community Emergency Plan (HI)</li> <li>- Empowering Physical settings (HI)</li> </ul> <p><b>Variable: Households preparedness</b></p> <ul style="list-style-type: none"> <li>- Knowledge about fire safety measures (HD)</li> <li>- Adoption of fire safety measures (HD)</li> <li>- Competencies and resources to respond to fires (HD)</li> </ul> <p><b>2. CAPACITY TO COPE</b></p> <p><b>Variable: Availability of physical resources</b></p> <ul style="list-style-type: none"> <li>▪ <u>Distance of water points (HD)</u></li> <li>▪ <u>Distance of fire-fighter</u></li> </ul>

COMPONENT 1. EXPOSURE	COMPONENT 2. SUSCEPTIBILITY/FRAGILITY	COMPONENT 3. LACK OF RESILIENCE
	<p><b>4. ECOLOGICAL DIMENSION</b></p> <p><b>Variable: Ecosystems conservation</b></p> <ul style="list-style-type: none"> <li>▪ <u>Conservation of rare or representative habitats (HI)</u></li> <li>- Permanent loss of “natural” environment (HI)</li> <li>- Loss of biodiversity(HI)</li> </ul> <p><b>Variable: Natural resources</b></p> <ul style="list-style-type: none"> <li>- Quality of water resources (HI)</li> <li>- Availability of water resources (HI)</li> <li>- Soil erosion (HI)</li> <li>- Increasing pollution (HI)</li> <li>- Time to recovery (HI)</li> </ul> <p><b>5.CULTURAL DIMENSION</b></p> <p><b>Variable: Cultural heritage values</b></p> <ul style="list-style-type: none"> <li>▪ <u>Identification of cultural heritage sites (International interest; National interest; Local interest)</u></li> </ul> <p><b>Variable: Traditional forest practices</b></p> <ul style="list-style-type: none"> <li>- Traditional fire use (HD)</li> <li>- Cultural practices on forest (HD)</li> </ul> <p><b>6. INSTITUTIONAL DIMENSION</b></p> <p><b>Variable: Legislation constraints</b></p> <ul style="list-style-type: none"> <li>- Planning legislation and practices (HI)</li> <li>- Top-down decisions and actions (HI)</li> </ul> <p><b>Variable: State attitude</b></p> <ul style="list-style-type: none"> <li>- Conflicts between agencies (HI)</li> <li>- Fire agencies prescriptive (HI)</li> <li>- Bureaucracy (HI)</li> <li>- Disempowerment (HI)</li> </ul> <p><b>Variable: Fire service evaluation of property defensibility</b></p> <ul style="list-style-type: none"> <li>- Houses defensibility (HI)</li> <li>- Forest defensibility (HD)</li> </ul>	<p><u>brigades to the settlements (HI)</u></p> <p><b>Variable: Community isolation</b></p> <ul style="list-style-type: none"> <li>▪ <u>Lack of road network access (HI)</u></li> </ul> <p><b>Variable: Fire ecosystem dependency (HD)</b></p> <ul style="list-style-type: none"> <li>- Fire dependent ecosystems (HD)</li> <li>- Fire sensitive ecosystems (HD)</li> <li>- Fire independent ecosystems (HD)</li> <li>- Fire influenced ecosystems (HD)</li> </ul> <p><b>Variable: Social inequalities</b></p> <ul style="list-style-type: none"> <li>- Deprivation index (HI)</li> <li>- Multidimensional Poverty Index (HI)</li> </ul> <p><b>Variable: Fire suppression resources and capabilities</b></p> <ul style="list-style-type: none"> <li>- Adequacy of technical and human resources (HI)</li> <li>- Training of fire-fighters teams (HI)</li> </ul> <p><b>3. CAPACITY TO RECOVER</b></p> <p><b>Variable: Natural resources</b></p> <ul style="list-style-type: none"> <li>- <u>Vegetation response capacity (HD)</u></li> </ul> <p><b>Variable: Insurance</b></p> <ul style="list-style-type: none"> <li>- Household insurance (HI)</li> <li>- Forest insurance (HI)</li> </ul> <p><b>Variable: Social inequalities</b></p> <ul style="list-style-type: none"> <li>- Deprivation index (HI)</li> <li>- Multidimensional Poverty Index (HI)</li> </ul>

Table 6.1 Indicators of forest fire vulnerability

Notes: The underlined indicators are the ones used in the elaboration of a forest fire vulnerability map at the municipal scale. HD - Hazard Dependent Indicator; HI - Hazard Independent Indicator

which implies an increasing number of dwellings close to or inside natural areas. The increase in WUI means more people and goods at risk but at the same time higher probabilities of wildfire ignition. The increasing number of wildfires involving this interface has become quite relevant. There is no single definition of WUI, but normally this concept includes three components: human presence, wild land

vegetation, and a distance that represents the potential for effects (Stewart et al., 2007). The number of buildings as well as the distance between them was used as the metric for human presence. The WUI can assume diverse characteristics with different fire risk (Caballero et al., 2007; Lampin-Maillet et al., 2009). The prevalence of human activities in areas without fuel management constitutes a permanent source of potential fire outbreaks (Jappiot et al., 2009). The level of risk in WUI is not only related with exposure. It is also explained by defensibility and evacuation facilities that are considered in the others components of the vulnerability framework. Pasture renovation using fire is a common practise in many countries. The proximity of settlements, WUI and forest areas to extensive grazing lands increase the exposure to forest fires. The identification of these areas can contribute to a strategic fuels management in order to prevent the spread of a fire when it is used to promote pasture renovation. The use of prescribed burning is still reduced and does not answer correctly the shepherd's needs. It is important to note that in Portugal the use of fire to renew grazing areas is an ancient behaviour, and usually people ignited a fire and remain in the local to prevent it from escalate. Nowadays, the prohibition to use prescribed fire led to people igniting a fire and then run away. The proximity of settlements and forest areas to the extensive grazing lands increases their exposure to wildfire. Population density reveals the presence and the amount of population or buildings which are exposed and can potentially be affected but also that could be necessary to evacuate. Higher concentrations of people means more evacuation difficulties (Johnson and Zeigler 1986; McMaster 1988, Cova and Church 1997, Cutter et al., 2000). More buildings exposed means more potential damages.

As indicators of physical susceptibility/fragility forest areas slope, species flammability, and forest accesses and fuel breaks were considered. Forest area slope has a great influence on fire behaviour. Forest on steeper slopes is more vulnerable than on low or moderate slopes. This is due to the difficult of suppression tasks, mitigation measures, but also because these areas are more susceptible to erosion risk after a fire. The species flammability has impacts on the ignition and propagation of fire. The flammability is related with the vegetation characteristics such as moisture content, percentage carbon compounds, volatile compounds, silica free mineral content, leaf thickness, surface area-to-volume ratio, particle density (Behm et al. 2004). More flammable fuels will increase fire propagation. Higher flammability means that the ignition of the vegetation when in contact with a heat source is easier than low flammable species. In an area with high flammable vegetation the spread of a fire is easier. Higher flammability does not mean higher vulnerability of the species because some highly flammable species could more easily recover from a fire than others. Forest roads are the most important infrastructure foundation of the forest landscape to fulfil forest management practices and to supply all functions of forest resources. Undoubtedly, forest roads play a key role in forested areas and in rural development as they facilitate the movements of human population over the forest land, and connect natural resources with societies and economies (Çoban et al., 2010). Forest roads may influence fire regimes by increasing fire ignition probability (Franklin and Forman, 1987) as a result of human activities that occur in the transportation corridors, reduced fire size as a result of physical barriers to fire movement, and increased accessibility for fire suppression activities (Covington and Moore, 1992) (Çoban et al., 2010).

As social susceptibility/fragility we were only able to map two indicators which limits the evaluation of this dimension. Dwellings used as first residence and population over age 75 were considered. The presence of people in the houses can contribute to the implementation of prevention measures, to the alert and consequently to an efficient initial attack. People over the age of 75 can reveal an increase of population fragility to forest fires. Firstly, they can be more susceptible physically which affects their capability for fire fighting or for personal protection or evacuation. Secondly, they can have physical and economic limitations to promote the reduction of fuel accumulation. Finally, ageing can contribute to the abandonment of agricultural lands.

Even though economic and institutional indicators were identified the lack of data prevents their use in the Portuguese case study.

The only indicator considered for ecological susceptibility/fragility was the conservation of rare or representative habitats. This vulnerability results from the habitats characteristics (i.e. the presence of interest or rare species referred for fauna or flora conservation), or to the important ecological function

that supported by these habitats (e.g. water resources, carbon sequestration). Given the fact that the budget available for preventive silviculture is usually limited or insufficient, is it reasonable to apply these tasks to areas with the highest ecological and landscape value (Bovio et al., 2006). In addition, when a forest fire is spreading, it would also seem reasonable for a fire manager to allocate fire suppression resources according to a certain scale of values. This scale would bear in mind not only the presence of population, property (buildings, etc.) but also high quality natural environments (Bovio et al., 2006).

The identification of cultural heritage sites was considered as a cultural indicator. It can be used to protect and mitigate cultural values from being damaged by forest fires.

It is also likely that exposure and susceptibility/fragility would fall with higher resilience (i.e. capacity to anticipate, to cope, and to recover). There are at least two components that contribute to the ability of communities to anticipate natural disasters. One is the predictive capacity of knowing when and where a disaster might occur, and the second is anticipating the impact of those disasters on communities (Gunderson, 2010).

Even though in countries with a dry and hot season forest fires are not inevitably related with meteorological conditions, the anthropogenic genesis of most of the forest fires puts accent in the importance of attacking the structural causes of the fires. The implementation of several measures can contribute to decrease vulnerability. People should know that if they are not able to control the outbreak of a fire they can significantly decrease its intensity and severity. The capacity to anticipate fuel management (e.g. thinning, mechanical cleaning, defensible space, prescribed burning) is the most efficient procedure to decrease the probability of damaging fires. Collins (2005) refers that the variables that influence the household level of vulnerability are related to the characteristics of houses and areas immediately adjacent to them rather than landscape scale vegetation and slope characteristics. The data to apply this indicator in a municipality is not yet available. As more than 95% of the forest fires are man-made the community engagement and preparedness indicators (Table 1) have great influence in fire occurrence and impacts. However, for these indicators data is also missing.

Early fire detection is an important issue because if a fire is detected on early stage its control could be possible with only an efficient initial attack. Areas that are not visible from any lookout tower are more vulnerable than the others that are visible. Visibility from surveillance look towers is an indicator that has a temporal component because lookout towers are not in activity all the year. Fire surveillance using lookout towers or mobile mechanisms is very important because fighting a large fire is more resources consuming.

The distance of fire-fighters brigade to the settlements is one of capacity to cope indicators. A small distance of the fire-fighters headquarters from the fire ignition point increases the possibility of efficacy in the initial attack. Higher distance increases vulnerability because it is easier to control a fire in the beginning than a fire with a larger perimeter. This distance could be fundamental to establish some priorities in the prevention measures as well as the strategic localisation of fire-fighters brigades. The two others capacity to cope indicators are: distance to water points and lack of road network access. The accessibility to water supplies is very important for suppression tasks in countries where water is the main tool to fight fires. A short distance of each area of the municipality to the closest water point is valuable primarily for terrestrial means. The physical isolation of a community can be measured by the road network access which is related with the possibility of evacuation in the outbreak of a fire. The population gets completely isolated and, consequently, more vulnerable to harm if the only road that serves a settlement gets closed by a fire. The capacity of ecosystems to cope with a fire is different. The fire ecosystem dependency indicators reveal the cope capacity of each ecosystem. The literature defines four categories of ecosystems related with their response to fire. Fire dependent ecosystems where fire is essential and species have developed adaptations to respond positively to fire. Fire sensitive ecosystems aren't very flammable, and species have not developed adaptations to respond to fire. In fire independent ecosystems fire plays a little role or no role at all. Fire influenced ecosystems are broader vegetation types where the responses of species to fire have not been documented or understood (Myers, 2006). Conversely, there are other areas where fire can lead to the destruction or loss of native species and habitats. These areas are called fire-sensitive. Finally, capacity to recover indicators was identified and they are: the vegetation response capacity, household and forest insurance and poverty or deprivation index. Unfortunately, there is no data to map them in each municipality.



Most of the indicators defined for forest fire risk are hazard independent and, consequently can be used in a multi-hazard vulnerability assessment.

## 6.5 Results & Validation

The purpose of vulnerability assessment was to inform decision making. The challenge was to express vulnerability in measurable units in order to be used to create a vulnerability map and for estimation of total risk.

We consider that the findings of Move project enhance the vulnerability knowledge and contribute to fill some existing fragilities in coastal erosion and forest fire risk assessment in Portugal. The implementation of vulnerability conceptual framework enhances fire prevention and suppression and the landscape planning in the coastal areas.

The stakeholders consider that Move framework is comprehensible and the indicators selected are important determinants of vulnerability in their territorial context.

It is not yet possible to define all the results of the vulnerability assessment for forest fire, however, with the information available to calculate indicators we are very satisfied with the results acquired because the first draft of an aggregated vulnerability map shows positive results. The stakeholders were fundamental in the selection and weighting of the indicators. The weights of each indicator described has relative importance in the context of all the vulnerability indicators, however, more research is needed to weight some variables differently. In consequence, two procedures were adopted: i) use the same value for all indicators; ii) attribute different weights to each indicator.

The validation of results of the forest fire vulnerability map is still in progress. The lack of data about fire impacts is also a relevant limitation in the validation of indicators and their weighting. Some interviews to fire-fighters and local communities affected by large fires are in progress as a tool to evaluate the soundness of the selected indicators.

One of the objective of the methodology was the evaluation of the transferability of the method to others geographical context. To answer the request two procedures have been adopted: 1) submit the list of indicators to the review of experts from different countries (Greece, Australia, USA); 2) validate the framework in other European context, several institutions related with fire management from Greece, Spain, Italy, and Bulgaria have already been contacted and will answer a questionnaire.

## 6.6 Discussion

Concerning coastal erosion vulnerability assessment the methodology employed is very useful to support decisions from policy-makers. The most significant limitation was the lack of information about the erosion rates. This data acquisition is a long-term process that was not considered in Move proposal.

Contrary to the other natural hazards forest fires are the most predictable ones and allow societies to develop efficient counteracting measures (Biro, 2009). At the same time fires can be both beneficial and detrimental depending how, where, when and why they are burning (Meyers, 2006). The bad side is related with the destruction of forests, damages such as loss of lives and property, as well as economic and environmental consequences. However, sometimes fire provides ecological benefits to the landscapes affected and also provides tangible benefits for local communities (Hann and Bunnell, 2001). The fact that fire has two faces—beneficial roles and detrimental impacts depending on the circumstances—has largely gone unrecognized by societies and governments that have demanded or developed ever more sophisticated fire suppression technologies and fire prevention campaigns (Meyers, 2006). These two characteristics make vulnerability a key concept in fire risk prevention and response. The vulnerability assessment seems an appropriate tool to understand when fire is improving or reducing ecosystem health and landscape condition (Barrett et al., 2000; Miller et al., 2000; Calkin et al., 2008, cited in Keanu & Karau, 2010) as well as when fire is threatening social and

economic systems. On the other hand, in Portugal, as in many other countries worldwide, despite the increase in suppression efforts (e.g. huge investments, the sophistication of the methods, tools and technology to prevent and fight the fires) the burned area remains significant and even though these investments have limited the damages they did not solve the problem in a sustainable way. Fire suppression costs are higher than ever and in many countries the possibilities to increase the fighting resources are practically exhausted (Vélez 2005). The maintenance of the funding for fire management in some countries like Portugal is expected to suffer significant reductions in the near future which demand more efficient proactive measures to deal with this risk. Forest fires cannot be eliminated and it is evident that the situation all over the world is not going to be solved by the use of more resources or a more aggressive fire suppression strategies. It is necessary to learn to live with fire. In the face of uncertainty of climate and societal changes, there is a need for moving from short term driven policy of fire control mainly based on huge technological investments, to a longer term policy of removing the structural causes of wildfires (Biro 2009). Forest fire vulnerability assessment can be useful to answer positively the uncertainty and the mentioned needs.

Specifically this framework is a good support for vulnerability assessment from local to national scale. The stakeholders involved in all the research process understood very well the generic framework even if they showed some difficulties in understanding its operationalization. They recognized its importance and utility in risk management (e.g. prevention practices, disposal of suppression means). During the last workshop the main concern of the participants was about the weight that should be imputing to each indicator. They are used to attribute a value to each indicator and apply it in different social and environmental contexts and for a long period of time. In fact, there are some physical indicators (e.g., vegetation type, slope, distance to forest, distance from fire fighters brigade, and distance from coast line) that are very similar independently of the location. However, the diversity of social characteristics advises us to not identify weightings independent of the assessment process conducted in a specific location. This means that an assessment process should be undertaken at the scale of analysis in order to identify the weightings applied to the indicator in each locality. Also this process should be repeated periodically to update knowledge of weightings to accommodate changes in social and economic network characteristics over time and/or as a result of resilience intervention (Paton and Tedim, 2011, in press).

The objective of building a map of vulnerability is very important because it can be integrated in risk assessment, and complement the hazard map, that is an important tool for planners and decision makers. Also the used of the selected indicators to build a vulnerability profile can contribute to a better support of risk management. This profile can be done at different spatial scales (e.g. community level, parish, municipality, region and even country)

## 7.7 Conclusions and recommendations

The vulnerability framework is very important in risk management. If the factors that influence vulnerability and adaptive capacity are understood, communities and civic protection agencies will be in a better position to make informed choices regarding risk and how the community can be mobilised to manage it. If it influences positively risk mitigation and response, it can also be seen as a way to promote a more effective management and distribution of limited human and technical resources.

Some of the indicators selected for coastal erosion and forest fire vulnerability assessment can be shared by several hazards and applied in different countries. Sometimes it was suggested for the same variable (Table 1) indicators that are very similar. This is a way to show that some variables can be measured using different indicators according to the scale of analysis, data availability, and the environment and social characteristics of the area. It reflects some flexibility on the framework operationalization without negative impacts in vulnerability assessment.

The development of Move's vulnerability framework points out that more data is necessary than the one available in Portugal at this moment to support a vulnerability assessment that could be used by several kinds of stakeholders to improve risk management in a more sustainable and integrated way.

The experience of work with stakeholders was very positive because most of them recognize the importance of assessing vulnerability, and are open to consider it in their daily risk management activities. On the other hand, the academics understood end-users needs.

The stakeholders and mainly the local representatives are better placed to make the risk management right choices and the implementation of vulnerability assessment can support better decisions. In general the vulnerability assessment contributes to more sustained risk management and a cost-effective use of technical and human resources.

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## 7 Vulnerability to Heat waves, Floods and Mass Movements in Mountainous Terrain: Test Cases in South Tyrol

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### 7.1 Case Study Description

South Tyrol is located in the east Alps south of the main chain. The climate is mild and dry. The average temperature is 12.3°C, in average there are 81 rainy days per year and the average of precipitation is 712 mm per year (period 1921-2010 at Bozen weather station).

It includes mainly the upper part of the Etsch /Adige river catchment and its contributors. The landscape is characterised by alpine mountains, of up to 3905 m.a.s.l. height and intensively used and densely populated valleys.

South Tyrol has a population of 500.000, which is split into 3 different language groups. German as native language accounts for 69%, Italian for 26% and Ladin for 4%. It is part of autonomous Region Trentino - Alto Adige and therefore has a wide independence in legislation.

The Hazards we investigated in this case study had different foci in scale and in stakeholders, that were addressed:

#### Mass movements:

- Scale: provincial (for the pilot study presented here the scale is local. When we add the results from the whole South Tyrol the scale will be regional).
- Stakeholders: local authorities (Hydraulic Engineering, Fire and Civil protection).

#### Flooding:

- Scale: local scale (Sterzing/Pfitsch).
- Stakeholders: residents and local Business, local and provincial administration.

#### Heat waves:

- Scale: local scale (Bolzano/Bozen).
- Stakeholders: Provincial and local health care services, Civil protection department, Public administration (regional and local authorities), residents (especially elderly)

#### The effect of climate change on mass movements and floods

In general increased frequency of precipitation due to climate change can trigger landslides and floods in some regions (ISDR, 2008). Higher temperatures can cause also glacial lake outbursts that can trigger floods and debris flows (ISDR, 2008). As far as landslides are concerned, climate change can affect their occurrence in two ways: increasing rainfall intensity and frequency, and changes in soil temperature which can lead to reduced slope cohesion and stability (UNU, 2006). More specifically, in South Tyrol, Staffler et al (2008) identified alpine torrents and river catchments in which the future climate change will modify the hazards situation as far as floods and debris flow are concerned. They suggest that the impact of climate change to natural hazards show remarkable regional differences. Their study showed that an increase in the intensity and frequency of flood and debris flow events is to

be expected. They also pointed out the importance of reducing the vulnerability of the elements at risk in order to reduce risk.

### **The effect of climate change on heat waves**

Time-series measurements of land-surface and sea surface temperature of the last century show a clear warming trend. In most of Europe an air temperature increase of about 0.8 °C on average can be proven. Outcomes of future modelling suggest a pronounced warming of several degrees (from 1.1 °C up to 6.4 °C) for this century. Moreover, the warming will be particularly accentuated in the Alps. A shift in mean air temperature may lead to a non-linear response in the frequency of extreme events such as heat waves (Houghton et al., 2001). Actually, recent regional climate models suggest an increased variability of temperature for the future in addition to an increase in mean temperature, which will even augment the frequency of extreme events (Schär et al., 2004).

In short, as a phenomenon of climate change the frequency and severity of summer heat waves is supposed to increase in the near future. A foretaste of an exceptional warm summer could already be experienced in 2003 when entire Europe was stroke by a long lasting heat wave that began in June, continued in July and peaked in August. Unusual high temperatures were measured especially in the northern part of the continent, though they were also felt in the more southern part. In South Tyrol for instance, the average temperature in the summer of 2003 was about 3 to 4 degrees above the average of the last four decades (Toniazzi et al., 2003).

### **Local preparedness**

**Mass movements:** The province of south Tyrol has produced a series of hazard zone maps for mass movements, floods and avalanches that can be found online (Geobrowser) together with the location of historic events. As far as mass movements are concerned the hazard zones concern rock falls, landslides and debris flows and they are made on a basis of intensity and possibility of occurrence. As far as snow avalanches are concerned, there are hazard maps available (1:25000) showing the location of previous events. Additionally, there are the hazard zone maps (1:5000 to 1:500) indicating high hazard, moderate hazard and no hazard areas. Moreover, there is real time online information in the website of the avalanche warning service of the Province of Bolzano and information on avalanches per email. At municipality level local hazard maps exist with classification and a report that describes the methods, models, definitions and software that has been used. Additionally these reports include events information, photos, and other data. All this information can be found online in a web-Platform called Hazard Browser Südtirol. An early warning system for landslides in two case study areas in South Tyrol has been developed within the project ILEWS (Integrative Landslide Early Warning Systems) (Rohr and Glade, 2010).

More specifically in our pilot study area (Martell) following the event of 1987 there was permanent removal of buildings and prohibition of building in areas previously built at the bank of the river. An early warning system that is connected to the reservoir was established and response exercises are regularly carried out. A protective reinforced concrete wall was built at the bank of the river in parts of the valley. Hazard zones are planned to be identified next year.

**Flooding:** A flood hazard map was produced for our research area Sterzing / Pfitsch, but has not been officially approved yet. Structural measures for flood protection are installed on the river Eisack and on most of the small contributors, nonetheless the exposure to flood risk for a big part of the town is rather high. A major river dredging is planned to reduce the risk level.

The provincial warning system is based on sirens combined with news in the local radio and TV stations. Early warning systems are based on weather information and an operational precipitation discharge model.

Emergency exercises are held regularly in the Province of Bolzano. In November 2005 Sterzing and Pfitsch were the scene for a big intercommunity emergency and simulated evacuation exercise on a flooding/ debris flow scenario. The provincial civil protection, local fire fighters and local administration participated in the exercise.

**Heat waves:** There is little experience with extreme high temperatures in South Tyrol compared to other natural hazards such as landslides or avalanches. In addition, the relation between heat waves and health problems is difficult to demonstrate in a small city like Bolzano. As a result heat waves are often not perceived as a real threat or underestimated in their potential to affect the population. The near future evolution does not only suggest an increase in the frequency of extreme hot days, but also an increase in the susceptibility at local level due to an increase in number and percentage of elderly people (the number of the generation aged 65 and more in Bolzano will increase from nowadays 23'000 to 24'000 in 2020).

Nevertheless, after the summer of 2003 the national civil protection has set up a national heat health warning system (HHWWS) for different Italian cities including Bolzano that monitors the heat health danger situation taking into consideration temperature, humidity and mortality rates during past events. In addition the local authorities of the Province of Bolzano have set up a regional forecast system and local initiatives for elderly people in case of heat waves. This local forecast system is based on meteorological parameters that are different from those used by the national authorities and hence also the heat wave warnings do not coincide.

The activities carried out by the local administration focus on short term measures that help to reduce the direct impact of emerging heat. Long term measures to mitigate impacts such as the avoidance of urban heat islands or the creation of fresh air corridors are currently foreseen (or are under discussion) within the context of urban planning. There are already some legal regulations e.g. in order to extend green surfaces in urban areas but there is a still potential for improvement. However, these measures have not been taken with the particular intention to reduce the impact of heat wave but in a more general way e.g. to improve the quality of life in cities.

## 7.2 Hazards

In this case study we will investigate three different hazards, that are characteristic for South Tyrol:

- **Mass movements**, including, landslides, avalanches and debris flows, for which a tool for damage assessment will be built based on a vulnerability curve (This case study only tests debris flow but can be extended).
- **Flooding**, In this case study we investigate risk awareness and the attitudes towards self-defence and responsibility. The research area is the flood plain of Eisack river in the community of Sterzing and Pfitsch.
- **Heat waves**, we investigated the perception and management of the heat wave issue as a health problem at the local level of the city of Bolzano and tried to identify relationships between measurements of meteorological parameters and socio-demographic data.

The three hazard case studies will be briefly described in the following three sections:

### 7.2.1 Mass movements

The province of South Tyrol has often been affected by mass movements such as landslides, debris flows, rock falls and avalanches. The documentation of events (debris flow, floods, landslides and avalanches) has started systematically in 1998. Every year there is a report describing the events, their location, intensity and impact in the entire South Tyrol. Our case study area (Martell) has suffered in the past from flood and debris flow events (1772, 1777, 1789, 1887, 1888, 1889, 1891) that have been caused not only by strong rain but also by the outburst of glacial lakes. However, the most disastrous event that has been recorded in the area until now and it is also the one that we are using in our case study is the event of August 1987 which was a combination of natural and man-made disaster. In more detail, the strong rain filled the neighbouring reservoir and the dam company decided to release water in order to avoid overflow. However, the channels could not be closed due to a

technical failure and a power cut leading to even more water being released in the valley. The height of water and debris reached at some areas in the valley the height of 2,5-3 m and the destruction was severe. At least 12 houses were totally swept away and many more were severely damaged. Roads were washed away, animals died, industry and agricultural buildings suffered damages and loss of equipment, water, sewage and electricity lines were destroyed. However, due to early evacuation there were no casualties. Although the event was partly man made, similar events can occur caused by glacial lake outbursts that are very common in the area. Following the event, an early warning system was established in the area which is connected to the reservoir in order to avoid similar events in the future. The system is tested often through evacuation and emergency exercises that are regularly carried out by the rescue teams involved.

### 7.2.2 Flooding

South Tyrol bears a high risk of flooding. Especially fast approaching flash floods caused by extreme precipitation contribute to this. Nevertheless, no big event appeared here in the last 20 years. A high number of structural flood protection measures also on smaller rivers has contributed to this. But this is no guarantee for safety. An extreme precipitation event can exceed the design level of protection measures and cause a flood in any catchment in South Tyrol. Our case study focuses on Sterzing and Pfitsch:

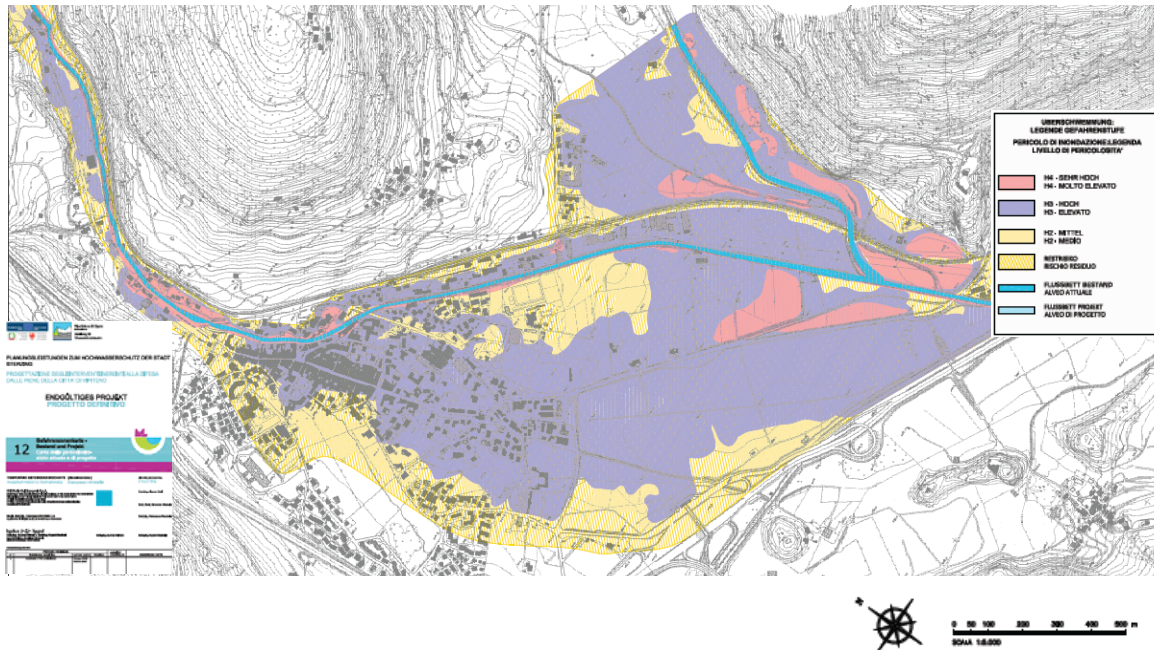


Figure 7.1 Flood hazard zone map of Sterzing and Pfitsch Source: Autonome Provinz Bozen Südtirol / Provincia autonoma di Bolzano Alto Adige.

The zones exposed to high flood risk includes a big part of the residential area of both communes and Sterzings historic city center. Situated at the bottom of the steep Eisack valley the built up areas bear a great potential flood damage. Natural conditions at the mouth of three contributors -Pfitscher Bach, Mareiter Bach and Faller Bach- increases the flood probability. Heavy precipitation events can produce very sudden flooding and debris flows in this steep terrain. Many flood events in history proof the high risk. In past events houses, streets and bridges have been damaged and destroyed and rendered inhabitants cut off from the outside world and transalpine traffic was disrupted. Earliest records of flooding and debris flows date back to the year 1041 or even 590. During the 19th century there are records for nearly 80 flooding and debris flow events.



Therefore river regulation works started in the 1870ies, reducing the number of floods and debris flows. In the 20th century there is record of only around 30 events in the Sterzing/Pfitsch area. Further river regulations on the contributors of Eisack in the 1970ies further reduce the number of events. The last flood causing big damage was 1965, since then only small events, damaging single buildings, infrastructure with low sensitivity (hobby airport) and agriculture occurred.

Today a flood hazard zone map shown in Figure 1 has been generated, but has not yet been officially legalised.

Monitoring conditions in the upper part of the basin are difficult. Flood warnings can only be issued based on precipitation radar data, that bear significant uncertainties. The steep relief allows fast surface runoff of extreme precipitation. Therefore flood warning lead times are only few hours.

### 7.2.3 Heat waves

Bolzano lies in the centre of the Southern-Eastern parts of the Alps at an altitude of about 250 m a.s.l. Due to its location in the basin of a deep valley during the summer months the city is affected by high temperatures and heat waves.

During the last 30 years the annual average temperature in Bolzano increased by +1,5°C (see figure 7.2). In July 2010 the average temperature was from +3°C to +5°C above the average for July. May 2009 was the hottest and driest May since the beginning of official measurements (Hydrographisches Amt, Climareport, Autonome Provinz Bozen). However, for the impacts of heat stress on human health not only the maximum temperature during the days is relevant but also the minimal temperature during the night. In Bolzano the number of tropical nights, were the minimum temperature remains above 20°C, has increased significantly over the last 20 years. Until 1995 Bolzano had only from 0 to 5 tropical nights per years, for 2010 the measurements showed 20 tropical nights.

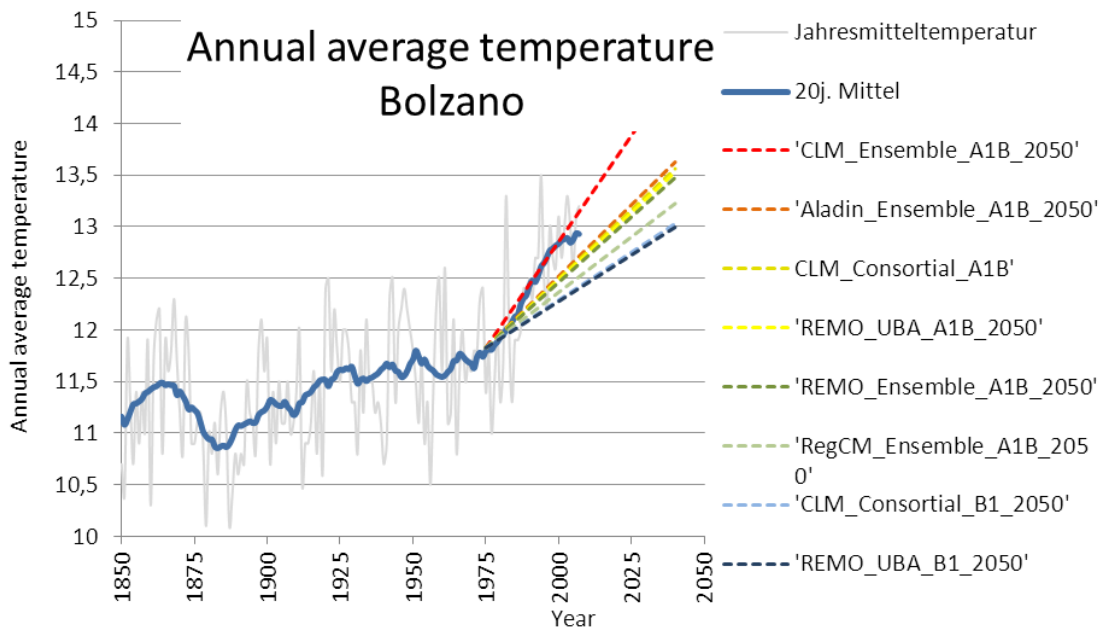


Figure 7.2 Warming in Bolzano. The graph shows the increase of the annual average temperature as yearly values (grey line) and smoothed as 20 year average (blue line) in the last 150 years since 1850. The colored dashed graphs represent the results of various climate scenarios for South Tyrol. Base is always the calculation of the warming from 1961-90 to the years 2030-50. It is obvious that the real warming of the years 1975 until today mainly follows the scenario with the highest values of temperature increase (red dashed line). Source: EURAC based on data provided by the Province of Bolzano.

## 7.3 Vulnerability assessment methods

### 7.3.1 Mass movements

This case study assesses Physical and economical vulnerability to debris flow. However, the results of the case study can be used in the future for risk management decisions including risk reduction (exposure and vulnerability reduction), prevention, and mitigation.

A quantitative methodology is used in this study. **GIS** is used only for the visualisation of the results and the acquisition of information (e.g. area of buildings). In earlier stages of the study there was a strong **stakeholder involvement**. The feedback of the stakeholder's was important in order to assess the intensity of the process and the monetary damage for individual buildings. The **uncertainty** of the results is being treated as a separate and parallel study from the colleagues in NGI.

The aim of our study is to design a vulnerability curve as a function of the intensity of the process and the degree of loss. The curve was based on data concerning the event of 1987 in the Martell valley. A stepwise description of our methodology follows:

1. Data collection: photos of the buildings, damage information and information on previous events.
2. Intensity assessment: from photos of damaged buildings following an event the height of the debris deposits can be assessed.
3. Monetary damage assessment: from photos the damages could be evaluated and with the help of price lists regarding the costs of repair/reconstruction the monetary damage may be calculated.
4. The degree of loss of each building was calculated as the monetary damage expressed as percentage of the overall value of the building.
5. Knowing the intensity and degree of loss for each building the vulnerability curve could be drawn.
6. A new way to document damages following a disaster is proposed (damage assessment)
7. A tool will be programmed in order to be able to assess the costs of the repair of the building knowing the intensity of the process.
8. Results: the curve can be improved in the future by adding more data of more buildings and it can be used for loss estimation of future events. The tool can allow rapid damage assessment and loss estimation.
9. Validation of results: the results can be compared to real compensation data.

### 7.3.2 Flooding

The flood hazard case study assesses:

- Spatial exposure
- Physical, institutional and social/cultural dimensions of susceptibility
- Resilience: capacity to anticipate and capacity to cope
- Adaptation: susceptibility reduction

The Methods used was a focus group discussion, triangulated with a small survey collecting data to characterise the participants. For background information we collected data on historic flood and debris flow events, existing and planned flood protection measures, social vulnerability of residents, the provincial natural hazard warning system and a flood hazard zone map. The choice to set the research in Sterzing / Pfitsch was made because residents here are not only highly exposed to flood risk, but the settlement has also faced many floods in its past, rendering Sterzing / Pfitsch to one of the likely most vulnerable communities in South Tyrol. New flood protection measures are in the process of planning, but have been fiercely discussed between residents affected by construction

measures and administrations trying to increase the flood protection level by buying off private land to include it in river dredging measures.

Furthermore Sterzing has been subject of several previous and ongoing research projects on natural hazards and social vulnerability (Floodsite, CLISP, DIS-ALP, ED30).

Our proceeding was to invite stakeholders for a focus group discussion through the local monthly magazine “Der Erker”. We planned to conduct 3 focus group sessions, one with local business and two with residents, but due to low participation we could only hold one session in a mixed group. The group included 6 residents of Sterzing and one representative of the administration of Sterzing, the administration of Pfitsch, the local fire fighters and the provincial flood protection agency. 3 out of the 6 residents also owned shops in the flood risk zone. The session was taped on a digital voice recorder and transcribed. To triangulate and characterise participating residents in more detail we also handed out a small survey after the discussion.

This way we generate qualitative data in the focus group discussion and quantitative data from the survey to support the analysis of the discussion. The intention of choosing focus group discussions as a method for vulnerability assessment was to identify attitudes of key stakeholders towards relevant issues of flood management. One big advantage of this method is the creative verbal interaction of different stakeholders, which allows to negotiate compromises and positions acceptable for all participants. The social interaction stimulates creativity of participants. It is easy to conduct, also with a low budget and allows for more complex answers, then most other methods and generate validated and sophisticated data in our case study with a focus on social and cultural susceptibility (flood awareness, self protection, precaution and responsibilities) .

### 7.3.3 Heat waves

The case study looks at the social dimension of vulnerability. To establish the impact of heat waves on the citizens of Bolzano, it seemed most reasonable to focus on subgroups which are most susceptible to heat waves. As already identified by previous studies (Drinkwater & Horwath, 1979; Basu & Samet, 2002), these are the elderly.

The exposure and vulnerability to heat waves of the city of Bolzano was assessed by means of the following dimensions:

- Spatial exposure
- Social vulnerability

For the vulnerability assessment we used 4 different methods:

1. Remote sensing (Spatial exposure):

Land surface temperature was derived from the thermal band of various Landsat Images after atmospheric correction in order to receive rough information about temperature distribution within Bolzano. We used overall 12 Landsat 5 scenes of summer the months (June, July, August and September) for the period 2003-2009 and calculated in each scene the temperature deviation from each pixel to the maximum temperature value of the same scene.

2. Statistical analysis: (Social susceptibility)

Correlation analysis were carried out comparing time series of demographic and health related data with respect to time series of meteorological data. Quantitative data provided by the Province and the regional hospital of Bolzano were analyzed and visualized with the statistical programming tool R. The demographic dataset was split into various subgroups according to age and gender. Hospital emergency / admission data were divided by gender and age to have a look at different kinds of subgroups. Two different age limits were chosen in order to establish a relationship between the climate data and the hospital data for men and women (A) aged 65y and older; and (B) aged 75y and older. A close look was given to the elderly women because due to longer live expectancy, they are considered to be more vulnerable than elderly men.

The aim of the statistical analysis was to see, if there is a correlation between the hospital admissions of the different subgroups and the temperature data and to find out the most

vulnerable population group. A correlation between the two data sets would show the impact of heat stress on the different subgroups and sustain the hypothesis that heat problems are an issue in Bolzano. Therefore we compared the means of the various subgroups by performing t-tests.

### 3. Potential Heat Wave Index (Social vulnerability):

A composite indicator was created which combines different factors, using the semi-quantitative fuzzy logic technique as done by Kropp et al. (2009). In this approach, the social vulnerability was assessed in a comparative way for the five different districts of Bolzano, considering spatial exposure and social susceptibility. Quantitative data provided by the Province and the regional hospital of Bolzano were analyzed and visualized with the statistical programming tool R as well as with Arc GIS. Within the scope of identifying the parts of the city which are more vulnerable than other ones, a comparative vulnerability assessment was then made within Bolzano. This technique has the advantage that variable values are allocated gradually rather than binary. Thus a ranking of the districts referring to possible heat wave impacts was created.

### 4. Stakeholder involvement (Lack of resilience, Risk Governance):

We organised interviews (single interviews and group interviews) with different kind of stakeholders:

- Experts from the regional meteorological office
- Local responsible for heat waves from the Civil Protection department
- Responsible for heat waves from the municipality of Bolzano
- Health care managers
- Representatives of volunteer organisations
- Representatives of Spatial Planning department of the Province of Bolzano

The aim of the stakeholder involvement was to gather information about:

- The awareness about impacts of heat waves among them
- The experience with heat waves during the last years
- The national and local monitoring and forecast system
- The information and management flow and system between different involved institutions in case of heat waves
- The information flow and media involvement to inform the population about heat waves
- The measures and initiatives for people at risk, especially elderly people
- The gaps in the current system and need for further action
- The potential for improvement when dealing with heat waves

## 7.4 Indicators

### 7.4.1 Mass movements

In the literature, physical vulnerability is often defined as the degree of loss. Although the physical vulnerability of an element at risk depends on a series of indicators and it is more complicated than a damage assessment, the degree of loss following a disastrous event bears information regarding the vulnerability of an element at risk. The indicator used in our methodology is the degree of loss. The degree of loss equals the monetary damage of an element expressed as the percentage of its overall value. In other words, the degree of loss is the percentage of the value of the building that is lost. It depends on two values: The monetary loss and the object value.

Therefore, our focus was to collect information in order to assess the monetary loss and the value of the elements at risk (the buildings in our study area).

- Monetary loss: Information regarding the costs of repair of buildings following a debris flow event was collected from 3 different sources. One of them was chosen as more reliable and it was used throughout the study with some necessary modifications. The monetary loss includes the costs of direct losses (cleaning, new paint on the walls, new doors and windows, testing and reinstalling electricity, heating and sewage systems etc.). It does not involve indirect losses such as loss of equipment, loss of furniture, accommodation costs whilst the house is not inhabitable, etc.
- Object value: The object value was calculated using the real compensation price for rebuilt (Italian Lire of 1989 was converted to Euros 2010).

The degree of loss was calculated for most of the affected houses in the area. However, ideally, all these buildings should share the same characteristics in order to be used in the same vulnerability curve calculation. Although this is not the case, we deliberately did not include wooden structures or non-residential buildings and we focused on residential 1,2 or 3 storey buildings with similar architecture, material and condition.

Additional background information:

- Information on historic debris flow events
- Information regarding existing protection measures
- Real compensation data for validation
- Information regarding damages to buildings and infrastructure following disastrous events
- GIS database including land-use map, location of structural protection measures, location of previous events (location of initiation and deposit in case of landslides and debris flow)
- Information regarding the elements at risk (from photos and field survey) such as type of buildings , use, material, number of floors, surroundings, openings (doors, windows) etc.

### 7.4.2 Flooding

The focus of the study was set on focus group discussions, which were to generate information on the core indicators:

- flood risk awareness. Only if the residents and business at risk are aware of the possibility and consequences of a flood, they may take action to protect their lives and prevent or mitigate material and immaterial losses.
- attitudes on responsibilities. Only if residents and business understand and know their own responsibility for flood protection measures, they might take action.
- attitudes on self precaution. Only if residents and business know possible measures of self protection and have a positive attitude towards them, appraising them as reasonable and feasible, they might take action.

Other qualitative indicators / criteria from focus group:

- risk perception
- flood believes
- social networks
- knowledge of warning system

Background information and other quantitative indicators collected in the survey supported the analysis of the core indicators and served as a trigger to stimulate the group discussion.

background information	criteria from the survey to support the analysis
historic flood and debris flow events	flood awareness

background information	criteria from the survey to support the analysis
existing and planned flood protection measures	flood experience
social vulnerability of residents	flood protection measures (taken/known)
the provincial natural hazard warning system	Knowledge of flood hazard map
flood hazard zone map	Reaction to flood warning
	living conditions (house ownership, exposure, elevation of living floors)
	demographic data (gender, age, household size, income, education level)

### 7.4.3 Heat waves

In this case study, we used different approaches (see chapter 1.3) to assess the vulnerability to heat spell issues. For the different methods we used the following indicators:

Statistical analysis:

- Maximum air temperature (exposure)
- Number of **heat days**; i.e. days with maximum temperature  $\geq 30$  °C (exposure)
- Number of **heat waves**, i.e. number of events with three consecutive days of maximum temperature  $\geq 30$  °C (exposure)
- Number of **tropical nights**, i.e. days with minimum temperature not falling below 20 °C (exposure)
- Number of combined heat days and tropical nights (exposure)
- **Relative air humidity** (exposure)
- Combined indicators like the **dew point temperature** and the **Heat-Index**. Both combine temperature and relative air humidity. The latter is an attempt after Steadman (1979) to establish the human perceived temperature (exposure)
- **Elderly population** divided by gender, considering different age classes ( $\geq 65y$  and  $\geq 75y$ ) (sensitivity indicator)

For this approach, climate data were set in relation to hospital emergency / hospital admission data of the of the elderly people who are most susceptible to heat waves. The sensitivity-related dataset included hospital data of the summer months (May until September) of the years 2003, 2006 and 2009.

Potential Heat wave Index;

- Percentage of **impervious area** (exposure)
- Percentage of area with **land surface temperature > 28 °C**, derived from LANDSAT images of July 2003 (exposure)
- **Population density** (people/km<sup>2</sup>) (sensitivity)
- **Population older than 65y** (sensitivity)
- **Population older than 65y living alone** (sensitivity)

The indicator factors were defined separately for the five different districts of Bolzano.

Stakeholder involvement:

- Risk monitoring and forecasting: we analysed the existing monitoring and forecasting system at national and local level. By conducting interviews with local stakeholders we tried to find out strengths, gaps and to identify future options to improve the existing system.
- Dissemination of information on risk and response measures to at risk groups, carers and responders: through stakeholder involvement we analysed the information flow in case of heat waves (responsible authority for the forecast, involvement of mass media, dissemination through health care institutions).
- Response measures for most vulnerable population groups: conducting interviews with managers of care homes and volunteer associations allowed us to have an overview of already existing and implemented adaptation measures (e.g. cooling centers for elderly people).
- Risk Governance: the whole stakeholder involvement tried to assess the procedures of risk governance in the case study areas (involved institutions, awareness of responsible, information flows, gaps and problems...)

## 7.5 Results & Validation

### 7.5.1 Mass movements

In order to validate our results, we plotted a vulnerability curve using data from the municipality of Martell regarding the compensation that the house owners received following the event of 1987. In this way, we could calculate the real degree of loss of a number of buildings and then compare it with our own results.

The final product of our study is the vulnerability curve (figure 7.3) based on the assessment of the intensity of the process and the monetary damage for individual buildings that were affected. The first results were not the expected ones. The curve was lying too low also for higher intensities and show no correlation with the validation curve (the same curve made by using the compensation data). It was obvious that the monetary damage in our results was too low. The reasons were the following:

- It was difficult from the photos to assess the damage in the interior of the building
- The reconstruction price list was originally made for buildings affected by flood. The occurrence of a debris flow might lead to additional damages caused by the floating debris such as damages of the fundamentals of the building, wall damages and damages of the surrounding wall of doors and windows.
- The compensation does not always represent the monetary damage due to a specific intensity. For example, some buildings received compensation to be rebuilt although the damage they experienced was not so significant.

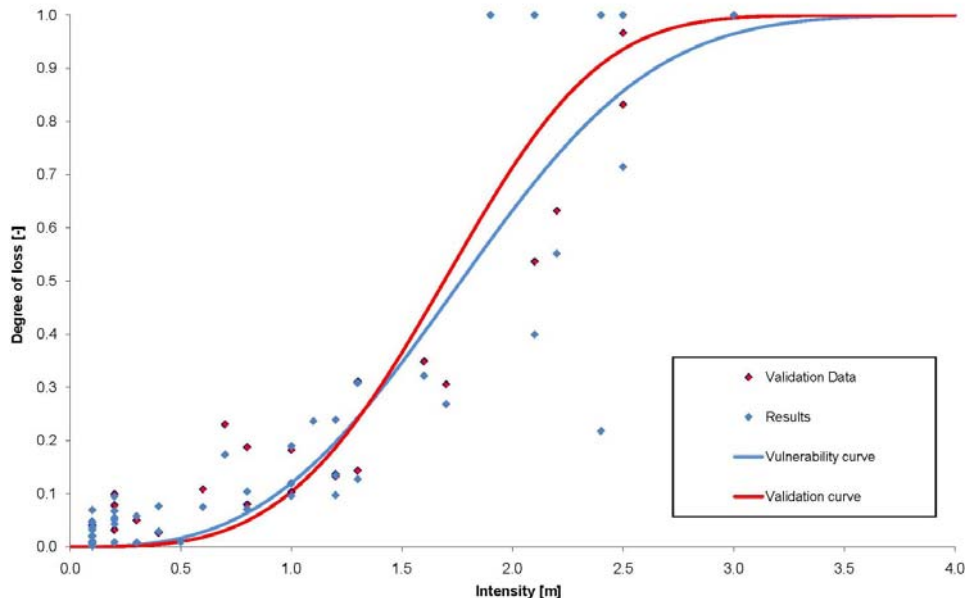


Figure 7.3. The vulnerability curve displayed together with the validation curve for the villages for buildings affected by the August 1987 event in Martell valley, South Tyrol. Data source: Municipality of Martell, South Tyrol.

Following some changes to the way we calculate the monetary damage, the curve looks now very similar to the validation curve and the difference between the results and the validation data is almost negligible.

## 7.5.2 Flooding

The focus group discussion showed, that among the participating residents and businessmen on the one hand there is a wide spread **risk awareness**, that a flood can happen anytime. It seems that existing flood protection works such as flood walls and embankments support risk awareness in many cases. On the other hand several residents doubt that the risk level is very high. Their reasoning is the absence of severe flood events since the construction of flood protection measures in the 70ies. Residents also rely on sufficiently long warning lead times and experiences from past events, when water level rose slowly within days and had limited speed and power. The provincial flood protection agency warns that early warning times are 6 hours maximum and floods can surprise people at night.

The discussion showed disagreement among participants as well on the scope of **self protection measures** as on the **responsibility for flood protection**. Some take measures to protect their house and hope for the best, because there is never a 100% flood security. Participants see a responsibility of affected house owners to protect their own property as much as possible with their private means. Others expect very little effect from private measures and deem responsibility with the authorities. The fire fighter chief attributes responsibility for structural flood protection measures to the public authorities and sees private measures as an optional additional protection. The local mayors agree to take over responsibility because it is more efficient and fair to solve the problem for all affected residents. One mayor adds, that residents living close to the river banks should know their high risk level and avoid doing anything increasing the risk or handicapping rescue work. All residents participating in the group discussion live or own land in high or very high risk zones and agree to appreciate public flood protection measures, even if they have to give away a part of their private land.

**Validation** of the results was originally planned to be done by the second and eventual a third focus group discussion. Due to the low number of participants this was not possible. Nevertheless this



method allowed a vivid discussion, wherein the participants discussed and negotiated opinions. This process guarantees a minimum of validation.

Another problem is that all residents and businessman who participated belong to the minority of people who have to give away land for the planned river dredging and strongly opposed the possible expropriation. This way we have no representation of the majority of residents who are not affected by the constructions but profit of the higher level of flood safety.

### 7.5.3 Heat waves

Land surface temperature maps that were produced based on Landsat satellite imagery clearly indicated the city centre as well as the city adjacent industrial zone as the hottest areas of Bolzano. These areas are coinciding with the areas of the highest values of soil sealing. Therefore the results require validation check in order to be used in heat wave studies that are mainly dealing with air temperature values. Nevertheless the land surface temperature may indicate areas representing urban heat island effect.

After the experience of the hot summer in 2003, the national civil protection established a national heat health warning system (HHWWS) for different Italian cities including Bolzano that monitors the heat health danger situation. According to the HHWWS Bolzano is one of the cities with most heat danger alerts. In parallel, the local civil protection has its own forecast and alert system for heat waves. The Province of Bolzano acknowledges that heat waves are a threat in general for all areas below 600 ma.s.l and in particular for the urban areas of Bolzano and Merano. Though the increasing impact of heat stress during the last years demonstrated by temperature data and observed by local experts, the impact of heat waves on the city has never assessed in detail. The aim of this study was to analyse in an interdisciplinary way the vulnerability of Bolzano and its population towards heat waves, to analyse the existing management structures, to identify gaps and to support stakeholders in improving it. After the heat-summer of 2003, various campaigns were made in order to inform people on how to behave in critical situations and in case of heat wave forecasts, HHWWS alerts the contact person in the local administration and the population by means of mass media. Problems of the forecast emitted at national level are due to the fact that the centralized system does not involve experts of Bolzano that have the local knowledge and field experience. The result is that the forecasts sometimes tend to overestimate Bolzano's heat-problem. For these reasons and due to diverging forecasts between the national and the local system, South Tyrol aims at constructing its own heat health warning system.

At local level, a special action plan was implemented after 2006. It targets the most susceptible subgroups, i.e. the elderly. Since then, on summer days with exceptional high temperatures, a local care home for old people offers his cooled lounge for non-resident elderly people during daytime. Volunteer organisations offer a free transport service for elderly people to get to the care home. Since the start of this initiative the number of people using this service during hot days permanently increased. The interviews with the care home managers showed that in most cases the elderly persons do not only come because of the opportunity to avoid the heat but also for social reasons such as the possibility to meet others and participate in the activities offered such as games, playing music etc. As this service is a kind of pilot initiative and there is no additional care personal working during heat days. The care home can offer this service only to a limited number of people and only to independent persons. It emerged among the elderly that used the care home service that there are more women than men and more Italian than German speaking persons. This could be partly due to the fact that the care home is located in one of the quarters dominated by Italian speaking population. Interviews with the care staff showed that often people are skeptic towards this initiative as it is offered in a care home for elderly people and they don't consider themselves as "old". Currently the service is offered only for the city of Bolzano and only in one care home.

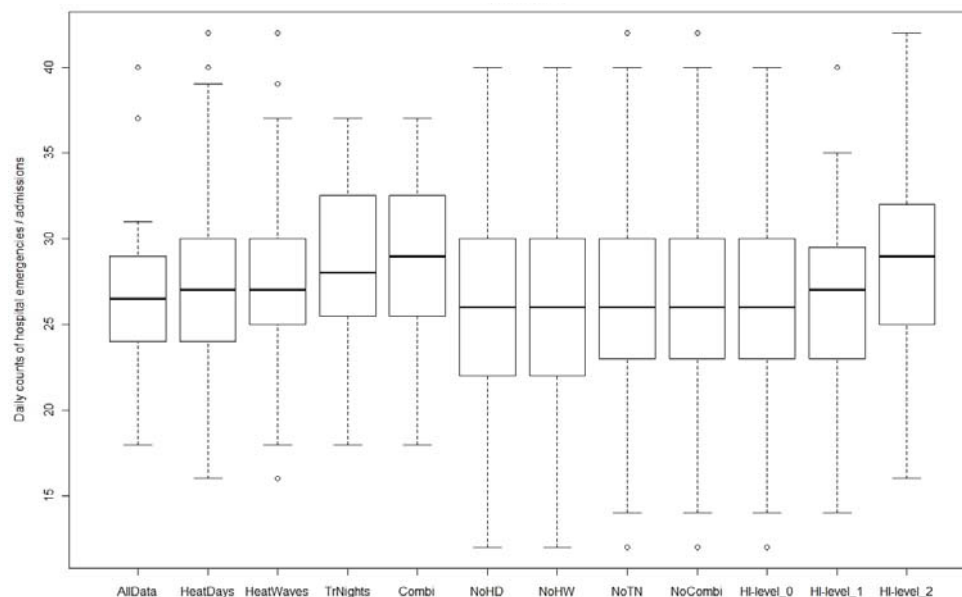
Though the installation of the cooling rooms for elderly people has been a successful initiative the local authorities pointed out that they perceive it as a small activity for a limited number of people. As possible long term solutions for all affected citizens the need was emphasized to adapt urban planning to reduce the impact of heat waves. There are already some regulations in place e.g. in order to

enlarge green surfaces in urban areas (though these regulations have not been formulated primarily in order to mitigate heat waves).

Stakeholders opinions were also important to get a first glimpse to what extent the heat wave issue is related to Bolzano and to get ideas which kind of social data should be further collected and analyzed. By looking at the mortality rate of the heat summer of 2003, the Province of Bolzano had suspected that the death toll among elderly women (age  $\geq 65y$ ) had increased because of the long lasting heat wave. Because of the generally high fluctuation in the mortality rate, no significant signal could be assigned though and therefore, the issue had not been investigated furthermore by the local authorities.

In order to identify the impact on heat waves on the elderly population of Bolzano, within the scope of the MOVE project time series of climate data and hospital emergency / admission data of the years 2003, 2006 and 2009 were analyzed in parallel and in comparison to each other. By means of simple correlation analysis the daily number of hospital emergencies / admissions were plotted against various exposure factors (maximum daily temperature, relative air humidity, etc). No relationship could be established. In a further attempt, only the 4<sup>th</sup> quartile of the daily number of hospital emergencies / admissions was plotted against these factors, but the outcome remained the same. Because of the fact that there can be a time-lag between the heat spell and the issue on physical health, possible time-lags from 0 days until 7 days were also taken into consideration, nevertheless no clear relationship could be shown.

Boxplots that visualize the distribution of the daily number of hospital emergencies / admissions according to these exposure factors confirmed that there is no extraordinary difference between the entities of those days where more emergencies / admissions would have been expected (because of heat spell issues) and the other days where less emergencies / admissions ought to be assumed. Nevertheless, with a time lag of 3 days, for the heat summer of 2003 a slight visible difference in the boxplots could be detected for the hospital data of both women  $\geq 65y$  and women  $\geq 75y$  between the subgroups of days without heat wave issues and the subgroup which considered only the hospital data for days with a combination of heat day conditions and tropical night conditions (see figure 8.4a and 8.4b). For the latter, the mean-value was visibly greater. However, the result of a Welch's t-Test which compares the mean values of the two entities shows that on a significance level of 95% there is no significant difference between the two.



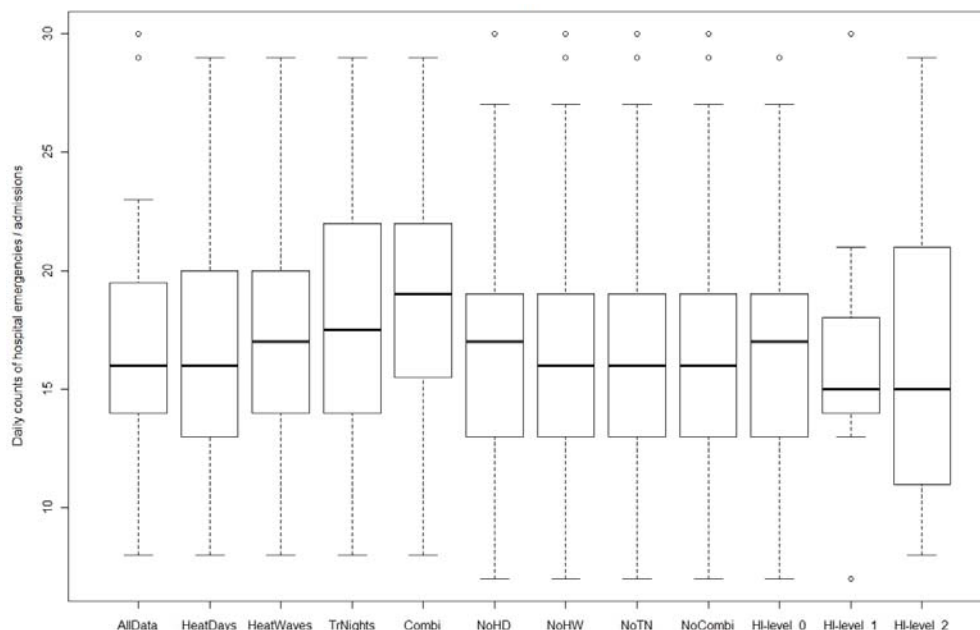


Figure 7.4a/7.4b: The boxplots visualize the distribution of daily hospital emergency / admission counts for women (a) aged 65y and older (the one above) and (b) aged 75y and older (the one below) of the summer 2003 (May – Sept.) according to various exposition factors with a time-lag of 3 days. The subgroup “Combi” (combination of days with heatwave and tropical night condition) has on average the most counts of emergencies / admissions in both plots.

Additionally, a potential heatwave impact index was developed for the different districts of Bolzano in order to identify in a semi-quantitative way, which districts within Bolzano are most susceptible to heat spells. The indicators used are those proposed by Kropp et al. 2009. Problems rose through the large areas of the administrative districts incorporating parts of the cities with a large variety of urban structure and population densities.

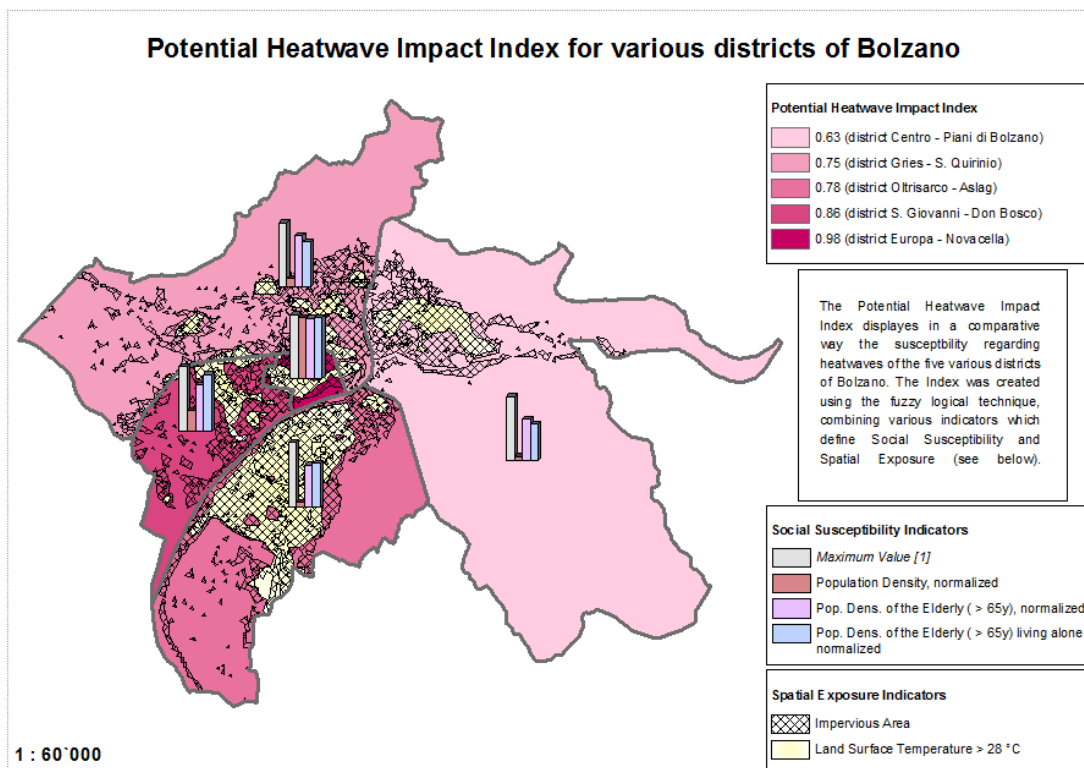


Figure 7.5 Potential Heatwave Impact Index for the districts of Bolzano. The highest value was assigned to Europa / Novacella (0.98), the lowest to Centro / Piani di Bolzano (0.63). In between there are the districts S. Giovanni / Don Bosco (0.86), Oltrisarco / Aslag (0.78) and Gries / S. Quirinio (0.75).

It must be acknowledged that the index-values just refer to the local reality and therefore, they have to be interpreted in a comparative way, that is to say rather as a ranking than as absolute values. An index value of 0.98 signifies that the susceptibility in the district Europa / Novacella is relatively higher than in S. Giovanni / Don Bosco or any other district. In the districts Oltrisarco / Aslag and Gries / S. Quirinio the susceptibility is about the same; and the district Centro / Piani di Bolzano is the least susceptible district. This is mostly due to the low fraction of impervious area when looking at the whole district and does not really reflect the situation in the most densely populated part of it.

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## 7.6 Discussion

### 7.6.1 Mass movement

In our case study post damage photographic documentation was used for the first time in order to calculate the monetary damage and the degree of loss of individual buildings. The vulnerability curve produced showed that total destruction of buildings can occur with intensities less than 2m. After the intensity of 1,4m the degree of loss raises rapidly. This can be explained by the fact that after 1-1,5 m the deposit height reaches the window and it is possible that it enters the interior which means more damages and costs. However, damages start already with intensities of a few cm due to damages in the basement. The vulnerability curve that was produced gives the opportunity to the local authorities, planners, scientists and other stakeholders to calculate the costs of future events not only for individual buildings but for the entire municipality. However, in order to improve the existing vulnerability curve or produce more for different types of mass movements (avalanches, landslides) improvements in the way damage assessment is carried out are necessary. For this reason, we propose a new way of documentation of damages in the post-event phase. The new documentation in combination with the vulnerability curve will be the basis of a tool that will be used for damage assessment and rapid loss calculation. The methodology can be transferred in areas with similar architecture and building material as it is and with modifications it can be transferred in any other places in the world facing the impact of similar hazards.

### 7.6.2 Flooding

Understanding attitudes and believes that lead to or prevent taking flood defence measures and resilient behaviour is a premise for successfully encouraging vulnerable populations to take measures for reducing vulnerability at individual level and to understanding social / cultural vulnerability.

Focus group discussions are an adequate and easy way to uncovering attitudes and believes. Social interaction and group dynamics generate high validity, but they are sensitive to low participation and depend on good group dynamics in the discussion. Due to low participation the results of the case study are validated by the discussion among stakeholders in only one focus group.

The case study found on the one hand aspects raising vulnerability of residents in Sterzing / Pfitsch such as a very high level of exposure in big parts of the city, including important economies and critical infrastructure with high susceptibility. Social cultural factors contribute to this, such as: overreliance in existing protection measures and the warning system, wrong assumptions from past flood experiences, underestimation of risks, often lacking feeling and acceptance of private responsibility for flood precaution, often poor knowledge of and very little implementation of private precaution measures. On the other hand we found aspects reducing vulnerability: Participants are well aware of flood risks, accept flood protection as prominent target of spatial planning and constructions for an extensive river dredging for flood protections are issued to start in 2011. Sterzing residents mainly have district heating, which bears -unlike oil heatings- much lower susceptibility and potential damage. Sterzing has a functioning siren based warning systems and short ways for evaluation and a functional local social network. Our findings are backed up by research on social vulnerability conducted by FLOODSITE (De Marchi et al. 2007).

This case study contributed to finding and fixing a compromise between local stakeholders and ease conflicts by solving misunderstandings and creating mutual understanding and create or regain trust in each other. This was an added value of the case study. Focus group discussions therefore proved to be an efficient way to allow public participation and avoid future conflicts in local planning.

### 7.6.3 Heat waves

Heat wave impacts are commonly measured by means of the mortality rate which can increase above the expected rate during extreme heat events. Bolzano is a little city with only about 100'000 inhabitants so it turned out to be much more difficult to clearly identify heat health related issues since it is not possible to assess the issue by means of the mortality rate as usually done in bigger cities.

To assess the social vulnerability of the citizens of Bolzano towards heat waves, daily counts of hospital emergencies / admission of the elderly were analyzed with respect to climate data. The focal point was given to those days where more hospital emergencies / admissions would have been expected because of severe climatic constellations which could cause heat health problems. Different aspects of heat wave related parameters were taken into consideration, namely air temperature and air humidity (floating and classified values); and also combinations of the two that denote different kinds of perceived air temperature. In contrast to the expected results, there were no additional hospital emergencies / admissions on critical days concerned by heat spells compared to those days without health endangering climatic constellations.

Elderly men were not susceptible to any kind of heat spell impact in any of the tested years. Concerning the parameter air humidity, not even a minimal tendency on the physical well-being could be identified nor for elderly men nor for elderly women.

For elderly women, there is a slight tendency that they were more susceptible to heat wave impacts in the record summer of 2003 when both temperature during daytime rose above 30 °C and temperature in the nighttime remained on a high level. However this difference is not statistically significant. The fact that none of the Welch`s T-tests reached the claimed significance level is probably due to the high fluctuation rate in the number of samples per day compared to the low number of samples per day. Therefore, for little cities with such small number of samples it seems to be difficult to show correlations of weather condition and health issues by means of statistical analysis.

In order to accomplish a social vulnerability assessment on a spatial level within the limits of Bolzano, a potential heat wave impact index was calculated based on quantitative data that were normalized and weighted. Exposure factors as well as social susceptibility factors were taken into account. The highest index was obtained for the district of Europa /Novacella mainly because of the high population density, and because of the fact that the district is most densely populated by elderly people of whom almost 50% are living alone. The least potential heat wave impact index was calculated for the district Centro / Piani di Bolzano which is the district least populated by elderly people. Moreover, an especially low percentage of impervious area and a low percentage of area with a land surface temperature above 28°C could be observed there. Centro / Piani di Bolzano even remained the least vulnerable district when the exposure factors were recalculated excluding the area covered by forest.

The interpretation of the results of the land surface temperature data acquisition by means of Earth observation data needs to take into consideration that the Land surface temperature is fairly equal to the air temperature and strongly influenced by the material covering the surface (e.g. asphalt, concrete, vegetation etc.)

## 7.7 Conclusions and recommendations

### 7.7.1 Mass movement

The results of the case study show that there is a need for detailed documentation of the damages following a disastrous event. The vulnerability curve produced during our case study together with a thorough damage documentation can provide the stakeholders and decisions makers with a tool for rapid damage assessment and loss estimation for future events. The documentation of damages and the vulnerability curve can provide information that can be used for vulnerability reduction of the elements at risk and reduction of loss due to mass movements in the future.

### 7.7.2 Flooding

flood hazard zone maps show in the current situation very high exposure for a big share of build up areas of Sterzing and Pfitsch. Therefore vulnerability must be rated high.

The group discussion shows, that participating residents are aware of flood risks, but assess the risk lower than flood management experts. Residents capacity to anticipate is hampered by the long absence of floods. Residents assess risk especially for loss of life as low. Reliance on positive experience of low damage in last floods and on public protection measures and the warning system contribute to underestimating risks. Nevertheless acceptance of the importance of new and better public flood protection measures is generally high among participants of the discussion. They support to reactivate the "Zivilschutzkommission" and putting flood defence higher on the political agenda.

Very low acceptance of self precaution and low knowledge on private flood protection measures and attitudes on split of responsibility often disclaiming own responsibility lead to very few citizens performing private flood protection measures and therefore a low coping capacity at household scale.

### 7.7.3 Heat waves

By means of a semi-quantitative potential heatwave impact index, a spatial susceptibility was shown for the five different districts of Bolzano in one approach. In another approach, on the basis of hospital emergency / admission data and climate data, no stringent heat health issues could be shown for the elderly population of Bolzano. Nevertheless, some tendencies could be revealed which at least cannot debilitate a possible heat health issue due to the combination of heat days and tropical nights on elderly women. It is interesting to acknowledge that this pattern could only be observed in the record summer of 2003 and not in the summers of the years of 2006 and 2009. This fact could sustain the hypothesis that there is a possible impact of heat waves on the well-being of elderly women in Bolzano but that this impact is only recognizable in the statistics during very extreme years. Future studies dealing with heat wave issues in Bolzano should take account for this. Considering future climate simulation on one hand, spatial exposure is supposed to increase because of an enhanced frequency of extreme events such as heat waves. On the other hand, the ASTAT (Landesinstitut für Statistik, Autonome Provinz Bozen) emphasizes that the population of Bolzano is an ageing population and prospects that especially the fraction of the very old people (> 80y) – hence the most vulnerable – will increase due to increasing life expectancy. Therefore, it is most probable that the vulnerability referring to heat wave issues of the city of Bolzano will increase and heat health impacts should be monitored more intensively in the years up to come.

Until now the studies about heat wave impacts and responding measures for impact reduction concentrate on the city of Bolzano. However, all areas of the province along the Adige river with altitudes below ca. 600 m are affected by summer heat waves. Early warning systems and measures to protect those most vulnerable should be extended to those areas affected by heat waves beyond the city of Bolzano.

Besides the short term measures that have been taken after the record summer in 2003 it is required to carry out long term adaptation activities addressing urban planning issues such as the avoidance of urban heat islands and the extension of green areas.

The Province of Bolzano is in a particular situation due to its autonomous status in Italy with a strong local civil protection. This situation results in two differing heat wave warning systems at local and national level that need to be coordinated in order to avoid unsettledness of the population.

The detailed information required in order to analyse the situation in Bolzano considering heat wave susceptibility and possible adaptation strategies can only be gathered through stakeholder interviews and involvement. Awareness of stakeholders and their interest in the envisaged investigations are therefore key for a successful study.

A general recommendation is to increase awareness of the heat wave problematic and the probable future aggravation of it amongst policy makers, institutions and citizens. This would build a stronger

base and would raise acceptance for measures to mitigate and adapt to heat waves in Bolzano and the other affected areas of the Province.

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