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1 Executive Summary

Natural hazards have always threatened human environment and have led to large damage. The cause of this damage is not only related to natural phenomena, but it is also closely linked to the development of human settlements and anthropic activities in areas at risk.

Human settlements can be represented as a tangible, perceptible spatial phenomenon where human beings and their activities subsist with reference to its spatial context. Any spatial analysis describes the spatial characteristic of the territory structures and explains the conditions and cause behind them, including social, economic and political factors and describe the interactions between these factors. This is also true in case of natural disasters, because natural hazards are recognized, recorded, and presented spatially.

In fact, space may be threatened by spatially relevant hazards, because a natural disaster is primarily distributed geographically (Greiving, 2006). Recognizing natural hazards, dealing with vulnerability and safety reviews are important principles in coping with natural hazards. The role of spatial analysis is a vital part of the study of vulnerabilities. It ensures land use function and structural pattern comprehension in the hazardous situation.

The impacts of natural hazards as well as the potential damage distribution in space are one of the main concerns of this deliverable. Aspects that are particularly vital are summarized in basic ideas and principles. This deliverable highlights the importance of spatially analyzing both hazard impact and human environment and activities in order to have an overall picture of the disaster. In fact, an understanding of the environment, such as land cover/use, allows for a critical characterization of the territory.

Moreover, every geographical area is also integrated in an urban network of structures acting at different spatial scales. Because of this, in order to have a global view, the analysis cannot stop at the core of the natural event but has to look beyond the study area. This aspect is particularly important in the case of the systemic vulnerability, for which the loss or continuation of functioning depends on the interdependencies among elements or systems located in the affected area and elements or systems located in the surrounding ones or even in areas far from the affected one but functionally linked to it.

The present deliverable also deals with scale matters referring to vulnerability assessment. In fact, due to the interrelationships among different types of vulnerabilities, some aspects have to be investigated at more than one geographical scale, since they could be relevant both at local scale and at wider geographical scales (regional, national, global).

As already mentioned, spatial analysis considers any relevant hazard that has a high correlation with space. Mapping is a basis for vulnerability evaluation and maps are vital tools for analyzing all spatially relevant activities. They create an abstract model representation of a territorial reality and contain extensive data of the area in addition of visual information. The scale of mapping appropriate for vulnerability maps depends both on the use and the amount of data available.

2 Introduction

The main concern of Del. 3.2 is focused on the spatial differentiation and characteristics of vulnerabilities and describes the causes behind them, including social, economic and political factors. The comprehension of this aspect contributes to prevent the increase of vulnerabilities in dangerous areas by determining which areas are threatened by natural hazards and what are the impacts. In fact, the spatial analysis approach to vulnerability issues is of high relevance for spatially relevant decisions, because the degree of safety can change for various spatial uses.

Other issues that are relevant for a diagnosis of the territory are discussed in the Del. 3.2 like (a) the spatial scale of the structure; (b) the patterns of different geographical contexts; (c) transfer of vulnerabilities across space; (d) tools for spatial analysis that represent an abstract model of the territory and allow the integration of different concepts into a single picture. Different case studies in relation with the topic discussed are examined.

In this deliverable, the appearance of different aspects of space and this vulnerability in different geographical contexts and different scales of study are discussed. The Chapter 3 reviews the relation between the spatial location and the nature of the threatened objects and provides a description of the phenomenon. The object exposed to a hazard can be of very diverse nature: people, buildings, infrastructures, agriculture, economy, cultural heritage, critical facilities, etc. The consequence is that the types of damage are also very diverse and so they are not comparable ones to others.

Initially, we overview the existing models explaining the mechanism of the spatial distribution of vulnerabilities and how it evolves in space in order to picture some inputs on vulnerability distribution. Examples of deductive and inductive approaches are presented. Then, a reflection is addressed on the distribution of so-called non-physical damage such as systemic or social vulnerability. This is particularly important when one considers systems like public supply services that is one of the foundations of our social functioning and included important aspects such as public health, infrastructure and emergency services.

The case studies are analyzed within the frame described above. Because of the close relationship between vulnerability and damage, damage analysis that occurred in the past events is considered as a fundamental starting point in understanding the main factors affecting the spatial patterns of vulnerability. This may provide in a second time a conclusion and suggestions for data bases and modeling the spatial distribution of vulnerabilities. Thus, different case studies that show different characteristics (natural hazard, scale of the impact, geographic features and type of damage) are presented. These include the case study of the earthquake of L'Aquila (Italy), flooding and contamination of oil caused by the hurricane Katrina in St. Bernard Parish (USA), the distribution of vulnerability in case of forest fires, and the spatial distribution of damage from past eruptions in the Campania region (Italy).

Based on the case studies presented, the main factors affecting the spatial distribution of vulnerability are highlighted and summarized. This part mainly covers the identification of key factors and definition to how the extent of distribution of the different facets of vulnerability can vary according to the core and the periphery of the disaster. The findings concerning the deductive and inductive approach in spatial analysis and vulnerabilities are plotted. Both methods share the different aspects of vulnerability and are not appropriate to be applied in all cases. A choice of the method (deductive or inductive) must be made according to the facet to explore.

The main objective of the Chapter 4, addressed to the transfer of vulnerabilities in space and based on the analysis of case studies, is to identify key processes that can contribute to the transfer of vulnerabilities in space. So far, this has been addressed on a prospect-related factor "time", even though this largely affects the spatial distribution of vulnerabilities. The transfer of vulnerabilities is addressed from two distinct aspects: the first is to define how each facet propagates in space and how it can act to turn to feed further the chain of damage or to stop it. The second aspect refers to the interrelations of different actors or agents that modify fuel and vulnerabilities through actions or in-actions.

The Chapter 5 is focused on key issues related to the importance of the scale factors and indicators in vulnerability analysis. It reviews the different aspects when dealing with scale, especially for representing analysis results and the choice of appropriate indicators according to the size of the analyzed area and the degree of detail in the analysis. A spatial area is perceived on different scales. Every location is therefore integrated into spatial structures on both from the micro to the macro scale. So, any vulnerability assessment is subject to scale. The scale at which a phenomenon is addressed has a great influence on the definition of the problem and the outcome of an evaluation. Because of this, an understanding of the issues of choice of the scale of work is vital for any analysis, because the result may differ depending on the data used. Unfortunately, it is also true that not all data are always available at the relevant scale.

For identifying the geographical distribution of damage, *mapping* is needed. This aspect is considered in Chapter 6. Vulnerability maps attempt to show the spatial or geographical distribution of expected losses from one or more natural hazards. Maps are a necessary tool for implementing all spatially relevant activities. This aspect is investigated in last chapter of this deliverable.

3 Spatial distribution of vulnerabilities

According to the Dow, the task 3.2 has to focus on "the spatial evolution/differentiation of vulnerabilities" and addressed to define "to what extent vulnerability characterization can be diversified with respect to the potential core and periphery of disastrous events". As largely verifiable when looking at current hazardous events, damage are displaced geographically and temporally (Cochrane, 2004). Such a displacement depends both on the features of the hazard at stake and on the features of exposed elements and systems. Different responses to a hazardous event, indeed, generally ground on different land use patterns, different patterns of settlements and buildings, "different modes of using territories and buildings" or different "linkages among systems and physical artefacts" (Menoni, 2008). Moreover, the spatial distribution of each vulnerability facet may vary too, according to the different geographical contexts and mainly to the different spatial and functional patterns of the settlements. For example, the spatial distribution of physical vulnerability will largely depend on the features of the different urban fabrics which significantly vary in the historical European cities, in American cities or in large metropolitan areas in developing or emerging countries. Drawing upon these insights, this chapter focuses on the main factors affecting the spatial distribution of different facets of vulnerability. Due to the close relationships between different types of vulnerabilities and different types of damage, such factors will be identified grounding both on the models developed in scientific literature to describe the spatial distribution of damage and on the damage occurred in past events in relation to different types of hazards.

3.1 Modelling spatial distribution of damage and vulnerabilities

The development of models able to explain spatial distribution of vulnerabilities is not an easy task, especially in relation to dynamic and complex events like volcanic eruptions, na-techs, multi-site mud-flows, etc. Nevertheless, it should be useful to review disaster models to draw out some inputs on vulnerability distribution. Damage, indeed, can be interpreted as tangible outcomes of vulnerabilities of a hit territorial systems.

In scientific literature, deductive spatial models of disasters have been set up starting from the Fifties. Such models have had alternate luck, until they have been largely replaced by inductive ones, based on the possibility to manage a great deal of territorial data through Geographycal Information Systems. In the disaster field, these tools have determined in a short time, the decline of the theoretical speculations aimed at supporting deductive models, in favour of inductive ones, based on the digital treatment of data.

Inductive models start from the hazard definition to define the spatial distribution of damage applying vulnerability parameters. Recently, digital dynamic spatial simulations of volcanic eruptions, tsunamis, tornadoes, etc. have produced very detailed models both of natural events and their potential outcomes.

Among inductive models, one of the most well-known is certainly the Hazus of FEMA, based on the processing in GIS environment of a huge amount of data related to hazards and to the vulnerability of exposed elements. In relation to this type of models, some scholars underline that often, although the large amount of quantitative data, they do not accurately represent the different aspects of disaster (Alexander 2000a). Inductive models, even though they currently represent the main tool for hazard, vulnerability and risk mapping, do not allow a fully understanding of the mechanisms regulating the spatial diffusion of impacts and damage due to a given event.

As above mentioned, deductive spatial models of disasters are less spread and more difficult to set up. To this aim, indeed, processes and relationships among the territorial elements which regulate the spatial features of disaster have to be "actively specified a priori" (Alexander 2000a). Moreover, these models generally require on-field surveys for defining the model assumptions and for identifying general rules and laws of spatial distribution.

Although both the mentioned models have been largely discussed and tested in literature, it is possible to state that "we are very long way from being able to conceptualize disasters deductively in terms of a general model" (Alexander, 2000a).

3.1.1 Spatial models of physical outcomes of disasters: the Wallace's model and its developments

Deductive spatial models refer to the description of the damage due to a given hazard in a given area. These models generally start from a very simplified geographical description of the affected area (homogeneous and isotropic) and from the hazard features (instantaneous, concentrated, etc.), trying afterwards to refine the model for what concerns the type of considered hazard, the morphological features of the area, the characteristics of the hit settlements, etc.

Referring to a homogeneous and isotropic geographical space and to a concentrated and instantaneous hazard, the hazard impact can be represented through a function linking the hazard to a spatial and sometimes temporal distribution of the damage which, in turn, correspond to some underlying features of vulnerability.

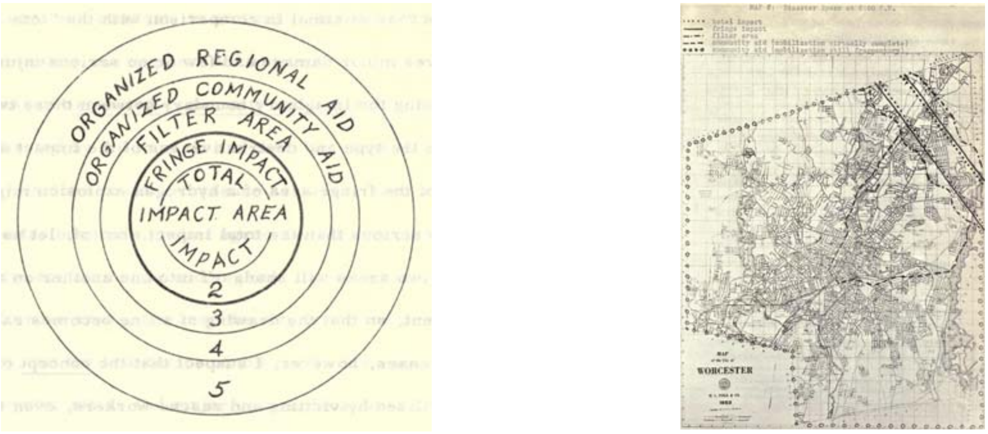


Figure 1: The Wallace's model: The original definition of the model in 1956 (on the left); The application of the model to the Worcester Tornado (on the right)

The simplest and probably the most well-known deductive model is certainly the one carried out by Wallace in 1956. This model was built up grounding on the empirical evidence of the Worcester tornado occurred in 1953 and was refined in 1976 by De Ville de Goyet and Lechat. According to some scholars, the Wallace's model, coming from the spatial economy model of von Thünen, establishes a general relationship among the hazardous event and the aid zones in which heterogeneous impacts and differences in the behaviour of the affected population generally occur. Spatial features of such zones depend both on spatial patterns of settlements and on the "spatial organization imposed by the impact itself" (Wallace, 1956).

Due to the difficulty to separate the spatial dimension of the disaster by its temporal one, the model was developed in relation to the temporal model of disasters carried out by Powell, Rayner and Finesinger in 1953. The latter was characterized by concentric circles, starting from the point where the event occurs, of impacted areas (Fig. 1). Wallace's model consists of four concentric areas: the inner one, the impact area, is divided into a total impact area, where the hazard occurs, and a fringe area, where the physical impacts are less relevant and the perception of the rescuers tends to minimize the magnitude of the disaster while the perception of people in the total impact area tends to overestimate the disaster.

The total impact and the fringe areas are defined according not only to the damage levels but also to the perception of rescuers. In some cases, for example in case of tornadoes, the differentiation between the two areas is very clear. In the Worcester tornado case-study, the fringe area, smaller than the total one with minor damage and few injuries, was easily defined since the rapid change in the damage typology.

The filtration zone, characterized by low physical damage and many homeless people, follows the impact area. Then, the organized community aid area and the organized regional aid zone are placed. The model was applied only few times, mainly due to the difficulty to define the extension of the latter area.

Wallace applied his model to the Worcester Tornado working out thematic maps which defined, according to different temporal phases, the disaster impact areas: in this case, the areas were shaped as strips progressively spreading upon the affected area with edges more and more irregular, due to the physical peculiarity of the considered hazard.

During the Sixties and the Seventies, grounding on the Wallace's model, different interpretations and applications were carried out. Burton et al. (1978) provided a three-dimensional representation in which the concentrated effects were represented by people died in the disaster, while the spread ones were represented by the population that payed for the recovery (Fig. 2). Other spatial models have been developed according to different distance-decay functions to describe the non-linear (exponential, Gaussian, etc.) spatial distribution of the disaster with reference to the different levels of impact concentration (Alexander, 2000a), sometimes introducing sub-isotropic variations within the model.

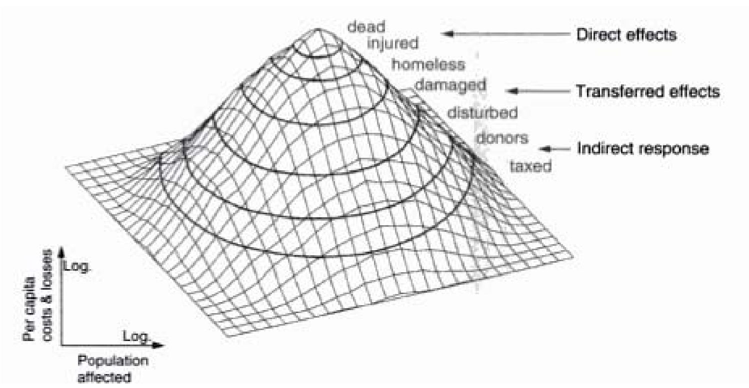


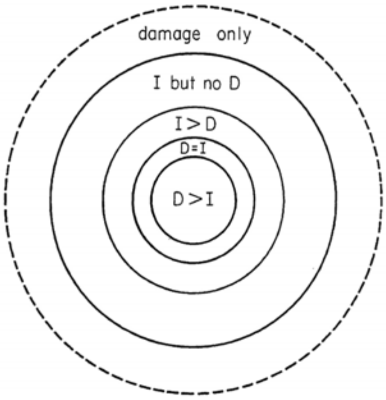
Figure 2: The three-dimensional representation of the concentric disaster model (Burton et al. 1978)

In 1986, Alexander further developed the Wallace's model, identifying five spatial zones; moreover, by applying the model to the mudflow occurred in Val di Stava in 1985, he noticed that the concentric areas followed an approximately logarithmic progression.

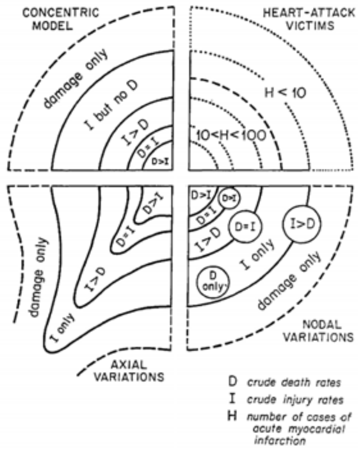
Furthermore, the outcomes of the 1980 Irpinia earthquake were generalized into a model characterized by concentric circles, based on experimental data referred to dead and injured people (Alexander, 2000b): "a working hypothesis concerning the basic pattern of casualties considered on a settlement-by-settlement basis".

The theoretical circular model shows that out from the epicentre, more injured than dead are generally recorded, mainly in medium and small towns where people die only as a consequence of small pieces of masonry falling or for panic or even as a consequence of isolated, and generally rare, building collapses.

Alexander systematized his data referred to seismic events, in particular to the 1980 earthquake, providing different generalizations of the concentric circles model, such as axial variations of the concentric pattern in case of linear settlements or in case of higher concentration of damage along a fault (Fig. 3).



Spatial model of casualties in earthquake disaster



Four hypothesis of the spatial distribution of casualties in earthquake disasters

Figure 3: The generalization for seismic events of the concentric disaster model developed by Alexander (1989).

In the lower right quadrant, nodal variations are due to the presence of anisotropy in the settlements' pattern (presence of cities with different population placed at different distances from the epicentre). Also the different seismic building resistance contributes to the deformation of the circular model.

Altough spatial patterns of damage distribution have been studied less intensively than temporal ones, they offer a similar purpose for the generalization and formalization of the models (Alexander, 1989). Some models have taken into account the non-isotropy of the territory (Fig. 4).

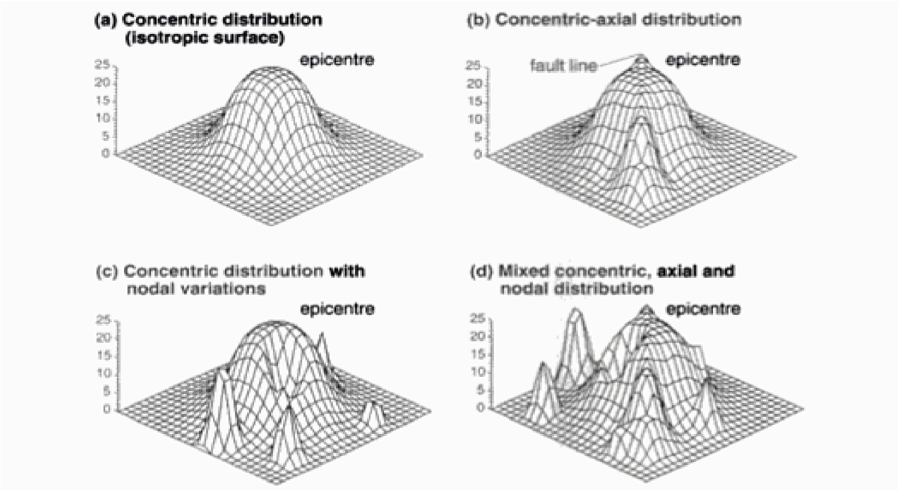


Figure 4: Non-isotropic disaster spatial models (Alexander 2000a)

Alexander singled out two possibilities for modeling disasters in a non-isothropic way, distinguishing non-isothropic hazard and response (Alexander 2000a). Both types of models may be divided in linear (fault lines, rivers, mudflows, roads, linear fabrics, etc.) and nodal variations (volcanic eruptions, widespread landslides, population density, emergency management capabilities, etc.). Geographical factors, such as the site morphology, and the patterns of physical and socio-economic vulnerability, may induce linear and nodal variations of the isotropic model. Sometimes useful results can be achieved also with few data and some basic assumptions, like in case of earthquakes (Alexander 2000a).

3.1.2 Spatial models of non-physical impacts of disasters

Another relevant topic in disaster analysis and modeling is the spatial distribution of damage with reference to the functional, economic, and social "weaknesses" of the hit territorial systems, especially for historical cities.

In relation to the mentioned topic, a relevant research work was carried out by an Italian scholar, Di Sopra, with respect to the 1976 Friuli earthquake.

The study carried out by Di Sopra (1981), based on a demand/supply approach, analyzed in-depth some interesting aspects of disasters according to a spatial perspective, mainly focusing on the roles and the spatial distribution of non-physical damage and vulnerabilities.

The Northern area of the Friuli Region before the earthquake was already characterized by a low capacity to attract population and to provide urban services. Therefore, the territorial system was already "weak" in ordinary conditions. Moreover, some of the larger towns were characterized by an old centre and a recent periphery. The earthquake destroyed the oldest and decayed buildings of the historical areas while the houses in the suburbs, generally built up with reinforced concrete, suffered minor damage. Consequently, the historical parts of the towns, where relevant urban activities are often located, were seriously damaged whereas peripherical areas withstanded the seismic impact (Di Sopra, 1981).

Moreover, the type of spatial patterns of the hit territorial systems plays a relevant role also in relation to the phases of the disaster cycle following the impact: the accessibility levels, the type of recovery actions, the costs and the time needed for recovering network systems are different in case of centralized or sprawled spatial patterns of the affected settlements.

The study carried out by Di Sopra focused also on the medium-long time damage due to the reduced organizational capacity and to the reduced ability of the hit territorial system to generate income as a consequence of the loss of economic assets (Di Sopra, 1981). Of course, the higher will be the pshysical damage and the longer will be the time for recovery, the more relevant will be the long term damage.

Medium-long term damage were represented by Di Sopra through a curve with a "wave" course, characterized by a rapid rise in the first phase and a slow decay over time. It is possible to identify three main phases: the entry one, with more or less rapid growth; the peak phase, which represents the maximum values of the curve; the decay, when the demand for services following the hazardous event decreases, since it has been satisfied.

The waves represent the onset of the crisis and the restoration of the system efficiency in terms of capacity to supply the demand for services following a hazardous event. For this reason, the model can be an useful for describing the "seismic behaviour" of urban and territorial systems or, in other words, to understand the factors generating the functional crises suffered by urban systems after a hazardous events.

Unfortunately, this model has never been linked to the spatial models of damage provided by Wallace or by following scholars.

Nevertheless, some studies started from the model of Di Sopra to carry out a spatial vulnerability model based on the relationship between demand and supply of services after a seismic events (Galderisi and Ceudech, 2010). Functional vulnerability has been interpreted as the difficulty of urban systems, due to their spatial and functional patterns, to supply the hit population with activities and services. In such a model, the assessment of the demand has been carried out taking into account the type and amount of users in each spatial unit in which urban areas can be divided, while the supply assessment has been worked out through indexes referred to the spatial and functionl features of urban fabrics. The comparison between demand and supply allowed to single out critical areas with high levels of functional vulnerability.

Other relevant models are the ones focused on the economic impacts of disasters, aimed at showing the spatial dimension of the economic impacts due to an hazardous event; these models had a large diffusion at the end of the Sixties and recently have been further developed (Okuyama and Chang, 2004).

Disasters generally accelerate the economic and social processes existing in the hit community and rarely cause its economic collapse. At regional scale, core-periphery models could be applied to highlight the different recovery speed of core and peripherical areas, in that marginal areas generally do not quickly recover from the event: marginalized regions will probably have insufficient access to funds and credit, and insufficient source of expertise. However, mere peripheral location within a country is not a good indication of marginal status: international economic cores can be more important than national ones, whereas marginalized lacunae exist in many highly central inner cities (Alexander 2000a).

At local scale, recovery and reconstruction occur in hetereogeneous manners since different factors (political, legal, administrative, etc.) affect these processes. In some cases, traditional economic models have been applied to the disaster analysis although the basic hyphothesis of these models are questionable in case of disasters. Therefore, disasters are very challenging for traditional economic models (Okuyama and Chang, 2004).

This led to the development of economic models adapted or specifically disaster oriented (I-O model, SIM, SAM, CGE, etc.). Furthermore, some models have recently tried to integrate the physical damage with the economic one especially with respect to the road and infrastructure networks. Moreover, some relevant findings are currently related to the resilience of economic and productive activities, to the dynamic processes, and to the integration of physical and economic outcomes of disasters, whereas long-term impacts have to be still deepened and the development of a multidisciplinary common modeling framework is still lacking.

3.2 Spatial distribution of damage and vulnerabilities: case studies

Due to the close relation between vulnerabilities and damage, the analysis of damage occurred in past events has been considered as a relevant starting point for a better understanding of the main factors affecting spatial distribution of the different vulnerability facets and for providing hints for modeling spatial distribution of vulnerabilities.
Hence, in this paragraph different study cases, in relation to the type of hazard at stake, to the features of the hit area and of occurred damage, will be examined.
In detail, the first case is referred to the earthquake which hit the city of L'Aquila (Italy) in 2009; it is focused on the spatial distribution of different types of damage and losses (physical, functional, socio-economic and systemic) and is addressed to identify the features of territory affecting such a distribution.
The spatial distribution of losses and vulnerabilities due to the flood and oil contamination disaster, determined by the Katrina hurricane and occurred in August/September 2005 in St Bernard parish and beyond, has been analyzed in the second case study, focusing upon physical, economic, social, systemic and institutional vulnerability facets, and examining how actual losses at the core propagate to the periphery, and how vulnerabilities at one scale are connected to those at other scales.
Moreover, the spatial distribution of vulnerabilities to forest fires has been analyzed through numerous case studies, highlighting the main input parameters which contribute to the distribution of the occurrence of forest fires and of their impacts. These parameters are grouped into three broad components: a human component, an ecosystem/ landscape component and a climatic component.
Then, some inputs on the spatial distribution of damage due to past volcanic events occurred in the Campania Region (Italy) have been provided.
Finally, a brief focus on multi-site landslides have been proposed in order to highlight that in these peculiar cases, the features of hazardous phenomena themselves and the numerous consequences of localized events occurring simultaneously or over a short time span in a wide area, make more and more complex the traditional approach core-periphery for modeling spatial distribution of vulnerabilities and damages.
It is worth noting that the factors affecting the spatial distribution of the vulnerability to droughts has not been explicitly considered here: the Negev case study, in which temporal and spatial distribution of vulnerabilities to droughts have been considered, has been indeed included in the deliverable 3.1. Therefore, the case study has not been reported, even though its main outcomes have been taken into account in paragraph 3.3.

3.2.1 *The Abruzzo earthquake*

The damage occurred as a consequence of the Abruzzo earthquake will be analyzed in this paragraph according to a spatial perspective in order to draw out inputs for a better understanding of the spatial distribution of pre-existing vulnerabilities. In the light of this purpose it will be also very useful to refer to the multiple facets of the vulnerability concept recognized in the ENSURE project.

First of all, it is worth providing a brief overview of the impact area of the hazardous event. As shown in fig. 5, the area hit by the major shake of the 6th of April 2009[1], is included in the Abruzzo region, in the central area of Italy. The figure shows also the lines of equal magnitude of the shake according to the Richter scale. The Abruzzo earthquake has been also defined as the L'Aquila earthquake, due to the huge losses suffered by the city of L'Aquila that, coupled with Pescara, is the main town of the region.

The area more severely affected by the earthquake, consisting of 49 municipalities for a total amount of 133.831 inhabitants, has been officially defined as the "crater"[2] (fig. 5). The level and the distribution of damage in this area has been very heterogeneous, as shown in fig. 6, and partially unexpected as a consequence of multiple factors apart from the distance of the different centres within the crater from the epicentre. Most of the centers of the crater area are scarcely populated (28 municipalities have less than 1.000 inhabitants) due to the fact they are placed in a mountain area.

This fact also explains the large relevance of the L'Aquila city (about 55% of the total hit population) in the crater area (CRESA, 2009). Also at regional scale, the residential density of L'Aquila is higher than the regional media (155 inhab/km^2 vs 120 inhab/ km^2) and the rate further growths if the relevant amount of students (about half of the total amount of students comes from other provinces) and of working people temporarily living in L'Aquila is considered.

The damage

A description of the main damage, divided according to a physical, economic and systemic perspective, will be presented to better highlight scale effects and to get hints on the factors influencing the distribution of vulnerability across space.

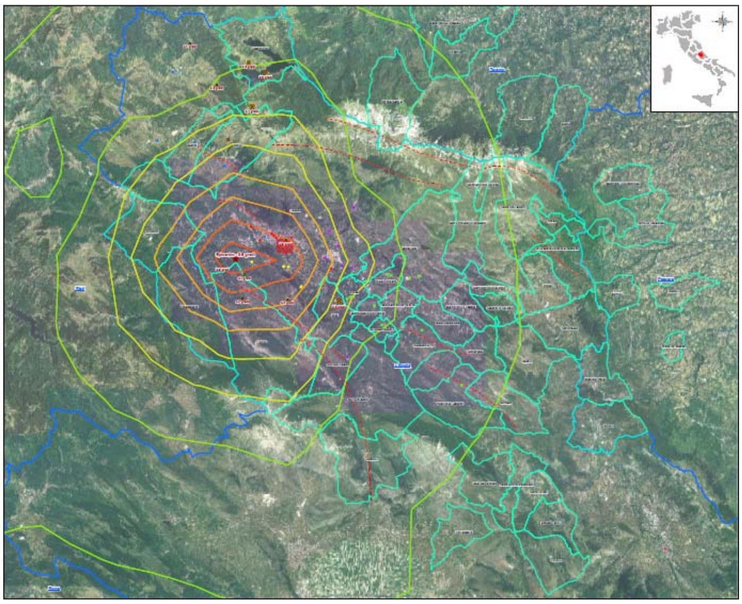


Figure 5: The crater area in the Abruzzo Region and intensity of the earthquake according to Richter scale (ipt, 2009)

1 The Abruzzo Region has been interested by a seismic activity which started on January 2009 and still persists. Seismic activity has been characterized by three medium intensity shakes between the 30th of March and the 5th of April and had is peak on the 6th.

2 "Specification of municipalities damaged by seismic events in the Province of L'Aquila and other municipalities of Abruzo Region" - Decree 16th April 2009 – Presidency of the Council of Ministers.

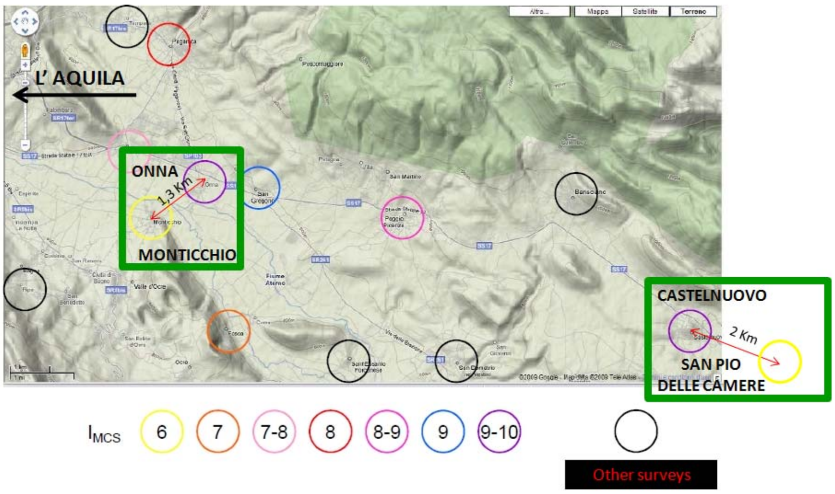


Figure 6: Intensity of the earthquake according to the Mercalli scale in the South Western area of L'Aquila city (adapted from Silvestri, 2009 and Monaco et al., 2009)

<u>Damage to people and buildings</u>

The Abruzzo earthquake severely affected population in terms of death toll compared with the magnitude of the shake (5.8 Richter scale). On the whole, 300 people died. L'Aquila experienced the major price in loss of lives in absolute terms, whereas, measured in percentage on the number of resident people, Onna had the highest percentage of died (Table 1).

In the immediate aftermath of the earthquake, numerous technicians were involved in surveys aimed at defining the fitness for use of building stock. All the buildings have been classified in a report[3] carried out by the Department of Civil Protection in last November, according to 6 categories (A: fit for use; B: temporarily unfit for use; C: partially unfit for use; D: temporarily unfit for use to be checked again; E: unfit for use; F: unfit for use due to external causes)

Many old centers of the crater, within the provinces of L'Aquila, Pescara and Teramo have been severely damaged. Nevertheless, a high level of damage has been recorded also in villages and areas recently built up. This fact has represented an unexpected peculiarity of the Abruzzo earthquake.

An in-depth analysis, in terms of physical damage, has to be devoted to the L'Aquila city. Apart from private buildings, many public buildings have totally or partially collapsed or damaged at different levels, such as the Prefecture (Palace of Government) or the civil hospital San Salvatore or even the Cadastre[4].

<u>Socio-economic damage</u>

By an economic perspective, it is worth noting that the economic activities of L'Aquila, before the earthquake, were mainly related to commercial activities (in both wholesale and retail forms), accommodation facilities, building sector, real estate, ITC and research and manufacturing (e.g. food, textile, engineering, pharmaceutical-chemical industries, furniture factories) (CRESA, 2009). Other Municipalities of the crater were, on the contrary, mainly based on agricultural activity, hunt and forestry. Moreover, it has to be highlighted that about half of the commercial activities, bars, hotels and restaurants of L'Aquila municipality

3 The total number of examined buildings is 78.256.

4 Referring to Cadastre, it is worth noting that many registries are still under the debris and that the preservation of entire databases concerning also private data and the documents of population is at risk.

were concentrated in the historical core. Hence, the interdiction of such an area (the red zone) has completely paralyzed the incomes coming from these activities, affecting the individual economic level of all people having their activities in the "red zone" although being residents out of the city.

Hamlet or Municipality	Resident population	Victims	Victims/residents (%)
ONNA	358	37	10,34
VILLA SANT' ANGELO	441	17	3,85
CASTELNUOVO	182	5	2,75
SAN GREGORIO	433	8	1,85
FOSSA	687	4	0,58
POGGIO PICENZE	1072	5	0,47
L'AQUILA	43575	197	0,45
ROIO PIANO	520	2	0,38
CIVITA DI BAGNO	287	1	0,35
PAGANICA-TEMPERA	5024	12	0,24
SAN DEMETRIO	1794	3	0,17
BAGNO	609	1	0,16
PIANOLA	1372	2	0,15
POGGIO DI ROIO	733	1	0,14
LUCOLI	995	1	0,10
ARISCHIA	1299	1	0,08
TORNIMPARTE	2986	2	0,07
PIZZOLI	3519	1	0,03
Total		**300**	

Table 1: Total victims of Abruzzo earthquake and victims related to the total population (CNI, 2009).

The CRESA report (2009) also highlights the fact that earthquake has further exacerbated a previous economic crisis, especially referring to the L'Aquila Province. In fact, the unfavorable economic condition rose in the late '90s was still in progress when the earthquake occurred, as confirmed by the negative trend of numerous indicators such as income, employment and investment. Furthermore, it should be taken into account that the global economic crisis which has affected also Italy in more recent years has further complicated the recovery from the local one.

Another relevant income source before the earthquake was provided by students. It should be taken into account that, according to CRESA (2009), on the amount of 14.000 non-resident students, about 9000 lived in the historical area. By considering that the average expense of a non-resident student (including university fees, food and house rent) is about 11.000 euro per year, the income stemming from students in the historical city appears as very relevant and, on the contrary, the economic losses resulting from the interdiction of the area are very relevant as well. University of L'Aquila has promoted some important initiatives aimed at avoiding further losses of enrolled students. For example, a survey on the mobility needs of students and employees, with the aim of knowing where they live after the displacement due to the earthquake and creating devoted transport services in order to reduce discomforts, has been launched on the internet site of University.

Nevertheless, an expected fall of enrolled students occurred both for the first year and the following ones as shown in fig. 7. Globally, by comparing data with the previous year, there has been a negative fluctuation of 18% referring to students enrolled at the first year and a negative fluctuation of 11,7% referring to students enrolled at the following ones.

Other activities with a high concentration in the historical area were the professionals ones (lawyers, engineers, accountant and business consultants), whose main damage, apart from buildings and interruption of the activity with related income flows, is represented by the loss of documents and databases, that is a heritage difficult to recover in short time.

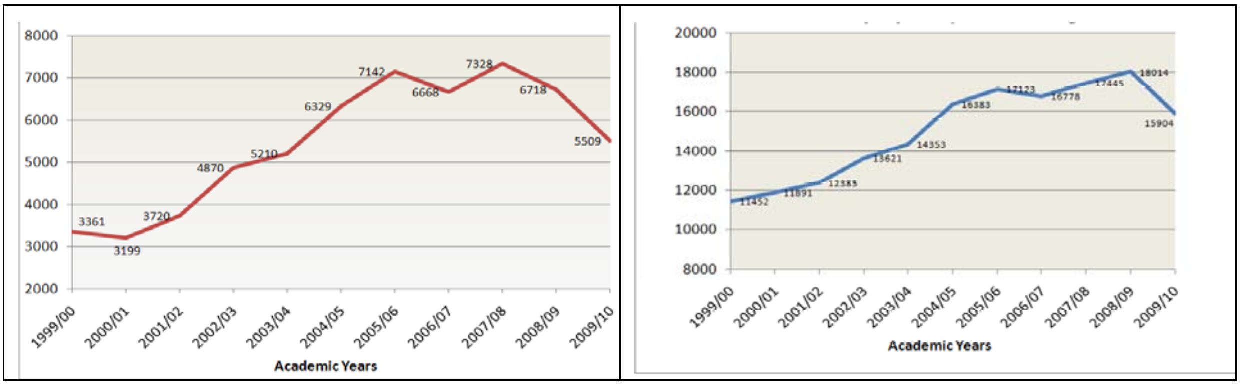


Fig. 7: University of L'Aquila: enrolled students at the first year (on the left) and at the following years (on the right). (University of L' Aquila, 2009).

Systemic damage

Numerous damage resulting from the L'Aquila earthquake can be classified as "systemic" ones, since they largely depend on the linkages or interdependencies among different elements and systems. Some examples are provided below.

Most of the financial and educational activities and all the main seats of Local Authorities (Region, Province and Municipality) were located in the historical city (CRESA, 2009). In the latter respect, the number of employees in administrative activities in the L'Aquila city is almost double than the number related to the whole Abruzzo region.

By considering also the central administration buildings collapsed or seriously damaged after the earthquake (e.g. Prefecture, Region), there are no doubts about the level of systemic damage induced at institutional level across the whole region.

Another systemic effect that goes even beyond the regional scale, refers to the University. L'Aquila was a relevant university town that drew, also due to the attractiveness of the historical city where the University was placed, a large amount of students also from other Italian regions. After the earthquake, the memory of the dead students and the lack of safe apartments have prompted many students to change their preference, in favor of other Universities.

By an economic perspective, an example of systemic damage comes from the manufacturing enterprises sectors. Due to the relevant concentration of services to manufacturing industries in L'Aquila city and also in the crater area, compared with the total amount located in the Abruzzo Region, the damage occurred in the crater area will surely have relevant repercussions on the whole region.

Vulnerability aspects

The damage due to the Abruzzo earthquake have been higher than the expected ones, especially if compared with the medium magnitude of the earthquake (5.8 Richter scale), due to some main reasons:

- an amplification of the hazard intensity depending on the site effects due to the geological topographical and morphological conditions, apart from the deformation effects induced by the "near fault mechanisms";

- a different response of buildings compared with the characteristics they were supposed to have in face of an earthquake, mainly depending on the lack of seismic retrofitting of relevant public buildings and on the scarce attention to previous seismic shakes as a preparatory signal of a more severe event.

The first point is strongly linked to the geo-morphological and structural (e.g. faults) features of the hit area. These factors can be so relevant to determine a significant difference in the level of damage in villages characterized by the same typology of buildings and of urban fabrics. In the latter respect, a good example is provided by the comparison between Castelnuovo and San Pio delle Camere: the two centers are only 2 km far one from each other (fig. 6) and they are very similar for what concerns building typologies in that both of them consist of 2-3 stories masonry buildings of poor quality, some of them retrofitted. The centre of Castelnuovo is located on the top of the hill and was nearly destroyed: a D5 damage level (full collapse) has been observed on 80% of the masonry buildings, while the remaining 20% has been classified as D4 (partial structural collapse). On the opposite, San Pio delle Camere suffered no damage (D0) or slight cracks. The shaking intensity in Castelnuovo was significantly greater than in San Pio delle Camere, due to the different geological characteristics[5] (Monaco et al., 2009). Furthermore, in Castelnuovo, a lower damage level has been observed on the buildings at the toe of the hill compared with the oldest ones located on the top, due to the hazard amplification effects induced by topographical factors. A similar comparison can be made between Monticchio, which experienced a VI MCS intensity degree and D0 e D1 (cracking of no structural elements) in terms of damage and ONNA that, even if far only 1,3 km from the former (fig. 6), has been almost completely destroyed. The village of Onna is mainly characterized by 2-3 stories unreinforced masonry buildings, with a minority of retrofitted ones, and very few reinforced concrete residential recent buildings. Monticchio mostly consists of 2-3 stories masonry buildings and to a lesser extent RC buildings. In Onna, unreinforced masonry buildings suffered a collapse rate (D5) of 80%, whereas reinforced concrete structures suffered minor or no damage (Monaco et al., 2009). By this perspective, qualitatively speaking, the building stock of Onna has had a behavior consistent with the supposed higher vulnerability of masonry buildings compared with the RC ones. At the same time, the low levels of damage in Monticchio drives to look beyond the vulnerability of the building stock in order to explain so relevant differences in damage levels, focusing on the above mentioned site amplification effects.

The second group of reasons are largely related to a relevant institutional vulnerability and to the relationships among institutional physical vulnerabilities (see del.2.1). The discrepancy between the expected resistance of numerous buildings, according to the available seismic knowledge and to the building codes in force when they were built up, and the real resistance they showed in face of the earthquake could be, in many cases, attributed to the lack of controls at the different stages of the building process. This possibility has been largely discussed in del. 3.1 in relation to the dormitory house for students, which represents a clear example of unexpected building collapse, according to the age and features of the building.

Even the lack of seismic retrofitting of strategic buildings can be reported as a form of institutional vulnerability. Generally, referring to the collapse of strategic buildings after an earthquake, numerous post-disasters analyses focus on the scarce "knowledge" of their vulnerability features due to a lack of vulnerability assessment for the building stock or, at least, for strategic facilities. By this perspective, L'Aquila city, as other cities in Central and

[5] Castelnuovo is settled on a hill mainly formed of fluvio-lacustrine deposits, whereas San Pio delle Camere is a hill slope built on breccias overlaying carbonate bedrock.

Southern Italy, wouldn't have been affected by this cognitive lack. In fact, a report[6] on the vulnerability of public, strategic and special buildings was carried out in 1999, under the coordination of the under-secretary of Civil Protection in charge in those years. All the masonry buildings that have collapsed after the earthquake in L'Aquila were included in that list (cs1, 2009).

The collapse of the Prefecture building, among the mentioned ones, due to the role of coordination that the Prefect has during the emergency phase, is of particular relevance. In detail, the vulnerability level of the Prefecture building was classified as a "medium-high" one. Hence, in the light of what has happened, two main solutions were possible:

- to move some functions of the Prefecture, at least for what concerns the coordination of emergency activities, toward buildings with a higher safety level;
- to proceed with a retrofitting program in order to reduce such vulnerability.

Nevertheless, none of the two alternatives has been undertaken and, although the main reasons might be attributed to the scarcity of available economic resources, this choice underlies once again the scarce awareness or the underestimation of the seriousness of the seismic threat on the side of the Local Authorities.

Linked to the previous one, the last point refers to the scarce attention paid to the previous seismic shakes as a preparatory signal of a more severe earthquake[7] that lead, for example, to the absence of a formal warning to population about the threat at stake on the side of the competent Authorities. Such decision would have had more and more severe consequences in term of loss of lives if the earthquake had occurred during the day when schools, university and other public activities were functioning.

Summing up, all these reasons have had devastating effects on the exacerbation and on the spatial distribution of physical vulnerability too.

It is worth noting that the sequences of shakes that have been occurred since January have not to be underestimated under the physical vulnerability perspective both in the pre and post-impact phase. As mentioned before, the shake of 6th April has been the strongest one even if the previous ones have surely had an impact on building stock by reducing its strengths. A similar thought can be shifted to the post-disaster phase in that, due to the following shakes (the last relevant one occurred on 20th of March), vulnerability has changed over time and, furthermore, other physical vulnerabilities could be risen or increased as a consequence of the initial damage (e.g. the collapse of a roof determines an easier and quick decay due to the effects of atmospheric agents).

Spatial distribution of vulnerabilities

The damage described above can be a useful clue to highlight previous existing vulnerabilities even though, due to the relevance of other factors (e.g. the amplification of the hazard due to geological and geo-morphological reasons or the proximity of the exposed element to a fault), a direct and reliable relationship between damage and vulnerability cannot be always recognized.

From a physical vulnerability perspective, the Abruzzo earthquake has been characterized by two main and partially opposite aspects. On the one hand, in fact, historical areas characterized by masonry buildings have been the most damaged ones. Therefore, damage distribution has been consistent with the vulnerability distribution, in that historical cities are

[6] The original title is "Censimento di vulnerabilità degli edifici pubblici, strategici e speciali delle regioni Abruzzo, Basilicata, Calabria, Campania, Molise, Puglia e Sicilia" (Census of vulnerability of public, strategic and special buildings of Abruzzo, Basilicata, Calabria, Campania, Molise, Puglia e Sicilia regions) but it is better known as Barberi report according to the name of the coordinator of the work.

[7] The topic has been widely discussed in del 2.1.

largely recognized as more vulnerable in face of an earthquake compared with recent urban fabrics, in which reinforced concrete buildings generally prevail.

On the other hand, some recent buildings, although supposed to be respectful of the seismic building codes, have unexpectedly collapsed or significantly damaged. That is what has happened for example in the L'Aquila city.

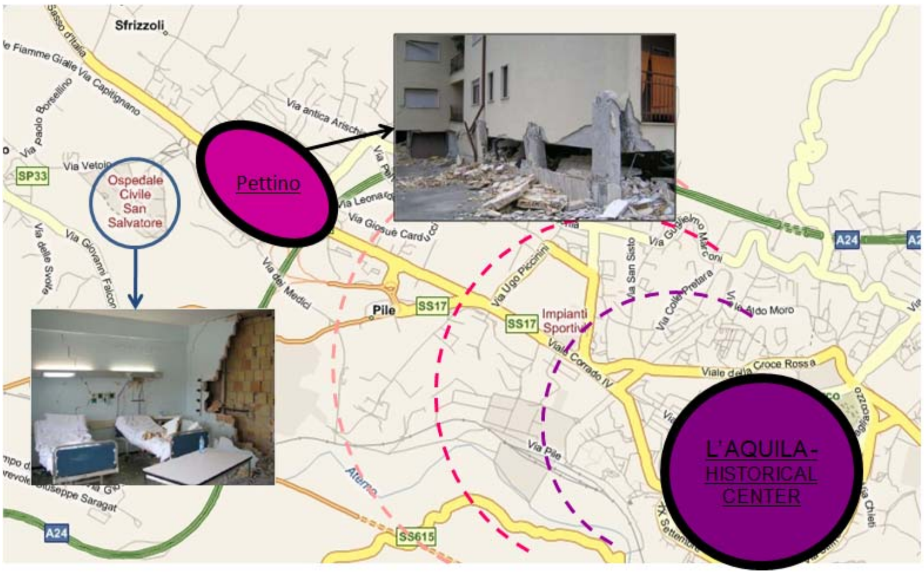


Figure 8: Level of damage in L' Aquila municipality. The violet intensity of dotted line shows the expected attenuation of damage according to the core-pheriphery model that fails in respect to what occurred in Pettino.

According to the core-periphery model, the level of damage should decrease moving from the core area toward the periphery, due to the fact that the former is generally characterized, in Italian cities, by the oldest building stock with a predominance of masonry buildings, whereas in the latter reinforced concrete buildings, typical of the more recent residential areas, prevail. Nevertheless, in L'Aquila municipality, many buildings classified as "E" (unfit for use) or "F" (unfit for use due to external reasons) are placed in the periphery of L'Aquila city, namely in the area of Pettino (fig. 8), in the north-western part of L'Aquila, which has been built up starting from the 1975 (lr1, 2009) and has become one of the most populated area of the municipality (about 25.000 inhabitants). Therefore, it is worth noting that Pettino has been built up after that seismic building codes were put in force (Law 64/74). Detailed surveys focused on the reasons for such anomalies in the building response and, consequently, in the distribution of physical vulnerability are still in progress. However, apart from the "near fault" effects due to the proximity of Pettino to an important geological discontinuity, a relevant role has been probably played by the consequences of what, within the ENSURE project, has been defined as "institutional vulnerability". In other words, a relevant role can be attributed to the lack of compliance in different stages of the building process, such as the control on the adequacy of the original design, on the correspondence of the building with the specification of the design and on the applied techniques and utilized building materials.

In relation to the economic vulnerability, the high concentration of economic activities in the historical core of L'Aquila induces a relevant dependency of many villages, especially those included in the crater area, from L' Aquila and, in detail, from its historical area. Thus, the spatial distribution of activities, and namely their concentration in a small and physically vulnerable area, induces a transference of vulnerability (to losses although not to stress) from the local toward the supra-local scales (fig. 9).

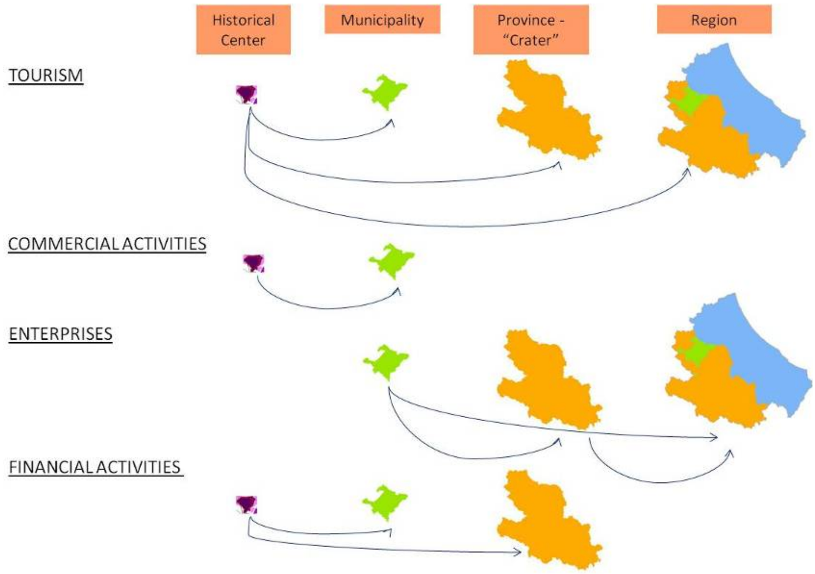


Figure 9: Transference of the vulnerability of some economic sectors from one scale to another

To better understand such phenomena, it is worth underling, for example, that the historical area of L'Aquila was:

- an important node for the whole municipality referring to commercial activities;
- an important node for the region and, surely, for most of the crater area, referring to institutional and financial activities;
- the most relevant touristic destination within the municipality and one of the most important within the Abruzzo Region.

while, L'Aquila municipality represented:

- an important node for the whole crater area referring to the presence of enterprises (about 50% of the total according to the CRESA data);
- an important university town within the Region.

In terms of accessibility, that is one of the crucial aspect for relief operations, the spatial distribution of vulnerability strongly depends on the spatial pattern and on the quality of the road network. Such aspect could have had a relevant role in the delay in the arrival of the relief teams (cs2, 2009) and in providing the first aids (lr2, 2009) reported by some national newspaper in Onna even if, as shown before, it has been the village that would have had a sudden help due to the higher level of damage and number of victims.

Looking at fig. 10, some considerations can be made:

- the distance of Onna from the access to highway (A24) and the peripherical position of Onna in respect to l'Aquila;
- the access way to Onna guaranteed by a secondary road;
- the lower hierarchical level of the Onna-Monticchio connecting road.

It is also worth adding that Onna is "divided" by Bazzano - placed as crossroad of two national roads, and, in such a way, better connected - by an industrial area (therefore empty during the night when the earthquake occurred) and, finally, that Onna didn't play a relevant role in the socio-economic context of the area due to the fact it is mainly a residential village.

Figure 10: Spatial patterns of road networks influencing accessibility of peripheral villages such as Onna.

Final Remarks

The damage of the Abruzzo earthquake have been used as a starting point to highlight some relevant factors which may influence the spatial distribution of vulnerability according to its different facets. Some findings refer to the role of institutional weaknesses that have negatively reverberate on the physical vulnerability of the building stock that, for their specific characteristics, should have had a different behavior in face of the earthquake.

Therefore, from the L'Aquila case study, the relationship between the physical and the institutional vulnerability clearly arises as a key factor, apart from considering site effects, to determine the spatial distribution of vulnerability. The effects of such relationship can invalidate, as happened in L'Aquila city, the core-periphery model often adopted for explaining the distribution of damage, mainly in relation to seismic events. In other cases, the inherent vulnerability of buildings due to their characteristics (age, construction techniques, building typologies) has been not so relevant to explain damage due to the interventions of other hazard-related phenomena such as "local" and "near fault" effects.

Furthermore, it has been highlighted how the monocentric functional patterns of strategic activities (e.g. institutional, economic) in a single area, namely the Historical Center that has been one of the most damaged area, has induced relevant phenomena of vulnerability transference from one scale to others and has largely influenced the distribution of damage, once the earthquake struck, according to a systemic perspective.

Finally, once again, the spatial patterns of road network have shown their relevance in the rapidity of relief operations, taking into account that a scarce accessibility is a widely recognized factor of vulnerability. According to a spatial perspective, it is worth noting that the vulnerability of the Abruzzo region, and mainly of L'Aquila city, is changing due to the post-earthquake interventions. A focus should be done on the C.A.S.E. plan, according to which 19 new villages are currently arising. In terms of physical vulnerability, there are no doubt about the efficiency of these new houses due to the presence of seismic devices, but, as cities "are more than the sum of their buildings" (Campanella, 2006), an in-depth investigation of the spatial and functional organization of urban settlements, namely of the distribution of strategic and economic activities has to be carried on.

3.2.2 The Katrina hurricane (MDX)

Vulnerability (i.e. susceptibility to loss) can be, to some extent, identified and traced by examining actual losses in a past disaster which are a manifestation of vulnerability. Where tracing vulnerability in this way becomes more difficult is in the relationship between a monetary loss and vulnerability, including the capacity to recover. As discussed in Del. 2.1, monetary loss is not always a sound guide to vulnerability and capacity to recover. Temporal evolution of vulnerability and disaster losses is accompanied by spatial expression i.e. that all vulnerabilities and losses may be described by the geographical scale(s) at which they may be observed, and that both propagate through space over time, either rapidly or at a slower rate.

This section examines this spatial distribution of losses and vulnerabilities in relation to the flood and to the oil contamination disaster due to the Katrina hurricane and occurred in August/September 2005 in St Bernard parish and beyond. The analysis focuses upon physical, economic, social, systemic and institutional vulnerability facets and proceeds by examining how actual losses at the core propagate to the periphery and how vulnerabilities at one scale are connected to those at other scales. There are numerous flood loss and vulnerability scale relationships, connections or influences in this case study: so the analysis below is selective, focusing upon examples of what might be termed 'loss and vulnerability pathways' (i.e. particular sets of relationships) which allow 'scale relationships' or 'scale interdependencies' to be identified and illustrated.

The physical and related institutional vulnerability pathway

The whole of St Bernard parish proved to be physically vulnerable to a tidal surge flood associated with a hurricane, and when the tidal surge associated with hurricane Katrina arrived in south-east New Orleans the whole of the parish was inundated. It is impossible to consider this physical vulnerability in isolation because, although the flooding of the parish formed a core, the floods were a consequence of systemic physical failure of an entire flood protection system designed for the whole of the New Orleans sub-region. This systemic failure owed its occurrence to widespread institutional vulnerabilities (i.e. failures) that are associated with organisations, some of which are local or sub-regional (e.g. the levee boards) and others of which have regional and national jurisdictional boundaries (e.g. USACE). (Here we use the definition of institutional vulnerability proposed in Del. 2.1 i.e. *'the potential for loss and reduced capacity to recover caused by the exposure of individuals, communities and local economies etc. to the uncontrollable adverse consequences of the critical shortcomings of institutions or institutional arrangements')*. The sub-region-wide New Orleans flood protection system comprises a complex set of interdependent levees (several lines of defence), pumping stations, floodgates and river diversion channels.

St Bernard parish was first flooded from the neighbouring Ninth Ward, as levees along the Mississippi River Gulf Outlet collapsed, and then from the direction of coastal wetlands (Lake Borgne), after two lines of flood protection were defeated. The disaster occurred like a set of dominoes falling, with the dominoes being the levees designed to prevent floodwater from spilling from neighbouring areas into St Bernard parish.

So already we can observe a somewhat complex pattern of spatial vulnerabilities emerging through the initial focus just on the physical vulnerability facet for this single parish (Fig. 12).

Physical vulnerability is manifested close to the core at the sub-regional level, whereas institutional vulnerability spans all the scales. The vulnerabilities were latent prior to Katrina disaster and were starkly revealed by the losses which occurred. It is noteworthy that in this case the institutional vulnerability facet connections act sideways in a local-to-local or sub-region to sub-region direction, and also in a downwards, federal to sub-regional direction. Whereas spatial vulnerability connections may operate in this way, loss connections propagate mainly sideways, outwards and upwards.

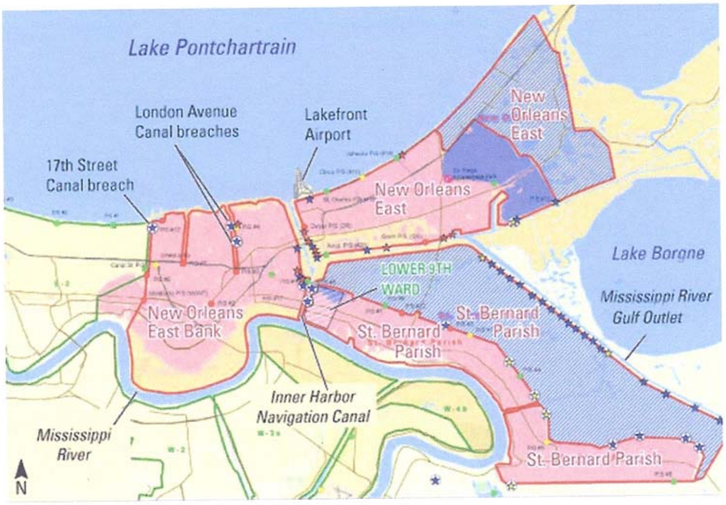


Figure 11: The New Orleans hurricane protection system and the location of St Bernard Parish. Source: National Academies Press (2009).

The economic and related institutional vulnerability pathway

Figure 13 represents an attempt to model the contributory effect of institutional vulnerabilities on economic losses in the flood and oil contamination event in St Bernard parish. Serious institutional vulnerabilities (i.e. failures) are officially recognised to have occurred at all levels i.e. from the federal scale right down to the local, city government scale (US Congress, 2006). In Figure 13 only the most serious of these failures, and their implications, are referred to in what is a much simplified presentation of the problems which arose. Essentially the federal, state and local government emergency management systems were ill-prepared for the catastrophic event, and what should have been a pro-active national, state and city response turned out to be a largely reactive one with many failures.

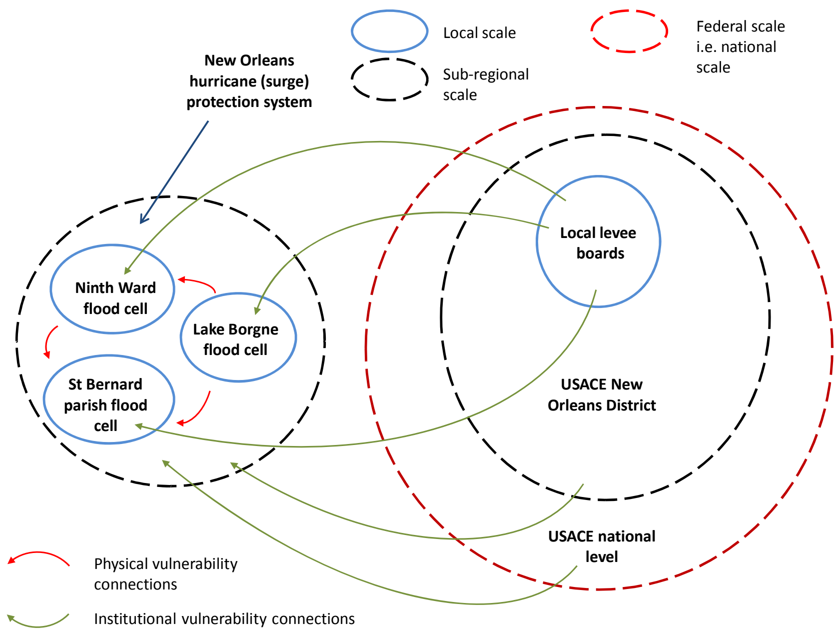


Figure 12: Spatial distribution and propagation of physical and institutional vulnerabilities specifically in relation to the design, construction and maintenance of the St Bernard parish hurricane flood surge protection system.

A particular failure, with serious effects in St Bernard parish, was the loss of life which could largely have been avoided if a mandatory evacuation order had been issued earlier and had emergency evacuation plans been prepared for most disadvantaged and less mobile segments of the population. Although large property losses were almost inevitable, the indirect losses could probably have been to some extent reduced by a more efficient pro active emergency response. Although Figure 13 shows institutional vulnerabilities cascading in a downwards direction, this is only the predominant flow of institutional failures. A more detailed exposé would also show upward-flowing shortcomings, including for example the failure to share information. It is difficult to trace and isolate the economic impacts of the events in St Bernard parish at the city, state and national levels, although such impacts exist, and doing so becomes more difficult as the analysis moves up-scale to the national level and the impact 'evaporates' or becomes almost completely obscured. Because it focuses on institutional vulnerabilities and losses only, what Figure 13 does not show is the massive down-scale flows of federal, state and city aid after the disaster, and that proportion which reached St Bernard parish and which collectively represents a set of resilience and recovery-building responses.

The social vulnerability and loss pathway

A similar figure to Figure 13 could be developed for the social and related institutional vulnerability pathway, although the outcomes are different. The 'social impacts' of Katrina on St Bernard parish were felt throughout New Orleans, the State of Louisiana, neighbouring states such as Texas, and more nationally through many other states.

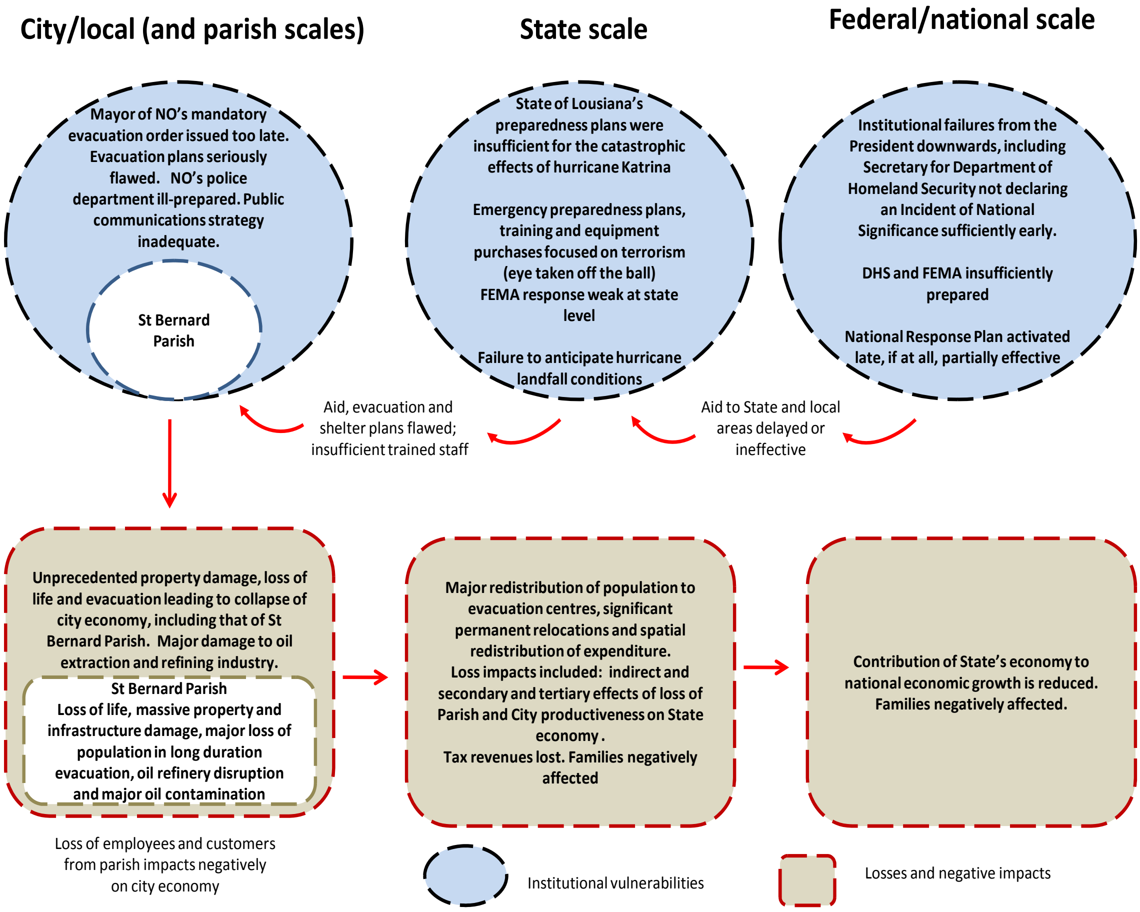


Figure 13: Down-scale cascading institutional vulnerabilities leading to up-scale flowing flood losses from the local to national levels

This is because of the a) loss of life and impairment of lives (through physical and mental injury and ill-health) and life stress and disruption and b) the scale and duration of evacuations, and also resettlement. However, although these social impacts reflect a social vulnerability to flood disaster, they are differentially translated through space as 'social losses'. The relatives and friends of those who either died, or who were injured or suffered ill-health, or who just experienced dislocation of life, who live outside of the flooded sub-region (in Louisiana or other parts of the USA) will have experienced various degrees of social impact and loss. However, people in the locations to which evacuees transferred or resettled will not have experienced social loss. Indeed, they might be considered to have experienced 'social gains', being the mirror image of the social losses experienced in St Bernard parish. Social losses appear, therefore, to differentially propagate through space (i.e. some do and some do not).

3.2.3 Forest fire events (PIK)

Earth is an intrinsically flammable planet owing to its cover of carbon-rich vegetation, seasonally dry climates, atmospheric oxygen, and widespread lightning and volcano ignitions (Bowman et al., 2009).

Over the past decade, a surge in the incidence of large, uncontrolled fires has occurred on all vegetated continents, irrespective of national fire-fighting capacity or management tactics

(UNEP 2002). These extreme fires have high economic, social and ecological costs as explored already in previous deliverables (see deliverables 2.1, 2.1 and 2.3). Such events calls into question our capacity for fire control and highlights our limited understanding of fire's causes, effects, and feedbacks. The spatial distribution of vulnerabilities to forest fires and the identification of typical vulnerability patterns across space can help us to understand the forces in place that are on the origin of such widespread phenomenon.

The distribution of forest fire vulnerability in space cannot be dissociated from two very important aspects. The first as to do with the fact that vulnerability to forest fires, this is, "the susceptibility to losses and capacity to recover", depends at great extent on human actions such as: forest ecosystem management (or lack of it), settlement pattern development and human activities as the major causes of fire ignitions. The second important aspect has to do with the role of climate conditions in influencing the propagation, probability and extension of forest fires. Although this may seem rather trivial, the example of forest fires does bring a new perspective to the spatial distribution of vulnerabilities.

Let us take as an example the case of vulnerability to an earthquake or volcanic eruption. In these cases the spatial distribution of vulnerabilities is limited to human actions that only influence (avoid or enhance) the possible consequences of the hazardous event. We can build better buildings that are able to maintain their structural integrity during a seismic event or place a good monitoring system that will help us to predict the eruption of a volcano but we cannot influence the probability of such events. In the case of forest fires not only man has the ability to lower possible damage and extent of forests fires but also to change its probability of occurrence. For example, the Mediterranean basin is marked by a prevalence of human induced fires, i.e. about 95% of fires (FAO, 2007).

In addition to the role of man, the occurrence and extension of forest fires are also influenced by local climatic conditions. The influence of climate variables in Mediterranean fire regimes has been explored extensively in the literature (Pausas 2004). It's known from climate sciences that global temperature and precipitation patterns are changing (IPCC 2007). This brings yet another dimension to the spatial distribution of forest fires since some regions may not depend exclusively on themselves to manage their vulnerable areas.

Despite the widespread human use of fire, the latter remains an unreliable tool, often evading control, especially during high temperature and low precipitation events associated to multiple ignition patterns. This imperfect mastering of fire management raises the on going question if whether humans or climate are more important in determining fire patterns (Bowman et al., 2009). This aspect is particular relevant when trying to distil the core factors that lead to the distribution of vulnerabilities concerning forest fires. In addition the modelling of the most vulnerable forest areas is a crucial tool for fire managers and local authorities. Understanding what are the core factors that set the patterns of spatial distribution of forest fires vulnerability and what proxies and inputs can be used for their modelling is a fundamental step to take. Finally, in the interest of the deliverable and according to the DOW, it is valuable to bridge examples of spatial distribution of vulnerabilities across developed and developing countries.

For each case study the main input parameters that contributed for the distribution of the occurrence of forest fires were investigated. These parameters were grouped into three broad components chosen for their scientific evidence in influencing the distribution and magnitude of the spatial occurrence of forest fires contributing therefore for the spatial distribution of vulnerabilities, namely: a human component, climatic component and Ecosystem/landscape component.

Human component

The Mediterranean bioclimatic region has endured a long period of human-induced perturbation; in fact, the long-term history of human presence in the Mediterranean basin has provoked intense disturbance regimes compared to other Mediterranean bio-climatic regions in the world (Fox and Fox 1986). Many centuries of severe human pressure resulting in burning, cutting and grazing of non-arable lands and clearing, terracing, cultivating and later abandonment of arable portions have created strongly human-influenced landscapes (Pausas and Vallejo 1999).

This tight relation between human activities and forest fire occurrences generates great interest in the ability to predict the spatial patterns of ignitions among managers, helping to improve the effectiveness of fire prevention, detection, and firefighting resources allocation. In the interest of this deliverable, such predictive model would be very useful in defining the most vulnerable areas spatially as well as the main human components that are required for the modeling.

Ecosystem/landscape component

The global distribution of fire has been revealed only recently by satellite observations available beginning in the 1980s (O. Arino et al 2002). Figure 14 shows a strong association between high fire activity and areas of intermediate primary production, particularly in tropical savannas (van der Werf et al 2008). Nevertheless, satellite measurements do not adequately capture fire activity in ecosystems that have long (>100-year) fire intervals, nor in cases in which fire behavior is highly variable, such as the case of Mediterranean ecosystems.

Despite this general relation, fires burn with different intensities depending on the type and load of fuel upon which the combustion is sustained. In addition, the landscape morphology and connectivity play crucial roles in the extension of a forest fire.

Recent laboratory work was conducted with the objective to assess the capacity of several fuel beds to be ignited by firebrands and to sustain a fire and the capability of different types of firebrands to ignite fuel beds. Selecting fuel beds and firebrands among the most common in southern Europe, Ganteaume et al (2009) argue that regarding fuel bed flammability grasses are more flammable than litter and, among litters, *Pinus* species are the most flammable.

Logistic regression models to predict fuel bed ignition probability were developed. As a whole, results show a relationship between ignition probability of fuel bed and type or weight of firebrands.

Pinus pinaster cone scale, *P. halepensis* cone scale, and *Eucalyptus globulus* leaf and bark can have ignition probabilities at least twice higher than pine bark when falling while in flaming combustion (Ganteaume et al 2009).

This shows that not all vegetation reacts to fire in the same way and therefore the spatial distribution of vulnerabilities will depend on the amount, type and even size of the fuels. Fuel accumulation rates, which depend on net primary productivity and fuel type, exert direct control over the fire return interval.

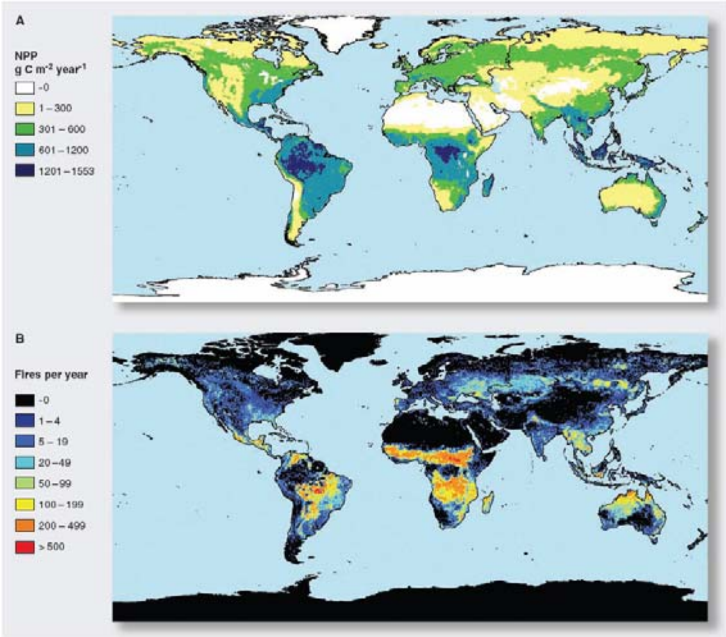


Figure 14: Current pyrogeography on Earth, illustrated by (A) net primary productivity (NPP, g C m−2 year−1) from 2001 to 2006, by 1° grid cells; and (B) annual average number of fires observed by satellite (Bowman et al., 2009)

Climate component

Over longtime scales, the occurrence of fires tends to be self-limiting due to the time needed to accumulate sufficient fuel to carry a new fire. This makes fire to a certain degree biologically controlled. However, this self-regulation can interact with factors not directly related with vegetation age such as: fire policies, forest management and weather. It is widely accepted that meteorological and climatic factors play a crucial role in fire behavior, affecting both the ignition and spread of wildfires, (Kunkel et al 2001). Meteorological variables alone or combined with vegetation and topographical information are frequently used to develop fire risk indices (for a complete assessment see Viegas et al., 1999).

Recent work made for two regions in Australia examined the probability of large-fire (≥1000 ha) ignition days using historical records. Relative influences of the ambient and drought components of the Forest Fire Danger Index (FFDI) on large fire ignition probability were explored using Bayesian logistic regression. The preferred models for the two areas (Blue Mountains and Central Coast) were composed by the sum of FFDI (Drought Factor, DF = 1) (ambient component) and DF as predictors. Both drought and ambient weather positively affected the chance of large fire ignitions, with large fires more probable on the Central Coast than in the Blue Mountains. The combination of drought and ambient weather had a marked threshold effect on large-fire ignition and total area burned in both localities. This may be due to a landscape-scale increase in the connectivity of available fuel at high values of the index. Higher probability of large fires on the Central Coast may be due to more subdued terrain or higher population density and ignitions. Climate scenarios for 2050 yielded predictions of a 20 - 84% increase in potential large-fire ignitions days, using the preferred model (Bradstock et al., 2009)

The most interesting aspect of forest fire hazards, and determinant when assessing vulnerability of forest fires in space, is the ability that the human component has in influencing the other two. These relations are expressed in a schematic way in figure 15.

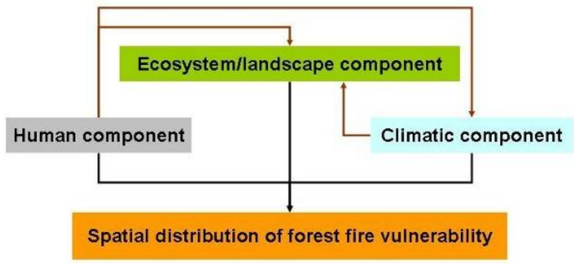


Figure 15: Main components contributing to spatial distribution of forest fires vulnerability

In this light the spatial distribution of vulnerability regarding forest fires will results from the interaction of three components: a human component, an ecosystem/landscape component and a climatic component. The interaction between the human and the ecosystem/landscape components mainly shapes the probability of forest fire occurrence and its extension; the interaction between the climatic and ecosystems/landscape components mainly shapes the extent and intensity of forest fires and the interaction between human and climatic components mainly influences the flammability of the vegetation and also the extent of a forest fire.

The four case studies we are going to present have been chosen from peer reviewed scientific literature and have their focus on four distinct parts of the world representing different fire regimes, institutional functioning, fire management practices and social-economic backgrounds. The systematic approach to the case studies is addressed to assess what are the main factors, investigated in each case study, contributing to the spatial distribution of forest fires vulnerability. A brief description of each case study as well as an overview of the main information retrieved for assessing the core elements driving the spatial distribution of forest fires vulnerability is now presented.

Main factors contributing to the spatial distribution of forest fires vulnerability: case studies

Assessing wildfire potential within the wildland–urban interface: A southeastern Ohio example

The purpose of this paper is to develop a methodology that aptly characterizes the spatial distribution of wildfire risk potential in southeastern Ohio. Hazard variables are defined as those factors of the environment that directly or indirectly affect the volatility of fuels; models for fuel type, solar radiation and topographic wetness index were generated to represent these hazards. Risk variables are those factors related to ignition source; population density and distance from roads were modeled as risk factors.

Human-caused wildfire risk rating for prevention planning in Spain

This paper identifies human factors associated with high forest fire risk in Spain and analyses the spatial distribution of fire occurrence in the country. The study covered a 13-year series of fire occurrence data. One hundred and eight variables were generated and input to a dedicated Geographic Information System (GIS) to model different factors related to fire ignition. After exploratory analysis, 29 variables were selected to build a predictive model of human fire ignition using logistic regression analysis.

Land use and vegetation fires in Jambi Province, Sumatra, Indonesia

The project goals were to determine where and why fires occur, the natural and cultural landscape features that influence the location of fires were analysed. The probability of fire occurrence was investigated as a function of predisposing conditions and ignition sources, such as land use, land use zoning, accessibility or land cover, to understand the spatial determinants of fires. The study area was the entire province of Jambi, central Sumatra, Indonesia.

Biophysical and anthropogenic controls of forest fires in the Deccan Plateau, India

In this study, fire count data sets from satellite remote sensing data covering 78 districts over four different states of the Deccan Plateau in India was used for assessing the underlying causes of fires. Spatial data for explanatory variables of fires pertaining to topography, vegetation, climate, anthropogenic and accessibility factors were gathered corresponding with fire presence/absence. A logistic regression model was used to estimate the probability of the presence of fires as a function of the explanatory variables.

Final remarks

The case studies present different elements used to assess the vulnerability to forest fires. Some of them include elements for all the three core components; others focus on specific components, such as the human component and downplay the relevance of the climatic and ecosystem/landscape components.

The climatic component was taken into account in three of the four cases studies. Both case studies conducted in a developing country context assessed the importance of the climatic component in the distribution of forest fires. The elements used were basically measures of precipitation and temperature, such as the mean annual temperature or specific precipitation thresholds.

Despite the similarity of elements used to assess the influence of the climate component in both case studies, the results reveals differences on the importance that these elements play in the overall model.

For example, while in the case study "Biophysical and anthropogenic controls of forest fires in the Deccan Plateau, India" the elements annual precipitation and average temperature of the warmest month can be found among the best predictors of forest fires, for the case study "Land use and vegetation fires in Jambi Province, Sumatra, Indonesia" the drivers of fires were mainly human driven with climate playing a not so significant role.

The human component was assessed in every case study present in this section. This reflects the substantial importance that anthropogenic actions have in the spatial distribution of forest fires, and, as seen in Figure 15, the relevance of the human component in influencing the ecosystem/landscape and climatic components. The most used proxy to derive the effect of anthropogenic influence on spatial distribution of forest fires was measures of population. Population density, rural population or population decrease are examples of inputs used on the predictive models explored by each case study. Other inputs used were economic trends, such as road density, unemployment rates or logging concessions.

In the case study "Human-caused wildfire risk rating for prevention planning in Spain", the explanatory variables included in the model pointed to agricultural landscape pattern, agricultural abandonment and development processes, as the main factors affecting the spatial distribution of fires.

The ecosystem/landscape factor was only present in the half of the case studies, nevertheless, this core element of spatial vulnerability of forest fires proved to be determinant. In the case study "Assessing wildfire potential within the wildland–urban interface: A southeastern Ohio example", it was observed that sites with deciduous vegetation, high solar radiation and low topographic wetness were particular prone to the occurrence of forest fires. Other ecosystem/landscape factors, such as forest area, biomass density and elevation, were also among the highest significant variables in determining the spatial distribution in the case study "Biophysical and anthropogenic controls of forest fires – India".

			Relevant elements		
Title	Author	Model	Climatic component	Human component	Ecosystem/landscape component
Assessing wildfire potential within the wildland–urban interface: A southeastern Ohio example	James K. Lein	Conceptual model of significant variables associated with the threat of wildfire ground-truthing	Temperature Precipitation Relative humidity Wind speed	Distance from roads Distance from rails Distance from utilities Population density Housing density	Fuel type Fuel moisture Fuel size and shape Amount of fuel Arrangement of fuels Elevation Slope Aspect Illumination Topographic position
Human-caused wildfire risk rating for prevention planning in Spain	Jesús Martínez	Logistic regression	No climatic component assessed	Population decrease Density of agricultural machinery Density of roads Agricultural land fragmentation Livestock density in extensive regime Urban/forest interface density Unemployment rate Density of railway lines Increase in number of owners of agrarian holdings Interface area between risk infrastructures Population increase Protected natural areas Agricultural area which became forest land	No Ecosystem/Landscape component assessed
Land use and vegetation fires in Jambi Province, Sumatra, Indonesia	F. Stolle	Logistic regression	Rainfall between 1800 and 2200 mm	Logging concession Allocated to production forest Allocated as transmigration area Distance to roads Distance to towns	No Ecosystem/Landscape component assessed
Biophysical and anthropogenic controls of forest fires in the Deccan Plateau, India	V. Krishna Prasad	Logistic regression	Mean annual temperature Average temperature and precipitation of the warmest quarter Mean annual precipitation	Rural population density Illiteracy rate Rural population to forest area ratio	Elevation Slope Aspect Compound topographic index Topographic position index Percent forest cover Biomass density

Table 2: Relevant components used for deriving the spatial distribution of forest fire risk and vulnerabilities

3.2.4 The Vesuvius volcano: past events and scenarios

Volcanic eruptions are characterized by different volcanic phenomena occurring in different temporal phases: thus, vulnerability changes in time and in space according to the different phenomena and, consequently to different affected areas and exposed targets. Obviously, it is very difficult to separate the investigations related to the spatial evolution of phenomena and vulnerabilities from the temporal development of phenomena and vulnerabilities themselves. Nevertheless, since temporal variability of vulnerabilities in case of volcanic events has already been investigated in the previous deliverable (del 3.1), we will focus here on the spatial dimension of vulnerabilities to volcanic eruption, grounding on the same case study: the Vesuvius volcano in the Campania Region (South of Italy).

The Vesuvius volcano is largely recognized as a high risky volcanic complex, because of its eruptive type, which is predominantly explosive, and because of its proximity to the densely populated urban area of Naples: these factors are useful to highlight the spatial dimension of changes in vulnerabilities too.

As already mentioned in the deliverable 3.1, the metropolitan area of Naples has been interested by phenomena of intensive urbanization, increase of population and relevant growth of illegal buildings in the last decades: such phenomena have determined one of the most densely populated volcanic area in Europe. The last Vesuvius' eruption occurred in 1944, but it "often experienced long periods of quiescence that lasted, in some cases, centuries or tens of centuries, with an *awakening* more and more violent the longer the repose-time preceding the eruption was" (Cioni et al. 2003). The most recent plinian events occurred in A.D. 79, A.D. 472 and A.D. 1631. The 1944 eruption started the new phase of activity (with obstructed conduit) which currently characterizes the volcano.

Spatial evolution of volcanic hazard, damage and vulnerabilities

During a volcanic eruption, different volcanic phenomena, showing different lengths, hitting different areas and territorial targets, can be generally recognized in different temporal phases. The temporal evolution of a volcanic event involves therefore remarkable spatial variations in the distribution of vulnerabilities to volcanic hazard.

The analysis of such variations is not an easy task, even though an in-depth knowledge of the damage occurred as a consequence of past events, interpreted as a tangible outcome of the interactions between hazard factors and vulnerabilities of the hit area, could be an useful starting point for defining the main factors affecting the spatial distribution and its variations according to the dynamic features of the type of hazard at stake hazard of vulnerabilities to volcanic phenomena.

In the deliverable 3.1, the temporal phases of explosive volcanic eruptions have been already described. During these phases, different volcanic phenomena, with heterogeneous impacts on exposed areas, may occur. As shown in fig. 16, each temporal phase is characterized by different phenomena which can involve areas different in size: some phenomena may indeed affect small areas (like volcanic bombs or earthquakes), others medium or large areas (like pyroclastic flows or ash falls).

For example, the 1906 eruption clearly highlights that volcanic eruptions are characterized by different temporal phases corresponding to different hazard phenomena with heterogeneous impacts. With reference to these heterogeneous hazards, the exposure of the territorial system is largely variable in short time too. For example during the first phase of the 1906 eruption, the effusive activity didn't threaten the population which, on the opposite, was exposed to pyroclastic falls and flows during the following explosive phase of eruption. Exposure is also variable in space. For example, the elements exposed to lava and pyroclastic flows were localized in the municipalities near the volcano, whereas pyroclastic falls heavily affected a wider geographical area, including the city of Naples.

Due to the dynamic nature of volcanic phenomena, during each phase the areas affected by the different phenomena may alternate and overlap. Moreover, the same area may be affected by different phenomena in different temporal phases. It is worth noting that, over time, physical vulnerability of territorial elements may change too: as already highlighted, indeed, this vulnerability facet is significantly hazard-dependent; therefore, it changes over time according to the heterogeneous volcanic events at stake.

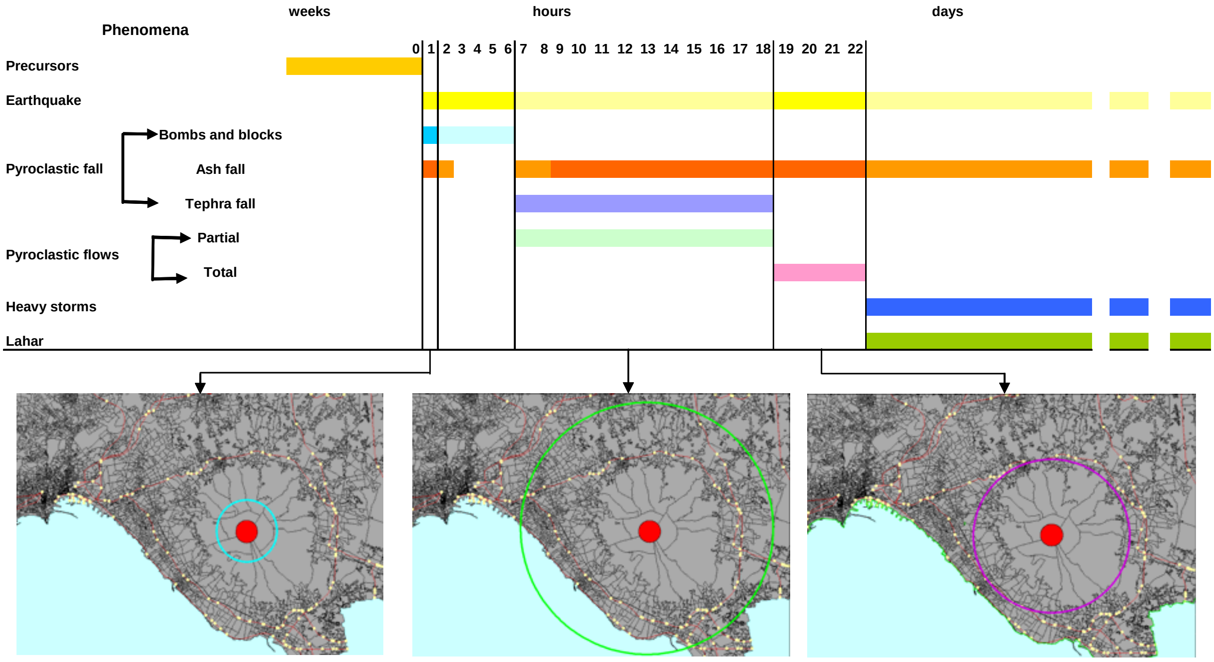


Figure 16: Areas affected by the heterogeneous volcanic phenomena which may occur during an eruption

Also in relation to the 79 A.D. eruption, which was characterized by different phenomena and different intensities too, relevant changes in exposure of people can be observed mainly due to their behaviour and to the change of phenomena and involved areas during the phases of the event.

For example, the archaeological discoveries showed many corpses included in the ashes erupted in the final phases of the eruption: it might have occurred indeed that, between the first phases and the final phases of the eruption, less intense phenomena would have occurred. Therefore, population went away during the first phase, came back later due to the reduced intensity of volcanic phenomena and were hit by ashes during the final phase.

Thus, during the different phases of an eruption, the size of the hit area varies according to the type and to the intensity of the volcanic phenomena which characterize each phase. Moreover, the exposed territorial elements also vary according to the different types of volcanic phenomena. Finally, vulnerabilities of the exposed elements and systems may change: for example, a given element being exposed to different volcanic phenomena might be vulnerable to one type of hazardous phenomenon and not to another one (since physical vulnerability is strictly dependent on hazard type), and because an element might change is vulnerability features over the phases of the eruption as a consequence of damage occurred in the early phases.

The variability of the affected areas is clearly demonstrated by past Vesuvius eruptions. For example, during the 1944 eruption, the towns mostly damaged by pyroclastic falls were

Terzigno, Pompei, Scafati, Angri, Nocera, Poggiomarino and Cava, whereas Naples was greatly favoured by the direction of the wind that turned away the cloud of volcanic ashes (Sansiviero et al., 2007). The eruption killed 26 people due to the building roof collapses in the area affected by the ash fall; two towns were partially destroyed by the lava flows; 3 year's crop were lost in the areas affected by the pyroclastic fall. More victims were avoided by the evacuations of the inhabitants of S. Sebastiano, Massa and Cercola, almost 12.000 people.

The overlapping of the effects of volcanic phenomena in a same area and on the same territorial elements is very clear looking at the effects of the 1631 eruption. The latter induced indeed strong rains, apart from ash falls. Therefore, in a large area around the volcano, many houses had their roofs collapsed because of the heaps of humid ashes, that have an high specific weight causing the collapse of roofs even in case of small thickness. Moreover ash falls induced relevant mudflows due to the almost overall waterproofing of the soil covered by the ashes fall which blocked the regular absorption of rainwater.

To better understand the different vulnerabilities at stake and their spatial distribution in case of volcanic events, it is worth reminding the research work developed by the UNINA team within previous EU funded Projects. In detail, within the SCENARIO Project, a likely scenario of a Vesuvius' eruption was carried out. Grounding on the main research findings of volcanologists, the most likely event and, in the meanwhile, the maximum expected one in case of unrest of the Vesuvius in a short time (10 years) was defined and its main potential impacts at local and European scale were sketched, grounding on the in-depth analyses on past eruptions. Moreover, starting from the main results achieved in another EU Project, the Armonia Project, the main targets of the different volcanic phenomena in each phase of the event were defined and a qualitative description of the potential damage due to the interactions between the likely phenomena and exposed targets was provided and articulated with respect to the different temporal phases.

Furthermore, the total amount of exposed targets (namely population, buildings, natural and agricultural areas, lifelines, strategic equipments) has been calculated in relation to the maximum areas affected by the different phenomena in some of the identified temporal phases. It's worth noting that these areas have been drawn as circular areas based on the maximum distance at which the impacts of each phenomenon were registered in the past events, without taking into account the potential location of future eruptive vents (fig. 17).

The Vesuvius' scenario clearly highlights the spatial variability of volcanic phenomena which over time affect different areas, activating, within the same area or in a different one, different physical vulnerabilities.

In most cases, agricultural and natural areas, with small and rural villages, are considered as the main targets of volcanoes, since built-up areas are generally located far from volcanoes.

Nevertheless, whereas large and densely populated urban areas are prone to volcanic phenomena, as in case of the Vesuvius, the spatial patterns of settlements and of urban fabrics may play a relevant role in determining the vulnerability of the hit areas and, consequently, the total damage.

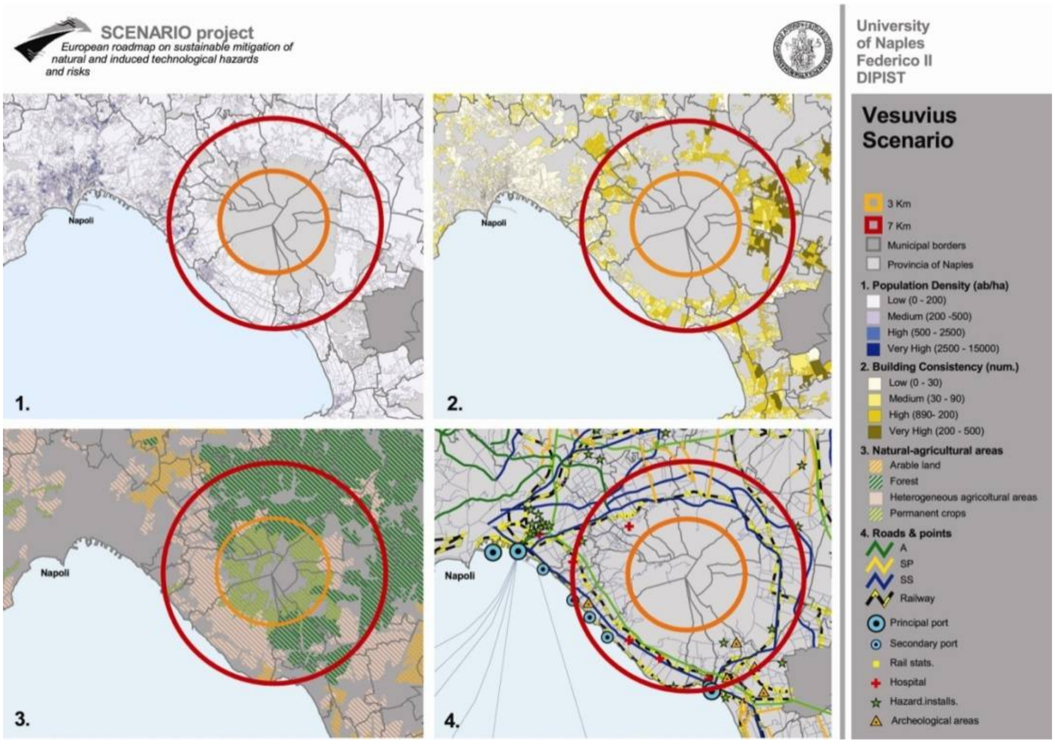


Figure 17: Spatial areas potentially affected by different volcanic phenomena in the first and peak eruptive phase (Scenario Project)

It is worth noting that spatial patterns of settlements can be relevant in relation to some volcanic phenomena, such as lava flows, even though they are not relevant in relation to others, such as pyroclastic flows: the latter phenomena indeed destroy everything along their path, independently from the features of the exposed elements.

Physical and functional organization of the settlements around the volcano is also relevant with reference to the potential obstructions of physical and functional links existing among built-up areas (different urban districts, road networks, functional dependencies among villages and urban areas, etc.). Therefore, surveys related to the morphological and functional features of the built-up areas around the volcano and of the physical and functional links among them are very relevant in order to understand the potential outcomes of volcanic eruptions.

The Vesuvius' area is characterized by a belt of medium-sized settlements, a circular network of nuclear and linear urban fabrics linked one to each other (fig. 18) which has developed all around the volcano with high levels of population density. Most of the urban fabrics have been built up in the last fifty years. As mentioned by Marzocchi et al. (2004) the Vesuvius area "is a good example of how risk can increase dramatically in a short time because value and vulnerability increase much faster than hazard. In 1944 about 300,000 people were living on its slopes. That population has more than doubled while schools and hospitals have been built on the volcano's slopes where in recent centuries eruptive vents opened".

In this case, the functional and physical networks among settlements and their spatial features have to be deeply investigated in order to understand the potential outcomes of Vesuvius' eruption both at regional and at local scale. Accessibility to strategic equipments, national and regional strategic road and rail networks could be involved into a Vesuvius' eruption.

Fig. 18: Settlements around the Vesuvius (Operative Strategic Plan of Vesuvius)

Furthermore, it is worth noting that in case of volcanic events, due to the temporal length of volcanic eruptions and due to the precursors of event allowing to predict the eruption several days before the event, emergency procedures are generally activated in order to move population out from the hazard prone areas. These procedures combined with often unexpected people behaviors may induce relevant spatial changes of exposure and vulnerabilities in the affected areas.

Finally, it has to be noticed that volcanic event may have large scale repercussions both as a direct consequence of the events themselves and as an indirect consequences of local damage reverberating into wider geographical contexts. For example, it is worth mentioning that during the 79 A.D. eruption, as reported in historical texts, the Vesuvius ashes reached Africa, Syria and Egypt too.

Moreover, whereas the volcanic event affects, as in the Vesuvius case, large urban areas their impacts may reverberate at regional, national or even wider contexts, depending on the physical, functional or economic links that the hit area has with other areas.

Therefore, the Vesuvius scenario has been focused on the potential systemic impacts due to the eruption too, highlighting some of the systemic damage which can be produced by an eruption. Among them, the climate change phenomena which can be induced by large volcanic eruptions reverberating from local to regional or wider geographical contexts, till to global scale; or even the immediate interruption of the flight connections due to ashes which represents one of the systemic damage occurring in the first phase of the eruption, involving national and continental flight connections. Also the interruption of passengers and freight flows supported by other means of transport is very common, with clear implications both at micro and macro scale.

Another example of transfer of damage due to a volcanic eruption from local to wider geographical areas might be referred to the stop of the export activities, which may affect wider economic regions due to the links among the hit area and external markets. The

dimension of the affected economic region highly depends on the type, number and intensity of economic connections between the hit area and the outside and, obviously, on the functional and economic, relevance of the hit area itself.
For example, after the 79 A.D. eruption, local economy was seriously damaged. Ash falls compromised agricultural activities for a long time; therefore, wine production was stopped and Rome begun to import wine and other agricultural products from Gallia instead of Campania, with evident economical consequences.

Final remarks

Summing up, grounding both on damage recorded during past Vesuvius eruptions and on the findings of the developed future scenario, the main aspects related to the spatial distribution of vulnerabilities in case of volcanic events can be synthesized as follows:

- the heterogeneity of volcanic phenomena during the different phases of an eruption entails that different areas and different targets are involved during each phase; consequently different vulnerabilities arise in the different phases with different distribution in space;
- due to the temporal length of volcanic eruptions and to the precursors of event allowing to predict the eruption several days before the event, spatial changes of exposed elements and of their vulnerabilities may occur during the eruption as a consequence of damage induced in the first phases of the eruption, of the emergency procedures activated before or during the eruption and of people behaviors in face of the event;
- even though agricultural and natural areas are generally considered as the main targets of volcanic events, in some cases, as in case of the Vesuvius, the spatial patterns of settlements and of urban fabrics may play a relevant role in determining the vulnerability of the hit areas and, consequently, the total damage.
- systemic vulnerabilities in case of volcanic events may arise not only as a consequences of physical or functional damage (vulnerability to losses) but as a consequence of the hazardous event too; therefore, impacts and damage may transfer from local to wider geographical contexts, affecting areas very far from the hit one.

3.2.5 Multi-site landslides: some examples (T6)

The following examples clearly show how a same factor (e.g. rainfall) may trigger numerous individual landslides in a given area, occurring simultaneously or over a short time span, and how multi-site phenomena may affect a large territory due to the many individual landslide phenomenon. Multi-site hazardous events are very relevant to understand how spatial distribution of vulnerabilities varies according both to hazard features and to the type of vulnerabilities at stake. In these cases, indeed, according to the features of the phenomenon, the distribution of physical vulnerability is generally very local and requires in-depth investigation on exposed buildings and infrastructure, whereas other facets of vulnerability, such as systemic, institutional and so on present a distribution on wider geographic scales due to the numerous relationships and interdependencies among elements and systems placed in all the area affected by the individual phenomena.

May, 5- 6, 1998: Sarno, Siano, Bracigliano – Multi-Site Landslides

On 5th and 6th May 1998, following a period of prolonged rainfall that occurred late in the wet season, a large number of landslides occurred in the Southern Apennines in the area of Sarno-Quindici (area located in the Campania Region, some 30 km SSE of Naples). The slope failures impacted upon the downslope towns, causing a high number of casualties and the destruction of houses and infrastructures; moreover, they visibly changed the local landscape. In particular, the event caused 160 fatalities, 115 people were injured and 1210 became homeless (Brondi & Salvatori. 2003). These events constituted a large cluster of landslides (150) that occurred over a very short period of time (12 h) and in a small area (about 30 km2). The mudflows originate from the detachment and fluidification of the shallow pyroclastic deposits that lie on the steep, vegetated slopes of this area. These layers were deposited during the emptions of "Phlegraean Fields" caldera and Somma-Vesuvio volcanic system (Rosi *et al.,* 1999); thus it lays on paleo-morphologic limestone bedrock, which is often characterized by very steep slopes. The total saturation of the pyroclastic layer due to continuous heavy rainfalls and seepage pressure reduced the stability of the layer, triggering mudflows The mudflows occurred on the SW, SE and NE slopes of the Sarno ridge (which trends NW attaining heights from 874 m to 1,133 m a.s.1.), affecting the municipalities of Sarno, Episcopio, Siano, Bracigliano and Quindici. The detachments of the highest pyroclastic-strata mudflows occurred at altitudes of 900 and 600 m a.s.l., while the flows hit urbanised areas between 250 m a.s.1. at Quindici and 30 m a.s.1. at Sarno. The most devastating mudflows, which came down from the Sarno slope, covered a distance of over 3 km. At the head of the mudflows, slopes angles varied from 35° to over 45°, while the mudflows came to rest on slopes varying from 12° to 15° on the piedmont fans. The approximate dimension of the detachment zones varied from tens to hundreds of square meters. Deep gullies, 20-30 m wide at the top, 6-10 m wide at the base and 30-40 m deep, incise the piedmont fans. The mudflows reached a thickness of 6-8 m near the buildings that obstructed the flow (Campagnoni *et* al., 1998) In this area, these phenomena were well known in the past (they were already well known during the Bourbon period, XIX century) but today they still represent a serious hazard. Within this region over 100 towns could potentially be affected, constituting one of the major problems for land-planning activity in the Campania Region. In order to reduce this hazards mud-flow regulation system was planned and constructed at the bottom of the Sarno slope at the junction between several gullies. The structure consists of a regulating dam built across a valley and a storage basin which allows the store of possible mudflows deposits. During low-water periods, the water is discharged through mouths located in the regulating dam. In the event of mudflows, no more than a limited amount could be discharged through the dams mouths (Castaldini, 2008).

Figure 19: Aerial views of the landslides in the towns of Quindici (http://www.commissario2994.it/)

The events in the Sarno-Quindici area were only the most recent ones of many landslides which have affected this territory in former times; therefore the zones at risk could have been defined well before the event had happened.

- The lack of a hydrogeological-hazard map and an urban planning allowed wild urbanisation without any control.
- Real-time critical weather conditions could have been predicted with meteorological tools (e.g. meteosat satellite images).
- Rainfall data records together with the data of past events would have helped to define rainfall thresholds for the definition of three alert levels (attention, warning and alarm). Italy's Civil Protection refers to these very levels to face disaster intervention activities and to plan any preventive evacuation scheme.

All the area was thus particularly vulnerable under physical, functional and systemic view points and the high number of casualties and large damage clearly witness this issue.

June 19, 1996 River Vezza basin (Nw Tuscany, Italy) – Multi-Site Debris Flows

The River Vezza basin is located in the north-western sector of Tuscany in the Apuan Alps with a total catchment area of 51.6 km2. It experienced on 19 June 1996 a severe rainstorm event in terms of intensity and cumulated rainfall. The rainfall started at 6:30 am and terminated at 19:00 pm.

478 mm of cumulated precipitation were recorded at Pomezzana corresponding to approx. 33% of long-term yearly average rainfall, with 158mm/h as a maximum intensity. The analysis of 3, 6, 12, 24 hours of rainfall heights referring to historical records provides return time values from 200 to 500 years (Burlando and Rosso, 1998). The rainstorm was promoted by the peculiarity of the micro-climate of Apuan Alps; this develops from the ascending and rapid cooling of Atlantic wet fronts over the Versilian chain (orographic effect), that resulted in a sudden and concentrated rainfall, in particular during the summer season.

This event caused disruptive and differentiated effects in the mountain and flood plane. A flash-flood destroyed the village of Cardoso causing 14 victims. Most of the road network was interrupted and disrupted while some hundred landslides (mostly debris flows) were triggered along the slopes Rapid infiltration of rainfall and the increasing of pore pressures can be considered the main trigger of debris/earth flows generation (Campbell, 1974; Wieczoreck, 1987, 1996).

Figure 20: Aerial photo of NE sector of River Vezza basin (Del Monaco et al., 2003)

Historical analysis has stressed that the study area is highly prone to simultaneous triggering of superficial landsliding and flooding associated with intense precipitation. Large floods occurred in 1774, 1885, 1902 while minor events have a 25–30 years return time. The flood of 25 September 1885 seems to be comparable with the 1996 disaster in terms of magnitude and associated damage (Martini and Paolini, 2000). The analysis of the 19 June 1996 disaster as well as historical occurrences of landslides, emphasizes that heavy rainfall promotes a generalised instability of the Vezza basin. This area is highly susceptible to superficial landsliding that involves mainly the soil cover of slopes.

As regards vulnerability, the same considerations made for the Sarno area can be made, with particular reference to systemic implications.

3.3 Factors affecting the spatial distribution of vulnerabilities

Based on the presented case studies, the main factors affecting the spatial distribution of vulnerabilities will be here highlighted. As clearly emerge from case studies spatial distribution of vulnerabilities depends both on the type of vulnerability and, in many cases, on the type of hazard at stake.

Therefore, such factors cannot be defined in general terms but in relation to the different facets of vulnerability, even though the mutual relationships among the different facets, may influence the revealing and the distribution across space of each facet, and mainly for what concerns physical vulnerability which is the most hazard-dependent vulnerability facet, in relation to different types of hazards.

Moreover, it is worth reminding that, even though it is possible to recognize some relationships between hazard features and spatial distribution of vulnerabilities, the latter depends only on the features of the elements and systems potentially affected by a given hazard. One of the most common mistakes is, indeed, to confuse spatial distribution of damage with that one of vulnerabilities. Even though damage distribution is a relevant starting point to better understand factors affecting or determining vulnerabilities as highlighted by case studies, it has to be considered that damage and their distribution depend on both hazards and vulnerabilities. On the opposite the distribution of vulnerabilities will depend on the distribution of factors which make a given target (a building, a road, a person, etc.) more or less vulnerable in relation to a certain type of hazardous event.

Physical vulnerability

The distribution in space of physical vulnerability to different types of hazards varies according to the change of some specific physical features of the exposed settlements. Such features have to be defined according to the different types of hazards. For example, if we consider the physical vulnerability of an urban area to earthquakes, ash falls, toxic releases or droughts, factors affecting spatial distribution of physical vulnerability will largely vary in that both the exposed targets and the features of these targets which determine their vulnerability will vary in relation to the hazard at stake.

It is obvious indeed that settlements are not the only type of exposed elements which can be damaged by a hazardous event. In many cases, rural areas or natural environment will be the main target of an adverse event. For example, whereas the main target of earthquakes are urban settlements and population, mainly as a consequence of physical damage to buildings, and rural areas are only secondary/minor target, other hazards like fires or droughts will primarily affect rural or natural areas. In the meanwhile, other types of hazards like volcanoes, floods, toxic releases, gas emissions, cold or warm waves may affect both urban settlements and rural/natural areas, by causing short and long term damage both to buildings and infrastructures and to crops and natural ecosystems. In any case, spatial distribution of physical vulnerability of exposed elements can be examined at different scales, from the macro scale to a very local detailed one, according also to the type of hazard at stake.

For what concerns urban settlements, factors affecting physical vulnerability are largely related to the features of built up areas, which, according to the different scales, can be referred to the features of different urban fabrics or to the features of individual buildings.

At large scale, settlements are characterized by different spatial patterns (linear, radial, etc.) according to the different morphologies of the site too, and are formed by urban fabrics which at the micro scale are, in turn, characterized by the aggregation of buildings, open spaces, roads, etc. It is therefore possible, with reference to each type of hazard, to establish a link between different morphological types of settlements, types of urban fabrics and buildings and different levels of physical vulnerability. In most cases, indeed, some features of buildings which are relevant to their vulnerability in face of some hazards (*age of buildings, construction techniques, building typologies*) belong to specific types of urban fabrics (historical fabrics, recent peripheries, redevelopment areas, etc.).

These considerations can be very useful to single out, at a Municipal scale, the most vulnerable areas among the exposed ones in face of a given hazard, grounding on the general features of the different urban fabrics, even though an in-depth analyses of the features of the exposed buildings are required to assess physical vulnerability at local scale and to map in detail its spatial distribution.

As previously stated, the analysis of the spatial distribution of vulnerability is not an easy task even though some relevant inputs can be result from the in-depth analysis of the damage occurred during past hazardous event, meant as tangible outcomes of the interactions between hazardous phenomena and vulnerabilities of the hit territorial systems.

The spatial variations in damage distribution can be verified, at different scales, in numerous past disasters, mainly when hazards characterized by spread effects, like earthquakes, are at stake. In these cases, damage distribution largely varies according to the distribution of the features of the building stock that makes it vulnerable to the hazard. As an example, the total amount of damage in the city of Naples, due to the Irpinia earthquake occurred in the South of Italy in 1980, was largely concentrated in the historical city, whereas damage to the building stock of the recent built up areas were less significant. However, also in the historical town the distribution of physical damage might be not homogeneous, according to the different urban fabrics that historical towns are made of.

Although the relation among types of urban fabrics and vulnerability levels is generally verified in seismic events, it is possible to find some singularities, such as the collapse of recent buildings that, according to the features they were supposed to have, would had better reacted to the impact. This is not a rare circumstance, since these singularities have been occurred in numerous seismic events, like the 1980 Italian earthquake or the more recent L'Aquila earthquake. These irregularities in the spatial distribution of damage in the different urban areas are mainly due to the fact that numerous buildings have been built up in the lack of adequate building codes or without an adequate control of the construction process quality, etc.

Furthermore, it has to be taken into account that the spatial distribution of the different urban fabrics largely varies according to different geographic contexts: numerous cities in developing countries are characterized by a recent core surrounded by a belt of informal settlements.

Moreover, in developing countries, informal or illegal settlements are in many cases located just in hazard prone areas. On the opposite, European cities are generally characterized by a historical core and different urban tissues whose features vary according to different temporal spans, from the core toward the periphery. Thus, looking at a typical European city, characterized by a large historical center and a recent periphery, it is possible to state that the spatial distribution of physical seismic vulnerability varies with reference to a core-periphery model and can be described as in fig. 21.

The levels of seismic vulnerability growths moving from rural areas toward the city center characterized by historical urban fabrics. The peak of this distribution is reached in the ancient nucleus of the town (for example the Roman or Greek nucleus closed by the ancient walls of the original village) and it seems to follow a Gaussian distribution.

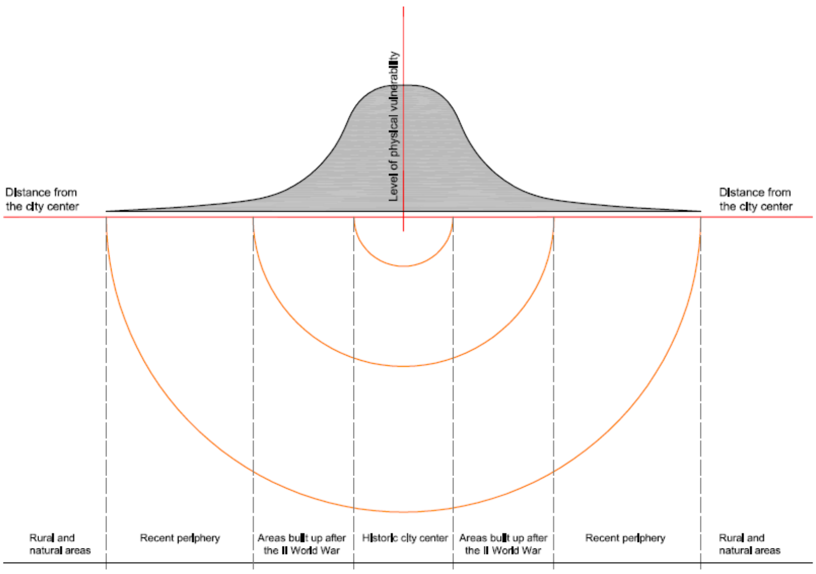


Figure 21: Spatial distribution of physical seismic vulnerability for a city characterized by an historical core and a recent outer periphery

Moreover, if we refer to a tridimensional space, we obtain a concentric distribution of areas with increasing vulnerability levels (see paragraph 3.1).

However, it is worth noting that in many cases this distribution is affected by the spatial variation of building density that, in this type of urban settlement, increases going from the periphery toward the city center. If we consider a homogeneous distribution of building, the spatial distribution of vulnerability will depend only on the features of urban fabrics. Therefore, sprawled urban systems are generally characterized by homogeneous (and generally very low) levels of vulnerability, since buildings are spread over the territory without relevant variations in the building density following patterns which do not generally differ one from each other.

In general terms and still in relation to earthquakes, urban settlements in different geographical contexts are characterized by different spatial patterns, as in case of sprawling cities very common in the Unites States (fig. 22) and by different patterns of transition (fig. 23) from the core to periphery.

Figure 22: A typical core-periphery urban pattern with the historical fabrics in the middle (left); A typical sprawled urban pattern (right).

Figure 23: Transition from rural areas toward the city center: changes in urban fabrics

For example, looking at a large urban system characterized by the presence of informal or even illegal settlements located out of the downtown, the spatial distribution of vulnerabilities might largely vary, as shown in fig. 24, since the peak points will be placed not in the core urban area but in correspondence of the informal settlements.

Summing up, both urban fabrics and buildings typologies generally change going from the rural areas toward the city center, following different patterns according to different geographical contexts. Thus, in European cities, due to the existence of a very common urban pattern (historical core in the inner area; consolidated periphery in the first circle after the core; more recent peripheries in outer circles), it should be stated that physical vulnerability to earthquakes can be represented through a traditional model core/periphery as that one showed in fig. 21. Such a model is based on the assumption that in the historical areas, buildings have been built up in the lack of building codes and that in such areas there is often a lack of building maintenance due to the fact that richest people has generally abandoned the historical towns.

Nevertheless, in many cases these statements are not true, since the historical areas have been largely renewed and, consequently, poorest people has been forcedly moved toward marginal location. In such cases, the distribution of vulnerabilities has to be explained through different models.

Furthermore, in some geographical contexts, we often have different patterns of spatial distribution of physical vulnerability, that mirror the different patterns of urban settlements (for example, recent downtown and informal or illegal settlements generally placed far from the city-core).

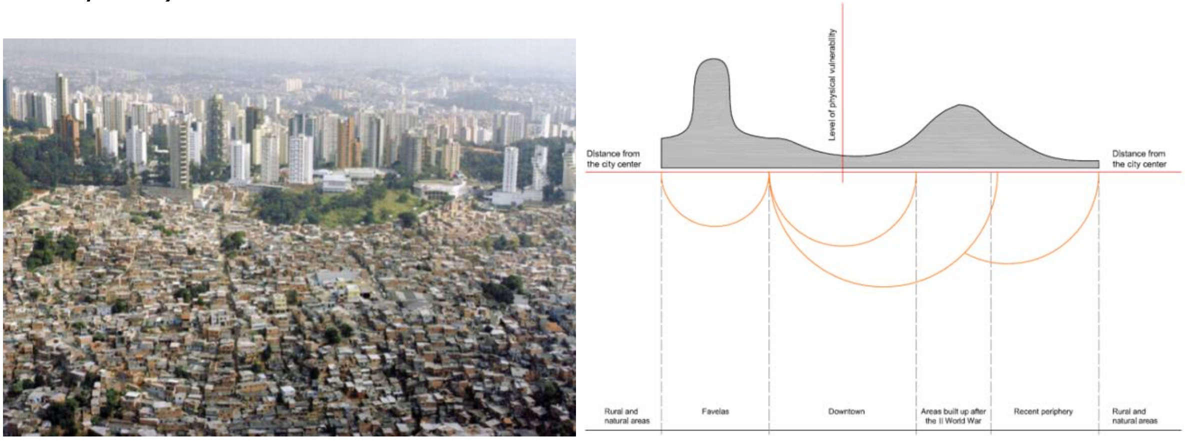


Figure 24: Spatial distribution of physical seismic vulnerability for a city characterized by a recent downtown and informal settlements out of the urban core

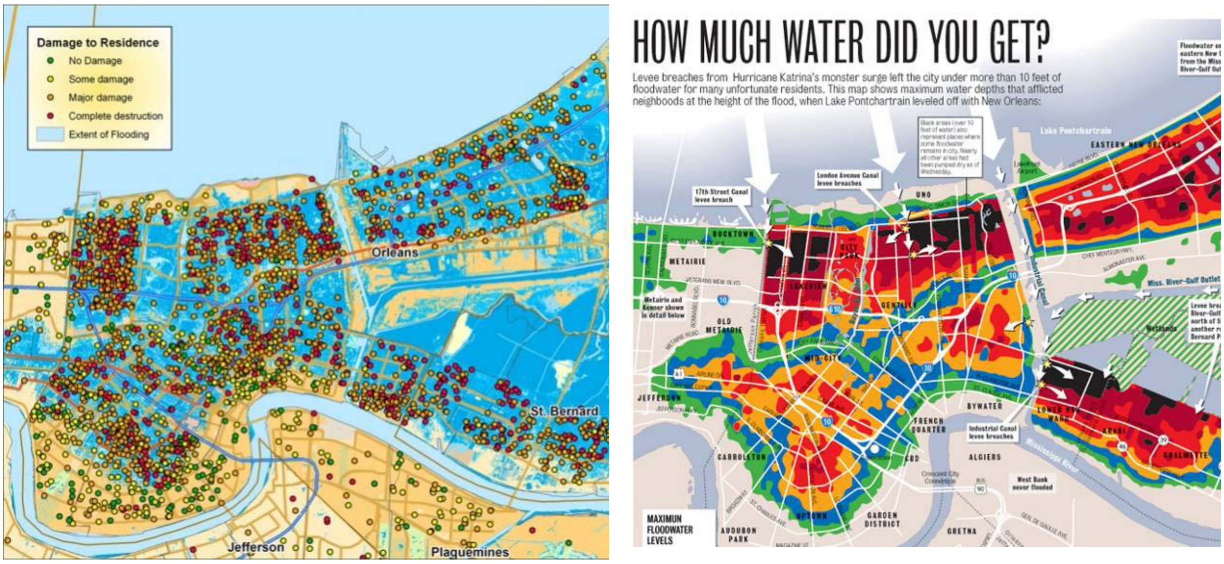


Figure 25: Physical damage to residential buildings and flood depth in the Katrina event

Similar considerations can be also referred to other types of hazard. Nevertheless, it is worth noting that in many cases spatial distribution of vulnerability cannot be not easily inferred from the damage distribution since the latter depend also on the change of hazard features according to the site morphology or to the environmental conditions (as in case of fires).

For example, in case of floods, damage distribution is strictly related to the flood path and to its depth, as shown by the Katrina case-study (fig. 25). In this case, the distribution of building typologies is homogeneous and damage distribution decreases going out from the boundaries of flooded area.

Moreover, it is undoubtedly difficult, for example, to model the spatial distribution of factors affecting physical vulnerability to ash falls, for example, without in-depth analyses of the characteristics of building stock. The features of buildings on which their vulnerability depend on (roof typologies, features and position of windows, etc.) cannot be easily classified grounding on building age or on a very general classification of building typologies.

In case of volcanoes with long periods of rest, it should be possible that the most recent urban areas, built up after a long time of rest of the volcanic activity, are the ones in which the roof typologies are more vulnerable to ash falls due to a lack of memory of past events by communities, planners and builders.

In some cases, the concentration of factors increasing physical vulnerability to a given hazard is due to the fact that the same area may be prone to more than one hazard. Thus, it may happen that buildings are sized for dealing with the more frequent hazard factors and perceived as a threat whereas they are highly vulnerable to others. As highlighted in the deliverable 2.2, for example, the background of the relevant damage due to the Great Hanshin-Awaji Earthquake (Kobe Earthquake) occurred on the 17th of January 1995 was largely lying down in structural deficits of old buildings: as "Japan suffers from big typhoons and heavy winds, the basic structural approach in building construction has been the combination of heavy roof and weaker walls (shear walls). However, this structural aspect of traditional Japanese houses carries great inherent vulnerability against earthquakes where buildings are likely to collapse as pancake form" (del 2.2).

Finally, it is worth noting that in relation to some types of hazards, such as landslides or lava flows, the main factor affecting vulnerability is the location (in terms of distance and position with respect to the hazard source) of buildings. Moreover, recent reinforced concrete buildings with secondary walls in light concrete blocks are, in face of some hazards, like mudflows, more vulnerable, with relevant consequences in terms of loss of lives, compared with ancient masonry buildings: the walls of the first type of buildings can easily collapse and the mudflow can flood the building and bury people that are inside the building.

Thus, according to the above considerations, spatial distribution of physical vulnerability in built environment depend on numerous and interrelated factors, such as building age and typologies, type of urban patterns (historical/new cities; compact or sprawled settlement, etc.) type of geographical context (developed/developing countries). The relevance of these factors will vary according to the type of hazard and to the geographical scale chosen for vulnerability analyses.

Different patterns of spatial distribution can be identified also in relation to the physical vulnerability of rural/natural environment to hazards which have agricultural or natural areas as main targets. In these cases, as shown also by the case studied presented in the previous paragraph, the main factors affecting spatial distribution of physical vulnerability can be identified in the type of land use, type of vegetation, type of soils, site morphology. Such factors cannot be modelled "a-priori" and require in-depth analyses in the hazard prone areas.

The table 3 shows the main factors affecting spatial distribution of physical vulnerability according to different types of hazards and consequently to their prevailing targets. For example, as concerns hazards which may directly hit population, such as toxic releases or cold or warm waves, the main factors affecting the spatial distribution of physical vulnerability are related to the features of population (age, health, etc.) and to their location in space. In other words, a relevant factor to define the spatial distribution of physical vulnerability in such a case, can be identified in the distribution of outdoor activities attracting large amount of people (open-air markets, exhibitions or competitions in open spaces).

In conclusion, the models core-periphery presented in the previous paragraph and its main variations largely spread in literature may be relevant to explain and model physical vulnerability in built environment, even though spatial patterns of vulnerability distribution will vary according to different settlement patterns in the different geographical contexts.

Social Vulnerability

Even though there is no universally accepted definition of social vulnerability, within the Ensure Project it has been defined as the susceptibility to, or the potential for, loss of human and social capital and the capacity to recover from these losses (Del. 2.1). According to this definition, social vulnerability may depend on numerous factors, such as the inherent features of exposed people (age, health, income levels, educational levels etc.), or the degree of social cohesion, the level of local knowledge, Furthermore, it may depend also on the poverty which, although defined by some authors as a key-component of the economic vulnerability, represents one of the main causes of the social one too.

Thus, it has to be noticed that whereas factors affecting physical vulnerability are largely hazard dependent, so that they vary according to the type of hazard at stake, factors affecting social vulnerability are significantly hazard independent, so that spatial distribution of such a vulnerability facet is less sensitive to the hazard types and changes. Nevertheless, some aspects, such as preparedness, should vary according to the hazard: for example a community should be highly prepared to very frequent hazards, completely un-prepared to other less frequent but more severe hazards. Some of the features affecting the spatial distribution of social vulnerability may characterize "integral members of community, such as the very young or the very old, or distinctly separate groups identified by settlements, ethnicity, or religious differences" (Lewis, 1999).

It is clear that spatial distribution of the factors related to the characteristics of integral members of communities (old people, young people,…) is difficult to be modelled "a-priori", but it can be easily defined through census data. Hence, spatial distribution of some aspects of social vulnerability can be easily investigated and mapped, grounding on data that are generally available and easily comparable (fig. 26).

Moreover, it is worth noting that some relationships between the spatial distribution of social and physical vulnerability can be traced, in that the most vulnerable urban areas are in general, from a physical point of view, that ones in which poorest population or marginal groups are concentrated (historical areas; illegal or informal settlements, etc.).

Nevertheless, the spatial distribution of social vulnerability may largely vary over time due to endogenous factors (e.g. people ageing) and/or economic or social changes occurring both at wider areas (immigration, economic changes inducing emigration flows, etc.) and at local scale (development processes, renovation of historical areas, regeneration of derelict lands).

It is very typical for example that the renewing of historical core areas induces gentrification phenomena with relevant socio-cultural changes in the renewed urban area. As a consequence, the lower-income previous residents are sent off the area and the average income of population generally increases.

Hence, due to the relevant sensitivity of the numerous factors which may affect the spatial distribution of social vulnerability to time, such factors have to be analysed over wide temporal spans, in order to provide an interpretation of their trends beyond the picture of their features in a given time instant (fig. 27). Nevertheless, as highlighted by Buckle (2000), the factors affecting social vulnerability are numerous and cannot be reduced to the above mentioned features. Social vulnerability may depend on numerous other factors, such as the perception of risk – which can be very low in force of a high reliance on institution and/or in implemented mitigation measures – or the level of preparedness, which can be low due to institutional weaknesses (lack of engagement of institutions).

Hazard	Targets	Factors affecting spatial distribution	Notes
Earthquakes		Features of urban fabrics Building features	Built up areas represent the main targets (even though not the only ones) of these type of hazards; thus, vulnerability analyses have to be mainly focused on the features of built up environment at different scales.
Landslide		Features of urban fabrics Building features	
Debris flow		Features of urban fabrics Building features	
Floods		Features of urban fabrics Building features	Both built up areas and natural/rural areas represent likely targets of these hazards; thus, vulnerability analyses have to be focused both on the features of rural/natural environment and on the features of buildings and urban fabrics.
Volcanic ash falls		Building features	
Industrial accidents (explosions, toxic releases)		Population features, Indoor/outdoor activities, Building features, Features of vegetation/cultivation	Human beings, buildings and rural or natural ecosystems are the main targets (even though not the only ones) of these type of hazards; thus, vulnerability analyses have to be focused on factors affecting people or building exposure and on the features of rural/natural environment
Cold or warm waves		Population features, Indoor/outdoor activities, Features of vegetation/cultivation	
Fires		Features of vegetation/cultivation, site morphology, Soils features	Rural and natural areas represent the main targets (even though not the only ones) of these type of hazards; thus, vulnerability analyses have to be mainly focused on the features of rural/natural environment
Drougths		Features of vegetation/cultivation, site morphology, Soils features	

Built up areas	
Natural/rural areas	
Both built up and natural/rural areas	

Table 3: hazards, targets and factors affecting spatial distribution of relative physical vulnerabilities

Obviously, the spatial distribution of these factors cannot be defined grounding on statistical and generally available data, but it requires specific surveys; moreover, these factors might be so spread within a given community to make difficult a spatial representation of their distribution at local scale, whereas such a representation might be more relevant at wider geographical scales (differences among communities emerging only at regional or even national scale) in that they largely depend on institutional behaviours.

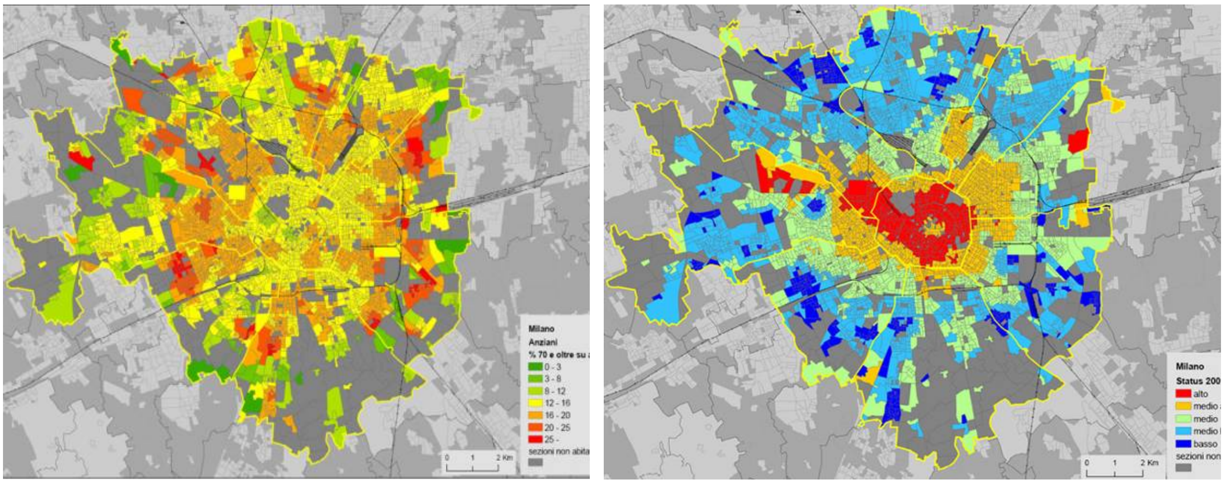


Figure 26: Spatial distribution of some features of social vulnerability. On the right: distribution of aged population; on the left: variation 1991-2001 in the income level distribution in the city of Milan. (Laboratorio GIS di Cartografia Sociale Milano Bicocca, Elaboration on Istat data)

The latter considerations clearly highlight the close relationships which may arise among different facets of vulnerability. In detail, institutional vulnerability can significantly affect social or even physical vulnerability. Such relationships highlight the difficulty to model or to map spatial distribution of the different facets of vulnerability without taking into account that some of them may have relevant effects at local scale, but they can be analysed only at wider scales (municipal, regional, national).

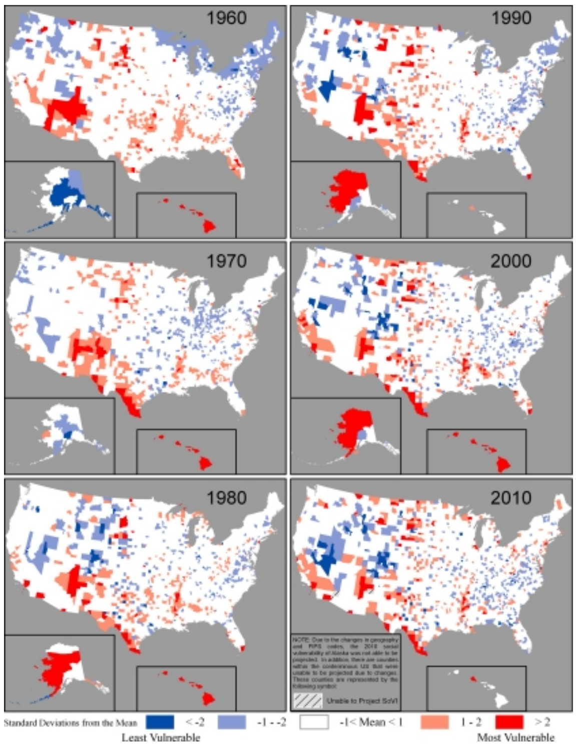


Figure 27: Social vulnerability in USA 1960–2010 (Cutter S.L., Finch C., 2008)

Such crossing inter-linkages have been in-depth analysed in the Katrina case study, providing a clear example of the different scales at which different vulnerabilities have to be analysed and how they interact among them.

Systemic/functional and economic vulnerability

The concept of systemic vulnerability, as underlined in the previous deliverables (see 2.1, 2.2), can be applied to different systems (social, economic, territorial). Each system is characterized by its own elements and by the relationships among them and interacts with other systems.

Hence, systemic vulnerability has to be referred to the capacity of a given system to continue functioning despite some level of physical damage to an element of the system itself (internal systemic vulnerability) or to elements belonging to other related systems (external systemic vulnerability). It is worth noting that, whereas physical vulnerability is generally characterized as a vulnerability to stress (better to the hazard factor), the systemic one (sometimes also the economic and the social ones) is generally characterized as a vulnerability to loss (in the same or in other systems), arising as a consequence of immediate damage due to an hazard factor, although some hazards might directly produce, even at short time from the event, systemic damage as in the case of volcanic eruptions with reference to flight connections and telecommunications.

As systemic vulnerability can be interpreted as the ability of a given system to continue functioning despite some physical damage within the same one or in other related systems or even as a propensity of systems to not fully accomplish its functions due to relevant, but also minor, damage to one or more elements within the systems itself or belonging to other systems, it can be even defined as a "functional vulnerability".

According to such a definition, systemic/functional vulnerability depends on the complex web of relationships among elements of the same system and among elements belonging to different systems. Thus, to better understand the main factors underlying its distribution in space, we have to focus on two main elements:

- the type of existing relationships (including the physical ones) among the elements of a given system or among different systems;
- the elements which induce such relationships (type, relevance and distribution of relevant activities) or, in other words, such physical or functional dependencies.

Like physical or social vulnerabilities, also systemic vulnerability, and consequently the factors affecting its distribution in space, can be investigated at different scales; hence, according to the geographical scale and to the exposed systems we are focusing on, the factors affecting the spatial distribution of such vulnerability will largely vary.

Focusing on the systemic vulnerability of an individual urban systems or of a network infrastructure, we can consider the relationships within that system, affecting the spatial distribution of the systemic vulnerability.

The main factors affecting the spatial distribution of systemic vulnerability of urban systems may be identified in the location and distribution of activities on which the system relies upon for its vital functioning (in ordinary conditions as well as in emergency phase). If relevant urban activities, indeed, mainly the strategic emergency facilities, are highly concentrated, even though they do not suffer relevant physical damage, they can suffer losses of functioning due to the growth in services demand which generally follows the occurrence of an hazardous event.

Hence, whereas physical vulnerability largely depend on spatial patterns of urban settlement or tissues (or in other words on the spatial organization of urban settlement), systemic/functional vulnerability largely depends on functional patterns or, in other words, on the localization and distribution of activities within the system.

Functional patterns of urban settlements, such as the physical ones, largely vary not only over time but according to different geographical contexts too.

In European cities, even though over the last decades there has been a tendency to the spreading of relevant urban activities (industrial activities, mega-stores) from the urban core toward periphery, strategic activities (mainly directional headquarters) are, still now, generally located in core areas: hence, despite a polycentric functional organization of the city, the decision centres and many strategic emergency activities are highly concentrated.

Shifting the attention from the individual urban centre to a wider territorial system, it is possible to refer our analysis to the urban networks, trying to develop a wider discourse on the functional vulnerability of the network systems, which can be referred both to networks of urban centres and to network infrastructures (road network, railway network, etc.).

Urban centres networks are constituted by cities linked through physical or functional (or even economic even though such an aspect will be further detailed in the following pages) relationships. These networks can be analysed at different scales, from global to municipal, in that even an individual city can be analysed as a network constituted by different elements linked through physical and functional relationships. According to such a definition, we can distinguish at least three main types of networks: hierarchical networks; multi-centred networks; equipollent networks.

In the first type of network, all the relevant activities are concentrated in one node or vertex of the network; all the others (which are all at lower hierarchical levels) are linked to the former and depend on it for their functioning. On the contrary, in polycentric networks, relevant activities are subdivided among different nodes (vertices), even though a hierarchical organization among them still persist (fig. 28). The third case is the only one in which all the nodes are placed at the same hierarchical level; in this case all the relevant activities are distributed in each node and there are no relevant dependencies among them.

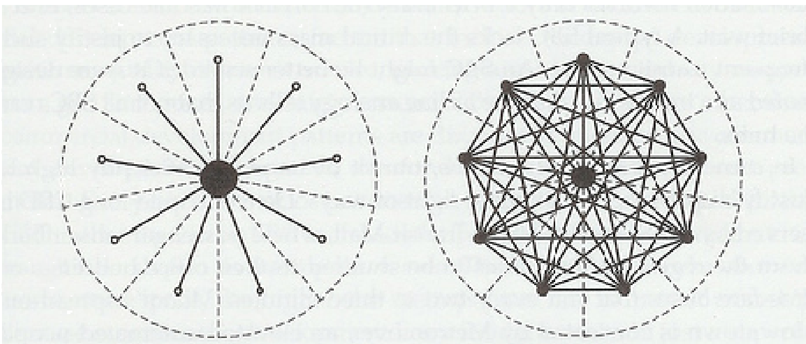


Figure 28: Hierarchical and multi-centred networks (http://www.flickr.com/photos/rllayman/490043232/)

Obviously, the first two patterns are the most common ones, even though the tendency to shift from monocentric territorial pattern toward multi-centred ones is more and more spread. Furthermore, it is worth noting that, in relation to different geographical scales, different patterns generally coexist inducing different relationships (physical, functional, economic) among the different nodes (e.g. monocentric patterns at regional scale, polycentric at national one).

Therefore, systemic vulnerability is generally higher in monocentric patterns characterized by high concentrations of relevant urban activities in one node and relevant interdependencies among principal and secondary nodes whereas multi-centred or equipollent network patterns characterized by a well-balanced distribution of urban activities may present lower levels of systemic vulnerabilities.

For example, after the 1980 Irpinia earthquake, the monocentric functional pattern of settlements in the hit area and the functional weaknesses which already characterized in ordinary conditions the urban settlements, determined a relevant growth in the service demand of services which largely affected the main cities (Naples above all). In this case, hospital facilities, especially in the city of Naples, although not damaged by the earthquake, suffered losses of functioning related to the peak of demand for activities and services arising from the city itself and from all the surrounding towns.

In specific territorial contexts, like islands or highly isolated urban areas, this picture can be also complicated by the presence of functional dependencies not adequately supported by the physical connections.

Summing up, the spatial distribution of systemic vulnerability largely vary according to the features of the complex web of interrelationships among different nodes and, starting from the node/nodes exposed and vulnerable to a given hazardous events, it should be investigated through the different geographical scales at which such relationships occur, from the local to the global scale.

It seems quite evident that, whereas physical or social vulnerability are characterized by different patterns of spatial distribution, although always developed within the hazard prone area, the spatial distribution of systemic vulnerability, starting from the area potentially hit by a hazardous event, can widen, through physical or functional links, up to areas very far from the one directly affected by the hazard. Thus, it has to be investigated, starting from the hit area, at different geographical scales.

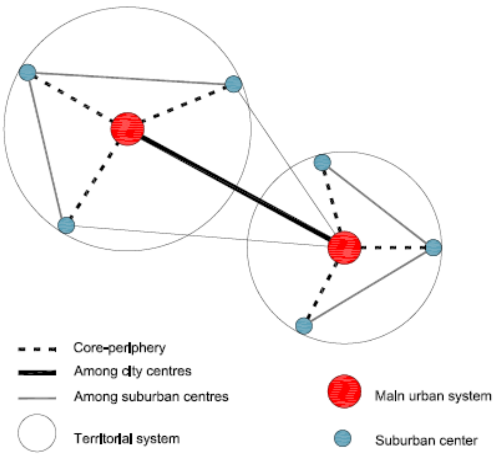


Figure 29: Types of functional relationships among urban systems

Similar considerations can be made for what concerns systemic vulnerability of network infrastructures (road networks, water or gas supply networks, etc), even though in this case we directly refer to a physical network whereas in that cases we have mainly focused on relationships having a physical or functional character or a twofold one (functional relationships supported by physical networks).

The distribution of systemic vulnerability in relation to network infrastructures largely depends on spatial, topological and functional features of the networks themselves: according to such features, some links or nodes of a given network can be more or less critical to the network as a whole, in that the failure of one element (link or node) may induce a loss of functioning of the whole network or of wider parts of it. For example, damage to railway network hub characterized by a crucial role within the whole system (rail network) may cause relevant consequences at wider scales, even at national scale.

Hence, systemic vulnerability of networks is generally dependent on the spatial organization of the network itself in that some models, due to the scarce dependencies among the elements of the network itself, are less vulnerable (from a functional point of view) in comparison to others characterized by relevant dependencies among elements.

As stated for physical vulnerability of urban fabrics and mainly for network systems, the morphology of network is relevant to understand the different levels of systemic (mainly to local and regional scale) and functional (at local or sub-local scale) vulnerability (fig.30). It is worth noting that in urban environment, generally, the morphology of the networks, such as roads, is strictly related to that one of the urban fabrics.

Moreover, shifting from an individual network infrastructure to the whole system of network infrastructures, it has to be taken into account that a given network can be vulnerable to losses or failures occurring in other networks. Thus, as in case of physical or functional dependencies among urban centres above mentioned, even in this case systemic vulnerability depends on the interdependencies among the different networks.

These relationships are very difficult to analyse and they can be revealed only in analyses of past disasters. Systemic interdependencies are explored, frequently, through conceptual maps or scenario techniques.

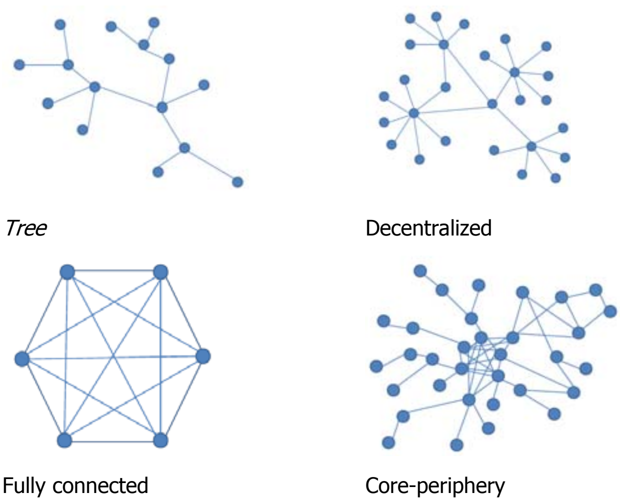


Figure 30: Morphological typologies of networks

Depends on	Water Supply	Gas Supply	Sewerage	Storm Water	Mains Electricity	Standby Electricity	VHF Radio	Telephones	Roads	Rail	Air transport	Fuel Supply	Fire Fighting	Air-conditioning	Total Importance
Water Supply		*	1	*	*	*	*	*	*	*	*	*	3	2	6
Gas Supply	*		*	*	*	*	*	*	*	*	*	*	*	*	0
Sewerage	*	*		*	*	*	*	*	*	*	*	*	*	*	0
Storm Water	*	*	*		*	*	*	*	*	*	*	*	*	*	0
Mains Electricity	2	1	2	2		*	2	3	*	1	3	2	*	3	21
Standby Electricity	3	1	3	3	*		1	3	*	*	3	2	*	2	21
VHF Radio	3	3	3	2	3	*		2	2	2	3	*	3	*	26
Telephones	2	1	1	*	1	1	2		*	1	1	1	2	*	13
Roads	2	2	2	2	3	2	1	2		2	3	2	3	1	27
Rail	*	*	*	*	*	*	*	*	*		*	*	*	*	0
Air Transport	*	*	*	*	*	*	*	*	*	*		*	*	*	0
Fuel Supply	3	1	1	1	*	3	1	2	3	2	3		3	*	23
Fire Fighting	*	*	*	*	*	*	*	*	*	*	2	1		*	3
Air-conditioning	*	*	*	*	2	2	*	3	*	*	2	*	*		9
Equipment	3	3	3	2	3	3	3	3	3	3	3	2	3	3	40
Total Dependence	18	12	16	12	12	11	10	18	8	11	23	10	17	11	
Priority Factor	24	12	16	12	33	32	36	31	35	11	23	33	20	20	

Note: 3 = High Dependence
2 = Moderate Dependence
1 = Low Dependence
* = No Dependence

Priority Factor = Importance + Dependence

Figure 31: Interdependencies among lifelines (Paton and Johnston, 2006).

Such interdependencies have been largely explored and some attempts to define the main interdependencies among different networks and their relevance are available (fig. 31). These studies are a relevant starting point to investigate the web of interdependencies which make networks, although not directly hit by a hazardous events, vulnerable to such event due to their direct or indirect links to other hit network/s.

The described interdependencies (physical or functional) represent a key mechanism to transfer or transform vulnerabilities through space and will be further investigated in the next chapter.

It has to be even noticed that potential breakdowns in some of the network infrastructures induce relevant impacts not only on other related networks but on other systems, which relay upon them for their functioning (e.g. breakdowns in telecommunication network may significantly affect economic activities or obstructions along the road network or breakdowns in electricity one may severely affect the functioning of strategic equipments such as hospitals).

For what concerns economic vulnerability, it can be interpreted as the susceptibility to or the potential for: the loss of economic assets and productivity; the loss of the livelihoods these support and the wealth and economic independence they create; the financial deprivation and debt dependence; and the capacity for recovering from these losses.

According to the definition provided within the Ensure Project (del 2.1), economic vulnerability has to be considered at two basic levels:

- level of the individual, household or social group/community
- level of the economy (e.g. local, sub-regional, regional, national, global).

Obviously, factors affecting the first considered level are more related to the income levels of exposed population, or to the value of exposed properties or to the amount of savings or investments. Some of these factors have been already examined in relation to social vulnerability, since they can be considered a relevant factor affecting the capacity of exposed population to resist and react to a hazardous event. Other factors, can be related for example, to the tenure of insurance or the access to financial compensation in case of hazardous events.

Therefore, spatial distribution of the first level of economic vulnerability can be analyzed and mapped in relation to some features of exposed population, grounding, as in case of social vulnerability, on statistical data. For example, some information on income levels of the population can be indirectly inferred by census data, whereas other aspects, such as the ones related to the possession of insurance, require specific surveys.

As concerns the second level of economic vulnerability, according to Van der Veen and Logtmeijer (2005), it is possible to "refer to the idea of an economy as a network of linkages of interrelated industries".

Grounding on such an idea, the main factors affecting the distribution in space of the second level economic vulnerability can be identified in:
- the degree of "centrality" of an activity in a given economic system (which corresponds to the role of a given node in a given network);
- the capacity of a business activity to be transferred in safe areas;
- the dependency of business from local customers;
- the interdependencies among different economic activities or, even, the degree to which an activity requires other activities to function normally.

Hence, the analysis of the spatial distribution of this facet of vulnerability do not significantly differ from the ones mentioned for systemic vulnerability, even though in this case, the nodes of the networks are represented by economic or productive activities and the links may be the different flows (of goods, people, information…) among them.

Thus, to analyze spatial distribution of economic vulnerability, the networks of interdependencies linking the economic activities located in the hazard prone area with others, which may be located even in areas very far from the hit one, have to be investigate. As largely highlighted in the Katrina case study, indeed, Obviously, the geographical scale of analysis will vary according to the centrality of the considered activity. An industry may be central to a local, regional, national or even global economic systems: the loss of an economic activity may reverberate at different geographical scales: from local scale to national or even global one. It is clear that the geographical scale that a given activity is central for, is determinant even to understand the geographical scale at which to investigate interdependencies.

Institutional vulnerability

Institutional vulnerability is often interpreted as part of the wider concept of social vulnerability, being institutions the key-organizations within a given community addressed to:

- drive general growth and development processes;
- prevent and/or mitigate hazard and/or risks;
- cope with the hazardous event and its impacts in the immediate post-event phases.

Nevertheless, in the Ensure Project, institutional vulnerability has been distinguished by the social one and identified as 'the exposure and vulnerability of individuals, communities or organizations to the uncontrollable adverse consequences of another organisation's critical shortcomings' (see deliverable 2.1).

The distinction between the two concepts is very relevant due to the fact that, according to their key mentioned key-roles, potential shortcomings or failures of institutions may induce relevant consequences, significantly affecting physical, social, economic and systemic vulnerabilities.

Several examples of the relevant interrelationships between institutional vulnerability have been provided in the case studies, mainly in that one of Katrina, in which "serious institutional vulnerabilities (i.e. failures) are officially recognised to have occurred at all levels i.e. from the federal scale right down to the local, city government scale (US Congress, 2006)".

Hence, according to the provided definition of institutional vulnerability, its spatial distribution depends on several factors related both to the inherent features of each institution in charge of relevant choices related to an exposed community and, mainly, to the interrelationships among them, at the same or at different geographical scales.

Among these factors, it is worth mentioning for example:

- the spread of responsibilities for disaster preparedness and emergency response across different institutions at different scales;
- the lack of coordination among institutions in charge of land use and development plans and institution in charge of risk prevention and mitigation;
- the general complexity of organizational and institutional arrangements and the difficulty to shared information among different institutions;
- the lack of control on building practices or development processes in order to avoid the gap between rules (building codes, land use or development plans) and practices.

The analysis and the spatial representation of such factors is not an easy task, since these weaknesses generally reveal themselves after a catastrophic event. Moreover, the main weaknesses of individual institutions and of their interrelationships largely depend on the different national and regional administrative structures; thus, they require in-depth and specific surveys.

3.4 Spatial distribution of vulnerabilities: final remarks

This chapter has been mainly addressed at identifying the main factors affecting the spatial distribution of different facets of vulnerability and defining to what extent the distribution of the different facets of vulnerability change with respect to the potential core and periphery of disastrous events.

In detail, due to the close relationships between different types of vulnerabilities and different types of damage, the main factors which determine vulnerabilities and, mainly, their spatial distribution, have been identified grounding both on the disaster models developed since the Fifties and on the several case studies provided, which show damage and vulnerabilities distribution in relation to different types of hazards.

The knowledge of the factors affecting spatial distribution of the different facets of vulnerability and the possibility to set up deductive model enabling us to define "a priori" the distribution in space of vulnerabilities can be very useful for establishing appropriate reference scales for vulnerability assessment. The choice of appropriate scales depends, indeed, both on the aims of the assessment and on the features of the investigated phenomena.

Nevertheless, according to the main findings arising from the work carried out in the task 3.2 and explained in detail in previous paragraphs, deductive spatial models of vulnerability can be developed only with respect to some facets of vulnerability.

As mentioned in the paragraph 3.1, deductive models are indeed based on experimental observations aimed at defining the model assumptions, at identifying generally rules and laws of spatial distribution; in other terms, deductive models require a specification "a priori" of the spatial distribution of the factors determining vulnerability.

Hence, as already stated in the previous paragraph, these types of models can be defined only with respect to some facets of vulnerability, namely with respect to physical vulnerability to some types of hazards and, in some cases, for systemic or economic vulnerabilities.

In detail, deductive models of spatial distribution of physical vulnerability in face of some types of hazards (e.g. earthquakes) can be developed, although they require a detailed classification of spatial patterns of settlements (in the previous paragraph only some examples have been provided) and they cannot be reduced to a traditional core-periphery model.

Referring to the systemic and economic vulnerabilities, in-depth investigations on past events are still required in order to identify general rules and laws useful for defining the vulnerability level linked to the different types of networks.

As other facets of vulnerability are concerned, deductive models seem not to be appropriate. In case of social vulnerability or even in case of some aspects related to the economic vulnerability, only inductive models should be used to analyze and map spatial distribution of vulnerability.

Furthermore, it is worth noting that whereas the distribution in space of some vulnerability facets (physical, social) can be analyzed and represented through deductive or inductive models at the scale of the hazard, or in other words focusing only on the hazard prone area, other facets (systemic, economic, institutional) have to be analyzed and represented at different scales, which can be defined in turn according to the interdependencies among elements and systems placed in the hit area and elements and systems placed in other areas, even far from the hit one.

Summing up, according to the main question that the chapter tried to answer, that is how the distribution of the different facets of vulnerability change with respect to the potential core and periphery of disastrous events and how such a distribution can be modeled, some general statements can be provided:

- the narrower the space focus, the greater the likelihood that relevant aspects of vulnerability will be underestimated;
- vulnerability analysis strictly related to the area directly affected by the hazard (the core) will narrow the investigation field mainly to physical vulnerability;
- according to different spatial and functional patterns of settlements, the distribution of physical and functional vulnerability largely vary;
- the model core-periphery has to be reviewed with respect to facets of vulnerability different from the physical one, taking into account that periphery cannot be confined to the areas immediately surrounding the affected one and is not necessarily contiguous to the core area; it can be a very wide area, depending on the role of the affected area in a wider geographical context and on the interdependencies among vulnerable elements and systems;

- the distribution of the different facets of vulnerability can be represented by using different spatial models (deductive and inductive ones) and such models may vary according to different geographical, social, economic contexts.

4 Transference of vulnerabilities across space

The main objective of this chapter is to identify, on the basis of case studies, the main processes which may induce, determine or contribute the transference of vulnerability through space. Up to now, such processes have been mainly investigated in relation to time factors which clearly prevailing, even though they largely affect spatial distribution of vulnerabilities.

For example, Etkin (1999) has clearly shown how the implementation of mitigation measures addressed to reduce the overall risk in relation to the most common or likely hazardous events, may induce an increase of risk and vulnerability at long term in relation to events which are "beyond" the expected. This process was defined by Etkin as "risk transference", even though clearly characterized in that case in relation to the "time" factor.

Nevertheless, the processes underlying the transference of vulnerability over time may have even relevant relapses, by affecting and changing the distribution of vulnerabilities across space. Therefore, in this chapter, we will analyze different examples of vulnerability "transference", focusing on their spatial consequences.

Transference of vulnerabilities from one territory to another or from one type to another may depend on numerous factors. For example, the effects of a given hazard can be transferred from an area to another through exposed vulnerable elements (see, for example, the Baia Mare disaster or the more recent petroleum release in the Lambro river in Italy). Moreover, a local event may affect elements which have relevant interdependencies with other elements or systems: therefore, through such elements, a local event may reverberate on areas placed far from the core area of the disaster.

Furthermore, actions undertaken by different "agents" or actors before the event or during the emergency phase can contribute to propagate, transfer or transform vulnerabilities. For example, in the case of Katrina hurricane, local authorities decided to remove the contaminated waters from the flooded area, by pumping them into the Lake Pontchartrain. The polluted water had a great impact on the lake's ecosystem, which was a relevant fishing site and a tourist attraction.

Finally, specific attention will be devoted in this chapter to the role of resilience defined in the WP2 as one of the main drivers for vulnerability transfer, transformation of vulnerability in the geographical, social, economic, political space.

Summing up, in this chapter the "drivers" for the transference of vulnerabilities in space will be analyzed by using two different lenses:

- the first one refers to the vulnerability facets and to their interrelationships; by using this lens the analysis will aim at defining how, or better through which processes, each facet may transfer itself in space, following the complex chains of hazards and impacts on vulnerable targets (elements or systems) which may act, in turn, as a further hazard sources or, due to their relationships with other elements or systems, may involve other targets not directly hit by the hazard.
- the second one refers to the different agents and to the interrelationships among them which induce, determine or change vulnerabilities (see del. 3.1); by using this lens the analysis will be more focused on the role played by different actors (households, communities, institutions....) in the transference of vulnerabilities through space.

4.1 Propagation, transference and transformation

In order to investigate the main processes driving the transference of vulnerabilities in space, there is the need for focusing not only on the concept of transference itself and on its meaning according to a spatial perspective, but even on other two concepts largely used to describe transference phenomena: propagation and transformation.

Starting from the term propagation, it is possible to state that it is generally referred to the spreading of a given phenomenon from an element or an area to a contiguous/adjacent element or area "through contact" or from an element or an area to another element or another area, although not contiguous, through a specific mean (e.g. air, water).

In the field of risk analysis, the term can be referred both to the spreading of the hazard source or of vulnerabilities themselves: in both cases propagation phenomena, which can develop very quickly or in a long time span, are very relevant to better understand how distribution of vulnerabilities change in space apart from in time.

It is worth noting that there are several examples of past disasters clearly highlighting propagation phenomena related to hazard factors: the latter may involve new exposed and vulnerable elements and systems, spreading the overall damage over areas significantly wider than the initially affected one.

Hazards can propagate through different elements or even thanks to human interventions. Thus, such phenomena may involve exposed elements and/or systems, let arising new vulnerabilities and increasing the overall damage: in this sense, hazard propagation represents one of the mechanisms determining an increase of vulnerabilities and it is very relevant to vulnerability analysis: the identification of potential elements of factors enabling the spread of the hazard factors or of their consequences may allow us to recognize new or different exposed elements and investigate their vulnerability.

Nevertheless, the term propagation can be referred to vulnerabilities too: for example, the increase of social or economic well-being within a community may affect traditional building practices, driving toward an innovation in building typologies, materials and construction techniques. Such a process may induce unexpected consequences: instead of reducing existing vulnerability, it can induce a "propagation" of vulnerability according to the spreading of new building practices which are not consistent with the hazard at stake and scarcely respectful of local knowledge resulting, in such a way, more vulnerable.

The term transference is generally referred to the shift of something from one place to another, one period to another, one actor to another. With reference to the vulnerability and focusing on spatial aspects, it can be referred to processes which result in a displacement of vulnerabilities or in a shift from one "agent" to another.

The concept of transference clearly differs from the propagation one when we focus on processes characterized by a decrease of vulnerability in one area or of some "agents" and, in the meanwhile, an increase of vulnerability in other areas or of other "agents".

Nevertheless, in some cases, transference phenomena may be referred to a shift of vulnerabilities from one area to another, from one geographical scale to another. Even in this sense, the concept of transference differ from the one of propagation: the latter is indeed always referred to a widening effect in space affecting areas or elements characterized by a spatial continuity (in that elements or areas are contiguous or linked through a mean), whereas transference can be referred to reverberating effects involving areas not contiguous or spatially linked one to each other.

Different processes may induce the transference of vulnerabilities: the reconstruction activities after a hazardous event; the implementation of preventative measures aimed at reducing vulnerabilities or even renewing processes starting independently from the occurrence of a hazard.

Finally, the term transformation can be referred, generally speaking, to a "qualitative change", from one form to another which is qualitatively different from the previous one. In relation to the vulnerability it can be referred to a change from one type of vulnerability to another. In detail, the term transformation can be referred to a change from a vulnerability to a given hazard toward a vulnerability to another one (generally in relation to the physical vulnerability) or can be applied to describe the change from one facet of vulnerability to another: for example, a social vulnerability which may result in a physical one or an institutional one which may transform in a social or even in physical one.

Obviously the three terms do not exclude each other, they can occur contemporarily: for example, in case of transference of vulnerability from one place to another or from one actor to another, a transformation from one type of vulnerability to another may occur too.

4.2 Propagation, transference and transformation of vulnerabilities: case studies

This paragraph includes several case studies highlighting factors or processes inducing vulnerability transference: some of them mainly focus on propagation, others on transference and transformation of vulnerabilities to different hazards. Due to the fact that the mechanisms which the three terms refer to, although different one from each other, may occur contemporarily, in some cases the different aspects of vulnerability transference have been not clearly distinguished. Moreover, some case studies provide a general description of factors underlining transference and/or transformation of vulnerabilities, even though the spatial implications of such phenomena are not punctually highlighted.

4.2.1 The Baia Mare na-tech event

The na-tech event occurred at Baia Mare is a clear example of hazard propagation, through a specific mean: such a propagation extends the effects of the hazard to a wider area, involving vulnerable elements located in areas far from the hazard source. In this case, the toxic release - namely the cyanide used by the Aurul company to remove precious metals from the tailing - has been carried, through the river waters, from the accident source placed in Romania, to other countries (Hungary and Yugoslavia). In such a way, the consequences of a localized event, in terms of both direct and indirect impacts, extended to a very wide area, spreading on natural environment, population, economic activities and organization of the emergency response (involving different national States, different organization and so on) of different countries too.
The description of the Baia Mare na-tech event has been already provided in deliverable 2.1 but it is worth focusing here on some details related both to hazard and vulnerabilities propagation.
For example, the concentration of toxic substances was supposed to significantly decrease along the path from Romania to Hungary in a short time, and, consequently, the impacts on environment and population should have been less relevant. Nevertheless, "ice on the rivers and low water levels in Hungary delayed the dilution of the cyanide, increasing the risk to municipal water supplies" (Unep/Ocha, 2000).

Figure 32: Propagation and impacts of Baia Mare event (UNEP/OCHA, 2000)

Hence, the drinking water of more than 2 million people in Hungary was poisoned and only the prompt action of the local authorities avoided serious damage to the water supply of the two largest cities along the Tisza river, Szolnok (120.000 inhabitants) and Szeged (206.000 inhabitants). Moreover, the flora and the fauna of the central Tisza river were seriously damaged. This case clearly highlights that propagation phenomena have to be analyzed contemporarily in relation to temporal and spatial factors: over time and according to the spatial features of the affected areas (in this case of the river waters), the hazard itself changes and, direct consequently, even the direct and indirect impacts on the exposed elements and systems change.

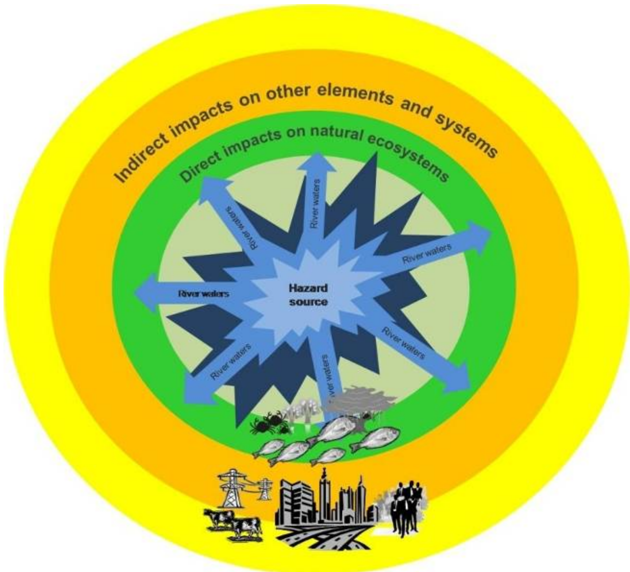


Figure 33: Hazard propagation as a factor affecting the "transference" of the direct and indirect impacts of the hazard across space.

4.2.2 Forest fires events (PIK)

The impacts of a forest fire event aren't by any means restrained in time and space. Forest fires can have significant impacts on local air quality, visibility and human health. In addition, emissions from forest fires can travel large distances, affecting air quality and human health far from the geographic location from the originating fires. Consequences of forest fires and enhancement of further vulnerabilities can be perceived in a wide spatial space that ranges from a few meters at the core of the hazard to trans-continental distances.

Regarding forest fires, propagation, transference and transformation of vulnerabilities depend on many aspects, for example intensity and duration of the hazard, institutional capacities, socio-economic background or landscape characteristics.

At some extent, humans are capable of interfering with these aspects contributing to a positive or a negative feedback of the vulnerabilities set in place by the occurrence of the hazard. On the other hand, there are factors that are beyond the control of mankind. Physical processes such as extreme weather events are essentially stochastic and cannot be yet be predicted.

At this point it is worth recalling the forest fire impact chain pushed forward in deliverable 2.2. In Figure 34 some of the main primary and secondary impacts that recur from and depend on the intensity and extension of a forest fire are synthesized.

Due to the multiple impact paths set in place during and after a forest fire event, it is not possible to observe in detail all of them. Therefore, for the purpose of this section, the main focus will be the propagation and transformation of vulnerabilities in space, concerning the impact path of forest fires where physical vulnerability leads to the emergence of social vulnerability, and what are the mechanisms influencing propagation and transference.

The analyzed case studies will deal with the aspects of propagation and transformation in a separate way. By this is meant that some case studies will focus on the propagation of vulnerabilities in space and the main aspect that contributes to the propagation while others will focus on the transformation of vulnerabilities, this is, how physical vulnerability gets transformed into social vulnerability in distinct spatial regions.

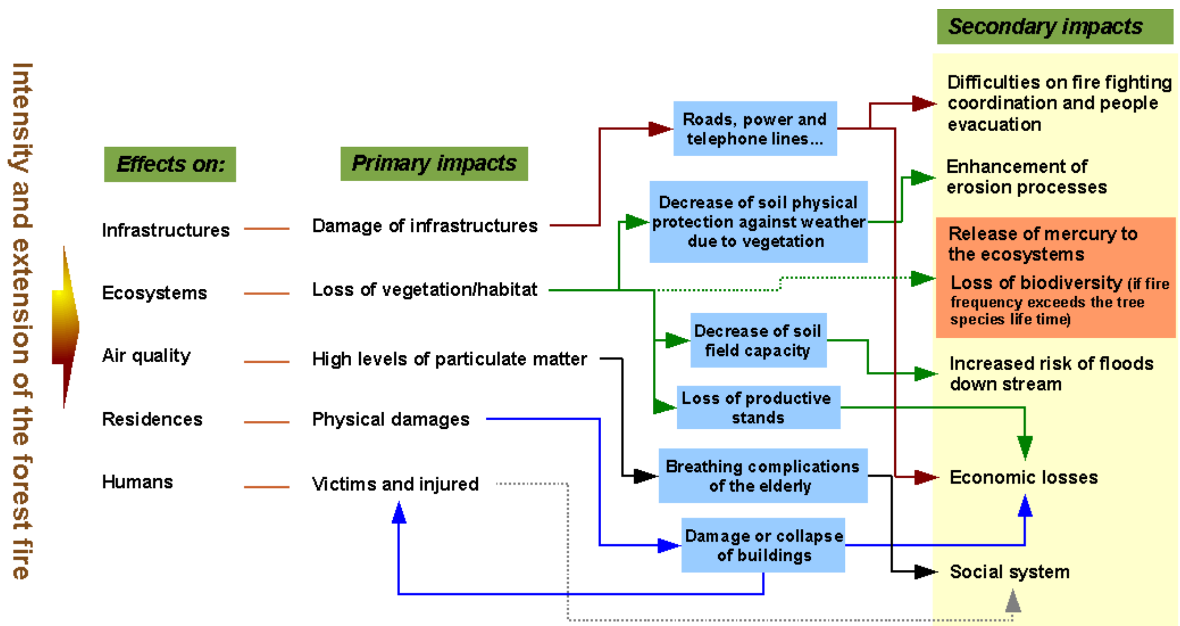


Figure 34: Impact chain of a forest fire event

Impact of the smoke aerosol from Russian forest fires on the atmospheric environment over Korea during May 2003

The broad spatial scale range of forest fire events could be clearly observed during the extensive fire activities that occurred in May 2003 across Siberia, Russia, particularly in the area between the Amur and Lena rivers east of Lake Baikal.

These forest fires released large amounts of particulates and gases into the atmosphere, resulting in adverse effects on regional air quality and radiation budget. On certain occasions, a smoke pollution plume from these forest fires was transported through Mongolia and eastern China, down to the Korean peninsula.

Since smoke plumes from the forest fires can travel horizontally over hundreds, or even thousands of kilometers, and reach the stratosphere under certain atmospheric circulation conditions (Fromm et al., 2000), their spatio-temporal distribution is highly variable. Smoke pollution plumes from the Russian forest fires were often transported to Northeast Asia, through Mongolia, eastern China and Korea.

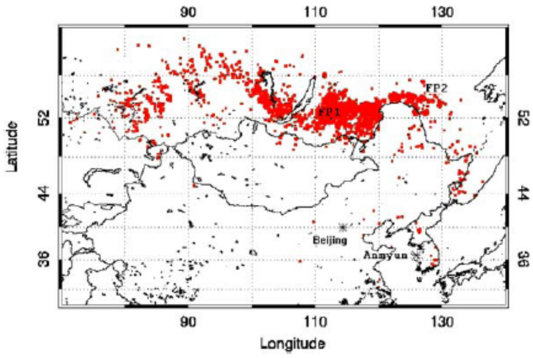


Figure 35: Fire positions from MODIS fire product (MOD14; 1km2 resolution) during the period 1–23 May 2003.

MODIS images of the forest fires burning in Russia were collected during the study period of 1–23 May 2003. Figure 35 shows active fires, marked with red dot. It shows that extensive fire activities occurred across the Siberian border of Russia between the Amur and Lena rivers (Lee et al., 2005). While smoke aerosol was emitted continuously from the Siberian forest fires, dispersion of the smoke plume depended on meteorological conditions. The evolution trajectory of the aerosol plume can be observed in Figure 36.

A continental high-pressure system generally lies in the middle of the Eurasian continent; the prevailing airflows in rim regions are generally northeasterly or westerly. Figure 36 shows that the smoke plume moved quickly in a southward direction, reaching North Korea on 8 May 2003. The trajectory results show that the air mass from forest fire areas near Lake Baikal moved southeasterly. Then it met a westerly air mass that picked up smoke while passing over Northeast Asia. Information on air-mass pathways can be used to investigate the effects of source contribution on the physical and optical characteristics of aerosol (Lee et al., 2005). For the smoke plume case on 20 May 2003, the trajectory lines show that the air masses reaching Seoul originated mainly from the Russian border areas and Northeast China and Korea.

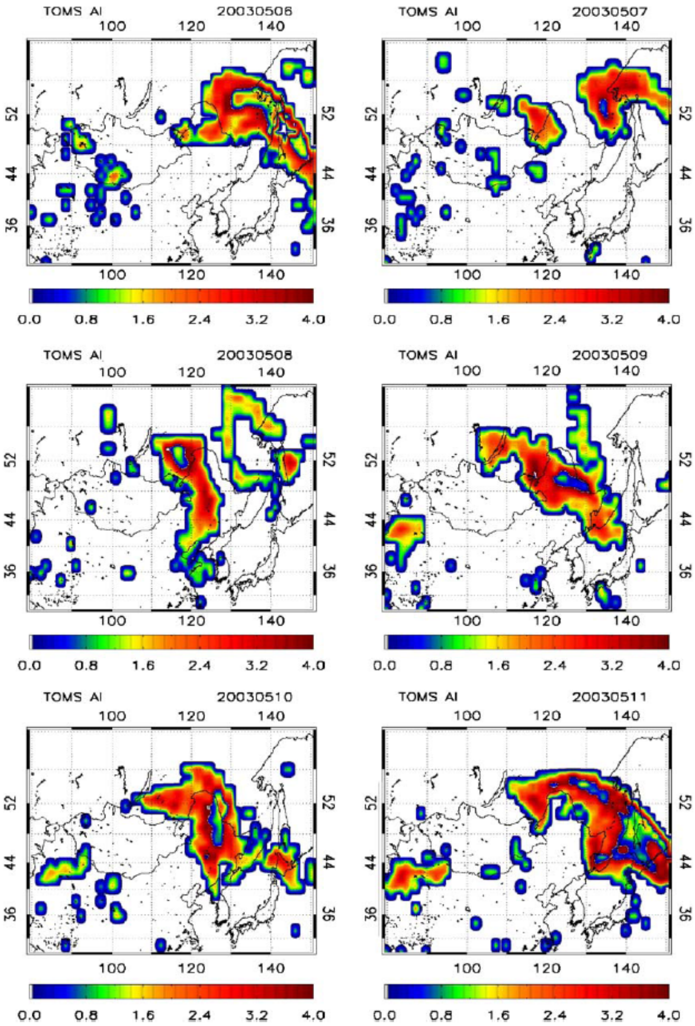


Figure 36: Aerosol index map for the period 6–11 May 2003

The propagation of the initial physical vulnerability caused by the occurrence of the forest fire is related to the dispersion of the aerosol plume originated from the forest fuel combustion. In addition the plume movement was controlled by movement of these air masses being dependent on synoptic weather conditions.

Impact of the forest fires in August 2007 on air quality of Athens using multi-sensor aerosol remote sensing data, meteorology and surface observations

From late August to early September 2007, Greece suffered the worst forest fires in the past 50 years. A total of 2700 square kilometers of forest, olive groves and farmland were destroyed by the fires, and 84 people, including firefighters, lost their lives. In addition to the direct fire damage, these devastating fires produced large quantities of gaseous air pollutants and particles (PM 10 and PM 2.5, airborne particles smaller than 10 micrometers and 2.5 micrometers in size, respectively) dispersed over the region. Athens, with a population of over four million inhabitants, was affected by both the Peloponnese and Evia fires. In addition to the deterioration of air quality, fire smoke has adverse health effects on exposed populations, such as increased respiratory diseases, asthma, bronchitis, and eye irritation (Naeher et al., 2007).

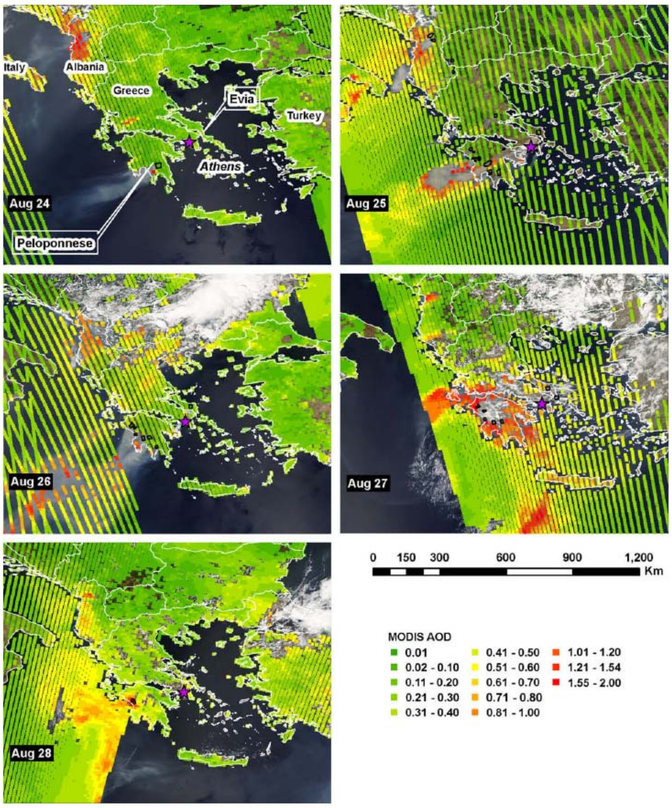


Figure 37: Images with fire spots (black polygons) over Greece from August 24 to 28, 2007. Athens is marked as the star.

MODIS imagery indicate that smoke plumes generated by the Evia fires passed directly over Athens on August 25 and 26, causing a substantial increase in background PM10 concentrations. MODIS AOD measurements suggest that the Peloponnese fires may have also affected the air quality in Athens on August 27, when the circling wind in southern Greece brought smoke plumes to Athens. Similar to the previous case study, weather related conditions determined the dispersion of the particulate matter from the area where the fire event took place, toward the city of Athens. Figure 38 shows average urban PM10 concentrations, regional background, and MODIS AOD values between August 23 and September 4. The time series of PM10 concentrations clearly indicate two pollution episodes defined by average urban PM10 concentrations above the European Union Ambient Air Quality Standard for daily PM10 (50 micrograms per cubic meter) from August 24 to 28, and August 30 to September 3. During each episode, urban average PM10 reached nearly 100 micrograms per cubic meter (Liu et al., 2009).

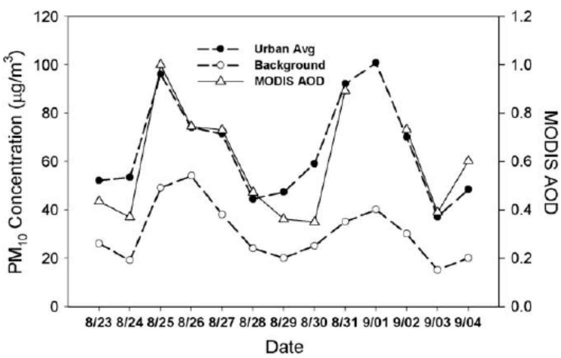


Figure 38: Time series plots of average daily PM10 concentrations at three urban sites

Cardio-respiratory hospitalizations associated with smoke exposure during the 1997 Southeast Asian forest fires

In 1997, uncontrolled forest fires burned in the Indonesian states of Kalimantan and Sumatra. The fires, in combination with a severe drought, produced a regional air pollution episode that affected Malaysia, Singapore, Thailand, Brunei and the Philippines. During a continuous two-month period, an estimated 20 million people were exposed to ambient concentrations of particulate matter (mostly PM10) that exceeded the US EPA's 24 h National Ambient Air Quality Standard of 150 micrograms per cubic meter (Brauer et al 2001). On September 22, 1997, 24-h PM10 concentrations peaked at 852 mg/m3 in Kuching, the capital of the state of Sarawak, Malaysia. This peak concentration exceeded the US EPA's 24h hazardous level of 500 micrograms per cubic meter.

Figure 39 shows the observed number of hospitalizations before and during the fire period. Forecasted estimations of hospitalizations based on the baseline period between January 1995 and July 1997 were obtained and compared with observations during the fire period. Results show that there was a significant increase of hospitalizations during the fire period up until October.

The findings demonstrate that many communities exposed to forest fire smoke during the Southeast Asian forest fires of 1997 experienced short-term increases in cardio-respiratory hospitalizations. Significant increases in respiratory hospitalizations, particularly those due to asthma, were observed in the 19-39 and 40-64 age categories. Analyses indicated that persons over age 65 with prior hospitalizations for respiratory diseases were significantly more likely than others to be re-hospitalized for their conditions during the forest fire (Mott et al., 2005).

Although persons over age 65 may be most susceptible to health effects associated with smoke exposure, the findings also demonstrated modest fire-related increases in hospitalizations among younger persons without a known history of cardio-respiratory diseases.

People of different ethnic backgrounds showed to be differentially vulnerable. For example; over 40% of the hospitalizations during 1995–1998 occurred to natives of Sarawak, 33% persons of mainland Malay descent, and 21% to persons of Chinese descent (Mott et al., 2005).

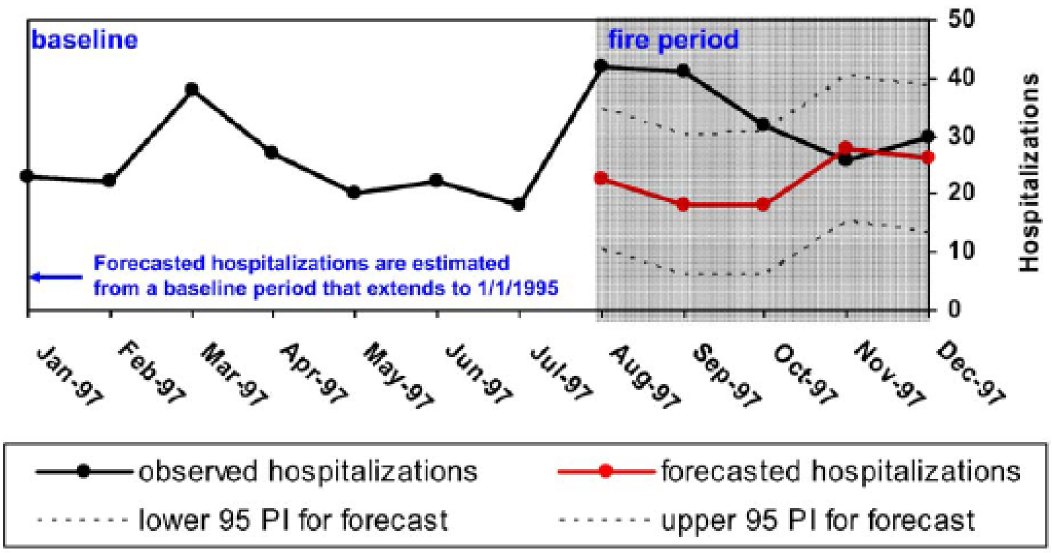


Figure 39: Time series analyses: Comparison of observed and forecasted hospitalizations from August 1 to December 31, 1997

However the impact of smoke exposure on this population appeared to be limited to the period during which the forest fires were burning, as long term assessments of re-hospitalization rates indicated that the survival functions of exposed cohorts resumed trajectories similar to unexposed cohorts during the 17 months following the end of the forest fires (Mott et al., 2005).

2002 summer fires in Lithuania: Impact on the Vilnius city air quality and the inhabitants health

The episodes with highly elevated concentrations of particulate matter (PM10), NOx, and CO were detected in the city of Vilnius between August and September 2002 and possible reasons were analysed. This increase was attributed to emissions from fires in the vicinity of the city of Vilnius when data on fire location and start, wind direction and concentrations of pollutants were analysed.

Figure 40: Map of the fire locations in the vicinity of Vilnius city and location of Kareiviu monitoring station.

The average hourly values of PM10 concentrations show a significant increase during several episodes in 2002: on August 19 - 21, August 25 - 30, September 02 - 04, and September 05 – 10. This could not be solely explained by unfavourable, for pollution dispersion, meteorological conditions (Ovadnevaite et al., 2006).

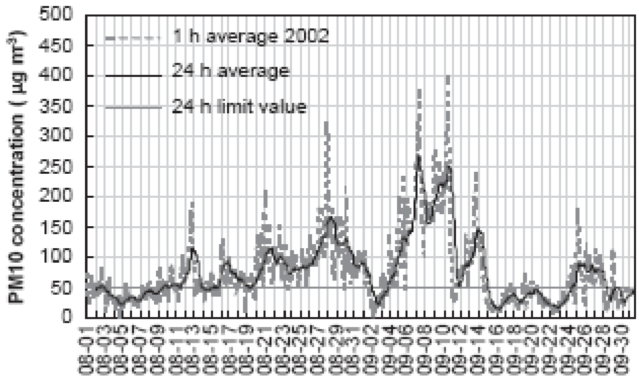


Figure 41: PM10 hourly concentration values measured in August–September

Data about fire location, beginning (time), wind direction and pollutant concentrations were compared. It was noticed that concentrations of PM10 and other pollutants increased right after the wind started blowing from the fire locations and decreased when the wind direction was dominating from the side with no fires at that time. It was observed that maxima pollutant concentration occurred at the time of fires in the vicinity of the city.

Vilnius Public Health Centre studied how the increment of pollutant concentrations in August–September 2002 affected the health of inhabitants in Vilnius city. The analysis indicated that health centers in Vilnius city registered an increment in respiratory and asthma complaints (see Table 4). The health situation in September was much worse than that in August because the highest pollutant concentrations were registered in the second half of August and at the beginning of September. Thus, more negative health impacts were reported after longer exposure to elevated ambient pollutants. The number of respiratory diseases and bronchial asthma complaints in September and July were compared. In September, this number was up to 20 times higher in some regions and about 3 times higher all over the city. The extreme environmental situation stimulated reaction of public health organizations with local media advising individuals to stay indoors (Ovadnevaite et al., 2006).

Health centre	Number of the respiratory diseases (average per day)				Exacerbation of the bronchial asthma (average per day)			
	July	August	September (1–18 days)	Ratio	July	August	September (1–18 days)	Ratio
Antakalnio	87.8	51.8	168.2	1.9	0.9	1.5	13.7	15.2
Šeškinės	15.8	11.6	36.7	2.3	11.4	8.6	17.5	1.5
Karoliniškių	10.5	9.7	141.1	13.4	8.3	8.2	16.6	2
Naujininkų	10.9	12.4	16.3	1.5	1.9	2.5	3	1.6
Lazdynų	4.2	4.7	27.9	6.6	0.4	0.4	5.4	13.5
N.Vilnios	3.0	3.6	58.9	19.6	0.2	0.6	4.1	20.5
Grigiškių	8.3	8.4	38	4.6	0.8	0.9	2	2.5
Centro	131.1	86.2	270.9	2.1	1.5	1.3	15.1	10.1
Overall in Vilnius city	33.9	23.6	94.8	2.8	3.2	3.0	9.8	3.1

Table 4: Number of the respiratory diseases (average per day) and exacerbation of the bronchial asthma (average per day) at the Vilnius health centers in July (month without fires) and August–September (months with fires) and their ratios in September and July

Final remarks

It was observed from scientific evidences of the four selected case studies that the vulnerability of forest fires is propagated and transformed in space. The initial physical vulnerability derived from the combustion of available fuel loads is transformed into another type of physical vulnerability, airborne pollutants, namely particulate matter. The airborne pollutants are not confined to the geographical location of the fire event but dependent on weather related events and regional atmospheric circulation patterns. These patterns lead to the propagation of the airborne pollutants within a country, has seen in the Greek and Lithuania, or even across countries, for example of the 2003 fire events originated in Russia impacted the air quality over the Korean peninsula.

The physical vulnerability caused by the dispersion of the airborne pollutants was transformed into social vulnerability depending on the age and health conditions of the population. The evidence of significant increases in the number of hospitalization both in a European and South-Asian context demonstrate the relation between a fire event and increased cardio-respiratory driven complications.

4.2.3 The Katrina hurricane (UNINA and MDX)

The Katrina case study, largely described in previous deliverables (2.1, 2.2, 3.1), has been here used to highlight different aspects of vulnerability transference since, due to the complexity of such an event, different phenomena of propagation, transference and transformation of vulnerability through space can be largely recognized.

In detail, the first part will be mainly focused on propagation of hazard impacts and on the consequent transference and transformation of vulnerabilities in space. The second part will be focused on the factors allowing both the transference (from one area to another or from one scale to another) of each vulnerability facet and the transformation of one facet into another.

Propagation in the Katrina case study

The areas hit by Katrina hurricane, New Orleans and numerous smaller towns in Louisiana, have been traditionally affected by environmental problems. Allen (2003) reported that the region between N.O. and Baton Rouge – also known as "The Chemical Corridor" – was characterized by a relevant concentration of over 130 chemical plants and petroleum processors. As stated by Colten (2006) "the extreme event that became a disaster was not just the results of Katrina but the product of three centuries of urbanization – and, we can say also of industrialization - in a precarious site. The drainage and levee system, built to protect the city from floods, has contributed to the regional coastal land loss and locally has produced subsidence in the neighborhoods toward the lakefront".

The Lake Pontchartrain is a relatively closed water body connected through the Lake Borgne to the Gulf of Mexico. According to the National Estuary Program, these areas constitute an estuarine ecosystem of national relevance. Moreover, the area represents the crucible of the Oil and Gas industry of United States too. Hence, before the Katrina Hurricane, Lake Pontchartrain was already highly polluted, due to several source of chemicals and organic substances, including fertilizers and animal wastes from agricultural practices, oil spills and discharges from wastewater treatment plants. On the other hand, according to many authors, the main source of pollution for the Lake was the urban runoff which represents one of the most dangerous byproduct of urban activities that potentially contains every possible source of chemicals.

Figure 42: The area of New Orleans hit by Katrina earthquake

Due to the importance of the Lake and its surrounding areas as natural ecosystems, since 2000 the Lake was interested by recovery interventions, under the responsibility of the Environmental Protection Agency (EPA) and Pontchartrain Basin Restoration Act Program. Thus, before Katrina, fisheries and touristic activities were developing within the Lake.

When Hurricane Katrina struck the coast near New Orleans, several breaches occurred in the levee network system which protected the city by surrounding waters. Due to these breaches almost (about the 80%) all the city was flooded. Hence, in New Orleans the majority of victims and damage were due not to the Hurricane itself but to waters that flooded, damaging infrastructure, buildings, industrial sites, oil pipelines and refineries. While at the very beginning of the flooding, waters were relatively fresh and clean, over time they became a mixture of toxic and organic substances which included volatile organic compounds (VOCs), metals, pesticides, polychlorinated biphenyls (PCBs), lead, hexavalent chromium and different typologies of bacterial organisms (Sheikh, 2005). These toxic substances may have different short and long term effects for biological species. PCBs, for example, has the same chemical activity of Dioxines and may affect the reproduction capability of numerous biological organisms (Marchetti, 1998).

After the storm, the immediate task for national and federal authorities was to "unwater" New Orleans. The city, in fact, had a scarce natural water drainage, since it is below the sea level. EPA and US Coast Guard had the primary responsibility for assessing and managing the toxic releases, while the Army Corps of Engineers (the Corps) was appointed to coordinate efforts for pumping waters out of the city (Sheikh, 2005).

The amount of water to be removed was accounted for about 114 billion liters: hence, its removal presented a number of relevant concerns. Lake Pontchartrain and Mississippi river were the two potential receptors of the water. Due to the fact that the latter was the main source for drinking water supply of the city, authorities decided to pump waters into the Lake. The treatment of floodwaters before pumping them was not possible due to the lack of full treatment technologies in place and the need for a quick unwater of the urban area.

According to the Report of the Congress (Sheikh, 2005), after the operations of pumping-in, the Lake had received the equivalent of several years of urban runoff in only few weeks.

According to many official reports, a fully understanding of the damage suffered by aquatic organisms will probably require many years. At short term, a decrease in dissolved Oxygen levels, which is probably due to the high level of dissolved organic matter within the lake, has been recorded. As regards long term effects, they are generally difficult to be predicted due both to the heterogeneity of toxic substances pumped into the lake and to their different physical and chemical behaviors. They might be diluted and degraded by bacteria and flushed out of the lake by tides or even accumulated in the sediments as worst case. Kilic and Aral (2006), using three selected chemicals as representative contaminants for their different physical and chemical properties, demonstrated that due to the highly hydrophobic nature of some of them, the dilution would have been difficult. Moreover, they estimated that the lake would have required about 80 years to recover from the stress created by the pumping of polluted waters after Katrina. However, due to the complexity of water dynamics and bio-accumulation processes within biological communities, it remains difficult to foreseen the nature and the relevance of future effects on the lake's ecosystem.

Summing up, the release of toxic substances into the Lake Pontchartrain and the consequent pollution of the Lake itself, can be considered a phenomenon of hazard propagation from the urban flooded area toward a natural ecosystem, in that the pumped flood waters (containing toxic substances) represented a source of hazard for the natural ecosystem of the Lake. It is worth noting that in this case the "mean" favoring the propagation was not a natural one (air, water, etc.) but a human (or better an institutional) choice. Local Authorities, largely unprepared to the occurred event, decided to pump flood waters from city to the lake, despite the relevant efforts for its environmental requalification. Hence, it should be possible to state that propagation in this case is the result of an existing institutional vulnerability.

Transference and transformation in the Katrina case study (MDX)

In relation to the Katrina Hurricane, the main factors driving the transference and/or the transformation of the different vulnerability facets through space will be investigated.

Physical vulnerability

In the case of New Orleans and St Bernard parish in particular, the principal underlying mechanisms driving the physical vulnerability are as follows:

1. the choice made by parishioners to locate themselves and their families in a low-lying, coastal, deltaic, former marshland zone within a hurricane belt (historically the area was attractive to migrating Canary Islanders and others) used to locate polluting oil refineries – thereby developing *exposure* to tidal surge flooding and to oil related na-tech disasters;
2. the choice made by two oil companies to locate oil refineries in the same zone principally because of its flat-land location adjacent to shipping waterways by which crude and refined oil products may be transported, and because the State of Louisiana offers preferential financial treatment to oil companies which are clustered there partly reflecting this – thereby developing *exposure* to tidal surge flooding;
3. the physical locational inertia - which *reinforced exposure* - which developed as a consequence of the development of tight-knit social networks comprising many generations of the same family living very close together, and also neighbourhood, faith and ethnic grouping social networks which bonded parishioners together in various cohesive, mutually-supportive groupings which made poor people independent of elements of governmental, welfare system support which failed them in various ways. Also the employment opportunities afforded to some by the oil refineries;
4. parishioners' *perceptions of flood risk and their under-estimation of the risk of tidal flooding* which stemmed from living in a hurricane zone but escaping catastrophic consequences for many years, misinformation about tidal flood surge risk from insurance agents, a general denial of the risk, and a belief in the impregnability of the New Orleans hurricane and flood protection system (i.e. essentially the levee system) despite warnings from experts that the defences would be defeated one day. Possibly also fatalistic attitudes and short time horizons (understandable amongst the elderly in particular).
5. *limited mean educational attainment levels* in this predominantly blue-collar community, tending to reinforce limited understanding of the risks of exposure and under-estimation of flood risk, and possibly constraining perceptions of alternative livelihoods in alternative locations with fewer risks;
6. the *provision of a flood protection system which constructed a major dependency*, with visible large-scale levees;
7. the choice, by the USACE, of *a flood risk management system which predominantly relies on large-scale structural engineering solutions*, and gives much less prominence to protecting and rebuilding natural wetland buffer zones and defences and non-structural risk reduction measures including flood insurance (though the latter has improved through the federal flood insurance program);

8. the *design of an interconnected, interdependent flood protection system* for New Orleans of which St Bernard's levee defences are part;
9. the fact that the *flood protection system had not been completed* when Katrina arrived;
10. *land subsidence* throughout the New Orleans sub-region, increasing the probability of tidal surge flooding.

The last five of the drivers of physical vulnerability listed above (6-10) may be considered as ones which drive physical vulnerability *transfer* through space within the New Orleans sub-region. Land subsidence increase, the risk of the protection system being defeated, and the other four drivers combine to transfer flooding in a part of the system to a threat to, and possibly a catastrophic failure, of the rest of the sub-region-wide system.

The first five of the drivers of physical vulnerability above drive the *transformation* of physical vulnerability into economic and social vulnerability.

Economic vulnerability

Economic vulnerability is fundamentally driven by physical vulnerability, as explained above. However, the mechanisms and factors which further (i.e. additionally) drive economic vulnerability are identified below. The economic analysis may be performed starting at two scales: a) the individual or community group scale, and b) the local parish economy scale.

The principal additional factors driving the (financial) vulnerability at the individual or community group level are:

1. the *income levels of the exposed population* of St Bernard parish (e.g. the mean annual income) and the degree to which these are below the national average reflecting a degree of poverty – this affects capacity to recover;
2. the *proportions of the wealth of the exposed population of St Bernard parish to be found in a) the value of exposed properties and b) as savings or investments* - most St Bernard parishioners were 'house poor' i.e. they held most of their wealth in the value of exposed properties and very little of it as savings or investments;
3. *disability of one form or another*, limiting income earning and recovery capacity;
4. *levels of ill-health limiting income earning and recovery capacity*;
5. *access to welfare or social care funding and dependency upon such funding*;
6. *dependency on employment* either in severely damaged businesses located in St Bernard Parish, or in severely damaged businesses located elsewhere in flooded New Orleans;
7. *whether or not employers continued to provide wages/salaries after the flood* (some employers did and others did or could not);
8. *access to wider family finances or finances from faith and similar groups*;
9. *access to other social capital which can help aid financial recovery* (e.g. entrepreneur clubs; chambers of commerce etc.);
10. *access to financial compensation* for oil contamination losses; and
11. *possession of flood insurance*.

In addition, the *income tax and social/employment benefit regime* which exists in the USA is a key contextual driver (working in a top-down direction) of financial vulnerability.

The principal factors acting as drivers for both *transference* and *transformation* of financial vulnerabilities in the local parish population are the 5th, 8th, 9^{th,} 10th and 11th factors in the list above, with access to financial compensation being very significant. As the emergency relief phase got under way, parishioners could also access numerous government and NGO aid funds which are examples of financial resilience which came into play for St Bernard parishioners once the flood and oil contamination disaster happened.

The drivers for the propagation and transference of economic vulnerabilities from the individual household or local parish community to other scales (sub-regional, state and national) are:

1. *access to funding from supra-local welfare and social care funds* (e.g. from national or regional charitable and care organisations);
2. *the existence of sufficiently strong out-of-locality family linkages*;
3. *access to other out-of-locality social capital which can aid financial recovery*;
4. *the existence of a supra-local source of financial compensation*;
5. *access to flood insurers with a wider than local or sub-regional scope*.

The principal additional factors driving the (economic) vulnerability at the local parish economy scale are:

1. the *composition of the local economy* in the case of businesses, and their particular vulnerability to loss and disruption of business: businesses vary enormously according to these factors, some being particularly vulnerable, others not being so (in the case of St Bernard parish there is a high incidence of fishing concerns which had limited susceptibility to flooding);
2. the *dependence of local businesses on other local, city-wide or region-wide businesses damaged by the disaster* (again this is highly variable);
3. the *dependence of local businesses on local customers and consumers who will have evacuated to distant locations*;
4. the *capacity of a business to transference its operations from a flooded to a non-flooded location* (this would be enhanced by business continuity planning – an example of a resilience measure – which made plans for such transfers);
5. *whether or not businesses could draw in financial resources and support from other parts of their business which were not so affected* (e.g. Murphy oil corporation was capable of doing this because it is a multi-national corporation);
6. *the capacity and ability of local businesses to return to trading, and who possess skills and know-how which have high utility in helping the local or city-wide economy to recover* (e.g. legal businesses, builders etc.);
7. *access to financial compensation* for oil contamination losses sustained;
8. *possession of flood insurance*.

In addition, *the USA's economic policy regime* (e.g. taxes, subsidies) play a major top-down role in setting the national economic context for local economic vulnerability.

Clearly, economic vulnerability varies according to spatial inter-dependencies as indicated above.

The principal factors acting as drivers for both *transference* and *transformation* of economic vulnerabilities in the local parish economy are all the factors above except for the first one. As the emergency relief phase got under way, local businesses could also access numerous government aid which are examples of financial resiliences which came into play for the local economy once the disaster happened.

The drivers for the propagation and transference of economic vulnerabilities from the individual household or local parish community to other scales (sub-regional, state and national) are:

1. *access to customers and employees from beyond the disaster struck area*;
2. *existence of business transfer locations free from disaster*;
3. *capacity to draw on funds from the wider business*; and
4. *access to insurers unaffected by the flood disaster* (i.e. from outside the local economy whose premises and systems were not damaged by the flood).

More fundamentally than this, *the market mechanism* underlies all of these drivers as a driver of economic vulnerability transference and transformation.

Social vulnerability

It is already possible to observe how social vulnerability interacts with, and influences, economic vulnerability (this is analysed in much greater detail in Del. 2.1, as is the reciprocal relationship).

The principal factors or drivers influencing social vulnerability are:

1. *susceptibility to loss of life and injury* as a result of flooding;
2. *susceptibility of individuals, households, families etc. to stress and stress-related illness (e.g. depression) and despair, and the degree to which this paralyses people's capacity to act to reduce their vulnerabilities*;
3. *willingness of victims to return to their communities*;
4. *personal qualities* of courage, persistence etc.;
5. *susceptibility of community norms, and normal behaviours, to break down*;
6. *presence and strength of family, neighbourhood, faith, school, ethnic and other social networks and support groups*, especially the degree to which they become spatially fragmented in the aftermath (in the case of St Bernard social networking was aided in the aftermath by NGOs providing internet access resources to reduce these impacts);
7. *susceptibility to loss of physical elements of social capital* e.g. schools, care centres, medical centres, hospitals, clubs, community centres, recreational facilities, cafes etc.; and
8. *access to family members and friends not directly affected by the disaster*.

In addition, *social, cultural and racial policies and norms which exist nationally and regionally in the USA* (for example, regarding attitudes towards charitable giving, racial discrimination etc.) provide a wider context for social vulnerability. These operate in a scale-wise, top-down manner.

The principal factors acting for the *transference* of social vulnerability are the 5^{th,} 6th and 7th ones in this list. The main driver of *transformation* of social vulnerability (i.e. its change in a significant, positive direction) appear to be the 3rd, 4th and 6th factors which are partially time-related (i.e. 'time heals').

The main drivers for propagation of social vulnerability from the local scale to other scales appear to be *personal and family relationships and the willingness of victims to return to their communities*. The actions of NGOs based from outside of the local area and which aid social recovery in the post-disaster period is an example of a resilience that comes into play once the disaster has happened.

Institutional vulnerability

The principal factors driving institutional vulnerability are:

1. *the diffused distribution of responsibilities for flood protection amongst an array of organisations at the local and sub-regional level* (US Congress, 2006);
2. *the distribution of responsibilities for disaster preparedness and emergency response across all scales within the USA*, from parish to the Federal government and the White House and the propensity for late and uncoordinated, ineffective disaster response which arises from this characteristic;
3. *failure of organisations to share information adequately in all stages of the disaster*;
4. *inoperability of communication systems of major emergency response organisations in the disaster phase* (US Congress, 2006);

5. *failure to adequately train, and in some cases appropriately equip, disaster preparedness and emergency response staff* (US Congress, 2006);
6. *lack of evacuation planning for those with less-mobility*; and
7. *general inherent complexity of organisational and institutional arrangements*.

The main driver for the propagation of these vulnerabilities in their latent form has been identified by the US Congress (2006) as *lack of leadership*. The occurrence of a catastrophic disaster and this lack of leadership combined to make these vulnerabilities manifest.

The main drivers for the *transference* of these vulnerabilities from one scale to another in their latent form are difficult to identify but they appear to be lack of clarity, lack of foresight and anticipatory capacity (US Congress, 2006), administrative insufficiency, sometimes insufficient funding, and lack of leadership. These are *mainly human shortcomings*. In their manifest form during the disaster, it was the disaster itself which was a key driver and 'revealer' of these vulnerabilities. Also localities struck by disaster often possess insufficient resources to respond adequately to the disaster, and the recognition of this leads to resources being deployed from surrounding areas, thereby moving the vulnerability (to some extent) and the response up-scale.

The main drivers which are capable of *transformation* of these vulnerabilities for the better are the reverse or reciprocal of these mainly human shortcomings e.g. better leadership, greater anticipatory capacity etc.

4.2.4 The 2001 El Salvador earthquake (BRGM)

During earthquakes, the elements of techno-human systems suffer damage, as a direct consequence of ground-shaking, but also due to the induced effects, such as soil liquefaction, landslides (e.g. El Salvador 2001) or fire (e.g. Kobe 1995). The damage/destructions of just a few individual elements may trigger considerable consequences for the functionality of the whole system (e.g. perturbation of the road systems during the 1994 Northridge and 1995 Kobe earthquakes, Chang and Nojima, 2001).

The following sections present the El Salvador case study, which has already been detailed in Deliverable 2.1.2 (WP2): the earthquakes that hit El Salvador in 2001 (January 13th - Mag. 7.4; February 13th – Mag. 6.1) provide a good illustration for spatial distribution of damage and vulnerability with respect to the different vulnerability facets.

Electrical network

– in San Salvador (capital)
The good behavior of the electric systems in El Salvador's capital was backed up by the interconnection (redundancy, *systemic vulnerability*) with the less exposed Guatemala's electrical system (19% of Salvadoran electricity comes from Guatemala), which effectively remained partially functional (AFPS, 2001).
– in rural areas
However, in rural areas, the situation was different: the lifelines and infrastructures suffered important damage, mostly due to the numerous induced landslides (645, see AFPS 2001) and falling structures.
Indeed the linear structures of lifelines suffer high *exposure* and exhibit high *physical vulnerability* to landslides.

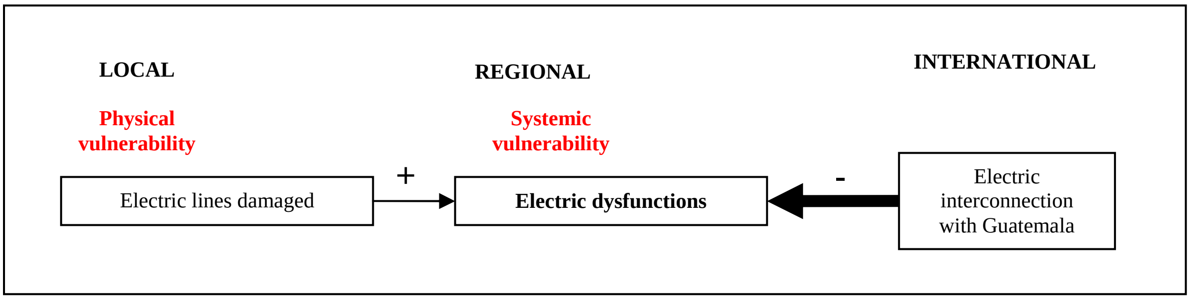


Figure 43: Decrease of internal systemic vulnerability of electric lifelines in San Salvador due to multiple sources of electricity generation (cause-effect relationship)

Furthermore, due to some topographical constraints (*territorial capital*) and to the lack of local development plans (*institutional vulnerability*), El Salvador's lifelines are often constructed along ridges or edges of cut slopes, making them even more exposed.

As a consequence, the destruction of electric lines, combined with failures of some generating plants in rural areas, have resulted in total electric outage in Central and Eastern regions (*systemic vulnerability*), for at least 3 days, made worse by the lack of formal emergency response and plans (*institutional vulnerability*) (Lund and Sepponen, 2002).

Water system

The consequences of the physical vulnerability of the pipes on the functionality of the water distribution systems were similar. Moreover, the dependence (*external systemic vulnerability*) of treatment and distribution facilities and pumps on electricity, exacerbated by the lack of emergency generators (*coping capacity*), aggravated the loss of functionality of the water distribution system (*systemic vulnerability*).

The situation of the water system worsened after the second earthquake, when the treatment plant in Chacahuatal was severely damaged. This plant ceased to supply water to the San Vicente area, making more than 22.000 people dependent on the delivery of drinkable water by trucks. This form of supply was itself dependent on road functionality (Lund and Sepponen, 2002).

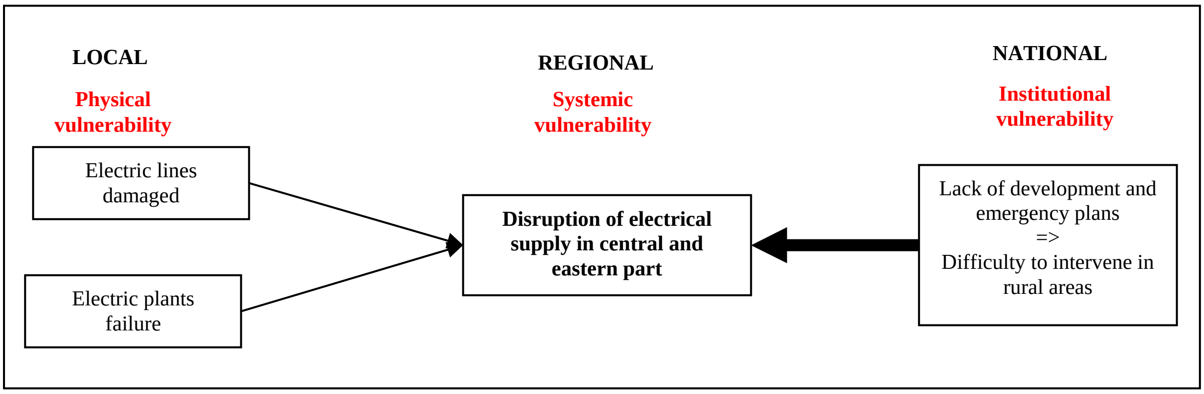


Figure 44: Internal systemic vulnerability of electric systems in rural area due to physical vulnerability and exposures (cause-effect relationship)

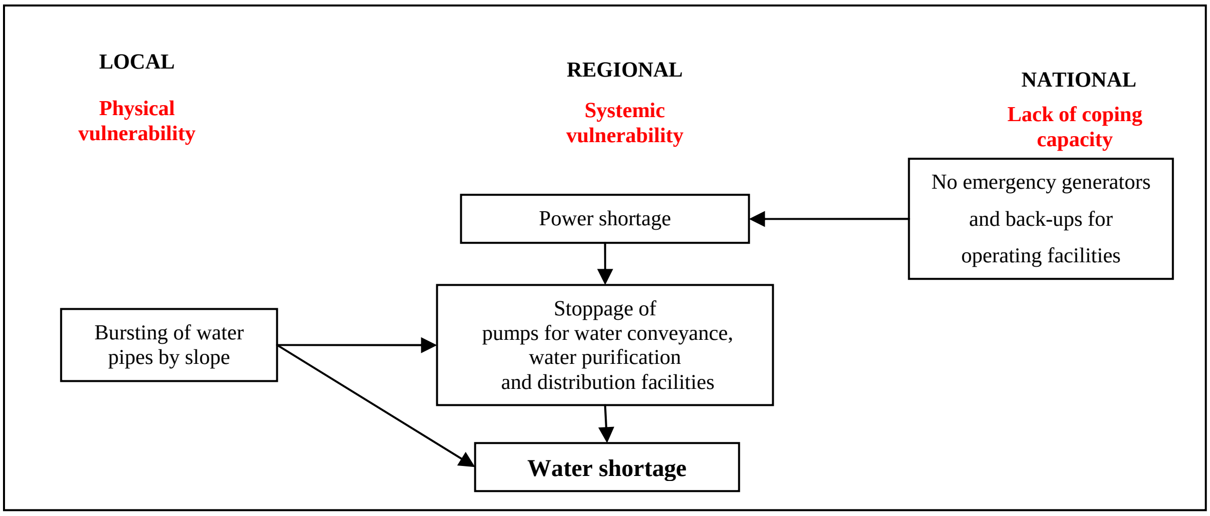


Figure 45: Systemic vulnerability of water supply in rural area (cause-effect relationships)

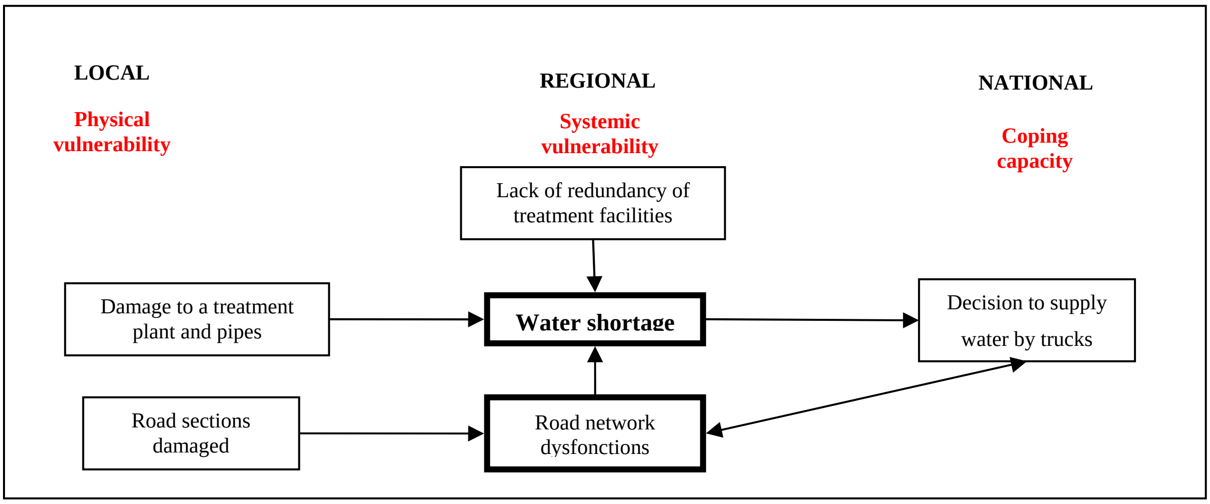


Figure 46: Transference of a systemic vulnerability to another system (transference-transformation relationships)

This disruption of the water distribution system triggered several induced effects on the human systems. For example, combined with physical destructions, the loss of functionality of the water system made more than 66.000 latrines unusable, raising severe concerns about health issues: in particular epidemics threats on an already affected population.

Transportation network

The transport networks were the lifelines most affected by the earthquakes and their induced-effects. The main Salvadoran highways (in particular, the Panamerican Highway CA1), backbone of national, but also South American economy, carrying the majority of passengers and goods traffic) were blocked for several weeks by numerous induced-landslides and rock falls at different locations (notably east and west of the capital). The scope of these obstructions could have been reduced by the implementation of slope stabilization programmes for critical roads (*institutional vulnerability* and *exposure*). Moreover, the lack of redundancy in the network (*systemic vulnerability*) combined with the lack of alternatives to land transport (i.e. air transport capacity is very limited), compounded the consequences of the blockages. As a result, the drivers had to make huge detours, increasing time and costs. The estimated indirect costs accounted for more than 80% of the total estimated cost of damage to transport infrastructures. Hence, even if the roads didn't suffer irreversible damage (*physical vulnerability*), the consequences of the earthquakes regarding loss of functionalities of transportation systems affected all the national sectors for months (Bommer *et al.*, 2002).

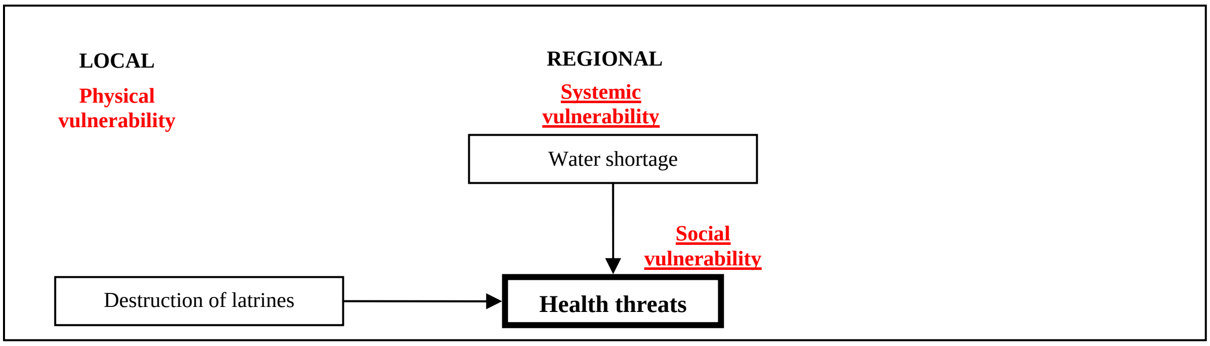


Figure 47: Human system vulnerability due to physical and lifelines systemic vulnerabilities (cause-effect relationships)

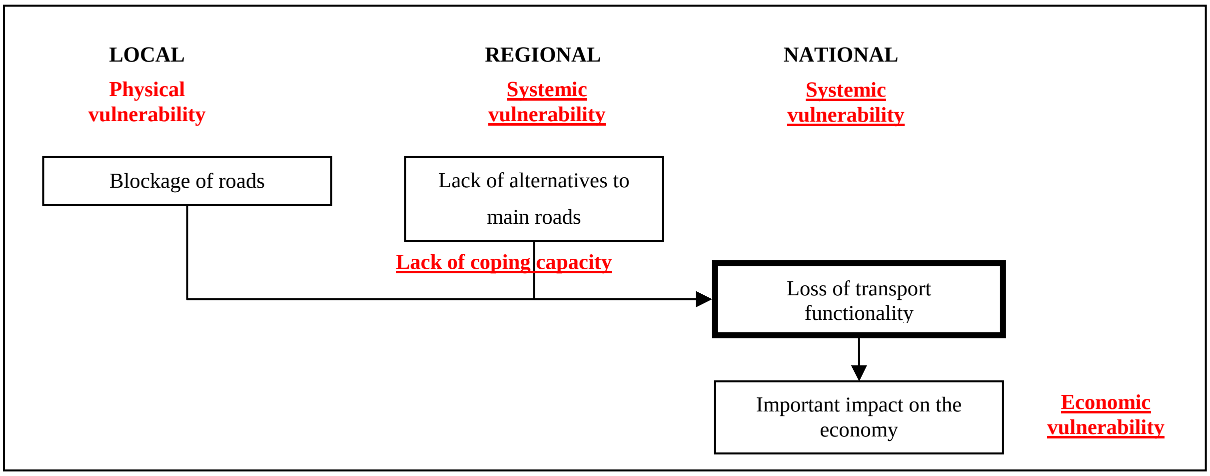


Figure 48: Systemic vulnerability of the road network due to exposure (cause-effect relationships)

Healthcare system

Even if none of the healthcare buildings were totally collapsed, the Salvadoran healthcare system suffered loss of functionality nationwide (*systemic vulnerability*). This disruption was certainly due to some structural damage (*physical vulnerability*), but mostly to non-structural damage (*physical vulnerability*), to systemic failure of lifelines (*external systemic vulnerability*) and deficit in trained staff (*human capital*) (Boroschek, 2004).

This loss of functionality was exacerbated by the centralized structure of the specialized services, the difficulty to transfer patients to other hospitals, due to their own loss of functionality as well (34% of the existing beds were temporarily lost at the national scale) but also due to the traffic disruption.

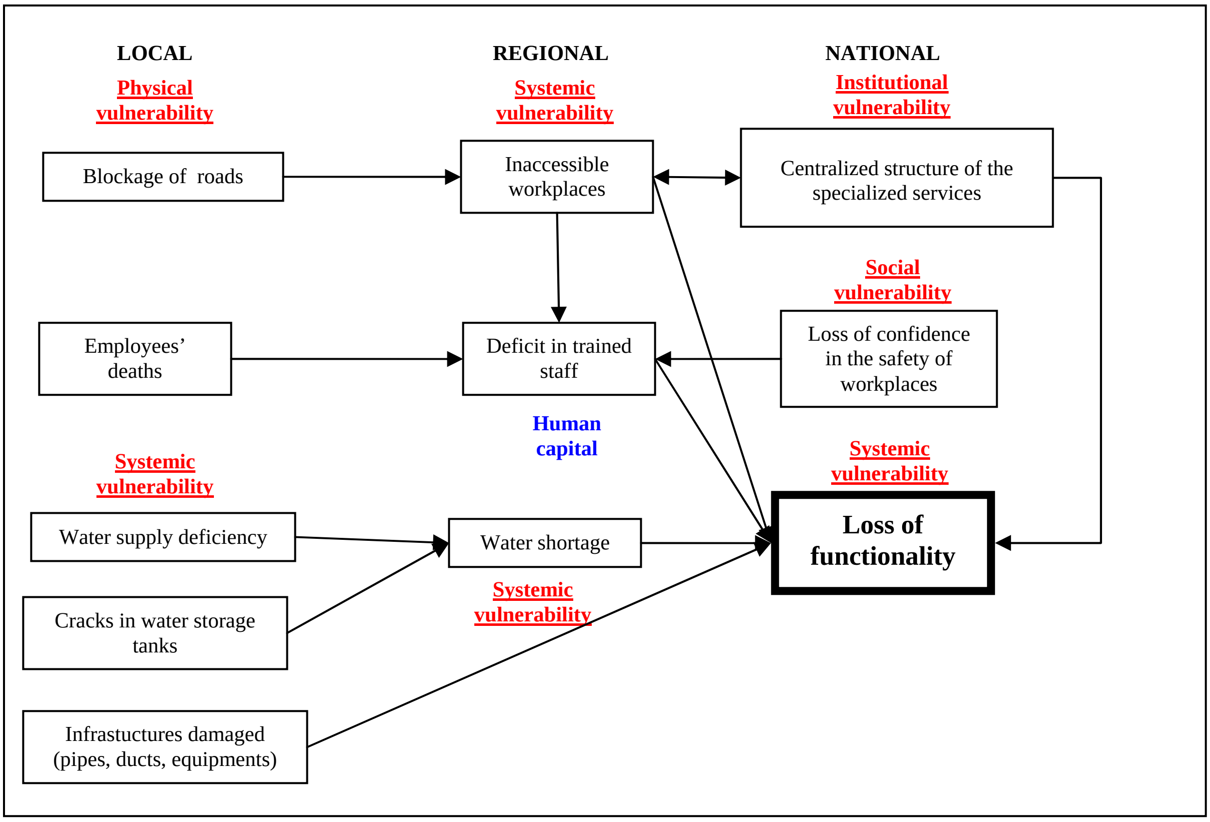


Figure 49: Systemic vulnerability of hospitals due to physical, social, systemic vulnerability

One year after the events, 28% of the existing beds were still in field hospitals, and some medical services in the country could not perform yet appropriately (e.g. oncology) (Boroschek, 2004).

Rural/Urban resilience

In Alarslan (2009), it is mentioned that, unlike in developed countries, urban settlements play a much more dominant role in developing countries. They are the concentration of political, administrative, economic, cultural, technical and infrastructural functions in developing countries. Whereas these zones are just "larger rings of the whole chain of infrastructure and services in developed countries". As a consequence, the vulnerability of such settlements turns into vulnerability of the country at large.

The dominance of urban settlements triggers a strong dependence of rural areas up on them.

In our case study, the loss of the health system functionality at the national scale was due to the concentration of hospital in specific urban zones which were heavily damaged and suffered non structural damage and transportation dysfunctions.

Many systems dysfunctions were stressed by the institutional vulnerability of the country and the lack of national response capacity, coming from the urban areas.

As developed in D3.1, the long term consequences of systemic vulnerability affected more rural areas than urban settlements (electrical cut, water shortage, physical damage + inaccessibility), which were quicker to recover (*local urban response capacity*).

4.2.5 Vulnerability transference in landslides' case studies (T6)

Landslides are generally very local, although in some case they may trigger further catastrophic processes, inducing new vulnerabilities at larger geographical scales, or may affect elements or systems with consequences that may reverberate from one element or system to others and from one area to others.

In relation to the first case, one of the best example is related to landslide dams. These are formed by various types of landslides, and they occur in different physiographic setting, ranging from rock slide and avalanches in steep-walled narrow valleys to slump and flows of sensitive clays in flat river lowlands (Alford and Schuster, 2000).

The water impounded by a landslide dam may create a dam reservoir (lake) that may last from short times to several thousand years. Because of their rather loose nature and absence of controlled spillway, landslide dams frequently fail catastrophically and lead to downstream flooding, often with high casualties. A common failure scenario is overflowing with subsequent dam breach and erosion by the overflow stream. Landslide dams are responsible for two types of flooding: backflooding (upstream flooding) upon creation and downstream flooding upon failure. Compared with catastrophic downflooding, relative slow backflooding typically presents little life hazard, but property damage can be substantial. While the dam is being filled, the surrounding groundwater level rises. The dam failure may trigger further catastrophic processes. As the water level rapidly drops, the uncompensated groundwater hydraulic pressure may initiate additional landslides. Those which fall into the dam reservoir may lead to further catastrophic spillages. Moreover, the resulting flood may undercut the sides of the river valley to further produce landslides downstream.

In relation to the second case, it is worth noting that one of the most important categories of vulnerable assets from landslides are linear infrastructure, like railways and highways. Examples of recent events occurred in different parts of Europe show how also events of limited intensity can cause relevant and extensive damage. Cases of landslides affecting road and railway infrastructures or also relevant assets clearly show how, due to the relevance and the interdependencies among hit elements or systems, vulnerability may transform form one facet into another, affecting different areas, elements or systems.

1911 Tajikistan - USOI Landslide dam and potential collapse of the lake

The Usoi dam was created in the winter of 1911 after an enormous seismogenic rock slide completely blocked the valley of the Bartang River in the Pamir Mountains of southeastern Tajikistan. At present the dam impounds 17 million cubic meters of water in Lake Sarez. Nowday there is a high risk of dam break with enormous potential damage in the downstream valley.

Flood volume and discharge estimates were made for several landslide generated floods that could overtop the dam. For landslide volumes of 200, 500, and 1,000 million cubic meters, estimated overtopping flood volumes were 2, 22, and 87 million cubic meters of water, respectively. Estimated peak discharge at the dam for these three flood scenarios were 57,000, 490, 000, and 1,580,000 cubic meters per second, based on triangular hydrographs of 70-, 90-, and 110-second durations, respectively (Risley et al., 2006).

Flood-routing simulations were made for the three landslide-induced overtopping floods over a 530-kilometer reach of the Bartang and Panj Rivers below the Usoi dam. A one-dimensional flow model using a Riemann numerical solution technique was selected for the study. A constant 50-meter wide rectangular channel, which represented the mean channel width, was used for the entire reach. A roughness coefficient of 0.038, appropriate for steep mountainous streams, also was used for the entire reach (Risley et al., 2006).

For the 87 million cubic meter volume overtopping flood scenario, the peak flows were approximately 1,100, 800, and 550 cubic meters per second at locations 50, 100, and 150 kilometres downstream of the dam, respectively (Risley et al., 2006).

The model was also used to simulate the less likely scenario of an instantaneous dam breach and draining of the total volume of the lake. Simulated peak flows were approximately 64,000, 52,000, 40,000, and 20,000 cubic meters per second at locations 50, 100, 150, and 530 kilometres downstream of the Usoi dam (Risley et al., 2006).

Figure 50: The Sarez Lake

April 12, 2010: Merano - Val Venosta: landslide

On 12 April 2010 a landslide occurred near Merano, Val Venosta (Autonomous Province of Bolzano, Italy), where a local train has derailed because of the impact of shallow landslide. The victims were 9 plus almost 30 injured. The cause is due to rupture of an irrigation system occurred upstream of the landslide; because of that the ground below was soaked and a sudden collapse occurred, probably triggered by train vibrations.

In this context we can recognize:

- high physical vulnerability, in relation to people affected on the train and, secondarily to the damage to the railroad functional vulnerability, spatially very local;
- medium functional vulnerability in relation to the interruption of the railway, affecting a larger area;
- low systemic vulnerability, in relation to the present activity and the spatial components and interesting a larger spatial asset. Moreover, the capacity to recover the proper functionality of the affected system is quite simple and demanding just few weeks.

Figure 51: Val Venosta landslide (http://www.ansa.it)

January 29, 2009: Salerno – Reggio Calabria Highway Landslide

On 25 January 2009, a landslide has invaded the highwayA3 Salerno - Reggio Calabria killing 2 people. The case is to be found in a landslide extended beyond 50 meters that affected the whole section of motorway. The mudflow, debris and vegetation, has sparked from a height of about sixty meters on the side facing the southbound carriageway, has invaded both carriageways for an extended about 25 metres and swept the retaining wall investing in a van with 7 people on board. In this context, in relation to the importance of the road, we can recognize:

- high local physical vulnerability, in relation to people affected on the train and, secondarily to the damage to the railroad functional vulnerability;
- high functional vulnerability in a large spatial area, in relation to the interruption of the railway;
- high systemic vulnerability in a large spatial area, in relation to the present activity and the spatial components. The highway is quite important in the North-South Italy infrastructure network and the landslide was limiting the communication and services along this major highway. Nevertheless, subsidiaries roads could be used for the transportations system, limiting the impact to people and goods. Since vulnerability, in this regard, refers to issues of interdependency, of uniqueness of given functions and to the possibility to surrogate/transfer/substitute lost functions, we can consider a medium impact to the territory.

Fig. 52: Salerno–Reggio Calabria highway (http://www.greenreport.it)

Maaloula – Damasco (Siria): Landslide and socio-economic implications

Maaloula is a small village located in north of Damascus (Syria), situated on the mountains Al Qualamoun, belonging to the chain Palmiride. It is a site of high cultural and historical importance because there are some of the most ancient of the Christian religion. In these sites is the St. Tecla monastery, that is located in a narrow morphological incision below a limestone cliff of about 60-70 meters. The cliff is affected by large falls and slides of rock that produced and still produce the destruction of the houses below. Also the of Santa Tecla's monastery is involved in these mechanisms: a large block of rock risks to detach from the wall undermining the conservation of the monastery and the archaeological settlement

Fig. 53: Santa Tecla's monastery (Margottini, 2009)

The landslides described above caused the closure of the site involving a high socio-economic damage for the village and the whole territory. In this case, the local hazard produced a very local physical impact in vulnerable structures (e.g. the church) but also a damage in the economy in a wider and vulnerable area, economically suffering for the missing of tourism.

4.2.6 The Iceland volcanic eruption, 2010.

On the 20th of March 2010, a first eruption of the Eyjafjallajökull volcano in southern Iceland, that has been dormant for 200 years, occurs. Few days later, on the 14th of April, a second eruption occurs. The latter, differently from the previous one, has occurred below a thick layer of ice that, when melting, increases the explosiveness of the volcano.

Due to the fact that the event is so recent and still in course, it is clearly difficult to come up with an accurate description of the event itself or with an exhaustive balance of its consequences at different geographical scales.

Nevertheless, it seems to be a paradigmatic example for better highlighting some of the concepts faced in chapter 3, related to potential "large scale" repercussions of a volcanic event, and in chapter 4, with respect to the transfer and transformation of vulnerabilities from one territory to another or from one type to another.

In relation to the large scale repercussions of volcanic events, it is worth noting that in the Vesuvio case study (see § 3.2.4) has been already highlighted that systemic vulnerabilities in case of volcanic events may arise not only as a consequence of physical or functional damage (vulnerability to losses) – as it frequently happens – but also as a direct consequence of the hazard itself. Therefore, although no physical damage occur, other types of damage (functional, economic, etc.) may occur, affecting areas very far from the hazard source and significantly wider than the one in which the hazard occurrs.

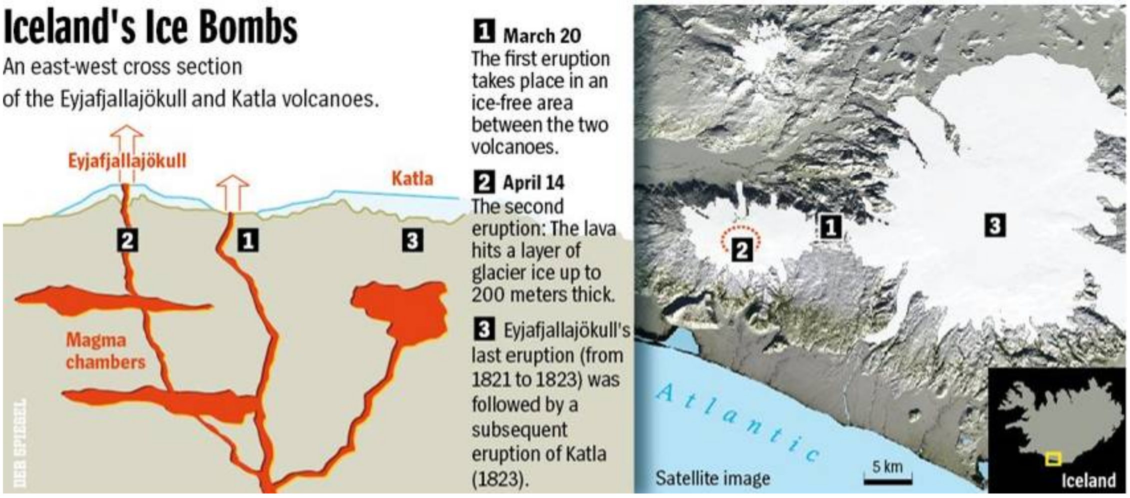


Figure 54: The eruptions of the Eyjafjallajökull volcano in southern Iceland (Source: Der Spiegel on line International Magazine, 04/17/2010, http://www.spiegel.de/ international/europe/0,1518,689601,00.html)

These kinds of phenomena are very clearly exemplified by the volcano eruption in Iceland: after the second eruption, occurred on the 14th of April, indeed, the ash plume has grounded flights all over Europe for one week, inducing severe consequences at European and global scale, as a direct consequence of the hazardous phenomenon itself. Chester et al. (2001) underline that the scale of the potential consequences of a local hazardous event mainly depends on "the strategic position of the threatened city within the economy of a country and/or region".

The Icelandic eruption has largely demonstrate that also an event occurring in places which do not hold a relevant or strategic position within a wider economic context, may induce damage in areas very far from the hazard source, also at a global scale. In the mentioned case study, indeed, apart from the local consequences of the eruption which are not faced here, the propagation of the phenomenon through air, due to the features of the ashes themselves and to the meteorological conditions, has determined phenomena of transfer and transformation of vulnerability.

The figure 55 provides a clear idea of the quick propagation of the phenomenon from Europe to Canada between the 19th and the 21st of April. On the 20th of April, the weather forecasts on the website of the BBC (http://news.bbc.co.uk/2/hi/europe/8631889.stm) reported: "Weather conditions should be more favourable by the end of the week"; thus, "the wind should change to the opposite direction: it could start to disperse some of the stuff that has been blown over from Iceland. (…) It means that ash will circulate over north-east Canada and the North Atlantic," (….) However ash will continue to fall on Europe".

Such a propagation has clearly transferred vulnerability across space but has also transformed it.

To better understand such a statement, we will briefly describe some of the complex chains of damage, failures and troubles due to the ashes propagation at different scales.

Leaving aside the damage due to the eruption at local scale, the first relevant consequence of the ashes propagation is that the most of the European airspace has been closed for several days (5 days after the eruption, only some of the European airports were going to open again). The stop to flight circulation is clearly due to the vulnerability of aircrafts to the ashes.

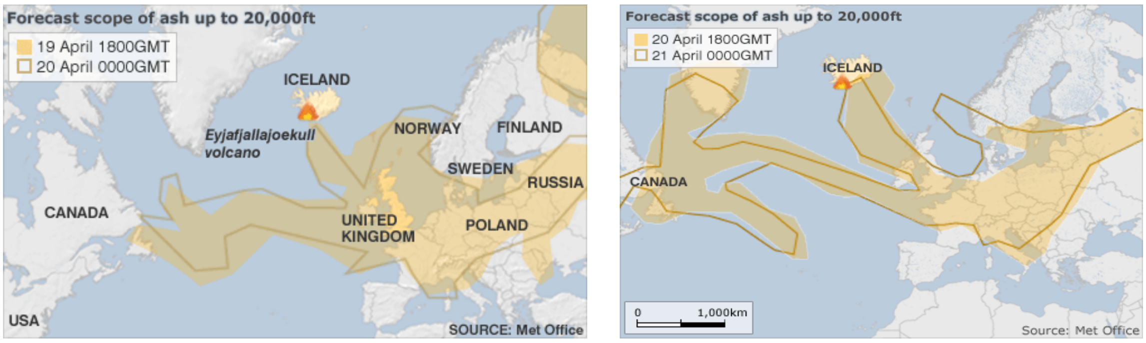


Figure 55: Propagation of ashes on 19th and 20th of April (http://www.metoffice. gov.uk/aviation/vaac/vaacuk_vag.html)

Ash particles, indeed, may induce relevant failures both in engines and in other essential systems of the aircraft (such as sensor systems, hydraulics, and so on); furthermore, they are highly abrasive and may damage aircraft components, particularly forward facing surface of external parts apart from the engine components: for example, pilot windscreens may become largely non-transparent.

Due to the large scale propagation of the phenomenon – as fine ash particles can be easily carried by the wind, reaching the height that aircraft generally fly – and to the physical vulnerability of aircrafts, numerous direct and indirect damage, failures and troubles have been induced at different geographical scales.
The closure of most of the European airports has provoked, besides the relevant troubles for passengers all over the Europe, relevant economic losses for airline companies. Official data are not available yet, even though media have highlighted that airline companies have lost about 200 million of dollars per each day. The total amount of economic losses on the 21st of April, is estimated in 1,5 billions of dollars.

Even though the hazardous phenomenon has directly affected European airspace, also airplane companies based far from Europe have faced relevant economic losses: the Thai Airways, based in Bangkok, has estimated that ash cloud has cost $3 million per day and has stranded 6,000 of its passengers (http://edition.cnn.com/2010/BUSINESS/04/19/volcano. economic.impact/index.html).

Furthermore, due to the closure of air space, relevant secondary impacts have been recorded too, so that the "butterfly effect" of the Icelandic eruption has been largely mentioned. Among them, the most relevant one is the stop of freight flows: even though only a small percentage of freights travels by air, relying more on road, sea and rail, it has to be taken into account that fresh and perishable goods mainly depend on air freight.

Therefore, besides the problem internal to European freight flights, relevant repercussions on exports of fresh food and flowers from Africa have been reported: for example, Kenya normally exports up to 500 tonnes of flowers daily, the 97% of which is delivered to Europe. Therefore, Kenyan farmers have been forced to dump stocks of fresh food and flowers destined for European consumers and, according to a report in Kenya's Daily Nation newspaper, the Kenyan economy is losing $3.8m a day as a result of flight cancellations to Europe.

Other relevant failures, with consequent further economic losses, have been determined, for example, by the cancellation of political and business meetings, of relevant cultural or sports events but, also, by the relevant delays to air mail, which is also very relevant for official documents and so on (fig.57).

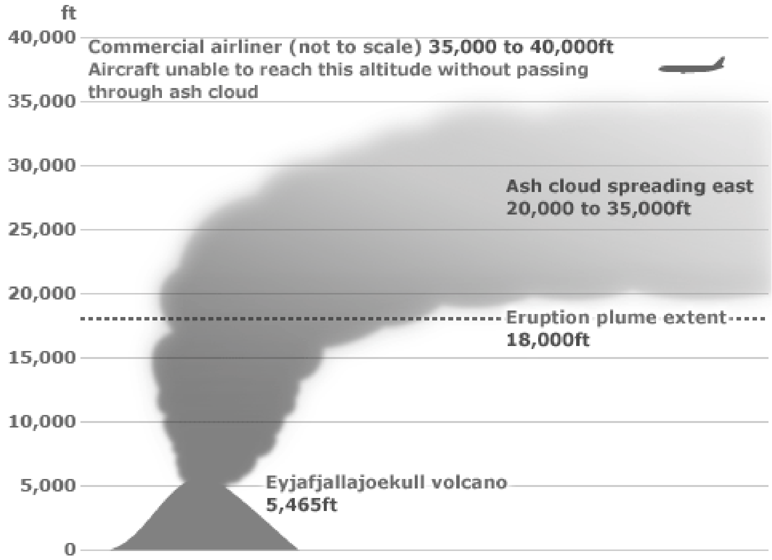


Figure 56: Height of ash cloud (http://news.bbc.co.uk/2/hi/science/nature/8629609.stm)

In conclusion, the eruption of the Eyjafjallajökull volcano has clearly highlighted how a given hazard occurring at a local scale can propagate itself and its impacts across space, inducing phenomena of transfer and transformation of vulnerability in areas very far from the hazard source.

The extension of the affected area largely depends on the interdependencies among territorial systems, activities, which are more and more developed in the current global economy.

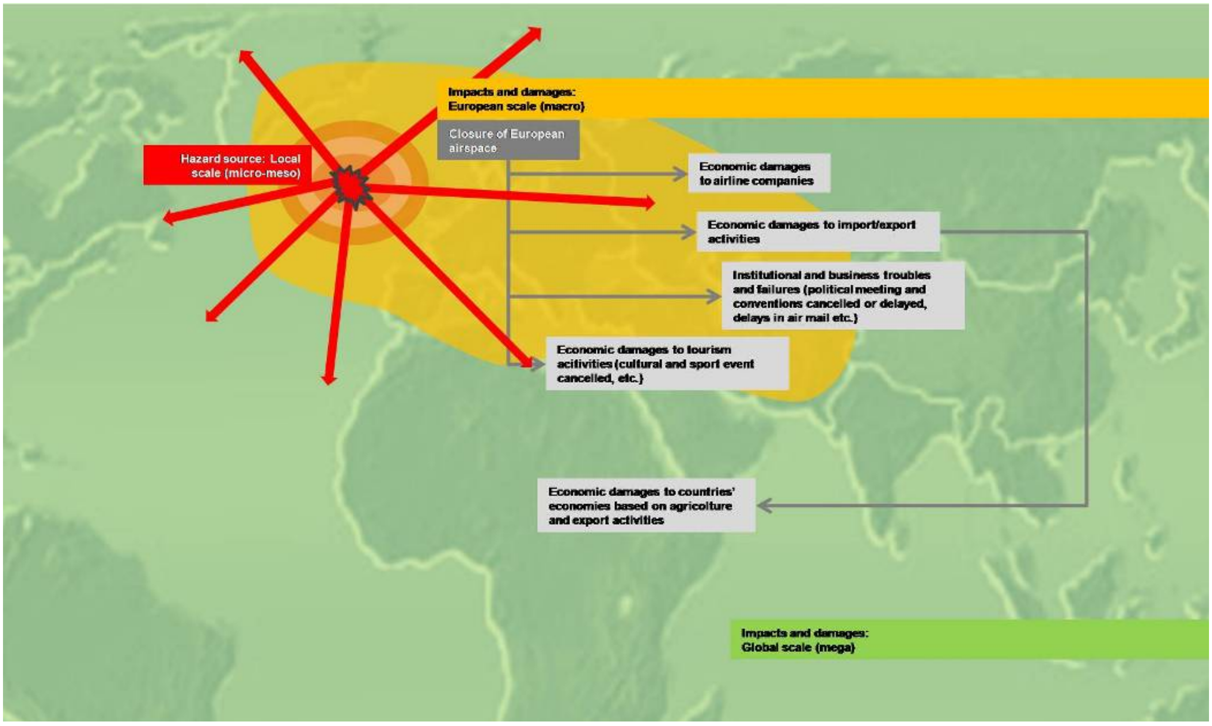


Figure 57: Examples of damage, failures and troubles at macro and mega scales due to the hazard propagation

In detail, it has been highlighted how, starting from the propagation of the volcanic ashes – which has affected a very large area as a consequence of the features of ashes and of the meteorological conditions – phenomena of transfer and transformation of vulnerability have been activated, in that the physical vulnerability of airplanes to ashes has been turned into a functional/systemic vulnerability of all the activities (airline industry, passenger mobility, commercial activities, business, etc.) depending on air flights. The latter vulnerability has been turned again into an economic vulnerability of enterprises or national economies depending on that activities. Transfer and transformation of vulnerability has occurred at different geographical scales from the macro up to the mega scale.

Therefore, in this case, although the event has occurred in an area which does not hold a strategic position in the global economic contexts, it has affected a strategic activity – the air freight – reverberating on activities and economies all over the world.

4.2.7 The 1999 Greek earthquake (HUA)

The presented case study highlights phenomena of vulnerability transference due to the role played by specific actors after the 1999 earthquake in Greece.

The 7 September 1999 Ms=5,9 earthquake that hit Athens, Greece, is reported to have had serious impacts on the city's well-being. Scientific reports, as well as extensive media coverage of that time, focused almost exclusively on physical losses (particularly collapsed and damaged buildings) and, consequently, losses of human lives. At that time little had been known about the indirect and often unseen impacts of the seismic shock, particularly those that were faced by firms. In the years that followed, research projects have been able to fill in that gap (HUA, 2003; Sapountzaki, 2005). The account at hand draws heavily from these reports and deals with relationships and interdependencies among systems and social actors which determine propagation, transformation and transference of vulnerabilities. And it does so by incorporating a fourfold focus on: Small Manufacturing Firms (SMFs), the western part of Athens, public policies on seismic reconstruction and the relationship between owners and tenants of SMFs' establishments.

The municipalities of Western Athens host a significant percentage of SMFs located in the Greater Athens Area; they consequently host a significant number of firms facing physical building losses from the seismic shock (2.103 firms, i.e. 26% of all damaged firm establishments in Athens according to the YPESDDA – ESYE census, 1999). Fifteen percent of all firms in Western Athens was reported to have been closed as a result of severe damage to their accommodating buildings. All other firms had to temporarily suspend operations in order to undertake building reconstruction work. Temporal halt of operations had been reported by firms' owners to be the most significant impact from the seismic shock, an impact that's rarely addressed by mitigation policies.

Mean employment for all firms is 2,4, meaning that the average size of firm is very small (YPESDDA – ESYE, 1999). Size of firm is reported to be an important factor explaining high degree of exposure to seismic risk, due to lack of information and organizational competences, inefficient own capital resources and limited access to funding (Tierney, 1995; Shin, 2004; Zhang et.al., 2009). In addition, failing lifeline systems further enhance firms' high degree of exposure (Dahlhamer and Tierney, 1996; Stallings, 1996). All these reasons have been empirically proven to be important in the case of Western Athens, but there are also a number of specificities that make this case a bit more complicated. These specificities are highly significant because they relate to the institutional, economic and cultural context within which SMFs operate.

One such specificity is the age of buildings and the quality of construction: most buildings had been built prior to the 1984 modification of the Greek Seismic Design Code and were later modified and/or equipped excessively, while an important number of premises had been built and/or later modified without construction license (actually a common practice in the history of urban development in this part of the city in the 1960s up to the 1980s). Additionally, a lot of these firms operate with no licence, and there is also a widespread contravention of health and safety rules. All these factors explain the SMFs' high degree of exposure and physical vulnerability.

Another specificity of determinant importance is ownership and tenure arrangements (Sapountzaki, 2005, pp. 203-208). Less than 50% of firms own their building space in Western Athens. Rented accommodation had led to entrepreneurs being ignorant of the building construction standards and history of their respective premises. Furthermore, they had not been willing to invest in order to make their building earthquake-resistant, and neither had been the owners of the buildings.

In relation to the reconstruction phase, owners of firms in rented accommodation could not favour from central state measures because: (a) the latter covered only a small part of the repairing costs and thus own investment was required, while access to additional interest-free loans required mortgaging the premise and would worsen the economics of already debt-owning firms, (b) measures aimed at physical damage of buildings and not of their content, i.e. equipment and inventory, (c) application prerequisites could not be met since in many cases there were no construction and/or operation license, (d) only owners of buildings – and not tenants – were entitled as applicants, and (e) applications and public funds awarding was a time-consuming – not to mention expensive – effort that run contrary to minimizing temporal interruption of operations.

Due to this particular combination of structural characteristics and inefficient public policies, manufacturing facilities were either not restored or underwent temporal and minimum repairs. Out of the 50 firms surveyed in HUA's (2003) fieldwork research, only 12 managed to have access to some sort of financial assistance; the rest had to rely on their own recourses. In this way, institutional actor's incapacities led to initial enhanced economic vulnerability of firms.

Another facet of vulnerability transference is based on the relationship between owners and tenants in SMFs' establishments. The former, since they were solely entitled to apply for public recovery funding, put pressure on tenants to evacuate their premises in order to allow for repair works. In this way the owner of a SMF had to face not only temporal halt of operations but also further, uncontrollable delays and also possible displacement, which led to extra costs of relocation and semi-permanent alienation from local networks of suppliers and customers. Furthermore, it was at the landlord's best interest to have his/her damaged building designated as non-viable/to be demolished; thus owners of rented properties put pressure to public authorities for such a designation, aiming at enhanced public funding and asset renewal. On the contrary, firms that rented their accommodation put pressure for the reverse designation, i.e. for severely damaged buildings to be labelled as repairable, thus being granted allowance to remain in damaged premises. So in the case of a temporal closure due to repair works, the physical vulnerability of the formerly rented establishment (i.e. of the owner) is reduced, but vulnerability is transferred to the SMF as economic – and consequently social – vulnerability. Furthermore, in case of relocation of the firm, it is possible that the new premises would be of an equally low quality and thus the initial physical vulnerability of the firm will be reproduced in a new location, while the economic vulnerability of the firm will be further enhanced due to the relocation process.

Internal rebalancing of vulnerability facets, as well as transferences of vulnerabilities from one actor to another, are shown in Tables 5 and 6. These features are further explained below.

One has to take into account that all the above systemic features of a semi-informal economy actually act as preconditions for the" successful" operation of these small firms, even though it would be more precise for one to speak of marginal survival and socially dominant modes of entrepreneurship than of successful business stories (cf. Vaiou and Hadjimichalis, 2002).

Rebalancing the facets / *Stagesof the disaster cycle / Actors*		*Physical*	*Social*	*Economic*	*Systemic*	*Institutional*
Pre-disaster adaptation	*Owners of buildings being rented to SMFs*	+ (by possessing vulnerable building structures)		- (by not investing for earthquake-provision improvements)		
	SMFs renting their building	+ (by occupying premises built prior to the new Seismic Design Code)		- (by occupying low rent buildings; by operating with no construction / operation permits)	+ (by increasing overall vulnerability of manufacturing zones and neighbourhoods)	
	State seismic prevention agencies			+ (*long term*) (by overcharging future loss account and reconstruction expenses)		- (*short term*) (by conniving at the violation of building law and contravention of health & safety rules)

Post-disaster response	*Owners of buildings being rented to SMFs*	+ (by making extemporary repairs)		- (by asset renewal and minimum investment in repairs)		
	SMFs renting their building	+ (by pressing for building designation as repairable & remaining in damaged buildings)	+ (by increasing exposure of working spaces)	- (by minimizing temporal shut-down and remaining in damaged buildings although using own funds for building repairs)	- (by minimizing time-span of temporal closure and thus avoiding disruption of business linkages)	
	State seismic reconstruction agencies			- (by limiting public expenses for reconstruction)		+ (by releasing reconstruction measures that are rejected by beneficiaries)

- Reduction + Increase

Table 5: Internal rebalancing of vulnerability facets by selective Actors in the pre-disaster and reconstruction phases in the case of Western Athens (HUA elaboration based on Sapountzaki, 2005).

Old age of buildings, lack of construction and operating licences, and lack of state control all lower capital and operational costs and thus add to the "competitiveness" of SMFs. What is even more important is that this state of affairs (i.e. employment of informal practices), although leading to high exposure and long-term vulnerability, has a positive impact on the SMFs' vulnerability in the short run. Lack of access to formal sources of capital is counterbalanced by loans and/or deferred payments provided by suppliers; other social networks are also activated to provide additional resources.

Vulnerability to / *Vulnerability from*	*Economic Actors (Owners of buildings being rented to SMFs)*	*Economic Actors (SMFs renting their building)*	*Institutional Actors (State seismic reconstruction agencies)*	*Social Actors (employees in SMFs)*
Economic Actors (Owners of buildings being rented to SMFs)		+ Physical, economic (making extemporary repairs or pressing for relocation)	- Economic (agencies charged with funds for building reconstruction)	+ Economic, social (force businesses to close or relocate, which leads to personnel dismissals)

Economic Actors *(SMFs renting their building)*	- Economic (asking for favourite building designation which leads to avoiding support of public funds)		- Institutional (no access to public support – defamation of public agencies and the state)	+ Economic, social, physical (business closure/relocation leading to personnel dismissals / reproduction of exposure in new, cheap settlements)
Institutional Actors *(State seismic reconstruction agencies)*	- Economic (public funds addressed to owners)	+ Economic, physical (public policies do not address renters, who also make low quality repairs)		+ Economic, social, physical (uncontrollable labour spaces and working arrangements, low quality repairs also no control on dismissals)
Social Actors *(employees in SMFs)*		- Economic, physical (contravention of safety rules, excess staff disposal, extemporary repairs)	+ Institutional (uncontrollable labour spaces and working arrangements, no control on dismissals, also mistrust & conflict with public agencies)	

- Reduction + Increase

Table 6: Transference of vulnerabilities from one Actor to another in the post-disaster phase in Western Athens (HUA elaboration based on Sapountzaki, 2005).

Second, the geographically dispersed network of suppliers and customers help minimize losses attributed to the breakdown of backward and forward linkages of the firm (i.e. its supplies and sells). Finally the occasional breaches of the law regarding building or safety standards, as well as informal labour practices, was a key condition for the "successful" re-opening of these businesses. "In other words, the pre-existing socio-economic context enhanced the ability of firms to function in abnormal conditions, that is, their resilience" (Sapountzaki, 2005, p. 205).

On the other hand, there is a negative side to the widespread informal practices regarding employment. Leaving aside the social cost of low safety standards etc, the initial stress and the consequent physical and economic vulnerability of the firm led to internal cost-saving pressures, which were translated into disposal of surplus labour. In this way, a firm's strategy to lower economic vulnerability has adverse effects on other social actors' vulnerability, namely the firm's workers. Therefore lowering the economic vulnerability of the firm has produced increased social vulnerability of the firm's workers.

All these processes and the particular mixture of SMFs' high exposure and high resilience have significant spatial outcomes regarding transfer and transformation of vulnerability. The first spatial outcome has to do with the shift of vulnerability from central state agencies to private enterprises (in the form of a shift of responsibility for vulnerability management). The central state was not efficiently involved in the recovery of SMFs, since its policies were aiming at either households or ideal-type businesses. The complex features that allowed for the proliferation of SMFs in Western Athens had not been taken into account in policy design. Thus local economic actors had to rely on their own and informal resources for survival, and in that way they actually reproduced the initial conditions of vulnerability. This is a manifestation of a scalar transference of vulnerability from the central state to local economic actors, which is also a transference of vulnerability from the public to the private domain. The importance of the informal economy in these social processes reveal that there may be other important factors other than liberalization policies that may explain transfers of vulnerability away from the public arena (Christoplos, 2003).

Second, and because of this scalar transference of vulnerability, there is a second-tier shift of vulnerability among local economic actors. In the case of SMFs in Western Athens, owners of firms in rented accommodation were the principal vulnerability carriers, exercising limited or no control over their physical vulnerability. The latter, being a priori transferred from landlords to tenants in cases of rented accommodation, was significantly enhanced due to institutional arrangements. Here the spatial dimension has to do with the spatial density of SMFs and the important percentage of rented facilities in the total number of businesses, a factor that consequently transform individual physical vulnerability to local-level territorial vulnerability. It also has to do with the relocation of small firms, a process that – given the preference of firms for relocating in a near-by facility – further augments local territorial vulnerability.

The third spatial outcome refers to the transference of vulnerability from firms to their respective employees. In the case of dismissals, firms produce social vulnerability which is carried by their former employees. The spatial scale of this transference and transformation of vulnerability (from firms to households and from economic to social respectively) is again local, since the majority of workers live in the same – or in an adjacent – municipality.

It is evident from Tables 5 and 6 that vulnerability actors make trade-offs between their vulnerability to seismic hazard and vulnerability to other non-natural risks, i.e. economic risks (such as risk of bankruptcy, company closure, losing own income etc), social risks (becoming unemployed etc).

4.3 The role of resilience in the transference of vulnerabilities

In the Del 2.1.2 resilience has been defined as a catalyst for vulnerability change, transference and transformation in the relief/recovery period and often as a determinant factor for an uneven distribution of response capacities and hence vulnerabilities in the geographical, social, economic and political space. In detail, Sapountzaki et al. (2009) refers about Greek mega-fires of 2007 after which, various actors, by trying to obtain resources for themselves or even upgrade their respective socio-economic status to levels higher than prior to the disaster, triggered multiple transferences of vulnerability from an actor to another, entailing in some cases vulnerability transformations.

It is worthwhile underlining that such attitude is not exclusively a prerogative of the relief and recovery period but can be referred also to the pre-disaster phase as a consequence of hazard-dependent mitigation measures or even hazard-independent processes of development.

Anyway, the mechanisms of propagation, transference and transformation of vulnerability as a consequence of a positive modification of resilience are relevant mainly by a "temporal" perspective whereas their spatial connotation is less evident. Hence, this paragraph aims at highlighting the role and the relevance of such processes by a spatial perspective.

In detail, three examples will be presented, namely the flood due to the Katrina hurricane, the Indian earthquakes and Vietnamese floods and typhoons in which the attainment of resilience in the pre-disaster phase contributes to an increase of vulnerability in face of given hazards.

The Katrina case represents one of the most investigated disasters caused by a natural hazard. It has been already largely examined in the ENSURE project according to different perspectives. An in-depth analysis of such event has been also provided in respect to the propagation, transference and transformation of vulnerability across time and space. Hence, it is worth noting that much of the mentioned vulnerabilities arise from some forms of resilience that, in such a way, become responsible for an increase of vulnerabilities in the hit area. In detail, despite New Orleans, and in particular San Bernard Parish, was a well-known flood prone area, the existence of an articulated flood protection system induced population to feel "safe" and spread the perception of no impediment to start or continue with the urbanization of the river belts, further motivated by the settlement of different industrial activities that make the area more attractive to workers. Among the industries, it is noteworthy to point out, due to the severe damage produced, the existence, in the flood prone area, of two oil refineries whose settlement benefitted from preferential financial treatment and was justified by the advantages related to the oil products transportation. The main result was an effective increase of the exposure coupled with a potential increase of vulnerability. The construction of a territorial flood protection system can be interpreted as a hazard mitigation measure addressed at increasing resilience in that it increases the robustness of the system through a positive modification of its resistance to the hazard impact.

This fact remarks the need for defining resilience in terms of specific actors (of who/what) and toward specific threats (to what). In fact, the levee system were designed to face a 100 years return event and, as a consequence, destined to fail in case of a major event characterized by a higher return period. In terms of vulnerability, the "levee effect", as named by Tobin (1995), could contribute to an increase of society's vulnerability in two possible ways (Pielke, 2000):

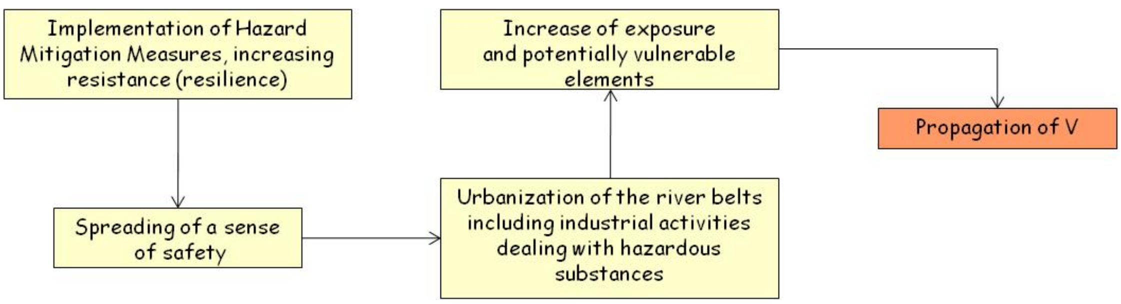


Figure 58: Propagation of vulnerability through space in the flood due to the Katrina hurricane

- by creating a sense of complacency, which can act to reduce preparedness in that the incentive to take precaution risks are removed;
- by creating incentives to build structures in areas subject to flooding.

The latter mechanism is exactly what happened in the Katrina case study (fig. 58), determining in such a way, an increase of the exposed elements potentially characterized by a own vulnerability. By this perspective, a propagation of vulnerability, in terms of a spatial widening of the exposed area and, consequently, of the potential vulnerable elements, occurred.[8]

Indian and Vietnamese case studies show similarities in the causes determining an increase of vulnerability and its propagation even if such causes arise in different phases of the disaster cycle, namely that are the post-disaster and the pre-disaster phase respectively.

India experienced two devastating earthquakes in the last decade, namely the Gujarat earthquake in 2001 and the Kashmir earthquake in 2005. As reported by Jigyasu (2008), after the Gujarat earthquake, traditional buildings, even where they were still standing, such as, for example, in the affected towns of Anjar, Bhuj and Morbi, were pulled down and substituted by modern structures that later demonstrated to be no better than the older ones due to a poor workmanship. Similar trends were seen after the Kashmir earthquake, where many traditional constructions that had performed fairly well against the earthquake were abandoned by their owners due to the widely prevalent perception that traditional buildings were "old" and "outdated" and therefore "unlivable" and "unsafe". Hence, due to misleading perceptions, innovative construction systems have been preferred at the expense of the traditional ones grounded on an indigenous knowledge developed over long time. In detail, in the Gujarat and Kashmir regions, the introduction of new materials such as concrete, adversely affected the structural integrity and seismic performance of vernacular structures.

By this perspective, Jigjsu (2008) notes that "partial replacement of traditional materials with modern ones, notably concrete, has not only reduced the inherent capacity of these structures but also increased their earthquake vulnerability to a great extent". In this case, the expected resilience (fig. 59), related to the spread perception that new materials, like cement, were stronger and safer than adobe and stone, turned into a physical vulnerability that broadened through space according to a discrete model in that the interventions rebuilding concerned individual buildings within a quite wide area.

A similar mechanism occurred in Vietnam, that is exposed to floods and typhoons, as effect of an increase of the community resilience due to significant changes in the economic policies which have been occurred since 1986. The new well-being pushes many householders to spend money into operations of renewal of their houses.

Figure 59: Propagation of vulnerability through space in the Indian case

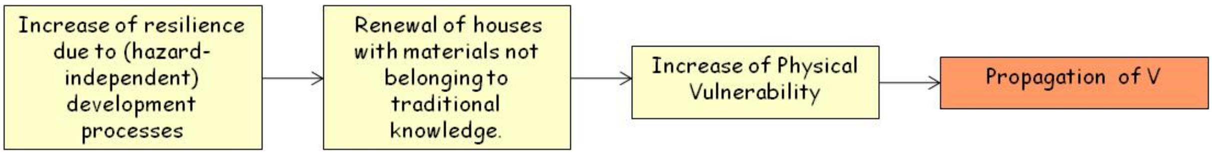


Figure 60: Propagation of vulnerability through space in the Vietnamese case

8 For a sake of completeness it is worth noting that in Katrina case the realization of mitigation measures as a form of resilience, have also induced a mechanism of "risk transference" according to a temporal perspective rather than a spatial one. Such phenomenon has been clearly shown by Etkin (1999).

The main effect of such actions was the replacement of about 70 per cent of provincial and rural housing stock by new homes with bricks, blocks, tiles, tin sheeting and concrete, all of which are costly materials (Norton and Chantry, 2008). Indeed, the new houses resulted to be more vulnerable to damage caused by flood and storms (fig. 60) even if householders considered them as more robust than the houses built in the past. In this example, the economic growth - that is surely a source of resilience allowing, for example, to undertake efficacious mitigation measures - is responsible *per sè* for an increase of physical vulnerability and its propagation in space.

To sum up, the mentioned cases show as an increase of resilience, even if under different forms (improvement of resistance, increase of resourcefulness due to hazard-independent processes, etc.) can play a relevant role in the mechanisms of propagation of vulnerability at different stages. In detail, the spatial area interested by these mechanisms varies accordingly with the lengths of time frame within such mechanisms develop.

4.4 Drivers of vulnerabilities in space: final remarks

In this paragraph, according to the numerous case studies provided in previous paragraphs, some of the main factors favoring the transference of vulnerabilities in space have been highlighted.

In detail, grounding on the factors arising from case studies in respect to specific threats and contexts, a shift toward more general factors to be taken into account in vulnerability assessment has been proposed.

Firstly, as clearly highlighted by case studies, the transference of vulnerabilities in space may occur as a direct consequence of hazard propagation. Such events are very common mainly when toxic releases or fires are at stake (Baia Mare and forest fires case studies). In the provided examples, the propagation of the hazard (toxic substances) or of its direct consequences (as the particulates and gases in case of forest fires) induce a transference, and in many cases a transformation, of vulnerability in space.

The second factor which has been underlined in some of the case studies is related to the physical, functional or economic interdependencies among elements and systems within the hit area and among them and other elements and systems placed out from the hit area.

These aspects have been largely outlined in the previous chapter, since they surely represent transference mechanisms but they can be also interpreted as an intrinsic property of some facets of vulnerability itself. In detail, the concept of systemic vulnerability can be applied to all systems (social, economic, territorial): each system is indeed characterized by its own elements and by relationships among them and interacts with other systems not necessarily placed in the same area. Such interactions or interdependencies clearly induce transference of vulnerability from one element, or one system, to another and, consequently, they might even induce a transference from one area to another.

Furthermore, the numerous mutual relationships (see deliverables 2.1, 2.2 and 2.3), that characterized all the facets of vulnerability, might induce a transformation from one facet of vulnerability into another and, in the meanwhile, a transference from one scale to another. Such mechanisms are clearly highlighted by some of the provided case studies (Katrina, San Salvador).

Ones of the most typical examples of transference of vulnerability due to the relationships among different facets of vulnerability are the ones induced by institutional vulnerability. As highlighted in case studies, weaknesses (e.g. lack of preparedness, lack of leadership) of the institutions in charge of risk prevention, mitigation and emergency response tasks, may favour phenomena both of hazard propagation (as in Katrina case study) and transference or transformation of vulnerabilities before, or even after, the hazardous event. All these possibilities are highlighted in the Katrina and San Salvador case studies.

Nevertheless, institutions are only one of the "agents" which may induce phenomena of transference and/or transformation of vulnerabilities in space. As clearly arises from the provided case studies (Athens earthquake, Katrina), transference phenomena are very often due to the interactions among different "agents" such as institutions and stakeholders within a given community. These kinds of mechanisms are very common in different phases of the disaster cycles.

For example, in Katrina case study, the lack of preparedness of Authorities to such an event, favoured the propagation of the hazard with a consequent transference of vulnerabilities.

Furthermore, development/transformation processes (renovation of historical areas, new building developments, etc) within a given community have to be mentioned among the main factors favouring the transference of vulnerabilities in space. Such processes may happen independently from the occurrence of a hazardous event, for example, as a consequence of changes in local economy, or in post event, due to the reconstruction. Very often such processes induce phenomena of transference and transformation of vulnerabilities, even though apparently addressed to reduce vulnerability and/or increase resilience, they often result in a transference of vulnerability from one area to another or even in an increase of vulnerability (see Indian and Vietnamese case studies).

Besides the mentioned processes, transference of vulnerabilities are often due to structural engineering mitigation measures which induce relevant changes in the risk perception, spreading a relevant sense of safety. The Katrina case study, for example, clearly highlights as the construction of levee networks has favored new building and even industrial development in hazard prone areas, spreading a false sense of safety. In such a way, exposure and vulnerability of the community significantly propagated in space.

Summing up, transference mechanisms highlight two basic needs for improving vulnerability assessment. The first one refers to the need for developing vulnerability assessment at adequate geographical scale depending both on the aims of the assessment and on the potential for transference over space of the different facets of vulnerability. The second one refers to the need for shaping the assessment, as already stressed in deliverable 2.2, as a "continuous cycle", in which the preventative assessment of the potential outcomes of mitigation measures or development or transformation processes – in terms of changes over time and in space of the different facets of vulnerability– and the monitoring of their effects have to be guaranteed.

5 Scale factors in vulnerability analysis: multi-scale and cross-scale analyses

In the previous chapters the main factors and mechanism affecting distribution and transference in space of the different vulnerability facets have been analyzed. In this chapter we will focus on the main questions related to the representation of such a distribution in space, focusing in detail on the importance of the scale matters of a vulnerability analysis.

Scale factors are largely recognized as crucial for vulnerability analysis. The study and the practice of vulnerability assessments increasingly recognize the importance of scale and cross-scale dynamics in understanding and addressing global and local disaster risk analysis. Territories have many connections and mutual relationships with the surrounding ones. Therefore, any spatial analysis - including vulnerability analysis - has to look beyond the area under investigation and take into account the relationships among the investigated area and the wider region that the investigated area belongs to. Natural disasters are cross-scale phenomena that require assessments at all scales and integration across scales in order to inform policy- and decision-making stakeholders most effectively. The intrinsic relationships existing between different facets of vulnerability can have consequences at different scales, as widely shown in previous research task (WP2). Large scale trends can also have repercussions on local scale trends. Economic and social factors acting on a very large scale, can also influence local scale vulnerabilities. At the contrary, the physical vulnerability that has an impact on a local scale, can have consequences in terms of function's disruption at larger scales. Therefore, the scale factor and mainly the need for cross scale analyses arise as one of the key elements for vulnerability analysis.

What is missing is a systematic way of thinking about how an assessment of different vulnerability facets has to be structured and how it can more consciously address scale and cross-scale interactions (Der Kiureghian and Song 2008). Natural hazards problems will continue to be disadvantaged by inefficiencies if we do not address the multi-scale nature of interactions between natural hazards and different vulnerability facets across scales.

5.1 Definition of scale

"Scale" refers to the measurable dimensions of phenomena. It determines the relative fineness and coarseness of different details, and the patterns that these data may form. It is expressed in physical units and is a measure of extent, span, size, or quantities. Thus scale is a window of perception through which analysis, knowledge and information can be defined (Zermoglio et al. 2005).

"Characteristic scale" refers to a particular extent over which a natural or social phenomena is characterized. Scale can also, and sometimes simultaneously, imply a level of organizational or a functional unit. In some literature, "level" refers to organizational and functional unit (Ahl and Allen 1996). Level is a characterization of perceived influence; not a physical measure, it is what people accept it to be. Two concepts of scale and level may coincide in the same unit (for example, a village), the scale of the village as a unit of land and population is a physical measure. A level of organization is not a scale, but it can have a scale (O'Neill and King 1998).

"Cross-scale interactions" refer to situations where events or phenomena at one scale influence phenomena at another scale (Zermoglio et al. 2005). Scale can be viewed as a "zoom tool" between micro and macro, but in practice the method that drives and shapes an assessment tends to be organized itself at some characteristic scale rather than to others (Willbanks 2006). Smaller scales are less complex but, as a result, are better in extrapolating relationships and understanding the phenomena in detail. Larger scales are more complex but have to be simplified in order to make analysis understandable and manageable (Kates et al. 2001).

Moreover, scale issues may appear different according to whether they are examined top-down or bottom-up. For instance, top-down analyses may not be appropriate for local scale, while bottom-up analyses can be so case-specific that extracting general pattern is difficult (Wilbanks 2005; Wilbanks et al. 2007).

5.2 Choice of the appropriate scale

The scale of analysis and assessment suggests that there is no simple answer to the question regarding vulnerability and that there is no one scales for every purpose. The choice of the scale depends on the analysis and the context (O'Brien et al. 2004). Impact and vulnerability assessments are carried out for different reasons: national and global level assessments can be useful for international comparisons, as well as for identifying the relative importance of impacts and potential adaptations within particular sectors.

At the regional and local scales, impact and vulnerability assessments begin to draw out the complexity of vulnerability and provide a stronger basis for understanding where, how, and why certain regions or groups are vulnerable (O'Brien et al. 2004).

Many processes have a characteristic scale. If a process is observed at a smaller or larger scale than its characteristic scale, there would be a likelihood of drawing the wrong conclusions. For this reason, it is important that the scale of analysis is congruent with the purpose of the assessment, and that conclusions from one scale are not erroneously applied to other scales (Wilbanks and Kates 1999, Gibson et al. 2000).

The scale selected can affect the results when boundaries are established between what is in and what is not, which can have social and political implications even if the selection is not politically motivated. In many cases, if the analysis intended to inform institutions about a particular matter, it is imperative to relate the scale to units for in which decisions are made (Berkes et al. 2006).

Research experience in a variety of fields notices that methods looking at a particular issue from the top down can reach conclusions that differ dramatically from methods looking at that same issue from the bottom up. In any case, an integrated vulnerability assessment should be structured on multiple scales rather than to be focused on a single scale. The choice of a single scale can frame an investigation too narrowly because questions and research approaches characteristic of that scale tend to dominate. However, phenomena, processes, structures and technologies, operate differently at different scales and thus the implications for action can depend on the scale of observation (Berkes et al. 2006). Cross-scale assessments often lose information or introduce biases because up-scaling or downscaling information from other scales requires compromises.

In the 6FP European Project "Armonia" (deliverable 5.1 "*Harmonised hazard, vulnerability and risk assessment methods informing mitigation strategies addressing land-use planning and management*") it has already been stressed that the scale concept incorporates at least three different aspects.

The first is closer to its "geometrical" interpretation and refers to the fact that some features that are obvious at a small scale, fade away on a larger scale, but also, vice-versa, some patterns that may appear very clearly at a large scale, lose their meaning when fragmented in a number of zooms, decomposing the entire picture in various pictures representing each a part of the area of concern.

The second interpretation leads to the recognition of substantially multi-scalar elements or processes or features, which may be well understood only crossing up and down the various scales. This is particularly true for economic forces shaping given environments. While the localization of some factories may appear purely occasional when considered locally, at larger scale their relation to access ways, to other factories, facilities, markets, services may become much more evident. Secchi (2000) states that one of the main and most difficult task planners currently perform is the constant verification of what they are doing at one scale with the consequences or the influences of/on other related scales.

The third interpretation is a more political one, and refers to the administrative, governmental level in charge of one scale or another. In this sense, scales are identified with administrative entities, such as regions (regional scale), counties, provinces, municipalities (local scale). Common to all those interpretations is the notion that larger scales not only may show patterns and processes that are not recognizable locally, but also that they may convey significantly different meanings, as larger scales are not the simple sum of a number of "small scales". The city is not just the sum of buildings and roads, the province is not just the sum of cities and infrastructures, etc. At different levels, interactions among systems and subsystems vary in quantity and quality. They also emerge in different ways, shaped and shaping social, cultural, economic and territorial processes.

5.2.1 The geometrical scale: a matter of spatial units

Human settlements can be represented as a tangible, perceptible spatial phenomenon where human beings and their activities subsist with reference to its spatial context. Spatial analysis describes the spatial characteristic of the territory structures and explains the conditions and cause behind them, including social, economic and political factors and describe the interactions between these factors (Greiving 2006).

For identifying the geographical distribution of potential damage, "mapping" is needed. Maps are based on measurable vulnerability values that can be used by politicians, administration, relief organization and operators of critical infrastructures on each geographical scale to present disaster situations by prioritizing activities and directing financial resources and personnel to the most vulnerable parts of the geographical region and the most vulnerable population subgroups (Queste and Lauwe 2006).

A spatial area is perceived on different scales. Every location is therefore integrated into spatial structures on both the micro and the macro levels. Any information gained from an analysis is subject to scale. This means that any analyzed functional or inherent pattern must be seen in relation to this spatial area. However, any planning area is autonomous. It will have many connections and reciprocal relationship with the surrounding areas, even the wider region. Any spatial analysis therefore has to look beyond the area under investigation and take into account its integration into the territory's structure. The decisive factor here is which element represents the smallest determining spatial unit for the analysis, expressed in factors like 1:20, 1:50; 1:100, 1:500, 1:1000, 1:5 000; 1:10 000; an so on. As an example, for a vulnerability assessment of the load-bearing structure of a building the choice of the working scale will be from 1:20 to 1:100. Instead, scale factors from 1:1000 to 1:10 000 are usually used for analyses at urban scale.

SCALE	LENGHT	AREA
MICRO (individual/household)	1 m - 1 km	1 m^2 - 1 km^2
MESO (regional/administrative)	1 km - 100 km	1 km^2 - 10 000 km^2
MACRO (country)	100 km - 10 000 km	10 000 km^2 - 100 000 000 km^2
MEGA (global)	> 10 000 km	>100 000 000 km^2

Tab. 4 Scale table

5.2.2 The crossing scale

In analyzing hazard impact, the challenge includes matching scales of physical, social and economical vulnerabilities with scales of management systems, avoiding scale discordance (matching the scale of the assessment with the scale of management). "Think globally and act locally" has become an environmental slogan; in the case of risks, local scale is really crucial in avoiding larger disasters, that may involve regions far away from the area directly hit by an extreme event or accident, and the effects of which can last for longer than the few moments in which it hits. Acting locally may mean sometimes avoiding extremely costly consequences for the settled communities but also for much wider regions (not to mention the fact that those effects are often trans-boundary across nations).

On the opposite, some global changes can act as drivers of change of hazard and/or vulnerabilities at local scale. Thus, to modify local dynamics an understanding of global ones is required. The only ways that those systems and dynamics can be meaningfully understood at anyone scale is to simultaneously capture the driving and constraining forces at both lower and higher scales (Pattee, 1973; Holling, 1978, 1986, 1995; O'Neill, 1988).

Using scale-dependent comparative advantages addresses the challenges in a number of ways. Scale discordance problems are likely to be diminished when parallel and integrated efforts of assessing the problem are undertaken at multiple scales. This approach appears particularly promising in the context of multi-scale problems in which perspectives, interests, capacities, and expertise shift from one scale to another.

As outlined earlier, the concept of vulnerability depends on the scale of analysis. Both exposure and distribution of vulnerabilities vary across scale (O'Brien et al. 2004). The vulnerability change when moving up and down in scale, from national to regional and local levels and vice versa. Macro analysis generalizations lose their relevance as a natural phenomena strike a region, a city, or a neighborhood. Changes in soil quality, topography, social groups and physical assets can vary across a county, resulting in disparity of exposure and consequences.

TYPE OF HAZARD			SCALE OF IMPACT
Meteorological / hydrological	Precipitations	Snow	Micro, meso
		Thunderstorms, rain, lightning, hail, wind	Micro, meso
	Floods	Static	Micro, meso, macro
		Dynamic (tsunami)	Micro, meso, macro, mega
		Flashfloods	Micro, meso
	Windstorms (hurricane)		Micro, meso, macro, mega
	Extremes temperatures	Cold waves	Micro, meso
		Drought, warm waves	Micro, meso, macro, mega
	Fire		Micro, meso
Gravitational	Avalanches	Snow avalanches	Micro, meso
		Ice avalanches	Micro, meso
	Ground instabilities	Landslide	Micro, meso
		Rock falls	Micro, meso
		Debris flows	Micro, meso
Seismic	Tectonic earthquakes	Ground shaking	Micro, meso, macro, mega
Volcanic	Eruptions	Pyroclastic density currents	Micro, meso
		Tephra fall	Micro, meso, macro, mega
		Lahars	Micro, meso
		Shockwaves	Micro, meso
		Gas emissions	Micro, meso
		Tsunami	Micro, meso, macro
		Volcanic earthquakes	Micro, meso
		Ground deformation	Micro, meso
		Lava flows	Micro, meso

Table 5. Scale of impact of different natural hazard

Even if exposure to a natural hazard is not constant across a country, some regions, sectors, or social groups may be more vulnerable to natural phenomena than others. A national-level assessment can sometime suggest that a natural hazard is not a threat for a country. However, when socio-economic differences and density of physical assets within a country are taken into consideration, then vulnerability emerges within some regions or localities (O'Brien et al. 2004). For example, communities that rely heavily on economic activities based on natural resources that are sensitive to climate and climate variability (e.g. winter tourism) are likely to be disproportionately vulnerable to climate change (O'Brien et al. 2004).

Assessments that include analyses undertaken at different scales must grapple with analytical issues not faced in a single- scale assessment. This include the establishment of methods for up-scaling or down-scaling in order to allow a comparison across scales, and the definition of mechanisms that ensure information flow across the scales (Zermoglio et al. 2005). This allows a better understanding of "causalities". In fact, the relationships among environmental, social, and economic processes are often too complex to be fully understood when viewed at one single scale (O'Brien et al. 2004). The information benefits that would be expected from a multi-scale assessment (in contrast to a single-scale assessment) is that a single-scale assessment tends to focus too narrowly on the issues and information most relevant to that scale. Perspectives gained from other scales would contribute to a fuller understanding of the issues (Kates and Wilbanks 2003).

5.2.3 The political and administrative scale

Another aspect that has to be taken into consideration when defining the scale of an assessment is that the choice of scale is not politically neutral, because that choice may privilege certain data.

> *"Scientific assessments are social and political processes in which competing interests, values, views, and options for action are negotiated. The definition of boundaries and the selection of scale are part of this negotiation. We know that in many cases existing spatial-administrative frameworks, emerging from other concerns, are not necessarily a good fit with the scales of natural hazards. The adoption of a particular scale for assessment limits the types of problems that can be addressed, the modes of explanation, and the generalizations that are likely to be used in analysis." (Zermoglio et al. 2005)*

Since different kinds of patterns or trends correspond to different scales, crossing scales helps to bring complementary knowledge, skills and capacity. But in many cases these mechanisms are limited by an unsupportive institutional context or a lack of respect or recognition by other stakeholders. Even where the institutional context is supportive, significant challenges remain (Berkes et al. 2006). These include difficulties in communicating concepts and ideas; and fundamental gaps in the capacity of people holding different types of knowledge.

The choice of what scale will dominate influence the agenda for decision making; it also influences which interests are most strongly reflected in the findings. Institutions operate at different scales and different scales tend to have different potentials and different restrictions for action (Berkes et al. 2006). For this reason, no single scale is ideal for broad-based investigation, although comparative studies at a single scale can contribute important insights (Schellnhuber and Wenzel 1998, Schellnhuber et al 2003, AAG 2003).

Sometimes, unfortunately, the integration of these analyses across scales can be limited by differences in who decides, who pays, and who benefits. But this political dimension also leaves the decision making process open to strategic interventions by particular stakeholders to shape outcomes in their own interests through the choice of scale. To be effective, most institutions must focus on particular scales; we cannot expect all institutions to deal with all scales and all systems of knowledge. Then, processes designed to cross scales and knowledge requires considerable time and effort. Time is needed to address many methodological, procedural and logistical issues (Berkes et al. 2006).

5.3 Scale in analysis

Addressing issues of scale in assessments require pluralism in ideas and approaches (Funtowicz and Ravetz 1993, Turner et al. 2003). The scope, complexity and interactions make impossible for any perspective, discipline, or approach to monopolize the answers and solutions. The scale at which an assessment is undertaken significantly influences the problem definition and the assessment results. Findings of assessments conducted at different scales diverge in the questions posed and/or the information analyzed. Assessments conducted at different scales tend to focus on indicators and impacts most relevant at each scale. These differences are the basis for some of the benefits of a multi-scale assessment process, since each component assessment offers a different perspective on the issues addressed (Zermoglio et al. 2005).

What highlighted in scientific literature is that analyses and assessments at different scales tend to be associated with different research paradigms and styles. As one example, in analyses of climate change responses, work at a global or national scale tends to be characterized by quantitative analysis, using net present value metrics, while work at a small-regional or local scale tends to involve integrated assessments, including significant stakeholder involvement (Wilbanks et al. 2007).

The variability among assessments in problem definitions, objectives, scale criteria, and methods of analysis and explanation increased at finer scales of assessment (for example, the visibility of social equity issues increased from coarser to finer scales of assessment). Downscaling and up-scaling, in fact, are likely to contribute different insights; for instance, bottom-up investigations often provide different understandings compared with top-down investigations mainly related to resolution issues and availability of indicators. Other findings include (a) that different scales are related to different institutional roles, and that the scale of decisions is often poorly matched with the scale of the processes being decided upon, and (b) that the choice of a scale and a set of boundaries is not politically neutral, even if the choice is not based on political considerations.

The most important aspect in addressing a cross-scale analysis is the recognition and judicious use of a mix of perspectives, methodological approaches, tools, and techniques. This includes complementary use of qualitative and quantitative measures as well as participatory and multidisciplinary exchanges; the combination and innovation of indicators, means of measurement; and development of common objectives.

Then, is the use of methodologies and analytical approaches that allow a more complete description and understanding of the relationships across scales and of the similarities and differences of processes and phenomena at different scales. This includes the analysis of scale-dependent and scale-independent factors, the use of up-scaling and downscaling techniques, the identification of characteristic scales of different processes or phenomena, and the introduction of methodologies to detect relevant changes at different scales, as well as seeking a meta-scale synthesis. Finally, is the translation of information and findings between and among disciplines (Berkes et al. 2006).

The scale matters: case studies

A spatial area is perceived on different scales. Every location is therefore integrated into spatial structures on both the micro and the macro scale. Any information gained from an analysis is subject to scale. This means that any analyzed functional pattern must be seen in relation to its spatial area. However, any "area" is autonomous. Actually, any spatial area has many connections and reciprocal relationship with the surrounding areas, even the wider region. For this reason, any vulnerability analysis therefore has to look beyond the area under investigation and take into account its integration into the territory's structure.). The correct scale for representing analysis results on a map must be chosen according to the size of the analyzed area and the degree of detail in the analysis. As an example, the areas of probable occurrence of hazards, particularly meteorological hazards such cyclones, are usually indicated on maps of much larger areas. These maps although not very detailed, nevertheless have an important role in warning development planners of large scale trends (Spence). The decisive factor here is which functional pattern element represents the smallest determining unit for an analysis (building, building plot, neighborhood, urban area, etc.)

In this paragraph different study cases, in relation with scale matters will be presented. The first case deals with the physical vulnerability to earthquakes at the micro, meso and macro scale of Istanbul. The complexity of city makes difficult any vulnerability analysis. A simplification of the city as "complex phenomenon" is required. To deal with this complexity, scaling methods and the choice of appropriate indicators could be a useful approach. The solutions in every sub-system are gathered to give us the whole picture for solving the original problem. In this case study, vulnerability in space will be explored regarding to different scales and system components.

The second case study is focused on the choice of the appropriate scale for the physical vulnerability assessment in landslide prone areas. Different cases of landslides through the world are presented and their impact and consequences analyzed.
In the third case study cross-scaling methods are analyzed for the Katrina flood disaster. A matrix for four scales of vulnerability analysis (individual or household, local, regional and national) with the related indicators are proposed and this for each period of the disaster phase. The matrix is structured in such a way as to permit each of eight vulnerability facets to be separately addressed.
Finally, the last case study discuss a method to visualize economic damage to floods in applying spatial modeling techniques with regard to scale matters in South Holland.

5.3.1 The case of Istanbul, Turkey (POLIMI)

The increasing population and growing rates of cities mark the last decades where natural hazards become the main risks for some cities. The reason lies behind the complex physical, economic and social networks in a city. The major question here is this; "What are the ways to understand and/or measure risk in a complex city system?" According to the definition of risk in the Living Risk report (UN/ISDR, 2004), risk is the probability of harmful consequences, or expected losses (deaths, injuries, property, livelihoods, economic activity disrupted or environment damaged) resulting from interactions between natural or human-induced hazards and vulnerable conditions. In other words, the value of risk depends on the severity of hazard and the vulnerability of the exposed systems. Geological and geomorphologic characteristics of an area and event scenarios could give an idea about the severity of a hazard. However, without any changes on the ratio of hazard, risk could be increased due to the vulnerabilities of physical, social, economical and organizational systems that exist in a city.

In an urban system, vulnerabilities can be observed in physical, economic and social patterns; also it can be affected in regional and local scales. Buildings, public facilities, plants and infrastructures are the contributors of physical vulnerability. Economic vulnerability is related with market and insurances. It can be divided in macro and micro level as the division in economy. Population in a city and organizational and institutional pattern of this population influence the social vulnerability. The coping and adapting capacity of a population affects directly the social system vulnerability. Cities are composed of these physical, demographic, social and economic systems. Moreover cities are not sum of these systems, there is also a strong interaction among these systems. Any action in a system could have also reaction in another one. So these interactions make the city system complex and challenging.

The complexity of city systems and strong interaction between parts of a city complicate vulnerability assessment procedure while examining it by using variables existing in cities. For this reason there is a need to simplify the city pattern. Making it simple also helps to see the interaction between parts as far as the city reinforce to earthquakes is concerned. To deal with this complexity scaling could be an useful method. In scaling, determination of the study area and the indicators in every scale is crucial. "Divide and conquer" approach in mathematics could be carried over to natural risk assessment as a scaling method to simplify the existing complexity. "Divide and conquer" approach is a powerful tool to solve the complex problems (Cormen et al. 2001; Brassard & Bratley, 1996). In this approach the entire system breaking down into the sub-systems. The solutions in every sub-system are gathered to give us the whole picture for solving the original problem.

In this section, vulnerability in space will be explored regarding to different scales and system components referring the case of Turkey at the macro scale through Istanbul and its districts on meso and micro scales respectively.

Spatial Vulnerability at National/Regional Scale (Macro Scale)

Besides several natural threats, Turkey is largely exposed to earthquake hazard due to its geographical location where it is situated on the Himalayan Alpine belt and among big tectonic plates. Two main fault systems travel the Anatolian land. The Eastern Anatolian fault (app. 700km) extends between the eastern end point of the North Anatolian Fault (NAF) and the city of Kahramanmaras through the southern direction. 1300 km-long North Anatolian Fault system extends from east side through the west side of Anatolia and parallel to the Black Sea. There are several short but highly active faults in the Central Anatolia and the Aegean Regions as well. Therefore, more than 90% of the total land of the country and the population are exposed to seismic hazards. In the last century, in Turkey, 130 devastating earthquakes occurred, and as the consequences of these earthquakes 80.633 people were killed, 54.380 people were injured and 441.611 housing buildings were destroyed (Bagci et al. 1994).

Physical vulnerability at the beginning of the 20th century was highly correlated with masonry buildings, whereas, despite technological advances in building construction using reinforce concrete, physical vulnerability has increased because of the mis-implementation and low construction quality. Especially cities which received mass migration flow during their history have become more vulnerable against natural threats. There are two main reasons of physical vulnerability in big cities: first, new comers to cities provided their need of shelter by themselves which means they constructed their own houses without any engineering contribution; second, contractors who had neither experience nor training on engineering constructed several buildings. Local administration in many cities became un-sufficient because of lack of personnel to control this development. Moreover, amnesty laws which usually were set before local administrative elections, encouraged illegal and unplanned development at the fringes of big cities.

On the other hand, 5 year development plans which have indicated development pattern in the nation wide, focused on industrial development in the periphery of large cities. The most relevant example is Kocaeli which is the industrial heart land of Turkey and unfortunately which was hit by a devastating earthquake in 1999. This earthquake showed that location choice for critical facilities and industries is very crucial especially if the site is exposed to seismic hazards.

From the socio-economic perspective, regional disparities in Turkey mostly cause and are caused by lack of spatial integration, poor economic development and lower capacities at the non-metropolitan regions. On the other hand, regional disparities in socio-economic and demographic structure reveal big pressures on metropolitan areas. Especially, considering the huge gap in GDP per capita between the eastern and western regions of the country, regional inequalities become more visible (Erkut and Baypinar, 2009). This aspect reveals two types of vulnerabilities on poorer and wealthier cities: poorer cities/regions are not capable to reduce their vulnerabilities because of the lack of any kind of resources (either financial or human force); and wealthier cities/regions give support to poorer cities/regions in the case of need but they have no guarantee to be supported when they face with a disastrous event. Kocaeli earthquake in 1999 is a remarkable example to explain this situation. Despite Kocaeli is not the primate city of Turkey, its function is very crucial for industrial development of the entire country. Once the earthquake hit this region, the major support came from Istanbul by the means of equipments, personnel, goods, medicines etc. Aftermath of the Kocaeli earthquake, the probability of occurrence of a severe earthquake, which would affect large territory including Istanbul, has been calculated regarding to earthquake catalogues and tension accumulated on the NAF due to most recent seismic events. In the following 30 years from 1999, it has been estimated about 62% of probability of occurrence of a big earthquake affecting southern Istanbul, whereas about 32% of probability for the following 10 years (Barka 2000, Parsons et al. 2000). From this point of view, the risk that Istanbul is carrying out, is very critical not only for this big city, but for the country as well.

Spatial Vulnerability At Provincial/Sub-Regional Scale (Meso Scale)

Istanbul, due to its strategic location and historical background as the capital of three empires, has been the heart of national and international economic activities in Turkey. In the beginning of 1950's, the development of Turkish economy reinforced the dominant economic role of Istanbul in all over the country. In this period, the rapid population growth due to migration from rural part of the country caused rising density and expending urban area. However, the planning processes remained insufficient against this "rapid development" and Istanbul gained a complex and uncontrolled urban pattern. Expansion of urban land in Istanbul showed linear development in the southern part of the city, from the eastern side to western side, parallel to NAF. Both population and building density increased in the fringes of the city. Newly developed sub-centers and industrial areas enabled to change mono-centric structure of Istanbul to poly-centric structure. Despite, this development process tends to arrange inner-city flows and protects forest land in the northern part of the city, earthquake vulnerability increased in Istanbul.

Figure 61 shows the expansion and the development axis of Istanbul since 1500. The development process of the city explained above is clearly seen on the schemes. Between 1500-1900, Istanbul was remained intra-murals of the city due to some defensive reasons. During the 20th century, the city experienced a great transformation and enlargement which was never seen before in its history. As indicated above, after building of bridges which are connecting two sides of the city, in other words two continents, provided huge commuting between European Side and the Asian Side of the city. The rapid migration flow, increase in the population rate and land re-adjustments usually supported by politicians enable the city to get the present macro-form showed in the last cell of Figure 1.

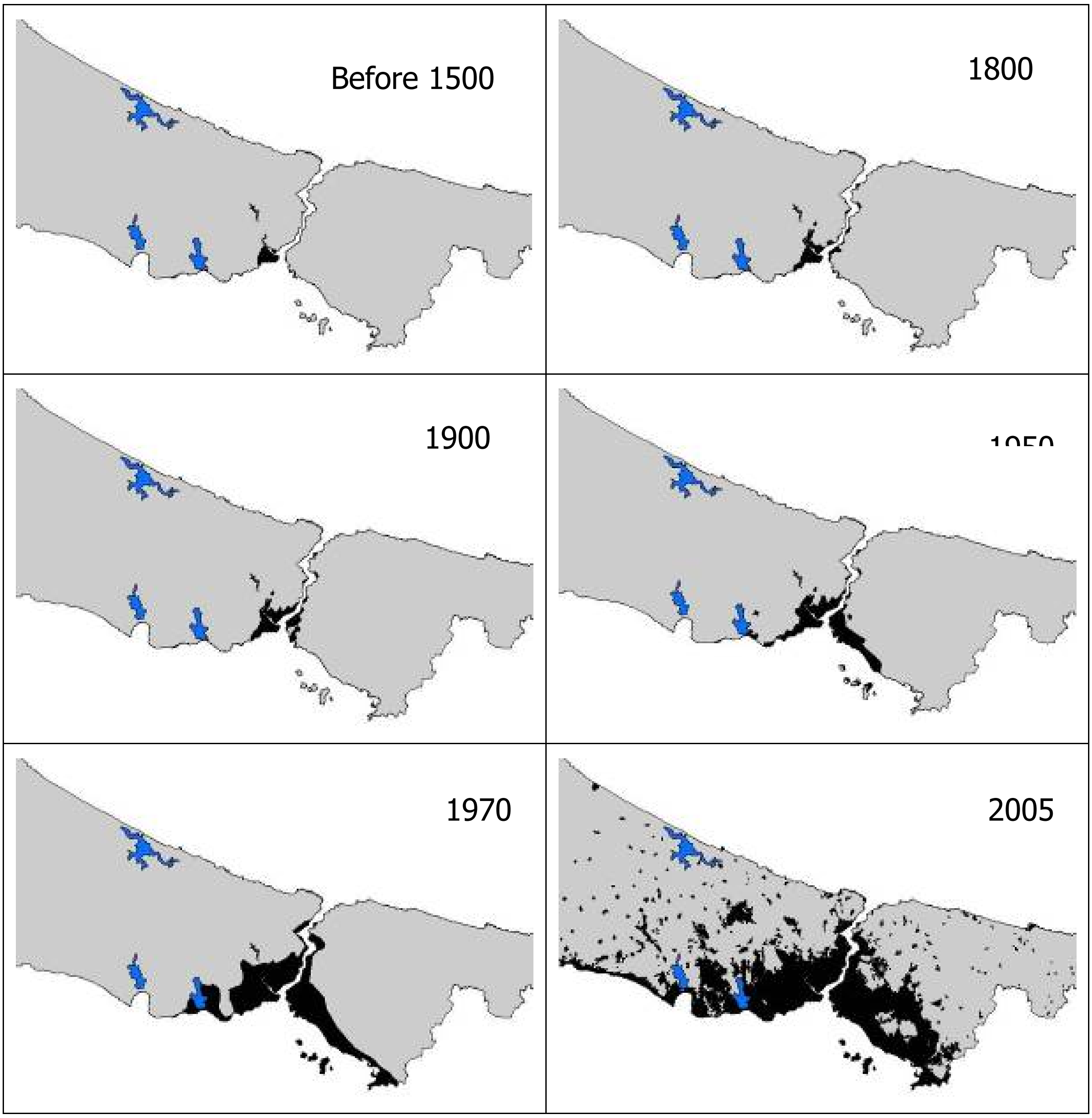
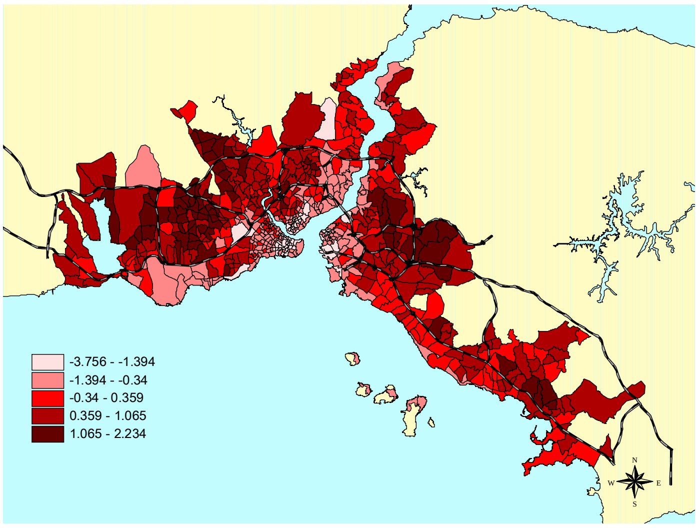
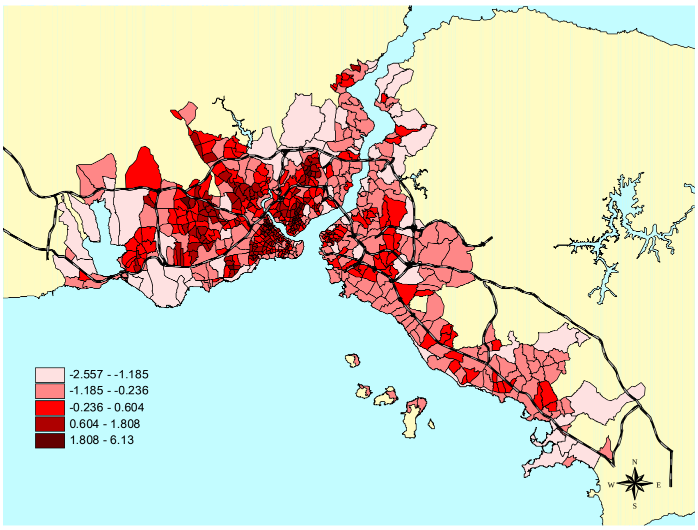


Figure 61 – Spatial Development of Istanbul between 1500 to present (Turkoglu and Kundak, 2006 adapted from JICA and IGM 2002)

With a population more than 10 million, Istanbul shows a great heterogeneity once comparing its districts and neighborhoods. This feature of the metropolitan city affects vulnerability and risk analysis in city wide. Kundak (2006) focuses in investigating vulnerability components affecting earthquake risks in Istanbul, caused by a probable seismic event expected in Marmara Sea, on the North Anatolian Fault. In order to examine the earthquake risk in Istanbul, 15 variables are used which represent hazard and vulnerability for 613 neighborhoods of the Istanbul Metropolitan Area. The methodology of the empirical part of this study is based on principle component analysis which provides to evaluate risk variables through the main factors. Originally, 27 variables were collected, but after testing for multi-collinearity among the variables, 15 independent variables were used in the statistical analyses. Besides multi-collinearity, representation of each variable in neighborhoods was crucial. For instance, as historical assets and old type wooden buildings (structures) are focused in the historical part of the city, these variables had to be taken out of the model. The model explained 67.3 percent of the total variance in the neighborhoods of Istanbul where the urban vulnerability components (demographic, physical and economic) represented 47.1 percent in the model (Figure 62).



Vulnerability related with land use and population



Vulnerability related with density and lack of potentials

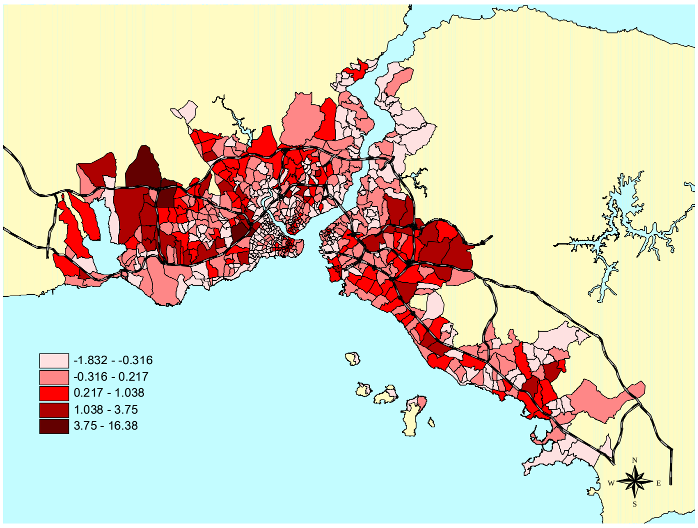
	Vulnerability related with business activities

Figure 62 – Vulnerability components of Istanbul at metropolitan scale (Kundak, 2006)

As a large metropolis Istanbul has a complex urban pattern with high heterogeneity which means the city covers sub-regions, districts and neighbourhoods considerably differing from each other. The standard deviation of each variable on city wide including 613 neighbourhoods and the historical site with 147 neighbourhoods shows the great differentiation in urban pattern. In the next research by Kundak and Turkoglu (2007), only historical part of Istanbul was analyzed regarding to earthquake risk parameters. Hereby, despite the data set was the same with the previous research, the scale and the focus of the analysis affected the findings. In this research the results illustrate that the 24 variables out of 27 are corresponding to the seismic risk with an explanation level of 76.2 % where urban vulnerability components represents 59,8 percent. Vulnerability of critical facilities due to land use decisions and concentration of economic activities were revealed as main components affecting earthquake risk in the historical part of Istanbul (Figure 63).

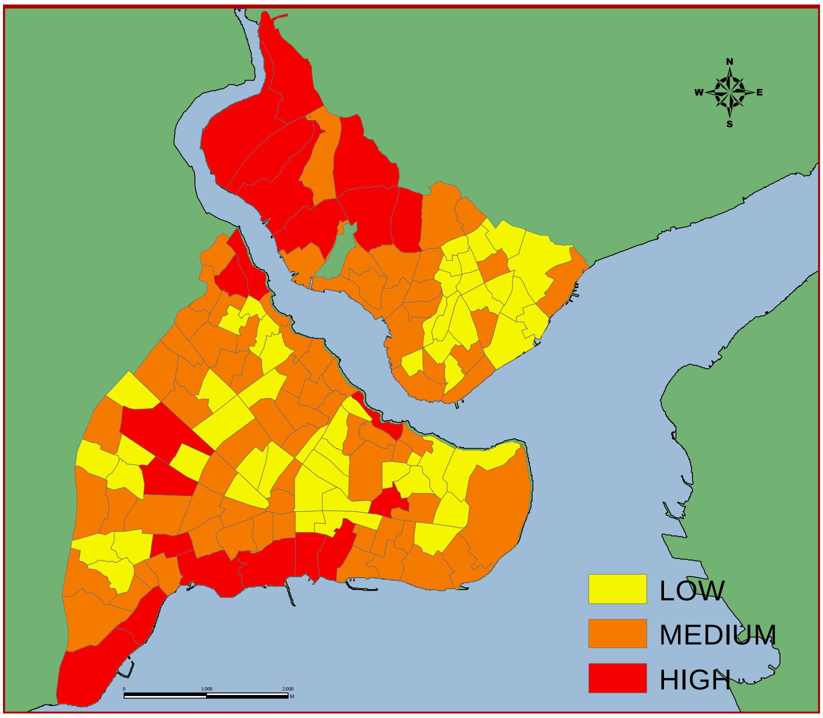


Figure 63 – Total risk scores for the historical part of Istanbul (Kundak and Turkoglu 2007)

Spatial Vulnerability At District/ Neighbourhood Scale (Micro)

As mentioned in the previous paragraphs, metropolitan cities have a complex and heterogeneous structure which makes challenging vulnerability and risk analysis respectively. The tiered classification (Bendimerad, 2001) provides different layers of resolution in data. Atun (2009) focused on the heart of the historical peninsula of Istanbul (Eminonu district) to underline vulnerability components of this specific area by using its demographic, physical and systemic characteristics (Figure 64). Firstly, demographic vulnerability is given by focusing on the distinction of day/night population and vulnerable groups according to their age (Figure 65). Secondly, the city pattern is simplified by dividing it into four distinct parts - artefacts, lines, voids and nodes - to understand the physical and systemic vulnerabilities.

Initially, the vulnerability analysis for artefacts is done in the Eminonu area by emphasizing on the four vulnerability indicators; building structure type, building maintenance degree, number of floor and way of uses (Figure 66). Then, vulnerability assessment of lines is done by considering road, water, gas, electricity and sewage systems with the data in the report of JICA and IMM (2002). All the linear systems merged together in a 500m-500m grid pattern by using the same colours in all the maps to asses the most vulnerable area (Figure 67). Besides, voids are considered, it is seen that 365ha of the area is urbanized and there is an only 143ha empty space which is 19% of the total coverage. After that, nodes are analyzed by dividing them into two, essential and hazardous facilities. While hazardous facilities lead to have an increase in the vulnerability of area, essential facilities provide opportunities. In addition, electrical transplants, gas stations and bridges are seen as hazardous facilities; ports, railway stations, public buildings (hospitals, schools; governmental, municipal and religious buildings) are seen as essential facilities. However, the existence of essential facilities does not guarantee having opportunities. The important thing is to constitute a good coordination among the facilities rather then just having them.

As a final product, the integrated risk map is created by merging the data that came from the analyses of hazard, vulnerability, land use and demography. The map determines the risk areas according to the considered vulnerability indicators. There could be diverse results by changing or adding more vulnerability indicators. The areas are divided according to their priority and three types of priority areas are classified. (Figure 68)

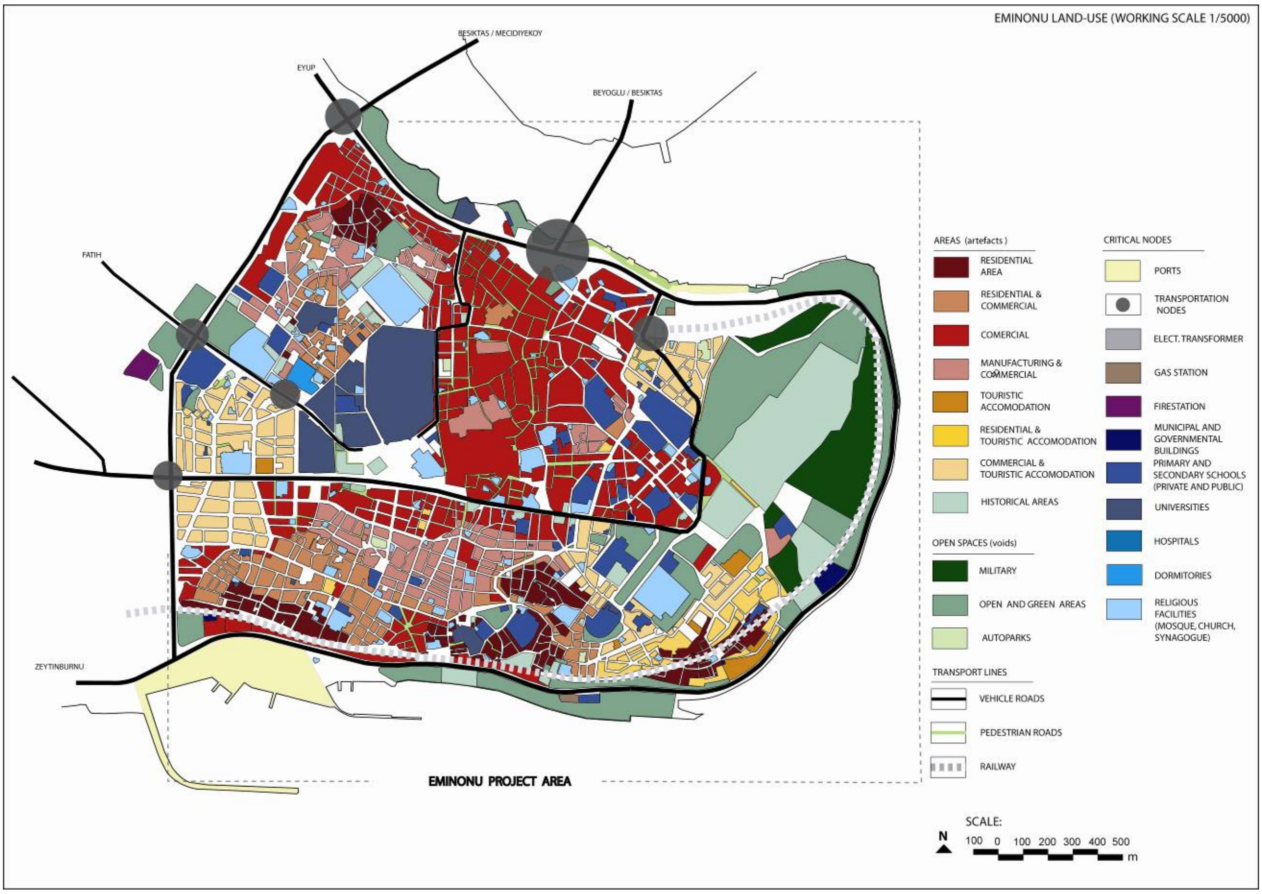


Figure 64 - Eminonu land-use plan (Working scale: 1/5000) (Atun, 2009)

Figure 65 - Vulnerability of population (in density and number) (Atun, 2009)

Figure 66 – Vulnerability of physical components of Eminonu district (Atun, 2009)

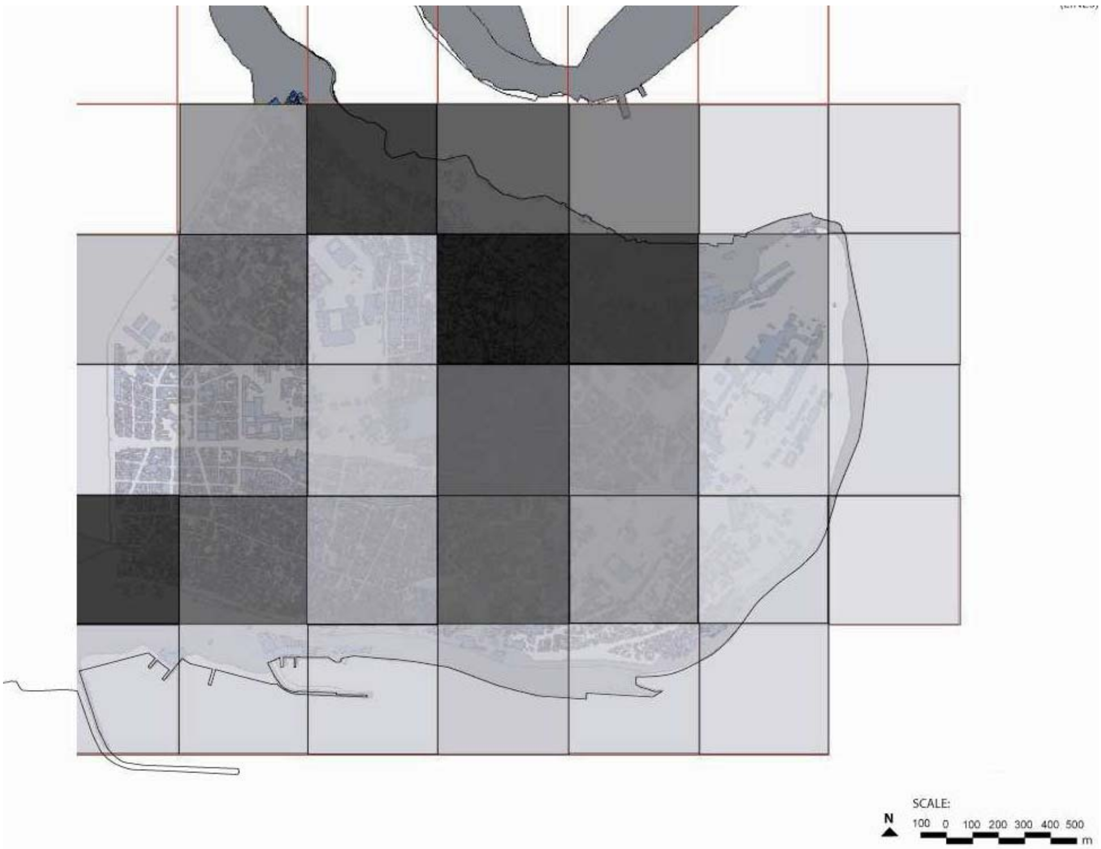


Figure 67 – Vulnerability of infrastructure of Eminonu District (Atun, 2009)

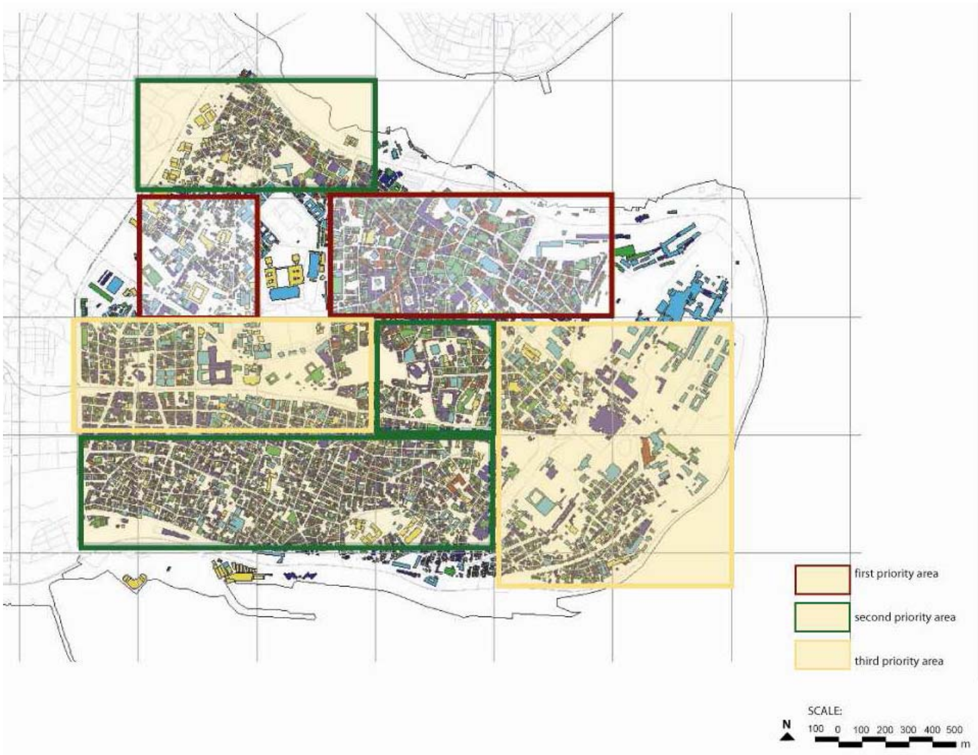


Figure 68 – Integrated risk map of Eminonu district (Atun, 2009)

5.3.2 The Katrina Hurricane (MDX)

Methodological development

One way of thinking about how an assessment of different vulnerability facets can be structured using both a multi-scale and a cross-scale methodology is displayed in Figure 69 and Table 6 below. The significance of different types of vulnerability (including vulnerability to stress, susceptibility to loss and capacity to recover) varies over disaster phases, as does the level or amount of vulnerability. It is necessary therefore to perform vulnerability assessment broken down into the principal phases of a disaster – in this case with one 'page' representing each phase (Figure 69). A prototype example of the first page is shown in Table 6. A similar matrix is needed for each of the four pages. The matrix is structured in such a way as to permit each of eight vulnerability facets to be separately addressed. In this example four scales of analysis are utilised – individual or household, local, regional and national, although scale can be used to represent any unit of space. For example, the analysis could focus upon economic entities such as businesses, and the sub-regional or city/metropolitan scale might be considered to be important. The scale analysis could also extend to a continental or global scale. Sub-divisions within vulnerability facets are likely to be necessary. For example, economic vulnerability can be broken down into at least two distinct forms: financial and the vulnerability of an economic system or economy. For the latter the analysis would skip the individual or household scale to the local level.

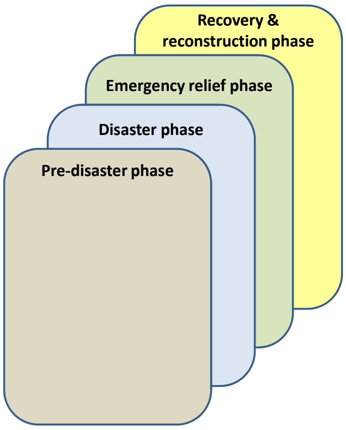


Figure 69 Prototype multi-scale and cross-scale vulnerability assessment matrix pages

Similarly, in previous deliverables several definitions or ways of interpreting institutional vulnerability have emerged and these differences could be reflected in the analysis. In considering social vulnerability three principal forms are identifiable from Del. 2.1. These are a) human capital b) social capital (e.g. family and neighbourhood networks and support groups) and c) physical elements of social capital (e.g. schools, social club premises, internet cafes).

The scale analysis is performed in several ways. First, vulnerability will be present to some degree at each scale (e.g. at the individual or household level, or at the local level) and the range of scales provides for a multi-scale analysis. Second, cross-scale analysis is also catered for in the 3rd, 5th and 7th columns of the matrix. The cross-scale analysis potentially operates in both directions – up-scale and down-scale.

Crucial to the analysis is the type and form of information and data which is entered into the cells of the matrix. Clearly, the information and data presented may be in various forms. Much depends upon the information and data which are available to the analyst, and this depends at least to some extent upon secondary sources and/or the resources available to the analyst to undertake primary information and data collection. Although, in theory it should be possible to obtain information and data for every cell of the matrix, in practice research advances are likely to be required for this theory to be translatable into reality and practice. Considerable research time and effort may well be required to undertake an analysis of just a single component of cross-scale linkage. For example, for the effects of hurricane Katrina, estimating the state-by-state economic impacts is a distinct and substantial piece of research (see Park *et al.,* 2008), as is the estimation of the regional economic impacts of utility lifeline disruption to households (see Rose and Oladosu, 2008). Economists have developed econometric models (e.g. input-output models) which allow the cross-scale of economic impacts of floods to be estimated (e.g. Islam, 2006).

Given the existing situation in which information and data are likely to vary considerably in their availability, quantitative or qualitative form, detail and quality, it would appear to be necessary to develop a simple hierarchy of assessment methods and data. This would range from a relatively crude, desk-top analysis using a mix of quantitative and qualitative readily available data up to a much more sophisticated, largely quantitative analysis based as much as is feasible upon the results of substantive research.

Table 6 Prototype multi-scale and cross-scale vulnerability assessment matrix

Disaster type: *tidal surge flood*	**Disaster phase – *Pre-disaster***						
Vulnerability facet	**1. Scale 2. Cross-scale (←→)linkages**						
	Individual or household	Individual or household ←→ Local	Local	Local ←→ Regional	Regional	Regional ←→ National	National
Physical							
Ecological							
Cultural							
Economic 1. Financial 2. Economy							
Social							
Systemic							
Institutional 1. 2.							
Territorial							

Information and data for economic vulnerability in the pre-disaster phase

As an example, we can take the financial vulnerability of the inhabitants of St Bernard parish. The kind of information and data which might be entered into the matrix cells is shown below. The example is relatively crudely developed here and requires much deeper examination than has so far been possible. There are some significant value estimation issues involved in developing such data. Also it has not yet been possible given the resources available to us to examine the forms of information and data which would be appropriate, for example, for institutional vulnerability or territorial vulnerability using such an approach.

Individual or household level

Susceptibility to loss of:

- The value of the properties of 66,000 individuals, circa 25,000 households.
- The mean economic output or income earning capacity of these individuals/households, measured as N thousand $US per annum.
- The mean purchasing power of individuals and households measured as N thousand of $US per annum.

Individual or household level to and from Local

Up-scale impact

Susceptibility of loss of:

- N local customers for local businesses i.e. reduction in local spending
- N local employees for local businesses i.e. reduction in local output

Down-scale impact

Susceptibility of loss of:

- N quantity of jobs lost as a result of local businesses being damaged
- N quantity of local suppliers lost for local customers

Local

Susceptibility to damage and loss of:

- 3,000 local economic/business entities
- N quantity of services and infrastructure supporting local businesses on which they depend
- N reduced tax revenues from businesses and homes

Local to and from Regional

Up-scale impact

Susceptibility of loss of:

- N% of local individual and household purchasing power lost to the region (this is proportionate to the number of evacuees moving to evacuation centres outside of the region)
- N% loss of employees from the local area who work in the region
- N% of local business purchases from other businesses in the region
- N% loss of local tax revenues to region

Down-scale

Susceptibility of loss to:

- N% of regional purchasing power normally expended in the local economy
- N% of jobs in the region filled by local employees which are lost as a consequence of the flood losses across the region

Regional

Susceptibility to loss of:

- The value of the output and exports of the local economy to the region
- The value of local economy expenditures in the region
- The economic multiplier impacts of the above losses

Regional to and from National

Up-scale impact

Susceptibility to loss of:

- The value of the output and exports of the regional economy to the nation
- The value of regional economy expenditures in the nation
- The economic multiplier impacts of the above losses

Down-scale impact

Susceptibility to loss to:

- The value of national purchasing power in the region
- The value of jobs in the nation filled by regional employees which are lost as a consequence of the disaster across the region

National

Susceptibility to loss of:

- The value of national output
- Economic growth and GDP

The form of multi-scale and cross-scale analysis performed in the prototype vulnerability analysis above accords most closely to the second interpretation of the scale concept outlined in Del. 3.2, Section 5.1. Further work is required to determine the extent to which the other two concepts of scale can be encompassed within such an approach.

5.3.3 Spatial explicit modeling of vulnerability to flooding (ITC)

Introduction and Problem statement

Socio-economic systems are highly vulnerable to disasters like tsunamis, floods and earthquakes. In this contribution, we introduce and discuss an method to visualize economic damage incorporating the capacity of an economy to cope with a disaster. We focus on the pitfalls in applying spatial modelling techniques to picture economic importance of grids in a region that is susceptible to flooding. In the following we will focus on the importance of considering scale in the analysis and explain in more details the method we proposed.

Damage concepts

The purpose of doing research on concepts of economic damage due to flooding is to draw policy lessons from previous experiences and to help designing better flood mitigation schemes. The concept of damage plays an eminent role in any such scheme since it constitutes the "benefit" side of the scheme. The benefit of any project on flood mitigation and flood protection lies in the damage that is prevented due to the scheme. We therefore need to know how damage is accounted for, who is receiving benefits and who is paying costs. This all refers to a particular level of analysis in time and space. From a cost benefit standpoint the choice of a level of analysis is obvious, literature prescribes that the regional and/or national level should be the level of analysis for any cost benefit analysis. To what extent can we account for national damage due to a local or regional flooding?

This problem makes us look for a definition of damage that goes beyond the definitions that usually are applied in systems that are dealing with depth-damage curves. Common practice in the flooding (engineering) literature is to visualize risk and thus the underlying effect by counting unit losses (Parker, Green and Thompson, 1987) With different flood-depths, depth-damage data is used to asses flood losses. The current state of this type of models (Vrisou van Eck and Kok, 2001) is that data on land cover is collected and downloaded into a GIS environment. Damage assessment then counts the number of units of a certain type in the affected area and multiplies this with a damage factor. The latter is a relationship empirically derived from surveys, in which a relationship is established between depth and damage. The damage factor is the heart of the method and thus plays an important role in estimating damage. In standard research on flood management, the value of damage is based on a replacement value. This might not reflect the economic value of the goods at risk. Equally important however, is that depth-damage curves are not equipped for dealing with the dynamics of a national economy, while evaluating damage on a local level and not accounting for the dynamics inherent to damage on a national level. In other words depth-damage curves are not dealing with the coping capacity of the non-flooded area.

Consequently, we should search for an indicator of damage that reflects the economic value of the goods at risk. The viewpoint for accounting damage we choose here is a national point of view applying the concept of *vulnerability*, with which we grasp some of the dynamics that are lacking in depth-damage models like the structural patterns in an economy; the treatment of forward and backward linkages; and interregional spill-overs.

Vulnerability

In the following, we will argue that vulnerability and economic damage are interrelated concepts. (Green, 2003) defined vulnerability in the context of resiliency and susceptibility:

> *Therefore, in defining vulnerability and resilience we must define what is the system, which is of concern. We can start by defining susceptibility as: "the*

> *nature and magnitude of the perturbations which can affect the system in question negatively." When that system is susceptible then vulnerability can be defined as: "the time varying status of some desirable or undesirable characteristic(s) of the system in question". So, in turn, the resilience of a system is: "the dynamic response of vulnerability over time to the perturbations to which the system is subjected." A resilient system is then one, which bends under stress, but does not break, and which returns to a desirable state after the perturbation have passed.*

Consequently, with respect to economic damage we are dealing with two aspects that relates damage to vulnerability. Firstly, there is the idea of an economic system that is in some state of equilibrium. Secondly, that due to an external shock this economic system is brought out of its equilibrium state with a propensity to return to a new equilibrium. We use the term redundancy to mirror this tendency. Depending on the redundancy in the system, an economy is able to cope with a disaster.

According to the Green (2003) vulnerability was *the time varying status of some desirable or undesirable characteristic*. In this contribution we take Value Added (a statistic from the worldwide used economic System of National Accounts) as the characteristic we want to measure: Value Added is taken as the economic value at risk.

In their seminal paper (Parker, Green and Thompson, 1987) presented vulnerability as determined by susceptibility, dependency and transferability. Susceptibility is the probability and the extent to which the physical presence of water will affect inputs or outputs of an activity. Consequently, susceptibility refers to the physical characteristics of an area. Transferability is what we nowadays would call redundancy. Dependency is the degree to which an activity requires a particular good as an input to function normally. The backward linkages in a regional/national economy determine this latter variable: a factory, which is flooded, will also affect the factories that deliver goods and services as an input. Via economic multipliers, the disaster spreads over the region. In conclusion, economic values at risk at a spot, susceptible to flooding, should be measured by vulnerability, which not only points to the importance of the spot itself, but also the relation with other spots, which are dependent on her existence. Moreover, it measures the redundancy in the system as a whole. In doing so however, we encounter some problems with the coupling of micro- and macro data. These are the problems that can be placed under the umbrella of Ecological Fallacy: it is possible to make inference about the group but this cannot be translated to the individual elements of the group (Robinson, 1950). In our case, this problem refers to the fact that we have data on tabular economic sectors that should be linked to spatial economic data on individual elements of the sector.

Spatial explicit modelling

Designing flood alleviation schemes comes down to making a spatial decision. It is location and nothing else that determines whether any scheme on protecting against natural disasters can be successful. Consequently, we want to model vulnerability in an economic system in such way that we are spatially explicit. What then does it mean to be spatially explicit? There seem to be four basic tests judging whether a model is spatially explicit (Berger *et al.*, 2001):

- The invariance test: A model is spatially explicit if its results are not invariant under relocation of the objects of study.
- The representation test: A model is spatially explicit if location is included in the representation in the form of coordinates or derivative spatial properties such as distances.

- The formulation test: A model is spatially explicit if spatial concepts such as location or distance appear directly in the model, in algebraic expressions or in behavioural rules.
- The outcome test: a model is spatially explicit if the spatial forms of inputs and outputs are different. In other words, a spatially explicit model modifies the landscape on which it operates.

Geographic information systems (GIS) provide one of the basic platforms for spatially explicit modelling. GIS software provides the foundation for representation and handling of spatially explicit information and makes it easy to add a wide range of analytical modelling and related functions.

In our empirical work, we choose to model vulnerability in a spatial explicit way by taking geo positions as the basis for our analysis. Moreover, distance is one of the key-elements in creating density surfaces.

Macro and micro data

By combining spatial explicit modelling based on location, and damage estimation based on the concept of vulnerability, we come across a problem, which is the heart of this paper: combining micro and macro data.

In computing an index for vulnerability, we need to relate micro information per grid to aggregate indicators of redundancy in a regional/national economy. This implies that we need to use kernel density estimation for the link between macro-data and a micro-level of analysis.

As an illustration, we present the result of a computation for the province of South-Holland in the Netherlands, where we simulated a large scale flood stemming from the river side (van der Veen and Logtmeijer, 2005).

In Figure 70 we show the vulnerable grids in the province of South Holland.

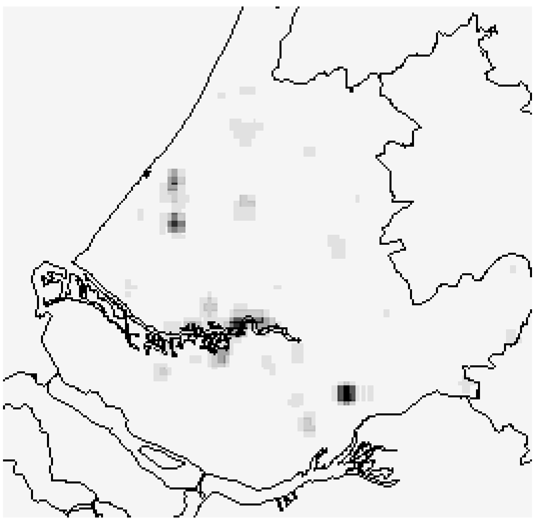


Figure 70 Vulnerable grids in South Holland; Combining micro information on 28 economic sectors with information on forward and backward linkages and information on redundancy in the rest of the Dutch economy.

We used an input-output framework as a starting point for our data assessing damage, both direct and indirect, and redundancy. With a simple overlay procedure, we estimated how many factories per SIC-code[9] were either damaged or destroyed. This on the assumption that when the site was flooded the production facilities of that site were either damaged or isolated and were not able to produce anymore.

Following this example we will establish the conditions for implementing vulnerability in a spatial explicit model. An overview is given of the proposed method and further research on sensitivity analysis is presented. First we focus on strengths and weaknesses of the model.

Spatial tools: potentials and pitfalls

The model we apply takes several steps to estimate hot and vulnerable spots. In this section we describe these steps en we look at several critical decisions in the process involved. These critical decisions can be traced back to three elementary steps:

1. Aggregation and scale
2. Weights
3. Kernel density estimation bandwidth

Aggregation and scale

Scale is important in two distinct ways (van der Veen and Otter, 2002): in the form of extent (the area covered by the model) and in the form of resolution (the level of detail inherent in the model). Scale related issues play an important role when it comes down to the process of validation, verification and calibration of the model. As mentioned earlier issues like ecological fallacy, the modifiable area unit problem and aggregation effects then come into play. There are no hard and fast rules for scale-related issues.

Based on the idea of the ecological fallacy we have looked for a level of analysis that allows us to overcome this problem. In our case we have found this level by aggregating data for individual sites to the level of sectors and we combining this information with the sectoral data available in our input-output tables. In this way we do not loose any information and we are still working with a level of detail that fits our purpose of finding regional hot-spots.

Weights

In our model we combine micro data on value added per grid with macro data characterising the regional and national economy. We deduct the characteristics of the national economy from an Input Output table and apply them in a weighted overlay procedure. A value in a cell is being corrected for its contribution to the entire economic system. The logic of this model is that we can account for sectoral differences by referring to each sector's role in the economy translating this into a data layer. This enables us to cope with aggregating sectoral information into a new single map of vulnerable spots.

Kernel density estimation bandwidth

In our model we have to combine spatial and economic data on the level of economic sectors. We need to aggregate data per zip code to a map of hotspots per economic sector.

[9] SIC code: Standard Industrial Classification. Classification of CBS. Central bureau of statistics.

To overcome this problem of combining micro-data to macro data we used kernel density estimation.

Several forms of Kernel density estimation exist. Each and every variant basically works on the same principle. A kernel is based on a specific cell and the values of a variable in the surrounding cells within a certain *bandwidth*. These cells are evaluated to see how much they contribute to the kernel cell. Based on surrounding values, the centre of a certain spatially distributed phenomenon is assessed. This phenomenon can be any kind of incident that occurs over space. In our case we examine the centre of economic activities. There are two main issues involved in the application of Kernel density estimation. Firstly, there is the choice of the formula according to which the values of the surrounding cells are to be evaluated. Secondly, there is the choice of the proper bandwidth. For the former some guidelines exist in the literature, for the latter no single guideline exists[10].

Five kinds of formulas for estimation are available. Literature (Levine, 2000) suggests that for our purpose the best way is to use the quadratic formula. This formula is described as following:

$$g(x_j) = \sum [W_i I_i] * \left(\frac{3}{h^2 \pi}\right) * \left(1 - \frac{d^2{}_{ij}}{h^2}\right)^2 \qquad (1)$$

in which

g = the total value per kernell

x = a point that contributes to the value of the kernel cel

i = the indicator of the kernel cel

j = the indicator of the neighbour cell

W= the weight given to the points and their relevant attributes

I = the intensity of a point, e.g. the value of the variable used in the analysis

h = the kernel density bandwidth

d = the distance between the kernel and the points.

One of the pitfalls in applying kernel density estimation is the influence of the procedure with respect to its spatial extent. One of the key elements of the assumed influence is that by changing bandwidths the way a certain sector contributes to the hot spots is changed.

[10] Some work is done with the k-nearest neighbourhood estimate (Williamson *et al*, 1991). However this does not show the case we make in the application of Kernel Density estimation in our model.

Basically we have to examine the influence of the bandwidths: with a smaller bandwidth there is less influence of the overlay procedure in the total result. A wider bandwidths creates some overlap between two hot spots in the different layers, resulting in one big hot spot in the final overlay procedure. Sensitivity analysis is needed to investigate the influence on the results. The rational behind this is shown in figure 71.

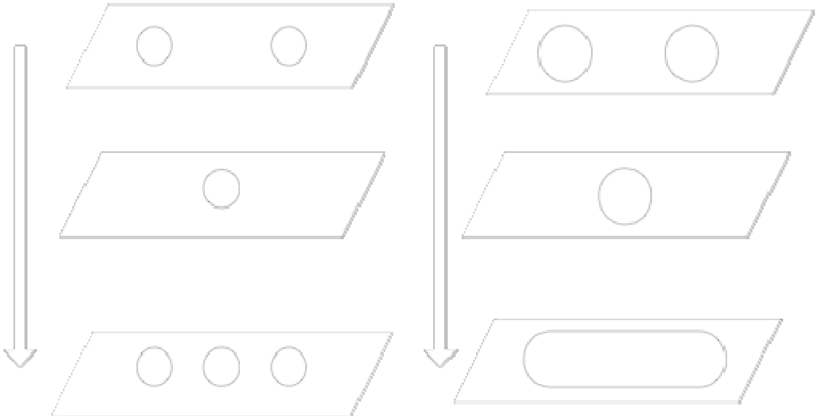


Figure 71. Differences in bandwidths and possible results on outcome in final layer

Figure 71 shows two possible situations. The left part depicts a small bandwidth with in the bottom layer the result after overlaying. The expected outcome is that there is no influence of the choice of bandwidth on the final result. In the right part however, a bigger bandwidth has been chosen. This results in more cases taken into account, possibly including less relevant layers. In the final layer this might result in a visualisation of clusters being too big.

Bandwidth

The choice of the bandwidth is thus very important. If the bandwidth is too wide, the density surface that is created will be too general and does not provide us with the optimum amount of information. Basically, we are confronted with an optimization problem: if we choose our bandwidth too small, we can not determine the correct centre and if we choose our bandwidth too wide irrelevant locations will be marked as relevant. This is due to the fact that less surrounding cells are taken into account.

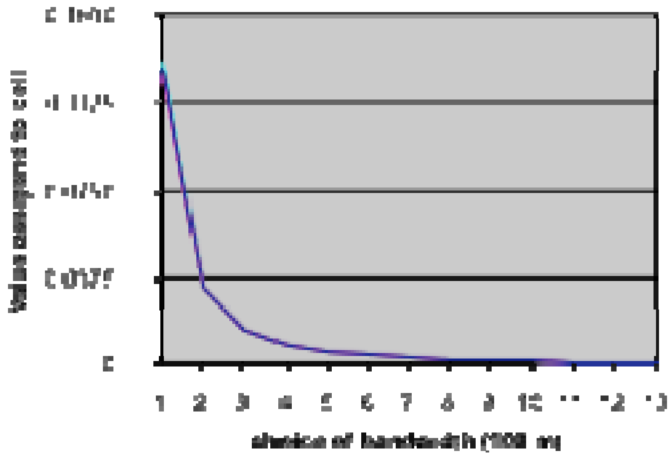


Figure 72: Relationship between choice of bandwidth, and cell values, based on formula (1).

The importance of the choice of bandwidth can also be demonstrated in figure 72, showing the relationship between the choice of bandwidth and inclusion or exclusion of cells. Wider bandwidths include more cells in the kernel and create more general surfaces. Excluding cells in bandwidths leads to less cells in the kernel creating more peaky surfaces. The problem here is a problem of clustering. How big is a cluster and to what extent is it still relevant if it is either too general or too peaky?

Figure 72 shows a first step towards a sensitivity analysis in determining the boundaries of the analysis. The figure reveals the relationship between bandwidth, value of cell and distance between kernel and points.

	a	b	c	d	e	f	g	h	i	j	k
h	200.00	300.00	250.00	80.00	127.00	32.00	500.00	1000.00	1500.00	2000.00	2500.00
100	0.126718	0.124145	0.125428	0.12984036	0.128613	0.125428	0.119079	0.106874	0.095329	0.084444	0.074218
200	0.032986	0.032986	0.032986	0.03298554	0.032986	0.032986	0.032986	0.032986	0.032986	0.032986	0.032986
300	0.01466	0.01466	0.01466	0.01466032	0.01466	0.01466	0.01466	0.01466	0.01466	0.01466	0.01466
400	0.008246	0.008246	0.008246	0.00824644	0.008246	0.008246	0.008246	0.008246	0.008246	0.008246	0.008246
500	0.005278	0.005278	0.005278	0.00527772	0.005278	0.005278	0.005278	0.005278	0.005278	0.005278	0.005278
600	0.003665	0.003665	0.003665	0.00366508	0.003665	0.003665	0.003665	0.003665	0.003665	0.003665	0.003665
700	0.002693	0.002693	0.002693	0.00269271	0.002693	0.002693	0.002693	0.002693	0.002693	0.002693	0.002693
800	0.002062	0.002062	0.002062	0.00206161	0.002062	0.002062	0.002062	0.002062	0.002062	0.002062	0.002062
900	0.001629	0.001629	0.001629	0.00162893	0.001629	0.001629	0.001629	0.001629	0.001629	0.001629	0.001629
1000	0.001319	0.001319	0.001319	0.00131943	0.001319	0.001319	0.001319	0.001319	0.001319	0.001319	0.001319
1500	0.000586	0.000586	0.000586	0.00058641	0.000586	0.000586	0.000586	0.000586	0.000586	0.000586	0.000586
2000	0.00033	0.00033	0.00033	0.00032986	0.00033	0.00033	0.00033	0.00033	0.00033	0.00033	0.00033
2500	0.000211	0.000211	0.000211	0.00021111	0.000211	0.000211	0.000211	0.000211	0.000211	0.000211	0.000211

Table 7. Relation between bandwidth and cell values, based on formula (1) with z= bandwidth and a,…….,k = random point values per grid

Bandwidth and overlay

Overlaying several kinds of sectoral data may have severe consequences for the size and proper estimation of hot-spots, as was shown in figure 71. However, from Figure 71 and Figure 72 it can also be learnt that the choice of bandwidth is less relevant on larger scales of analysis. The numerical part behind figure 72 (See Table 7) shows that values start to converge for bandwidths larger than, say, 300-400 m.

In our case study we applied the procedure for making hot-spots to different layers of economic data in four different situations with four different bandwidths. The results can be found in figures 73a-73d. The main difference between figure 73a en 73b is the way "hotness" emerges in the landscape. This implies that increasing the bandwidth from 100 to 200 does indeed have an effect on the location of hot-spots.

In figure 73c-73d, however, effects are more drastic.

The distortions that appear are clearly due to the choice of bandwidth. This distortion is something to keep in mind when applying kernel density in overlay procedures. One should carefully consider how accurate one wants to be when designing a map. In our case we applied a 5000 m bandwidth, because we wanted to analyse hotspots at a regional scale. Consequently, a bandwidth of 100-200 m was not considered by showing too much detail.

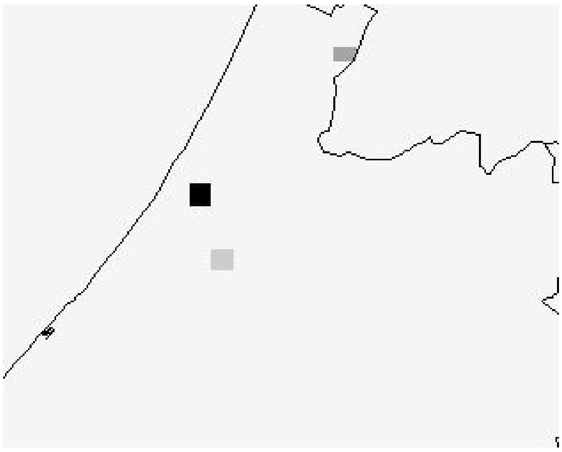


Figure 73a: bandwidth of 100 m in overlay procedure

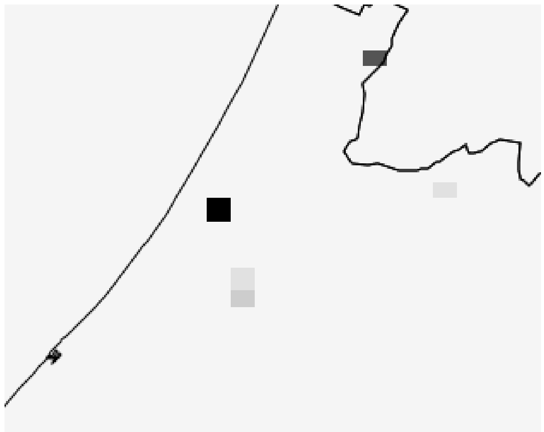


Figure 73b: bandwidth of 200 m in overlay procedure

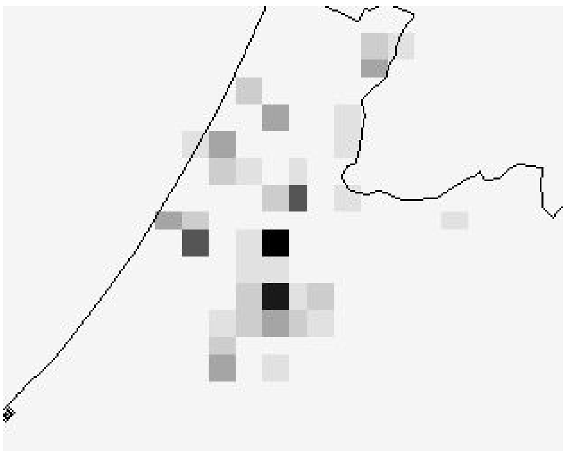


Figure 73c: bandwidth of 1000 m in overlay procedure

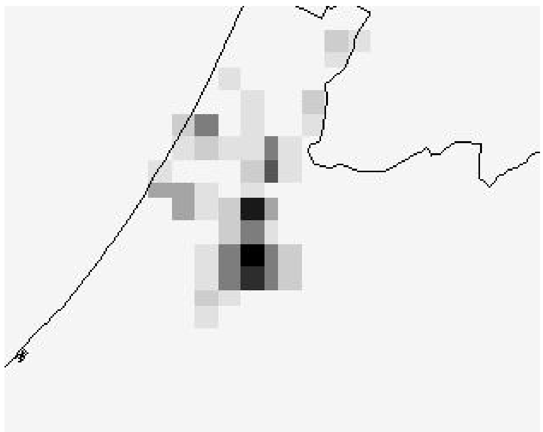


Figure 73d: bandwidth of 2000 m in overlay procedure

Conclusions

In this contribution we discuss challenges of the spatial modelling of vulnerability to flooding and we present a specific way to measure and visualise possible economic damage. We argued that economic damage is intrinsically related to the vulnerability aspect and that scale-issues play an important role when it comes to the measurement and spatial modelling of vulnerability. Ecological fallacy, the modifiable area problem and aggregation problems are some the problems to overcome when dealing with scale related issues. Particularly the issues of combining of micro and macro data and finding an appropriate spatial level of analysis are addressed in this paper.

In this contribution a specific method to arrive at a proper identification of economic hot spots is presented. By combining input-output analysis with spatial modelling we tried to visualise hot-spots. By applying kernel-density estimation to sectoral data we carefully tried to avoid falling into some of the methodological errors. The issue of the choice for the correct bandwidth was explored. Sensitivity analysis demonstrated the significant effect of scale in the measurement and visualisation of vulnerability areas.

5.4 Data availability and indicators

Data are rarely available for analyses at all relevant scales. Even where comparable data may be available, rarely research studies explore the relevant causal mechanisms for different processes or phenomena at different scales. Where data are available only for certain scales, the analysis should be made in developing techniques for up-scaling and downscaling information. The main challenge in this approach remain the question in understanding what types of information are scale dependent or scale independent and which is useful or not (Wilbanks, 2003). Methodologically, this is the most serious defy in cross-scale interactions for two reasons. First, most databases are scale specific rather than scale crossing. Second, most analyses and assessments focus on a particular scale of interest rather than on cross-scale linkages and transfers (Berkes et al. 2006). For example, global scientific indicators can characterize global patterns of climate change effectively, but they have serious shortcomings in providing solutions given the site-specific context and constraints in which any solution must be implemented. Because climate change and other natural hazards occur at multiple scales, no single indicator is the "correct" one for analysis. For example, indicators for local assessment tend to be more context dependent than indicators for global analysis. But at the same time, many aspects of local indicators are highly relevant at meso and macro scales. What emerges is a view of highly overlapping features concerning the value, relevance, and utility of indicators at different scales. Since coupling occurs between different levels, indicators must be analyzed simultaneously across scale (Berkes et al. 2006). For example, focusing exclusively at a local scale can lead to explanations in terms of local causes when some important determinants lie in processes at larger regional and global scales. Focusing exclusively on a larger scale can lead to ready generalizations that are just that – much too general (O'brien et al. 2004).

The indicators that are considered important within the context of a vulnerability assessment change with the scale of analysis (Tab. 8). The way in which an assessment could be constructed as a cross-scale assessment is by adapting or modeling the information from other scales (O'Brien, 2004). What constitutes a legitimate indicator? What scale can help the decision maker use the most relevant information and interpretation regarding a particular issue? The choice of the scale for the assessments should derive from distinctive needs, interests, and capacities. In some cases, the process of identifying the appropriate scale and relative indicators for analysis is a research activity in itself (Zermoglio et al. 2005).

The most important issue is to extrapolate information across spatial scales by including interactions among micro and mega scale processes with an emphasis on connectivity among scale units and indicators (Peters and al. 2004).

SCALE	VULNERABILITY INDICATORS	TYPE OF HAZARD
MICRO		
Social	Age, health, psychological and physical strength, education, neighborhood network	Precipitation Flood Windstorm Extreme temperatures Fire Avalanches Ground instabilities Earthquake Volcanic eruption
Physical	Building quality, building layout, materials, age, location, accessibility, hazard mitigation measures, land ownership, fire safety measures, vegetation	
Economic	Income, personal savings, family related insurance, GDP per capita, productivity per capita	
Environmental	Soil quality	
Systemic	Access to information and health care, building use, building density, dependence of utilities	
MESO		
Social	Population structure, disaster preparedness (civil protection means, early warning, emergency plans), access to resources, decision making, autonomy, legal regulations, perception of risk, social participation, stakeholder communication, environmental management	Precipitation Flood Windstorm Extreme temperatures Fire Avalanches Ground instabilities Earthquake Volcanic eruption
Physical	Building code, urban pattern, , urban development period, land use function, disaster protection measures, topography, reinforcement and retrofitting public assets, preventive structures, biodiversity	
Economic	Economic vitality	
Environmental	Environmental degradation, , climate conditions	
Systemic	Transportation, communication networks, energy delivery, emergency services, urban settings (accessibility of various functions and services), urban sustenance (performance, capacity of lifelines)	
MACRO		
Social	Political stability, type of government, national disaster planning, emergency management system and capacities, social equity,	Floods Windstorm Volcanic eruption
Physical	Safety standards and norms, legal regulations, implementation of hazard control and protection techniques, built area density	
Economic	Economic system, economic dependency, insurance services, sustainable growth, capital efficiency, government funds response and loss transfer strategies, mitigation loans, reconstruction loans, assistance to household and private sector	
Environmental	Environmental degradation, natural resources	
Functional	Infrastructure and health care system, energy delivery and storage, nuclear plants, communication, transportation	
MEGA		
Social	International political relations	Windstorm Extreme temperatures Volcanic eruption
Physical	Urbanized areas	
Economic	Trading activities	
Environmental	Climate and geological settings	
Functional	Traffic and energy networks (gas)	

Tab. 8 Scaling of vulnerability indicators

For example, at the national level, vulnerability may be shaped by the macro economic situation, exemplified by indicators such as GDP. At the local level, vulnerability may be tied more closely to entitlements such as crop insurance, savings, and so on. Conclusions derived from impact and vulnerability assessments are valid for the scale of the assessment, and should not be generalized to other scales (Wilbanks and Kates, 1999). Ignoring the scale-dependency of results can be problematic in terms of understanding and addressing climate change, particularly if conclusions are derived from coarse scale assessments (O'brien et al. 2004). Local assessment activities can help to understand the global trends. To the other hand, global syntheses often leave out local details. Often conclusions or indicators clearly diverge from the on-site reality at a specific smaller scale. This situation can arise when the problem is not adequately defined, or when the "best available' data used for global syntheses are in fact not sufficiently reliable to enable local interpretation (Zermoglio et al. 2005).

The following table proposes an example of possible indicators per vulnerability facets taking into account the different working scale and the pertinence of the data at the given scale.

5.4.1 Vulnerability indicators for floods (MDX)

Table 9 sets out a number of possible, proposed indicators of flood vulnerability, broken down by vulnerability facet. These are derived partly from knowledge of the New Orleans flood risk and the UK Thames Estuary flood risk. The Thames Estuary flood risk management plan (which incorporates London) employs ten principal indicators to monitor changes in flood vulnerability over time and these are incorporated into the table (Environment Agency, 2009). This plan is also based on a number of detailed vulnerability studies, key points from which are also included in Table 9.

Vulnerability facet	Proposed indicator
MICRO (taken as individual or household or business entity)	
Physical	Building or installation type, layout, materials, incorporation of resilience measures
Social	Age, disability, personal fitness, health status, health history especially incidence of stress-related illness and depression, level of educational attainment, degree of involvement in, or isolation from, local social networks
Economic	%age by which mean or median annual incomes depart from the national or regional mean, %age of population living below the official poverty line, mean ratio of savings and investments to house value, %age insured for flood loss, mean value of the level of profitability of business entities
Environmental	Soil permeability, typical rainfall-runoff lag times, degree of coverage of permeable natural surfaces with paved impermeable surfaces, degree of absorption of sustainable urban and rural drainage methods at the micro level, extent of erosion, many other physical parameters e.g. flood depth, duration, velocity, sediment load, salt load
Functional	Ease of access to flood risk maps and related flood risk information, ease of access to advice on how to respond to flood warnings, ease of access to advice and information on household/building specific resilience measures
MESO (taken as local or sub-regional or city-wide)	
Physical	Types, ages and condition of flood defence structures, frequency of different building types, layouts and materials, and the degree to which they are flood susceptible, density of buildings, frequency of employment of property level resilience measures (e.g. flood proofing), frequency of employment of community-based resilience measures (e.g. demountable flood defences), location of buildings: number of buildings in rapid inundation zones behind breachable defences and defences which may be overtopped, number of underground rail stations in flood risk zones, lengths of roads, rail lines, airports etc. in flood risk zones, number of road tunnels in flood risk zones, number of fire stations, police stations, hospitals, schools in flood risk zones, number of critical infrastructure installations in flood risk zones (e.g. electricity stations, power stations, major sewage treatment installations, telecoms installations)
Social	**Human capital:** statistical profile of population employing human capital indicators above (mean, variance), presence/absence and degree of development of local leadership **Social capital:** number and quality (i.e. degree of development of) local social networks and support groups, and degree of participation in them, presence/absence of a local flood action group/committee; and local environmental

	interest groups, degree of engagement of community in owning and managing flood risks, degree of encouragement of flood risk management agencies for local community engagement, presence/absence of riparian and land owner obligations for flood risk management, %age of population who are aware of flood risks and flood warning/evacuation procedures, %age of population with flood experience, %age of population who take at least one measure of flood preparedness, %age of population with a family flood response plan, %age who are able to demonstrate that they know flood warning procedures, presence/absence of local neighbourhood flood wardens, measures of community cohesion Social capital physical aspects: presence/absence of safe havens, presence/absence of designated safe flood evacuation routes, presence/absence of local mechanisms for retaining flood histories and memories (e.g. flood museums)
Economic	Per capita GDP, basic statistical profile of business entities (according to the likely degree of susceptibility of their plant and equipment, raw material and finished goods which are of high, medium and low susceptibility to damage from floodwater), basic statistical profile of business entities according to the likely degree of susceptibility of their business to business interruption (i.e. high, medium and low), %age of business entities with significant parts of their operation outside of the vulnerable area where business may be transferred, %age of business entities which have high, medium and low dependence on other businesses in the vulnerable area which are their significant suppliers, %age of business entities which have high, medium and low dependence on employees who live in the vulnerable area, %age of business entities with business continuity plans, presence/absence of local emergency funds
Environmental	As above for Micro Measures of biodiversity
Functional	As above for Micro. See also Meso physical which incorporates transportation and other functional infrastructure. Frequency of closure of flood gates and barriers
MACRO (taken as region)	
Physical	As above for Meso. %age of region which is in flood risk areas, physical and infrastructure planning mechanisms which recognise constraints on regional development imposed by flood risks
Social	As above for Meso.
Economic	As above for Meso. %age GDP contributed to the region by the locality, measures of the economic vitality of the region, presence/absence of regional flood emergency funds, existence of well rehearsed evacuation and related traffic management plans
Environmental	As above for Meso. Rate of mean sea level rise, rare of rise of peak surge tide levels, rate of land subsidence, increase in fluvial flows, frequency and extent of pluvial flooding
Functional	As above for Meso
MEGA (taken as national)	
Physical	As above for Meso. Existence of a national flood risk management policy and funding strategy which incorporates multi-disciplinary structural and non-structural approaches, existence of a climate change policy linked to reducing flood risks, mechanisms and procedures for regular monitoring of the condition and integrity of flood defences, existence of a robust, state-of-the-art, flood forecasting and warning capability, presence/absence and quality of spatial planning mechanisms and standards which recognise constraints on development posed by flood risks, %age of planning applications for new development in flood risk zones permitted/rejected, building control/compliance and regulation system which incorporates measures to reduce susceptibility to flooding, existence/absence of financial incentives to avoid locating buildings in flood risk zones and to incorporate resilience measures in those that must be located in flood risk zones; also retrofitting incentives and mechanisms
Social	As above for Meso. Public and political attitudes towards flood risk, presence/absence of social equity policies, political stability, type of government, quality of national disaster planning, emergency response capacities
Economic	As above for Meso. %age GDP contributed to the nation by the region or locality, availability of a flood insurance program, existence of government funding programs to manage and respond to flood risks and to economic vulnerabilities, access to social solidarity funds of a larger entity (e.g. European Union) for disaster funds
Environmental	As above for Meso
Functional	As above for Meso

Tab. 9 Indicators of flood vulnerability

As highlighted in tables 8 and 9, natural disasters cause great losses in human lives, property and productive capacity. Entire regions and urban areas become more vulnerable to natural hazards as urbanization expands, population increases and economic activities develop.

For this reason, indicators should not be considered only as scale and assessment dependent. The choice of the indicators depends also on the socio-economic context of the analyzed area. This is particularly evident when studying developing countries with respect to developed countries.

While absolute level of economical loss are great in developed countries due to the larger density and cost of infrastructure and production levels, less-developed countries suffer higher levels of relative loss. As already mentioned in the previous chapters, the destruction of infrastructures and livelihoods are direct outcomes of disasters and can also aggravate other financial, health and environmental aspects destabilizing in this way politics especially in developing countries. Such disaster losses may setback social investments aiming to ameliorate poverty, education, health services, safe housing, drinking water and sanitation infrastructures, or to protect the environment as well as the economic investments that provide employment and income.

Figure 74 show economic loss by world region for disaster event triggered by natural hazards between 1991-2000.The unequal distributions of impacts is clear. In Europe and America, losses are shown to be higher than in Africa, but this is a reflection on the value of the infrastructure and assets at risk, not impact of development potential. In less developed regions of the world, low losses reflect a deficit of infrastructure and economic assets rather than a low impact of development. Even a small economic loss may be critically important in the case of countries with very low GDP. Africa's much smaller economic losses may be more significant in terms of slowing process in human development.

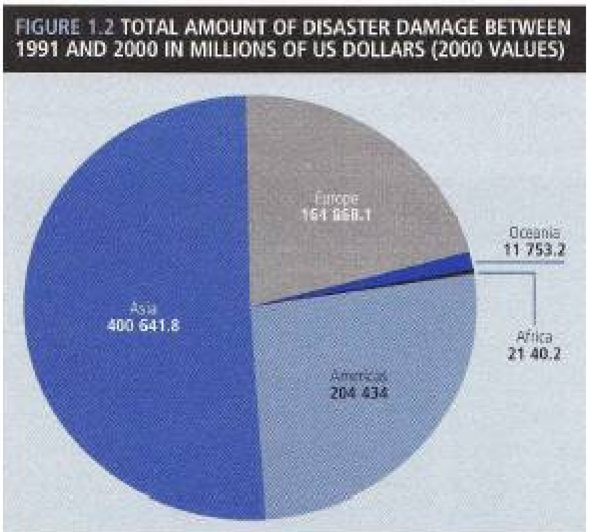


Fig. 74 Total amount of disaster damage between 1991 and 2000 in millions of US dollars (2000 values)

There are number of factors that contribute to the configuration of vulnerability in cities. For example, it is important where cities have been built or expanded into hazardous locations. In developing countries, rapid population growth and accelerated urbanization in the region exposed to natural disasters is an example of generating new vulnerabilities. For example, poverty affects urban vulnerability because it forces people to live in the most uncontrolled and unsafe areas. The growth of informal settlements and inner city slums create unstable living environments. They live in poor-quality housing, without clean water, sewage, drain and paved roads. The sanitation system, garbage collection and public health services are also inadequate in those locations.

When population expands faster than the capacity of urban authorities or the private sector to supply housing or basic infrastructure, risk in informal settlements can cumulate quickly. Often, local government may refuse to provide services to informal settlements on the grounds, because that will imply the recognition of the land they have settled and as consequence the obligation of the construction of public facilities with a budget they don't have. However, this makes those people more vulnerable to hazard.

Informal urbanization can also modify hazard patterns. Through process of urban expansion, cities transform their surrounding environment and generate new risk. As an example, the urbanization of watersheds can modify hydraulic regimes and destabilize slopes, increasing flood and landslide hazard. Moreover, ineffective or inappropriate development programs increase vulnerability to hazards, and hence lead to more disasters, great and small.

6 Tools for vulnerability analysis and representation

Maps, diagrams and graphs have always been, and continue to be, hard to produce. Initially they were hand drawn, piece-by-piece. Later they were etched on copper-plate and manually colored. Still later, lithography and photo-etching, and most recently, computer software was used, but graphic-makers have always had to struggle with the limitations of available technology—and still do today. Most recently, advances in statistical computation and graphic display have provided tools for visualization of data unthinkable only a half century ago. Similarly, advances in human-computer interaction have created completely new paradigms for exploring information in a dynamic way, with flexible user control, particularly for the display of large networks, hierarchies, data bases, text, and so forth, where problems of very-large scale data present continuing challenges. We can resume visualization tools as following:

Information visualization

Graphs and maps, whether static or dynamic that provides some means to see what lies within, determine the answer to a question, find relations, and perhaps apprehend things which could not be seen so readily in other forms. The term *information visualization* is generally applied to the visual representation of information.

Scientific visualization

This area is primarily concerned with the visualization of 3-D+ phenomena (architectural, meteorological, medical, biological, etc.), where the emphasis is on realistic renderings of volumes, surfaces, illumination sources, and so forth, perhaps with a dynamic (time) component.

Data visualization

The science of visual representation of "data", defined as information which has been abstracted in some schematic form, including attributes or variables for the units of information. This topic could be taken to subsume the two main foci: statistical graphics, and thematic cartography. Both of these are concerned with the visual representation of quantitative and categorical data, but driven by different representational goals. Cartographic visualization is primarily concerned with representation constrained to a spatial domain; statistical graphics applies to any domain in which graphical methods are employed in the service of statistical analysis. In addition, cartography and statistical graphics share the common goals of visual representation for exploration and discovery. These range from the simple mapping of locations (urban settlements, rivers, etc.), to spatial distributions of geographic characteristics (species, diseases, ecosystems), to the wide variety of graphic methods used to portray patterns, trends, and indications.

6.1 An overview of data visualization tools

The graphic representation of quantitative information has deep roots. These roots reach into the history of thematic cartography, statistical graphics, and data visualization, which link one with each other.

In the 18th century, map-makers began to try to show more than just geographical position on a map. Towards the end of this century, the first attempts at the thematic mapping of geologic, economic, and medical data are recorded. As economic and political data began to be collected, some new visual forms were invented to portray them. So, the data could "speak to the eyes".

Over the 19th centuries, numbers pertaining to population (social, medical, and economic statistics) began to be gathered in large and periodic series. Official state statistical offices were established, in recognition of the growing importance of numerical information for social planning, industrialization, commerce, and transportation. The birth of statistical thinking was also accompanied by a rise in visual thinking: diagrams were used to illustrate mathematical functions; various graphic forms were invented to make the properties of empirical numbers– their trends, tendencies, and distributions— more easily communicated, or accessible to visual inspection. Concerning statistical graphics, all modern forms of data display were invented: bar and pie charts, histograms, line graphs, time-series plots, contour plots, etc. In thematic cartography, mapping progressed from single maps to comprehensive atlases, depicting data on a wide variety of topics and wide range of forms of symbolism were introduced.

In the first middle of the 20th century, the enthusiasm for visualization which characterized the late 1800s had been supplanted by the rise of quantification and formal, often statistical, models in the social sciences. Numbers, parameter estimates and indicators were defined. This period is considered as a time of application and popularization, rather than one of innovation. In this period graphical methods were used, perhaps for the first time, to provide new insights, discoveries, and theories in sciences. Graphic innovation was also awaiting new ideas and technology: the development of the machinery of modern statistical methodology, and the advent of the computational power which would support the next wave of developments in data visualization.

Computer processing of data had begun, and offered the possibility to construct old and new graphic forms by computer programs. True high-resolution graphics were developed, but would take a while to enter common use. By the end of this period significant intersections and collaborations would begin: computer science research combine forces with developments in data analysis and display and input technology (pen plotters, graphic terminals, etc.). These developments would provide new paradigms, languages and software packages for expressing and implementing statistical and data graphics. In turn, they would lead to an explosive growth in new visualization methods and techniques. Other themes begin to emerge, mostly as initial suggestions: (a) various visual representations of multivariate data; (b) animations of a statistical process; (c) perceptually based theory (or just informed ideas) related to how graphic attributes and relations might be rendered to better convey the data to the eyes.

It is harder to provide a succinct overview of the most recent developments in data visualization, because they are so varied and across a wider range of disciplines. It is also more difficult to highlight the most significant developments. However, a few major themes could be selected:

• development of a variety of highly interactive computer systems,

• new paradigms of direct manipulation for visual data analysis (linking, brushing, selection, focusing, etc.)

• new methods for visualizing high-dimensional data (scatterplot matrix, parallel coordinates plot, etc.);

• the invention of new graphical techniques for discrete and categorical data (fourfold display, sieve diagram, mosaic plot, etc.), and analogous extensions of older ones (diagnostic plots for generalized linear models, mosaic matrices, etc.) and,

• the application of visualization methods to an ever-expanding range of substantive problems and data structures.

These developments in visualization methods and techniques arguably depended on advances in theory and technology. Some of these are: (a) software engineering; (b) extensions of classical linear statistical modeling to wider fields; (c) vastly increased computer processing speed and capacity, allowing computationally intensive methods and access to massive data problems.

6.2 Maps as a basis for spatial vulnerability analysis

Maps are an essential practical tool in any spatial analysis. For identifying the geographical distribution of potential damage, *vulnerability mapping* is needed. Vulnerability maps attempt to show the spatial or geographical distribution of expected losses from one or more natural hazards. Spatial analysis considers any relevant dangers that have a high correlation with space and it create an abstract, model representation of a territorial reality to serve as a basis for future planning measures.

Thorough assessment of the prevailing hazards and risks in a specific region, it is possible to assure any kind of development activity that has a spatial impact. This is particularly important in disaster-prone areas. Those maps contain extensive data of the area in addition of visual information. The appropriate scale of mapping depends both on the use of the maps and the amount of data available.

This allows to have a picture of the situation on the field and to think in which direction to address the efforts for any further action. Vulnerability maps that are based on the measured vulnerability values can be used by politicians, administration, relief organization and operators of critical infrastructures by prioritizing activities and directing financial resources and personnel to the most vulnerable parts of the geographical region and the most vulnerable population subgroups.

As an example of tools for vulnerability mapping, the Federal Emergency Management Agency (USA) develops the methodology HAZUS for analyzing potential losses from floods, hurricanes and earthquakes. The method couple engineering knowledge with the geographic information system (GIS) technology to produce estimates of hazard-related damage before, or after, a disaster occurs. Potential loss estimates analyzed in HAZUS include:

- **Physical damage** to residential and commercial buildings, schools, critical facilities, and infrastructure;
- **Economic loss**, including lost jobs, business interruptions, repair and reconstruction costs; and
- **Social impacts**, including estimates of shelter requirements, displaced households, and population exposed to scenario floods, earthquakes and hurricanes.

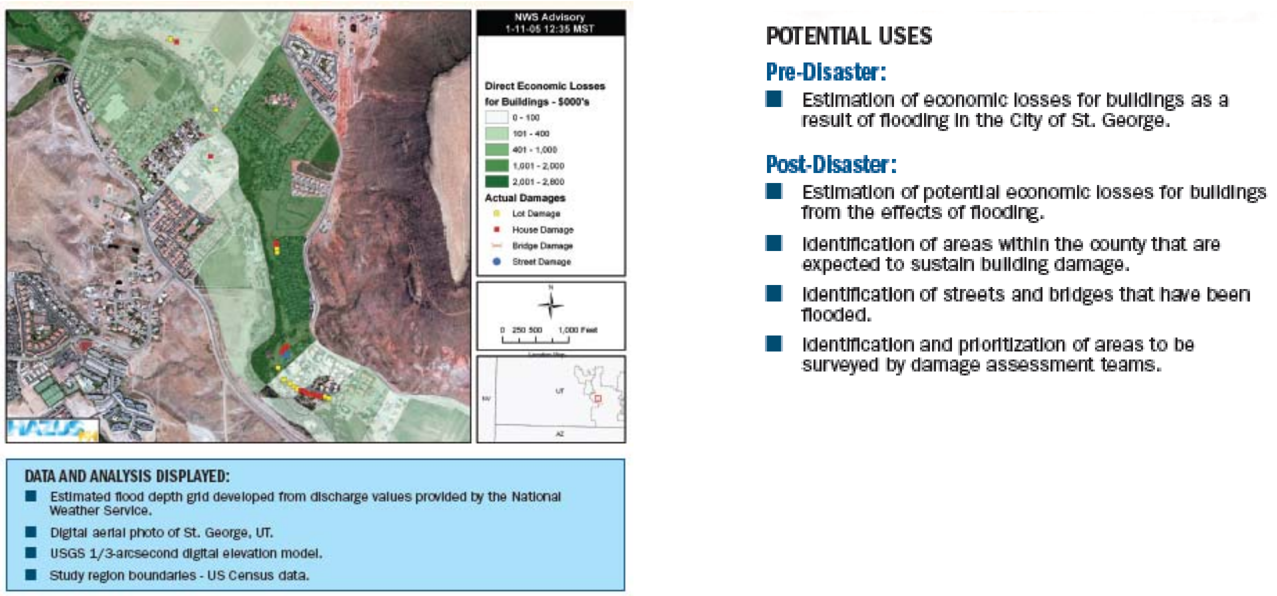


Fig. 75 HAZUS application: the example of Santa Clara and Virgin Rivers Floods: the city of Saint George, Utah

6.2.1 Traditional and innovative tools for vulnerability analysis (PIK)

Visualization is becoming increasingly important in the scientific context. It can be used as well for the exploration of large and complex scientific datasets, the confirmation of hypotheses on the data, and the communication of results. Especially computer supported interactive techniques, allowing the user to directly manipulate the visual representation, can increase the usefulness of visualization in this context.

Sheppard (2005) concludes that the persuasive use of visualizations (in concert with other methods) is justified if they can be effective, and may even be vital in communicating climate change urgently. He suggests various standards that should be adhered to, particularly related to disclosure (i.e., so the content of the visualizations is crystal clear) and defensibility of the methods and data used. As he says, "we should test carefully every potentially powerful weapon in the fight against climate change, especially those which promise rapid results. Visualization tools are potentially too powerful either to be ignored or used without careful consideration." It is hard to disagree with this.

In the context of this deliverable vulnerability is being analysed in the light of its spatial characteristics. It is therefore logic that an obvious tool for vulnerability visualization is the use of maps. Maps have the advantage of presenting data in an easily accessible, readily visible and eye-catching manner.

The maps can combine information from different sectors to provide an immediate comprehensive picture of the geographical distribution of vulnerable groups at sub-national level. By providing a visual overview of the major issues affecting vulnerability, the maps highlight gaps and shortfalls in information and thus areas needing attention. The mapping approach for vulnerability visualization has been explored in the context of food-security, some examples:

Food and Agricultural Organization (1998) developed Food Insecurity and Vulnerability Information and Mapping Systems (FIVIMS) that can assemble, analyze and disseminate information about the problem of food insecurity and vulnerability.

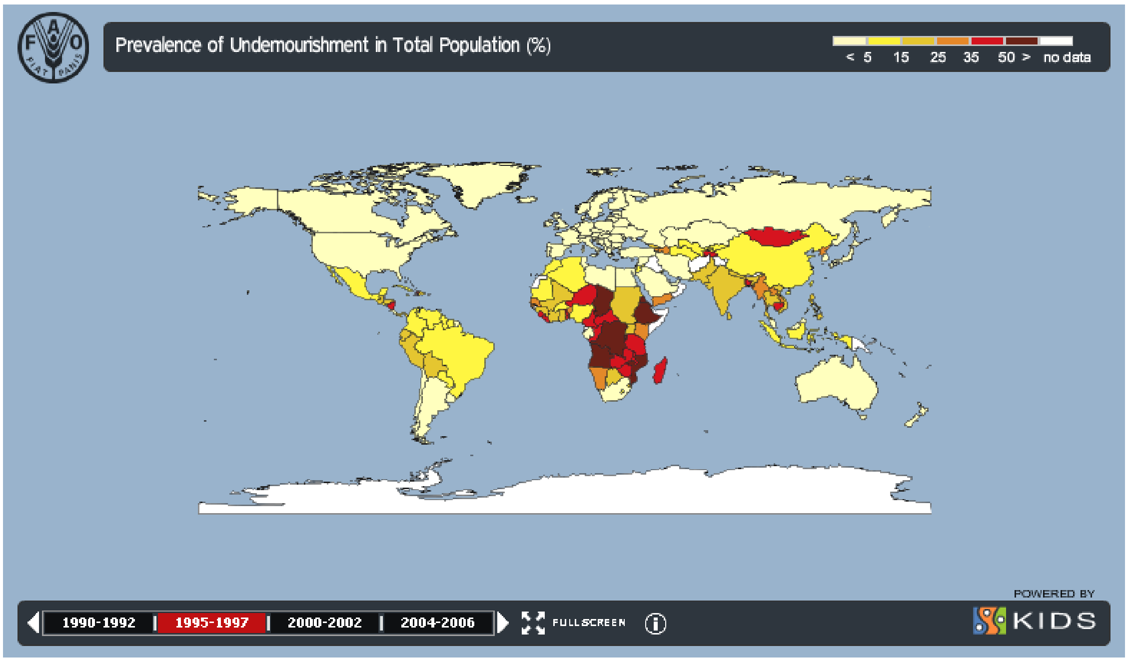


Fig. 76- GECHS (2000) Project from the University of Victoria used GIS software packages for ranking different countries in terms of a vulnerability index.

Vulnerability analysis and Mapping (VAM) of World Food Programme (1999) prepared composite maps of vulnerability by putting different weights on different indicators. In work related to hurricane Mitch, UNEP-GRID Sioux Falls (1999) prepared an interactive map of Central America showing vulnerability to different natural hazards. (http://grid.cr.usgs.gov)

Traditional mapping approaches have the benefit of visualizing data in its geographic context and thus are of great use for dealing with vulnerability information. However, since vulnerability data is typically multivariate, means have to be applied to represent this multidimensional data in an appropriate manner. While geographical maps are the tool of choice to visualize geographic context, several techniques have been developed to generate visual representations of multivariate data, including scatter plots, star plots, parallel coordinates or icons like.

The combination of such techniques with maps allows combining the representation of multivariate data in its geographical context. Two approaches can be distinguished. One approach is to locate icons on a map to directly visualize information in its spatial context (e.g. information on a set of cities). Yet, this direct representation of geographic context can only be applied for a limited set of data due to constraints in available screen space.

Thus, a second approach is to combine maps and multivariate representations in a multi view display, using several interlinked representations. Here, the representation of geographic context is given indirectly and thus less intuitive; nevertheless this approach can be used for larger datasets and allows applying all techniques for visualizing multivariate data.

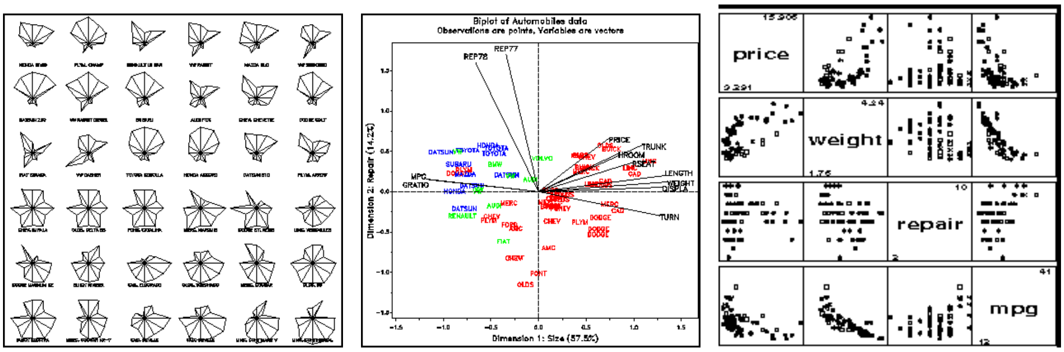


Figure 77 - Examples of multivariate data visualization (from left to right, Starplots, Biplot and Scaterplots)

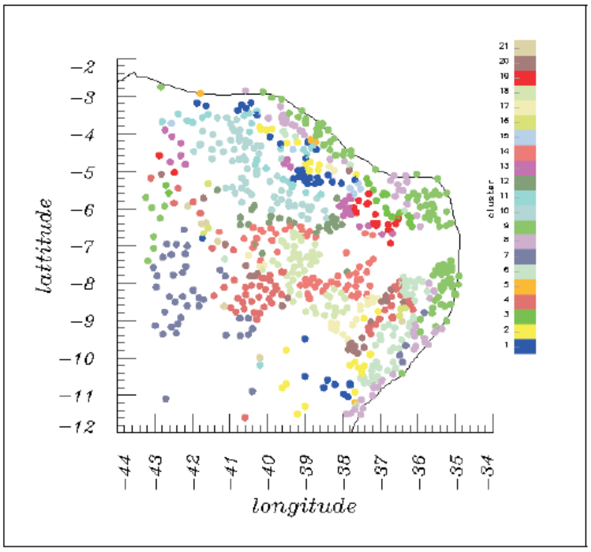


Figure 78 - Visualization of clusters representing the risk of a drought for maize cultivation during the year 1983 in the semi-arid Northeast of Brazil based on regional climate model results (Nocke 2005).

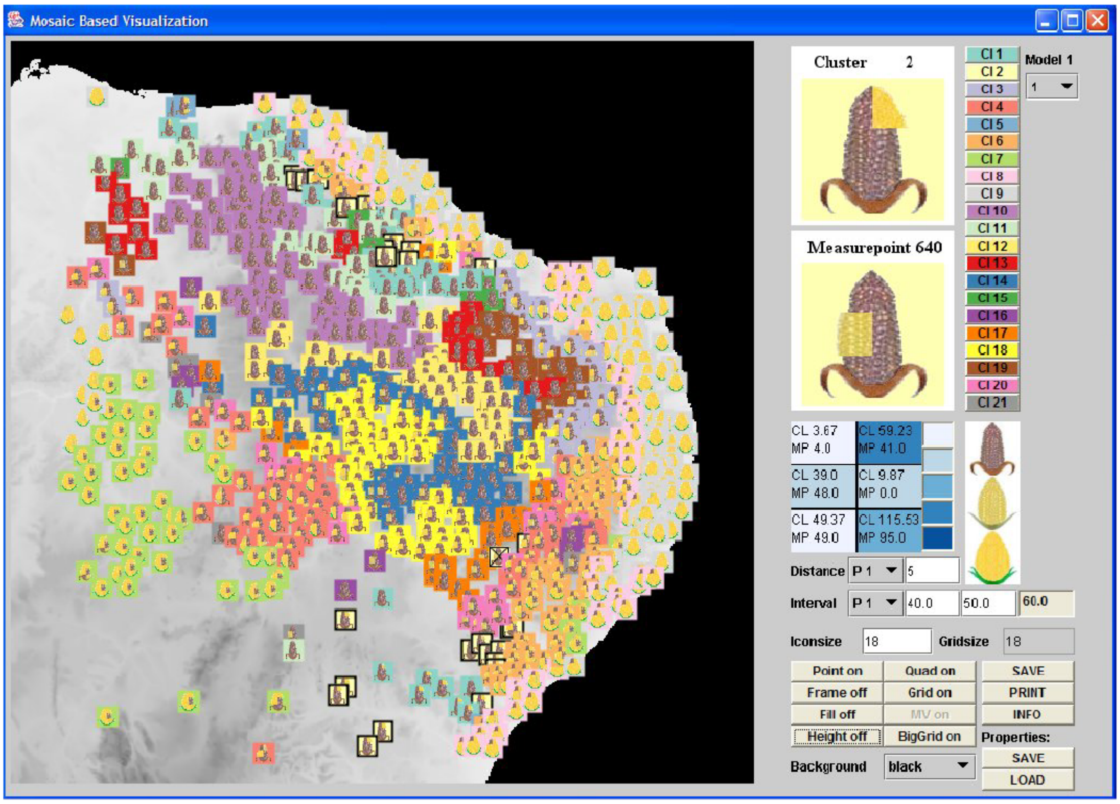


Figure 79 - Visualizations of the risk of potential total yield loss of maize according to several climate models

An alternative approach is to reduce the dimensionality of the multivariate data before visualizing it, e.g. to cluster the multivariate information into a number of classes and to represent each class on the map e.g. using a different colour. An example for this approach are the Koeppen climate maps, where multivariate climate information (based on temperature, and precipitation) is mapped into a set of classes can then be represented as grid cells in different colours (Kottek 2006).

We saw that vulnerability is a spatial phenomenon and therefore the use of maps seem to be appropriate to the task of visualizing vulnerability. On the other hand vulnerability is also a concept, which means that it carries many meanings to many different authors. Also here new tools for visualizing vulnerability concepts can come into help. Examples include techniques to visualize tree structures (like Cone Tree or Tree Map), techniques to visualize focus and context information (like the Table Lense or the Hyperbolic browser) or techniques to visualize collections of documents.

The concept-graphing tool available through the HERO Web portal allows scientists to visually encode knowledge structures using conceptual graphing techniques. Users of this tool can produce diagrams to represent the relations between concepts or the process of an experiment or workflow. The example shown in Figure 79 depicts one user's view of the concept of vulnerability to environmental change. Here, vulnerability is a product of three "subconcepts": exposure, sensitivity, and adaptation. Each of these concepts is in turn described by other concepts. All are linked together by using a set of relationships with defined semantics that allows the concept graph to be decomposed into a set of concept definitions stored in description logic (MacEachren 2004).

The use of these kind of tools allows to visualize where communalities and interlinks between "subconcepts" are. By doing so it helps to identify were more clarification is needed and what common understanding should be reinforced.

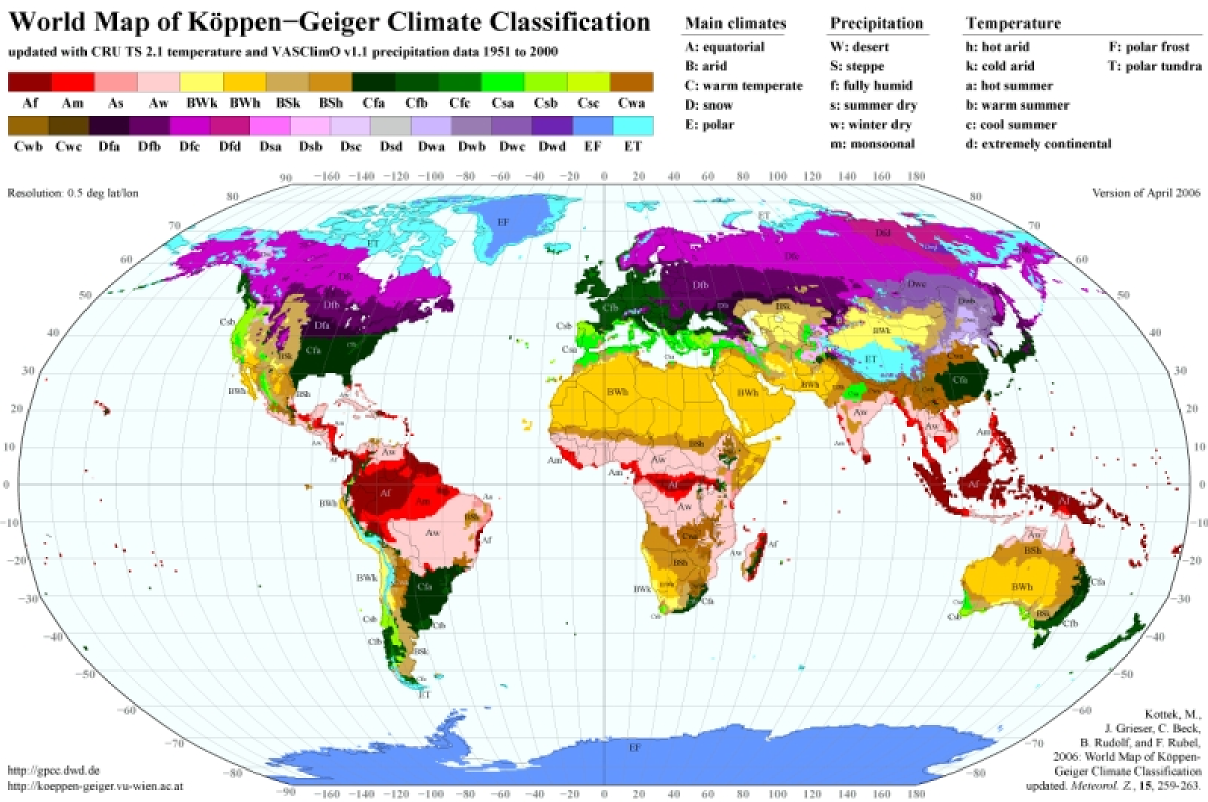


Figure 80 - World map of Koeppen Climate Classification

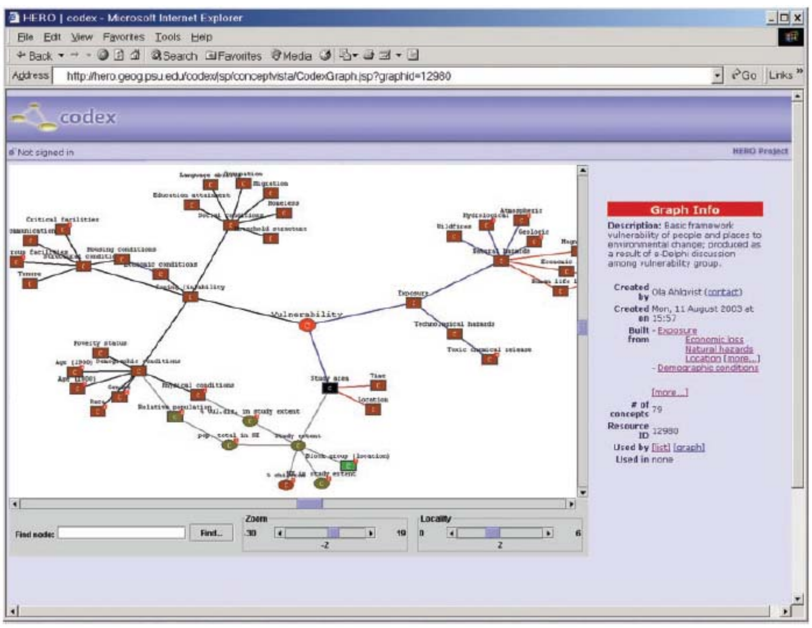


Figure 81 - A concept graph that depicts a HERO researcher's conceptualization of vulnerability. The graph allows concepts, data, and tools to be linked in visual

6.2.2 3D dynamic modelling of buildings (BRGM)

Evaluation of the seismic vulnerability of structures is performed through an appropriate earthquake damage analysis. Different analysis procedures are used in practice, but their assumptions (analysis method, structural idealization, seismic hazard characterization, damage models) strongly influence the derived fragility curves and have been seen to cause significant discrepancies in the seismic risk assessments made by different groups for the same location, structure type and seismicity.

For instance, current physical vulnerability assessment methods consider a single hazard parameter (e.g. peak ground acceleration, PGA, or macroseismic intensity, etc.), which is generally used to characterize the earthquake loading to be applied to the studied structure. Very recently, some efforts have been made to account for the effect of several ground-motion parameters on the structural damage (Seyedi *et al.*, 2010), by introducing the fragility surface concept in risk assessments for actual structures modelled through nonlinear time-history analysis of multi-degree-of-freedom systems. In this approach, ground-shaking is characterized by two intensity measures, which are selected in order to be poorly correlated. On the contrary, the structural damage is correlated to the selected parameters. To this end, the damage level of a typical reinforced concrete (RC) structure can be evaluated by the use of nonlinear numerical calculations. By considering the parts of the structure that would suffer significant damage during strong ground motions (plastic hinges), an adequate 3D nonlinear robust-yet simplified finite element model is created to allow the numerous computations, with an acceptable cost (see Figure 82). The maximum inter-story drift ratio is used to define the damage level of the studied structure. The relationships between various intensity measures and the computed damage are compared. Such a study can help to find a small number of ground-motion parameters that lead to, when used together to characterize the shaking, the smallest scatter in the estimated damage. Fragility surfaces are then proposed for the studied structure. In this methodology, only the scatter in the estimated damage level due to ground-motion variability is investigated and it is assumed that there is no variation in the material or geometric properties of the structure.

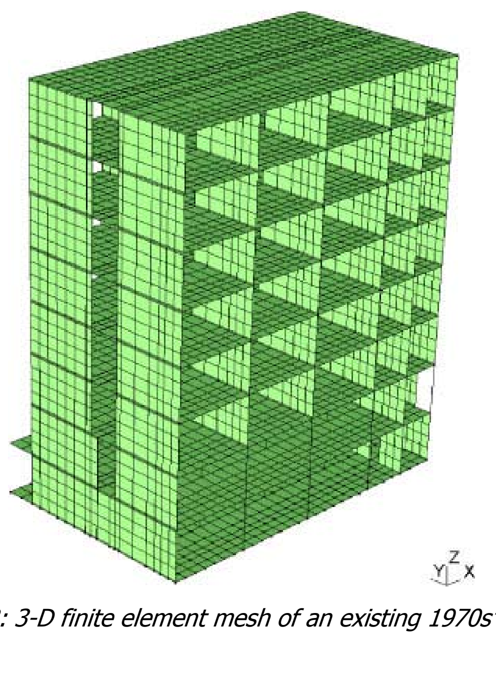


Figure 82: 3-D finite element mesh of an existing 1970s' building

7 Conclusions

The present Deliverable has been addressed at identifying a) the main factors affecting the spatial distribution of different facets of vulnerability and defining to what extent the distribution of the different facets of vulnerability change with respect to the potential core and periphery of disastrous events; b) the main processes which may induce, determine or contribute the transference of vulnerability through space; c) how scale factors can influence vulnerability assessments and the choice of indicators; d) tools that can be used in vulnerability assessment.

The knowledge of the factors affecting spatial distribution of the different facets of vulnerability and the possibility to set up deductive model enabling us to define "a priori" the distribution in space of vulnerabilities can be very useful for establishing appropriate reference scales for vulnerability assessment. The choice of appropriate scales depends, indeed, both on the aims of the assessment and on the features of the investigated phenomena.

Nevertheless, according to the main findings arising from the work carried out in the task 3.2, deductive spatial models of vulnerability can be developed only with respect to some facets of vulnerability, namely with respect to physical vulnerability to some types of hazards and, in some cases, for systemic or economic vulnerabilities. In detail, deductive models of spatial distribution of physical vulnerability in face of some types of hazards (e.g. earthquakes) can be developed, although they require a detailed classification of spatial patterns of settlements and they cannot be reduced to a traditional core-periphery model.

Referring to the systemic and economic vulnerabilities, in-depth investigations on past events are still required in order to identify general rules and laws useful for defining the vulnerability level linked to the different types of networks. As other facets of vulnerability are concerned, deductive models seem not to be appropriate. In case of social vulnerability or even in case of some aspects related to the economic vulnerability, only inductive models should be used to analyze and map spatial distribution of vulnerability.

Furthermore, it is worth noting that whereas the distribution in space of some vulnerability facets (physical, social) can be analyzed and represented through deductive or inductive models at the scale of the hazard, or in other words focusing only on the hazard prone area, other facets (systemic, economic, institutional) have to be analyzed and represented at different scales, which can be defined in turn according to the interdependencies among elements and systems placed in the hit area and elements and systems placed in other areas, even far from the hit one.

The main processes which may induce transference of vulnerability through space was also studied in this deliverable. Up to now, such processes have been mainly investigated in relation to time factors which clearly prevailing, even though they largely affect spatial distribution of vulnerabilities.

For example, Etkin (1999) has clearly shown how the implementation of mitigation measures addressed to reduce the overall risk in relation to the most common or likely hazardous events, may induce an increase of risk and vulnerability at long term in relation to events which are "beyond" the expected. This process was defined by Etkin as "risk transference", even though clearly characterized in that case in relation to the "time" factor.

Nevertheless, the processes underlying the transference of vulnerability over time may have even relevant relapses, by affecting and changing the distribution of vulnerabilities across space. Therefore, in this chapter, we will analyze different examples of vulnerability "transference", focusing on their spatial consequences.

Transference of vulnerabilities from one territory to another or from one type to another may depend on numerous factors. For example, the effects of a given hazard can be transferred from an area to another through exposed vulnerable elements (see, for example, the Baia Mare disaster or the more recent petroleum release in the Lambro river in Italy). Moreover, a local event may affect elements which have relevant interdependencies with other elements or systems: therefore, through such elements, a local event may reverberate on areas placed far from the core area of the disaster.

Furthermore, actions undertaken by different "agents" or actors before the event or during the emergency phase can contribute to propagate, transfer or transform vulnerabilities. For example, in the case of Katrina hurricane, local authorities decided to remove the contaminated waters from the flooded area, by pumping them into the Lake Pontchartrain. The polluted water had a great impact on the lake's ecosystem, which was a relevant fishing site and a tourist attraction.

The second factor which has been underlined in some of the case studies is related to the physical, functional or economic interdependencies among elements and systems within the hit area and among them and other elements and systems placed out from the hit area.

These aspects have been largely outlined in the previous chapter, since they surely represent transference mechanisms but they can be also interpreted as an intrinsic property of some facets of vulnerability itself. In detail, the concept of systemic vulnerability can be applied to all systems (social, economic, territorial): each system is indeed characterized by its own elements and by relationships among them and interacts with other systems not necessarily placed in the same area. Such interactions or interdependencies clearly induce transference of vulnerability from one element, or one system, to another and, consequently, they might even induce transference from one area to another.

Furthermore, the numerous mutual relationships (see deliverables 2.1, 2.2 and 2.3), that characterize all the facets of vulnerability, might induce a transformation from one facet of vulnerability into another and, in the meanwhile, a transference from one scale to another. Such mechanisms are clearly highlighted by some of the provided case studies (Katrina, San Salvador).

Ones of the most typical examples of transference of vulnerability due to the relationships among different facets of vulnerability are the ones induced by institutional vulnerability. As highlighted in case studies, weaknesses (e.g. lack of preparedness, lack of leadership) of the institutions in charge of risk prevention, mitigation and emergency response tasks, may favour phenomena both of hazard propagation (as in Katrina case study) and transference or transformation of vulnerabilities before, or even after, the hazardous event. All these possibilities are highlighted in the Katrina and San Salvador case studies.

Nevertheless, institutions are only one of the "agents" which may induce phenomena of transference and/or transformation of vulnerabilities in space. As clearly arises from the provided case studies (Athens earthquake, Katrina), transference phenomena are very often due to the interactions among different "agents" such as institutions and stakeholders within a given community. These kinds of mechanisms are very common in different phases of the disaster cycles.

Furthermore, development/transformation processes (renovation of historical areas, new building developments, etc) within a given community have to be mentioned among the main factors favouring the transference of vulnerabilities in space. Such processes may happen independently from the occurrence of a hazardous event, for example, as a consequence of changes in local economy, or in post event, due to the reconstruction. Very often such processes induce phenomena of transference and transformation of vulnerabilities, even though apparently addressed to reduce vulnerability and/or increase resilience, they often result in a transference of vulnerability from one area to another or even in an increase of vulnerability (see India and Vietnam case studies).

Besides the mentioned processes, transference of vulnerabilities are often due to structural engineering mitigation measures which induce relevant changes in the risk perception, spreading a relevant sense of safety. The Katrina case study, for example, clearly highlights as the construction of levee networks has favored new building and even industrial development in hazard prone areas, spreading a false sense of safety. In such a way, exposure and vulnerability of the community significantly propagated in space.

Summing up, transference mechanisms highlight two basic needs for improving vulnerability assessment. The first one refers to the need for developing vulnerability assessment at adequate geographical scale depending both on the aims of the assessment and on the potential for transference over space of the different facets of vulnerability. The second one refers to the need for shaping the assessment, as already stressed in deliverable 2.2, as a "continuous cycle", in which the preventative assessment of the potential outcomes of mitigation measures or development or transformation processes – in terms of changes over time and in space of the different facets of vulnerability– and the monitoring of their effects have to be guaranteed.

Then, the deliverable continues on focusing on questions related to the representation of such a distribution in space, focusing in detail on the importance of the scale matters of a vulnerability analysis. Territories have many connections and mutual relationships with the surrounding ones. Therefore, any spatial analysis - including vulnerability analysis - has to look beyond the area under investigation and take into account the relationships among the investigated area and the wider region that the investigated area belongs to. Natural disasters are cross-scale phenomena that require assessments at all scales and integration across scales in order to inform policy- and decision-making stakeholders most effectively. The variability among assessments in problem definitions, objectives, scale criteria, and methods of analysis and explanation increased at finer scales of assessment.

Visualization of data information is an important issue in the scientific context, especially the communication of results. The term *information visualization* is generally applied to the visual representation of information. Computer supported interactive techniques can increase the usefulness of visualization in this context.

This topic could be taken to subsume the two main foci: statistical graphics, and thematic cartography. Both of these are concerned with the visual representation of quantitative and categorical data, but driven by different representational goals. Cartographic visualization is primarily concerned with representation constrained to a spatial domain; statistical graphics applies to any domain in which graphical methods are employed in the service of statistical analysis.

In the context of this deliverable vulnerability is being analyzed in the light of its spatial characteristics. It is therefore logic that an obvious tool for vulnerability visualization is the use of maps. Maps are an essential practical tool for identifying the geographical distribution of potential damage. Vulnerability maps attempt to show the spatial or geographical distribution of expected losses from one or more natural hazards. They create an abstract, model representation of a territorial reality. Maps have the advantage of presenting data in an easily accessible, readily visible and eye-catching manner.

Since vulnerability data is typically multivariate, means have to be applied to represent this multidimensional data in an appropriate manner. Finally, the Deliverable offers an overview of possible use of tools for vulnerability visualization.

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