	ENSURE PROJECT *Contract n° 212045*

ENSURE E-LERNING TOOL

F05
Vulnerability in space

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Del. 3.2: Analysis of vulnerability factors versus space (synthesis from all chapters)

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1 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.

1.1 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).

1.1.1 *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.

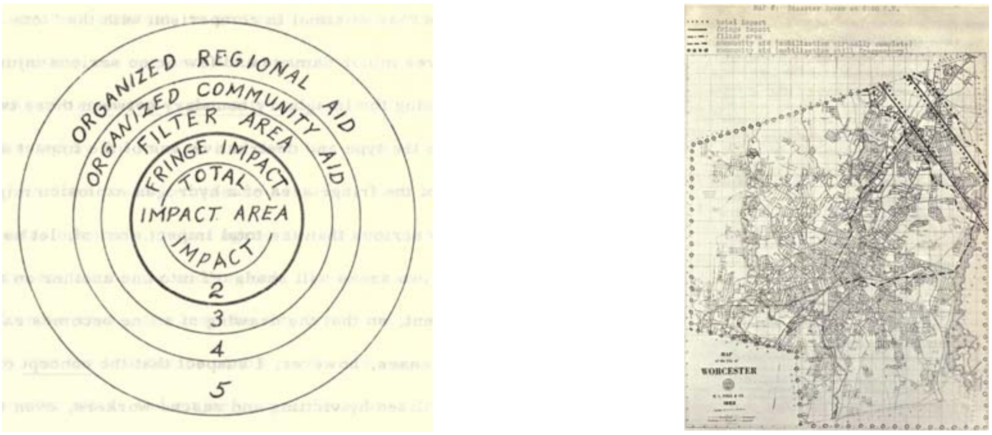


Figure 1: The Wallace’s model: The original definition of the model in 1956 (on the left); The application of the model to the Worcester Tornado (on the right)

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.

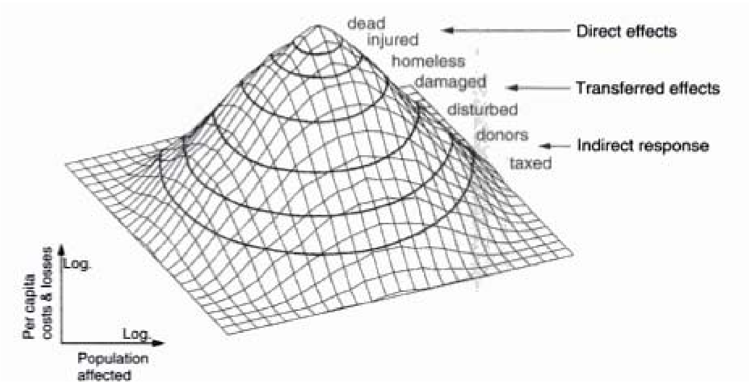


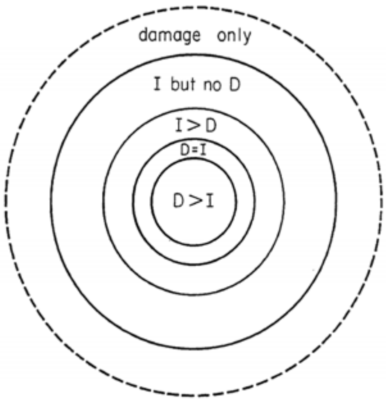
Figure 2: The three-dimensional representation of the concentric disaster model (Burton et al. 1978)

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.

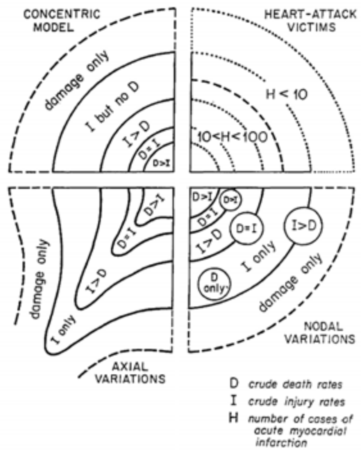
Furthermore, the outcomes of the 1980 Irpinia earthquake were generalized into a model characterized by concentric circles, based on experimental data referred to dead and injured people (Alexander, 2000b): "a working hypothesis concerning the basic pattern of casualties considered on a settlement-by-settlement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

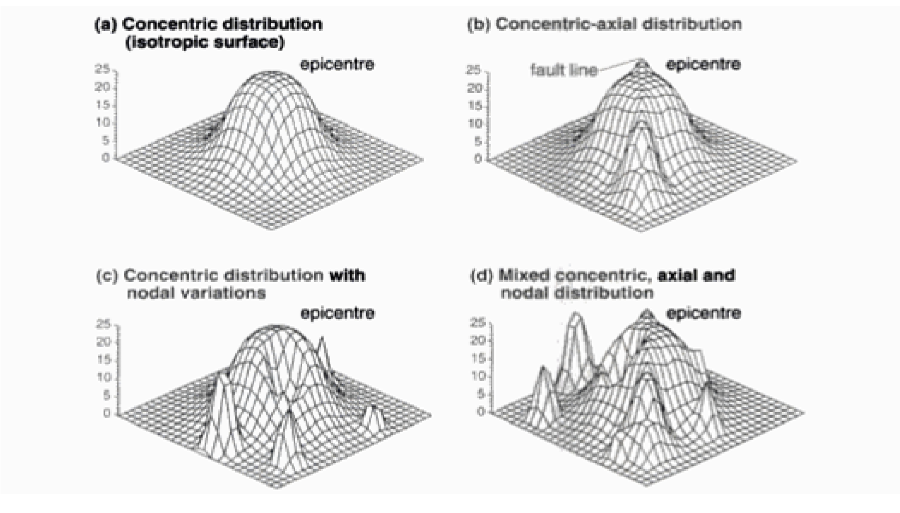


Figure 4: Non-isotropic disaster spatial models (Alexander 2000a)

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).

1.1.2 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.

1.2 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.

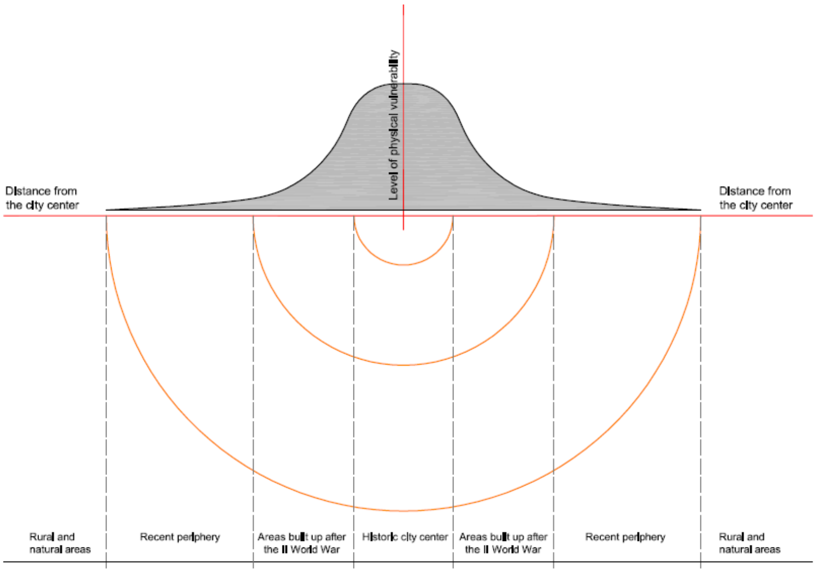


Figure 21: Spatial distribution of physical seismic vulnerability for a city characterized by an historical core and a recent outer periphery

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.

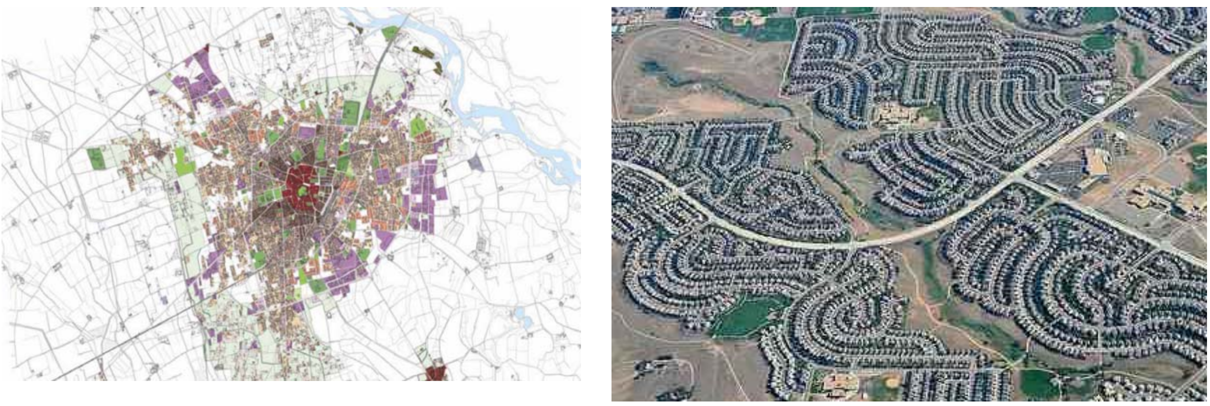


Figure 22: A typical core-periphery urban pattern with the historical fabrics in the middle (left); A typical sprawled urban pattern (right).

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).

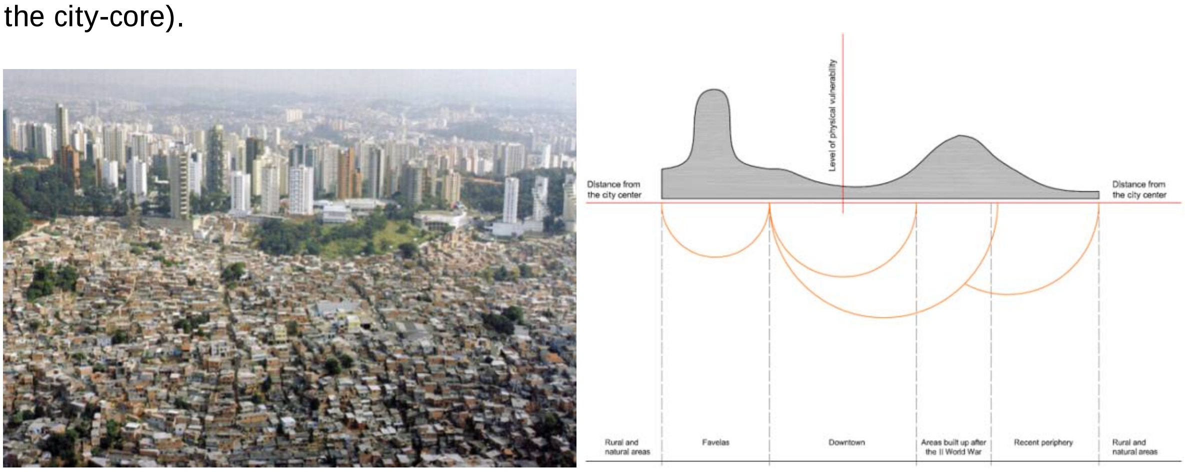


Figure 24: Spatial distribution of physical seismic vulnerability for a city characterized by a recent downtown and informal settlements out of the urban core

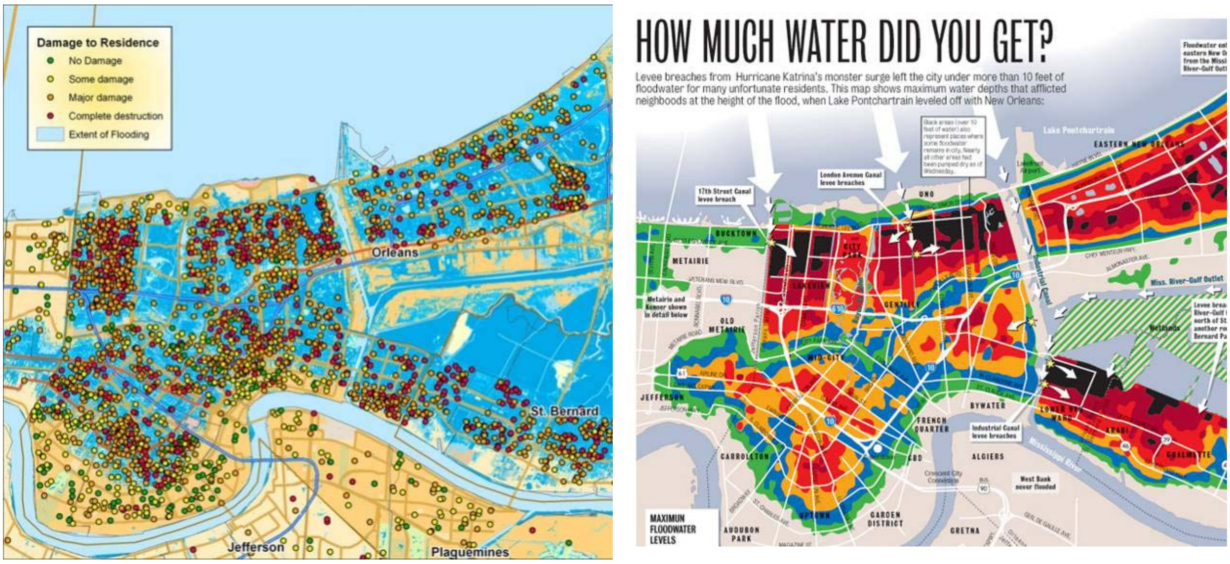


Figure 25: Physical damage to residential buildings and flood depth in the Katrina event

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

Volcanic ash falls		Building features	focused both on the features of rural/natural environment and on the features of buildings and urban fabrics.
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
Droughts		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.

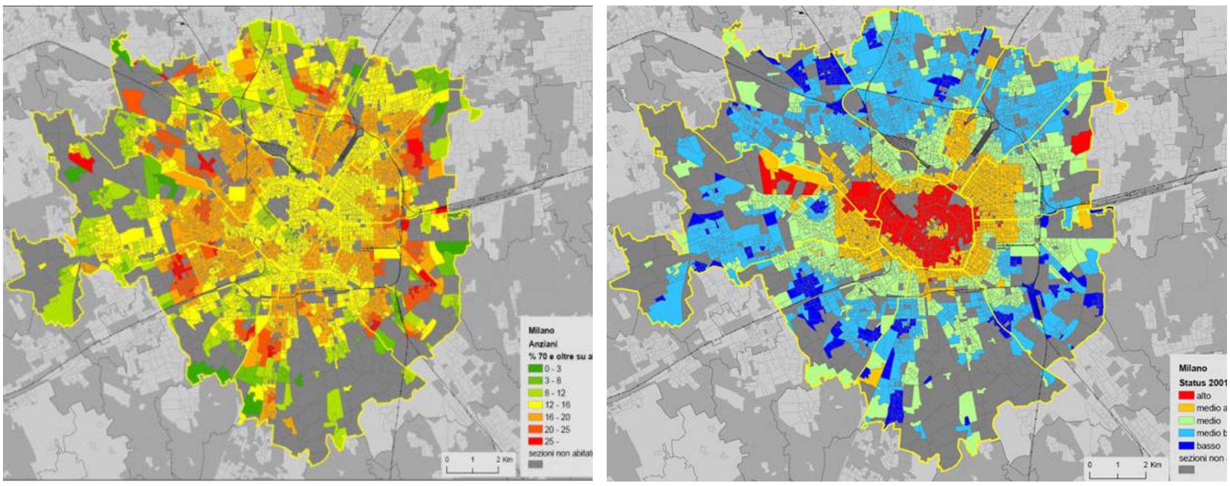


Figure 26: Spatial distribution of some features of social vulnerability. On the right: distribution of aged population; on the left: variation 1991-2001 in the income level distribution in the city of Milan. (Laboratorio GIS di Cartografia Sociale Milano Bicocca, Elaboration on Istat data)

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).

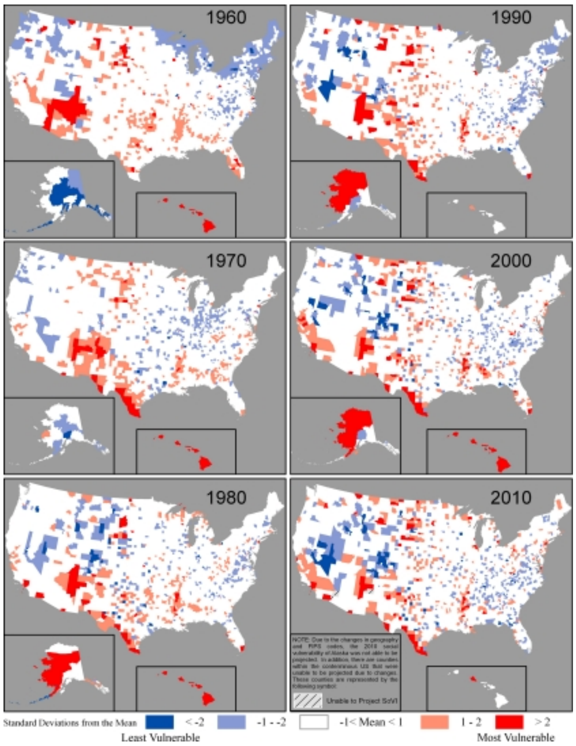


Figure 27: Social vulnerability in USA 1960–2010
(Cutter S.L., Finch C., 2008)

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.

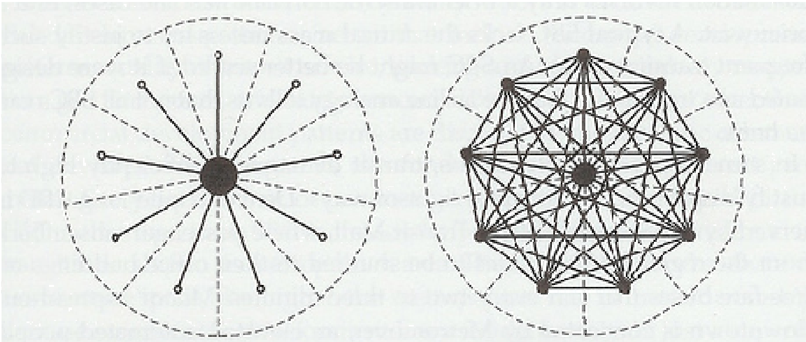


Figure 28: Hierarchical and multi-centred networks (http://www.flickr.com/photos/rllayman/490043232/)

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.

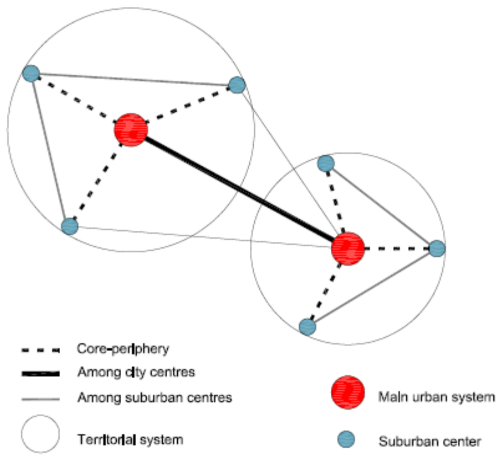


Figure 29: Types of functional relationships among urban systems

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.

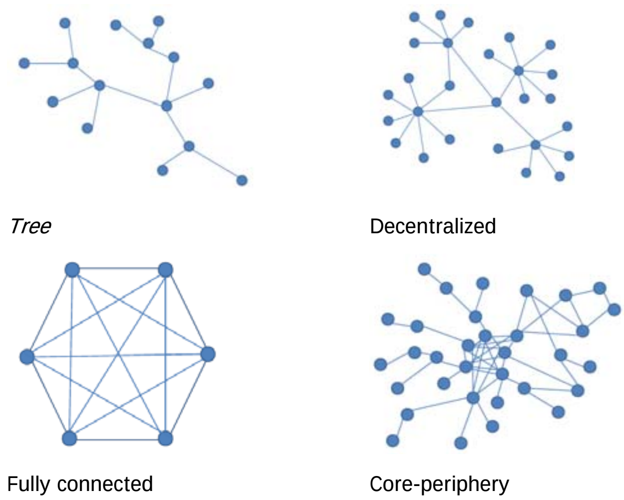


Figure 30: Morphological typologies of networks

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.

1.3 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.

2 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.

2.1 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.

2.2 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):

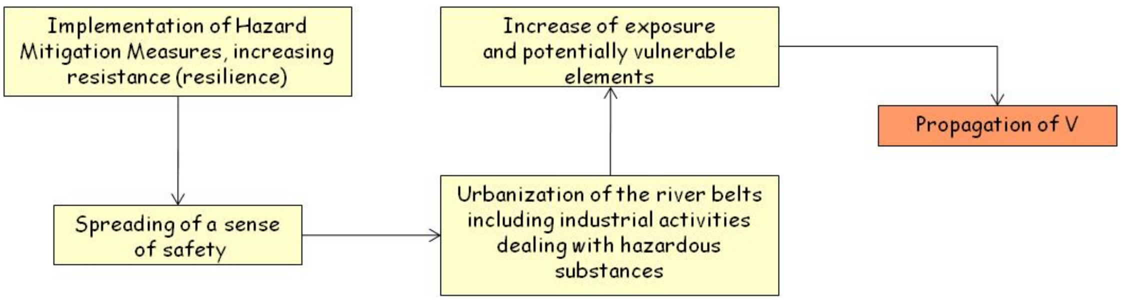


Figure 58: Propagation of vulnerability through space in the flood due to the Katrina hurricane

- 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.[1]

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

1 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).

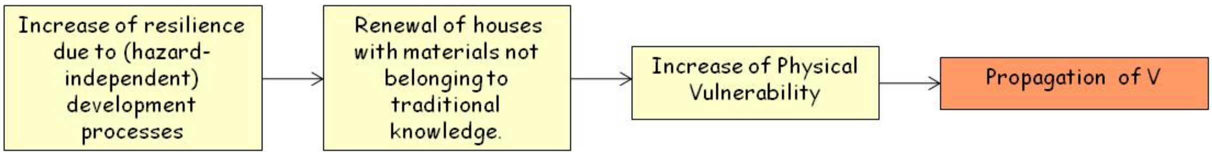


Figure 60: Propagation of vulnerability through space in the Vietnamese case

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.

2.3 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.

3 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.

3.1 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).

3.2 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.

3.2.1 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

3.2.2 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).

3.2.3 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).

3.3 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
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	

		Volcanic eruption
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.

3.3.1 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.

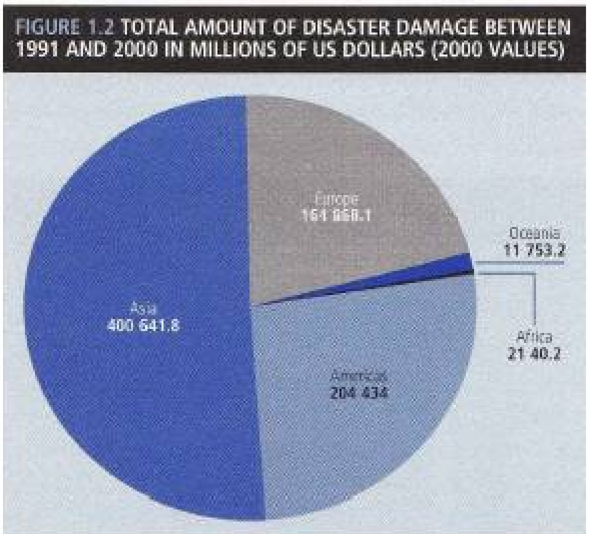


Fig. 74 Total amount of disaster damage between 1991 and 2000 in millions of US dollars (2000 values)

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.

4 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.

4.1 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.

4.2 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.

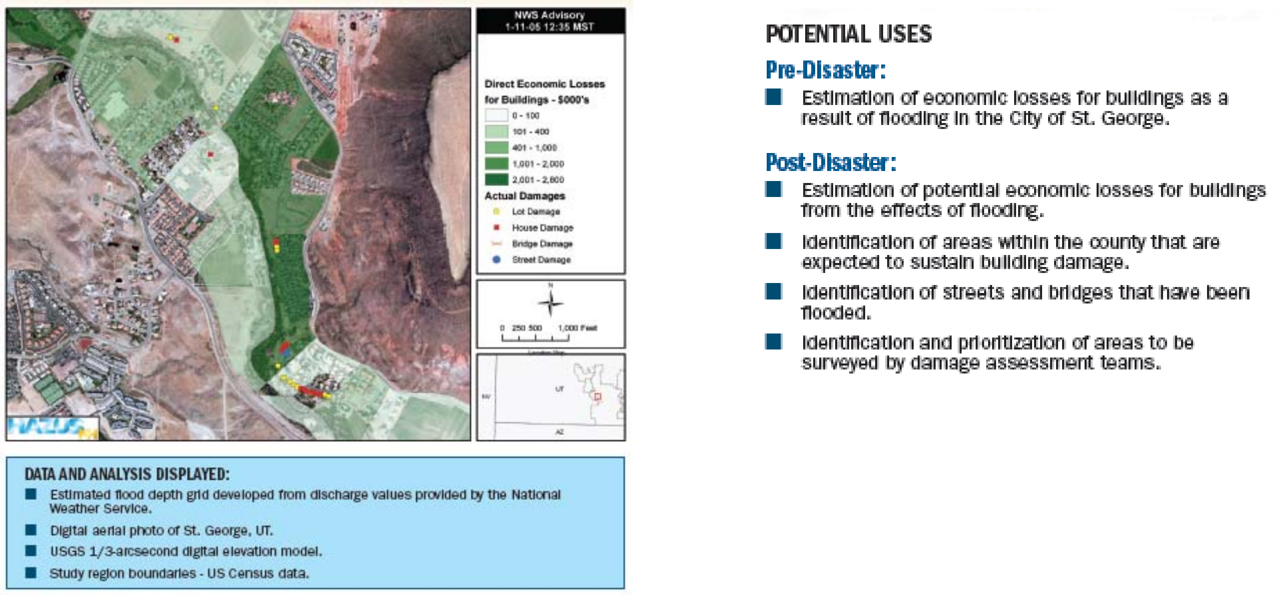


Fig. 75 HAZUS application: the example of Santa Clara and Virgin Rivers Floods: the city of Saint George, Utah

4.2.1 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.

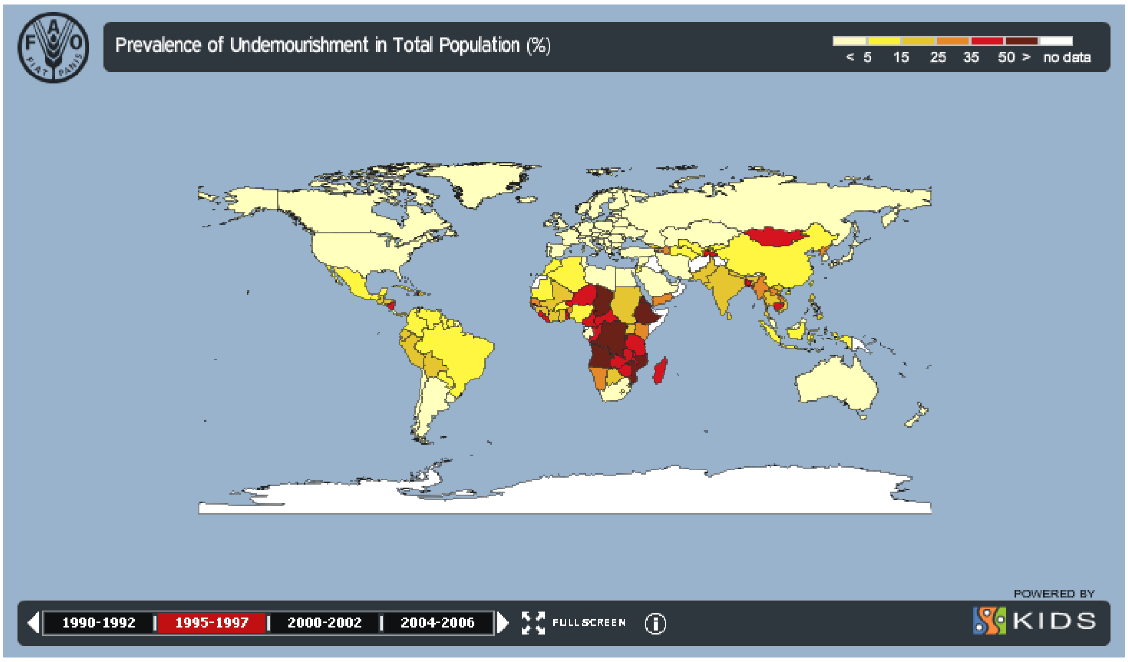


Fig. 76- GECHS (2000) Project from the University of Victoria used GIS software packages for ranking different countries in terms of a vulnerability index.

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.

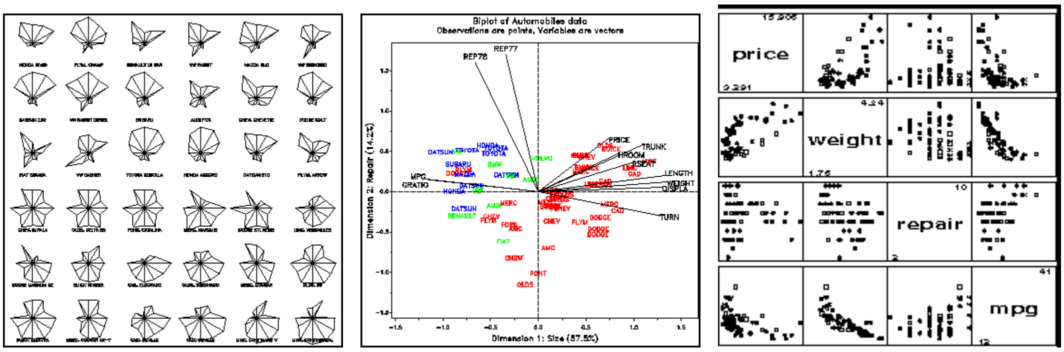


Figure 77 - Examples of multivariate data visualization (from left to right, Starplots, Biplot and Scaterplots)

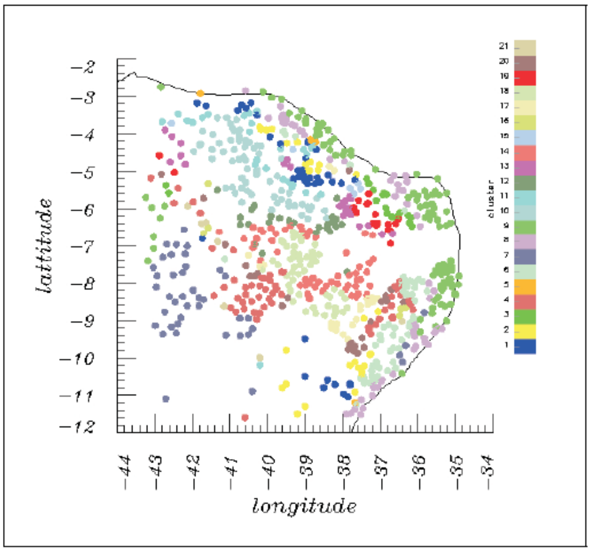


Figure 78 - Visualization of clusters representing the risk of a drought for maize cultivation during the year 1983 in the semi-arid Northeast of Brazil based on regional climate model results (Nocke 2005).

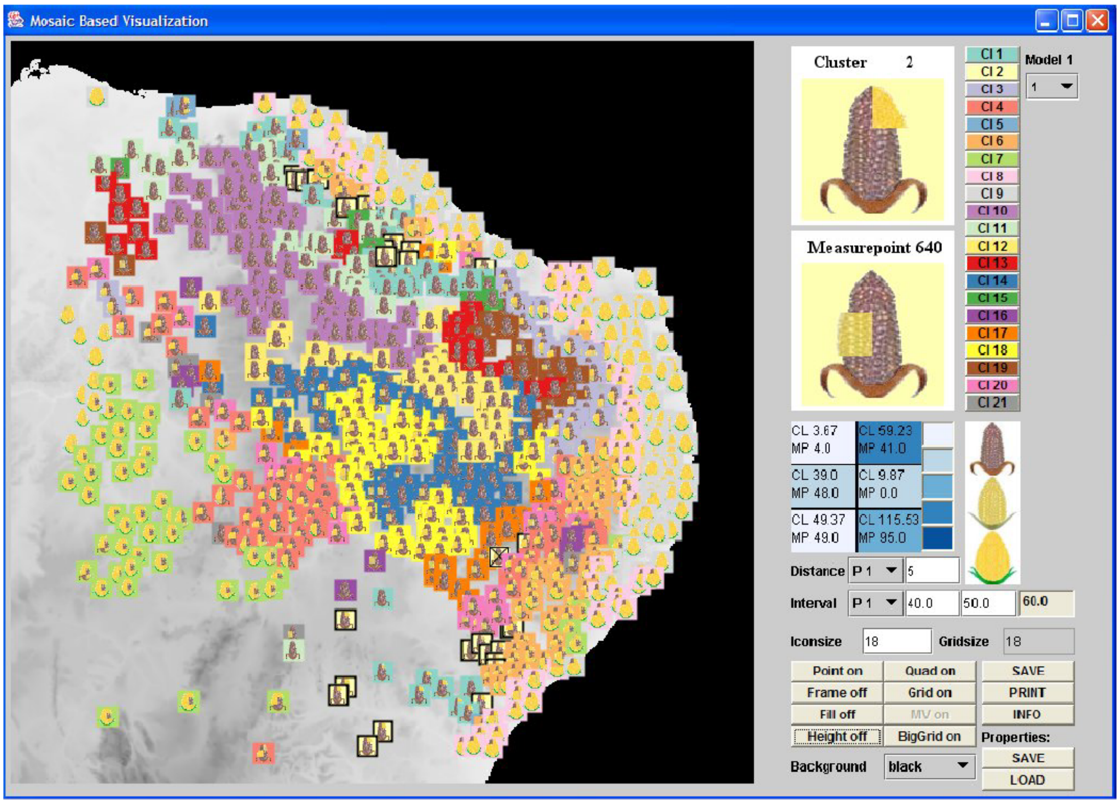


Figure 79 - Visualizations of the risk of potential total yield loss of maize according to several climate models

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.

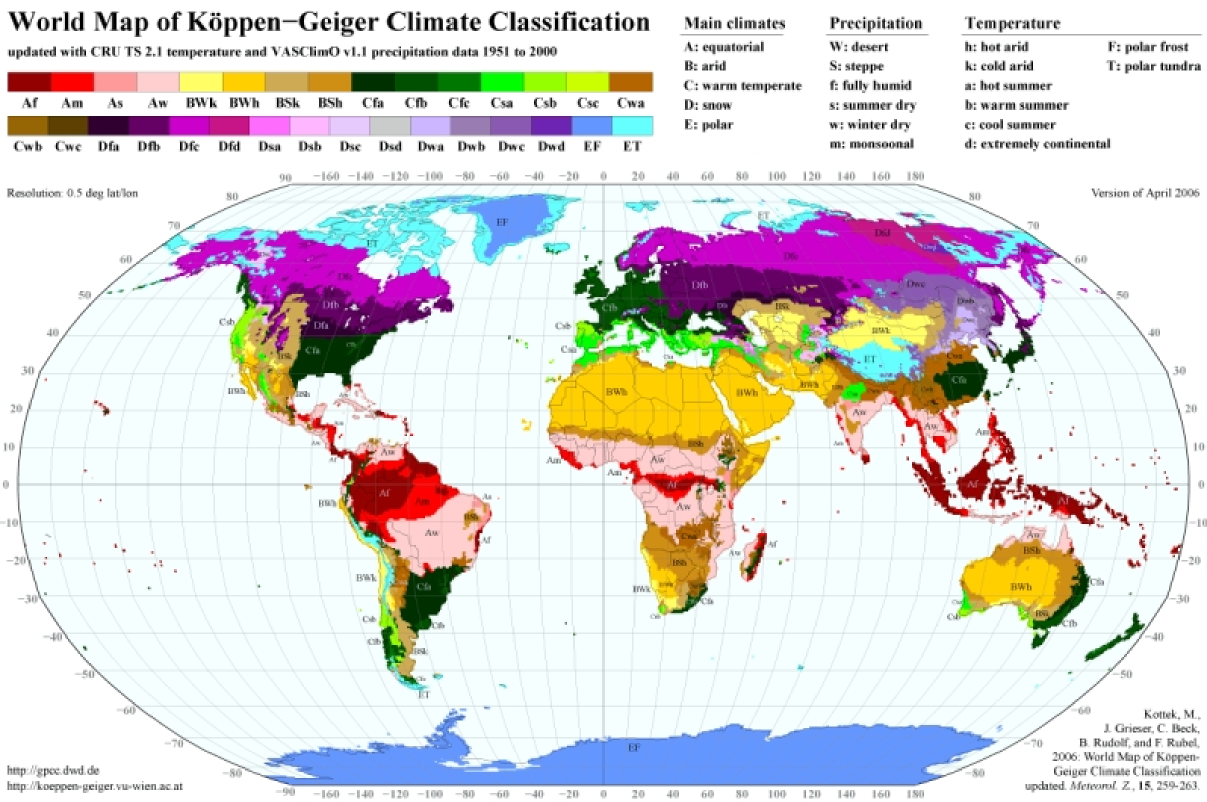


Figure 80 - World map of Koeppen Climate Classification

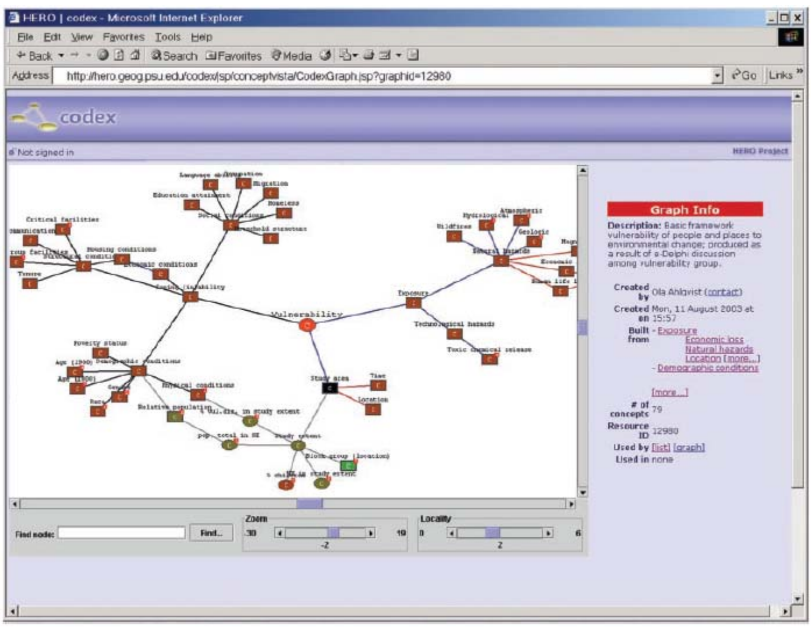


Figure 81 - A concept graph that depicts a HERO researcher’s conceptualization of vulnerability. The graph allows concepts, data, and tools to be linked in visual

4.2.2 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.

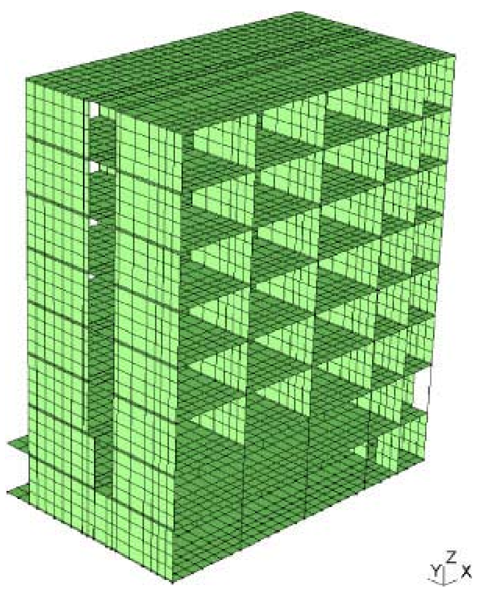


Figure 82: 3-D finite element mesh of an existing 1970s' building