VULNERABILITY ACROSS SPACE: A FOCUS ON THE UNDERLYING MECHANISMS

Galderisi A.[1], Ferrara F.F.[2]

Abstract

Vulnerability is widely recognized, both in scientific literature and institutional documents, as a key-component of risk, crucial for improving risk knowledge, assessment and management. In the last decades, vulnerability has been largely investigated according to different aims and disciplinary perspectives: nevertheless, the challenge for integrating current approaches has to be still faced and many gaps related to vulnerability understanding and measuring have still to be bridged.

Despite some scholars have clearly outlined that "vulnerability rests in a multi-faceted coupled system with connections operating at different spatio-temporal scales" (Turner et al. 2003), till now vulnerability is often represented as a static and crystallized feature of elements/systems or, according to Roberts et al. (2009), "as a static factor" rather than a process, neglecting in such a way the significant changes affecting both its facets and the relationships among them over time and across space. Hence, a clear idea of the path to be followed for analyzing and measuring the time and spatial dependency of vulnerability (Birkmann, 2006) and for grasping its dynamic nature is still missing.

For long, vulnerability has been associated, up to an absolute identification, to the concept of damage even though, according to a shared interpretation, it can be more precisely defined as "the characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard" (UNISDR, 2009). The UNISDR glossary (2009) highlights that vulnerability concept includes numerous aspects - arising from physical, social, economic and environmental factors - and that it significantly varies over time, but does not emphasize the variability of vulnerability, and of its different aspects, across space despite the entity and the far-reaching dimensions of the consequences produced by such a variability, as largely shown by recent disasters.

Even if different from each other, the concepts of vulnerability and damage are closely related and the recognition of damage patterns may represent one of the key-tool for in-depth analyzing some aspects of vulnerability not sufficiently investigated up to now. Accordingly, Cochrane (2004) states that "damages are displaced geographically and temporally". Therefore, looking at the different phases following the impact of a hazardous event, might the analysis of the spatial distribution of damage help us to better understand factors and mechanisms able to induce a displacement of vulnerabilities across space?

The present work aims at answering this question; in detail, grounding on some case studies, an overview of the main spatial mechanisms that can favor the displacement

---

[1] University of Naples Federico II, Dipartimento di Pianificazione e Scienza del Territorio, Naples, Italy - galderis@unina.it

[2] AIAT – Italian Environmental Engineers Association - floriana.ferrara@gmail.com

and the change of vulnerability across space and some hints devoted to an in-depth conceptualization of the spatial dynamics of vulnerabilities will be provided.

1. The dynamics of vulnerability

Hazards are generally recognized as spatial phenomena: spatial patterns of hazardous events as well as damage distribution in space have been an important concern of scientific literature in the disaster field. On the opposite, despite some scholars have clearly outlined that “vulnerability rests in a multi-faceted coupled system with connections operating at different spatio-temporal scales” (Turner et al. 2003), the dependency of vulnerability on time and space seems to be still hard to grasp.

Nowadays, vulnerability is widely recognized as an intrinsic feature of elements and systems: the UNISDR glossary provides a definition of vulnerability as “the characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard” (UNISDR, 2009), emphasizing that the concept includes numerous aspects, arising from physical, social, economic, and environmental factors and that it may significantly vary over time. Nevertheless, the UNISDR definition does not lay stress on the variability of vulnerability and of its different aspects across space, despite the entity and the far-reaching dimensions of the consequences produced by such a variability, as largely demonstrated by recent disasters.

Moreover, although at present territorial, social, economic systems are widely recognized as complex systems, continuously varying over time and across space, and vulnerability interpreted as an intrinsic feature of such systems, the latter is still now, surprisingly, often considered “as a static factor that modifies the amount of loss caused by threats” (Roberts et al. 2009) and approached as a state, rather than as a dynamic process developing over time and across space.

Due to such a prevailing approach, factors and mechanisms that may induce or contribute to the displacement of vulnerability across space have not been exhaustively investigated.

As an example, “risk transfer” processes have been up to now analyzed mainly in respect to the financial mechanisms (Benson and Clay, 2004; Arnold, 2008), such as insurances, and defined as “the process of formally or informally shifting the financial consequences of particular risks from one party to another whereby a household, community, enterprise or state authority will obtain resources from the other party after a disaster occurs, in exchange for ongoing or compensatory social or financial benefits provided to that other party” (UNISDR, 2009).

In some cases, risk transfer processes have been also investigated in relation to the “time” factor (Etkin, 1999). On the opposite, an effective conceptualization able to explain the displacement of vulnerability in space is still missing.

In detail, what has to be in-depth investigated are factors and mechanisms that, by acting as “drivers” of vulnerabilities across the space, can lead to different damage distribution.

As it will be better highlighted through the following case studies, factors and mechanisms inducing a displacement of vulnerability across space vary according to the type of vulnerability at stake in that, for example, the ones that may induce a transfer of physical vulnerability across space can be different from those which may determine a transfer of other aspects or facets of vulnerability.

Therefore, for our purposes, two "facets" of vulnerability will be mainly considered: physical vulnerability, which can be referred to "the fragilities that can lead to physical disruption and harm when facing the stress provoked by a given hazard" and systemic vulnerability, which can be referred to the susceptibility of elements and systems to be indirectly damaged, as a consequences of their functional or economic relationships with the hit elements and systems (Ensure Consortium, 2011). According to such definitions, it is possible to state that physical vulnerability is strongly hazard-related ("vulnerability to hazard" as a form of stress) whereas systemic vulnerability, weakly or indirectly dependent on hazard, can be interpreted as a "vulnerability to losses". The stronger the interdependencies among systems and system components are, the more relevant the "systemic vulnerability" is. Therefore, by a scale perspective, physical vulnerability can be analyzed on the hazard scale, according to its distribution across space, whereas systemic vulnerability has to be investigated on different geographical scales, depending on the functional and economic linkages between elements and systems (Polsky et al., 2007; Bonadonna et al., 2011).

Grounding on these considerations, two main mechanisms able to induce a displacement and in many cases a change of physical and systemic vulnerabilities across space will be here investigated: propagation and transfer.

Both the mentioned mechanisms can be referred to the shift across space of physical vulnerability due to the propagation or transfer of hazard factors. Furthermore, transfer mechanism is also useful to understand how systemic vulnerability, due to the interdependencies among elements and systems which characterize the hit territorial system, reveals itself at different geographical scales, moving from a local up to a regional or a global level. It is worth noting that the dynamics of vulnerability across space largely depend on the context, which is always crucial in vulnerability analysis (Anderson-Barry and King, 2005; Roberts et al. 2009). Social, economic, environmental as well as spatial and functional organization of the hit territorial systems, indeed, not only characterize the different facets of vulnerability but will also influence their dynamism across space.

Propagation and transfer mechanisms may develop very quickly or in a long time span, giving rise to huge and unexpected effects over areas significantly wider, sometimes very far from the one directly hit by the hazardous phenomenon. In other words, such mechanisms might determine a final distribution of vulnerabilities and, consequently, of damages significantly different from the one resulting in the immediate aftermath of the hazardous event.

The term "propagation" suggests, for analogy to some physical phenomena (e.g. sound, light), the existence of a "mean" allowing the spread across space of vulnerability or, better, of the factors that determine vulnerability. Therefore, the term propagation may be referred to the spread of a given phenomenon from an element or an area to a contiguous/adjacent element or area "by contact" or, even, from an element/area to another element/area, although not contiguous, thanks to the "connecting" action of a specific mean (e.g. air, water).

The spread of vulnerability, and namely of physical vulnerability across space, is very often a direct consequence of hazard propagation. Such consideration is not surprising, since, as mentioned above, this aspect of vulnerability is strongly hazard-related.

Hazards can propagate through different means, involving elements and/or systems not directly hit by the hazardous event and, consequently, determining new vulnerabilities, increasing the overall damage and influencing spatial distribution of both vulnerability and damage. Nevertheless, even though spatial distribution of hazards is generally investigated, the potential propagation of hazards, despite its relevance into vulnerability analysis, is often neglected mainly in case of na-tech hazardous events (Galderisi et al, 2008).

On the opposite, the identification of potential elements or factors able to spread hazards across space may allow us to recognize new or different exposed targets, highlighting the need for investigating their vulnerability and for singling out the most appropriate scale for developing vulnerability analysis.

The concept of transfer differs from the propagation one in that while the latter is generally referred to the widening in space of the impacts of a given hazardous event, capable to affect areas or elements characterized by spatial continuity (in that elements or areas are contiguous or linked to each other through a mean), transfer can be the result of reverberation effects and can involve elements or areas not contiguous or spatially linked to the place of occurrence of the hazardous phenomenon.

Transfer mechanisms overcome the concept of spatial proximity, in that the presence and the continuity of a mean does not represent a key-requirement as in case of propagation mechanisms.

As mentioned before, transfer mechanisms can be referred both to physical and to systemic vulnerability. The displacement of physical vulnerability is generally due to a transfer of hazard factors across space, whereas the shift of systemic vulnerability from one area to another is generally due to functional and economic interdependencies among elements and systems located in the hit territorial context and other placed in other contexts, not directly hit by the hazardous events.

It is worth noting that propagation and transfer mechanisms do not exclude each other: they can occur contemporarily and, according to the well accepted idea that vulnerability is a “multifaceted” concept, they can also turn one “facet” of vulnerability into another, qualitatively and quantitatively different from the previous one.

The above mentioned mechanisms will be more in-depth analyzed in the following paragraphs through different case studies, focusing on the occurred damages interpreted as the result of hazards and vulnerabilities of exposed elements and systems. In detail, the Baia Mare (2000) and the Katrina (2005) disasters will be shortly described for clarifying how hazard propagation and transfer mechanisms may induce a displacement of physical vulnerability across space. More attention will be devoted to the transfer mechanisms due to the interdependencies among elements and systems, looking at the earthquake occurred in 2009 in the Abruzzo region (Italy) and at the eruption occurred in 2010 in Iceland: both of them largely emphasize how pre-existing functional and economic relationships among elements and systems located at different geographical scales may induce a displacement and a change of vulnerability across space, turning in many case physical vulnerability at local scale into systemic vulnerability at upper scales.

2. Transfer and change of vulnerability across space: case studies

2.1 Hazard propagation and transfer: effects on dynamism of vulnerability

The Baia Mare accident

The disaster occurred in Romania, near to Baia Mare village, in 2000 represents a clear example of hazard propagation through a “mean”, capable of extending the effects of hazard to a wider area as well as to involve new, and potentially vulnerable, elements located in areas far from the hazard source, inducing an increase in the overall vulnerability to the hazardous event.

In the mentioned case, toxic substances, namely the cyanide used by the Aurul company to remove precious metals from the tailing, were released into the Lapus River; then these substances travelled downstream into the Somes and Tisza rivers into Hungary, before entering the Danube. The cyanide was carried out by the river waters from the source placed in Romania, to Yugoslavia and Hungary, putting at risk the water supply of more than 2 million of Hungarian citizens. The concentration of toxic substances was supposed to significantly decrease along the path from Romania to Hungary, with less and less impacts on environment and population. Unfortunately, conversely to what was more likely, the presence of “ice on the rivers and low water levels in Hungary delayed the dilution of the cyanide, increasing the risk of municipal water supplies” (UNEP/OCHA, 2000).

Only the prompt action of the local authorities avoided serious damage to the water supply of the two largest cities along the Tisza river, Szolnok (120.000 inhabitants) and Szeged (206.000 inhabitants).

In such a situation, river water was the “mean” responsible for hazard propagation: hence, new vulnerable targets were involved and the consequences of a supposed localized event, in terms both of direct and indirect impacts, extended over areas very far from the one directly hit, affecting natural resources (such as the flora and fauna of the central Tisza river), population, economic activities and organization of the emergency response (involving different national States, different organization and so on) of different countries too. Therefore, the propagation of hazard through the river water has induced a propagation of physical vulnerability across space and, in the meanwhile, it has also determined a change of vulnerability, from the physical vulnerability of the heterogeneous targets directly or indirectly affected to the social and institutional vulnerability arising from the threat to the water supply and to the need for local authorities in different States to deal with such a threat.

Figure 1 - Vulnerability propagation due to hazard propagation. (Source: own elaboration)

The Katrina Hurricane

Although rare, a displacement of physical vulnerability may occur also as a consequence of hazard transfer. A paradigmatic example in this line of thought is the Katrina Hurricane which hit the city of New Orleans in 2005. After the hurricane broke the levees of the Mississippi river, the immediate task for National and Federal Authorities was to drain out flood water from the city. The latter indeed, being placed below the sea level, was characterized by a not fully effective natural water drainage. The amount of flood water to be removed was accounted for about 114 billion liters. In the immediate aftermath of the event, also due to the accident to the Murphy Oil, flood water rapidly become a mixture of toxic and organic substances (Sheikh, 2005). Therefore, the water drainage presented a number of significant concerns. Lake Pontchartrain and Mississippi river were the two potential receptors of the flood water. Due to the fact that the latter was the main source for drinking water supply of the city, Local Authorities decided to pump waters into the Lake Pontchartrain. Furthermore, the treatment of flood waters before pumping them was not possible, due to the lack of full treatment technologies in place and the need for a quick drainage of the water from the urban area. Thus, Local Authorities decided to pump flood waters from the city towards the mentioned Lake that is a water body relatively close to the city itself and connected through the Lake Borgne to the Gulf of Mexico (Fig. 2).

Figure 2 – The area around New Orleans affected by hazard transfer. (Source: National Academies Press, 2009)

Due to the importance of the Lake and of its surrounding as natural ecosystems, the Lake – highly polluted as a consequence of the numerous sources of chemicals and organic substances – had been already interested since 2000 by recovery interventions, under the responsibility of the Environmental Protection Agency (EPA) and Pontchartrain Basin Restoration Act Program. Thus, before Katrina, fisheries and touristic activities were largely developing on and around the Lake.

According to the Congress Report (Sheikh, 2005), after the operations of pumping-in, the Lake, despite the relevant efforts for its environmental recovery, had received in few days the equivalent of several years of urban runoff. Kilic and Aral (2006) estimated that the Lake would have required about 80 years to recover from the stress created by the pumping of polluted waters after Katrina.

Summing up, the release of toxic substances into the Lake Pontchartrain and the consequent pollution of the Lake itself can be considered a “man-made” phenomenon of hazard transfer: by involving new targets, namely the natural ecosystem of the Lake, a transfer of physical vulnerabilities occurred accordingly to hazard transfer which, as in the previous case, has turn into other facets of vulnerability (for example the economic one, due to the loss of economic activities which were largely developed around the Lake).

2.2 Functional and economic interdependencies: effects on dynamism of vulnerability

The Abruzzo earthquake

The Abruzzo earthquake, occurred in central Italy, with a 5.8 local magnitude (APAT, 2009), on the 6th of April 2009. It caused the death of 298 people, 1600 injured, the destruction of the historical centre of L’Aquila – the main city of the Abruzzo region –and severe physical damages in other minor centers located in an area identified as “the crater” (PCM, 2009) for a total toll of over €10 billion.

Looking at the earthquakes experienced by Italy over the last century, after Messina (1908), L'Aquila has been the first big urban center[3] severely hit by a seismic event.

By an engineering perspective, L'Aquila was characterized by a high level of physical vulnerability to earthquake, due to a prevailing stock of ancient masonry buildings.

By an urban planning perspective, even if the city core of L'Aquila is a medieval center, its development has been quite atypical. The growth of the city has not occurred, according to a traditional “core-periphery” model, around the historical city but according to the model of a modern “city region”, even if concentrate in a quite small territory. This means that urban growth has occurred through the development of numerous hamlets and villages, quite distant from the city center but strongly related to it from a functional and economic point of view (Fig. 3). In some cases, these small villages are formally recognized as districts of the city. More precisely, the growth of the city mainly occurred after the Sixties, when the Highway A24 connecting L'Aquila with Rome was built up. In the Master Plan approved in 1975, and still in force at the time of the earthquake, 4.200 ha of new residential and industrial settlements were included and all of them have been realized. Thus, between the 1951 and the 2001, the population grew from 54.633 to 68.503 inhabitants, while the urbanized areas from 500 ha (the area of the city core) to 3.100. Thus, the urban development has entailed the establishment of a monocentric urban model characterized by a strong dependency of the new developments on the city core, the historical city, where most of the institutional, administrative, commercial activities and an important university pole were concentrated.

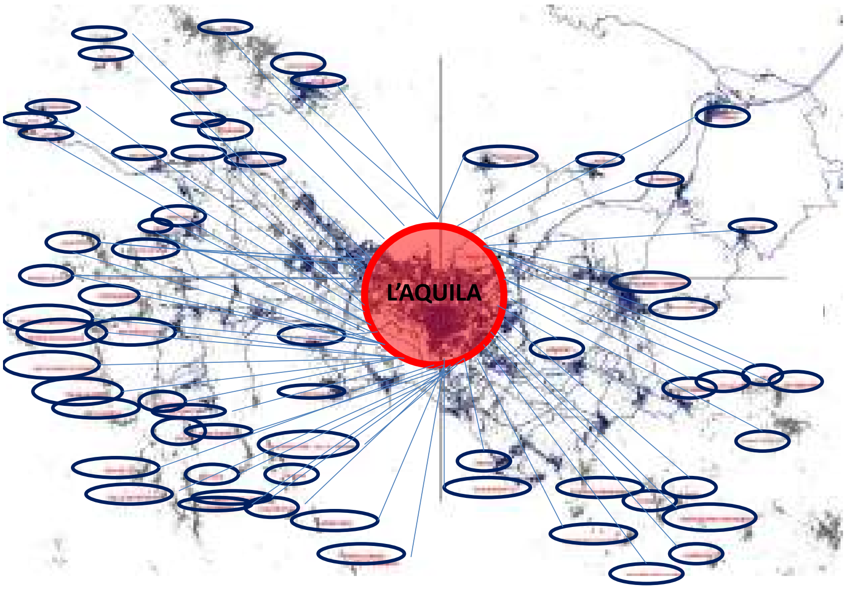

Figure 3 – The city-core and the near villages and hamlets which form the L'Aquila City Region. (Source: own elaboration)

---

[3] 72.988 inhabitants in 2008. Source: http://www.comuni-italiani.it/066/049/statistiche/recenti.html

Thus, the historical city, which represented the most physically vulnerable area to a seismic event, played a primary role in functional and economic terms for a significantly wider geographical area.

In detail, in terms of institutional and administrative activities L'Aquila was home to the Court of Law, the Cadastre, the Prison, the Regional Council. These buildings, mostly placed in the historical city, have suffered severe structural damages or collapsed, as in the case of the Palace of Government, head office of the Prefecture that is also the public body in charge of coordinating activities during an emergency phase. As a consequence, the prefecture was prevented from meeting these specific commitments included in its institutional competences.

Moreover, in the historical center of L'Aquila, numerous commercial and touristic activities (bars, hotels, restaurants, accommodation facilities), also due to its touristic attractiveness at regional and national level, were placed. After the earthquake, such area, due to safety problems related to the risk of collapse for parts of heavily damaged buildings, was declared as “red zone” (Fig. 4). Such a declaration has induced the interdiction to access for all citizens and, in turn, the paralysis of the incomes of all people having their source of livelihood in the red zone.

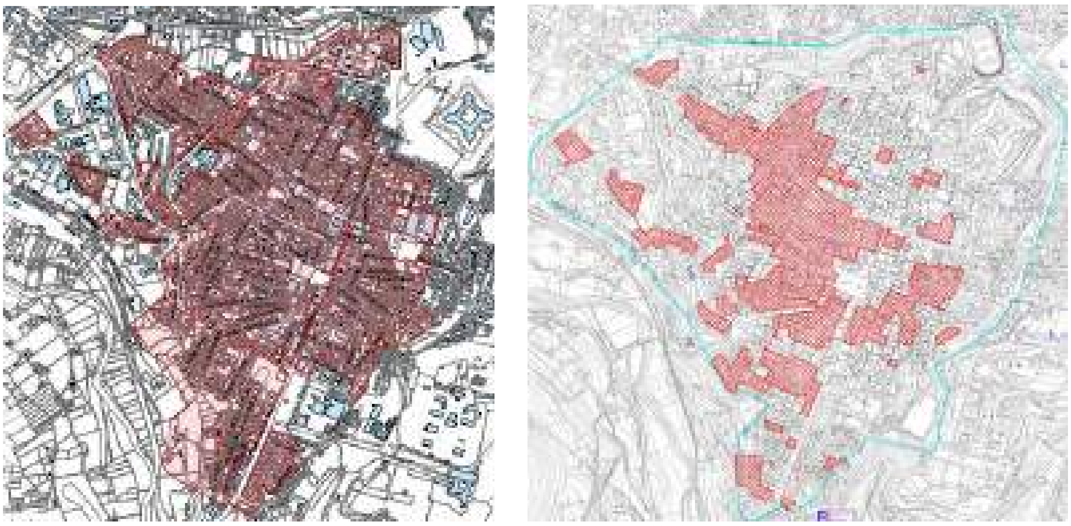

Fig. 4 – Boundaries of the red zone (December 2009 – August 2011) (Source: http://www.comune.laquila.gov.it/pagina52_zona-rossa-della-citta.html)

Apart from commerce and tourism, before the earthquake, economic activities in L'Aquila were mainly related to building sector, real estate, ITC, manufacturing that provided goods and services to other small Municipalities of the crater whose economy was, on the contrary, mainly based on agricultural activity, hunt and forestry (CRESA, 2009).

Lastly, L'Aquila was famous for being an important university pole. University was very important for the city both in terms of identity - being the most ancient University in the Abruzzo Region and also one of the most important in Italy - and for its economic significance. About half of the 27.000 students enrolled at the

L'Aquila University before the earthquake were non-residents (CRESA, 2009), which means that they were the main users of numerous services and economic urban activities, such as local transport, accommodation facilities, commercial activities and so on.

After the earthquake, the registrations at university have decreased and only some adopted contingency measures, such as the promotion of free public transport and free fees for students, have prevented the collapse of a well-established economic activity. Nevertheless, the identity of the city, by this perspective, has been seriously jeopardized.

Furthermore, relevant damages to tourism and to private small enterprises have been recorded in the city core, with ripple effects reverberating from the local scale up to the regional one. As mentioned before, functional and economic damages represent an indirect consequence of the hazard itself, in that rather than related to a “vulnerability to hazard”, namely to the earthquake, which generally reveals itself at the hazard scale, they are generally related to interdependencies among elements and systems which pave the way to a “vulnerability to losses” at wider geographical scales.

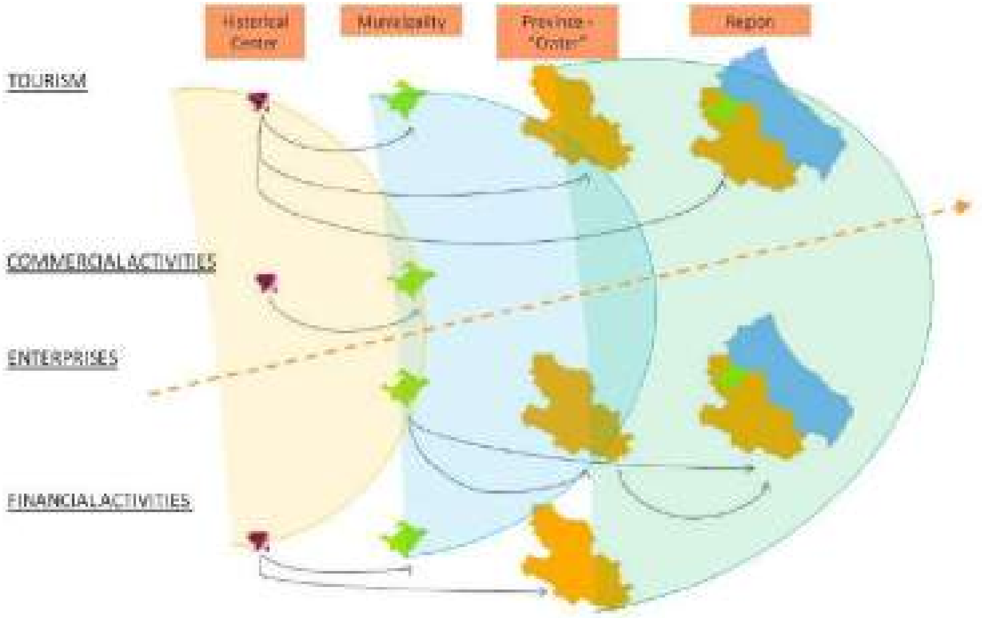

Figure 5 - Transfer of vulnerability across space due to functional and economic interdependencies. (Source: own elaboration)

To sum up, the important functional and economic role of a (small) physically vulnerable area to earthquake (the historical center), due to the concentration of numerous and important activities, and to the interdependencies between the city center and wider geographical areas, has induced a transfer of vulnerability from a sub-municipal, municipal level up to the regional one and, in the meanwhile, has determined a change in the prevailing facet of vulnerability, in that physical vulnerability at local scale has been turned into a systemic and economic vulnerability at wider geographical scales (Fig. 5).

Furthermore, it is worth stressing that the persistence of an interdicted “red zone” in the historical center of L’Aquila induces also an extension of the time needed for an effective recovery and a likely worsening of the conditions which have determined the vulnerability to losses, with the effective threat of widening vulnerability factors far beyond the involved area.

The 2010 Eyjafjallajökull eruption

Iceland is a well-known volcanic area, with about 130 volcanoes. The last significant eruption of the *Eyjafjallajökull* happened on the 14th of April 2010, after a previous and less intensive episode occurred some days before. The eruption was characterized by a high explosiveness index coupled with a significant production of ashes. Chester et al. (2001) underline that the scale of the potential consequences of a local hazardous event mainly depends on “the strategic position of the threatened city within the economy of a country and/or region”. This is not the case of Iceland that has neither a “core” position nor an important economic role in the European and in the global context. Nevertheless, the impacts of the hazardous event have been very relevant because a strategic activity in the globalized world economy, namely the air transport of freights and people, has been affected as a consequence of the propagation of hazard through the air space (Galderisi et al., 2011).

According to a physical analysis of the phenomenon, in the immediate aftermath of the eruption and in the following days, a cloud of exceptionally fine-grained ashes was driven toward Central Europe. Ash particles may induce relevant failures in engines, in essential systems of aircrafts (e.g. sensor systems, hydraulics) and external aircraft components such as pilot windscreens that may become largely non-transparent. Concerns about safety condition led to the closure of large portions of European air space, including some strategic airport as London and Paris over the week 15-21 April. So, on the one hand, the air traffic of some important hubs, connected to each other, were suspended, interrupting in this way the provision of important services at global level; on the other hand, the use of a “global shared” resource, the air space, used as a physical mean for covering the distance from one city to another, was interdicted.

The cancellation of flights across Europe affected about seven million passengers (Oxford Economics, 2010) and has entailed, only for European flights companies, economic losses for $2.6 billion in GDP. What initially seemed to be only an inconvenience for passengers (e.g. tourists, businessmen) and commercial activities soon showed the dimension of a planetary trouble especially by an economic point of view. The effects of the crisis extended indeed far beyond the direct impact on the air transport industry (Oxford Economics, 2010). Due to the closure of air space, significant secondary impacts have been recorded too, so that a “butterfly effect” for the Icelandic eruption has been largely mentioned.

One of the most severely damaged sectors by the air space restriction has been the import-export one. In Europe, most of the export “made in Italy” of fresh fruits (mainly strawberry), mozzarella cheese and flowers was interrupted, whereas in

Africa, relevant repercussions on exports have been reported in Kenya due to the fact that this country normally exports up to 500 tonnes of flowers daily, the 97% of which is delivered to Europe. Therefore, Kenyan farmers have been forced to dump stocks of fresh food and flowers destined for European consumers and, according to Kenya's Fresh Produce Exporters Association Daily Nation, the loss for local producers of flowers, fruit and vegetables has been US$ 3 millions a day as a result of flight cancellations to Europe (Oxford Economics, 2010). The same amount has been estimated for market losses related to flower export to the EU from Latin America and mainly from Ecuador and Argentina. Referred to the import-export sector, the Japanese carmaker Nissan announced a one-day suspension of production of three of its models too, because of the impossibility to import relevant components from the Irish Republic (BBC, 2010).

Other relevant failures, with consequent further economic losses, have been determined by the cancellation of political and business meetings, of relevant cultural and sporting events and also by the delays to services of air mail companies.

As comprehensive data, the total impact on global GDP caused by the first week's disruption amounts to approximately US$ 4.7 billions (Oxford Economics, 2010).

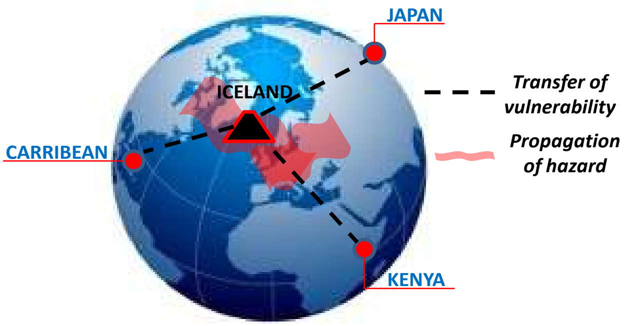

Figure 6 - Transfer of vulnerability across space due to hazard propagation combined with functional and economic interdependencies. (Source: own elaboration)

The Icelandic eruption has clearly demonstrate that the consequences of local hazardous events occurring in places which hold a strategic position within a wider economic context or which affect activities characterized by a key role in the global economy may induce damage which reverberate on areas very far from the hazard source, also at a global scale.

In detail, the propagation of the volcanic ashes - due to the features of the eruptions and to the meteorological conditions - has triggered a transfer and a change of vulnerability: physical vulnerability of airplanes to ashes has been turned into a systemic vulnerability of all the activities (airline industry, people mobility, commercial activities, business, etc.) depending on air flights. The latter vulnerability has been turned again into an economic vulnerability of enterprises or national economies depending on those activities (Fig. 6). The transfer of vulnerability has been clearly favored not only by the hazard propagation but, mainly, by the existence of well-established functional and economic interdependencies, which allow to overcome the boundaries of any physical contiguity.

3. Conclusions

Hazardous events generally induce significant multi-scale and cross-scale effects: thus, an effective vulnerability analysis has to look far beyond the area directly hit by a hazard, taking into account factors and mechanism which may favor the displacement across space of the different facets of vulnerability.

Up to now, spatial patterns of hazardous events as well as damage distribution in space have been largely investigated. On the opposite, factors and mechanisms inducing a displacement of vulnerability across space are still hard to understand and foreseen.

In this paper, some hints for a conceptualization of the spatial dynamics of different facets of vulnerability have been provided, focusing on propagation and transfer mechanisms, interpreted as "drivers" of physical and systemic vulnerability across space. Propagation mechanisms can be referred to the spread of a given phenomenon from an element or an area to a contiguous/adjacent element or area "by contact" or, even, from an element or an area to another element or another area, although not contiguous, through a specific mean (e.g. air, water). Transfer mechanisms can be referred to effects of reverberation, able to involve elements or areas not contiguous or spatially linked to the place of occurrence of the hazardous phenomenon.

Moreover, according to the Ensure Project, physical vulnerability has been defined as a "vulnerability to hazard", whereas systemic vulnerability has been interpreted as a "vulnerability to losses". Such a difference has allowed us to deepen the discussion on propagation and transfer mechanisms, highlighting how dynamics of physical vulnerability are mainly related to propagation and transfer of hazard across space; whereas dynamics of systemic vulnerability largely depend on interdependencies among elements and systems. These mechanisms may develop very quickly or in a long time span and may occur separately or contemporarily; furthermore, they can turn one "facet" of vulnerability into another, qualitatively and quantitatively different from the previous one.

In detail, the Baia Mare (2000) and the Katrina (2005) disasters have clearly highlighted how hazard propagation and transfer mechanisms may induce a displacement of physical vulnerability across space; the Abruzzo earthquake (2009) and the Iceland eruption (2010) have allowed us to explain how pre-existing functional and economic relationships among elements and systems located at different geographical scales may induce a displacement and a change of vulnerability across space, turning in many case physical vulnerability at local scale into a systemic one at upper scales.

All case studies have been analyzed grounding on damage distribution which, being the result of hazards and vulnerability of exposed elements and systems, has contributed to a better understanding of spatial dynamics of vulnerability. Case studies have clearly shown how, as a consequence of propagation and transfer mechanisms of the different facets of vulnerability, physical as well as functional or economic damage may affect areas even very far from the hazard source and significantly wider than the one directly hit by hazard itself. Involved areas cannot be confined to the areas immediately surrounding the hit one and they are not necessarily contiguous to it; they can be very wide, depending on the existence of a mean able to propagate hazard, to the role of the affected area or the affected element/system in a wider geographical context, and on the interdependencies among vulnerable elements and systems. These findings open the way to the matter of the appropriate scale for carrying out vulnerability analysis, in that the focus on the hazard scale may lead us to underestimate important aspects of vulnerability and of its dynamics across space: systemic vulnerability, indeed, largely depends on the interdependencies among systems and their components and, as a consequence, the width of the related investigation area has to be determined according to the specific context.

4. References

Arnold, M. (2008), *The Role of Risk Transfer and Insurance in Disaster Risk Reduction and Climate Change Adaption*, Commission on Climate Change and Development. Available at: http://www.ccdcommission.org/Filer/pdf/pb_risk_transfer.pdf

BBC (2010), *Iceland volcano cloud: The economic impact.* Available at http://news.bbc.co.uk/2/hi/8629623.stm

Benson, C.; Clay, E.J. (2004), *Understanding the financial and economic impacts of natural disasters*, The World Bank, Washington DC.

Birkmann, J. (2006), “Measuring Vulnerability to Promote Disaster-Resilient Societies: Conceptual Frameworks and Definitions”, in Birkmann J. (ed.), *Measuring Vulnerability to Natural Hazards. Towards Disaster Resilient Societies*, UN University Press.

Bonadonna, C.; Simicevic A.; Galderisi, A. et. al. (2011), *Analysis of vulnerability factors vs space deliverable*, Deliverable 3.2, Available at: http://www.ensure project.eu/ENSURE_Del3.2.pdf

Chester, D.K.; Degg, M.; Duncan, A.M.; Guest, J.E., “The increasing exposure of cities to the effects of volcanic eruptions: a global survey.” *Environmental Hazards* 2: 89-103, 2001.

Cochrane, H.C. (2004), “Indirect losses from natural disasters: measurement and myth”, in Okuyama, Y.; Chang, S.E. (eds.), *Modeling spatial and economic impacts of disasters*, New York: Springer-Verlag, pp. 37-52.

CRESA (2009), *Economic consequences of the 2009 L’ Aquila earthquake: an interim report*, Available at: www.cresa.it.

Ensure Consortium (2011), Enhancing Resilience of Communities and Territories facing Natural and Na-tech Hazards. Aspects and Methodologies of Vulnerability assessment: the Integrated Multi-Scale Approach of the ENSURE Project. Ensure Consortium 7FP.

Etkin, D. (1999), Risk Transference and Related Trends: Driving Forces Towards More Mega Disasters, *Environmental Hazards* 1, 69-75.

Galderisi, A., Ceudech, A., Pistucci, M. (2008), “A Method for Na-Tech Risk Assessment as Supporting Tool for Land Use Planning Mitigation Strategies”, *Nat Hazards*, 46:221–241.

Galderisi, A.; Kropp, J.P.; Ceudech, A.; Kallache, M. (2011), “From Global to Local and From Local to Global: Examples of Event Scenarios in Europe”, in Menoni, S.; Margottini, C. (eds.), *Inside Risk: a Strategy for Sustainable Risk Mitigation*, Springer Verlag Italia, Milano.

ISPRA (2009), *Geological effects induced by the L’Aquila earthquake (6 April 2009, Ml=5.8) on the natural environment.* Available at http://www.apat.gov.it/site/_files/Inqua/2009_abruzzo_ earthquake_ report.pdf (last access on 13th of April, 2012).

Kilic, S. G., Aral, M.M. (2006), Preliminary Analysis of Lake Pontchartrain Pollution after Hurricane Katrina, *Proceeding Paper at the World Environmental and Water Resource Congress*, May 21-25, Omaha, Nebraska.

National Academies (2009), *The New Orleans Hurricane Protection System. Assessing Pre- Katrina Vulnerability and Improving Mitigation and Preparedness*, Committee on New Orleans Regional Hurricane Protection Projects, Water Science and Technology Board, Division on Earth and Life Sciences, Board on Infrastructure and the Constructed Environment, Division on Engineering and Physical Systems, National Academy of Engineering and National Research Council, National Academies Press, Washington, DC.

Oxford Economics (2010) *The economic impacts of air travel restrictions due to volcanic ash.* Available at http://www.oxfordeconomics.com/OE_Cons_Descns.asp

PCM (2009), *Presidenza del Consiglio dei Ministri Decree “Individuazione dei comuni danneggiati dagli eventi sismici che hanno colpito la provincia dell'Aquila ed altri comuni della regione Abruzzo il giorno 6 aprile 2009”*. Available at http://www.interno.it/mininterno/export/sites/default/it/sezioni/ servizi/legislazione/protezione_civile/0976_2009_04_16_DCDTA16042009.html (last access on 13th of April, 2012).

Polsky, C.; Neff, R.; Yarnal, B. (2007), “Building comparable global change vulnerability assessments: The vulnerability scoping diagram”, *Global Environmental Change*, Vol. 17, Issue 3-4, pp. 472-485.

Roberts, N. J.; Nadim, F.; Kalsnes, B. (2009), “Quantification of vulnerability to natural hazards”, *Georisk: Assessment and Management of Risk for Engineered Systems and Geohazards*, 3: 3, 164 - 173.

Sheikh, P.A. (2005), *The Impact of Hurricane Katrina on Biological Resources*, CSR –Congressional Research Service, http://digital.library.unt.edu/govdocs/crs/ permalink/meta-crs-7672:1.

Turner, B.L.; Kasperson, R.E.; Matson, P.A.; McCarthy, J.J.; Corell, W.; Christensen, L.; Eckley, N. (2003), “A framework for vulnerability analysis in sustainability science”. *Proceedings of the National Academy of Science of the United States*, 100: 8074-79.

UNEP/OCHA (2000), *Cyanide spill at Baia Mare Romania*, Available at http://www.natural-resources.org/ minerals/cd/docs/unep/Baia_Mare%20_mission_report.pdf

UN/ISDR (2009), *Terminology on Disaster Risk Reduction*, Available at www.unisdr.org/ eng/library/UNISDR-terminology-2009-eng.pdf