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GIS4RISKS project. Synergic use of GIS applications for analysing volcanic and seismic risks in the pre and post event

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Abstract

Recent studies have provided important input and methodologies to analyse geodynamic hazards and risks in areas exposed to seismic and volcanic events but the link between the geophysics and engineering aspects and the humanistic and economic parameters are often weak. Thus, the GIS4RISKS project sets out to underline and make operative the possible interactions between different fields of research for a socially useful analysis, with the support of GIS and other geospatial technologies which promote the dialogue and the synergy between studies that conducted together can notably increase their impact on actual knowledge. In particular, the attention is focused on the L'Aquila and Naples Provinces (Italy), because they are very interesting study areas to evaluate the added values provided by GIS and geotechnologies in the pre and post event phases. Starting from these representative study areas, the GIS4RISKS project is aimed at elaborating interdisciplinary models and applications which can provide support for meticulous and innovative analysis of multiple variables, also giving remarkable input regarding the educational level and the raising of awareness of the population subject to risk.

Keywords: GIS, Seismic and Volcanic Risks, Pre and Post Event, Disaster Resilience, Interdisciplinary Approach

1. Introduction

Different studies, in scientific areas like geophysics and engineering, have provided analytical methodologies to evaluate geo-dynamic hazards in areas particularly subject to seismic and volcanic events. On the other hand, some humanistic and economic research has proposed parameters which can be preparatory for an evaluation of people and buildings potentially exposed to risk. Nevertheless, there is a lack of studies able to combine different methodologies in a rigorous approach aimed at achieving relevant developments in terms of risk evaluation and management and civil protection, giving the right importance to anthropic parameters in the scientific risk formulas. For example, recent research has examined many studies focused on the Vesuvius and Phlegraean areas, showing that the main aspects considered are often physical, and those concerning the eruptive behavior and hazard, while the social-demographic parameters seem secondary (Pesaresi and Marta, 2014, p. 40).

Thus, the main aim of the GIS4RISKS project is to promote and enhance the synergic interactions between potentially collaborative fields of research for a socially useful integrated analysis. On the other hand, the need has been felt for a long time to "amalgamate" the technical-physics sphere with the anthropic-social one in unitary and detailed research and an intervention strategy that is fundamental for an adequate analysis and consequential organization of seismic-volcanic areas, which have often recorded impetuous modifications due to chaotic and uncontrolled saturation of the spaces (Famoso, 1988, pp. 8, 5). Using GIS and sophisticated geospatial technologies, as a key support to different theoretical and operative knowledge, in a combined optic we set out to test geographical, geophysics, engineering and interdisciplinary models with the aim to provide innovative applications useful to deal with geodynamic events and risks. In fact, the potential advantages which can be obtained are considerable – in natural hazard risk modelling – by the development of a fusion among the philosophy of risk management, the inter-disciplinary approach and the strength of GIS as a neuralgic tool (Zerger, 2002, p. 287)[1].

Therefore, focussing the attention on the Naples and L'Aquila Provinces (respectively in the Campania and Abruzzo Region, Italy), as testing study areas, we intend to define and validate methodological approaches which can be exported to other territorial contexts with similar conditions of vulnerability[2] and risk exposure[3], obtaining a considerable positive impact for public safety.

Particularly, the name GIS4RISKS, which identifies a "multidisciplinary project" just financed by the Sapienza University of Rome (in the category "research projects with high innovation level"), is related to the aim to consider *seismic* and *volcanic risks* in order to define a strict reference framework useful both in the *pre* and *post event* phases. We intend to elaborate interpretative models, GIS and geospatial applications which can provide precious inputs for the detailed and integrated analysis of multiple variables, also considering the anthropic parameters, the historical and cultural heritage and the construction period of housing, which are usually neglected, and creating web applications useful in terms of disaster resilience and the spreading of risk awareness.

2. The framework of the project and its main aims

In the *EU Framework Programme for Research and Innovation* of Horizon 2020[4], into the pillar "Societal Challenges", there is a section called "Secure societies – Protecting freedom and security of Europe and its citizens" where it is underlined that the first aim is "to enhance the resilience of our society against

[1] Already twenty-five years ago it was underlined the necessity to understand the importance "to develop stable long-term international programs needed to address the global problem of volcanic hazards mitigation on a systematic rather than an ad hoc basis. While refinements in methodology and new technologies will be needed to improve hazards assessments and eruption forecasts, significant gains are more likely to be obtained in the near term by wider application of existing technology to high-risk […] volcanoes in densely populated regions" (Tilling, 1989, p. 263).

[2] For example, the "2009 L'Aquila earthquake has highlighted the vulnerability of such historic centres, both in Italy and across much of the Mediterranean region, and provides a valid argument for the establishment of major retrofitting programmes in order to avoid far worse seismic disasters in future" above all in case of seismic events with a major magnitude (Papanikolaou et al., 2009, p. 26).

[3] For this purposes it is need to define formulas, parameters and devices which can be replicated adopting them to local factors.

[4] "Horizon 2020 is the financial instrument implementing the Innovation Union, a Europe 2020 flagship initiative aimed at securing Europe's global competitiveness" (http://ec.europa.eu/programmes/horizon2020/en/what-horizon-2020).

natural and man-made disasters, ranging from the development of new crisis management tools to communication interoperability, and to develop novel solutions for the protection of critical infrastructure"[5]. Effectively, the: "Risk decision-making in natural hazards often requires spatial selection using a plethora of risk factors" (Chen et al., 2001, p. 396). Moreover, these aspects are also related to the concept of "social vulnerability" which "refers to the capacity of a human community exposed during the impact of a natural hazard event […] to resist, cope with, and recover from that impact" and which can influence the risk perception (Armaş, 2008, p. 397). "It is a multidimensional construct" where a lot of social-demographic, economic and infrastructural and settlement variables play an important role (Cutter and Finch, 2008)[6].

In the pillar "Societal Challenges" of Horizon 2020 several *topics* underline the importance of promoting a tangible progress in the approach to natural disasters according to different aspects.

For example, the *topic* "Crisis management topic 7: Crises and disaster resilience – operationalizing resilience concepts" states: "To increase Europe's resilience to crises and disasters is a topic of highest political concern in the EU and its Member States and Associated Countries. This concerns both man-made threats […] and natural hazards such as e.g. floods, storms, earthquakes, volcanoes and tsunamis. […]. Resilience concepts namely need to be developed for critical infrastructures (supply of basic services like water, food, energy, transport, housing/shelter, communications, finance, health), but also for the wider public to integrate and address human and social dynamics in crises and disaster situations, including the role of the population, the media, rescuers (staff, volunteers and ad-hoc volunteers)"[7].

Geodynamic events occupy a central position because they often cause many victims and considerable damage, with connected problems of resilience, and can generate social and economic disasters, also causing the loss of a valuable cultural heritage. In this viewpoint, the two study areas of the GIS4RISKS project, the L'Aquila and Naples Provinces, respectively for the seismic and volcanic risk, are particularly representative in Italy.

In fact:

- the Naples Province is "unique" in the Italian scenario, because according to the data of the last Census (2011) it continues to be strongly the Italian Province with the highest population density (2,591 inhabitants/km^2)[8] and the cases of Casavatore (12,224 inhabitants/km^2), Portici (12,110), San Giorgio a Cremano (11,089), Melito di Napoli (9,688) and Naples (8,082) are emblematic of this. Moreover, on the basis of the 2009 land use data of the Campania Region, the amount of artificial surfaces in the Naples Province is 33%[9], while this value is about 7% in Italy. Hence the "explosive" anthropic and building presence (Gasparini, 2005; Giacomelli and Pesaresi, 2005, pp. 62-70; La Foresta, 2005; Pesaresi and Scandone, 2013, pp. 228-234; Petrosino et al., 2004), a typical chaotic sprawl (Pesaresi

[5] http://ec.europa.eu/programmes/horizon2020/en/h2020-section/secure-societies-%E2%80%93-protecting-freedom-and-security-europe-and-its-citizens.
In this perspective, a recent study – which has focussed the attention on volcanic hazards and vulnerabilities of exposed elements – has reviewed disruptions and damages recorded by critical infrastructures due to four volcanic phenomena (tephra fall, pyroclastic density currents, lava flows and lahars) during eruptions in the last 100 years. Many important data and information have been done regarding critical infrastructures (for example transportation routes, communications, specific components, energy sector infrastructure, water supply and wastewater networks) showing the importance to conduct researches finalized to the protection of critical infrastructures (Wilson et al., 2014).

[6] For specific insights concerning "social vulnerability", related indicators and connected factors see: Dwyer et al., 2004.

[7] http://ec.europa.eu/research/participants/portal/desktop/en/opportunities/h2020/topics/1072-drs-07-2014.html.

[8] After the Naples Province, we find the following Provinces: Monza e della Brianza (2,072 inhabitants/km^2), Milan (1,928), Trieste (1,095), Rome (745) and Varese (728).

[9] As emblematically affirmed by Dobran (2006): "Vesuvius is today surrounded by a sea of humanity" (p. 26) which is "hostage" of the volcano (p. 6).

and Marta, 2014) and the saturation of the spaces (D'Aponte, 2005; Leone, 2005, 2013) are here peculiar aspects, in places where these elements considerably increase the exposure to volcanic risk and where instead specific and finalized planning would be required. On the other hand, the Naples Province, and above all the coastal zone, in the grip of the Somma-Vesuvius volcanic complex and the Campi Flegrei volcanic field (Phlegraean Fields), denote one of the most delicate, articulated and potentially dramatic situations connected to volcanic risk in the world since the consequences of an explosive eruption – from one of these apparatuses – would be impressive;

- the L'Aquila Province is worthy of note because on 6 April 2009 it was heavily hit by an earthquake (Ml=5.8; Mw=6.3) which caused more than 300 victims and extensive damage. It brought about a situation which continues to be dramatic in terms of resilience and disaster management (Forino, 2012), since the restarting of many economic activities and a kind of daily normality (Calafiore, 2012; Pesaresi, 2012), the recovery of the pre-existing houses (Casagrande and Pesaresi, 2012) and the complete restoration and re-opening to the visitors of important historical and cultural structures continue to be delayed (Leonardi, 2012; Reggiani, 2011, 2012, pp. 113-168)[10]. Consequently, the sense of identity and belonging is weakened due to distrust and resignation. "The L'Aquila earthquake of 6 April 2009 was a classic example of a medium-power seismic event. However, given the high vulnerability of building stock in the mountains of Abruzzo, it had a disproportionately large human impact" (Alexander, 2010, p. 326)[11]. And similar affirmations take on particular relevance since the considerable modifications recorded over the centuries by the town of L'Aquila, in terms of urban and structural planning, are strictly related to the seismic events and related effects (Centofanti and Brusaporci, 2011; Properzi, 2011) so that L'Aquila has been defined the "city of earthquakes" (Fiorani, 2011).

Methodologies and tools operating in a synergic way aimed at social utility are therefore strongly required and particular attention must be paid to:

- the geophysical mechanisms;
- the demographic and social-economic aspects which can increase the levels of risk and the demographic thresholds which should be reached to reduce these levels;
- the "census sections", in multiscale analysis, which can make it possible to have particularly detailed "photographs" of the local situations, identifying conditions of a potentially high dramatic nature;
- the vulnerability of buildings and infrastructural system;
- the historical and cultural heritage;
- the orders of priority among the municipalities subject to risks;
- the scientific and cognitive story maps useful in terms of disaster resilience, for the spreading of risk awareness and for creating an effective multimedia framework.

In order to achieve relevant developments, the importance of interdisciplinary methodologies and coordinated approaches is evident since there is the need to promote and enhance the synergic interactions between geophysical and engineering research with geographical-anthropological and social-demographic analysis.

[10] Moreover, from a geographical and economic point of view, due to the width of the area involved and affected (57 municipalities according to Decrees No. 3 and No. 11 of the Presidency of the Council of Ministers issued on 16 April and 17 July 2009), it was stated that: "The 2009 earthquake, as well as the loss of lives and the destruction of material goods, risks irremediably compromising the already quite fragile and contradictory relationship existing between the coastal towns of Abruzzi, […], and the Apennines, exposing it to the risk of a progressive loss of competitiveness in the twilight zone mapping out the uncertain future of the administrative centre of the region" (Lolli, 2011, p. 83).

[11] The damage caused by earthquakes usually show the deficiencies and problems of infrastructures and buildings of "*an Italy that is socially ill before being geologically ill*" (Famoso, 1988, p. 7).

First of all it is important to:

- introduce specific anthropic and social-economic data in appropriate risk formulas;
- use refined criteria to estimate the historical and cultural relevance of the various historical centers exposed to destruction;
- consider, in addition to construction materials, the construction period of housing during the vulnerability evaluations.

These are only some examples of aspects that are generally omitted or scarcely considered in the scientific studies which could support the emergency planning.

The development of GIS applications and the coordinated use of sophisticated geospatial technologies and drones is an essential element to converge the different knowledge towards innovative applications useful to tackle geodynamic risks. In fact in the last ten years many studies have been conducted both for seismic (Baiocchi et al., 2012a, 2013a, 2013b, 2013c; Casagrande and Pesaresi, 2012; Hashemi and Alesheikh, 2011; Papadimitriou et al., 2008; Pesaresi et al., 2013; Rivas-Medina et al., 2013) and volcanic research (Alberico et al., 2004, 2011, 2012; Bellucci Sessa et al., 2008; Esposti Ongaro et al., 2008; Fea et al., 2013; Pesaresi et al., 2008; Petrosino et al., 2004; Zuccaro et al., 2008).

Also being based on the input of international literature in specific research fields, the interdisciplinary use of GIS will make it possible to aspire to innovative research aimed at filling the gaps as a result of studies in singular sectors. Important geographical aspects, with different levels of detail, will be provided by the analysis of satellite imagery[12] and images, in both visible and thermal light, obtained with specific overflights on the localities damaged by recent earthquakes (Figures 1 and 2) and on those exposed to volcanic risk (Figures 3 and 4).

Furthermore, the project sets out to catch the attention of public administrators on a highly neuralgic issue, often not adequately considered and managed, and to provide keys of interpretation to the population, both for seismic and volcanic risks, which require a greater raising of awareness and the right behavior to follow in case of emergency. One of the aims is in fact to constitute a network whereby the progress recorded in terms of prevention, risk evaluation and reduction, facing emergencies, resiliencies will be shared to define a rigorous framework of models and methodologies. In this viewpoint, valid support will be also given by the new potentialities of ArcGIS Online which enabling us to produce and share scientific and highly communicative elaborations having a relevant impact in terms of raising awareness.

3. A synthesis of the progress of knowledge from the geographical point of view

As far as concerns the progress of knowledge from the geographical point of view, it can be useful to underline the different aspects which can be pursued in the case of volcanic and seismic analysis.

For example, with regard to the volcanic risk in the Naples Province, in a pre event condition, the main results can be used to:

- define a classification of the municipalities subject to major risk and provide specific values in ascending order, taking up the approach used by Pesaresi and Scandone in 2013;
- update and extend the model of "social risk" introduced by Pesaresi et al. in 2008;
- identify, by simulations, the demographic thresholds which would permit the reduction of the risk level;
- evaluate the historical and cultural importance of the historical centers and their connected loss in case of events;
- elaborate scientific story maps to show – also through the overlay between historic and actual cartography – transformations over the centuries and in the last decades, critical areas and scenarios of eruptions, promoting a widespread risk awareness.

[12] As recently underlined, in the case of earthquakes: "Remote sensing techniques play an important role in obtaining building damage information because of their non-contact, low cost, wide field of view, and fast response capacities. Now that more and diverse types of remote sensing data become available, various methods are designed […] for building damage assessment" (Dong and Shan, 2013, p. 85).

Figures 1 and 2. Above, a general view of the town of L'Aquila undergoing works of propping up and reinforcing buildings and provisional patching and waterproof covering of the roofs (blue, red or black) in March 2012. Below, a view of L'Aquila with "piazza del Duomo" in the center. Considerable damage (i.e. in the red oval) and conspicuous work of undergirding and securing (i.e. in the white circumference) of the churches, provisional patching and waterproof covering of the roofs (black or blue or red) and several cranes were evident in March 2012 at this geographical scale and other details become more clear with progressive zooms. Photos: Geographical Unit (Department of Documentary, Linguistic-Philological and Geographical Sciences) of the Sapienza University of Rome (in collaboration with GREAL, European University of Rome).

Figures 3 and 4. Above, the municipality of Monte di Procida, in the Phlegraean area, and its delicate position among geomorphological, anthropic and road aspects. Below, the municipality of Pozzuoli, in the Phlegraean area, where the population density, the presence of important economic activities and notable archeological sites determine very high conditions of volcanic risk (October 2012).
Photos: Geographical Unit of the Sapienza University of Rome (in collaboration with GREAL).

Figures 5 and 6. Some examples of images – of the end of 1800 and beginning of 1900 – focused on the Naples Province (above the Pompeii excavations and the Somma-Vesuvius complex; below a lava flow in Boscotrecase emitted by Vesuvius), which can be used to elaborate GIS applications and story maps with a high documentary, emotional and historical-geographical value. Photos: Archive of Geographical Unit (Department of Documentary, Linguistic-Philological and Geographical Sciences) of the Sapienza University of Rome.

Figures 7 and 8. Other examples of images – of the end of 1800 and beginning of 1900 – focused on the Naples Province (above Naples and behind the coastal zone near the Vesuvius with a considerably lower anthropization than now; below Pozzuoli). Photos: Archive of Geographical Unit of the Sapienza University of Rome.

In this perspective another added value can also be provided by the enhancement of the photographic archives and "photographic plates", as for example the archive of the Geographical Unit of the Department of Documentary, Linguistic-Philological and Geographical Sciences, Sapienza University of Rome, which can make it possible to have precious information and visualise the modifications recorded in terms of morphology, urbanised surfaces and sprawling housing, the damage produced by past phenomena and the faces of people who suddenly lost their houses, and progress in the findings of archaeological elements and areas etc. (Figures 5-8). These iconographic materials – dating back to about the second half of 1800 and the first decades of 1900 – can be "harmonized" and carefully selected to elaborate GIS applications with a high documentary, emotional and historical-geographical value.

Instead, regarding the situation in the L'Aquila Province some years after the seismic event, the main progress can be used to:

- identify the housing structures affected by major collapse according to the construction period and technical parameters, also investigating to see whether there is a particular construction period characterised by weak and badly-made houses and evaluating if it is a local factor or a general tendency that can be found also in other territorial contexts;
- define an integrated framework of the weak elements which can contribute to the collapse of buildings;
- realise a cognitive story map based on the micro-histories of everyday life to devise strategies useful for the disaster resilience. In fact, in the post event phases, it can be very important "to draw up a map of social needs and create a cognitive mapping which would reveal the complex nature of the actual situation" (Simonicca et al., 2012, p. 115) and the production of specific elaborations – which can also show the changes recorded at territorial level – can be highly representative and show the different needs in the various municipalities involved.

4. A synthesis of the progress of knowledge from the engineering point of view

The progress of knowledge from the engineering applications aims to highlight the different aspects which can be achieved in case of volcanic and seismic analysis for the purpose of risk management (Guarascio et al., 2009a).

This approach analyses the seismic and volcanic events to define a set of quantitative indicators that will be implemented in a GIS platform. The innovative idea is to set up an integrated and interdisciplinary dataset for territorial safety design and the attention will move to the system as a whole. In a seismic event, like for example the seismic risk in the L'Aquila Province, the risk that affects the single buildings is not only its intrinsic characteristic, but the result of the relationships between the various components.

Both for volcanoes and earthquakes the main goals of the safety engineering are to:

- focus on the territorial dimension of the seismic or volcanic event;
- connect the seismic or volcanic event to a multiscale, dynamic and complex database;
- make a preliminary vulnerability analysis (societal, urban, infrastructural evaluation) (Dolce et al., 2006);
- define territorial quantitative indicators of societal (fatalities), urban (buildings) and infrastructural (road, rail, port…) risks;
- implement these quantitative indicators in a GIS platform able to produce detailed and multitemporal elaborations.

In fact, data processing, useful to define risk maps, is the disaster management instrument that allows the organization of the post seismic or volcanic emergency and the drawing up of rescue services priorities.

So, during 2002 a methodology for assessing the vulnerability (Baiocchi et al., 2012b) of an urban center was developed as part of an effectiveness collaboration between the Italian Civil Protection Department and the University of L'Aquila. The urban territory is the complex of physical and functional connections of specific elements and not a simple sum. The main goal of a preliminary vulnerability analysis is to evaluate the multiple factors simultaneously. The hazard maps related to seismic vulnerability of buildings in the territory (locally) aim to define the emergency evacuation plan for natural disasters (Beolchini, 2003).

The assessment of rescue is primary in the seismic or volcanic emergencies. In order to define the emergency priorities, a logistic model is necessary that subdivides the area into irregular polygons containing a constant number of buildings.

The risk maps, useful to risk assessment, aim to characterize the connections of hazard (in terms of vulnerability index) and damage (in terms of expected number of fatalities) in order to organize the emergency evacuation plan for natural disasters in the best possible conditions.

5. Methodological considerations from the engineering point of view

Relevant progress, which can be followed by the GIS4RISKS project, is related to the safety design applied to natural hazard and risk. For this purpose the correct knowledge and methodology are required in order to plan the evacuation procedures and to highlight possible critical situations of the emergency plans (Guarascio et al., 2007; D'Ayala et al., 2002).

In effect the physical and geodynamical phenomena, which predict natural disaster, are very difficult to identify and to describe in an a priori analysis. The design engineer should have skills which cover geodynamics, geophysics and structural engineering. The formalization of a risk assessment procedure is a necessary tool to educate the specialists.

5.1 Mosaic Model

For a rational management of the emergency it is appropriate to divide the area subject to risk in sub-areas (tiles), in order to associate synthetic indicators to each, evaluated from the risk analysis. This conveys useful information to the rescue team already in the first hours of the event.

This spatial subdivision can be achieved through the application of the so-called *Mosaic Model* that divides the entire area into "tiles", drawn as irregular polygons and delimited by the urban road network. Indeed, each is defined as a function of the main access roads that allow the rescue teams to rapidly reach the buildings of single tile.

Each tile is defined by a variable extension depending on the type of area in terms of economic development and geomorphology (commercial area, rural area). The tile includes a limited number of buildings, which can generally vary from 10 to 20, circumscribed by access roads which make it possible to reach the same area. The single tile is generally composed of a building having similar structural properties (spatial autocorrelation). This evidence is intrinsically linked to the dynamics of urban and regional development, denoted by specific construction techniques.

For each tile various data can be attached, such as spatial data, seismic or volcanic hazard, population exposure, vulnerability etc.

5.2 Evaluation of tile vulnerability

The evaluation of the expected damage to a seismic or volcanic event is related to the sub-areas, which may represent the basic element on which to make estimates of the damage after the disaster, in order to define the priority of emergency operations and to organize the rescue. It is therefore necessary to select the data for each tile associated with a sub-area.

In the case of an earthquake, if you know the probability of collapse and the resulting damage, associated with each urban aggregate, it is possible, through the use of the binomial distribution, to determine the probability of the simultaneous collapse of a fixed number of buildings compared with those of the tile, if the selected buildings (centroid of the cluster) are isolated and typical of the design characteristics related to the tile.

Assuming that a single tile can be represented by n buildings, you can assess the probability of the collapse of m buildings ($m \leq n$) by *Event Tree Analysis* (ETA), to know the derived scenarios (2^n).

Figure 9. Application of the vulnerability model to test it in a case study area: the Province of Reggio Calabria.

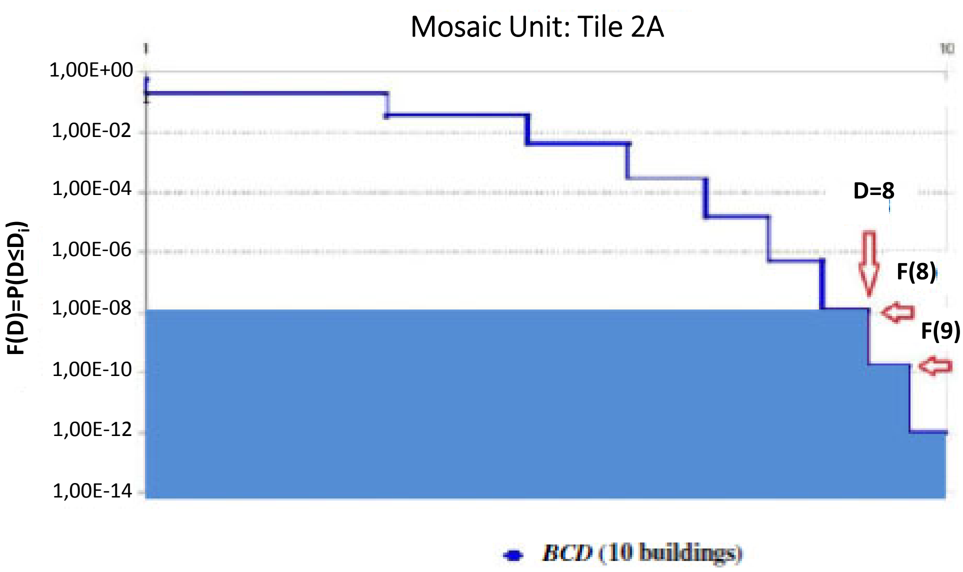

Figure 10. Back-Cumulated Distribution of threshold of damage equal to eight collapsed buildings ($D_i = 8$).

The probabilities associated with the branches are generated by the product of the probabilities of collapse or non collapse of each building considered on the Event Tree, i.e. the product of the probabilities corresponding to the branches of the generic path (if the collapse/non-collapse of each building results in an event independently of the other). Consequently, it is possible to estimate the probability for each tile corresponding to the scenarios of the same damage (number of collapses).

An application of the above was carried out for the Province of Reggio Calabria (Calabria Region, Italy)[13], which can be assumed as the

[13] The choice of the Province of Reggio Calabria as case study to test the *Mosaic Model* is related to the complexity of the urbanized territory, which is highly representative of the conditions present on the overall territory of Italy. Moreover, the Province of Reggio Calabria is particularly appropriate, as case study to test the *Mosaic Model*, for its very high values of seismic hazard and risk.

case study to test the model and which can provide useful methodological and operative input for further analysis in the selected study areas (Figure 9). The area was subdivided into a limited number of tiles and for each of them the vulnerability of ten buildings representative of the area was evaluated, using the simplified data sheet. Then the Back-Cumulated Distribution *(BCD)* of damage was evaluated.

The *BCD* is the indicator of cumulative risk, defined as the probability of a damage level equal to or greater than a given threshold D_i of the random variable *D*. The area under the *BCD* is equivalent (numerically) to the expected value of damage E[D] associated with a defined Initiating Event (*IE*). For example, in Figure 10 the blue area represents the *BCD* of threshold of damage equal to eight collapsed buildings (D_i = 8) in the tile.

Therefore, the *BCD* of each tile was compared with the extreme performance obtained by the "optimistic and pessimistic" binomial probability distributions, respectively calculated by assigning to the buildings of the tile the minimum or maximum probability of collapse (Figure 11).

Thus if K tests, repeated and independent and related to the "dichotomous" outcome collapse/not collapse, are performed (ten in the case study equal to the number of buildings considered for each tile), if the probability of collapse *d* is known (the probability of non collapse is equal to $q = 1–d$), then the probability of simultaneous collapse of K buildings can be estimated by binomial probability distribution:

$$P(X=k)=\binom{n}{k}d^k(1-d)^{n-k}=\frac{n!}{k!(n-k)!}d^k(1-d)^{n-k}$$

(1)

If the analysis is applied to the minimum and maximum probability of collapse (identified on each tile) and the *BCD* is calculated, the sub-area of the compliance plan, where the *BCD* described above is placed, is identified as shown in Figure 12.

The bi-logarithmic plan, adopted for the *BCD*, could be the tool to verify the acceptability of risk, in analogy with the safety design of the complex systems. For example, for the compliance of the safety of road tunnels two curves (thresholds of acceptability and unacceptability) are introduced.

The equation of acceptability criteria is:

$$F(N) = b \cdot N^{-1}$$

(2)

The area under the straight green line identifies a zone characterized by acceptable risk; the area over the straight red line a zone characterized by unacceptable risk; the area between two straight lines identifies the ALARP (As Low As Reasonably Practicable) zone, characterized by the need for safety improvement. The above criteria define the Safety Functions as a comparison of areas under the respective curves that have the described meaning;

– Safety Factor (*SF*):
FS_{UN} = R/B
FS_{AC} = V/B

– Safety Margin (*MS*):
MS_{UN} = R – B
MS_{AC} = V – B

where:
R = area under unacceptability criterion (UN);
V = area under acceptability criterion (AC);
B = area under *BCD* (10 buildings).

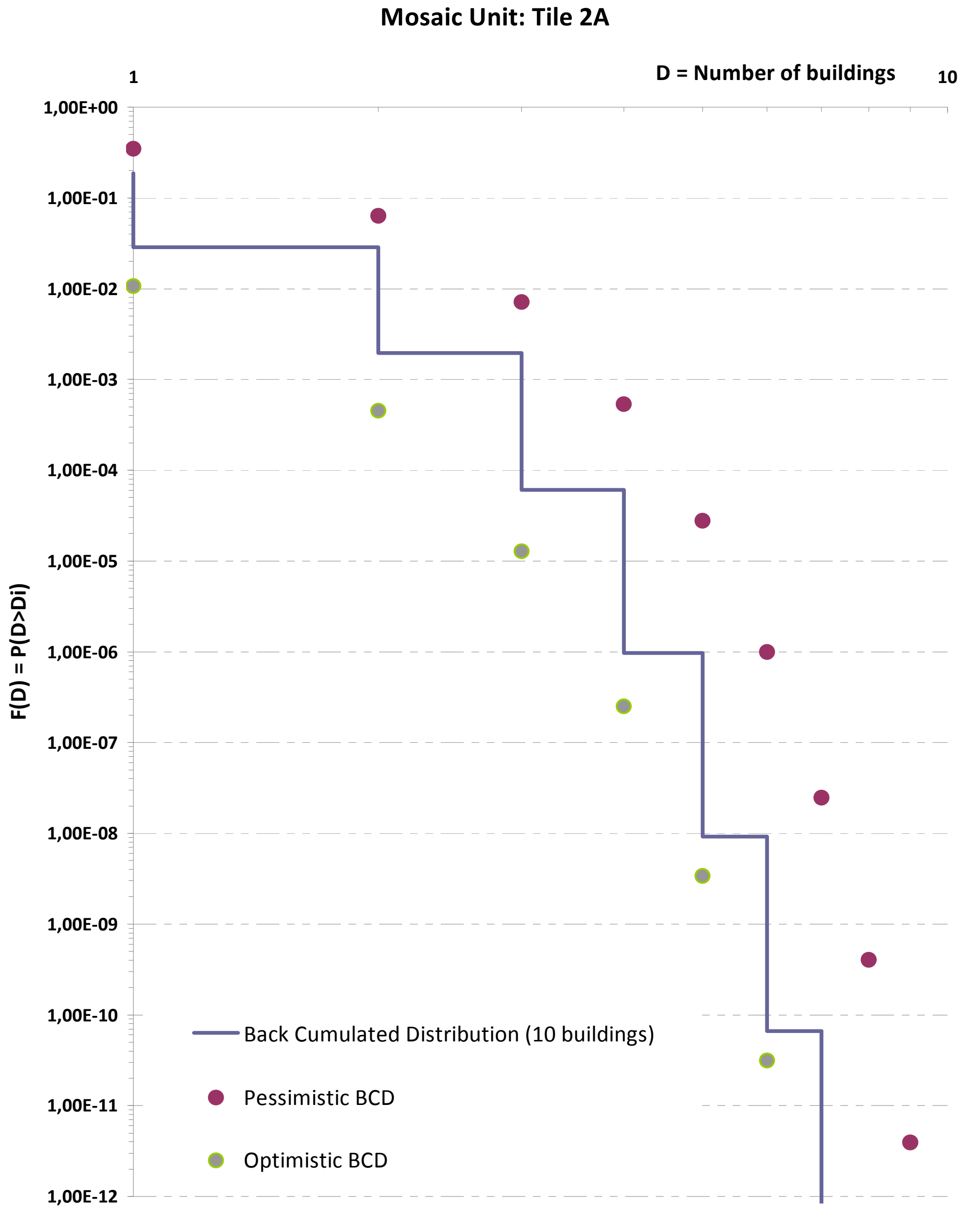

Figure 11. Extreme positions of the Back-Cumulated Distribution on the minimum and maximum probability of collapse. The variability range was evaluated on a Mosaic Unit (Tile 2A) of selected areas.

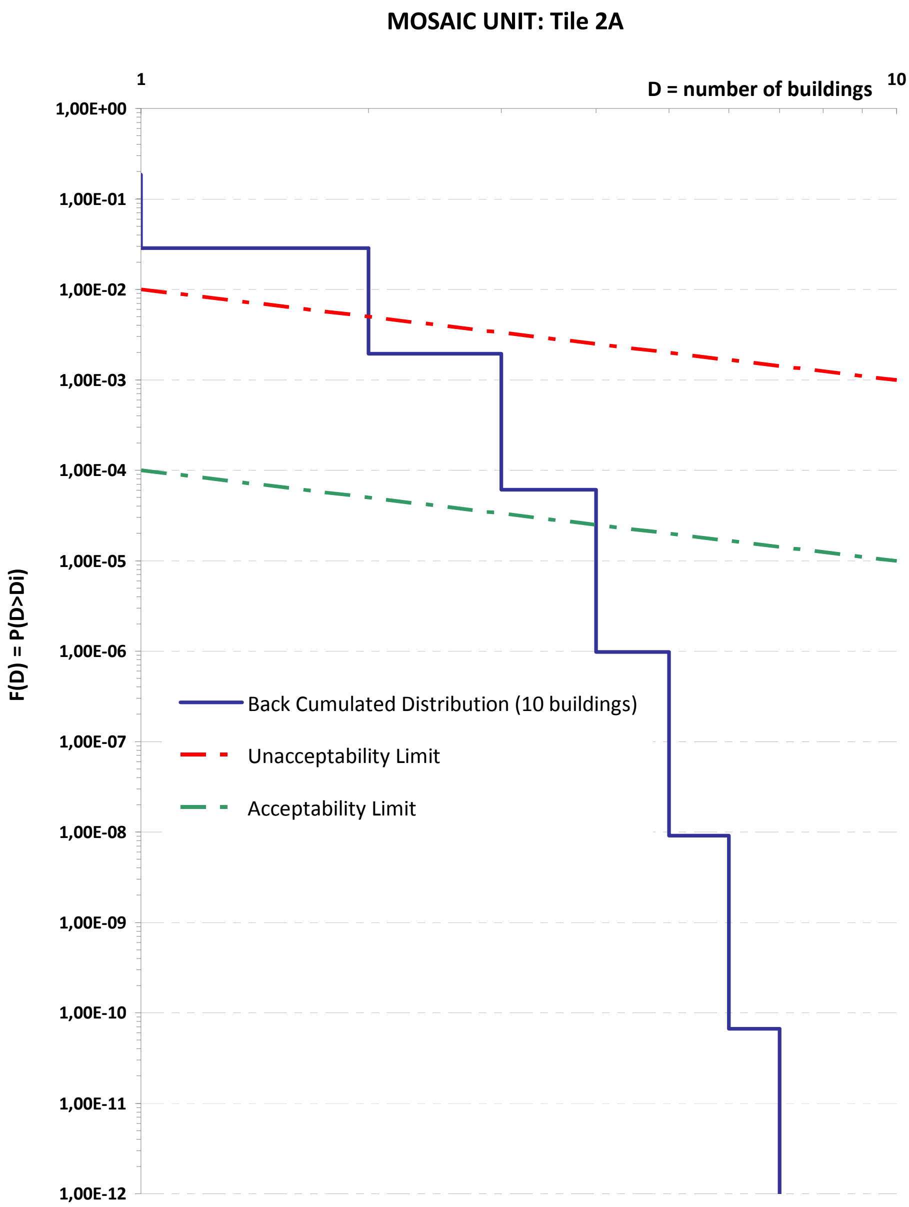

Figure 12. Test of compliance on the acceptability plan [Safety Criteria of road tunnels ex Legs. Decree No. 264/2006: Unacceptability limit (straight red line) and acceptability limit (straight green line)].

Therefore, on Tile 2A the following values are calculated (Table 1):

	UN	AC
SF	$4.32\ 10^{-2}$	$4.32\ 10^{-4}$
SM	- 0.75	- 0.78

Table 1. Safety Function Value and Safety Margin Value of the case study area of Reggio Calabria Province (Tile 2A).

If the procedure for each tile is repeated, the *SF* and *SM* are calculated and represented on the Geographic Information System (GIS) to map the area according to the risk of the building heritage (collapsed/not collapsed buildings).

In Figure 13 the synthesis of safety evaluation is shown.

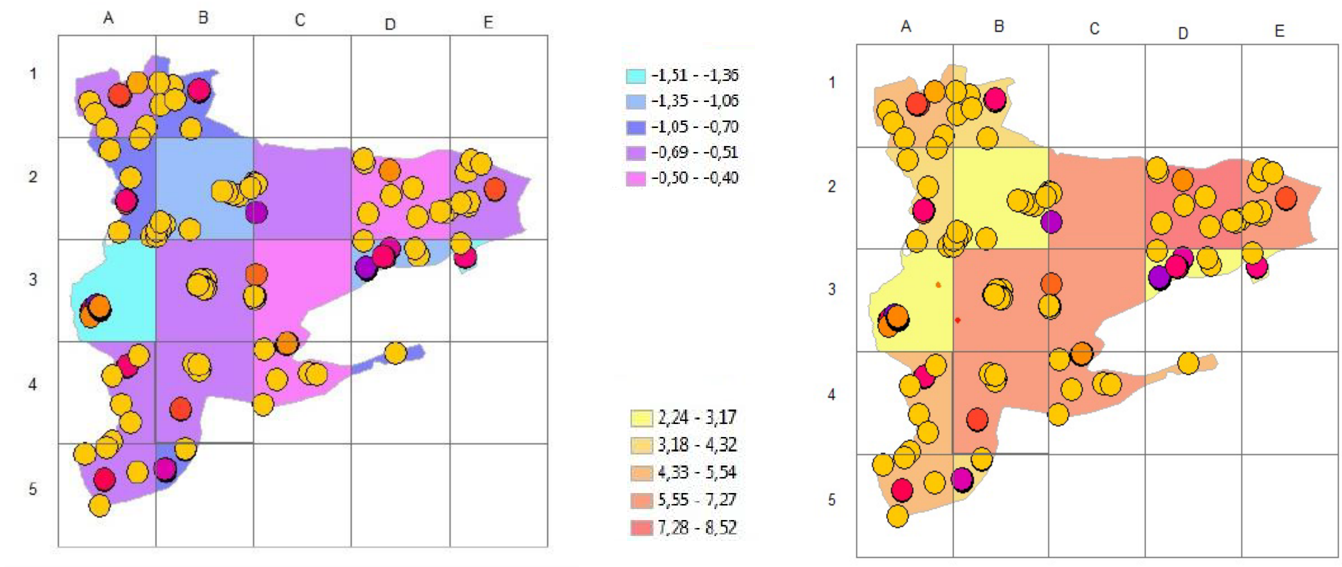

Figure 13. Mapping of Safety Function (left) and Safety Margin (right).

5.3 Tile file

In the perspective of the GIS4RISKS project, given the numerous assessments of vulnerability and risk that can be made for a single tile, it is useful to make a file for each, enclosing the following tools and key information.

- *Vulnerability Card*: information relating to indicators of vulnerability;
- *Exposure Card*: exposure conditions of the population as a function of different time periods;
- *Hazard Card*: evaluation of Initiating Event and evolution of the hazard flow (Event Tree Analysis);
- *Damage Card*: definition of consequences analysis;
- *Risk Card*: estimate of safety indicators (BCD).

The information in the tile file enables us to establish a hierarchy of the tiles with the aim to optimize the rescue. Often there is no intervention protocol adopted by the rescue services during the emergency, that in detail identifies the priority areas.

The processing allows the emergency management on a "large geographical scale", contrary to the requirements currently to be found in the programs. The information details make it possible to manage the early phases of the emergency in order to prioritise the rescue procedures that require complex planning.

Through regular exercises, the application of the *Mosaic Model* on a scale as an urban district makes a preliminary management to quantify the resources needed to deal with the disaster.

The emergency management must be accompanied by a conscious approach to risk and the "risk communication" appears a key variable which requires specific strategies since for the population it is difficult to correctly understand and quantify the expected damage during the evaluation phase.

6. Educational considerations

Further remarkable progress, which can be reached with the GIS4RISKS project, concerns just the educational level. In fact, environmental education, in the case of natural hazard and risk, requires the correct information and involvement of the population, to promote the success of the evacuation procedures and to make up for any lack of emergency plans (Scandone and Giacomelli, 2012, p. 32). The phenomena which characterise geodynamic events are very difficult to categorize and the precursor signs can be difficult to interpret in the case of volcanic eruption and practically almost unpredictable if referred to seismic events.

Moreover, we have to consider that feelings and attachment to their own residential area is a factor of statistical significance for the people's danger perception, since a "strong affective bond offers a feeling of safety and leads to neglect and even total denial of the danger" (Armaş, 2006, p. 1233). Similar aspects are particularly to the point, for example, in the case of the Naples Province because the attachment to the land is deep-rooted in the centuries[14].

In previous studies, people living in the Vesuvius area demonstrated "low levels of perceived ability to protect themselves from the effects of an eruption. These Vesuvius residents also demonstrated low levels of awareness concerning evacuation plans, and low levels of confidence in the success of such plans" (Davis et al., 2005, p. 1). Moreover, another piece of research, regarding the volcanic risk perception of young people in the urban areas of Vesuvius, has stated that the general preparedness of respondents and the inadequate risk education underline the necessity of a relevant effort to improve communication strategies finalized to facilitate eventual evacuations. "Therefore, it is important to take advantage of the present period of quiescence at Vesuvius to improve the accuracy of risk perception of youth in local communities" (Carlino et al., 2008, p. 229). In the meantime, a further study, conducted in the Vesuvius area, "demonstrated a widespread lack of knowledge about the emergency plan, a lack of confidence in the plan's success and in public officials and low feelings of self-efficacy. People want to be more deeply involved in public discussions with scientists and civil protection officials on emergency planning and individual preparedness measures. It is clear from the results that a major education-information effort is still needed to improve the public's knowledge, confidence and self-efficacy, thereby improving their collective and individual capability to positively face a future volcanic emergency" (Barberi et al., 2008, p. 244)[15]. On the other hand, a contribution with regard to the volcanic risk perception in the Campi Flegrei area has recently showed that many people involved affirmed having not received specific information regarding the possible effects of an eruption, which moreover could be highly explosive. The results of the study underline that many residents in the Campi Flegrei area have not enough information about local volcanic hazards and that local authorities and public administrators, in collaboration with the scientific community, should encourage targeted programmes finalized to better educate the population on volcanic risks and possible eruption phenomena (Ricci et al., 2013).

It is equally important to foster a correct raising of awareness and education concerning seismic events and the probability of an earthquake occurring in specific areas. Thus: "Addressing middle- and high-school students in their classroom about earthquakes, about structural engineering, and the design necessary to ensure safety during earthquakes is a very effective way to propagate knowledge about earthquake engineering into our society. Students of all ages, elementary, middle and high school benefit from knowing what happens

[14] "Since time immemorial Man has been engaged in a continuous fight with Vesuvius, seeking to control and counter the destructive forces of the volcano, which have often been exceptionally violent. On various occasions the Giant has threatened and submerged inhabited centres and farmland, claimed numerous victims, and has defeated the patient farming work of many generations of peasants. But before its devastating fury, the losses of the Vesuvian population have but been temporary, as after each eruption[…], they have always returned to the place of the disaster and successfully begun to conquer it again" (Formica, 1966, p. 30).

[15] Moreover, we have to remember that – according to a study based on direct interviews and questionnaires aimed at investigating how the threat from Vesuvius is perceived – some problems, for example regarding communication and understanding specific terminology, are also between decision makers and scientists, since "the answers […] revealed divergent and unrealistic opinions that, innocuous in normal circumstances, have the potential to exacerbate conditions during an emergency" (Solana et al., 2008, p. 311). Obviously, similar problems would tend to accentuate the difficulties in the "dialogue" with the population and clearly indicative of the need for general education programmes.

in earthquakes, what to expect in the future, and also from learning about this interesting engineering job where they can design buildings to ensure the publics safety" (Mendoza et al., 2008, p. 1). At the same time, a geographical education about seismic risk is fundamental to better know the conduct to adopt, to know the exposure according to the province of residence, to increase risk awareness and to visualise through maps, photos and aerial images the changes recorded in some areas before and after an earthquake[16]. For example, a study regarding the perception and communication of seismic risk in the case of 6 April 2009, the L'Aquila earthquake has shown "that despite the long list of historical earthquakes that struck the [Abruzzo] region and the swarm of foreshocks occurring up to four months before the main shock of 6 April, the residents of L'Aquila had a rather low earthquake risk perception and an unjustified confidence in the seismic safety of their houses" (Marincioni et al., 2012, p. 159). Another piece of research, aimed at discussing "how to approach the problem of the social mitigation of seismic risk, in order to reduce damage and grief consequent to earthquakes", focussing the attention on the 6 April 2009 L'Aquila earthquake, has highlighted that there are several crucial relationship factors which must be improved. Particularly, these factors concern the communication problems among politicians, the scientific community and citizens and can be summarised in the following way: "1) a serious gap between researchers and citizens; 2) measures adopted by local administrators and the National Civil Protection Service not agreed by the population; 3) misunderstanding originated from a lack of clarity of communication about scientific terminology; and 4) the lack of an alert procedure protocol. In the current situation, all these problems are crucial and contribute to the unpreparedness to face a seismic event, and thus greatly increase the risk" (Stoppa and Berti, 2013, p. 78). Thus, the dramatic effects of the L'Aquila earthquake, in terms of human fatalities, building and cultural heritage damage and economic and productive activities, have shown the need for a general review process of the methods aimed at assessing seismic hazard and risk in the areas highly subject to this kind of events.

Therefore, one of the inputs that the GIS4RISKS project can pursue is to promote the progress of scientific knowledge[17], through field surveys, the interdisciplinary approach and the potentialities offered by geotechnologies. At the same time a widespread education to geo-dynamic risks must be fostered, involving people and above all young people in a communication and didactic system which can reach everyone as based on web application and social network, but not random but connected to the geographical sciences and conveyed by GIS.

The paramount challenge for geographers, engineering, volcanologists, geologists and other scientists of this field of study as well as emergency-planning and management officials is to prevent a volcanic or seismic crisis from turning into a general disaster (Tilling, 2008, p. 9).

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[16] "If, […], 'everyone can learn from people who have been hit and that, by their example, can say whether and how it is possible to heal their suffering', it is just as true that each territory can 'learn' from its past and from the experiences of others the way to 'heal the suffering endured'" (Leone, 2011, p. 23).

[17] After underlining the importance of local knowledge and aspects, a recent study has affirmed that they "must be balanced with fresh ideas and expertise in a combination of disciplines to produce an advisory context that is conducive to high-level scientific [and widespread didactical] discussion" (Donovan et al., 2012, p. 1005).

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