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The hazard indices as a tool to support the territorial planning: The case study of Ischia island (Southern Italy)

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ABSTRACT

The best knowledge of hazardous events and the precise mapping of the zones that they could involve are essential to plan the actions aimed at reducing the territorial vulnerability and promoting the development of a resilient community. In this framework, the main goal of the present research is to propose a quantitative spatial modeling approach that, starting from hazard indicators, defines multi-hazard indices to compare the degree of hazard among different zones allowing the establishment of intervention priorities for risk reduction. The method was applied to the case study of Ischia island, located in the north-western zone of Napoli bay (Southern Italy): indeed, the exposure to many natural hazards (seismic, volcanic, landslide, coastal erosion and marine inundation) coupled with the intense urbanization make the island a good test area to validate the methodology here proposed. Taking into account the different recurrence times of natural events, two multi-hazard indices were quantified, the total multi-hazard index that illustrates the hazard status of the territory considering all the natural events and the partial-hazard index that only takes into account those occurring yearly to decadally. Moreover, with the aim of easily and globally visualizing the hazard status of the territory, the indices were depicted into maps that could facilitate the communication to stakeholders and consequently the reduction of social vulnerability.

The municipalities of Serrara Fontana, Barano d'Ischia and Casamicciola Terme show the highest total multi-hazard index of the study area, all the other municipalities display a value (always exceeding 0.5) that, although lower than in the previous three, signifies that the entire island needs attention with regard to natural hazards. The partial multi-hazard index confirms the highest value for Serrara Fontana and Barano d'Ischia. Multi-hazard hotspots, identified at the censual district scale for the Forio d'Ischia municipality, enlighten the areas where a comprehensive risk assessment is needed. We also took advantage of spatial and temporal analysis in order to compare the evolution of population and urban development to spatial distribution of hazard zones over the last 80 years. This analysis evidenced that the urban development was insensitive to the dangers impending on the territory, as the expansion in the zones with medium-high level of hazard testifies. Because of this, the present status of the island postulates the urgent need of integrating disaster risk reduction into future spatial planning.

1. Introduction

Some natural events become dangerous when they affect a densely populated area, where they can pose hazards and turn into disasters. Risk is defined by UNISDR (2009) as the combination of the probability of an event and its negative consequences. Mostly for geophysical risks (Sleiko, 1993; Glade, 2003; Petrosino et al., 2004; Marzocchi et al., 2008; Pesaresi et al., 2008; Lirer et al., 2001, 2010; Grezio et al., 2012), the notation proposed by UNESCO (1972) and Fournier d'Albe (1979) Risk = Hazard × Vulnerability × Exposure is adopted. Hazard is the likely frequency of occurrence of a dangerous event in a fixed future time, Exposure measures people, property, systems, or other elements present in hazard zones that are thereby subject to potential losses, Vulnerability is the proportion of lives or goods likely to be lost, and accounts for the characteristics of a system or asset that make it susceptible to the damaging effects of a hazard. This definition identifies vulnerability as a characteristic of the element of interest (community, system or asset) which is independent of its exposure (UNISDR, 2009). Ultimately, the notation points out that the risk can be reduced both by lowering exposure and acting on vulnerability.

The concept that the impact of a hazardous event can be reduced only through technical interventions and regulations, aiming at population reduction and land use changes, was recently joined to the

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resilience concept (Holling, 1973, Cannon, 2008; Cutter et al., 2013; Alexander, 2013; Serre and Barroca, 2013). The latter is defined as the capacity of a system, community or society potentially exposed to hazards to adapt, by resisting or changing in order to reach and maintain an acceptable level of functioning and structure (UNISDR, 2004), coping with the hazardous event. To plan the actions necessary to reduce the risk and promote the development of a resilient territorial system, the knowledge of areas exposed to one or more hazardous events is essential for local authorities.

The multi-hazard is a wide concept that, similarly to resilience, amply developed during the last decade. It can be seen from two points of view (Garcia-Aristizabal et al., 2014): as the process of assessing the role and the effects of various independent hazards endangering the same area or as a process dealing with the possible interactions among the different hazardous events.

Recent scientific literature evidenced an uttermost attention to the definition of methods aimed at assessing multi-hazard and multi-risk, as the Hazus-MH (FEMA: HAZUS-MH, 2003), ARMAGEDOM (Sedan and Mirgon, 2003), RiskScape (King and Bell, 2005), MATRIX (last connection 04/07/2013) and Armonia (last connection 27–06–2013).

These projects highlight the utmost importance of the space-time window to assess the different degrees of hazard linked to the single natural events for each risk analysis. The time window is fundamental to define the probability of occurrence of the events, as well as the probability that a natural event (i.e. earthquake) could trigger another one (i.e. landslide), known as cascade (Marzocchi et al., 2009) or domino (Delmonaco et al., 2006) effect. Kappes et al. (2010, and references therein) report different examples of event chains that trigger landslides as earthquakes, dam breaks of old landslides, and forest fires. Cascade and conjoint effects such as seismic swarms triggered by volcanic activity have been recently investigated by Scolobig et al. (2014) to assess multi-hazard both for Naples (Italy) and Guadeloupe. Greiving (2006) highlighted the key role of spatial approach to determine multi-hazard as a combined overall potential hazard for each region of a defined area. Kappes et al. (2010) evidence the possibility to create through the multi-hazard analysis a framework containing all the hazardous processes and most of all the relations and interconnections between them. In areas exposed to several hazards, we can record both triggering of one hazard event by another, eventually leading to subsequent hazard events (e.g. eruption inducing flank failure inducing tsunami) and influence of one hazard on another (e.g. pyroclastic flow deposits diverting the course of a river and possibly exposing to inundation an area previously supposed safe). Although for the former effect, known as cascade, domino effect, follow-on event, a uniform conceptual approach exists, for the latter, generally pointed to as compound hazards, interactions, interrelations, or synergic effects, the conceptual approach is far from being definitive. Because of the complex interaction between all these processes, in fact, it is not always easy to define where cause–effect relation ends and where interrelation between hazardous factor begins (Kappes et al., 2012).

Within this framework, we proposed a GIS-aided quantitative methodology to define multi-hazard at municipality scale, in an area exposed to several types of natural events where both the probabilities of occurrence of single events and the cascade effects are not quantified.

Starting from the hazards impending on the same municipality, we firstly identified monothematic indices, describing the weakness of the territory in relation to a single type of hazard and successively summed them up to express the territorial susceptibility to the occurrence of several natural events. In the complex matter of multi-hazard assessment, in fact, differing and hence not directly comparable parameters can be quantified through hazard indices, that make it possible to evaluate the difference between two hazard levels instead of only ranking them, thus allowing the passage from a qualitative to a semiquantitative approach (Kappes et al., 2012), that is the more valid the more the input data are collected over a wide time span and well distributed over the study area. The indices here developed at municipality scale, can be also scaled at regional or national level considering the smallest scales with increasing extent of the investigated area, or at sub-municipality level. In this frame, we integrated the analysis identifying the hazard hotspots at the censual district (ISTAT, 2012) scale, which is the smallest geographical unit featuring the territorial system. The main outcome of the present research are multi-hazard maps, which proved useful to prioritize the interventions within the same municipality and to compare the different multi-hazard exposure on the short and long periods in the whole endangered area. These maps provide vital tools to communicate with stakeholders, whose participation in the territorial planning is essential to favor the development of a resilient community.

The method was applied to the case study of Ischia island, located in the north-western zone of Napoli bay (Southern Italy), because it is exposed to many natural events (seismic, volcanic, landslide, river flooding, coastal erosion and marine inundation events) that represent sources of risk for both the tourists that visit the island and the population that lives there all year round. As a matter of fact, the spatial planning policies of the Eighties, which did not take into account the possible occurrence of dangerous natural events, allowed the growth of urban zones in high-hazard areas, hence severely increasing the natural risk (Petrosino et al., 2004; Alberico and Petrosino, 2014).

2. Methodology

A methodology that takes full advantages of the spatial analysis available in a Geographic Information System (Pareschi et al., 2000; Alberico et al., 2002; de Silva and Eglese, 2000; Petrosino et al., 2004; Toyos et al., 2007; Pesaresi et al., 2007; Alberico et al., 2008; Martì et al., 2008; Rapicetta and Zanon, 2009; Lirer et al., 2010; Alberico et al., 2011; Mahendra et al., 2011; Lichter and Felsenstein, 2012; Sandri et al., 2014) was worked out. The implemented geo-spatial model makes it possible to capitalize on hazard zoning data and to integrate them into monothematic and multi-hazard indices.

The different recurrence of hazardous events postulates the need to assess two multi-hazard indices (partial and total). The two indices accounting for the different recurrence of hazardous events simply and objectively evidence the link between time (time windows considered for the hazard assessment) and hazard (probability of occurrence of dangerous events), when the lack of a significant number of data prevents the statistical assessment of the latter parameter.

The flow chart of Fig. 1 shows the type of input data and the algorithms used to quantify the indices. A key point of our model is the availability of hazard zoning: a rich dataset with a spatial resolution appropriate to the extent of the investigated area, in fact, is fundamental to draw the hazard maps which represent our input data (source hazard map in Fig. 1).

The spatial intersection between the geographical data of the single source hazard maps and the municipality boundaries allowed to define the extent of the hazard zones pertaining to each municipality.

The ratio between these values and the municipality area, as indicated in Eq. (1), gives the monothematic index values (Fig. 1):

$$Hi = \sum_{1}^{n}\left(\frac{F}{M} \times w\right) \tag{1}$$

where:

Hi = monothematic hazard index, F = extent of hazard classes for each municipality or number of the points features falling inside the single municipality, M = municipality area or length of the coast pertaining to the single municipality, and w = numeric value introduced as weight term when the hazard (i.e. volcanic hazard) is ranked into several classes (i.e. low, medium and high hazard).

In detail, we attribute a numeric value (w), according to a linear scale, to the classes of hazard for the single natural event possibly affecting the area. The values of the hazard index, normalized according to the maximum value recorded over the municipality area, provide a