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Mapping social vulnerability to natural hazards in Italy: A suitable tool for risk mitigation strategies

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ABSTRACT

Italy is one of the European countries that are most heavily exposed to a wide range of natural hazards, which might cause large economic losses. In this context, the assessment of social vulnerability has an important role for evaluating the capacity of a community to prepare for, respond to and recover from disasters. However there are currently no published studies analysing social vulnerability and its spatial distribution in Italy. Within this framework, this paper aims to apply a proven method for assessing social vulnerability at the national scale, while considering the contribution of the socioeconomic and demographic factors that affect the Italian population. The proposed methodology is based on the Hazard-of-Place Model approach, and uses free and open source software applications (FOSS). Specifically, we selected significant components through Principal Component Analysis and derived their spatial distribution. Using component scores, we derived a social vulnerability index, evaluated its geographic distribution, and performed a cluster analysis on its spatial variation. The analysis identified different spatial patterns across Italy, providing useful information for identifying the communities most likely to experience negative natural disaster impacts due to their socioeconomic and demographic characteristics. This research represents an important contribution to improve the potentiality of risk mitigation strategies and in designing risk custom-made policies.

1. Introduction

The concept of vulnerability in the framework of classical natural hazard, multi-hazard and risk assessment traditionally refers to the fraction of the total value at risk of being lost after a specific adverse event (Marzocchi et al., 2009). However, over the last few years, the term 'vulnerability' has been frequently cited in the scientific literature in relation to the socio-economic aspects that influence societal conditions, including exposure, sensitivity, coping, adaptive capacity and social capital. Therefore, the definition of vulnerability depends on the research perspectives employed. Some perspectives focus on a single factor, such as the physical side of vulnerability (biophysical vulnerability), while others consider social aspects, such as gender, employment, age, or a combination thereof (Cutter et al., 2003; Wisner at *al.*, 2004). In the context of climate change, the IPCC (Pachauri et al., 2014) defines vulnerability as the propensity of human and ecological systems to suffer harm, and their ability to respond to stresses imposed as a result of climate change effects. Many other definitions can also be found in the literature. For example, Adger (2006) defines vulnerability as the exposure of a group or an individual to stress due to social as well as environmental changes that disrupts livelihoods. To date, a shared theoretical construct of vulnerability does not exist (Cutter, 1996; Fekete et al., 2014). Within this backdrop, vulnerability assessment is frequently applied in different studies, such as those that measure the effect of climate change on societies (e.g., drought, heat waves and/or intense hurricanes), study livelihood and poverty (Prowse, 2003), and conceptualize disaster risk reduction (Cardona, 2005; Cutter, 2008; Fekete et al. , 2014).

In the context of disaster risk reduction, three elements can reveal the vulnerability of a society and place: risk (R), hazard (H) and vulnerability (V). These elements are related to each other and can be schematize using the following pseudo-equation (1) (Wisner et al., 2004):

$$R = H * V \quad (1)$$

Considering this equation, risk is the result of interaction between hazard, a dangerous event that may affect different places at different times (with a certain intensity and frequency of occurrence) and vulnerability, the characteristics and

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circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard. According to Wisner (2004) « the risk of disaster is a compound function of the natural hazard and the number of people, characterized by their varying degrees of vulnerability to that specific hazard, who occupy the space and time of exposure to the hazard event». Indeed, the disaster entity varies drastically depending on the local context.

There is an important relationship between the natural elements and the cultural, social and economic organization of the affected society. As mentioned by Cutter et al. (2003), the probability that a natural disaster has more devastating effects on one place than another depends on the local vulnerability of each place. For this reason, the lack of social studies on hazard and risk assessment highlights the need to better integrate information on social vulnerability into emergency and risk management decision-making.

Over the last years, several approaches to measure social vulnerability at different scales were proposed. These studies were developed for different scopes as evaluating climate-change impacts, defining what are the societal responses to natural hazards or measuring progress toward disaster risk reduction (Dolan and Messen, 2012; Tate et al., 2010). Some countries, like the United States of America (Wu et al., 2002; Cutter et al., 2003; Chakraborty et al., 2005), Australia (Dwyer et al., 2004), the United Kingdom (Tapsell et al., 2002; Kuhlicke et al., 2011), 12 countries in Latin America and the Caribbean (Cardona, 2005), Spain (Weichselgartner, 2002), Israel (Felsenstein and Lichter, 2014), Germany (Fekete, 2009) and Indonesia (Siagian et al., 2014) developed social vulnerability indices at the national or sub national scales.

Despite Italy being one of the five European countries with the highest probability of a disaster and related economic losses (Beck et al., 2012), there are no studies assessing its social vulnerability. Understanding the differential impact of hazardous events is critical to reducing the negative impact of natural disasters. The overall aim of this paper is to define a social vulnerability index (SVI) for Italy by applying an inductive method, where measurements of social vulnerability are based on the underlying factors that influence a community's ability to prepare for, deal with and recover from an impact (Cardona, 2005; Tate, 2012). This SVI aims to increase the understanding of the dynamics and socio-economic characteristics of the Italian population, as well as to identify areas with different ability to react to catastrophic natural events.

Specifically, based on the Hazards-of-Place model approach (Cutter, 1996), this paper first outlines the main variables that indicate aspects of vulnerability of Italy to natural hazards. It then applies a Principal Component Analysis (PCA) to identifying the underlying components that make a territory socially vulnerable to natural hazards. Finally, the article explores the spatial patterns of SVI across Italy, using cluster analysis.

This revealed to be a useful tool to identify potentially vulnerable areas, proposing finally the possibility to integrate the social vulnerability index into emergency management plans and disaster risk reduction strategies.

2. Materials and methods

2.1. Tools and data

The proposed methodology is based on FOSS (Free and Open Source Software) applications. By starting from the implementation of hazard and vulnerability database, it is able to statistically analyse different socioeconomic variables in order to produce maps of SVI. FOSS applications were selected because they permit the methodology to be easily replicable without any royalty cost. In particular, the following tools were used: DBMS-system PostgreSQL/PostGIS (http://www.postgresql.org) for data storage, R software (http://www.r-project.org) for statistical analysis, GeoDa software (http://geodacenter.asu.edu) for spatial statistics analysis and QGIS software (http://www.qgis.org) to visualize and produce maps.

Secondary data about demography in the 2011 Italian population and housing census were taken from the official repository of the Italian National Institute of Statistics (ISTAT) (ISTAT, 2015). The information used included population, social variables and geographically referenced information at different administrative units (census tract, municipality and regional). Census socioeconomic variables were downloaded as csv file for all 8092 Italian municipalities and, in order to improve the management and processing data, the variables were stored as a single table into PostgreSQL/PostGIS database, using ISTAT municipality code as the primary key. This procedure has allowed to obtain an aggregate information of socioeconomic data at municipality level. The range of residents population counts for the Italian municipalities is between more than 2.6 million people for Rome municipality and 30 people for Pedesina municipality, a small town in Sondrio province (north Italy). Then, a metadata table with description of the variables was prepared, stored and linked to the socioeconomic census data. Additionally, a geographic layer of Italian municipalities borders was added and joined to the census socioeconomic variables for the visualization of their spatial distribution along Italian territory.

2.2. Construction of social vulnerability indicators

Social vulnerability is a theoretical concept that is hard to quantify. A method must then be developed to make this concept countable (Hinkel, 2011). Through the use of different indicators it is possible to assess social vulnerability; indeed, an indicator is a quantitative or qualitative variable that is derived from a series of measurements, has different meanings and can be observed across time and space. For example, indicators of social vulnerability, like age or socioeconomic status, can be assessed for their change over time or for how they compare across geographic or social entities (Hinkel, 2011).

Within this framework, we first selected suitable indicators in order to create their proxy variables. We examined census data and then created 18 variables representing the Italian socio-economic conditions, using appropriate SQL queries (Table 1).

A brief description of each indicator along with its influence on social vulnerability follows.

1. Family structure: large families often have limited finances to outsource care for dependents, and thus must balance work responsibilities and care for family members. Large family size may also reduce evacuation ability and resilience to natural hazards (Cutter et al., 2003).
2. Education: it reveals the ability to understand information about emergency plans or warning information and to avoid dangerous situations (Elstad, 1996; Morrow, 1999; Cutter et al., 2003).
3. Socioeconomic status: this indicator represents a measure of the ability to absorb losses and enhance resilience to hazards (Collins and Bolin, 2009; Adger et al., 2009; Lee, 2014). Among variables that compose this indicator we identified (i) a *containment index*, a measure of the number of people who work within their residence municipality, and (ii) an *attraction index*, which evaluates the capability of a municipality to appeal commuters.
4. Employment: it is often related to the potential loss of job activities after a hazardous event, increasing therefore the