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A GIS-based approach to identify the spatial variability of social vulnerability to seismic hazard in Italy

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ABSTRACT

This paper argues for a multidisciplinary framework to assess the relationship between environmental processes and social sciences that can be adapted to any geographic location. This includes both physical (earthquake hazard) and human (social vulnerability) dimensions in the context of disaster risk reduction. Disasters varies drastically depending on the local context. Indeed, the probability of a natural disaster having more devastating effects in one place than in another depends on the local vulnerability components of the affected society (cultural, social and economic). Therefore, there is an important correlation between the potential risk and the social resistance and resilience of a specific place, thus the disaster response varies according to the social fabric. In this context, the evaluation of social vulnerability is a crucial point in order to understand the ability of a society (studied at individual, household or community level) to anticipate, cope with, resist and recover from the impact of natural disaster events. Within this framework, the paper discusses how it is possible to integrate social vulnerability into the seismic risk analysis in Italy. Specifically, socioeconomic indicators were used to assess and mapping social vulnerability index. Afterwards, a Geographic Information System (GIS) approach was applied to identify the spatial variability of social vulnerability to seismic hazard. Through the use of a risk matrix, the classes of a social vulnerability index map were combined with those of a seismic hazard map proposed by INGV (National Institute of Geophysics and Volcanology). Finally, a qualitative social vulnerability exposure map to an earthquake hazard was produced, highlighting areas with high seismic and social vulnerability levels. Results suggest the importance of the integration of social vulnerability studies into seismic risk mitigation policies, emergency management and territorial planning to reduce the impact of disasters.

Contents

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1. Introduction

In the last decades the impact of natural hazards has increased due to increased population density in hazardous zones, often associated with poor human planning, and to the increase in the frequency and intensity of extreme events as a consequence of climate change (Pachauri et al., 2007). Italy, owing to its intrinsic geological/geomorphological peculiarities and climatic conditions, is characterized by high exposure to natural hazards with potentially severe consequences. A natural hazard only becomes a disaster when it affects a human population that is exposed and vulnerable (Uitto, 1998). Italy is one of the five European Countries with the highest probability of being involved in a disaster and suffering economic losses (Welle, Birkmann, Rhyner, Witting, & Wolfertz, 2012). Table 1 shows the major disasters, caused by poor environmental management and natural hazard events that occurred in Italy from 2000 to 2013, with the deaths, number of people involved and economic losses (Guha-Sapir, Vos, Below, & Ponserre, 2014). In this context, the term disaster is interpreted as a result of the combination of: the exposure to natural hazards, the conditions of vulnerability featured by the place and insufficient ability or measures to reduce or cope with the potential negative consequences (UNISDR, 2016). Natural disasters are not preventable, but vulnerability assessments, hazard mitigation and emergency management planning can reduce the impacts of disaster events and facilitate recovery.

Hydro-geological and earthquakes events are certainly the most relevant natural phenomena for their high diffusion, but many others are far from negligible, for example large active volcanoes close to densely populated areas (e.g. Vesuvius area). According to the study carried out by the Institute for Environmental Protection and Research (ISPRA) in 2008, 70.5% of Italian municipalities are affected by landslides (ISPRA, 2011). Otherwise, on the basis of the seismic hazard map (Fig. 1), by National Institute of Geophysics and Volcanology (INGV), 37.6% of Italian municipalities fall into the two higher classes of earthquake hazard (Zones 1, the most dangerous areas, where major earthquakes may occur and Zone 2, areas that may be affected by rather strong earthquakes) (INGV, 2003).

According to Alexander (1993), a hazard may be assimilated as the pre-disaster situation in which some risks of a disaster event exist, principally because the human population has placed itself and its socio-economic characteristics in an exposed situation with overlaid differential vulnerabilities. The disaster extent varies drastically depending on the local context. Indeed, the probability of a natural disaster having more devastating effects in one place than another depends on the local vulnerability of an affected society, intended as a cultural, social and economic organization (Cutter, Boruff, & Shirley, 2003). In this context, risk assessment and management through appropriate forecasting and prevention measures play a fundamental role in redefining areas prone to natural hazards and in reducing future phenomena at all levels. Several Italian public authorities and research centers are examining these topics to propose efficient methodologies to reduce the impact of hazard events on vulnerable elements. However, these studies converge particularly on the physical side of vulnerability, focusing on the damages and economic losses estimated for buildings and infrastructures, omitting the social component of vulnerability. Natural hazards do not have a random effect on the local community and generally the most affected groups are the more vulnerable ones, already marginalized by socio-economic classes (i. e. people that have the same social, economic, occupation or educational status), race, ethnicity and gender. These marginalization factors are a central component of vulnerability and they can be defined as the susceptibility of social groups to the impact of hazards, influencing economic losses, injuries and fatalities (Blaikie, Cannon, Davis, & Wisner, 2014; Cutter et al., 2003). Therefore, natural hazards can be more or less devastating according to vulnerability, which depends on the time and place where the event happens and the socio-economic conditions of the population affected. This highlights the need to better integrate social science research concerning social vulnerability into territorial planning and emergency management decision-making. Within this framework, the vulnerability of a place can be modeled by studying the potential hazard of a place on the basis of the interaction between risk (a measure of the potential damages or losses in lives, health status, livelihoods, assets and services, which could occur to a particular community or a society over some specified future time period) and mitigation (measures to lessen risks or reduce their impact) (Cutter et al., 2003).

2. Methodology

The method presented in this paper had been applied at national scale and consists in a qualitative and quantitative approach including spatial analysis through Geographic Information System (GIS) and statistical modeling. Effective use of both methods (quantitative and qualitative) and of different tools at one's disposal (geospatial tools, statistical techniques and others) can lead to enhanced research opportunities and, more importantly, for applied geography, a deeper knowledge of the geographic phenomena being studied (Yeager & Steiger, 2013). Following the hazard-of-place model approach proposed by Cutter et al., 2003, the methodological framework for assessing the social vulnerability index (SVI) to seismic hazards for Italy was conducted

Table 1
Major natural disasters occurred in Italy from 2000 to 2013.

Dates	Location	Type	Killed	Total affected	Est. Damage (US$ millions)
04/10/2000	Pimont, Val d'Aoste, Ligurie	Flood	25	43,000	8000
20/11/2000	Tuscan, Lombardy, Friuli, Venezia, Trentino	Flood	5	2000	50
18/07/2001	Nicolosi, Catania province (Sicily)	Volcano			3.1
14/09/2001	Naples (Campania region)	Flood	2		100
04/08/2002	Brescia, Venice, Lombardy, Friuli, Liguria	Flood		20	296
06/09/2002	Sicily, Palermo	Earthquake	2		500
31/10/2002	San Giuliano di Puglia (Campobasso, Molise region)	Earthquake	30	8533	796
11/04/2003	Alessandria (Piemont)	Earthquake		232	561.352
29/08/2003	Udine province, Frioul-Venetie Julienne	Flood	2	350	655
11/12/2008	Rome, Venice, Calabre	Flood		3	278
06/04/2009	Aquila, and the neighboring municipalities	Earthquake	295	56,000	2500
01/10/2009	Messina, (Sicily)	Flood	35	5140	20
20/05/2012	Finale Emilia (Ferrare region)	Earthquake	7	11,050	15,800
11/11/2012	Venice, Rome, Tuscany, Umbria	Flood	4	1200	15
18/11/2013	Olbia, Arzachena (Sardaigne)	Flood	18	2700	780

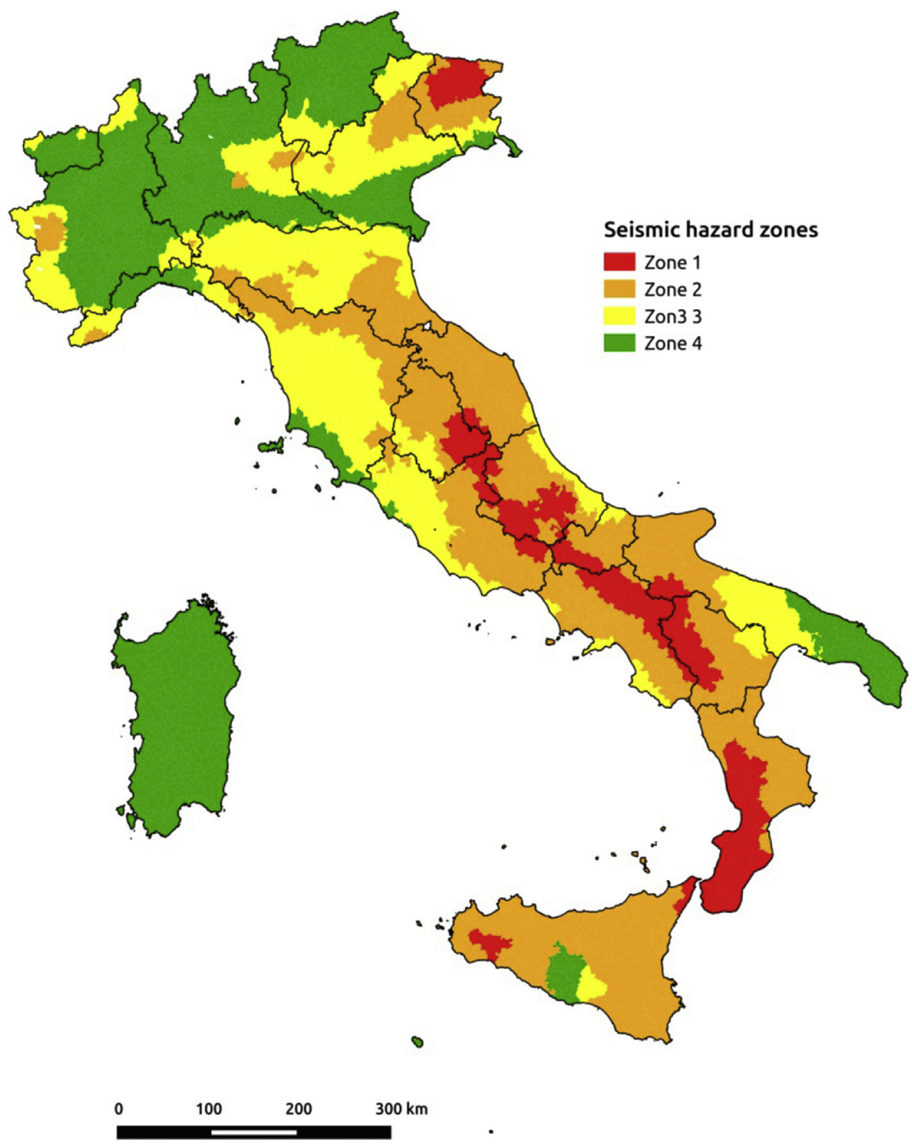

Fig. 1. Seismic hazard map.

through four major steps:

1 Constructing of social vulnerability indicators;
2 Performing multivariate statistical analysis on the selected indicators;
3 Constructing and mapping of SVI; and
4 Obtaining a social vulnerability exposure map combining the derived SVI map with seismic hazard.

2.1. Social vulnerability indicators

This study is based on the 2001 data warehouse of the 14th population and housing census that describes the demographic and social structure of the population residing in Italy and on Italy's housing stock (Istat, 2016). There is a general consensus within the social science community about some of the major factors that influence social vulnerability. These range from lack of access to resources to building stock and age, to the presence of frail and physically limited individuals and to the type and density of infrastructure and lifelines (Blaikie et al., 2014; Jacobs, Smith, & Goddard, 2004; Frazier, Thompson, & Dezzani, 2014). In addition, some authors also include social capital, in terms of social networks and connections that might determine a different degree of resilience of the local community to hazards (Cutter et al., 2003; Ojerio, Moseley, Lynn, & Bania, 2010; Jabareen, 2013). In addition, some authors also include social capital, in terms of social networks and connections that might determine a different degree of resilience of the local community to hazards (Blaikie et al., 2014; Cutter, 2001; Lindell, Tierney, & Perry, 2001).

The choice of the major indicators that influence social vulnerability represents a critical point for constructing a social vulnerability index because it depends strongly on both the quality of the available variables and on the subjectivity of their selection (Nardo et al., 2005). Indeed, there is no guideline concerning which data to use and how to treat this data for the construction of the index. In fact, there is a high social and cultural heterogeneity that changes from country to country and different methodologies can be used to assess social vulnerability at different scales and systems. In view of these considerations and of the data availability, an indicator-based approach was used to assess social vulnerability index for Italy.

After a careful review of related literature, the most relevant factors that influence social vulnerability to natural hazards (Cutter et al., 2003; Cutter & Emrich, 2006; Rygel, O'sullivan, & Yarnal, 2006; Birkmann, 2006; Utami, 2008; Cutter, Emrich, Webb, & Morath, 2009; Wood, Burton, & Cutter, 2008), six indicators were selected: age, employment, education, urbanization, quality house and ethnicity (Table 2). Within these indicators, 15 proxy variables were considered: these explain the Italian population socio-economic conditions that influence the ability of a community to prepare for, respond to, and recover from hazards and disaster. The variables explain both positive and negative factors that increase or decrease social vulnerability.

Finally, the 15 variables were collected for every census block and then grouped and summed considering a municipality scale.

A brief description of each indicator and of its influence on social vulnerability is given below: Age is a relevant dimension to assess social vulnerability. There is a general consensus that children and youth are more vulnerable, highly dependent on adult members' decisions and not addressed in recovery policies. Also aging can influence vulnerability, according to social norms and culture: limited mobility, illiteracy and economic vulnerability. Among the most used variables can be mentioned the percentage of children under 5 years of age and elderly people over 65 (Bolin & Stanford, 1991; Morrow, 1999; Cutter, Boruff, & Shirley, 2006; Burton & Cutter, 2008; Frazier et al., 2014). Employment is often related to the potential loss of job activities after a hazardous event, increasing therefore the number of unemployed workers in a community (Cutter et al., 2003); Education 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). Anthropization indicates the degree of urbanization; a rapid population growth is often unlikely to be absorbed by the country providing inefficient services to the population (Cutter et al., 2003). The indicator Residential property represents the quality of residential construction and finally Ethnicity is used for the societies that include several ethnic groups with different languages, cultures and educational levels that could determine cultural barriers in a community (Bolin & Stanford, 1991; Cutter et al., 2003). These considerations show how social vulnerability appears to be clearly a product of social inequalities (Cutter et al., 2003; Blaikie et al., 2014; Bolin & Stanford, 1991), produced by inequalities of income, class, ethnicity. More factors often interact with each others, creating a vicious circle in which, for example, as mentioned by Peacock et al. «lower-income households successively inhabit homes and neighborhoods as they deteriorate physically, allocating poor and minorities to older and poorer-quality homes in less desirable and potentially more risky neighborhoods» (Peacock, Van Zandt, Zhang, & Highfield, 2014).

2.2. Multivariate statistical analysis

The use of multivariate statistical analysis techniques e.g. PCA (Principal Component Analysis) and FA (Factor Analysis) to reduce the number of variables and to extract the underlying dimensions of social vulnerability have been employed in several studies (Cutter et al., 2003; Rygel et al., 2006; Khan, 2012; Fekete, 2009; Zebardast, 2013).

In order to confirm the selection of the variables and to derive a set of components that explains the social vulnerability characteristics for Italy, FA was used. The 15 proxy variables (dependent variables), mentioned in Table 2, were used as input for the computation of FA. Considering that the indicators in a data set often have different measurement units, normalization is required prior to any data aggregation (Freudenberg, 2003; Jacobs et al., 2004). Thus, before applying FA, standardization (Z-score) was used to convert the 15 social vulnerability variables to a common scale with a mean of 0 and standard deviation of 1. Then, all factors with an eigenvalue larger than 1 were extracted and rotated using Varimax orthogonal rotation with Kaiser normalization: this step places the respective components as much apart from each other as possible (Todeschini, 1998; Nardo et al., 2005). Another instrument to select and limit the number of factors is the scree plot (Fig. 2): the factors on the steeper slope in the curve are those that best explain most of the data.

The interpretation of the component matrix generated four main factors that explain the relationship between all variables unfolding the 74.6% of the variance in the entire dataset. These factors, with their percentage of variance explained, were interpreted as follows: Age (29.5%), Employment (22.4%), Education (12.9%) and Anthropization (9.5%). The spatial distribution for each factor was then derived (see the results in Section 3).

2.3. Constructing and mapping of social vulnerability index

In order to assess overall social vulnerability it is necessary to combine the scores of each factor (Age, Employment, Education,

Table 2
Variables, indicators and their impact on social vulnerability. The variable "Quality residential (buildings from 1972)" refers to the Italian law on the classification and regulations for buildings in seismic zones.

Variables	Indicator	Impact on social vulnerability
Rate of children <14 years Rate of elderly >65 years Population dependency ratio Elderly index	Age	Increase
Female labor force employed Labor force employed Unemployment rate Commuting rate	Employment	Decrease Increase
Index of high education Index of low education	Education	Decrease Increase
Population density Urbanized index for residential use Crowding index	Anthropization	Increase
Quality residential (building from 1972)	Residential property	Decrease
Foreign residents	Ethnicity	Increase

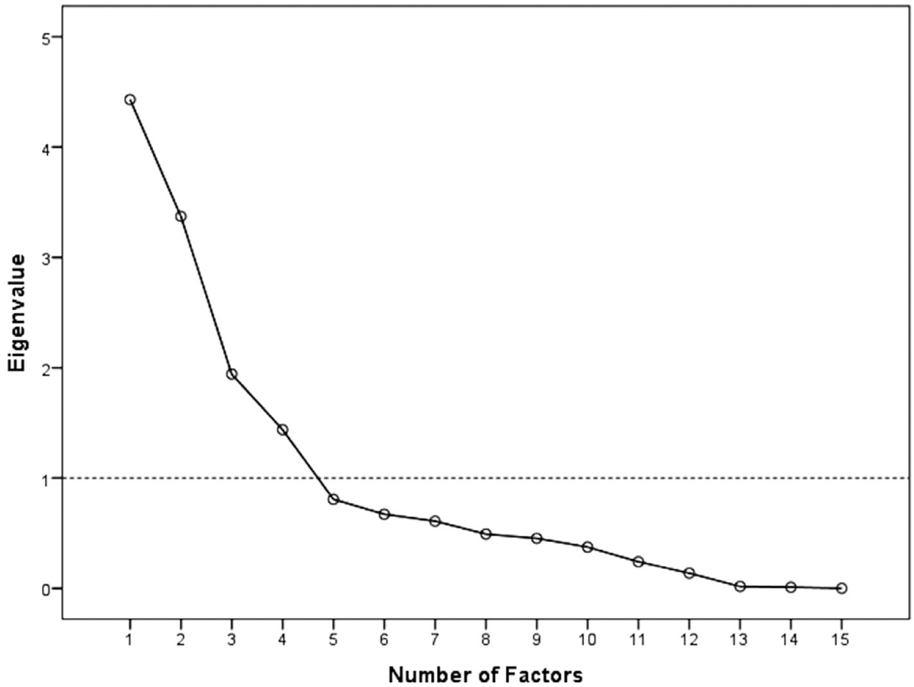

Fig. 2. Scree plot of the 15 variables: only the first 4 factors have an eigenvalue greater than 1.

Anthropization) into a single measure. This is at the base for the computation of SVI at municipality scale. The aggregation method to generate composite indices is the main method used by most researchers interested in social vulnerability studies (Ge et al., 2013). The direction of the four mentioned factors was determined with respect to their known influences on vulnerability, which are identified from the existing literature: positive (+) directionality was given to factors that increase vulnerability (Age, Employment and Anthropization) and negative (−) directionality to factors that decrease it (Education, in this case, was considered negative because as results from the FA in the loading matrix, the variable "Index of high education" has a higher factor score than its opposite variable) (Cutter et al., 2003).

Furthermore, not all factors have the same influence in assessing final social vulnerability. For these reasons, the construction of a weighted composite vulnerability index is recommended. Since there is not a common methodology in the scientific community for assigning weights (Rygel et al., 2006), several authors used different methods to weight the index (Cutter et al., 2003; Rygel et al., 2006; Fekete, 2009). In this analysis, factor scores were weighed by multiplying them with the corresponding percentage of the variance explained by each single factor and dividing them by the total variance, as proposed by Siagian, Purhadi, Suhartono, and Ritonga, (2014). Finally, the SVI for all Italian municipalities was calculated with the following equation:

$$\mathrm{SVI} = \sum\left(\frac{29.5{*}\mathrm{factor1}}{74.6}\right) + \left(\frac{22.4{*}\mathrm{factor2}}{74.6}\right) - \left(\frac{19.9{*}\mathrm{factor3}}{74.6}\right) + \left(\frac{9.5{*}\mathrm{factor4}}{74.6}\right) \quad (1)$$

After the construction of the SVI, its spatial distribution was derived. In particular, the obtained data was mapped using QGIS software (www.qgis.org) and classified into four classes using standard deviation methods in order to obtain the final map. The derived classes were named considering the entity of social vulnerability: High (1), Medium (2), Low (3) and Very low (4). It is important to consider that there are inherent difficulties in deciding where a break should be inserted for the classification into categories but it is fundamental to classify quantitative thematic map contents allowing non-expert users to better understand the meaning of the map. The proposed classification method is particularly suitable for displaying data that has a standardized normal distribution. The first class includes municipalities with the highest values of the SVI, while the second and the third class are more generalist and have a medium and low impact of social vulnerability on the territory. The last class, classifies municipalities with the lowest index values of social vulnerability where the socio-economic conditions are positive.

2.4. Social vulnerability exposure to seismic hazard

One of the applications of the SVI map is to combine it with hazard maps in order to obtain social vulnerability exposure maps. This allows for the identification of hot-spot areas, in which the social fabric could amplify the consequences of a potentially dangerous event.

Therefore, the main objective of the study was to produce a social vulnerability exposure map concerning seismic hazard. This typology of natural events was selected for the analysis because of to the susceptibility of the Italian territory to earthquakes. Data is available at a national scale for each municipality. In fact, the peculiar location of the Italian Peninsula in the Mediterranean geodynamic context (e.g. convergence between European and African plates, presence of Alpine and Apennine mountain ranges), makes Italy one of the European countries with the highest seismic hazard.

In order to reduce the effects of earthquakes, the Italian government has concentrated its attention on both the application of special regulations for buildings in areas identified as seismic, and on territorial classification, considering past earthquakes intensity and frequency. In particular, the Ordinance of President of the Council of Ministers of 28 April 2006 (OPCM 3519/06) proposed a territorial classification introducing intervals of acceleration (ag), with a probability of exceeding the threshold equal to 10% in 50 years, applying so all Regions to define four seismic areas (Table 3).

Firstly, INGV data provided by Civil Protection (http://www.protezionecivile.gov.it) was used to create a seismic hazard map for Italy using QGIS software (Fig. 1). Analyzing the derived map, the most affected areas are located in Friuli and along the central and southern Apennines, especially in the intra-Apennine basins, along the Tyrrhenian coast of Calabria and eastern Sicily. In these areas several earthquakes with a great intensity have occurred, with peaks of magnitude greater than 7 in Calabria, Sicily and the eastern and south-central Apennine and around 6.5 along the Apennine Mountains and the eastern Alps (INGV, 2003). This map provides an easily understandable visualization of seismic hazard spatial distribution and could be used by the disaster management community during the decision-making phase and to perform the cost/benefits analyses of management strategies. Taking into account the risk equation:

$$Risk = (hazard) \times (vulnerability) \tag{2}$$

Risk is defined as the interaction between hazard and vulnerability (Blaikie et al., 2014). Vulnerability is often defined in an economical way, by the fraction of the total value at risk that could be lost after a specific adverse event (Rucco, 2012). However, considering the hazard-of-place model, it is evident that not only biophysical aspects are fundamental in assessing vulnerability, but also the social fabric of a territory is fundamental for producing the overall place vulnerability (Cutter et al., 2003).

Because the main limitations concern the availability of biophysical vulnerability data at a national scale and the difficulty to assess it, it was not possible to make a risk analysis and in this paper only the social components of vulnerability were considered in the risk equation.

Afterwards, in order to assess the spatial relationship between social vulnerability and seismic hazards, a GIS based approach was used. The risk matrix (Fig. 3) proposed by a directive issued by the Lombardy region for qualitative hydrogeological risk assessment (Lombardy Region, 2005) was adapted to build a qualitative social vulnerability exposure map. The matrix was calculated by combining the different classes of social vulnerability with those of seismic hazard and then reclassifying the values in four categories (Very low, Low, Medium and High).

Finally, the exposure map was obtained, identifying the hot-spot areas: zones with high levels of seismic hazard and at the same time high levels of social vulnerability.

3. Results and discussion

As mentioned in paragraph 2.2, four main factors were identified as relevant in explaining the relationship among all variables. Thefirst factor, Age, is the most relevant dimension, explaining 29.5% of the variance. It is evident, also in consideration of the relative literature, how the presence of children and elderly people significantly increase the vulnerability of a community (Buckle, Mars, & Smale, 2010; Morrow, 1999; Bolin & Stanford, 1991;

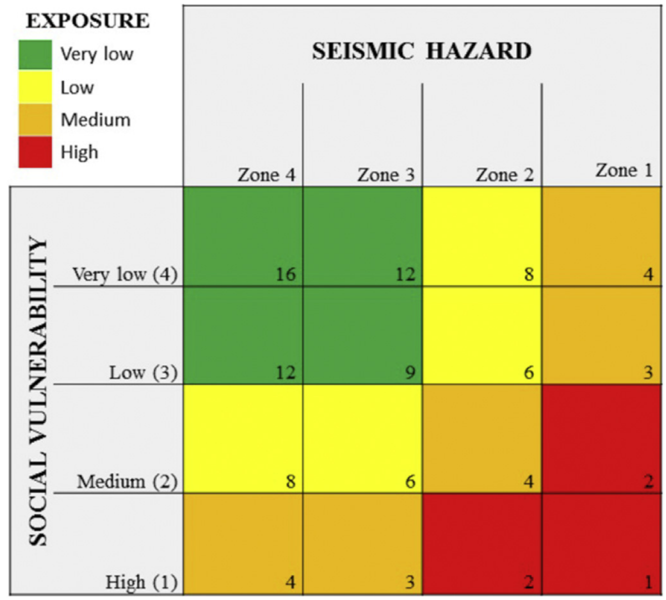

Fig. 3. Risk matrix.

Blaikie et al., 2014). Employment is another important factor (22.4% of the variance) and is often related to the potential loss of job activities after a hazardous event, increasing, therefore, the unemployment rate in a community (Cutter et al., 2003). Furthermore, unstable employment is more common in the low-paying jobs, which are more likely to be lost when businesses close or move after a disaster (Morrow, 1999). Another variable that increases social vulnerability is the "Commuting rate", intended as people who commute daily from one municipality to another to work or study.

Education (12.9%), is the only extracted factor that decreases social vulnerability: in fact, a high level of education is related not only to the ability to understand information about emergency plans or warning information, but also to the socioeconomic status: better job opportunities and higher income are linked to a high level of education (Elstad, 1996; Morrow, 1999).

The last factor was interpreted as Anthropization (9.5%). It is related to density and population growth and it increases social vulnerability: high population density makes evacuation harder, increasing the risk of losses and a rapid population growth is unlikely to be absorbed by the country by offering inefficient services to the population (Cutter et al., 2003).

The maps presented in Fig. 4 allow for a better understanding of the spatial distribution of these factors at a national level. Furthermore, considering the significant heterogeneity of Italy, this data is important in highlighting the contribution of each factor in the determination of the overall social vulnerability in a specific place.

The map representing factor 1, shows the distribution of Age. It is important to highlight that Italy is the second country in Europe, after Germany, with the highest aging index (in 2013, 151.4%) and this is attributable to the increase of the elderly population, to the

Table 3
Seismic hazard zones with their ag values.

Seismic zone	Acceleration with probability of exceeding equal to 10% in 50 years (ag)
Zone 1	ag >0.25
Zone 2	0.15 < ag≤0.25
Zone 3	0.05 < ag≤0.15
Zone 4	ag ≤ 0.05

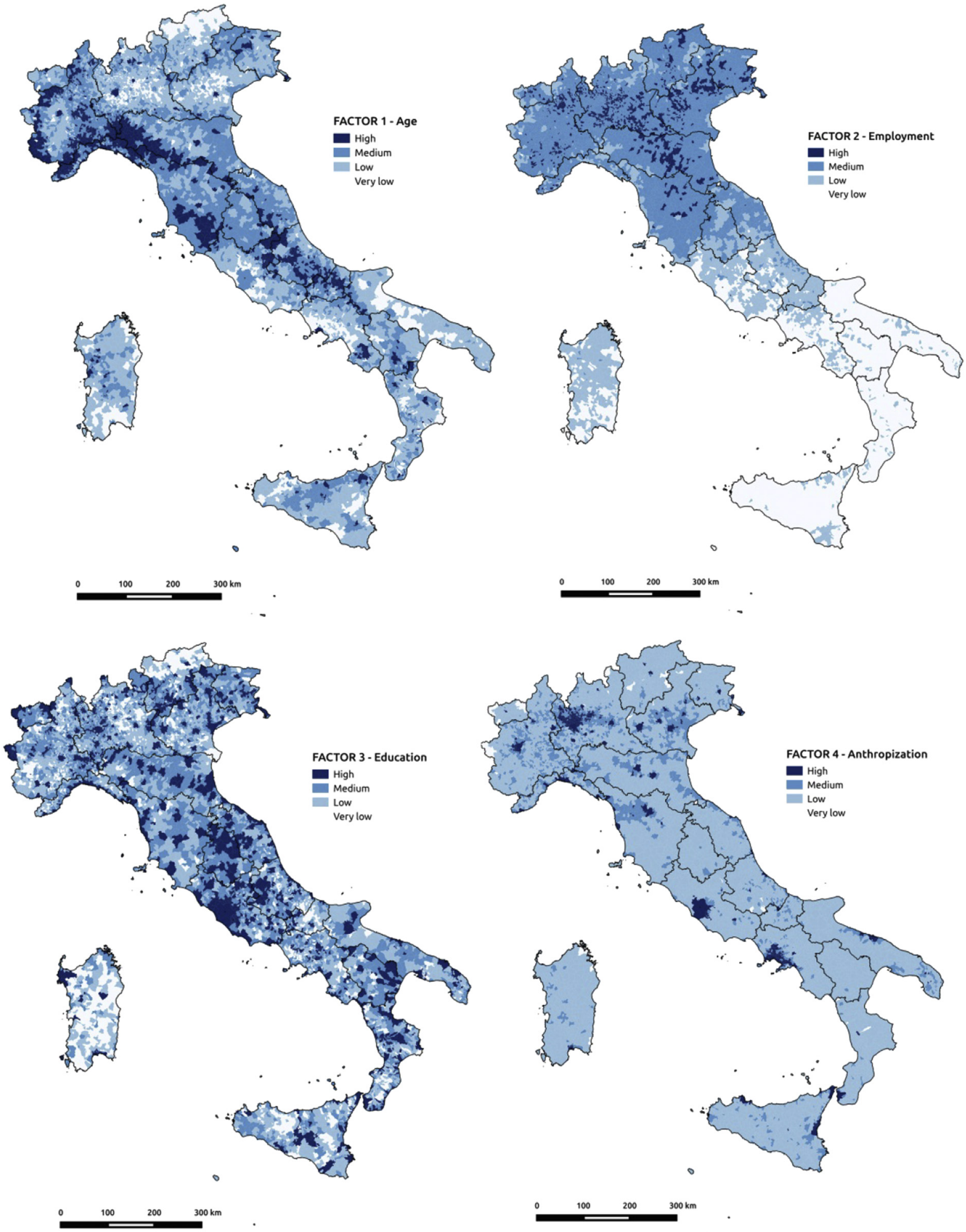

Fig. 4. Spatial distribution of the four factors derived from factor analysis: age, employment, education and anthropization.

reduction of younger people, to the increase of life expectancy and limited fertility (ISTAT, 2013). Observing the map, the distribution of the factor Age reflects the Italian topography quite well: the areas where it has the most influence are located along Appennine mountain range and partially on the west part of the Alps. This could be related to the fact that these areas are often characterized by the presence of small historical towns where the percentage of young people is quite low. In spite of this, over the last decades the structure and dynamics of the population have undergone profound changes due to a depopulation of mountain areas and land abandonment, resulting in the migration to valley, thanks to the presence of industrial and service sectors.

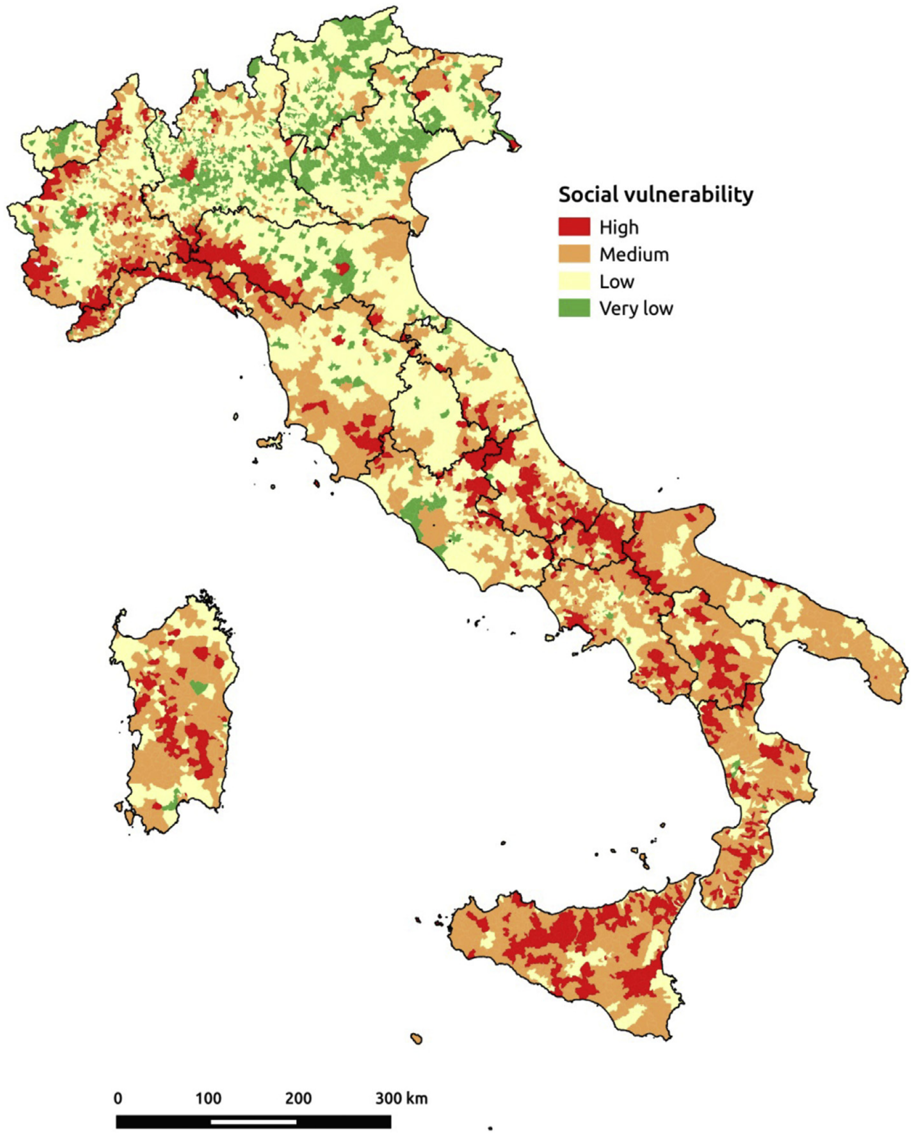

Fig. 5. Social vulnerability index map.

The second map (factor 2) depicts the employment conditions. The variable mainly correlated to this factor is the Unemployment rate and it is often related to the potential loss of job activities after a hazardous event, increasing the number of unemployed workers in a community (Cutter et al., 2003). Furthermore, unstable employment is more common in low-paying jobs, which are more likely to be lost when businesses close or move after a disaster (Morrow, 1999). The persistence of unfavorable conditions in the labor market in recent years has led to an intense growth of unemployment in Italy and the areas most interested are the central and southern regions. Analyzing the map, Italy is clearly divided into two different economic regions: the northern part, thanks to the high concentration of industrial activities and services, has greater job opportunities and so its economic development is more important than the southern part. This particular condition is well supported also by 2013 ISTAT data: i.e., in this year, the unemployment rate of southern regions is 2.5 times higher than northern ones (7.7% in the Northeast, 19.7% in the South), reflecting the presence of industries in those areas (North: 70.2/1000 inhabitants; South: 51.8/1000 inhabitants in 2012) (ISTAT, 2013). However, it is necessary to highlight that the availability of employment may be problematic if factories are damaged and might suffer greater impact from natural hazards; but people with stable occupations before the impact of hazard events, have more employee benets plans, which provide income and health cost assistance in the event of personal injury or death (Brodie, Weltzien, Altman, Blendon, & Benson, 2006).

The spatial distribution of the third factor, Education, has a more irregular pattern then the other; high level of education is often related to the presence of big cities, where the presence of schools and universities is higher and job opportunities often require a higher literacy rate. This factor is relevant for the determination of social vulnerability of a place. In fact, education influences not only the risk perception, skills and knowledge but also reduces poverty and improves health, guaranteeing better job opportunities and thus, a higher income. Educated individuals, households and societies are assumed to better respond to, prepare for, and recovery from disasters (Ahsan & Warner, 2014; Elstad, 1996; Morrow, 1999; Cutter et al., 2003).

The last factor (Anthropization), draws attention to the new major metropolitan aggregation areas. The values are on the average quite high, given that Italy is the fourth country in EU by

Table 4
Percentage and number of municipalities falling into social vulnerability classes.

Vulnerability class	Number of municipalities	Percentage (%)
High	1085	13.4
Medium	2592	32
Low	3305	40.81
Very low	1116	13.8

population (after Germany, France and the United Kingdom) (ISTAT, 2013).

Even though the maps previously analyzed can be useful to understanding how single factors influence social vulnerability, their overall assessment requires their combination into a single measure. Fig. 5 represents the spatial distribution of social vulnerability index, obtained as a result of Equation (1).

Even if the social vulnerability map does not clearly show the contribution of each single factor, it allows us to easily visualize the social vulnerability spatial distribution at a national scale, supplying decision makers with a useful tool for emergency management and territorial planning. As can be seen from Fig. 5, significant variations can be observed within the country. The upper right map shows municipalities with low and very low index values versus the upper left map highlights medium and high values; the same vulnerability situation can be seen along the Appennine mountain range and for the two main islands (Sicily and Sardinia). More specifically, dense, built-up city centers are shown to be more vulnerable than their surroundings and, analyzing the results of FA and visualizing the factors maps, this can be attributed to the presence of human activities, population density and structures. The analysis of the index values reveals great heterogeneity and relevant interactivity of the components that affect social vulnerability in Italy. The heterogeneity is also underlined by Table 4 that presents the distribution of all Italian municipalities by social vulnerability levels.

The index distribution denotes that 2592 municipalities (32% of the total) exhibit medium levels of social vulnerability. A total of 1085 districts (13.4% of the total) are classified in the high social vulnerability class and 1116 municipalities (13.8% of the total) are categorized as very low vulnerability. The residual districts are classified as low vulnerability (3305 municipalities, 40.8% of the total) in terms of social vulnerability.

Finally, the exposure map was derived through the implementation of a risk matrix, as described in section 4.3 (Fig. 4). Despite this last step being based on a qualitative analysis, it represents a first step towards identifying, at a large scale, areas that need more in-depth attention carrying out afterwards a detailed investigation. This result identifies that areas more susceptible to seismic events are those that have high social vulnerability. For this reason, the map could be considered a useful tool for disaster

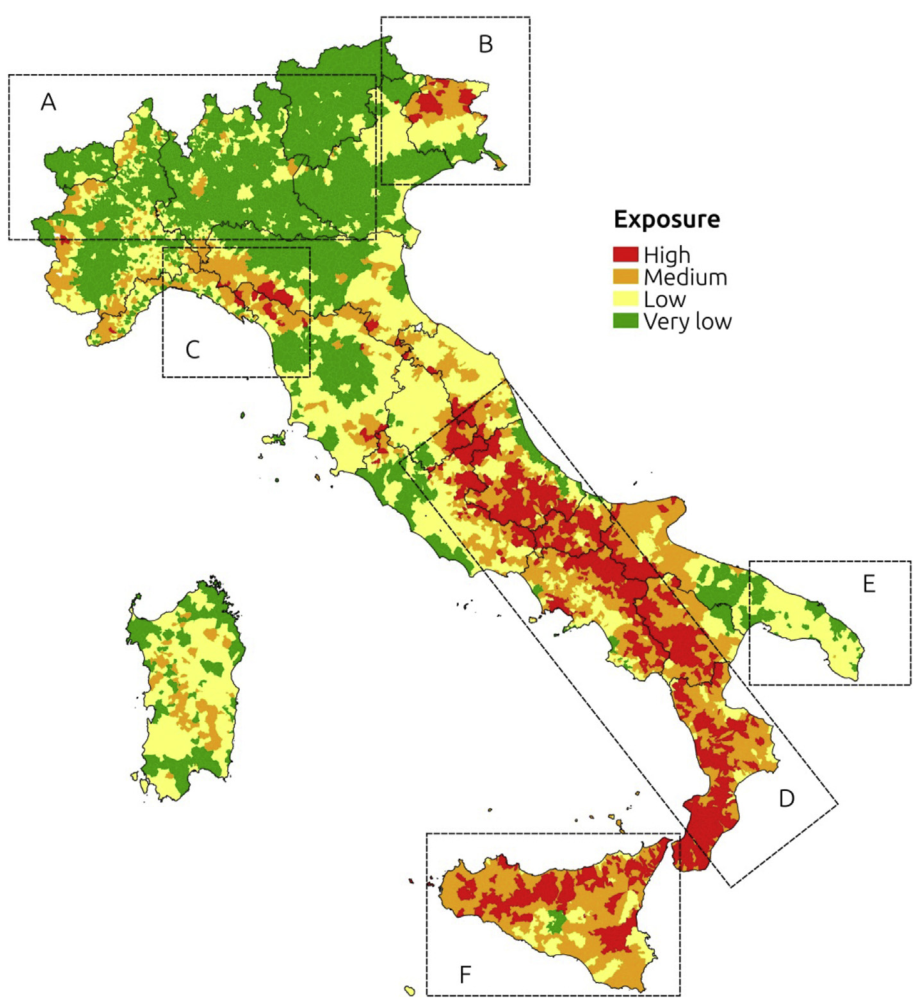

Fig. 6. Exposure map: this map represents the social vulnerability exposure to earthquake hazard. The 4 classes (high, medium, low and very low) were derived from the risk matrix presented in Fig. 3. Moreover, the country was subdivided in six zones (labeled: Box A–F) to better explain the results in the geographic context of the Italian regions.

impact modeling because it highlights the spatial distribution of areas with different social fabrics that can amplify the negative effects of earthquakes.

The use of the matrix is founded on the assumption that an institutionally and legislative approach allows us to highlight, clearly and simply, critical areas for Italy; on the one hand, it provides a simple instrument for policy makers to implement environmental and socio-economic sustainable policy, on the other hand it helps local communities to improve their awareness about natural hazards. Fig. 6 reveals different spatial patterns regarding the combination of social vulnerability and earthquake hazard. High values of social vulnerability and areas of greatest seismic hazard are located in the Boxes B and C that represent the territory of Friuli Venezia Giulia region and the border areas among Liguria, Emilia Romagna and Tuscany regions, respectively. The same situation, but with higher exposure values, can be observed for the zones of the central-southern Apennines included in the Box D. Sicily region, highlighted in the Box F, also has very large concentrations of exposure, with a significant number of municipalities classified as medium or high. Only the central part of southern.

Apulia (Box E) and Sardinia region (the other big island on the left of the Box F), where the seismic hazard is very low, have a total exposure of low or very low. The areas included in Box A: Valle d'Aosta, Lombardy, Trentino and part of Piedmont and Veneto regions, instead benefit with very low total exposure.

Considering the potential impact of this results in risk mitigation strategies, it is essential for policy makers know which are the more socially vulnerable areas against seismic hazards. The maps can be used to define appropriate actions to be implemented at national or local level, for example in the National Plan for seismic risk prevention. Knowledge about the spatial variation of social vulnerability exposure to earthquake hazard allows to improve damage scenarios that represent tools to forecast possible damage and consequent effects on the population. However, a scenario based approach is often evaluated hypothesizing earthquake magnitude, fault geometry, kinematic parameters and building vulnerability. In addition to physical hazard mapping, it is therefore essential to consider human vulnerability analysis. To this regards the results highlight how it is important to evaluate the interactions between human activities (social and urban system) and earthquake hazards, ensuring also the most vulnerable populations that may be less likely to respond to, cope with, and recover from a natural disaster.

In this context, indicators and maps could provide support to Regional Authorities for the latter's planning and policies supplying information to reduce social vulnerability in a certain place (Frigerio & De Amicis, 2016; Frigerio, Strigaro, Mattavelli, Mugnano, & De Amicis, 2016).

4. Conclusion

In conclusion, the methodology presented in this paper aims to develop a procedure based on a socio-economic analysis of the Italian population, capable of identifying areas with a different ability to react to catastrophic natural events. It provides a useful tool for assessing and identifying the spatial distribution of social vulnerability and for understanding what are the Italian socioeconomic conditions that make a community more vulnerable than another. The main results of this research include a significant selection of socioeconomic variables to evaluate SVI in Italy. Moreover, multivariate statistical analysis proved to be a useful method to reduce the dataset, confirming the choice of the input variables explaining the 74.6 percent of the variance in Italy using four independent factors. Another important result was the spatialization of the four factors that highlighted their geographic variability along the country. Following the hazard-of-place model, this method produced a social vulnerability map at a national scale that could be used in a preliminary stage of regional planning.

The visualization of SVI map provides an adequate base for understanding the spatial variation in social vulnerability across Italy. This study also reveals the importance of integrating social vulnerability with hazards. In this case, the combination between SVI map and earthquake map produced a qualitative social vulnerability exposure map. Regarding the literature about social vulnerability in Italy, this study represents the first analysis that aims to understand the spatial relation between social vulnerability and earthquake hazard, pointing out areas that need a detailed scale analysis.

Therefore, the proposed methodology depicts an instrument to identify appropriate cost-effective risk reduction measures to be implemented at a national level. The future developments are aimed at assessing the spatial relationship between social vulnerability and different hazards by combining the maps of SVI with those of hazardous events through a GIS-based approach. In this way, it is possible to identify areas with high hazard levels and high levels of social vulnerability. An additional topic that few scholars address in terms of this issue is the classification of the social vulnerability and exposure maps. This aspect is crucial in the process of communicating the results to non-expert users because this information can be included in the emergency plans to better allocate resources, such as people, materials and financial funds, in response to improving emergency management against disaster events. It is evident that in analysing these maps, results can be interpreted to assist in determining the causes, processes and consequences of social vulnerability related to hazardous events.

Finally, the results presented in this research could help obtain a global vision on seismic processes which can interact with human communities; consequently, incorporation of social vulnerability components seems to be inevitable for the countries with high earthquake hazards.

Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.apgeog.2016.06.014

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