# Assessment of Social Vulnerability to Floods in the Floodplain of Northern Italy

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ABSTRACT

Practices for reducing the impacts of floods are becoming more and more advanced, centered on communities and reaching out to vulnerable populations. Vulnerable individuals are characterized by social and economic attributes and by societal dynamics rooted in each community. These indicators can magnify the negative impacts of disasters together with the capacity of each individual to cope with these events. The Social Vulnerability Index (SoVI) provides an empirical basis to compare social differences in various spatial scenarios and for specific environmental hazards. This research shows the application of the SoVI to the floodplain of northern Italy, based on the use of 15 census variables. The chosen study area is of particular interest for the high occurrence of flood events coupled with a high level of human activity, landscape transformations, and an elevated concentration of assets and people. The analysis identified a positive spatial autocorrelation across the floodplain that translates into the spatial detection of vulnerable groups, those that are likely to suffer the most from floods. In a second stage, the output of the index was superimposed on the flood hazard map of the study area to analyze the resulting risk. The Piemonte and Veneto regions contain the main areas prone to flood ''social'' risk, highlighting the need for a cohesive management approach at all levels to recognize local capacities and increase communication, awareness, and preparedness to mitigate the undesirable effects of such events.

## 1. Introduction

Among natural and anthropogenic hazards, water-related disasters represent one of the main environmental risks of our time, causing the major obstacles to human security and development (Adikari and Yoshitani 2009). Floods affect on average about 70 million people each year (UNDP 2004; United Nations 2011), and the severity of such events will increase in the future (Swiss Re 2012). These data have intensified the attention of public authorities and researchers in understanding the factors contributing to such risks (IPCC 2012). In a general sense, risk derives from the combination of hazard, vulnerability, and exposure to the elements present in a community that may translate into possible adverse effects (Cardona et al. 2012). The vulnerability is the fragility of the human–environment system to disturbances and losses (Smit and Wandel 2006) related to the social, economic, and environmental conditions of the community (UNISDR 2004; Kasperson et al. 2005). In this framework, social vulnerability can be defined as the vulnerability of the human environment (Brooks 2003) and can be related not only to some individual characteristics such as gender, age, education, economic welfare, and race, among others, but even to complex community dynamics and support systems that may influence certain individuals in their ability to respond to particular threats (Cutter et al. 2003; Mechanic and Tanner 2007). Besides social and economic inequalities, as expressed by several authors, social vulnerability may

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include housing characteristics (Flanagan et al. 2011; Armaş 2008; Ludy and Kondolf 2012; Mechanic and Tanner 2007) and critical infrastructures (Adger et al. 2004; Flanagan et al. 2011; Cannon et al. 2003; Fekete 2009). The interaction among these factors across space may help in the definition of so-called vulnerable groups (Cutter et al. 2013). However, labeling all the people as vulnerable according to one or more general characteristics has been seen to be quite problematic (De Marchi and Scolobig 2012). In fact, measuring the vulnerability of a society implies the identification of the social, economic, and political context behind people's susceptibility into a defined spatial and temporal setting (Borden et al. 2007). Spatiotemporal parameters may influence the presence or the absence of some variables used for the overall computation of the social vulnerability. For example, as shown by Zhou et al. (2014) there is not a unique temporal set of variables for the assessment of vulnerability. And similarly not all the variables explain the vulnerability for all hazard settings. As commented by Weichselgartner (2001), concentrating attention on a single hazard may produce accurate and in-depth analysis surrounding it because of the unique physical process characteristics. This means that there are factors related to vulnerability at a broad spectrum (e.g., Zhou et al. 2014; Guillard-Gonçalves et al. 2015; Masozera et al. 2007; Chakraborty et al. 2005; Cutter and Finch 2008; Siagian et al. 2014) and some others that are more hazard-dependent (Schneiderbauuer and Ehrlich 2006)—for example, for tropical cyclones (Anderson-Berry 2003), hurricanes (Myers et al. 2008; Cutter and Emrich 2006; Rygel et al. 2006), earthquakes (Schmidtlein et al. 2011; Noriega and Ludwig 2012), landslides (Santha and Sreedharan 2012; Eidsvig et al. 2014), drought (Iglesias et al. 2009), volcanic hazards (Hicks and Few 2015; Chester et al. 1999), and floods (Rufat et al. 2015; De Marchi and Scolobig 2012; Koks et al. 2015; Fekete 2009; Pelling 1997; Zhang and You 2014; Tapsell et al. 2002). Analyses of social vulnerability to floods are justified by the intrinsic characteristic of these natural phenomena: the likelihood of occurrence, the speed of onset, the potential damage, and the society's capacity to be prepared for and to cope with these events (Rufat et al. 2015).

The spatial identification and the inclusion of vulnerable people into the risk management planning process have been widely discussed and fostered in the Sendai Framework for Disaster Risk Reduction (Aitsi-Selmi et al. 2016). It emerged that it could enhance effective mitigation plans aimed at increasing social capacities (Dunning and Durden 2011) serving as a communication tool among all the actors involved in the disaster management framework, from academic communities to political, governmental, and humanitarian agencies (Eakin and Luers 2006). Having a prior recognition of a community's needs (Morrow 1999; Fernandez et al. 2016) and a mapped representation of the people that require extra consideration prior to, during, and after a flood might help the monitoring, forecasting, and assistance phases (Flanagan et al. 2011). As argued by Morrow (1999), maps are considered as ''low-tech'' technologies that can communicate the same message to different stakeholders, and that can be enriched with useful information (such as shelter places) and made readily available to the population. The geographic information system (GIS) as a tool for illustrating the spatial vulnerability to floods, has the advantage to monitor the results through time and space (Hebb and Mortsch 2007; Fedeski and Gwilliam 2007; Van Westen 2013). This advanced monitoring could be achieved by updating the vulnerable human indicators, supplementing updated hazard-related data, economic losses, and urban infrastructures, among others. In this way, politicians and public authorities could prioritize those areas that require specific management actions.

## 2. The study area physical environment and flood risk

The trend of floods within the European continent shows increasing numbers since the 1980s, mainly due to the constant rise of meteorological events (Munich Re 2012). Twenty-six major flood disasters were recorded between 2003 and 2009, mostly affecting Romania, the United Kingdom, and Italy (CRED EM-DAT 2015). Italy has been hit by several flood events since the late seventh century, where the oldest event, for which the number of casualties is recorded to be around 1000, occurred in in the year 671 in the Lombardia region (northern Italy) (Salvati et al. 2010). As reported by the authors in a systematic review from 671 to 2008, 2770 flood events have been recorded, with a total of 41 265 victims (encompassing deaths and missing and injured people). In the period 2009–14, 99 fatalities have been registered and more than 37 000 people have been displaced (IRPI-CNR 2014). In particular, the floodplain of northern Italy is an area where the high level of human activity, the ongoing concentration and sensitiveness of assets, and the increase of unequally exposed people (Alfieri et al. 2016) have magnified the damages caused by floods. Since the early 1860s, the floodplain of northern Italy has stood out by being the leading area in agricultural productivity. This has led to a need for a large labor force, generating the first significant immigration fluxes in the floodplain (Bonifazi and Heins 2011). After that, its landscape and environment have


FIG. 1. Floods have recurred in the floodplain of northern Italy: (a) 2000 flood in Piemonte region in the Po River basin (Angelini 2014), (b) Cresole Municipality (Province of Vicenza) hit by the All Saints flood in 2010 (Ribichini 2011), (c) 2014 Baganza flood in Parma (Olivetti 2014), and (d) 2014 Secchia flood in the Modena floodplain in the locality of Bastiglia (Solignani 2014).

seen numerous transformations, making it in recent times the most extensive populated area in Italy (Menichini 2005). Because of its geomorphic and topographic settings and the complex drainage system articulation, this floodplain presents numerous areas prone to flooding (Sofia et al. 2014; Sofia and Tarolli 2017; Sofia et al. 2017). Among the latest notable flood events, there is the 2000 inundation that occurred in Piemonte (13–16 October 2000) causing more than 40 000 homeless, 5 missing people, and 3 deaths (Fig. 1a). The Veneto region was involved in a large event in 2010 when 540 mm of rainfall in 24 h fell during the days around All Saints' Day. This flood caused 200 000 dead animals, 500 000 displaced people, 140 $km^2$ of inundated surface, and over a billion euros worth of damages (Fig. 1b). In June 2011, the Province of Parma (Emilia-Romagna region) was hit by a dramatic flood causing more than 7.5 M euros of damages (including private, public, and industrial properties), with more than 185 families displaced (Fig. 1c). Recently, in 2014, a flood in the province of Modena covered a land area of 75 $km^2$ with water, causing 1000 evacuations and one victim (Fig. 1d).

According to its physical environment and the high flood risk exposure, there is a need to develop a GIS-based multicriteria evaluation framework for the identification of potential vulnerable people. In accordance, this work proposes a social vulnerability analysis at a municipality level by the use of the Social Vulnerability Index (SoVI). This methodology has been adapted to this study case according to the societal and historical construction of the area. In a second stage, this research offers a spatial identification of the areas that might be highly exposed to flood risk by a combination analysis of the SoVI scores and recent flood hazard data. The chosen area could seem relatively small. However, the municipalities included represent 34% of all the municipalities in Italy. In general, a larger scale would have hidden details regarding local differences that are important in tracking the vulnerability of people. According to the way the SoVI responds to some social constraints, it is easier to address the needs of people for the management of floods. The results and lessons offered by this case study could be compared to countries with the same social, cultural, geomorphological,

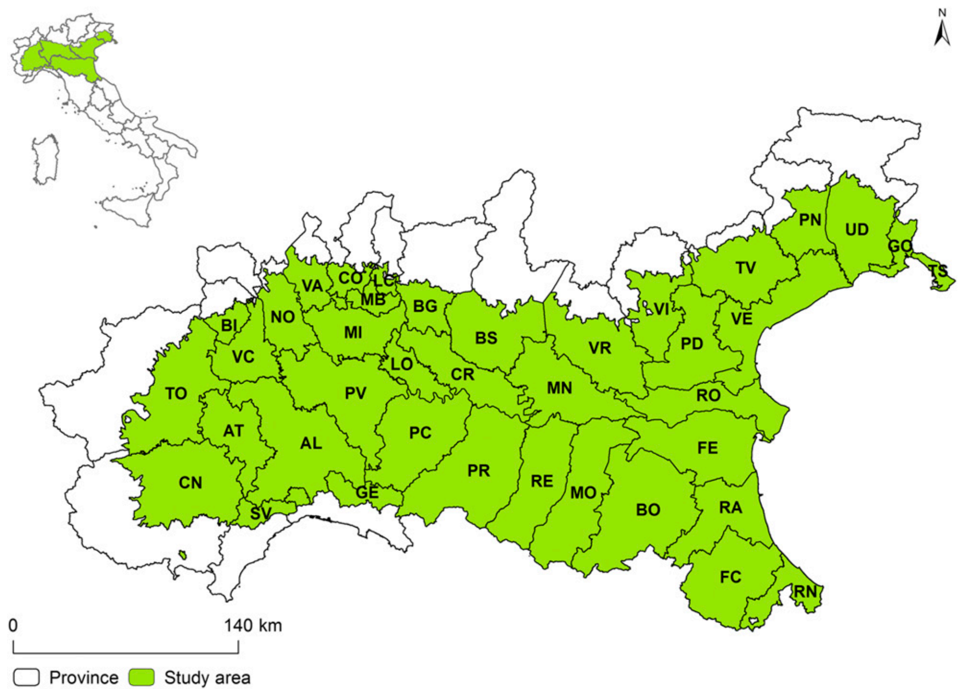


FIG. 2. Map of the study area and abbreviation of the provinces (regions of which each province is composed are shown in italics): *Piemonte,* CN (Cuneo), TO (Torino), BI (Biella), VC (Vercelli), AT (Asti), AL (Alessandria), and NO (Novara); *Liguria,* SV (Savona), GE (Genova); *Lombardia*, PV (Pavia), MI (Milano), VA (Varese), CO (Como), LC (Lecco), MB (Monza-Brianza), LO (Lodi), CR (Cremona), Bergamo (BG), and Brescia (BS); *Emilia-Romagna*, PC (Piacenza), PR (Parma), RE (Reggio nell'Emilia), MO (Modena), BO (Bologna), FE (Ferrara), RA (Ravenna), FC (Forlì-Cesena), and RN (Rimini); *Veneto*, VR (Verona), VI (Vicenza), TV (Treviso), PD (Padova), RO (Rovigo), and VE (Venezia); *Friuli-Venezia Giulia*, PN (Pordenone), UD (Udine), GO (Gorizia), and TS (Trieste). Top left picture shows the regional subdivision of Italy where the study area (green area) is located.

and environmental settings, giving the basis for practical management guidelines.

## 3. Materials and method

The area considered for the study is bounded on the north by the Alpine mountain range, on the south by the Po River and by the Upper Apennine range, and on the east by the Adriatic Sea to which it declines gradually. It covers an extent of approximately 67 700 $km^2$, including 2772 municipalities, distributed in 38 provinces and 6 regions (Fig. 2). Similar to the Great Hungarian Plain (Carpathian basin) and the Rhine-Meuse Delta (Netherlands), it represents one of the largest alluvial environments of Europe (Fontana 2012).

### *a. Data*

The data used for the assessment of the social vulnerability analysis to floods are census data, while for the risk evaluation we used recent flood hazard data. Census data have been extrapolated from the Italian national census database of ISTAT (National Institute of Statistics) and the income data provided by the Ministry of Economy and Finance (Ministero dell'Economia e della Finanza 2011) for the 2011 timeframe. As already noted, many indicators are responsible for increasing (or decreasing) the social vulnerability of people. Those selected for this study are based on the work conducted by Cutter et al. (2003) and consequently readapted, including and excluding some variables according to data availability and the construction of northern Italy society. As Burton (2015) argued, it is important to focus on a single dimension of the social vulnerability to highlight a particular context under flood hazard. For this reason, we considered only socioeconomic and demographic variables excluding housing characteristics, critical infrastructures, awareness, and coping capacities. For the purpose, 15 variables have been selected, as shown in Table 1.

Flood hazard data (updated in May 2015) (Fig. 3) were provided by ISPRA (Istituto Superiore per la Protezione e la Ricerca Ambientale; Trigila et al. 2015) and given by a three-class flood probability distribution [see the guidelines proposed by Ministero dell'Ambiente e della Tutela del Territorio e del Mare (2013)] (Table 2).

Table 1. Indicators that may influence the vulnerability of people in the area under study. All the data have been collected at a municipality scale for the year 2011, except the population growth variable that is derived from the decade 2001–11. Total number of municipalities $N = 2772$. Mean ($M$) and standard deviation (SD) are also shown.

| Indicator | Description | Variable name | $M$ | SD |
|---|---|---|---|---|
| Socio-economic status | Percentage of housing units without basic sanitation installations | NOBASICSANITATION | 0.7 | 0.8 |
| | Percentage of rent houses at family unit | RENTHOUSE | 13.4 | 5.3 |
| Gender | Percentage of female | FEMALE | 50.6 | 1.8 |
| Ethnicity | Percentage of no native people | NON-NATIVE | 8.1 | 4.0 |
| Age | Percentage of dependent people (<4 and >85 years old) | AGEDEPENDENT | 7.8 | 1.3 |
| Education | Percentage of illiterate people | ILLITERATE | 0.5 | 0.4 |
| | Percentage of people with less than 8 years of education | EIGHTYEARSEDU | 13.2 | 2.4 |
| Employment | Percentage of unemployed people | UNEMPLOYED | 3.4 | 1.1 |
| | Percentage of retired people | RETIRED | 27.2 | 6.3 |
| | Percentage of active people involved in the agriculture sector | EMPLOAGRICULTURE | 3.5 | 3.3 |
| Family structure | Percentage of single parents (both female and male headed) | SINGLEPARENT | 7.8 | 7.1 |
| | Percentage of family with more than six members | MORESIXMEMBERS | 1.3 | 0.8 |
| Population consistency | Population growth index | POPGROWTHINDEX | 0.1 | 0.1 |
| Income | Mean annual income per single inhabitant | INCOME | 13054 | 2012 |
| Special needs people | Percentage of people living in assistance institute | NEEDASSISTANCE | 0.8 | 1.9 |

### b. Methodology

The social vulnerability was assessed by using the Social Vulnerability Index, developed in 2003 to underline the social vulnerability to environmental hazards among U.S. counties (Cutter et al. 2003). This index provides a social vulnerability map by synthesizing socioeconomic and demographic factors through principal component analysis (PCA) [see Dunteman (1989) for further details]. For assessing the SoVI (Fig. 4), the variables have been collected and normalized according to a $z$-score normalization (mean of zero and a standard

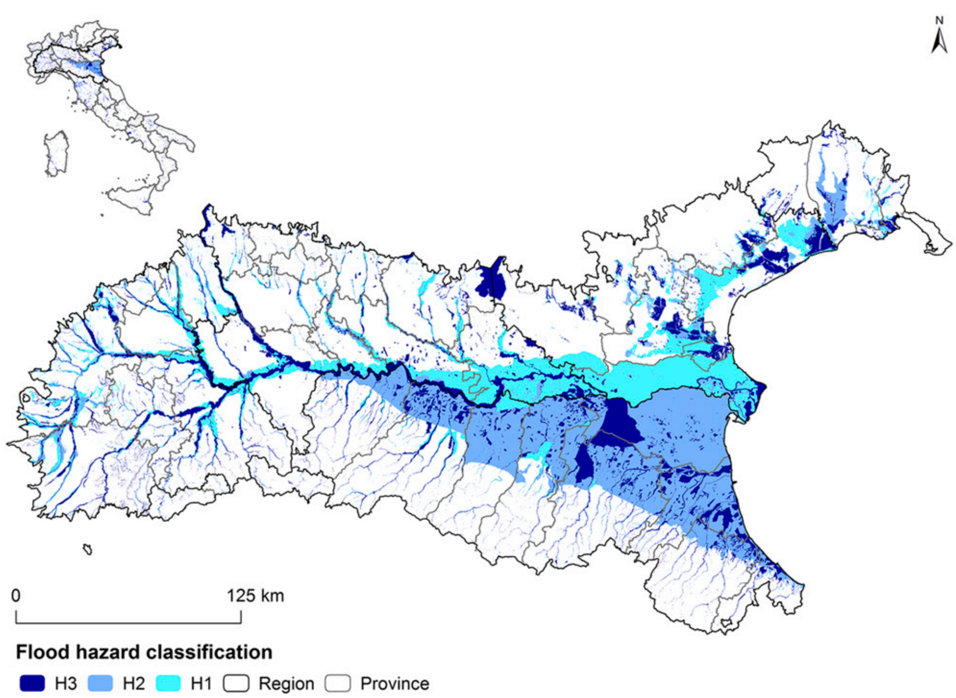


Fig. 3. Flood hazard map of the study area; H3 stands for high, H2 for moderate, and H1 for low hazard probability. Top left picture shows the flood hazard map for the whole Italian territory. Own elaboration from ISPRA (2015) and Trigila et al. (2015).

TABLE 2. Definition of the Italian flood hazard classification. Flood hazard areas in the floodplain of northern Italy and the Italian territory are shown in $km^2$. In brackets, the percentage of the flood hazard layers with respect to the whole study area surface is shown. National level data come from ISPRA (2015) and Trigila et al. (2015).

| Flood hazard classification | Definition | Study area ($km^2$) | National level ($km^2$) | % |
|---|---|---|---|---|
| High (H3) | High floods occurrence. Return period of 20–50 yr | 6306 (9.3) | 12218 | 51.6 |
| Moderate (H2) | Moderate floods occurrence. Return period of 100–200 yr | 15477 (22.9) | 24411 | 63.4 |
| Low (H1) | Low floods occurrence/extreme floods | 19443 (28.7) | 32150 | 60.5 |

deviation of one). To avoid interference between the variables, we performed a multicollinearity analysis. After recognizing that no variables were predictors of one other, a PCA was conducted with varimax rotation and a Kaiser criterion for component selection (with eigenvalues greater than 1). The resulting Bartlett's sphericity test showed a highly significant value ($p < 0.000$), demonstrating that the data were appropriate for further analysis. The selection of the components was determined by looking at the latent variables and at the resulting scree plot (Fig. 5). The figure displays eigenvalues in descending order ($y$ axis) opposed to the number of the components ($x$ axis) to assess which components explain the most of the variability of the data. According to the SoVI approach, to understand the meaning of the generated components, variables are significant only if they present a correlation value higher than 0.5 or lower than $-0.5$. According to Guillard-Gonçalves et al. (2015), these variables are called ''drivers of the component.'' Before summing the social vulnerability scores, the variables were aligned, implying that positive or negative directionalities were attributed matching the potential positive or negative contribution to the vulnerability. According to the procedure for weighing the factors, the literature encounters a crossroad with different approaches. Authors such as Cutter et al. (2003), Fekete (2009), and Chen et al. (2013) used equal weighting since they assumed that no factor is more important than another. A weighting method based on the contribution of the total variance explained has been undertaken by Schmidtlein et al. (2008) and Wood et al. (2010), for example. The Pareto rankings method orders the cases on multiple criteria, but this approach is less common for social vulnerability analysis (e.g., Rygel et al. 2006). Notably there is no appropriate methodology for the calculation of the index; therefore, it remains to the authors' discretion. Considering the original approach, the output of the PCA, and the study area characteristics, we equally weighted the components. The mapped social vulnerability is then divided using Jenks natural breaks classes because this optimization method seeks to reduce the variance within classes, maximizing it between them (Jenks 1967). A three-level classification was chosen, first because it can better detect the differences between the classes in a visual way (without using intermediate

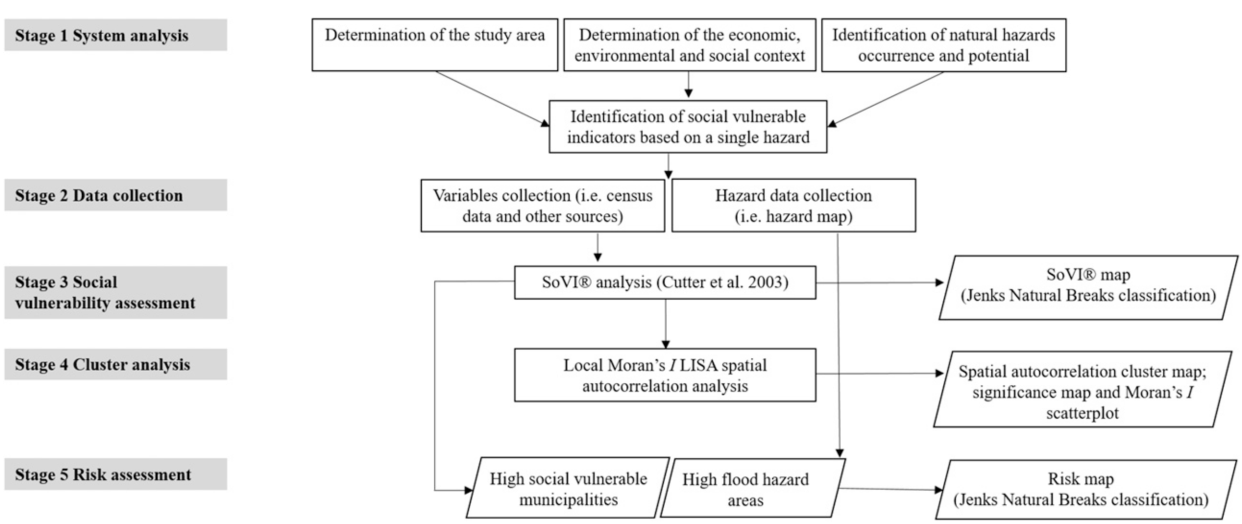


FIG. 4. Visual representation of the methodology for the assessment of the Social Vulnerability Index, and the flood risk assessment in the floodplain of northern Italy. Squares represent processes, while outputs are bordered by rhombuses.

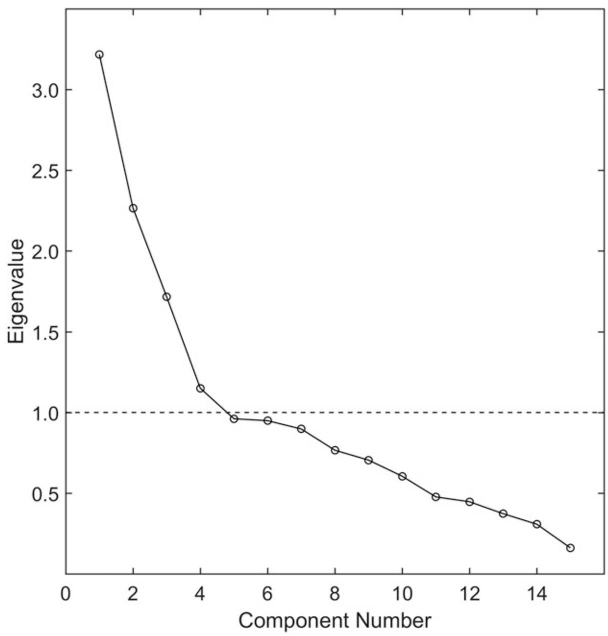


FIG. 5. Scree plot of the principal component analysis showing the eigenvalues explained by the resulting components. The threshold line set at 1 shows the explanatory components extracted from the PCA.

levels of medium-low and medium-high), enhancing a quicker interpretation for nonexpert users, and second for consistency with the flood hazard classification, which is also based on three classes.

To identify the spatial aggregation of the social vulnerability, we performed a local spatial autocorrelation with Moran's $I$ with the GeoDa 1.8.14 software. This computes a measure of spatial association for each location, giving an indication of the extent of significant spatial clustering of similar values around that observation (Anselin 1995). A spatial weight file was created to analyze the neighborhood structure of each location. For this purpose, we applied a rook contiguity method, which provides a more rigid contiguity definition (Anselin 2005) and is the most used in spatial autocorrelation analysis (Corrado and Fingleton 2012; Zhou et al. 2016; Fang et al. 2006; Frigerio and De Amicis 2016). A map showing locations with significant local Moran statistics, classified by types of spatial correlation, is defined as a LISA (local indicators of spatial autocorrelation) cluster map (Anselin 1995). Five scenarios emerge: significant ($p$ value $< 0.05$) concentrations of 1) high values (high–high) or ''hot spots'', 2) low values (low–low) or ''cold spots'', spatial outliers 3) low–high and 4) high–low, and 5) locations of no significant spatial autocorrelation ($p$ value $> 0.05$). The same setup is easily detected from a Moran's scatterplot that shows observed values ($x$ axis) against the averaged value of their neighbors ($y$ axis). A significant test was performed through the permutation test set to 999, under a random distribution with a significance level threshold of 0.05.

## 4. Results

### *a. The Social Vulnerability Index*

The Social Vulnerability Index has been computed according to 12 variables extrapolated from the PCA explained by four components with adjusted directionality (Table 3). Each factor contributed differently to the score of the index, according to the following formula: SoVI = factor 1 − factor 2 + factor 3 + factor 4. Three variables, corresponding to the percentage of ''low educated'' people (those with less than eight years of education and those illiterate) and age-dependent individuals, have not been extracted from the rotation matrix as a result of their low correlation value ($<0.5$ or $>-0.5$). The SoVI scores ranged from −23.21 (lowest social vulnerability value) to 24.19 (highest social vulnerability value) with an average of 0.00 and a standard deviation of 3.55 (Fig. 6). Note 22% of the total municipalities contribute to the high vulnerability of the study area, followed by 25% with a medium contribution, while the remaining 53% are considered as low contributors (Table 4). The Piemonte and Lombardia regions are the highest contributors to the high vulnerability of the study area, with respectively around 62% and 18% of highly vulnerable municipalities over the highest. Following, in decreasing order, are Veneto (7%), Emilia-Romagna (7%), Liguria (4%), and Friuli-Venezia Giulia (2%). These data do not reflect the variability within each region as expressed in Table 4. Overall, two regions (Veneto and Liguria) suffer from an underestimation of the SoVI computation that needs to be proper underlined. The Veneto region is ranked only at the third position of the most vulnerable locations. This is mainly due to the exclusion of the low educated people variable from the principal component analysis. This region, in fact, has higher mean values respect the average, considering the whole study area. Similarly, Liguria registers 78.8% of the high vulnerable scores among its area. In fact, it suffers from the exclusion of age-dependent variable. According to SISTAN (2015), Liguria has the highest ageing index[1] with a rate of 238 elderly people (aged 65 and over) per 100 young people (persons under 14). The birth rate began to decline in the nineteenth century (Castagnaro and Cagiano

[1] Demographic variable that provides an index of the age of the population; it is computed by dividing the number of people over 65 by those less than 14 years old (ISTAT 2011).

TABLE 3. Predictor variables (or factors) affecting vulnerability extracted from the principal component analysis with varimax rotation. Sign adjustment, loading variance of each component, and the cumulative variance explained are shown. Correlation numbers are shown within brackets.

| Factor | Sign adjustment | Dominant variables | Variance explained (%) | Cumulative variance (%) |
|---|---|---|---|---|
| Population consistency | + | RETIRED (0.84), NOBASICSANITATION (0.77), POPGROWTHINDEX (−0.71) | 21.5 | 21.5 |
| Economic status and ethnicity | − | INCOME (−0.75), MORESIXMEMBERS (0.71), NON-NATIVE (0.65), EMPLOAGRICULTURE (0.54) | 15.1 | 36.6 |
| Family structure and employment | + | SINGLEPARENT (0.71), UNEMPLOYED (0.62), RENTHOUSE (0.51) | 11.4 | 48.0 |
| Gender and special needs people | + | NEEDASSISTANCE (0.70), FEMALE (0.57) | 7.7 | 55.7 |

de Azevedo 2013); by the early 1950s, the average number of children per woman had fallen to 1.4, well below the national average level of 2.3.

Concerning the spatial location of vulnerable areas (Fig. 7), high–high (HH) municipalities (municipalities with high values of social vulnerability surrounded by similar features) represent 15.7% of all municipalities (Table 5). The main HH clusters are concentrated in the western part of Po River basin, and in the east near its outlet. The Po River basin is characterized by very high indexes of population growth (one-third of the Italian population lives in this area; Mosello 2015) and human activity (Giuliano 1995; Marchina et al. 2015). Similarly, the economic growth, given by the development of the industrial, zootechnical, and agricultural sectors, resulted in a gross domestic product of 40% the national income (Marchina et al. 2015). This anthropogenic footprint has dramatically modified the natural and the

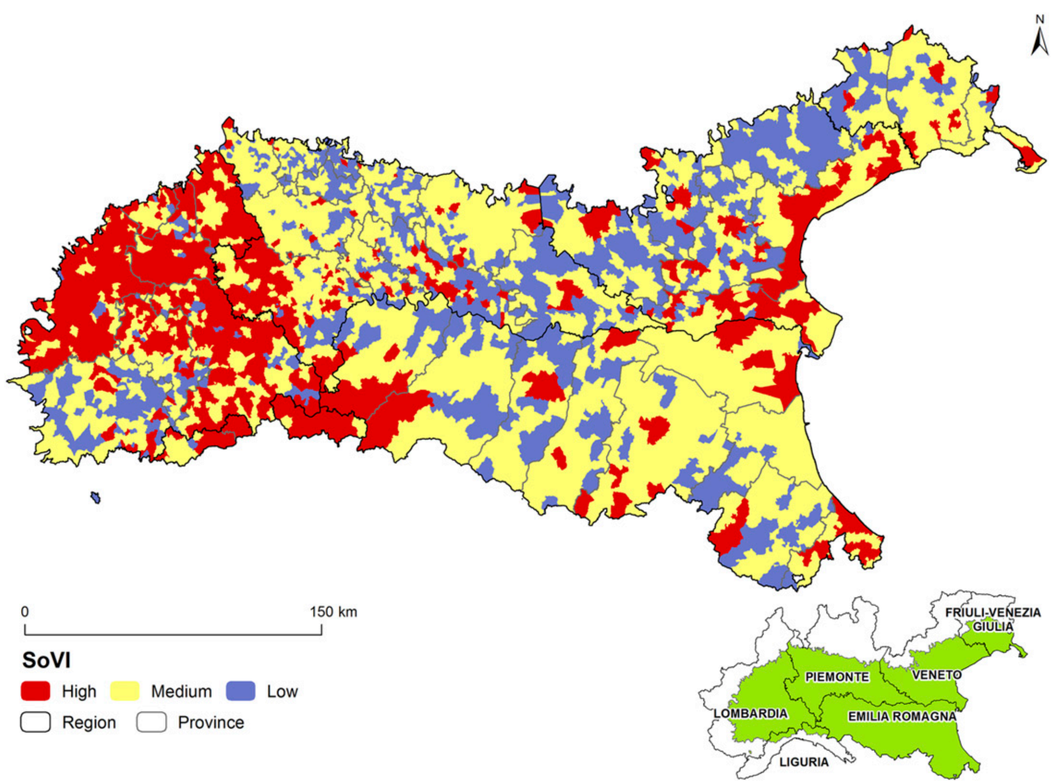


FIG. 6. Spatial distribution of the Social Vulnerability Index among the municipalities of the northern Italy floodplain classified into a three Jenks natural breaks classification. The lower right picture refers to the regional boundaries of the study area.

TABLE 4. SoVI classification (high, medium, and low) within the study area and among the six regions expressed by the number of municipalities; percentages are shown in parentheses.

| SoVI | Floodplain Northern Italy | Emilia-Romagna | Friuli-Venezia Giulia | Liguria | Lombardia | Piemonte | Veneto |
|---|---|---|---|---|---|---|---|
| High | 612 (22.1) | 44 (12.9) | 11 (7.7) | 26 (78.8) | 111 (10.7) | 379 (47.6) | 41 (9.6) |
| Medium | 704 (25.4) | 92 (204) | 47 (33.1) | 5 (15.2) | 281 (27.2) | 184 (23.1) | 95 (22.2) |
| Low | 1456 (52.5) | 204 (60.0) | 84 (59.2) | 2 (6.1) | 642 (62.1) | 233 (29.3) | 291 (68.1) |
| Total | 2772 (100) | 340 (100) | 142 (100) | 33 (100) | 1034 (100) | 796 (100) | 427 (100) |

geological environment of the basin (Carminati and Martinelli 2002) so that it has been estimated an unyielding increase of exceptional river discharge (Dankers and Feyen 2008).

Conversely, low–low clusters denoting a low social vulnerability (11.5% of all the municipalities) are spotted in all the considered regions, without any particular grouping. Spatial significance outliers of low–high and high–low areas are respectively represented by 66 and 58 municipalities (2.3% and 2.1%) as shown in Table 5 and Fig. 7a. A Moran scatterplot (Fig. 7b) illustrates the value of the original variable (percent of the index score in the tract) on the horizontal axis (standardized incidence) and the spatial standardized lag of the variable (average percent of SoVI scores in the tract's neighbors) on the vertical axis. The graph is divided into four quadrants indicating positive and negative spatial autocorrelations, and the slope of the regression line is

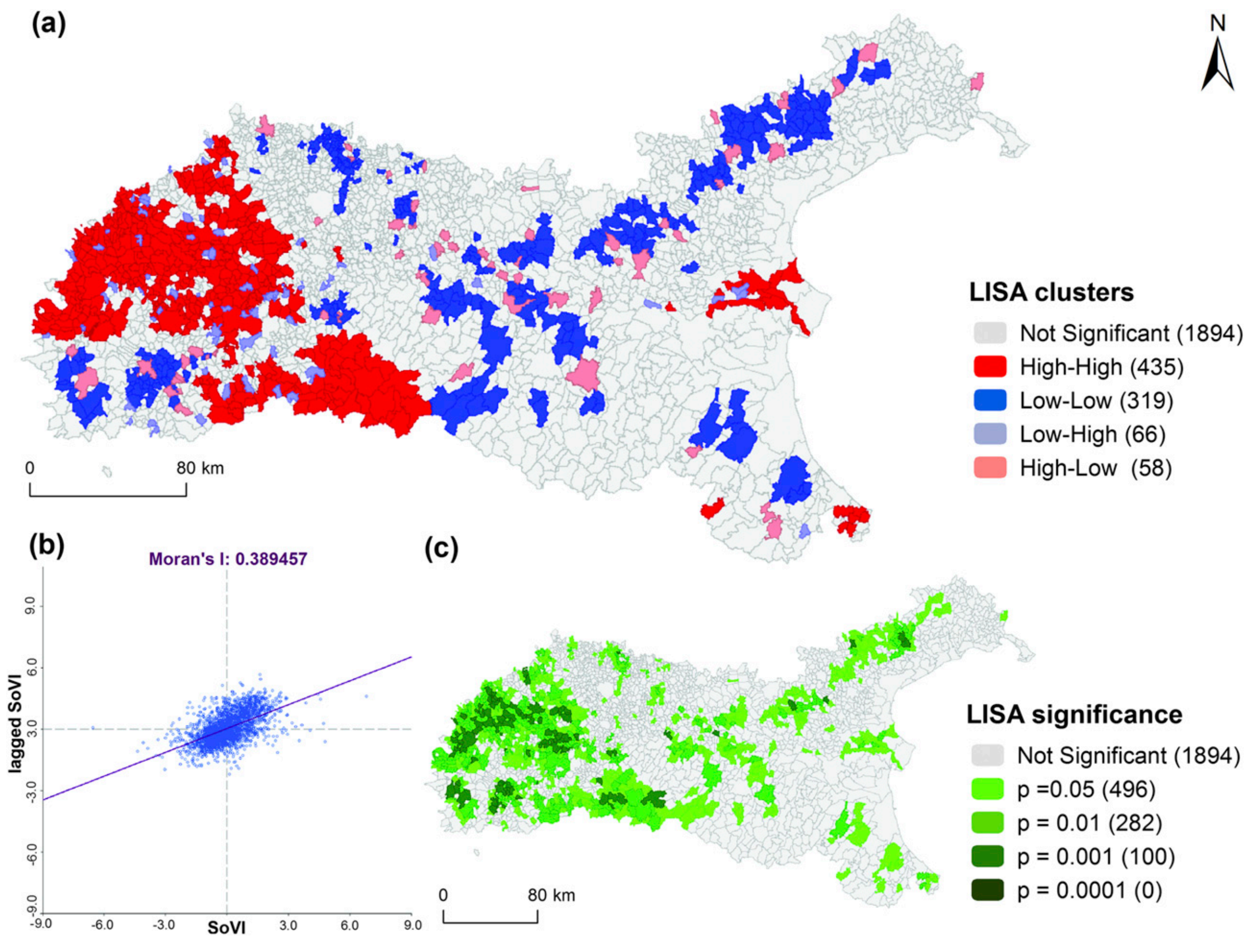


FIG. 7. Local indicators of spatial autocorrelation (a) cluster map and (c) significance map. (b) The Moran's scatterplot shows the standardized values of the variable on the $x$ axis whereas the vertical axis shows the standardized spatially lagged variable. The plot is divided into four quadrants in accordance with the four scenarios emerged from the LISA clustering. The slope of the regression line is the Moran's $I$ that identifies a positive spatial correlation.

TABLE 5. LISA cluster categories for the SoVI expressed by the number of municipalities and the percentage in accordance. Moran's $I$ spatial statistic is also shown.

| | No. of municipalities | % |
|---|---|---|
| Significant local spatial clusters and outliers | | |
| High–high | 435 | 15.7 |
| Low–low | 319 | 11.5 |
| Low–high | 66 | 2.4 |
| High–low | 58 | 2.1 |
| Not significant spatial clusters | 1894 | 68.3 |
| Total | 2772 | 100 |
| Moran's $I$ value | 0.389 457 | |

Significance threshold is set at $p = 0.05$

approximately 0.39, indicating that the spatial distribution has a positive correlation.[2]

### b. The SoVI components and their local geography

The first component, "population consistency," explains three variables with a cumulative variance of 21.5%. A total of 140 municipalities present high social vulnerability, and they cover 5% of the entire study area. The Piemonte region, with 109 municipalities, is the greater contributor to the high social susceptibility of this component, followed by the Liguria region with 45% of its municipalities at risk (Fig. 8). The main drivers considered are the percentage of retired people, households with no basic sanitation facilities, and population growth. In Italy, the progressive increase in the average lifespan implies a higher payment for retired people for a longer time, while contribution revenue has decreased due to the slowdown in the economic growth. Since retired people receive lower income, their financial security puts them at higher risks when facing a possible disaster situation (McKay et al. 1998). The ageing of the population, with the gradual retirement of people expected in the coming years, will result in both a reduction in the workforce and an increase of labor inactivity. According to Eurostat in 2013, Italy ranked the first according to median age and number of elders (both >65 and >85 years old) within Europe (Morcaldo 2007). Generally speaking, physiological status is a key factor in the ability of persons in responding to a disaster (IPCC 2012). Elders are likely to be disproportionately vulnerable to floods because they might have different physical and functional limitations, illnesses, and imbalances in the sensorial sphere than younger people (Lowe et al. 2013). In addition, they might no longer have children at home, and they might be isolated from their relatives, thus having as a consequence a progressive decline in their networks. Liguria has a high number of retired people (37.6%) compared to other regions and to the floodplain average (27.2%). A similar finding can be observed for the lack of basic sanitations (3.2% against the average area with 0.7%). Households living without toilet installations or bath/shower facilities in Italy represent a very small proportion of families (Vitaletti 2010) but they may reflect poor economic conditions [see, e.g., Guillard-Gonçalves et al. (2015) on Portugal]. The related poor sanitation conditions (including lack of safe water and toilet facilities) can increase the risks derived from floods (INFOSAN 2005). The population growth variable reflects the increase in population from 2001 to 2011 (year of the latest census). It is agreed that population growth, composition, and distribution are among the main factors for increasing risks from floods, since they translate into a demand for built-up areas (Marfai et al. 2015) with a massive pressure on sewer systems near rivers (Alfieri et al. 2016) and in urban centers (Walker et al. 2009). This rapid phenomenon in some parts of the world has resulted in illegal and squatting constructions (Hung et al. 2007), contributing to present-day flood high occurrence (Sofia et al. 2017; Sofia et al. 2014; Tarolli 2016; Tarolli and Sofia 2016).

The second component, "economic status and ethnicity," is explained by four variables with a variance of 15.1% (cumulative variance 36.6%). The drivers of the component are income, families with more than six members, nonnative people, and people working in the agriculture sector. While the highest amount of economic damage is often observed for people owning high-value possessions, the major consequences of floods are generally carried by less wealthy individuals (Hajat et al. 2005; Henry et al. 2015). Zahran et al. (2008) found that income, especially for unprivileged people, is a significant factor predicting higher physical injuries from flooding, as well as psychological and emotional distress (Biswas et al. 2010). On the opposite, wealthier people are more disposed to invest for their protection and their economic stability can ensure proper recovery/reconstruction phases (Kousky 2011). The Veneto region stands out for having the lowest average annual income per inhabitant (with a mean value of 11 909 euros, compared to an average value of 13 054 euros for the whole floodplain). This trend could be ascribed to the presence of people who are not economically independent. Education is linked to socioeconomic status since a higher educational status often results in greater lifetime earnings and more highly skilled job (Braun and Aßheuer 2011).

Ethnic minorities, most of the time, live in unfavorable living conditions with lower income (Fullin and

[2] Moran's $I < 0$ indicates negative spatial correlation distribution and Moran's $I = 0$ indicates a spatially random distribution.

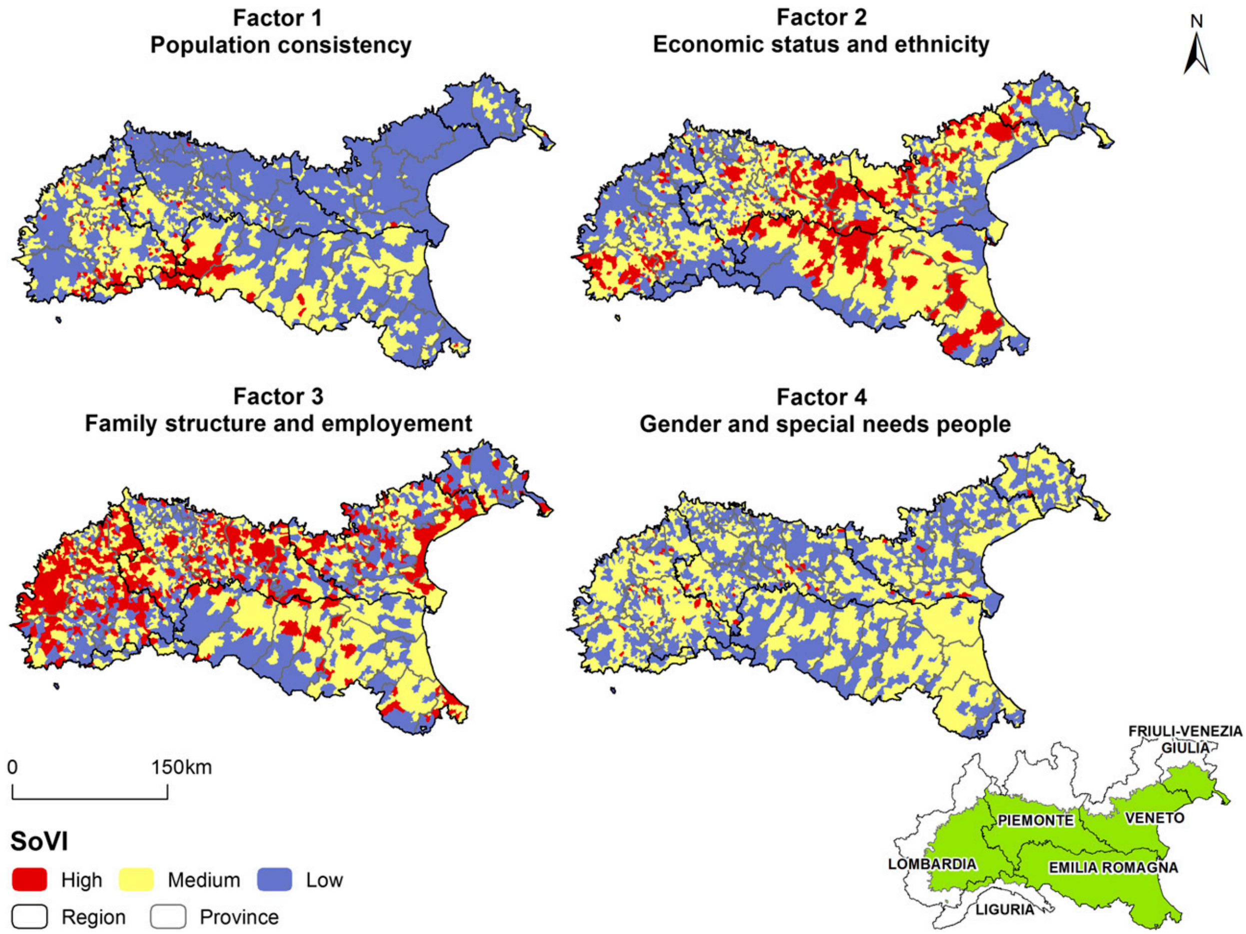


FIG. 8. SoVI maps of the four factors derived from the PCA analysis across the of northern Italy floodplain. The bottom right picture refers to the regional boundaries of the study area.

Reyneri 2011), poorer education, and fewer employment opportunities (Fothergill 1999; Gencer 2013). Thus, it is reasonable that people living in their nonnative place are prone to a higher danger. The lack of language proficiency, in some cases, puts people at some disadvantage when they look for risk information (Morrow 1999) or early warning signals. The combination of these attributes may lead to difficulties even in the relief phase of the disaster when applying economic aid or insurance (Donner and Rodríguez 2008). The United States is the leading country in giving importance to ethnic/race differences in the disaster context. However, second only to Spain, Italy is the European country that has seen the most considerable immigration fluxes in the past 15 years (Fullin and Reyneri 2011), with a particular focus in the northern Italy. According to the trends registered in the Italian peninsula by ISTAT census track, the share of foreign citizens among total residents has seen a continuous increase since the early 1970s. During the twenty-first century the foreign population has grown exponentially from 1.3 M in 2000 to 4.2 M in 2010, unevenly distributed within the country: a higher percentage live in the northern and central areas (9.9% northwest, 10.3% northeast, and 9.6% center) and just 3.1% in the southern area and 2.7% on the islands. Among them, women may bear the largest effects of disasters. Those coming for family reunification may have intensified their vulnerability given their economic dependency on the husband's income. In fact, it has been reported that they can suffered from high difficulty in finding a job, with higher unemployment rates with respect to their male counterparts (Reyneri 2007). Women moving for a job found more often positions as in-home nurses or housekeepers. They consequently might face some obstacles in cases of flood evacuation or management due to linguistic barriers. Similarly, families with a large number of members might find the same impediments. Despite a significant decrease in the number of large families in Italy, from 3.35% in 2000 to 2.40% in 2011, a big family might reflect greater strains on the distribution of household resources for ex-post flood events (De Silva and Jayathilaka 2014). Lombardia stands out for its numbers of nonnative people, approaching 23.5% of the total according to the latest census. According to Blangiardo (2014), the number of foreign residents in Lombardia region is projected to increase by 0.9% for 2020 and 3.3% for 2035.

The category of people that suffer the most after the consequence of flood events is people who are highly dependent on the environment (Tiraboschi 2014). Farmers are generally the poorest category (Saldaña-Zorrilla 2008) since any flood event might reduce future farm productivity by altering the chemical structure of the soil (Israel and Briones 2013). According to Coldiretti (2014), the agricultural production of many Italian farmers is estimated to be in the magnitude of 22 billion of euros for the last 20 years. Thus the potential damage caused by flood events is dramatic, especially for Piemonte, which accounts for the highest number of farms in Italy (ISTAT 2011). This could be the reason for the high vulnerability of this component in this area (36% of high vulnerable municipalities, among the highest). Also, it should be added that in some recent alluvial events occurring in northern Italy agricultural fields have been deliberated flooded to protect houses and buildings.

The third variable, ''family structure and unemployment,'' reflects 11.4% of the variance with a cumulative variance of 48%. The drivers are single-parent household, unemployed people, and rent tenure of the house. Single-parent families might suffer a greater stressful pressure than two-parent units in the wake of flood events (Flax et al. 2002). This could be ascribable to their economic and social responsibilities and limited support (López-Marrero 2008). According to Nyakundi et al. (2010), for the Nyando District of southern Kenya, female-headed households were generally perceived to be more vulnerable to floods as compared to households with both spouses. This could be explained by the fact that two-parent households are better placed both financially and psychologically and thus might be able to respond to flood risks in a better mental and emotional state. In Italy, the structure of families has undergone several changes, shifting from traditional large families to so-called single individual units. From 1971 the number of these households increased from 12.9% to 31.2%, constituting around 1/3 of the families at the national level (ISTAT 2011). This is a consequence of several social and demographic dynamics that have occurred during the recent decades, including the gradual increases of the ageing index, the increase in legal separation and divorces, and the number of foreign citizens who live alone when the first arrive.

Unemployed people are vulnerable to floods because of inadequate financial resources to overcome the economic losses after a disaster (Jacinto et al. 2015). A higher rate of unemployment in a society may translate in a significant ex-post economic aid from the government, which needs to move vast quantities of resources to help the poorest. In 2011 in the northeast of Italy, the unemployment rate was 37% higher than national level; Friuli-Venezia Giulia was one of the highest regions (48%), followed by Veneto (Porcellato 2011). These data justify the high vulnerability of these two regions expressed in Fig. 8. The unemployment could be the result of the severe labor market distress starting in 2009 (De Belvis et al. 2012) that showed a dramatic fall of gross domestic product. The subjects who were most severely affected were young people (especially females) and low skilled workers (Fullin and Reyneri 2011).

People with lower economic welfare are more likely to rent their homes, thus increasing the threat from natural hazards (Fernandez et al. 2016). Fekete (2009) suggests that a lower income may translate in difficulty in accessing to financial aid in the recovery process. Tenants might face some impediments in taking direct actions to protect their property given the terms of their contracts (Tapsell et al. 2002). The Friuli-Venezia Giulia, Lombardia, and Piemonte regions (with 20% of the total municipalities) showed higher proportions of tenants compared to homeowners with respect to the study area average (Fig. 8).

The last factor, ''gender and special needs people,'' contributes 7.7% to the overall variance explained. The drivers included gender and special needs people. People living in assistance or care institutes encounter some impediments in the access and the use of those resources necessary in pre- and postdisaster stages (McGuire et al. 2007). People with physical or medical dependency might encounter higher injury and mortality (Smith and Notaro 2009; UNISDR 2014), difficulty in evacuating (Uscher-Pines et al. 2009), and difficulty in finding specially equipped shelters for the provision of their needs (Risoe et al. 2013). Furthermore, failing to include in risk planning the needs of people with medical dependencies might increase their lack of preparedness, putting them in higher jeopardy (Risoe et al. 2013). The gender contributor exerts a powerful influence within the disaster context, and an extensive literature exists in this respect [see Fothergill (1996) for further details]. Even though women are increasing power in many communities with larger independence and personal capacities (De Marchi and Scolobig 2012), they may still face impediments during and after emergency situations. In Italy, in the last

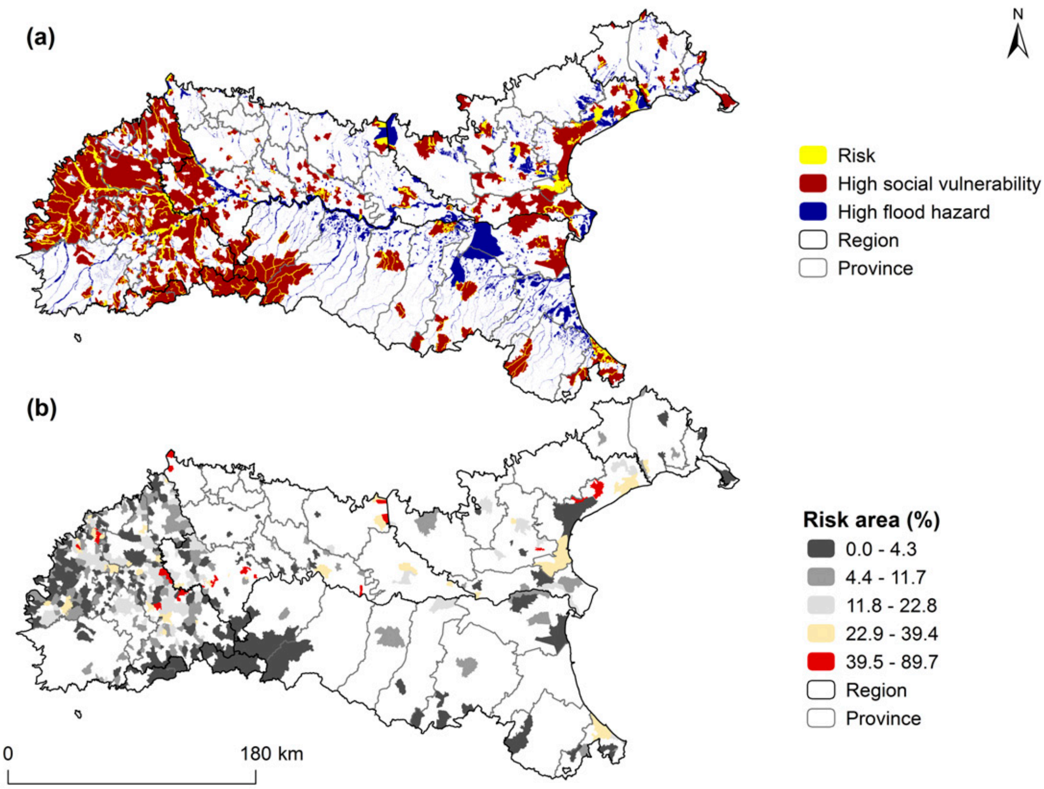


FIG. 9. (a) Risk map (yellow area) derived by clipping the high socially vulnerable municipalities and the high hazard (H3) flood layer. (b) Risk map expressing the percentage of risk for each municipality represented using a five Jenks natural breaks classification. The bottom right picture refers to the regional boundaries of the study area.

40 years, the role of women in the employment sector has dramatically changed. The country has been characterized by a large amount of women involved in housekeeping from early 1964, representing twofold with respect to other type of workers (e.g., in the industry, agriculture, and tertiary sectors) (Novelli 1996). Although housekeeping has gradually been abandoned, the actual situation demonstrates that women have the lowest workforce participation in the labor market compared to other developed countries (Bernardi 2004). One of the main reasons is the low coverage of protection for maternity leave, and the related consequences of this lack of social support (Sargeant 2014). As estimated by Enarson (2000), women are employed mostly in jobs belonging to the informal economy such as domestic, microenterprise, and other forms of precarious engagement, putting them at a higher risk of losing both their house and their economic activity at the same time. In addition, their low perceived preparedness with respect their male counterparts, as underlined in several research papers in northern Italy (De Marchi et al. 2007; Miceli et al. 2008; Scolobig et al. 2012), justifies the presence of women as a variable contributing to the social vulnerability of the study area. This factor has 2% of high vulnerable municipalities, including the regions of Piemonte and Lombardia with respectively 33 and 22 highly vulnerable municipalities (Fig. 8).

### c. *A combination of social vulnerability and flood hazard*

One of the main outcomes deriving from social vulnerability maps might be the assessment of ''social'' risk, as an interaction of the highest hazard scenario with the high vulnerability of the human environment. The combination of these types of visual assessment could be a further step to enable authorities to target risk reduction initiatives in a more focused way. For this reason, the highest socially vulnerable areas (red municipalities of Fig. 6) have been shown together with the high flood hazard layer (defined as H3 in Fig. 3), showing the resulting flood risk (yellow areas of Fig. 9a). Clearly, the flood hazard area does not perfectly overlap with the area of the municipality, and thus the resulting risk might not affect the entire municipality but only a variable amount. For this reason,

TABLE 6. Jenks natural breaks classification of risk for each region and the total study area. The numbers correspond to the absolute number of municipalities included in each class (where 1 correspond to the lowest percentage of risk and 5 the highest); the percentage values are shown within brackets. Total values displayed in the last column consider each single region, whereas the total displayed in the row considers the contribution of each class to the floodplain.

| | Jenks natural breaks classification of risk | | | | | |
|---|---|---|---|---|---|---|
| | Class 1 (0.0–4.3) | Class 2 (4.4–11.7) | Class 3 (11.8–22.8) | Class 4 (22.9–39.4) | Class 5 (39.5–89.7) | Total |
| Emilia-Romagna | 30 (73.2) | 9 (22.0) | 2 (4.9) | 0 (0.0) | 0 (0.0) | 41 (100) |
| Friuli-Venezia Giulia | 4 (44.4) | 4 (44.4) | 0 (0.0) | 1 (11.1) | 0 (0.0) | 9 (100) |
| Liguria | 23 (88.5) | 1 (3.8) | 0 (0.0) | 2 (7.7) | 0 (0.0) | 26 (100) |
| Lombardia | 35 (43.8) | 12 (15.0) | 14 (17.5) | 9 (11.3) | 10 (12.5) | 80 (100) |
| Piemonte | 133 (40.5) | 95 (29.0) | 67 (20.4) | 24 (7.3) | 9 (2.7) | 328 (100) |
| Veneto | 7 (25.0) | 4 (14.3) | 9 (32.1) | 5 (17.9) | 3 (10.7) | 28 (100) |
| Total | 232 (45.3) | 125 (24.4) | 92 (18.0) | 41 (8.0) | 22 (4.3) | 512 (100) |

the flood risk area was evaluated as the percentage of the municipality that overlapped with the flood hazard surface (Fig. 9b). Within the floodplain, there are only 22 municipalities in a high-risk area (ranging from 39.5% to 89.7%; Table 6). These municipalities are located in three main regions: Lombardia (10; 12.5%), Piemonte (9; 2.7%), and Veneto (3; 10.7%). These regions are the most economically competitive regions within the north of Italy, where the elevated levels of human–landscape interactions have affected the equilibrium of its drainage network. The provinces of Alessandria, Venice, and Padova (respectively AL, VE, and PD in Fig. 2) emerge as the riskiest provinces.

The lowest part of the Po River basin, corresponding to the Polesine region, presented very low scoring of flood risk attributed to low scores of the index. However, this area is well known for being a lowland constantly prone to land modifications and submergence caused by rivers flooding (Amadio et al. 2013). For this reason, a deeper social vulnerability analysis would be suitable at smaller scale (e.g., in high flood exposed areas) since the Social Vulnerability Index changes according to the scale extension. In accordance, specific areas, provinces, or basins can be viewed in a macroscale analysis with a municipality-scale subdivision to see in detail the societal characteristics of the community and their locations. This would benefit practitioners and managers to produce rapid flood emergency evaluations and focused land plans. To this point, one must note that in Italy the responsibility for flood control is quite complicated, and the decentralization of the authorities in charge may lead to some obstacles in achieving effective flood management. Disaster risk governance consists of an intercorrelation of ‘‘[...] norms, organisational and institutional actors, and practices that are designed to reduce the impacts and losses associated with disasters’’ (Tierney 2012, p. 344). In other words, it includes all the actors (civil society, public and private sectors) and the actions that influence the risk management (Holley et al. 2012). In Italy, there are several actors involved in the flood risk management (Cirillo and Albrecht 2015), such as the following:

1) the Regional Authority, in charge of drafting flood management plans in coordination with other regional authorities and the National Department of Civil Protection (DCP);
2) the DCP, which coordinates the functional multihazard centers and promotes risk culture, prevention, and preparedness and coordinates and assists relief actions in case of disaster events;
3) the Reclamation Consortia management bodies (subregional level), which have the role of implementing structural works and urgent measures and controlling and repairing preexisting hydraulic structures for flood prevention;
4) the Civil Engineering Department (province level), which works for the maintenance of flood safety of the main hydrographic network through surveillance, monitoring, and maintenance activities, and verifies the hydraulic compatibility of new urban constructions or changed land use;
5) provinces and municipalities, which are responsible for the building and the maintenance of water installations adopting all safeguarding measures listed in the flood plans; and
6) the river basin district authority (river basin level) in charge of developing flood risk management plans.

This multiactor setting of flood risk management is rather complex when responsibilities and duties overlap, reflecting a difficult engagement of the community in the decision-making process. Public participation is an essential way to achieve a successful emergency response. According to the Institute of Medicine (2013), a bottom-up approach to the disaster management can be obtained by a two-way communication: ‘‘informing community members of sensitive policy decisions and receiving community input on difficult matters'' (p. 4).

## 5. Discussion

The indicators of socially vulnerable groups are based on the most common characteristics of individuals and can be easily monitored through time since they are based on census data (King and MacGregor 2000). However, it is plausible that there could be room for subjectivity when choosing the variables and weighing them when scoring the index. For this reason, it is important to have a broad understanding of the societal construction of the area under study, and of its cultural, economic, and political dynamics. From an ethical perspective, it is not in doubt that the people or groups targeted as vulnerable are *all* vulnerable. For example, in some countries of the world, women, children, seniors, and farmers have developed unique skills to overcome the impacts of natural disasters. According to the guide for relief agencies during emergencies published by UNICEF (2007) during the 2004 Indian tsunami, children saved their peers who had been divided from their parents. A report recently published by the World Bank group (Kiyota et al. 2015) underlined how recognizing the social capacities of elders has led to the whole community's ability to overcome the shocks caused by natural hazards by creating flexible support mechanisms. Similarly, in some parts of the world, women have developed unique skills to cope with natural hazards. They have been demonstrated to be very knowledgeable about the territory where they live, more so than their male counterparts, increasing rational decision-making when situations call for participation (Anderson 2002; Morrow and Enarson 1996). Midwives and women's health care providers have a long history of assessing and addressing public health issues and thus they can be a crucial resource in providing expertise relevant to disaster planning and response (Keeney 2004). Farmers developed means to manage the lands and overcome the hydraulic pressures in their areas (Pivot and Martin 2002). All these groups have demonstrated that they have the skills to overcome the negative consequences of disasters. In fact, there is urgent need to include focused management actions from the main institutional bodies by going beyond gender, age, income, and profession stereotypes by creating openings for personal and institutional renovation.

In addition, with institutional and financial supports (public or private), it seems easier to encourage people to take an active role in flood risk management. The general household economic instability, underlined by numerous attributes in this research, supports the need for a stronger market for flood insurance schemes. At the present time, the Italian insurance market has few products (Gizzi et al. 2016), resulting in low penetration rates. In 2001, only 0.4% of all Italians subscribed to an extension for household flood protection (ANIA 2011). Insurance is an instrument that can reduce anxiety and stress and simultaneously provide consolation in the case of loss (Michel-Kerjan and Kunreuther 2011). Thus, flood insurance schemes can be negative contributors in the assessment of vulnerability, meaning that they can reduce the burdens of individual's fragility. In accordance, the increased role given to risk financing measures in recent years modifies the standard ''vulnerability'' factor for the risk appraisal into ''vulnerability-coping capacity'' (Wamsler and Lawson 2011). The need for a national regulation for flood compensation is much more relevant in those countries where the population and the related properties are foreseen to increase. In keeping with this, recent projections show that the Italian peninsula will register a growth of 2.16% in 2020, up to 62.5 million people (OECD 2016).

The United Nations (2007) predicted that Italy's population in 2050 would be largely made up of post-1995 immigrants or their descendants (29% and 39% respectively), being more than 10 times the proportion of the foreign-born population in 1995. Members of socially dominant groups see threats (to self and the community) as less risky and more manageable than do members of nondominant groups (Solberg et al. 2010). Thus, it is important to raise natural hazards awareness and preparedness to the new members of the community (e.g., specific multilanguage activities; Frigerio and De Amicis 2016) because people judge, react, and recover differently according to their cultural norms, religion, and beliefs (Croson and Gneezy 2009). It means that racial/ethnic diversity should be considered when studying population vulnerabilities and perceptions, to address policymakers on sensitive risk management toward minority groups.

Educational and institutional support systems aimed at identifying and fostering local capacities of less powerful people are the key to an efficient disaster management planning (Agrawal 2011). In this context, an increase communication between all the stakeholders acting in a possible environmental hazard situation can lighten the fragility of exposed individuals (Lazrus et al. 2012; Roder et al. 2016). These actions are possible and could be effective if there is grounded mutual trust among interested parties. As found in a study conducted in Sri Lanka and the United States, the mistrust of people in the government's management capacities and caring attitudes appears to have an influence on their willingness to take action in front of a disaster (Duggan et al. 2010). However, when trust in public authorities is consolidated, people are more disposed to adopt protection measures (Motoyoshi 2006).

## 6. Conclusions and step forward

This article provides a social vulnerability assessment to floods in the floodplain of northern Italy using the SoVI approach adapted to the societal and historical construction of the area, according to the real vulnerability that individuals might face in the actual century and the structural conformation of the Italian society and the economic and the political background. The major dimensions of the social vulnerability of the study area are clustered into specific locations, emerging in the Piemonte, Lombardia, and Veneto regions within the floodplain. At a general consideration, economic welfare and the population growth, age, and ethnicity are the major social attributes affecting the residents in the northern Italy floodplain. These characteristics coupled with the potential flood hazard can magnify the adversity of such events. Risk maps derived from the combination of the high social vulnerable municipalities and the high flood hazard zones emphasize the hotspots within this anthropogenic landscape. These data mark the importance of having visual and intuitive maps that could orient decision makers on where risk reduction practices are needed the most.

The adverse consequences of floods on risk-prone communities may be exacerbated in the future, and the costs to those vulnerable people might increase disproportionally. Undeniably, social vulnerability and risk maps are only a part of the efforts needed to reduce the risk posed by environmental hazards. In fact, there is a need for multistakeholder participation at all levels, from managers to politicians, to plan, finance, and finalize those actions aiming at reducing the vulnerability of people living in natural hazard-prone regions. To achieve this, there is the need first to explore public concerns to be able to address specific management measures in front of vulnerable groups. Risk perception appraisals could be a catalyst for the success of community-based management actions for mitigating the effects of flood events in the region. Qualitative research on peoples' perceptions and beliefs in high-risk areas is a necessary contribution to a quantitative work, and this is the primary focus documented by the Flood Directive 2007/60/EC. This directive of the European Parliament and the Council of European Union established a framework for ''community action in the field of water policy'' that requires river basin management plans for the mitigation of floods adverse effects and the ecological restoration of the rivers (see https://www.eea.europa.eu/policy-documents/directive-2007-60-ec-of).

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