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Assessing social vulnerability to earthquake hazard: from statistical to spatial analysis

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INTRODUCTION

In the framework of natural hazard, multi-hazard and risk assessment the concept of vulnerability is always referred to the fraction of the total risk value that could be loss after a specific adverse event (Mazzocchi et al., 2009). However, over the last few years the term 'Vulnerability' is frequently cited in scientific literature in regard to different context, focusing particularly to social-economic aspects that influence societal conditions such as exposure, sensitivity, coping, adaptive capacity and social capital (Adger, 2006; Gallopin, 2006).

Indeed, the natural hazards does not have a random effect on the local community and generally the most affected groups are the more vulnerable ones, already marginalized by class, race, ethnicity and gender (Blaikie et al., 1994). 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 socioeconomic conditions of the population affected (Cutter et. al., 2003).

METHOD

Following the hazard-of-place model approach, used by Cutter et al. (2003), the methodological framework for assessing social vulnerability index to natural hazards for Italian country consists of four major steps:

1. development a geospatial database using spatialite and construction socio-economic indicators;
2. performing multivariate statistical analysis on the selected indicators (PCA);
3. constructing and mapping the social vulnerability index (SVI).
4. elaboration of exposure map combining earthquake hazard map and SVI map, using risk matrix.

1. SOCIAL VULNERABILITY INDICATORS

After a careful literature review about the most relevant factors that influence social vulnerability (Cutter et al. 2003; Cutter and Emrich 2006; Rygel et al. 2006; Birkmann 2006b;), 15 proxy variables were created and stored into spatialite database. The variables, listed in table 1, explain both the positive and negative factors that can increase or decrease social vulnerability. They represent the indicators proxy variables that better explain Italian population socio-economic conditions that influence the capacity of a community to prepare for, respond to, and recover from hazards and disasters.

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	Employment	Decrease
Unemployment rate Commuting rate		Increase
Index of high education	Education	Decrease
Index of low education		Increase
Population density Urbanized index for residential use Crowding index	Anthropization	Increase
Quality residential (building from 1972)	Residential property	Decrease
Foreign residents	Ethnicity	Increase

Tab. 1 Variables used for assessing social vulnerability.

2. PRINCIPAL COMPONENT ANALYSIS

Use of multivariate statistical analysis technique to reduce a dataset has been employed in several studies of social vulnerability. This second step was to apply on the 15 proxy variables a multivariate statistical analysis.

Through different **R** packages (e.g. vegan, princomp, outliers) principal component analysis (PCA) was performed to reduce dataset. At the end of this operation, the interpretation of the component matrix generated 4 main components that explain the relationship between variables unfolding the 74.6 % of the variance in the entire dataset. These components are interpreted as the follow:

- **AGE** (29.5%)
- **ERMPLOYMENT** (22.4%)
- **EDUCATION** (12.9%)
- **ANTHROPIZATION** (9.5%)

Using the factor scores, related to each municipality, it is possible to visualize the spatial distribution of the four factors on Italian territory. The exploitation of standard deviation as classification method, four maps, one for each factors were created (Fig. 1).

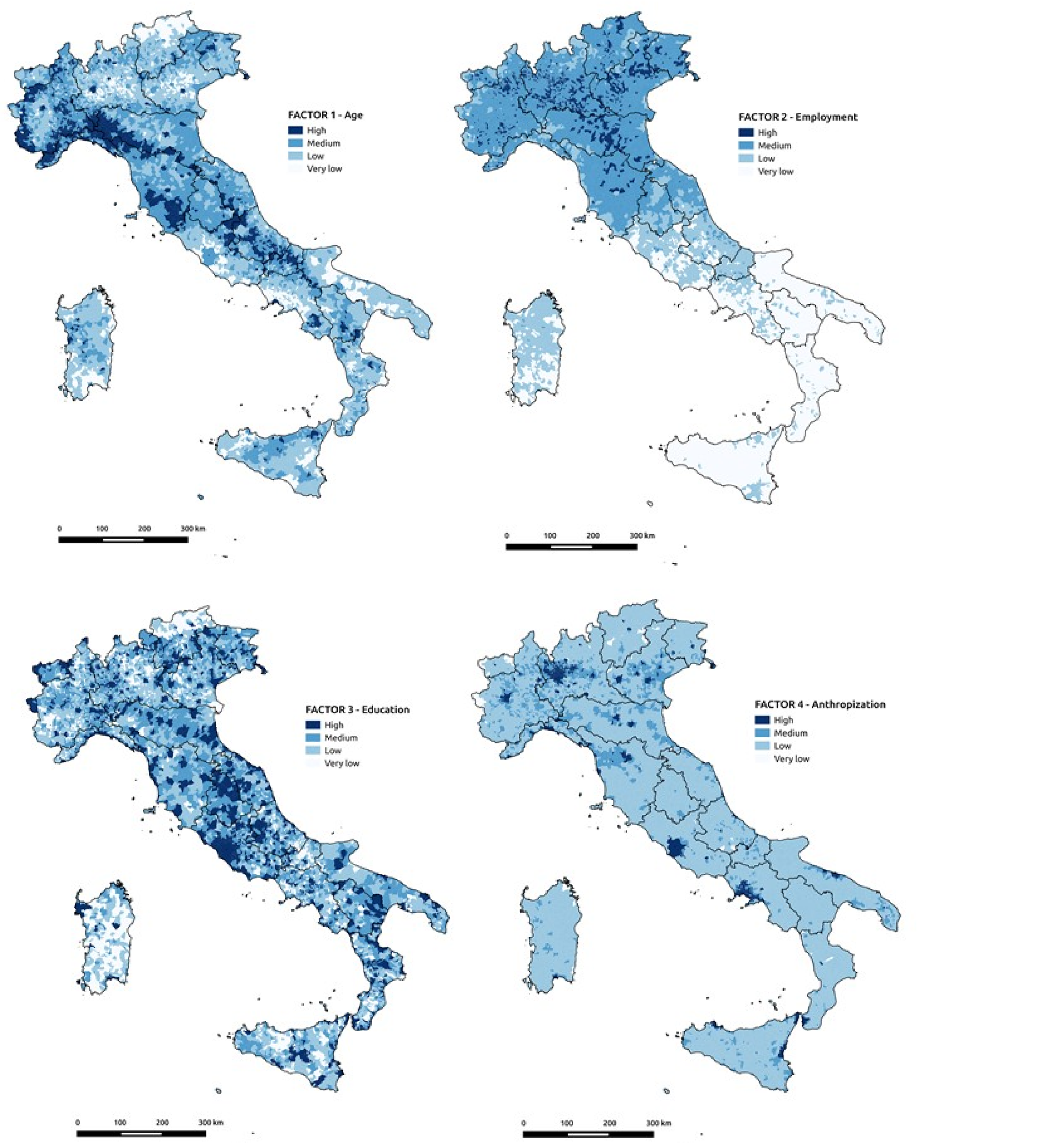

Figure 1 – Spatial distribution of the components.

3. CONSTRUCTION AND MAPPING OF SOCIAL VULNERABILITY INDEX

Even though the four maps of each factor can be useful, it is easiest to assess overall social vulnerability combining the each factor scores into a single measure.

These factors can be used for the computation of the Social Vulnerability Index (SVindex) for the Italian country at municipality scale (Fig. 2). The aggregation method to generate composite indices is the main method used by most researchers interested in social vulnerability studies.
The direction of these four 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 and negative (-) directionality to factors that decrease it (Cutter et al. 2003). So, the SVindex for all municipality were calculated with the following equation:

$$SVindex = \sum\left(\frac{Factor1 \times 29.5}{totalvariance}\right) + \left(\frac{Factor2 \times 22.4}{totalvariance}\right) - \left(\frac{Factor3 \times 12.3}{totalvariance}\right) + \left(\frac{Factor4 \times 9.5}{totalvariance}\right)$$

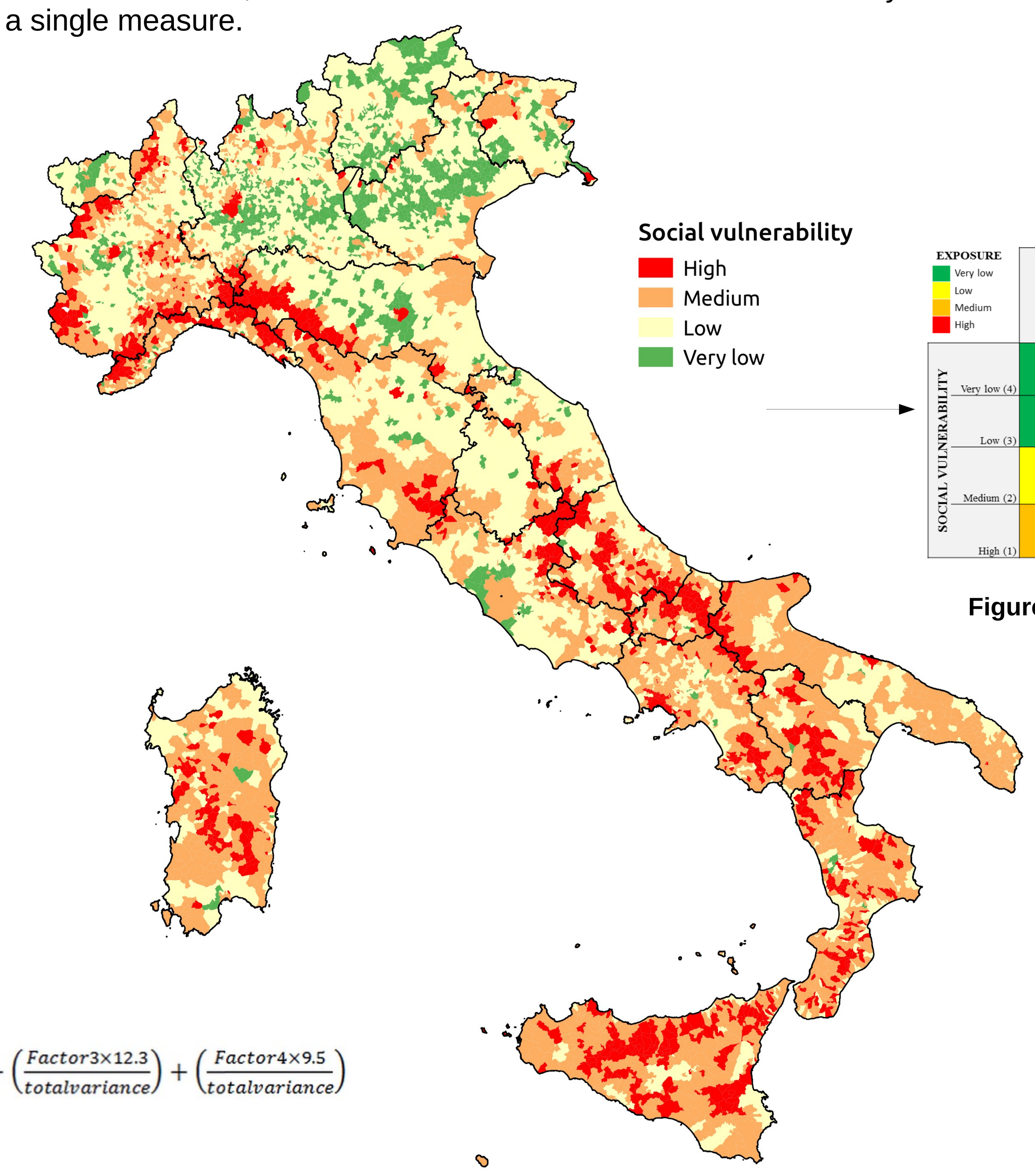

Figure 2 – SVindex

4. CONSTRUCTION OF EXPOSURE MAP

Seismic hazard map (Fig. 3), developed by INGV (National Institute of Geophysics and Volcanology), classifies the entire Italian territory according with the four classes mentioned in the table 5.

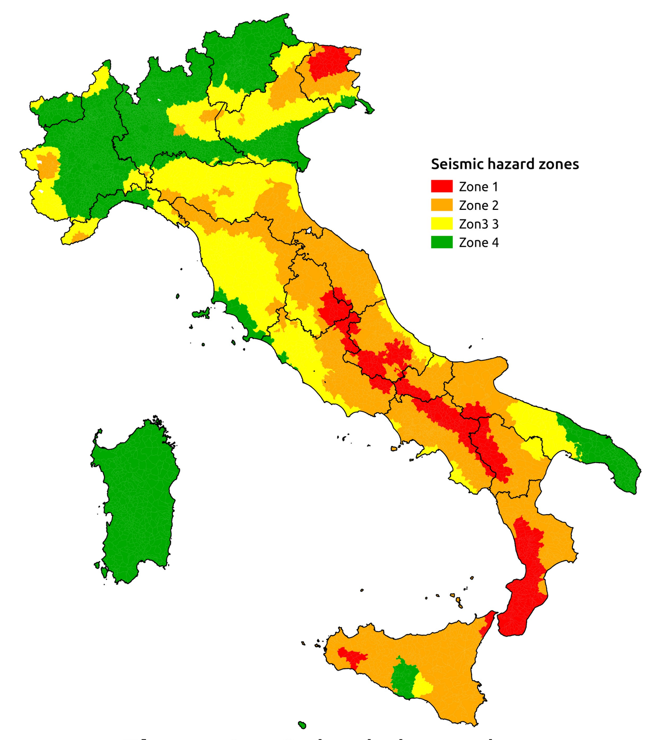

Figure 3 – Seismic hazard map

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

Table 2 - intervals of acceleration (ag), with a probability of exceeding the threshold equal to 10% in 50 years

The risk matrix, proposed by a directive issued by Lombardy region for qualitative hydrogeological risk assessment (Lombardy region, 2005), was used and adapted to build the exposure map.
The matrix was calculated by adding the different values of social vulnerability and seismic hazard classes. The result of this operation was reclassified in four categories. The exposure map presented in figure 6, identifies the hot-spot areas: zones with high levels of seismic hazard and at the same time an high levels of social vulnerability.

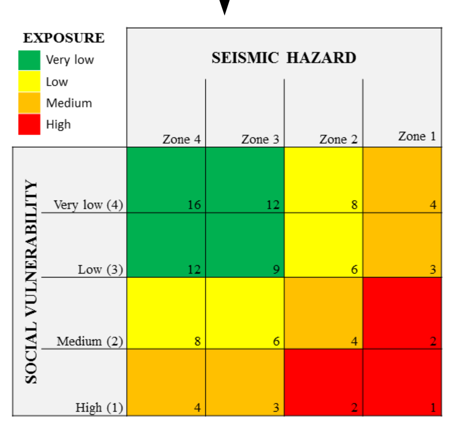

Figure 4 – Risk matrix

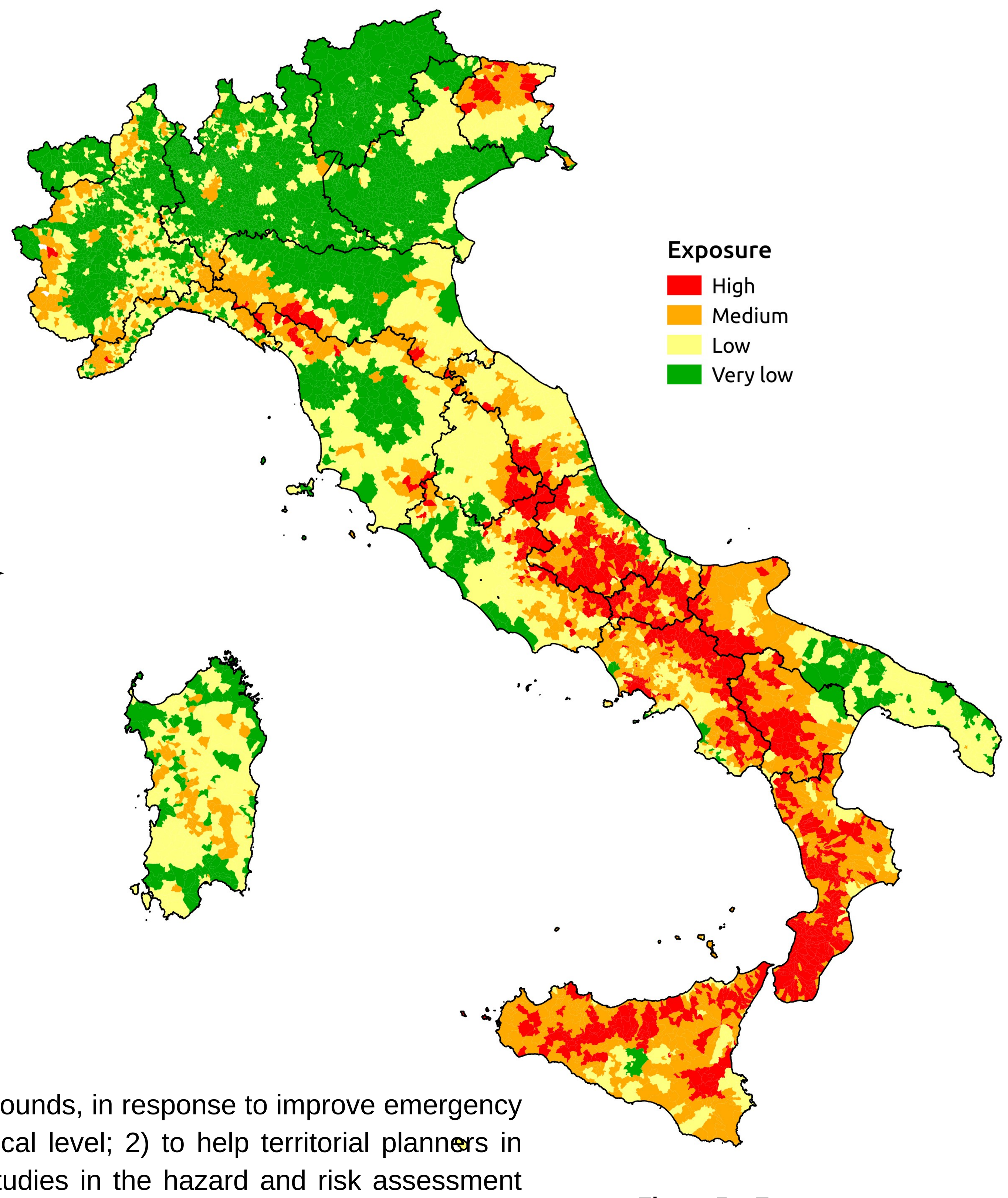

Figure 5 – Exposure map

CONCLUSION

The exposure map can be integrated into emergency plans in order to better allocate resources such as people, materials and financial founds, in response to improve emergency management against disaster events. This study allows: 1) also to identify appropriate cost-effective risk reduction measures at a local level; 2) to help territorial planners in managing the relationship between natural processes and human communities using FOSS softwares; 3) finally, the lack of social studies in the hazard and risk assessment highlights the need to better integrate social science research concerning social vulnerability into emergency and risk management decision-making.