Criteria for the identification of landslide risk areas in Europe: the Tier 2 approach

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Establishing landslide hazard and risk for an entire nation is a difficult task and only a few, largely empirical, attempts have been pursued. The main difficulty to determine landslide susceptibility, hazard and to ascertain the associated risk for very large areas lies in the complexity and diversity of the landslide phenomena, and in the limited availability of relevant information for territories extending for hundreds of thousands of square kilometres (Chacón et al., 2006; Crozier and Glade, 2005; Guzzetti, 2006). At European level and according to the common criteria established by the Soil Information Working Group (SIWG) of the European Soil Bureau Network (ESBN), quantitative model-based (Tier 2) assessment of landslide susceptibility requires geographical information on landslides. According to the "tiered" approach for risk area delineations as proposed by SIWG (Eckelmann et al., 2006), quantitative inventory-based evaluations on landslide susceptibility should be conducted in areas identified as critical by the Tier 1 assessment. It is possible to perform quantitative evaluations of landslide susceptibility adopting statistical assessment techniques only where landslide inventory maps and/or associated databases are available.

In Italy, relevant information has become available to attempt a quantitative, nationwide (synoptic) assessment of landslide hazard and of the associated risk to the population. Preliminary to the definition of landslide hazard is the selection of an appropriate mapping unit. The municipality (an administrative and political subdivision) was selected as the terrain-partitioning unit. Italy is divided into 8103 municipalities, ranging in size from 0.11 km^2 (Atrani, Campania) to 1285 km^2 (Rome) (mean area = 37.3 km^2, mode = 26.3 km^2, std. dev. = 50.0 km^2). We prepared two hazard/risk models exploiting two catalogues listing historical information on damaging landslides and on landslides with human consequences in Italy. The two catalogues cover the 52-year period from 1950 to 2001 (Guzzetti and Tonelli, 2004). For modelling purposes, the catalogues were split in two sub-sets: (i) a training set, covering the 41-year period from 1950 to 1990, and (ii) a validation set, spanning the 11-year period between 1991 and 2001. The spatial probability of landslides (i.e., "where" landslides are expected) was obtained through multivariate analysis of synoptic thematic information (Fig. 1) (Guzzetti et al., 2005; Guzzetti et al., 2006), including lithological, soil and climate data, and a set of morphometric variables obtained from a 90 m × 90 m digital elevation model (DEM) acquired by the Shuttle Radar Topography Mission (SRTM) in February of 2000. Lithological information was obtained from a synoptic geological map published by Compagnoni and his collaborators in the period from 1976 to 1983. For the statistical analysis, the large number of rock units shown in the synoptic geological map (145 units) was grouped into 20 lithological types. Similarly, the 34 soil types shown in the synoptic soil map of Mancini (1966) were grouped into 8 classes of soil thickness and 11 classes of soil parent material. As the dependent variable, the presence or absence of damaging landslides (or of landslides that have resulted in casualties) in each municipality was used. To estimate the temporal probability of landslide occurrence (i.e., "when" or "how frequently" landslide events are expected), we first obtained an estimate of the average recurrence of landslide events in each municipality. Landslide event recurrence was obtained dividing the total number of damaging landslide events (or the total number of events with casualties) in each municipality by the time span of the investigated

period (41 years). Next, the recurrence time of damaging landslide events (of landslide events with casualties) was assumed constant, and a Poisson probability model was selected to describe the temporal distribution of damaging landslide events (and of landslide events with casualties). Finally, the exceedance probability of having one or more damaging landslide event (or landslide event with casualties) in each municipality was computed for different periods, from 1 to 20 years. The temporal prediction models and the spatial prediction models were tested using independent landslide information, i.e., information not available to construct the models. Landslide validation sets covering the 11-year period between 1991 and 2001 were used to test the temporal models, the spatial models, and the joint hazard/risk models. Result of the model validation revealed that more than 70.0% of the landslides used as validation set occurred in municipalities classified as unstable (probability > 0.55). The validation revealed the ability of the model to predict where future landslides may occur in Italy.

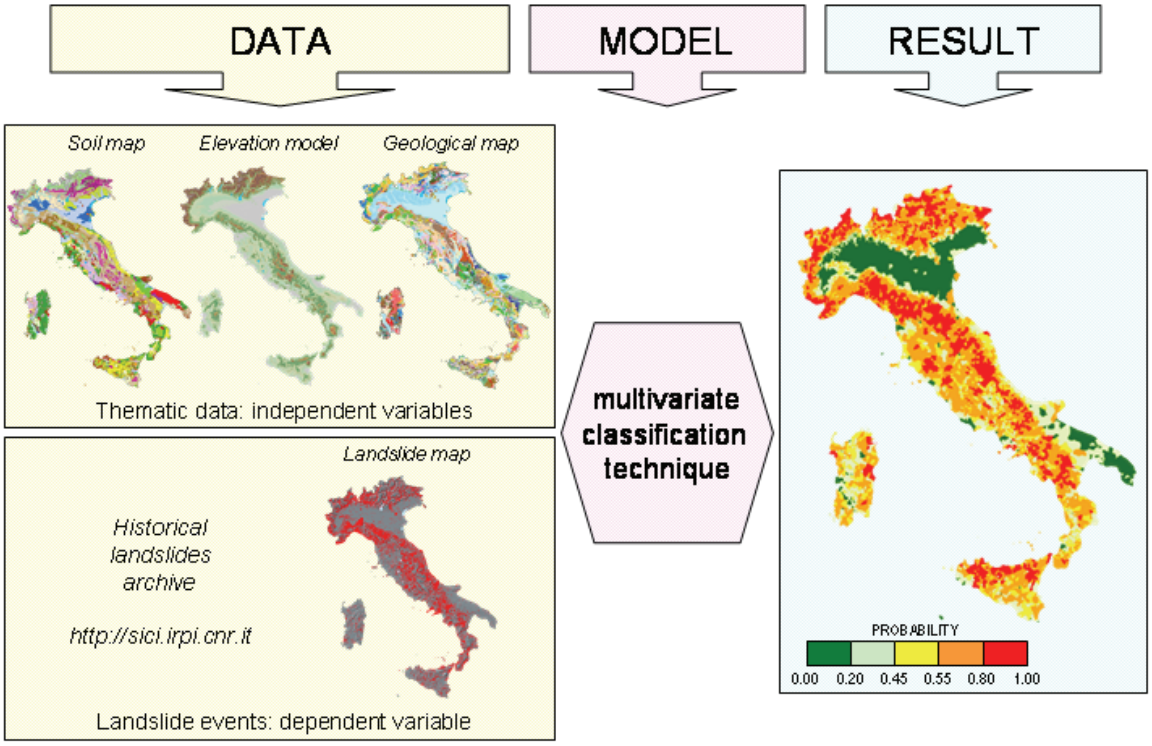

Figure 1: Probabilistic landslide susceptibility model for Italy. Figure shows the thematic and environmental data used to ascertain landslide susceptibility, the adopted statistical classification model, and the resulting susceptibility assessment. Probability of landslide spatial occurrence (susceptibility) is shown in 5 classes, from low (green) to high (red).

Combining the spatial and the temporal probability of damaging landslides and landslides with fatalities, we obtained two different models. The first model attempts to forecast the occurrence of all type of damaging landslides in Italy and is a type of hazard model (Fig. 2). The second model predicts the subset of damaging landslides that result in fatalities and can be used to estimate landslide risk to the population of Italy. Results of the hazard/risk modelling are shown using synoptic maps that portray landslide hazard/risk in the 8103 Italian municipalities in five probability classes, from very low to very high. The maps, albeit preliminary, are remarkable, and may be used by national and regional civil protection authorities, by national and regional environmental agencies, and by insurance and re-insurance

companies to determine levels of landslide hazards and of landslide risk to the population of Italy.

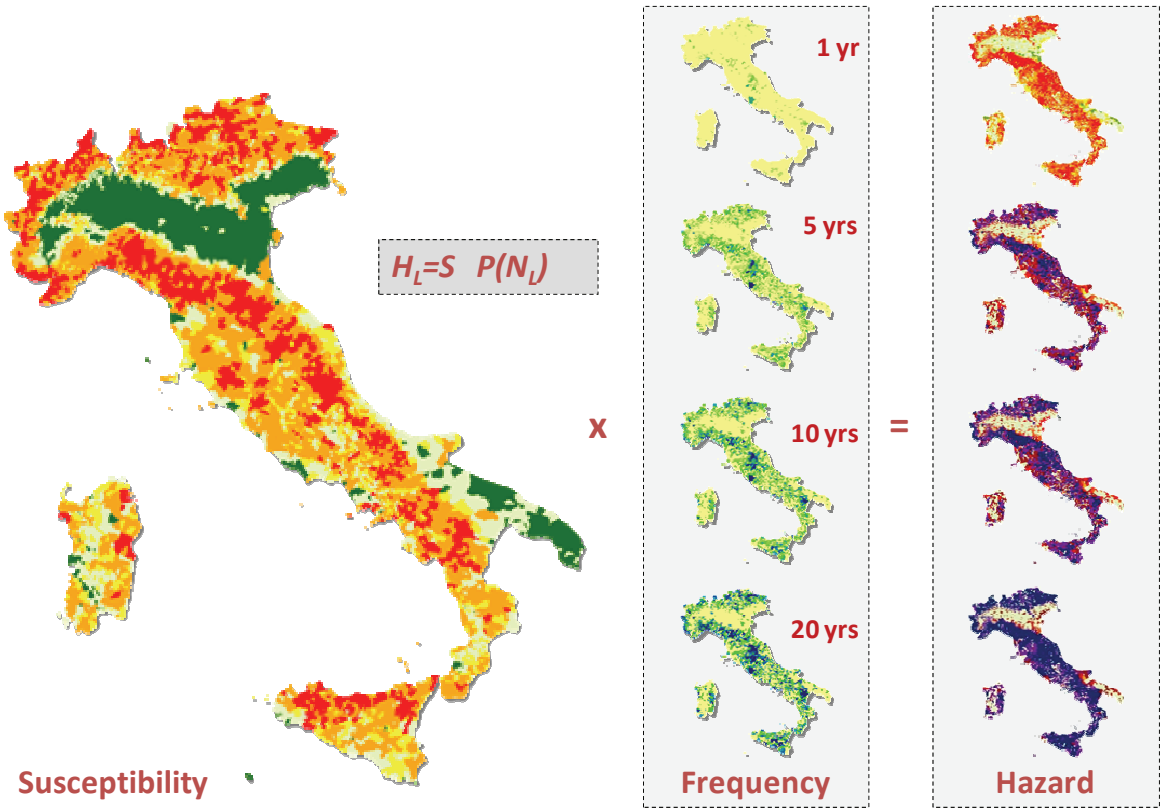

Figure 2: The figure shows a set of hazard scenarios obtained combing the susceptibility estimate of future damaging events with the exceedance probability for different time intervals.

Landslide hazard and risk models as proposed for Italy could be prepared for all the European nations whenever a landslide inventory map is or become available. To guarantee the comparability of the results throughout Europe, a standard on landslide inventories should be established, a suitable mapping unit should be discussed and quantitative landslide susceptibility evaluations should be carried out exploiting similar thematic information.

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