Harmonised approaches for landslide susceptibility mapping in Europe

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ABSTRACT: The EU Thematic Strategy for Soil Protection and the associated Proposal for a Soil Framework Directive establish a framework to prevent further soil degradation and preserve its functions including the capacity of development of human activities. This framework first suggests identifying the areas in Europe where a number of soil threats including landslides are likely to occur by using a comparable approach based on the use of common thematic data. In this context, the European Landslides Expert Group hosted by JRC has developed guidelines and obtained preliminary results from harmonised susceptibility assessment and mapping in Europe at various scales using geographically-nested, multi-step Tier approaches. In these approaches, areas identified as of high susceptibility in the initial Tier (Tier 1) are subsequently assessed and mapped at larger scale and higher accuracy by successive Tiers (Tier 2 and 3). Preliminary harmonised European-wide generic landslide susceptibility mapping at 1:1 Mil. scale has been performed in Tier 1 by calibrating bivariate information values for a reduced number of already available pan-European datasets representing landslide conditioning factors. Since no harmonised landslide inventory is available for the whole continent, model production is performed using available landslide information in a number of countries. The first results show a relatively good performance of the model in many areas at this synoptic scale, but better results are expected in the near future. The importance of sufficient and well-distributed landslide information for model calibration is confirmed from a Tier 1 heuristic approach developed and applied to France. A Tier 2 landslide susceptibility assessment is recommended in areas of high susceptibility as identified by Tier 1, using a quantitative model and landslide inventory data. This approach is shown to be appropriate for national or regional scale mapping (1:1 Mil. to 1:250,000). A Tier 2 experiment has been carried out for Italy using a multivariate statistical model and a higher number of variables. In addition, separate temporal datasets from the AVI historical landslide database of Italy have been used for training and validation of the model. Finally, some recommendations for Tier 3 susceptibility mapping at local scale are provided.

1 INTRODUCTION

The European Union's Thematic Strategy for Soil Protection and the associated Proposal for a Soil Framework Directive establish a framework to prevent further soil degradation and preserve soil functions including the capacity of development of human activities (Commission of the European Communities 2006a, 2006b). This framework first suggests identifying the areas in Europe where a number of soil threats including landslides are likely to occur by using a comparable approach based on the use of common thematic data. In this context, given that spatiotemporal information on landslides to carry out hazard and risk assessments are currently not available in many areas, the European Landslides Expert Group set up by JRC decided to develop guidelines for landslide susceptibility assessment and mapping across Europe using harmonised approaches and common datasets (Hervás et al. 2007). The approaches are based on "Tiers" (Eckelmann et al. 2006). These are hierarchically-ordered, geographically-nested approaches, whereby areas identified as of high susceptibility in the initial Tier (Tier 1) are subsequently assessed and mapped at larger scale and higher accuracy by successive Tiers.

First, the expert group suggested to producing a European-wide Tier 1 landslide susceptibility map at small scale (1:1 Million). In the areas identified as

landslide prone by Tier 1, more detailed, quantitative Tier 2 susceptibility assessment is then required. A Tier 1 landslide susceptibility map is urgently needed as, in contrast to most other soil threats, for landslides still no reliable susceptibility map is available for the continent. This is mainly due to the lack of a detailed European landslide database. In the next sections the approach suggested by the European Landslide Expert Group is presented together with preliminary results obtained from experiments for Tier 1 and 2.

2 TIER 1

Tier 1 susceptibility assessments are suggested to be carried out with a reduced set of available pan-European datasets representing landslide conditioning factors (namely slope angle, bedrock/soil type and land cover; Table 1). In a later stage, the obtained susceptibility values could optionally be linked with the most important landslide triggering parameters like climatic and seismic factors to obtain a first estimate of landslide hazard (Hervás et al. 2007, Günther et al. 2008).

Table 1. Common elements / criteria for the identification of areas at risk of landslides at EU level.

Common elements	Available datasets
Occurrence /density of existing landslides	Does not exist at EU level
Topography	SRTM and GTOPO30
Soil typological unit (STU)	European Soil Database (ESDB; JRC)
Bedrock	ESDB (JRC)
Land cover	CORINE, PELCOM
Climate*	MARS (JRC), PRUDENCE project
Seismic*	GSHAP

* Eventually for landslide hazard in a later stage.

Following these recommendations and due to the lack of a harmonised landslide database at the continental scale, a model based on purely heuristic (expert-based) weighting of the conditioning factors was tested (Günther et al. 2010). From results of a preliminary test it became clear that calibration of the weights with available landslide data was necessary. Therefore, in a further test, landslide locations from published nation-wide landslide maps for as many European countries as possible were collected. For countries for which landslide data were available, bivariate information values (Yin & Yan 1988) were calculated for each independent variable class (Table 1 and Fig. 1). For the remaining territory, global parameter information values (using the complete ensemble of available national landslide datasets) were derived.

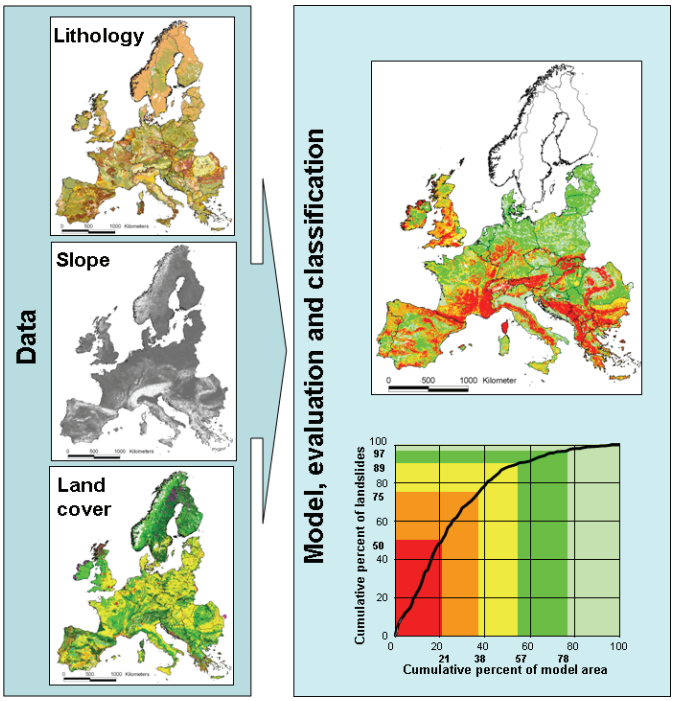

Figure 1. Example for a continent-wide Tier 1 analysis using lithology, slope, and land cover classes as predictor variables. Information values for each variable class were calculated using landslide location and density information from various published maps for different calibration areas. The preliminary susceptibility estimate was classified through model success rate evaluation in 5 classes comprising 50%, 25%, 14%, 8% and 3% of the gathered landslide locations and 21, 17, 19, 21 and 22% of the model area.

Then, an experimental susceptibility estimate was computed by spatial summation of the information values obtained for the individual variables. Finally, this continuous map was classified into five classes through model success rate curve evaluation containing 50%, 25%, 14%, 8%, and 3% of the obtained spatial landslide information. These five classes contain 21, 17, 19, 21 and 22% of the study area. In a later phase this map could then be validated with external landslide data not used for the calibration of information values. Figure 1 shows preliminary results obtained with a reduced landslide dataset (Günther & Reichenbach 2010). Although subject to be improved and biased in some regions, the map correctly assigns high susceptibility to many areas known to be prone to landsliding.

Application of a modified Tier 1 approach to six departments in France by Malet et al. (2009) allowed suggesting additional improvements to be included in the European-wide landslide susceptibility map. Unlike for the European-wide experiment above, a geomorphological differentiation (i.e. plain and mountain areas) was performed in the French departments, and a multi-criteria evaluation technique was applied for assessing the weights allocated to the conditioning factors.

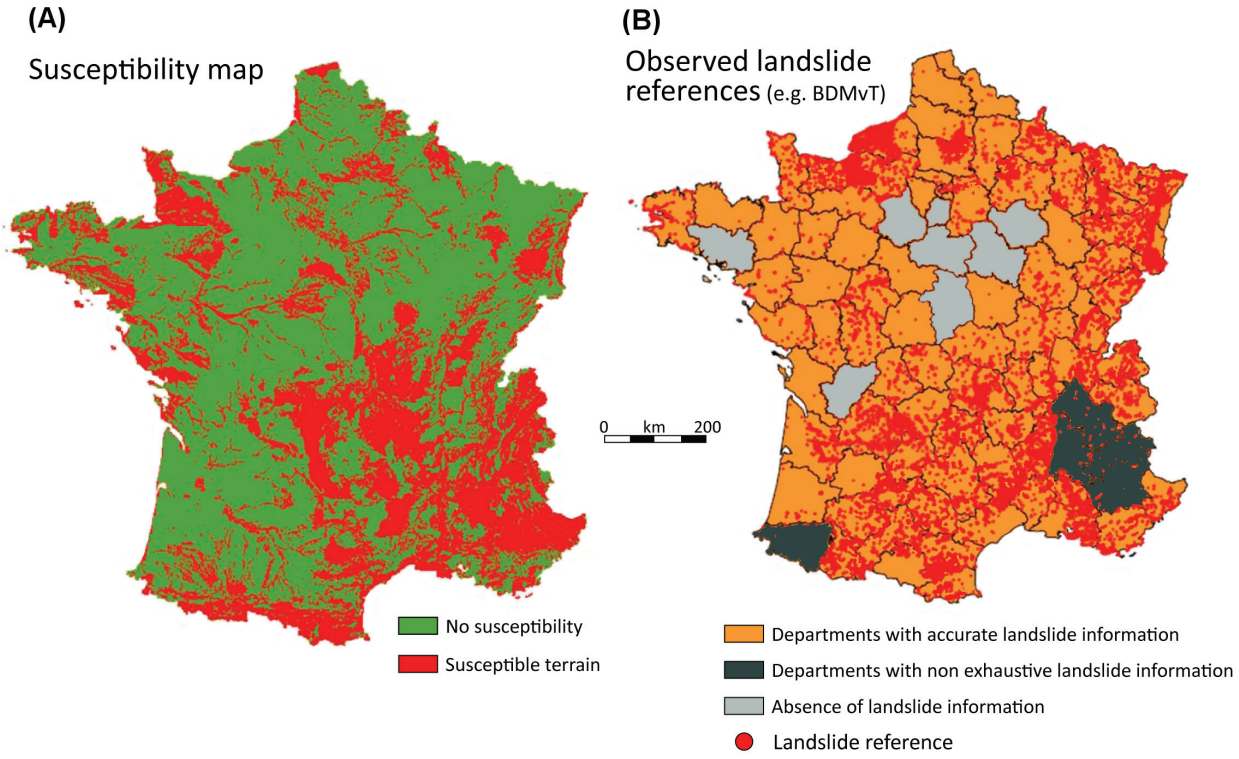

Figure 2. (A) Example of landslide susceptibility map for France according to the Tier 1 approach, showing two susceptibility classes; (B) Simplified landslide inventory map of France based on the BDMvT database, indicating the completeness of the database information for each department.

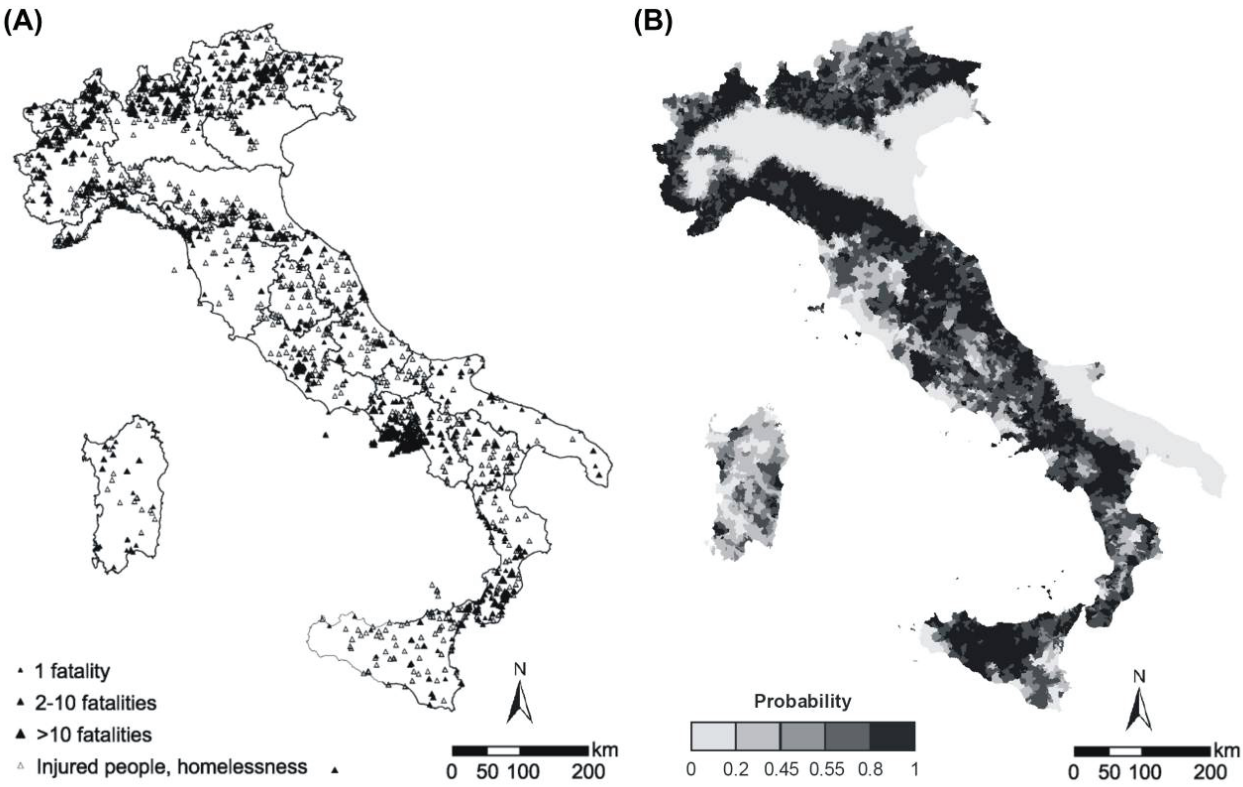

Figure 3. (A) Distribution of landslides with human consequences in Italy from AD 1279 to 2002. The size of the symbol indicates the intensity of the event: Small symbol: 1 dead or missing person; medium symbol, 2–10 deaths or missing persons; large symbol, more than 10 deaths or missing persons. Open symbols indicate sites where injured people, homeless people, or evacuated people were reported (Guzzetti et al. 2005a); (B) Landslide susceptibility map of Italy (Günther et al. 2008).

As the BDMvT mass movement inventory of France (Fig. 2B) used in this work contains information on the landslide type for most of the country, separate susceptibility estimates were performed for main landslide types for the whole of France. In addition, for easier comparison with the European-wide generic landslide susceptibility map, the separate susceptibility maps were combined into a unified landslide susceptibility map of France showing two classes (i.e. susceptible and non-susceptible areas; Fig. 2A). Based on these experiences, it is expected to improve the continental map by using a more complete landslide dataset and morpho-climatic mapping units.

3 TIER 2

National or regional scale Tier 2 susceptibility assessment requires detailed geographical information on landslides as the use of quantitative statistical models is suggested. In Italy, relevant information is available to attempt a quantitative, nation-wide assessment of not only landslide susceptibility, but also of landslide hazard and the associated risk to the population. For this municipality boundaries were selected as mapping unit (Reichenbach et al. 2007, Günther et al. 2008). Two hazard models were prepared exploiting catalogues with historical information on damaging landslides and on landslides with human consequences in Italy. The catalogues were derived from the AVI historical landslide database (Fig. 3A; Guzzetti & Tonelli 2004). They cover the period from 1950 to 2001 but were split in a training (1950 – 1990) and a validation (1991 – 2001) set. The spatial probability of landslide occurrence was obtained through multivariate discriminant analysis (Guzzetti et al. 2005b, Guzzetti et al. 2006), including lithological, soil and climate data, and a set of morphometric variables obtained from the SRTM 90 m × 90 m DEM. 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, first an estimate of the average recurrence of landslide events in each municipality was obtained. Next, the recurrence time of damaging landslide events (of landslide events with casualties) was assumed constant, and a Poisson probability 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 (Reichenbach et al. 2007, Günther et al. 2008). The temporal and spatial prediction models and the joint hazard models were finally tested using the independent validation set. The model validation revealed that more than 70% of the landslides used as validation set occurred in municipalities classified as unstable (probability > 0.55; Fig. 3B). The validation thus revealed the ability of the model to predict where future landslides may occur in Italy.

4 CONCLUSIONS

In this contribution, the recent approaches towards the establishment of a common methodology for the assessment of landslide susceptibility within the European Union's Soil Thematic Strategy have been presented. Starting from the policy framework and requirements for the spatial assessment of soil threats in general, the suggested methodological approaches for Tier 1 and Tier 2 landslide susceptibility assessments have been outlined and illustrated with results obtained so far by the European Landslide Expert Group. In the future, the Tier 1 landslide susceptibility map is expected to be improved by using a larger landslide dataset for the calibration of the information values and by subdividing the continent in morpho-climatic regions. Also, application of a nation-wide Tier 2 statistical approach could be extended to countries such as France and UK, where large landslide inventories exist.

Although this contribution does not focus on medium to large scale Tier 3 assessments, it might be required to apply such a more detailed inventory-based and physically-based susceptibility and hazard analysis for different types of landslides and triggering factors within areas of high to very high landslide susceptibility as delineated by Tier 2.

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