Proceedings of

The First World Landslide Forum

18-21 November 2008

United Nations University, Tokyo, Japan

Parallel Session Volume

Global Promotion Committee of

The International Programme on Landslides (IPL)

ISDR

Approaches for Delineating Areas Susceptible to Landslides in the Framework of the European Soil Thematic Strategy

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Abstract. In the framework of the European Soil Thematic Strategy, and the associated preparation of a directive on the protection and sustainable use of soil, landslides were recognized as a soil threat requiring specific strategies for risk assessment and management. The criteria for harmonized risk area delineation proposed by the Soil Information Working Group (SIWG) of the European Soil Bureau Network (ESBN) adopt a nested geographical approach based on "Tiers" and exploit thematic and environmental data of different type, quality, and resolution using a variety of methodological and technological approaches suitable for the spatial evaluation of any specific soil threat. The main requirement for a continent-wide "Tier 1" assessment for the delineation of areas subject to soil threats in Europe is the availability of relevant input data. At present, such a continent-wide assessment of landslide susceptibility in Europe is feasible only when adopting a qualitative evaluation technique since high-quality, pan-European landslide conditioning- and triggering factor data is available, but a European-wide coverage of landslide locations is missing. "Tier 1" landslide susceptibility evaluations are described to serve for general risk/priority area identification and must at least be able to discriminate areas subjected to more detailed spatial assessments against those where no further action has to be taken. Quantitative evaluations of landslide susceptibility according to a "Tier 2" assessment require the availability of landslide inventory maps and databases. We outline the current advances towards the development of a common methodology for assessing the landslide threat in Europe. We refer to limitations, data needs and future work to be carried out, and present examples of nationwide assessments.

Keywords. European Soil Thematic Strategy, soil threats, continental-scale landslide susceptibility analysis

1. Political background

The European Union's Thematic Strategy for Soil Protection is a long-term political process that led to the formulation of a draft of a European framework directive devoted to the protection and sustainable use of soil in the European Union (Commission of the European Communities 2006a, 2006b). Within this process, eight individual soil threats that are likely to hamper soil functionalities or lead to soil degradation within the European territory have been identified and are subjected to risk/priority area delineation procedures and the implementation of suitable risk mitigation strategies: erosion, organic matter decline, salinisation, compaction, landslides, contamination, sealing and loss of biodiversity. Landslides are recognized as one of these soil threats. The Soil Information Working Group (SIWG) of the European Soil Bureau Network (ESBN) developed a uniform framework for risk area assessments of the first five soil threats mentioned above in such that hierarchically ordered, nested geographical analysis schemes ("Tiers") are envisaged, leaving the issues of data quality, map resolution and costs open to the individual EU member states (Eckelmann et al. 2006). In this context, European-level continent-wide "Tier 1" risk area delineations for individual soil threats should be conducted with already available data, should render a relatively low spatial resolution (tentatively 1:1 Mill.), and should follow a qualitative zonation approach or a model approach combined with thresholds. "Tier 1" assessments are considered to serve for general risk/priority area identification and should be able to delineate zones where no further measures or spatial analysis have to be taken against those that are subjected to more detailed "Tier 2" assessments. "Tier 2" risk area delineations within areas identified by "Tier 1" should thus render higher spatial resolution, could be conducted by quantitative modelling approaches, and will most likely require data not yet available. For each soil threat, the European Commission is searching for a common methodology for risk area delineations that will enable each member state to conduct the analysis. A set of common criteria for spatial analysis procedures was elaborated by SIWG of ESBN and is already annexed in the current draft of the framework directive. The discussion on a common methodology and on data requirements was more recently put forward by the European landslide experts group hosted by JRC Ispra (Hervás et al. 2007).

2. Methods and data requirements

In contrast to the other soil threats, landslides cannot be simply regarded as a soil degradation process but must be considered as a threat posing risk to other vulnerable objects. Therefore, we suggest that the impact of the landslide threat in the context of the Soil Thematic Strategy could be best evaluated with landslide susceptibility and hazard assessments. A wide range of assessment procedures exist, including empirically-based heuristic and statistical as well as physically-based evaluation techniques, each requiring different data and suitable to be implemented at different scales and for different types of landslides (e.g. Guzzetti 2006; Hervás and Bobrowsky 2008). Due to the complexity of landslide phenomena, the highly variable impact of the landslide threat in different European regions, and the differences in data availability, continent-wide "Tier 1" assessments can at the moment only be conducted using a reduced set of data. This should mainly consist of ground conditioning factors and optionally include the most important landslide triggering parameters like climatic and seismic factors. Since a systematic, harmonized coverage of landslide events does not exist throughout Europe, a continent-wide “Tier 1” landslide susceptibility zonation is at the moment only feasible using heuristic, index-based analysis techniques (Günther et al. 2007).

Within the areas susceptible to landslides as delineated through a “Tier 1” model, quantitative, inventory-based statistical landslide susceptibility and hazard modelling can be performed through multivariate statistical analysis (Reichenbach et al. 2007). In Italy, a country with a long tradition in landslide inventorying and spatial landslide hazard and risk assessment, it is shown that national-scale “Tier 2” evaluations can be performed and validated when appropriate mapping units are established and landslide inventory maps with associated databases are available in addition to high resolution ground material, topographic and landslide triggering thematic factor data. It is recommended that quantitative “Tier 2” analysis techniques should be conducted at scales in the order of 1:250,000, implying that mapping units with a higher resolution than the current EUROSTAT regions must be chosen. Even though administrative mapping units do mostly not reflect environmental or geomorphologic conditions, their use for a “Tier 2” assessment is favourable when considering the usability of the resulting maps for spatial planning and environmental protection measures.

The concept of a common methodology for risk area delineations according to soil threats implies the provision of an assessment technique and guidelines on data needs, but does not explicitly account for data resolution and accuracy. It should be left open to individual European countries to use their national datasets when implementing “Tier 2” assessments on the landslide threat. The rationale on methodological approaches presented here show the limitations of “Tier 1” evaluations in countries where landslides are a widespread natural hazard and higher developed evaluations on a national scale exist (e.g., Italy). “Tier 1” must be considered to be important at the continental scale and for those countries where nation-wide landslide inventory data is not available or incomplete (e.g., Germany).

3. “Tier 1” analysis

Recent advances in harmonizing European geological and soil databases resulted in the availability of high-quality thematic data on ground conditioning parameters portraying hydrological, textural and structural properties of the weathered slope zone where most landslides originate. Additionally, continent-wide topographic, land-use, climatic and seismic data are available at resolutions that can be combined with the ground conditioning factor data. The recommendation for preparing a heuristic European “Tier 1” landslide susceptibility model was formulated in such that a suitable weighting and scoring scheme should be elaborated to combine soil/parent material properties, slope angle and land cover to derive a landslide susceptibility index on a grid basis with a cell size fixed by the topographic raster data involved (Hervás et al. 2007). This speculative susceptibility model can be extended to a heuristic landslide hazard map in such that climatic (precipitation sums) and seismic (ground acceleration) landslide triggering factor data can be added. The grid cell-based susceptibility or hazard index values may be aggregated to suitable European administrative regions (e.g., EUROSTAT NUTS regions) using simple zonal statistics in order to combine landslide susceptibility and hazard information with European census data.

In Germany, a national landslide inventory database is not available. However, high-resolution thematic data on topography, lithology, and soil properties are available and were used to prepare a preliminary synoptic landslide susceptibility map (Fig. 1). For this purpose, a three-step, heuristic procedure was adopted. First, the information stored in the German Soil Database (BÜK 1000) was analyzed. The 72 bedrock/soil associations listed in the national database were classified heuristically by expert knowledge into 6 classes, based on their expected susceptibility to landslides. Each bedrock/soil association was classified based on the rock/soil type, the degree of weathering, the soil/regolith thickness, the presence of permeability contrasts and nature of soil/bedrock interfaces, and the presence of discontinuities. Next, a 50 m × 50 m digital elevation model (DGM 50) was used to obtain a map of terrain gradient. The slope map was reclassified into 6 classes, based on the expected propensity to landsliding of each class of topographic gradient. Finally, the landslide susceptibility map based on lithology and soil types, and the susceptibility map based on terrain gradient, were combined. Combination of the two maps was performed on individual pixels (50 m × 50 m), adopting a weighted average technique and assuming the same importance (i.e., equal weight) for the topographic and the lithological/soil information. The pixel values where aggregated to EUROSTAT NUTS 3 regions using the median of the values within each terrain unit (Fig. 1).

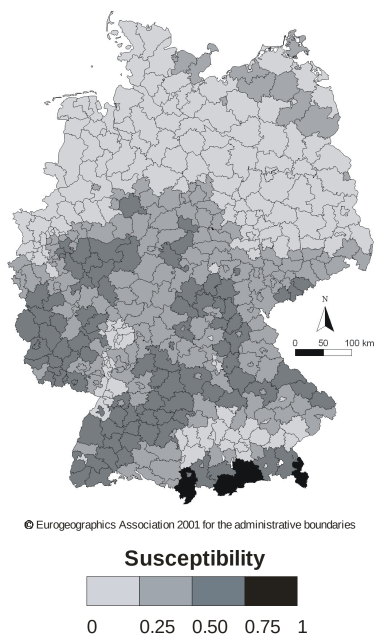

Fig. 1 Preliminary heuristic landslide susceptibility map for Germany as an example for a “Tier 1” analysis

The map shown in Fig. 1 portrays a qualitative zonation of landslide susceptibility in Germany, based on topographic and lithological/soil information. It is worth pointing out that no information on the location, type, or abundance of landslides was used to prepare the map. This is a limitation that should be considered when using the map. The geographical distribution of the susceptibility classes is in relatively good agreement with published field observations, and with the existing expert knowledge on landslides in Germany (see e.g. Glade and Crozier 2005, and references therein). However, due to the aggregation of the original grid data to relatively coarse administrative units, a significant loss of detail could be observed. The original grid-based map (Günther et al. 2007) largely resembles an earlier qualitative landslide susceptibility map for Germany based on the heuristic analysis of a 1:1,000,000 scale geological map and topographic data prepared by Dikau and Glade (2003).

4. "Tier 2" analysis

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 a continent-wide "Tier 1" assessment. It is possible to perform quantitative evaluations of landslide susceptibility adopting statistical assessment techniques only where landslide inventories 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. For the definition of landslide hazard municipality boundaries were selected as mapping unit. Two hazard/risk models were prepared exploiting two different 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 (Guzzetti et al. 2005; Guzzetti et al. 2006), including lithological, soil and climate data, and a set of morphometric variables obtained from the SRTM 90 m × 90 m digital elevation model (Fig. 2). Lithological information was obtained from a synoptic geological map published by Compagnoni et al. (1976–1983). 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), first an estimate of the average recurrence of landslide events in each municipality 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 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. 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 thus revealed the ability of the model to predict where future landslides may occur in Italy.

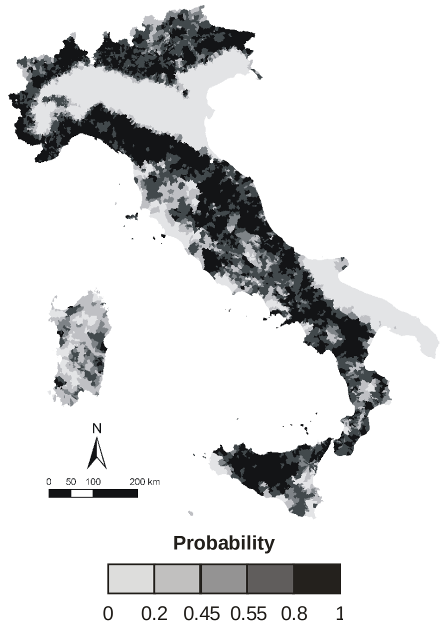

Fig. 2 Probabilistic, inventory-based landslide susceptibility model for Italy as an example for a "Tier 2" analysis

Conclusions

In this contribution, we have outlined the recent approaches towards the establishment of a common methodology for the assessment of the landslide threat within the European Union's Soil Thematic Strategy. We have referred to the framework and requirements for the spatial assessment of soil threats in general and accordingly described preliminary methodological approaches for "Tier 1" and "Tier 2" assessments of landslide susceptibility.

The preparation of a robust European heuristic "Tier 1" landslide susceptibility or hazard model requires the calibration of suitable weighting and scoring schemes with representative landslide data, and probably also local reclassifications of these to account for specific landslide types in particular European regions. From these circumstances, it is clear that the preparation of a "Tier 1" landslide susceptibility map must be considered as a multiphase approach, requiring input of expert knowledge at each step of model improvement. In any case, even the preliminary “Tier 1” assessments presented herein can be shown to perform much better than the European landslide hazard map produced by ESPON, which is solely based on expert opinion and suffers from data gaps (Schmidt-Thomé 2006).

For the evaluation and calibration of “Tier 1” as well as the preparation of “Tier 2” landslide susceptibility evaluations as described above geographical information on landslides is mandatory. It is recommended that the minimum requirements for a pan-European landslide database consist of location and type of historical landslides. Additionally, this inventory should include date of occurrence, soil/bedrock material involved, surface extent and direct impact of landslide events. Since many European countries do operate and maintain national or regional landslide inventory systems, an attempt should be made to gather and harmonize the minimum required information stated above from these databases to serve as a nucleus for a European landslide event inventory.

Regarding the fact that landslides are more localized and diverse phenomena than all the other soil threats, it is a matter of debate if higher resolution assessment schemes beyond “Tier 2” may be required in a common methodology to assess this particular soil threat. We thus recommend the application of more detailed inventory-based and physically-based landslide susceptibility and hazard models for different types of landslides and triggering factors within areas of high to very high landslide susceptibility as delineated by “Tier 2”.

Acknowledgments

We thank Andreas Richter (BGR) for collaborating on the landslide susceptibility classification of the soil/bedrock associations of the German soil database. We are very much indebted to Rainer Baritz (BGR), Fausto Guzzetti (CNR-IRPI) and the members of the European landslide experts group for all the fruitful discussions on the assessment of the landslide threat in the context of the Soil Thematic Strategy.

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