New Developments in Harmonized Landslide Susceptibility Mapping over Europe in the Framework of the European Soil Thematic Strategy

Andreas Günther, Miet Van Den Eeckhaut, Paola Reichenbach, Javier Hervás, Jean-Philippe Malet, Claire Foster, and Fausto Guzzetti

Abstract

In the context of the European Soil Thematic Strategy, and the formulation of a draft of a European framework directive devoted to the sustainable use of soil, landslides are recognized as one of the eight soil threats requiring harmonized spatial hazard assessments over the EU territory. The general framework for such assessments consists of a nested geographical approach based on "Tiers", where a low-resolution (1:1 Million) evaluation ("Tier 1") using already available pan-European datasets should enable the delineation of priority areas requiring more detailed assessments with additional data ("Tier 2"). In this contribution, we present new developments in the elaboration of a "Tier 1" generic landslide susceptibility evaluation based on a heuristic modelling approach exploiting the most important landslide conditioning factors. Extensive landslide locations available at small spatial scales have been collected and harmonized over the EU territory to be used for input parameter specification and model calibration, evaluation and classification. Since the analyzed area is highly complex in terms of climato-physiographic conditions controlling landslide occurrences, a preliminary landslide terrain differentiation is proposed consisting of eight calibration zones where specific predictor class weights have been allocated through a heuristic indexing approach. The spatially combined preliminary pan-European susceptibility estimate classifies 13 % of the EU territory as prone to landslides, thus requiring more detailed, quantitative inventory-based susceptibility evaluations ("Tier 2").

Keywords

Landslides • Susceptibility map • Heuristic model • Soil Thematic Strategy • Continental scale

Introduction

The relevance of landslide zoning for environmental policy and decision making in Europe is above all set forth in the framework of the European Union's Thematic Strategy for Soil Protection, adopted on 22 September 2006 (EC 2006a). This Strategy considers landslides as one of eight soil threats in Europe for which identification of areas where they are likely to occur in the future (so-called priority areas in the Strategy) and design of risk reduction measures is needed. To achieve these objectives, the Soil Framework Directive was proposed as a legislative instrument (EC 2006b).

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For the identification of priority areas for soil threats, the Soil Information Working Group (SIWG) of the European Soil Bureau Network (ESBN) selected a set of common thematic data (i.e., landslide occurrence or density, topography, bedrock, soil type, land cover, land use, climate and seismicity; Eckelmann et al. 2006) and envisaged a nested geographical assessment scheme based on "Tiers", where a "Tier 1" assessment is aimed for the general delineation of areas prone to the generic landslide threat at the continental scale. The initial work of SIWG in ESBN on the landslide threat was put forward by the European Landslide Expert Group (http://eusoils.jrc.ec.europa.eu/library/themes/Landslides) created in 2007.

In this paper, the recent developments in the preparation of a continent-wide "Tier 1" generic landslide susceptibility map are presented. Since the European territory covered by the 27 EU member states, Norway, Switzerland and the Balkan countries is highly complex in terms of climatological, physiographical and seismotectonical conditions, we suggest a preliminary landslide terrain differentiation over the study area resulting in eight distinct model zones. We then briefly introduce the thematic data representing the landslide conditioning factors for a "Tier 1" susceptibility evaluation as well as the results of an extensive survey undertaken to collect available landslide locations from national and regional databases held by different institutions.

We finally present a preliminary pan-European landslide susceptibility estimate produced from spatial combination of the results obtained for each model zone using a heuristic model, in which the collected landslide locations were used for landslide conditioning factor class weight calibrations, and model evaluations and classifications.

Data and Thematic Information

Climato-physiographic Landslide Regions

A preliminary attempt to delineate climato-physiographic regions with broadly distinct landslide controlling characteristics was done through aggregation of the 36 climatic areas of the "Soil Regions Map of Europe 1:5 M" (BGR 2005) into seven model regions (Fig. 1). Additionally, the coastal areas have been extracted as a separate model zone using a 1 km buffer landward from the coastline (Malet et al. 2009). This seems important since coastal landslides and their controlling/triggering characteristics are not comparable to inland phenomena. For landslide susceptibility evaluations, each of the eight model zones is treated separately.

When examining the terrain differentiation shown in Fig. 1, it can be inferred that the delineated zones display individual characteristics in terms of the spatial distribution of important geofactors and climatic attributes, whereas within most zones especially elevation and precipitation show a high degree of intercorrelation. However, the zonation shown in Fig. 1 must be considered preliminary mainly because it does not show a good differentiation in central Europe since not sufficiently considering physiographic characteristics.

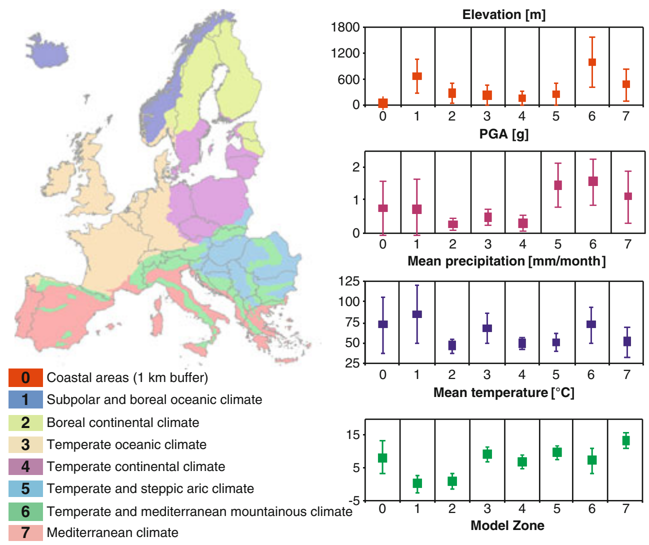

Fig. 1 Preliminary climato-physiographic terrain differentiation resulting in eight individual model zones (*left*) and basic zonal statistics (mean values with standard deviations) of important first-order morphologic, seismologic and climatic factors attributed t0 landslide occurrence (*right*)

Landslide Conditioning Factors

According to the specifications for a "Tier 1" assessment over Europe, the three most important landslide conditioning factors, slope gradient, lithology and land cover, are used for susceptibility evaluation (Hervás 2007; Günther et al. 2008; Hervás et al. 2010) (Fig. 2). At the given analysis scale, these factors can be assumed to have a high degree of conditional independence and also can be considered the major predisposing elements controlling the occurrence of all types of landslides. All input parameters derived from common pan-European or global datasets have been selected against alternative data based on their individual predictive capability to the compiled landslide database (see below). More specifically, the data used for this assessment consists of (Fig. 2):

- A slope gradient map derived from the EU27 DEM (Reuter 2009). This DEM covers the 27 EU member states and Norway and Switzerland as well as the non-EU Balkan countries, but lacks information on Iceland

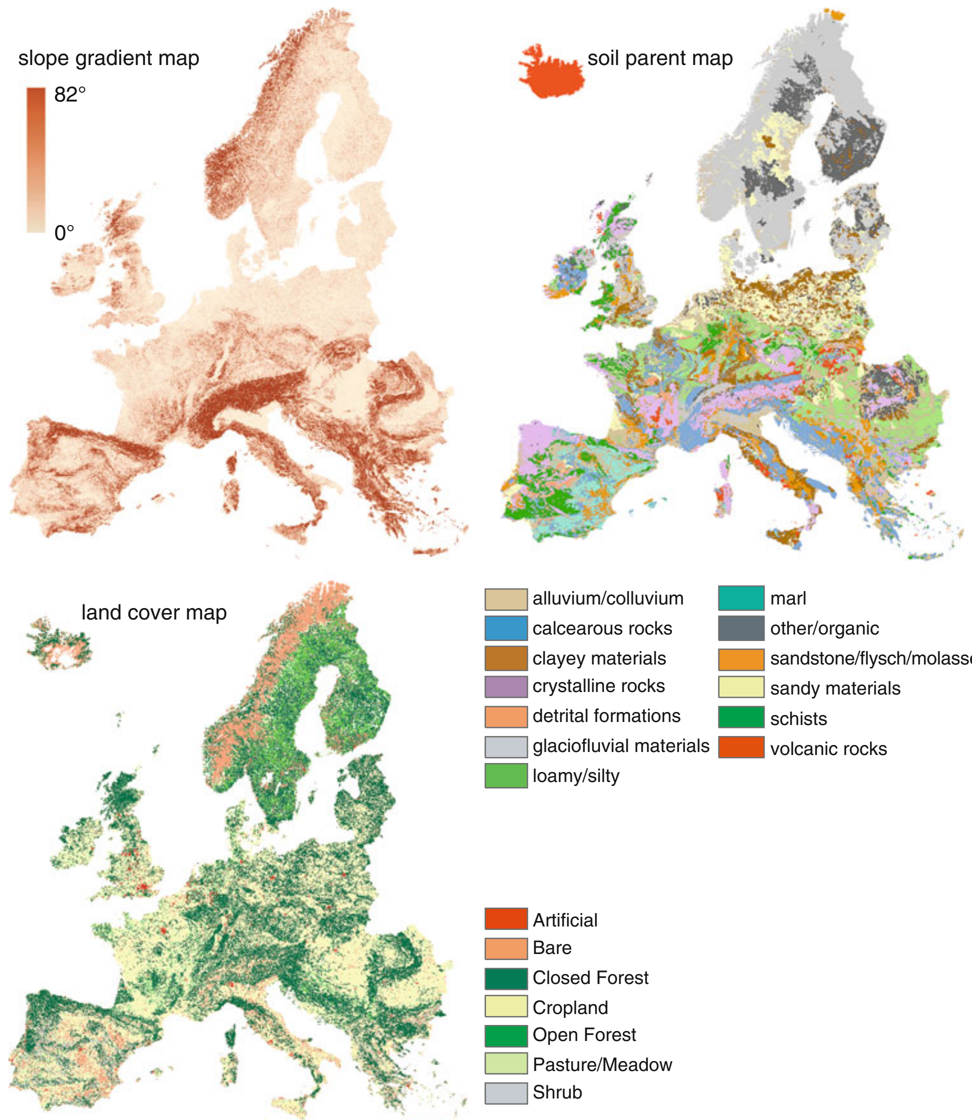

Fig. 2 Thematic information of the landslide conditioning factors used for the continental level "Tier 1" analysis

and Cyprus. The continuous slope raster derived from this dataset was classified into eight slope classes using the frequency distribution of the landslides over the integer slope.

- A soil parent material map derived from the "Soil Geographical Database of Europe 1:1 M" (Panagos et al. 2012). The dominant parent material information stored as attributes of soil typological units (STU's) was further aggregated from 42 classes available at level 2–13 classes based on expert knowledge, landslide distribution and class size. The vector data was rasterized to a grid with a cell size of 1 × 1 km.
- A land cover map derived from the global land cover dataset GlobCover produced by the European Space Agency (ESA) (http://ionia1.esrin.esa.int/_). The 23 classes have been aggregated into seven land cover classes for this assessment. The grid cell size of the GlobCover dataset is 300 m.

Landslide Information

Throughout the EU, vast information on landslides is available from national and regional level landslide inventories compiled for different purposes with different levels of detail by different institutions (Van Den Eeckhaut et al. 2011), but so far no attempt has been made to harmonize this information to produce a homogeneous pan-EU landslide location coverage. For this study, we conducted an extensive survey collecting landslide point information from different sources that can be used for the establishment and evaluation of susceptibility estimations.

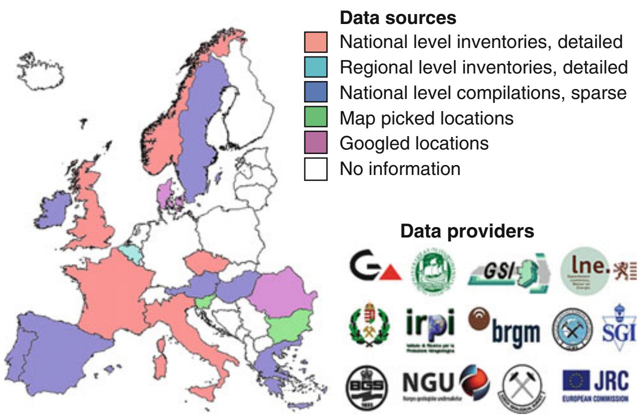

Fig. 3 Current status of landslide location information used in this study for individual European countries compiled from different sources

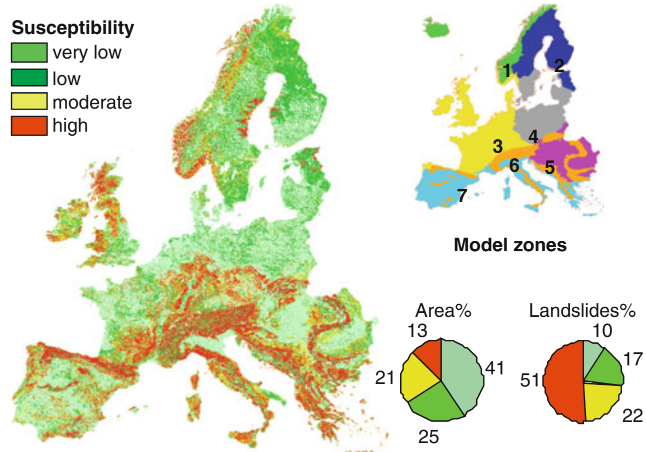

Fig. 4 Preliminary landslide susceptibility map obtained from spatial mosaicking of zone-specific reclassified susceptibility indices

Figure 3 shows the current state of the landslide inventory compiled. It can be seen that many areas (especially north-eastern Europe and the Balkan region) lack information and that the landslide locations show a highly uneven distribution throughout the model zones in terms of level of detail. However, most of the area not covered by landslide information belongs to model zones 2 and 4 which can be considered comparably less affected by the landslide threat over the majority of the area. In a whole, more than 100,000 landslide points have been integrated into the assessment by now.

Landslide Susceptibility Evaluation

For landslide susceptibility mapping, each model zone is treated separately and a first pan-European map was produced by spatial mosaicking of the individual zone-specific estimates. The preliminary susceptibility evaluation and classification process consists of a heuristic assessment involving the following steps:

- Assignment of global parameter weights (w_j) through pairwise comparison of the three predictors, where the highest importance is given to the slope parameter (Malet et al. 2009, 2011).
- Zone-specific allocation of standardized parameter class weights (x_{ij}) utilizing landslide frequency ratios derived from the harmonized landslide inventory and expert knowledge combined with trial-and-error model runs and analysis of false negatives.
- Calculation of a landslide susceptibility index S for each model zone using

$$S = \sum_{j=1}^{n=3} w_j \cdot x_{ij} \tag{1}$$

where w_j is the weight of predictor j and x_{ji} is the weight of class i in predictor j.

- Evaluation of the zone-specific susceptibility index grids using ROC curves and slicing into four susceptibility levels at True Positive Ratios (TPR) breaks of 0.5, 0.75, 0.9.
- Spatial mosaicking of the resulting zone-specific susceptibility maps (Fig. 4).

Preliminary Conclusions and Work in Progress

The preliminary pan-EU susceptibility map shown in Fig. 4 has certain important limitations, but is able to classify 13 % of the area as comparably landslide prone since >50 % of the landslide points are situated therein. In many portions of the study area, even this preliminary assessment has a reasonable performance. The preliminary estimate chiefly suffers from the fact that the model zone delineation needs to be improved, and that the zone-specific susceptibility maps cannot be straightforwardly associated through spatial mosaicking since the susceptibility classes must be assumed to differ in terms of landslide intensity across the model zones. Moreover, there is need for further elaboration of the heuristic analysis scheme, and validation of the results against other assessments. Currently, the following improvements are carried out:

- Delineation and testing of alternative and more appropriate model zones across Europe.
- Incorporation of additional landslide locations (especially in underestimated areas) and enhancement of data standardization to increase the signal obtained form landslide occurrence.
- Implementation of a more advanced heuristic analysis scheme employing spatial multi-criteria evaluation

(Malet et al. 2009, 2011) also considering more appropriate spatial associations of the zone-specific estimates.

- Cross-validation of the heuristic model with multivariate statistical analyses (stepwise logistic regression, Van Den Eeckhaut et al. 2010) using the same data in representative areas of the model zones where the inventory information has a high level of completeness.

In a future stage, it also seems important to produce landslide-type specific susceptibility estimates (Malet et al. 2009, 2011). This may be considered a general advancement in EU-wide "Tier 1" landslide susceptibility evaluations since the information for a rough typological differentiation (e.g., flows, slides and falls/topples) is available in or may be assigned to most of the inventory data collected for this study.

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