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Estimating the quality of landslide susceptibility models

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Abstract

We present a landslide susceptibility model for the Collazzone area, central Italy, and we propose a framework for evaluating the model reliability and prediction skill. The landslide susceptibility model was obtained through discriminant analysis of 46 thematic environmental variables and using the presence of shallow landslides obtained from a multi-temporal inventory map as the dependent variable for statistical analysis. By comparing the number of correctly and incorrectly classified mapping units, it is established that the model classifies 77.0% of 894 mapping units correctly. Model fitting performance is investigated by comparing the proportion of the study area in each probability class with the corresponding proportion of landslide area. We then prepare an ensemble of 350 landslide susceptibility models using the same landslide and thematic information but different numbers of mapping units. This ensemble is exploited to investigate the model reliability, including the role of the thematic variables used to construct the model, and the model sensitivity to changes in the input data. By studying the variation of the model's susceptibility estimate, the error associated with the susceptibility assessment for each mapping unit is determined. This result is shown on a map that complements the landslide susceptibility map. Prediction skill of the susceptibility model is then estimated by comparing the forecast with two recent event inventory maps. The susceptibility model is found capable of predicting the newly triggered landslides. A general framework for testing a susceptibility model is proposed, including a scheme for ranking the quality of the susceptibility assessment.

Keywords: Landslide susceptibility; Statistically based model; Discriminant analysis; Quality; Uncertainty; Validation; Landslide prediction; Map

1. Introduction

Susceptibility is the propensity of an area to generate landslides. In mathematical form, landslide susceptibility is the probability of spatial occurrence of known slope failures, given a set of geoenvironmental conditions (Guzzetti et al., 2005). Assuming landslides will occur in the future because of the same conditions that produced them in the past (Guzzetti et al., 1999), susceptibility assessments can be used to predict the geographical location of future landslides (Chung and Fabbri, 1999; Guzzetti et al., 2005). Many methods have been proposed to evaluate landslide susceptibility at the basin scale, including direct geomorphological mapping, heuristic approaches, statistical classification methods and physically based models (Carrara et al., 1995; Soeters and van Westen, 1996; Chung and Fabbri, 1999; Guzzetti et al., 1999, and references therein). Statistical classification methods are particularly suited to determining landslide susceptibility over large and complex areas (e.g., Cardinali et al., 2002). Such methods provide quantitative estimates of "where"

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landslides are expected, based on detailed information on the distribution of past landslides and a set of thematic environmental information. The former becomes the dependent variable and the latter the independent variables for the statistical modelling. Landslide susceptibility does not forecast "when" or "how frequently" a landslide will occur or how large and destructive the slope failure will be (Guzzetti et al., 2005).

In recent years, many landslide susceptibility assessments (often referred to as hazard assessments) have been published. We counted at least 40 papers in major international journals in the 6-year period from 2000 to 2005 discussing landslide susceptibility. The majority of the published papers present a statistically based susceptibility model and discuss the data and the method used to prepare the model, but provide little or no information on the quality of the proposed model. This is a limitation of much previous research (Chung and Fabbri, 2003), including some of our own work (e.g., Carrara et al., 1995; Guzzetti et al., 1999; Cardinali et al., 2002).

Any attempt to ascertain landslide susceptibility in a region needs proper validation. Validation should establish the quality (i.e., reliability, robustness, degree of fitting and prediction skill) of the proposed susceptibility estimate. The quality of a landslide susceptibility model can be ascertained using the same landslide data used to obtain the susceptibility estimate, or by using independent landslide information not available to construct the model. The former allows for (i) evaluating the degree of match between the predicted susceptibility levels in a given region, and the distribution and abundance of known landslides in the same region; (ii) evaluating the role of the thematic information in constructing the model; (iii) assessing the ability of the model to cope with variations in the input data; and (iv) determining the error associated with the obtained susceptibility estimate. The latter allows for determining the prediction skill of the model to forecast the location of new or reactivated landslides (Chung and Fabbri, 2003; Guzzetti et al., 2005).

In this paper, we provide a comprehensive validation of a landslide susceptibility model prepared through discriminant analysis of thematic information for the Collazzone area in central Umbria (Fig. 1). The landslide susceptibility model is first presented. A set of tests is then performed, aimed at evaluating the quality and robustness of the model. We further test the ability of the model to predict new landslides by comparing the susceptibility estimate against the distribution of slope failures that occurred after the model was prepared. Results obtained are discussed, and a general framework is proposed for evaluating and ranking the quality of a statistically based landslide susceptibility model.

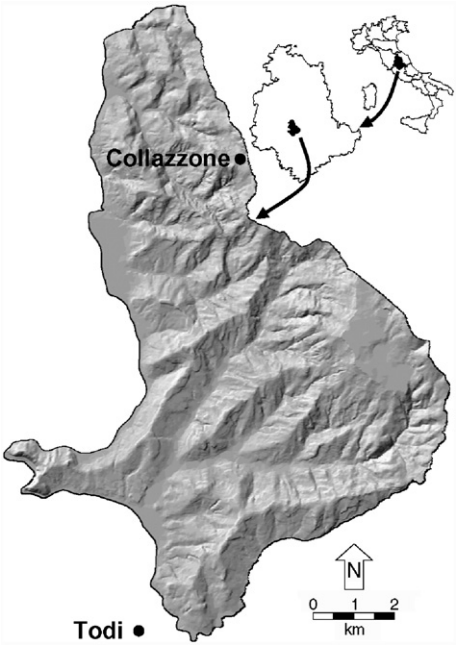

Fig. 1. Location of the Collazzone study area in Umbria, central Italy. Shaded relief image shows the hilly morphology of the area.

2. The study area

The Collazzone area extends for 78.9 km^2 in central Umbria, Italy (Fig. 1). Elevation in the area ranges from 145 m to 634 m above sea level, with an average value of 273 m (standard deviation = 96.1 m). Terrain gradient computed from a 10 m × 10 m DTM ranges from 0° to 63.7° degree, with a mean value of 9.9° and a standard deviation of 6.4°. In the area the terrain is hilly, valleys are asymmetrical, and the lithology and attitude of bedding control the morphology of the slopes. Gravel, sand, clay, travertine, layered sandstone and marl, and thinly layered limestone, Lias to Holocene in age, crop out in the area. Soils range in thickness from a few decimetres to more than 1 m; they have a fine or medium texture and exhibit a xenic moisture regime, typical of the Mediterranean climate. Precipitation is most abundant in October and November; with a mean annual rainfall in the period from 1921 to 2001 of 884 mm. Snow falls on the area on average every 2–3 years. Landslides are abundant in the area, and range in age, type, morphology and volume from very old, partly eroded, large and deep-seated slides to young, shallow slides and flows. Slope failures are triggered chiefly by