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Is it beneficial to approximate pre-failure topography to predict landslide susceptibility with empirical models?

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Empirical landslide susceptibility maps spatially depict the areas where future slope failures are likely due to specific environmental conditions. The underlying statistical models are based on the assumption that future landsliding is likely to occur under similar circumstances (e.g. topographic conditions, lithology, land cover) as past slope failures. This principle is operationalized by applying a supervised classification approach (e.g. a regression model with a binary response: landslide presence/absence) that enables discrimination between conditions that favored past landslide occurrences and the circumstances typical for landslide absences. The derived empirical relation is then transferred to each spatial unit of an area.
Literature reveals that the specific topographic conditions representative for landslide presences are frequently extracted from derivatives of digital terrain models at locations were past landslides were mapped. The underlying morphology-based landslide identification becomes possible due to the fact that the topography at a specific locality usually changes after landslide occurrence (e.g. hummocky surface, concave and steep scarp). In a strict sense, this implies that topographic predictors used within conventional statistical landslide susceptibility models relate to post-failure topographic conditions – and not to the required pre-failure situation.
This study examines the assumption that models calibrated on the basis of post-failure topographies may not be appropriate to predict future landslide locations, because (i) post-failure and pre-failure topographic conditions may differ and (ii) areas were future landslides will occur do not yet exhibit such a distinct post-failure morphology.
The study was conducted for an area located in the Walgau region (Vorarlberg, western Austria), where a detailed inventory consisting of shallow landslides was available. The methodology comprised multiple systematic comparisons of models generated on the basis of post-failure conditions (i.e. the standard approach) with models based on an approximated pre-failure topography. Pre-failure topography was approximated by (i) erasing the area of mapped landslide polygons within a digital terrain model and (ii) filling these “empty” areas by interpolating elevation points located outside the mapped landslides. Landslide presence information was extracted from the respective landslide scarp locations while an equal number of randomly sampled points represented landslide absences. After an initial exploratory data analysis, mixed-effects logistic regression was applied to model landslide susceptibility on the basis of two predictor sets (post-failure versus pre-failure predictors). Furthermore, all analyses were separately conducted for five different modelling resolutions to elaborate the suspicion that the degree of generalization of topographic parameters may as well play a role on how the respective models may differ. Model evaluation was conducted by means of multiple procedures (i.e. odds ratios, k-fold cross validation, permutation-based variable importance, difference maps of predictions).
The results revealed that models based on highest resolutions (e.g. 1 m, 2.5 m) and post-failure topography performed best from a purely quantitative perspective. A confrontation of models (post-failure versus pre-failure based models) based on an identical modelling resolution exposed that validation results, modelled relationships as well as the prediction pattern tended to converge with a decreasing raster resolution. Based on the results, we concluded that an approximation of pre-failure topography does not significantly contribute to improved landslide susceptibility models in the case (i) the underlying inventory consists of small landslide features and (ii) the models are based on coarse raster resolutions (e.g. 25 m). However, in the case modelling with high raster resolutions is envisaged (e.g. 1 m, 2.5 m) or the inventory mainly consists of larger events, a reconstruction of pre-failure conditions might be highly expedient, even though conventional validation results might indicate an opposite tendency. Finally, we recommend to consider that topographic predictors highly useful to detect past slope movements (e.g. roughness) are not necessarily valuable to predict future slope instabilities.