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# Engineering geology characterization of slope deposits and physically-based assessment of shallow landslide susceptibility (Alpi Apuane, Italy)

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In this work we present the results of engineering geology characterization of slope deposits and assessment of shallow landslide susceptibility by means of a probabilistic physically-based model for the Western sector of the Alpi Apuane (Northern Apennines, Italy). The Alpi Apuane are a Tertiary metamorphic complex which is undergoing fast tectonic uplift, exhumation and erosion in respect to neighboring regions (the coastal Versilia Plain and Garfagnana Valley). For these reasons, the morphology of the Alpi Apuane is characterized by high relief energy, as highlighted by elevation differences up to around 2,000 m and deep river valleys with steep slopes. Moreover the study area records annual precipitations among the highest in Italy (up to around 2,500 mm/y) and, especially in the last decades, frequent intense rainfall events (i.e.: 1996, 1998, 2000, 2011, 2013, 2014). In this framework landslides are widespread, especially shallow landslides involving unconsolidated slope deposits overlying bedrock. In order to assess shallow landslide susceptibility we used a hydrological model coupled to a limit-equilibrium infinite-slope stability model. Reliability of results by physically-based models depends on accuracy of map distribution of input data which, however, is usually almost unknown. Hence, fieldwork and laboratory tasks were carried out to map engineering geology characters of slope deposits. For a set of hundreds of field sampling points, we acquired: depth to the bedrock, geotechnical horizons, unit weight, as well as soil samples for lab analysis. The distribution of points were chosen by observing that engineering geology properties of slope deposits depend on both bedrock lithology and morphometric conditions. Then, for a subset of the sampling points, we performed hydraulic conductivity measurements. Geotechnical determinations allowed us to estimate the friction angle ranges for different slope deposit types. In order to obtain the map distribution of engineering geology parameters, we implemented a spatial analysis by clustering morphometric variables stratified as a function of bedrock lithological units. Multitemporal visual interpretation of orthophotos (2003-2016) allowed us to obtain the database for a new shallow landslide inventory, which later underwent field accuracy assessment. By integrating the inventory to geology, we identified those bedrock lithological units where the infinite-slope assumption for shallow landslide modeling could be reasonably applied. In order to take into account and evaluate the effects of input parameters uncertainty, we implemented the slope stability-hydrological model by means of a Monte Carlo simulation. Assuming that the cohesion of slope deposits change in space and time depending upon seasonal variation of land cover and precipitations, we calibrated the model by means of a back-analysis aimed at estimating the cohesion intervals which allow for optimization of the final predictive performance within the shallow landslide regions. This task was performed by using both prediction-rate curve and ROC diagrams. Finally, the results of susceptibility assessment, as well as maps/diagrams useful to describe the variability/uncertainty of results are critically discussed.