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Derivation of landslide-triggering thresholds by Monte Carlo simulation and ROC analysis

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Rainfall thresholds of landslide-triggering are useful in early warning systems to be implemented in prone areas. Direct statistical analysis of historical records of rainfall and landslide data presents different shortcomings typically due to incompleteness of landslide historical archives, imprecise knowledge of the triggering instants, unavailability of a rain gauge located near the landslides, etc.

In this work, a Monte Carlo approach to derive and evaluate landslide triggering thresholds is presented. Such an approach contributes to overcome some of the above mentioned shortcomings of direct empirical analysis of observed data. The proposed Monte Carlo framework consists in the combination of a rainfall stochastic model with hydrological and slope-stability model. Specifically, 1000-years long hourly synthetic rainfall and related slope stability factor of safety data are generated by coupling the Neyman-Scott rectangular pulses model with the TRIGRS unsaturated model (Baum et al., 2008) and a linear-reservoir water table recession model. Triggering and non-triggering rainfall events are then distinguished and analyzed to derive stochastic-input physically based thresholds that optimize the trade-off between correct and wrong predictions. For this purpose, receiver operating characteristic (ROC) indices are used. An application of the method to the highly landslide-prone area of the Peloritani mountains in north-eastern Sicily (Italy) is carried out. A threshold for the area is derived and successfully validated by comparison with thresholds proposed by other researchers.

Moreover, the uncertainty in threshold derivation due to variability of rainfall intensity within events and to antecedent rainfall is investigated. Results indicate that variability of intensity during rainfall events influences significantly rainfall intensity and duration associated with landslide triggering. A representation of rainfall as constant–intensity hyetographs globally leads to non-conservative thresholds. When a time-variable rainfall-rate event is considered, the simulated triggering points may be separated with a very good approximation from the non-triggering ones by an I–D power-law equation. Such an equation thus turns out to be adequate to represent the triggering part due to transient infiltration produced by rainfall events of variable intensity. This provides a physically based justification for the I-D power-law threshold form, which is valid when landslide occurrence is mostly due to that part, i.e. in hillslopes of low specific upslope contributing area, with soils of relatively high hydraulic conductivity and high critical wetness ratio. Otherwise, rainfall time history occurring before single rainfall events influences landslide triggering, determining the need to take into account antecedent rainfall.