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Derivation of debris flow critical rainfall thresholds from land stability modeling

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The aim of the work is to develop a system capable of providing debris flow warnings in areas where historical events data are not available as well as in the case of changing environments and climate. For these reasons, critical rainfall threshold curves are derived from mathematical and numerical simulations rather than the classical derivation from empirical rainfall data.
The operational use of distributed model, based on the stability analysis for each grid cell of the basin, is not feasible in the case of warnings due to the long running time required for this kind of model as well as the lack of detailed information on the spatial distribution of the properties of the material in many practical cases.
Moreover, with the aim of giving debris flow warnings, it is not necessary to know the distribution of instable elements along the basin but only if a debris flow may affect the vulnerable areas in the valley. The capability of a debris flow of reaching the downstream areas depends on many factors linked with the topography, the solid concentration, the rheological properties of the debris mixture and the flow discharge as well as the occurrence of liquefaction of the sliding mass. In relation to a specific basin, many of these factors may be considered as not time dependent. The most rainfall dependent factors are flow discharge and correlated total debris volume. In the present study, the total volume that is instable, and therefore available for the flow, is considered as the governing factor from which it is possible to assess whether a debris flow will affect the downstream areas or not.
The possible triggering debris flow is simulated, in a generic element of the basin, by an infinite slope stability analysis. The groundwater pressure is calculated by the superposition of the effect of an “antecedent” rainfall and an “event” rainfall. The groundwater pressure response to antecedent rainfall is used as the initial condition for the time-dependent computation of the groundwater pressure response to the event rainfall.
Antecedent rainfall response is estimated in the hypotheses of low intensity and long duration, thus assuming steady state conditions and slope parallel groundwater flux. The short term response to rainfall is assessed in the hypothesis of vertical infiltration.
The simulations are performed in a virtual basin, representative of the one studied, taking into account the uncertainties linked with the definition of the characteristics of the soil.
The approach presented is based on the simulation of a large number of cases covering the entire range of the governing input dynamic variables. For any possible combination of rainfall intensity, duration and antecedent rain, the total debris volume, available for the flow, is estimated. The resulting database is elaborated in order to obtain rainfall threshold curves. When operating in real time, if the observed and forecasted rainfall exceeds a given threshold, the corresponding probability of debris flow occurrence may be estimated.