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Physical interpretation of rainfall threshold for debris flows triggered by surface erosion

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Rainfall thresholds for landslide occurrence are commonly defined using a combination of selected precipitation measurements (such as event rainfall P, duration D, or average intensity I) that describe critical rainfall conditions. Intensity-duration (ID) thresholds are the most widely used for forecasting shallow landslides and debris flows. Interestingly, many empirical ID thresholds follow an approximately straight line when plotted in a log(D)-log(I) plane and can be expressed by a power-law of the form I=αD̂(-β), where α is a scaling coefficient and β is the exponent of the power function. Typical values for α and β are in the range 5÷40 and 0.4÷0.8 respectively. The different values of the threshold parameters reflect the variability of geological, hydrological and geotechnical conditions as well as the effect of the different factors that control slope stability. In many cases, field conditions are so complex that a physical interpretation of the empirical rainfall threshold is not possible.

In this work, we take advantage of 6-years monitoring data and of the relatively simple triggering conditions to provide the physical interpretation of the rainfall threshold for an active debris flow basin in the Eastern Italian Alps (the Dimai Basin). The Dimai basin is located 2 km north of Cortina d'Ampezzo (Northern Italy) along the river Boite valley. The upper part of the basin consists of a steep headwater watershed incised in dolomitic limestone rocks. The rocky watershed has an area of only 0.032 km2, an average slope 72°, and feeds an ephemeral channel incised in talus. Debris flows are triggered by the surface water runoff that is concentrated at the outlet of the headwater watershed, and initiate by progressive bulking of storm runoff with sediment eroded from the channel bed. The hydrologic response to rainfall in the initiation area of the debris flows has been documented for 6 years (from 2010 to 2016) by a monitoring system. The system consists of a rain gage, 2 time-lapse cameras, 1 sharp-crested weir built at the watershed outlet, and 3 pressure sensors buried into the channel bed.

Over the monitoring period, we recorded 471 rainfall events. Most of them are short-duration convective thunderstorms resulting from the rapid vertical movement of unstable air masses. Data analysis allowed to classify each rainfall event according to the observed hydrologic response and to define two empirical rainfall thresholds. A first threshold separates the rainfall events that produce and not produce overland flow at the outlet of the rocky watershed (outflow threshold). A second threshold separates the rainfall events that produce and not produce runoff in the debris flow channel (runoff threshold). Both these threshold are power-law in the DI plane with a similar exponent $\beta\approx$0.8. Simple hydrological analyses prove that our empirical thresholds can be explained using a simple "leaking barrel" model for slope hydrology. In this model the most important parameter is the initial abstraction in the headwater watershed, which include rainfall lost to interception, depression storage and wetting of the rocky surface.