A backward dynamical methodology for estimation of rainfall threshold associated to debris-flow

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ABSTRACT

A novel, dynamical-based method for the determination of the intensity and duration of the rainfall pertaining to a debris-flow event is presented. The method has been used for the determination of a rainfall threshold for a study area.

1 INTRODUCTION

Forecasting if a storm can produce a debris-flow is a quite demanding challenge, even just within a probabilistic framework. The approaches present in the literature are based on the determination of the so called rainfall threshold, i.e. curves that split the Intensity-Duration domain in two zones, one above the threshold and one below. If a given storm shows a couple of values (I, D) that falls in the zone above the threshold, there is a high probability of debris-flow occurrence, if it falls below, there is a low probability.

Indeed, the methodologies so far present in the literature (see e.g. Marra et al. 2014) give rise to thresholds that are unlikely low, and therefore they can not be used effectively in a forecast framework. For this reason, a novel method for the determination of the volume of rain pertaining to a debris-flow event was developed and hereafter presented.

2 METHODOLOGY

Usually, after a debris-flow occurrence, the regional agency measures the volume of sediments deposited (V_{dep}). Starting from the knowledge of this volume, the liquid volume (i.e. the rain V_{rain}) responsible of the mass movement can be back-reconstructed using a set of relations obtained considering a convenient simplified description of the dynamics of the debris flows. These relations are derived from the integration in space, over three suitable control volumes (see Fig. 1), and in time, over the event interval, of the solid and liquid phases mass balance under suitable assumptions on the debris-flow dynamics.

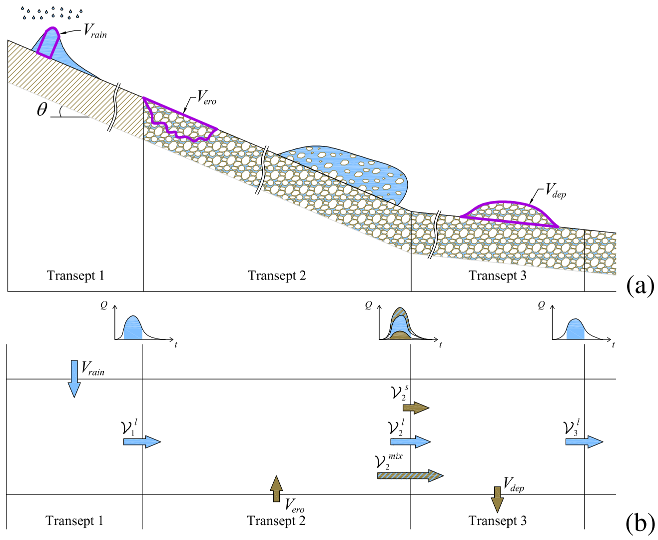

Figure 1: Conceptual scheme of a debris-fow dynamics used in the present approach: (a) Lagrangian point of view; (b) Eulerian point of view.

The main resulting relation is

$$V_{rain} = \frac{c_b - c}{c} V_{dep} \tag{1}$$

where c_b is the constant concentration of the solid phase in the bed and c is the equilibrium concentration evaluated according to Takahashi 1978

$$c = \frac{i_f}{\Delta \left(\tan\psi - i_f\right)} \tag{2}$$

where $\Delta = (\rho_s - \rho_l)/\rho_l$ is the sediment relative submerged density, ρ_l and ρ_s are the liquid and solid density respectively, ψ is the internal friction angle and i_f is the average slope.

Once the rain volume is evaluated, the relevant average intensity I and duration D of the event can be determined knowing the relevant hyetograph $i(t)$ and the area of the basin A_b. In fact,

$$V_{rain} = A_b \int_{t_{\max}-\Delta t}^{t_{\max}+\Delta t} i(t)\, dt \tag{3}$$

where $t_{\max}$ is the time relevant to the maximum value of rain intensity while Δt is assumed to be half of the event duration, namely

$$D = 2\Delta t$$

Once the duration has been obtained by solving eq. (3) with a trial-and-error method, the averaged intensity can be computed with:

$$I = \frac{V_{rain}}{A_b D}$$

If a sufficiently wide number of couples (I, D) can be evaluated on the basis of field data the frequentist method (see Peruccacci et al. 2012 for details) can be applied to obtain a rainfall threshold.

3 APPLICATION

The proposed backward dynamical method for the estimation of debris-flow pertaining rainfall has been applied to Trentino-Alto Adige region, located in the Italian Alps. The resulting threshold is plotted in Figure 2 along with the relevant $I - D$ points.

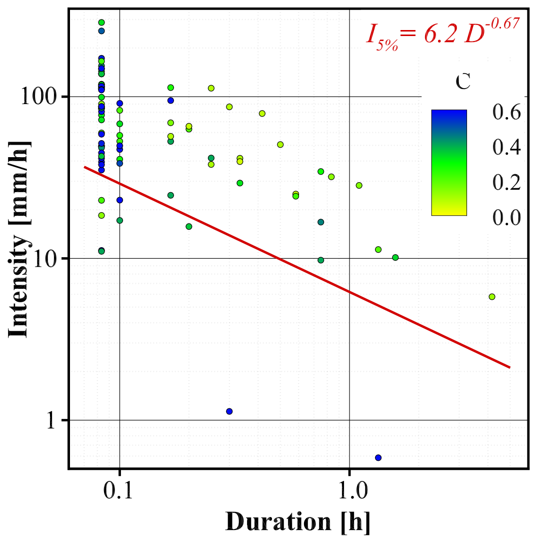

Figure 2: Debris-flow rainfall threshold evaluated using the proposed dynamical-based method. The colour of the dots correspond to the equilibrium concentration evaluated using eq. (2)

A comparison of this threshold with the threshold obtained, for the same area, with a classical literature approach based on the Critical Duration (Bonta and Rao 1988) is plotted in Figure 3. In this figure we do not extend the validity of each threshold outside the domain used for its determination, since is not completely correct. In this way we can highlight the characteristic time scale deriving from the two approaches.

In particular, from the dynamical-based method emerged that debris-flows are characterized by short or very short storm durations, ranging from $0.1\,\mathrm{h}$ to $1\,\mathrm{h}$, while the CD method suggested quite longer durations, ranging from $1\,\mathrm{h}$ to $10\,\mathrm{h}$. It is worth noting that the two time scales differ for one order of magnitude. The comparison highlights also that the proposed method shows a higher threshold: the relative difference respect the CD data spans from 25% to 31%.

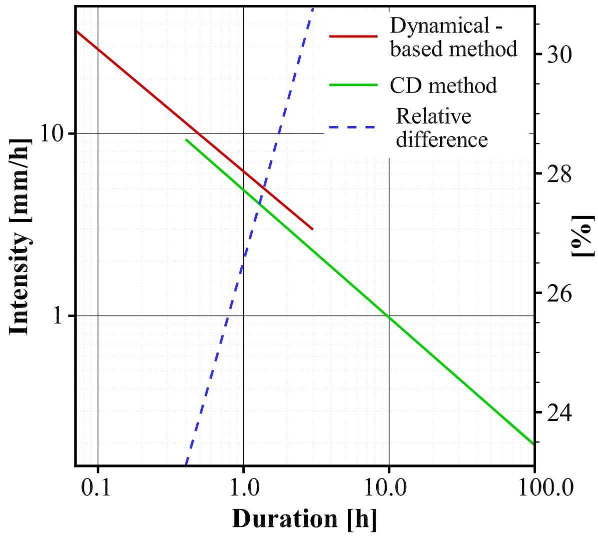

Figure 3: Comparison between the proposed dynamical-based method and the Critical Duration (CD) method for the study area and their relative difference respect the dynamical-based values

4 ACKNOWLEDGE

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