Triggering-runout modelling of rainfall-triggered debris flows: A case study in the Campania region, Italy

Triggering-runout modelling of rainfall-triggered debris flows: a case study in the Campania region, Italy

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Abstract. Debris flows are unpredictable phenomena, listed among the hugest natural hazards, since they can cause important damages to humans and structures. Rainfall can trigger this type of movements, as it provokes the pore water pressure increasing, and so the soil strength reduction. The phenomenon modelling is a key aspect to predict and prevent damages. This article shows an approach for triggering and runout analysis: triggering is studied through an infinite slope stability model of rainfall-triggered shallow landslides, while runout is modelled using a depth-averaged numerical method, which replace the real heterogeneous flow with an equivalent homogeneous fluid. The work focuses the attention to events characterized by multiple triggering zones and releases converging on the same area, whose complexity is represented by the time- and space-distribution of the different flows. The proposed approach is applied to an event that hit part of the Campania region, Italy, in 1998, causing several damages. Two rheological laws are considered and compared for the analysis. The back-analysis allows the calibration of the rheological parameters and validation of the method. Results are discussed to identify the most suitable rheology for the benchmark event.

1 Introduction

Debris flows [1] are high-speed soil movements, constituted by water and debris, which can cause big damages to human lives and structures. One of the main triggering causes is rainfall. It increases the pore water pressure in the susceptible soil, and reduces its shear strength, till possibly provoking the instability and triggering of the mass flow [2]. These phenomena are analysed in two main aspects: triggering and runout, this last including propagation and deposition. The event modelling can help in predicting the behaviour in terms of path and damages and designing effective mitigation structures.

In this paper, the authors face both triggering and runout modelling. Triggering is analysed through a grid-based slope stability model (TRIGRS [3]), while runout is simulated with a continuum mechanics-based depth-averaged model (RASH3D [4]), following the approach of La Porta et al [5].

The method is applied to a huge event which hit the Campania region, Southern Italy, in 1998. The phenomenon involved many zones of the Sarno area, with multiple triggers on each single slope. Consequently, causalities and damages to structures were registered [6].

Two rheological laws are considered for the study case, and the suitability is discussed: the Voellmy law, consisting of a frictional and a turbulent term, and the Bingham law, considering a yield stress and a viscous dissipation term. The rheology parameters are calibrated through back-analysis.

In the paper, after a brief introduction of used methods and of the benchmark event, a comparison of the runout simulations obtained with the two rheologies is shown and discussed, to highlight strong and weak points of the proposed approach.

2 Methods

2.1 Triggering

The triggering is analysed through TRIGRS (Transient Rainfall Infiltration and Grid-based Regional Slope-Stability model) [3], a Fortran program for modelling the trigger of rainfall-induced shallow landslides. Starting from Digital Terrain Model (DTM), rainfall data, and lithological and morphological characteristics of the site, the software allows the calculation of pore water pressure changes provoked by rainfall infiltration, and consequent factor of safety variation of the slope. As output, the distribution of the unstable mass is given.

2.2 Runout

The runout is modelled with RASH3D [4], a continuum mechanics-based depth-averaged model. The heterogeneous mass, made of debris and water, is

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modelled as an equivalent fluid, whose rheological characteristics simulate the behavior of the real mixture.

The aim of the study is to compare two rheologies for the benchmark event and identify the most suitable one. Voellmy and Bingham rheologies are considered. The Voellmy rheology consists of two terms, in the definition of the basal shear resistance τ_z: a Coulomb frictional term, and a turbulent one. The rheology equation is the following:

$$\tau_z = \gamma h \tan\varphi + \frac{\gamma v^2}{\xi}, \quad (1)$$

in which γ is the bulk specific weight, h is the flow height, φ is the bulk friction angle, v is the depth-averaged velocity and ξ is the turbulence coefficient [7].

The Bingham rheology defines the basal shear resistance τ_z as a combination of a viscous dissipation term and a constant yield stress τ_0:

$$\tau_z = \tau_0 + \nu_B \frac{\partial v}{\partial t}, \quad (2)$$

with ν_B the post-yield dynamic viscosity [7].

3 Description of the study case

Sarno is a small town in the Campania region (South Italy). The area is characterized by shallow pyroclastic deposits, coming from the Vesuvius and Somma volcanoes activity. The zone of Sarno, Siano, Quindici and Bracigliano, was hit by many huge rainfall-triggered debris flows in May 1998, causing around 160 casualties and important structure damages [6]. Fig. 1 shows the aforementioned debris flows in the focusing area of this paper. At the deposition area, the observed maximum flow heights during the event were around 4 m [8].

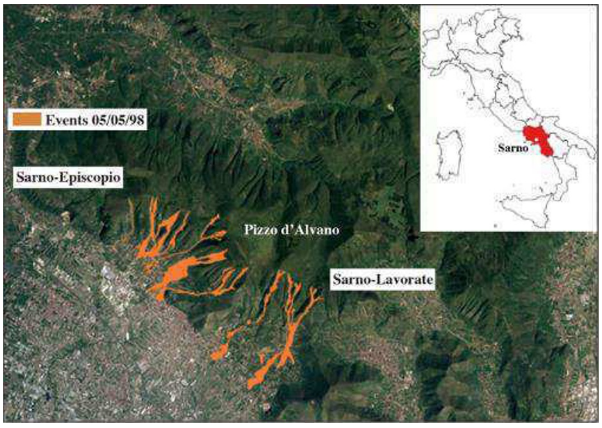

Fig. 1. Debris flow event of May 1998 in the focusing area of the article (modified from [9]).

4 Triggering-runout modelling

4.1 Triggering model

Previous research provided the morphological and mechanical parameters of the site. Additionally, the area was already modelled in the literature through TRIGRS. For instance, Sorbino et al. [10] proposed a comparison of TRIGRS and another common triggering model for the Sarno event of 1998. Table 1 contains the soil characteristics from Sorbino et al. [10].

Table 1. Mechanical characteristics of Sarno soil, adopted for the triggering analysis [10]. Here, ϕ' is the friction angle, c' the cohesion, γ_s the soil unit weight, K_s the hydraulic conductivity, D_0 the diffusivity, α a triggering numerical fitting parameter, θ_r the residual water content and θ_s the saturated water content.

ϕ' [°]	c' [Pa]	γ_s [N/m^3]	K_s [m/s]
38	5000	15000	$1 \cdot 10^{-5}$
D_0 [m^2/s]	α [m^{-1}]	θ_r [-]	θ_s [-]
$5.9*10^{-5}$	6.3	0.20	0.66

These values are adopted for the triggering analysis, except for the hydraulic permeability, which is calibrated within the range of typical values characterizing the area [8]. The goal is an overall calibration of the triggering model with reference to the estimated triggering and runout volumes [11]. The best fit is obtained with a K_s of $3 \cdot 10^{-5}$ m/s.

The collected rainfall data during the event, at the San Pietro pluviometric station, registered a cumulative rainfall of around 120 mm in thirty hours (Fig. 2). Although the rainfall event was not particularly intense, it appears that the area was particularly susceptible to soil movements due to natural and anthropic predisposing factors [12].

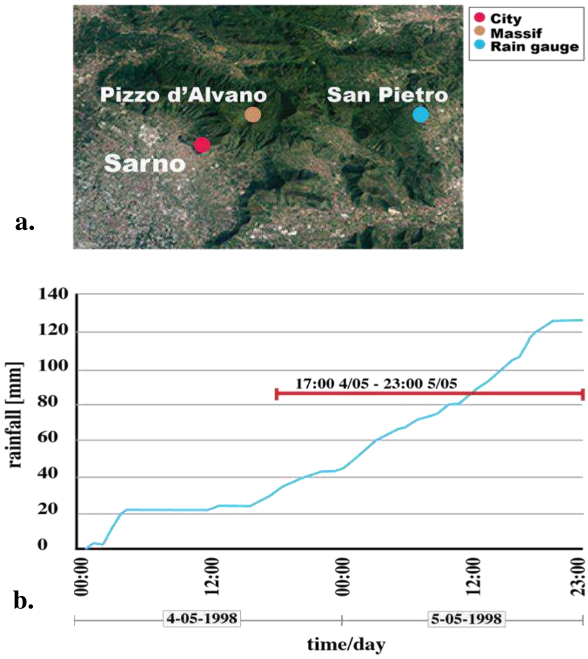

Fig. 2. Rainfall event of Sarno, of the 4th and 5th of May 1998. a) Positioning of the closest pluviometric station to the interest area, San Pietro; b) cumulative rainfall data.

Fig. 3 shows the triggering areas, an output of the analysis with TRIGRS. Additionally, the surveyed real path is reported.

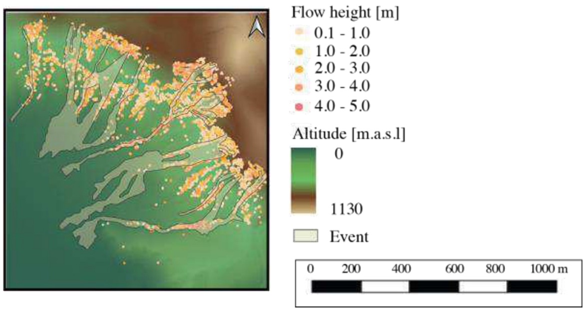

Fig. 3. TRIGRS analysis of the Sarno event: instability areas, provoked by the rainfall event considered.

The previous instances of back-analysis available in the literature provide a quick validation of the proposed model. However, some input parameters are not easily accessible or indeed measurable (e.g., the susceptible soil distribution), thus requiring further calibration. Therefore, the discrepancies that can be observed when comparing with the results of Sorbino et al. [10] are expected due to the multiple simplifications.

4.2 Runout model

For the runout model, the aforementioned rheologies are tested on the study case. Parameters are calibrated referring to typical ranges of the literature [13, 14]. With the Voellmy rheology, φ is calibrated between 3 and 10°, and the turbulence coefficient ξ between 300 and 2000 m/s^2, while using the Bingham rheology, τ_0 is calibrated between 700 and 2000 Pa, and ν_B between 300 and 500 Pa*s.

Fig. 4 contains two representative results at different runout instants: a comparison of the simulated propagation model while using the two rheologies is shown. In the picture, the Voellmy rheology is characterized by $\varphi = 7°$, and $\xi = 1000$ m/s^2, while the calibrated Bingham rheology is defined by $\tau_0 = 1000$ Pa and $\nu_B = 500$ Pa $*$ s.
The sequence contained in the picture shows that the flow characterized by the Voellmy rheology stops when reaching gentler slopes. In order to follow the real flow path, an almost null friction should be considered. This aspect motivates the use of the Bingham rheology.
In terms of flow heights, the flux characterized by the Voellmy rheology takes excessive simulated values, with respect to the observed ones [8], because of the frictional contribution, which forces the stop of the flow; contrarily, the Bingham rheology proves to be more suitable, since the simulated flow heights are closer to measured values from the field.
Unfortunately, with respect to the deposit, the Bingham flow better follows the real covered branches and the deposition shape, but still showing important discrepancies.

5 Conclusions

In this paper, an approach for modelling triggering and runout of rainfall-triggered debris flows is presented.

Triggering is analysed with TRIGRS, a program for

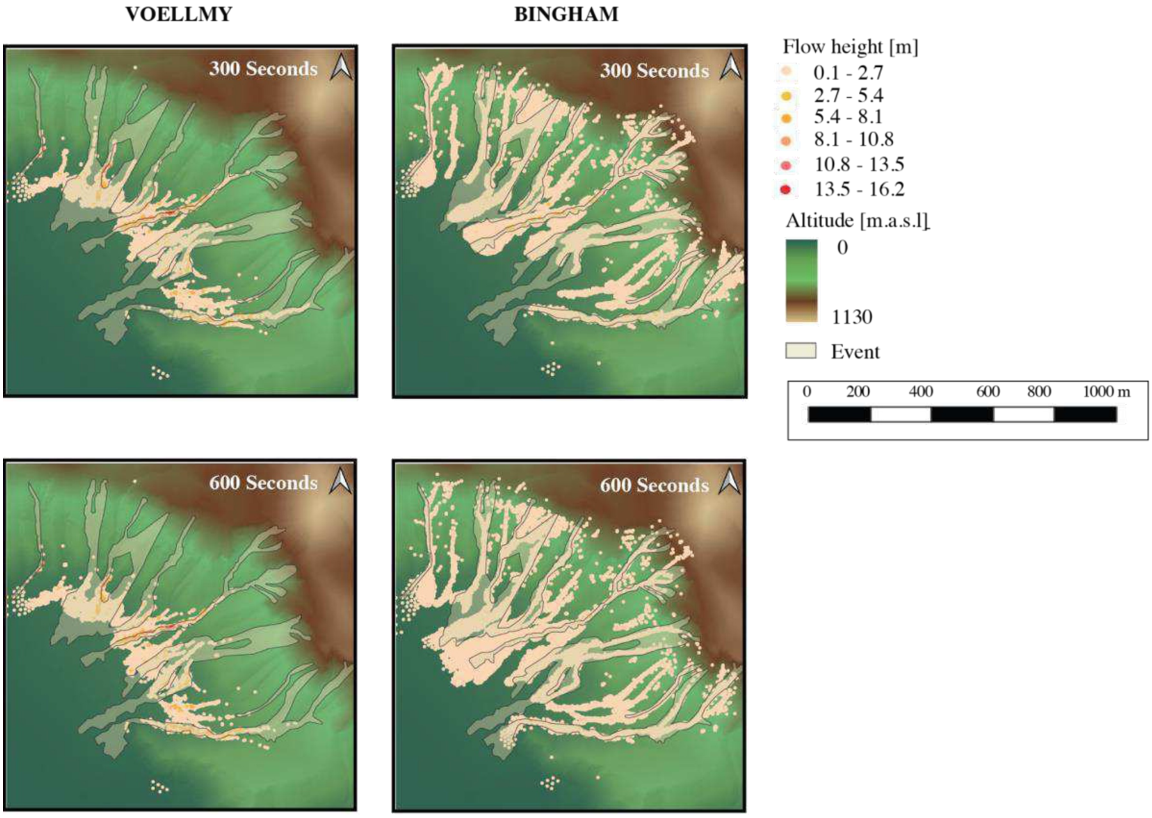

Fig. 4. RASH3D model of the Sarno event. Comparison of Voellmy and Bingham rheologies, at multiple runout instants.

the grid-based slope stability definition, through the calculation of the pore water pressure and consequent factor of safety variation, during a rainfall event. The runout is studied with the aid of RASH3D, a depth-averaged model, based on the continuum mechanics approach. The real flow is modelled as a homogenous flux, whose behaviour is governed by the adopted rheological law.

Two rheological equations are considered: the Voellmy and the Bingham. Voellmy rheology consists of two terms: a frictional and a turbulent one. Bingham rheology is defined by a yield stress and a viscous dissipation term. The suitability of the analysed rheologies is discussed through a benchmark case, represented by the huge event of Sarno, Campania region, Italy, of 1998. The phenomenon was characterized by multiple triggering areas on each slope.

The flow with Voellmy rheology cannot properly follow the real path since the frictional term causes its halt when gentler slopes are encountered. On the other hand, the Bingham reology allows a spreader flow path. Even in terms of flow heights, the Bingham rheology shows to be more suitable for the study case. Unfortunately, the deposit shape still shows to be far from the real path from field observations.

The complexity of multiple triggering debris flows, i.e. events characterized by many triggers on the same slope, stays in the time- and space-distribution and interaction of the flows. It seems realistic, and even confirmed by real observations, that not all unstable areas detached at the same instant. Further research will focus on studying a reliable time- and space-combination and distribution approach for modelling these particular events.

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