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DEVELOPMENT OF PRELIMINARY ASSESSMENT TOOLS TO EVALUATE DEBRIS FLOW HAZARD

Bregoli F.*, Ciervo F.†, Medina V.*, Bateman A.* , Hürlimann M., Chevalier G.* and Papa M.†**

* Sediment Transport Research Group (GITS), Technical University of Catalonia (UPC),
e-mail: francesco.bregoli@gits.ws, web page: http://www.gits.ws

† Consorzio Inter-Univesitario per la Previsione e la Prevenzione dei Grandi Rischi. Univesitá degli Studi di Salerno (CUGRI), e-mail: fabio.ciervo@libero.it, web page: http://www.cugri.it

**Department of Geotechnical Engineering and Geosciences, Technical University of Catalonia (UPC), e-mail: marcel.hurlimann@upc.edu, web page: http://www.upc.edu

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Summary. In the framework of the IMPRINTS European Research Project (FP7), a toolbox for fast assessment of debris flow hazard has been developed. The aim of this toolbox is to implement different existing models inside a common package useful for a fast evaluation of potential hazard. The initiation and propagation of the debris flow is included. One of the requirements of the projects is to define different scenarios with different detail levels in data input. As an example of this, the results could be obtained just using topographical data or improve accuracy by adding geological and hydrological data.

1 INTRODUCTION

Because of the mixture of water and sediment, debris flow has a very complex physical behaviour and, at the same time, represent one of the most dangerous geomorphologic process that occur in mountainous areas, involving powerful flows with high destructive capacity.

Usually, two types of assessments can be distinguished: (i) studies at regional scale and (ii) studies at local scale. Debris flow hazard assessments at regional scale generally apply a Geographic Information System (GIS)[1], in combination with statistical analysis[2], simple physical based and dynamic approaches[3]. Detailed studies at the local scale are not so common and numerical models or comprehensive field work are necessary to determine the hazard in the debris flows deposition areas[4].

The aim of that paper is to present a fast methodology to assess hazard due to debris flow at regional scale as a useful toolbox for basin's authorities. Finally the methodology is applied in two basins with different characteristics and some preliminary results are presented.

2 DEBRIS FLOW HAZARD ASSESSMENT METHODOLOGY

As the hazard assessment at regional scale is concerning a wide area it's necessary to find a general and common methodology able to describe the phenomenon in a huge range of cases. In a first attempt the uncertainty of the model was discarded, but the result was poor due to the overestimation of debris flow prone areas. Then the uncertainty was included reaching a better issue. A flow chart of methodology is defined as **¡Error! No se encuentra el origen de la referencia.** and described below.

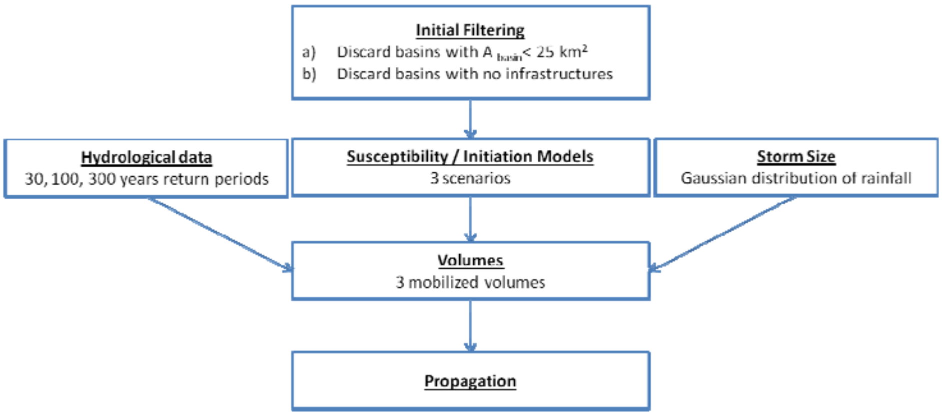

Figure 1: debris flow hazard assessment methodology's flow chart

2.1 Initial filtering

Dealing with a wide area is crucial to bound potential debris flow triggering basins to keep the calculation faster. In literature it's common to find a threshold of less than 25 km^2 of potential debris flow's basins**¡Error! No se encuentra el origen de la referencia.**. It's important to point up that there are cases where was observed debris flow events in basins with area of more than 25 km^2, especially dealing with mudflows.

In general the hazard assessment, as debris flow is a natural process, is useful in such basins with presence of human activity. If there are no infrastructures or anthropic presence, the catchment is removed from calculation, due to the lack of vulnerability.

2.2 From the triggering factors to intensity and hazard assessment

The rainfall is selected as a main triggering factor, discarding other factors like earthquakes or volcanoes. Three scenarios are associated with three return period of rainfall, coming from typical hydrologic analysis. Return period of 30, 100 and 300 years are selected as proposed by some author[5]. A simple way to relate event intensity to hazard is defining a volume of mass propagated. At the same time, volume of debris influences directly the run off distance. Different debris flow triggering models, based on rainfall analysis, as well as propagation models are selected and described in paragraph 3. To include uncertainty in the methodology, typical rainstorm characteristics should be explored.

3 IMPLEMENTED MODELS

The difficulty to achieve a good result from debris flow's modelling increase when trying to up-scaling the local process at basin or regional scale. To reach this scope is necessary to discard important behaviours that could influence the quality of the result. A tree included the different approaches proposed is defined in Figure 2.

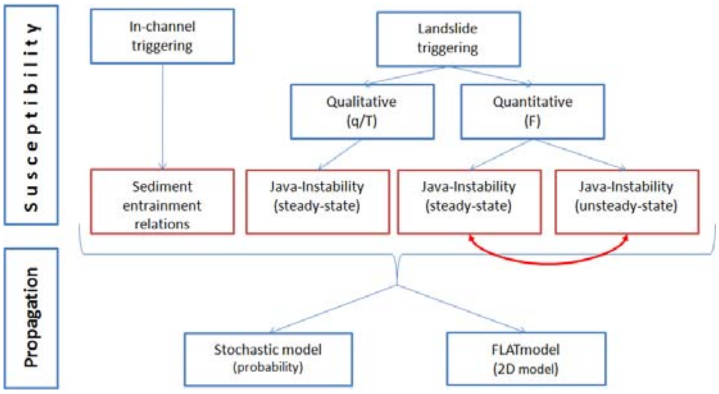

Figure 2: debris flow models

3.1 Susceptibility models

The initiation of debris flow is possible by mean of various factors, depending on the study area[6]. Mobilization from landslides[7] seems to be the most common process. Starting from that, it's decided to include in that framework two models that describe the common behaviours of debris flow initiation: shallow landslide and in-channel entrainment of sediment. The two models can be work coupled as they are complementary.

3.1.1 Landslide triggering

Shallow landslides can trig a debris flow mainly due to water infiltration. That kind of rapid downslope movement of material occurs along a well defined shear plane. These movements are triggered during intense rainfall when high pore pressure is produced at the contact between the soil mantle and an impermeable layer, consequently reducing the factor of safety due to soil saturation. The behaviour is defined by the typical Coulomb failure approach to an infinite slope stability[7].

In that paper is done a difference between steady state and unsteady state saturation mechanism. Steady state saturation is referring to the configuration of a constant-in-time water table, while unsteady state saturation is dealing with a variable water table, depending, in that instance, only with vertical infiltration of rainfall.

If the final result will be qualitative (relation between rainfall and soil transmissivity), the model used will be a steady state of complete saturated material (water table coincides with free surface). The equation 1 describes the qualitative model of infinite slope stability,

$$\frac{q}{T}=\frac{\sin\alpha}{(a/b)}\left(\left(\frac{c'}{\rho_w g z\cos^2\alpha\tan\varphi}\right)+\left(\frac{\rho_s}{\rho_w}\right)\left(1-\frac{\tan\alpha}{\tan\varphi}\right)\right) \tag{1}$$

where q is the rainfall intensity, T is the soil transmissivity, α is the slope, a/b is the cumulated area per with of flow, ρ_w is the density of water, z is the thickness of soil, c' is the soil cohesion, φ is the soil internal friction angle and ρ_s is the saturated bulk density of the soil. In that case the output of the model will assess only the most prone areas of ruptures and the volume of debris is defined with a given thickness. If the final result will be quantitative, the model used will be a steady state (long term, equation 2) or an unsteady state (short term, equation 3) partial saturation of material,

$$F_s(z,t) = \frac{c'}{z\gamma_s \sin\alpha\cos\alpha} + \frac{\tan\varphi'}{\tan\alpha}\left(1 - \frac{q(t)\gamma_w a z}{\gamma_s b \sin\alpha}\right) \tag{2}$$

where F_s is the safety factor, γ_s is the specific weight of saturated soil, γ_w is the specific weight of water.

$$F_s(z,t) = \frac{\tan\varphi'}{\tan\alpha} + \frac{c' - \Psi(z,t)\gamma_w \tan\varphi'}{\gamma_s z \sin\alpha\cos\alpha} \tag{3}$$

where $\Psi(z,t)$ is the pressure head coming from the solution of the Richards equation that describe the one dimensional infiltration at the ground surface, with only vertical flow through the unsaturated zone[8]. The criterion to shift from one to other model is done by relationship 5 that describes the minimum rainfall duration to fulfil the steady infinite slope stability factor theory (**¡Error! No se encuentra el origen de la referencia.**).

$$\tau_s = \frac{1}{n}\sum_{i=1}^{n} \frac{a_i}{b_i} \frac{\theta_{s_i}}{K_i \cos\alpha_i \sin\alpha_i} \tag{4}$$

where n is the basin cells number, τ_s is time, θ_s is the water content at saturation. In that case prone areas and volume will be assessed.

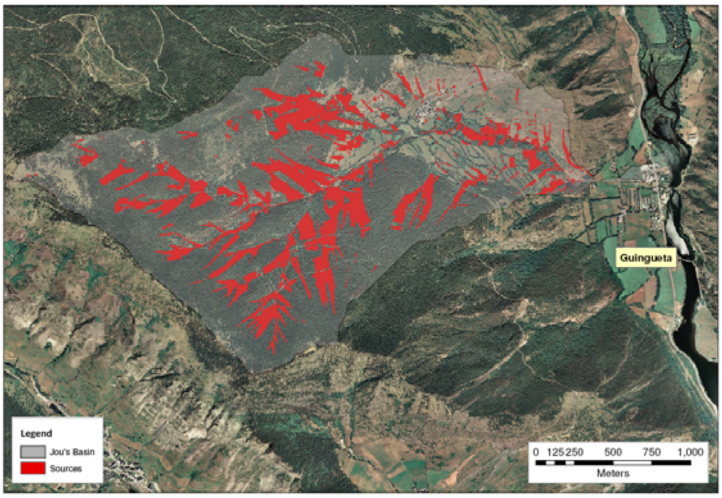

Figure 3: initiation point due to shallow landslide in Jou catchment; East Pyrenees, Spain.

3.1.2 In-channel triggering

Where the soil is saturated, but stable due to relatively low slope, a debris flow can be initiated due to the basal erosion of the run-off inside a path. That phenomenon is known as "sediment entrainment" and was described by Takahashi et al (1991)[9]. Balancing the shear stress in the bed we have the erosion depth *s*:

$$s = \frac{\tan\alpha - C\Delta(\tan\varphi - \tan\alpha)}{C_b\Delta(\tan\varphi - \tan\alpha) - \tan\alpha} h \tag{6}$$

where $\Delta=(\rho-\rho_w)/\rho_w$ is the differential density, ρ is the bulk density, C is the total concentration of sediment, C_b is the bed concentration of sediment, h is the depth of flow.

The C limit value for s tending to zero is given by the following:

$$C_\infty = \frac{\tan\alpha}{\Delta(\tan\varphi - \tan\alpha)} \tag{7}$$

When the $C_\infty>0.4$, a debris flow initiation is considered.

3.2 Propagation models

Models with different complexity are implemented and described below.

3.2.1 Stochastic model

That model consists in a flow routing algorithm incorporated into a random walk to generate trajectories of debris flow. Gamma (1999)[10] and Hürlimann et al. (2008)[11] combine a D8 flow routing algorithm (O'Callaghan and Mark, 1984) with Montecarlo and random walk theory applying successfully the method in some Italian Alps and Spanish Pyrenees catchments. The model used here is a modification of previous with the incorporation of computation of local velocity of flow and a stopping mechanism.

Starting from initiation points evaluated with methods in paragraph 3.1, that procedure permit to obtain a flow path of propagation for each point, and subsequently n_{iter} flow trajectories were calculated. Finally, probability, P_{xy}, was computed for each cell of the DEM using the following equation

$$P_{xy} = \frac{n_{afect}}{n_{iter}} \tag{8}$$

where n_{afect} is the number of debris-flow trajectories that invaded a cell. Thus, the result of this method is a map containing information on the spatial probability in each cell of the DEM to be affected by a future debris flow. The result depends strongly with DEM resolution and number of iteration that is recommended to be set to 10^4 by Hürlimann et al. (2008)[11].

Computation of velocity is achieved applying the Voellmy Fluid Flow Rheology for Granular Debris Flow (1955) through the paths evaluated:

$$\frac{1}{2}\frac{dv^2}{ds} = g\left(\sin\alpha - \mu_m \cos\alpha\right) - \frac{v^2}{k} \tag{9}$$

where v is velocity of the mixture, s is the flow path line, μ_m is the sliding friction coefficient, k is the “turbulence coefficient, also called “mass to drag ratio”. μ_m and k should be defined by back-analysis, but typical values can be settled.

The stopping mechanism of the routing is assessed by the following relationship between the reach angle and the volume, carried out by Corominas (1996)[12]:

$$\tan\beta = H/L_{\max} = 0.97V^{-0.105} \tag{10}$$

where β is the reach angle, H is the gradient between centre of mass of landslide and fan, L_{max} is the travel distance and V is the volume in m^3 of total amount of mobilized sediment coming from susceptibility models in paragraph 3.1.That method is extremely simple and has a very short computing time, but the response is only in a probabilistic way and not include the depth of deposit. However the velocity is assessed and hazard can be mapped.

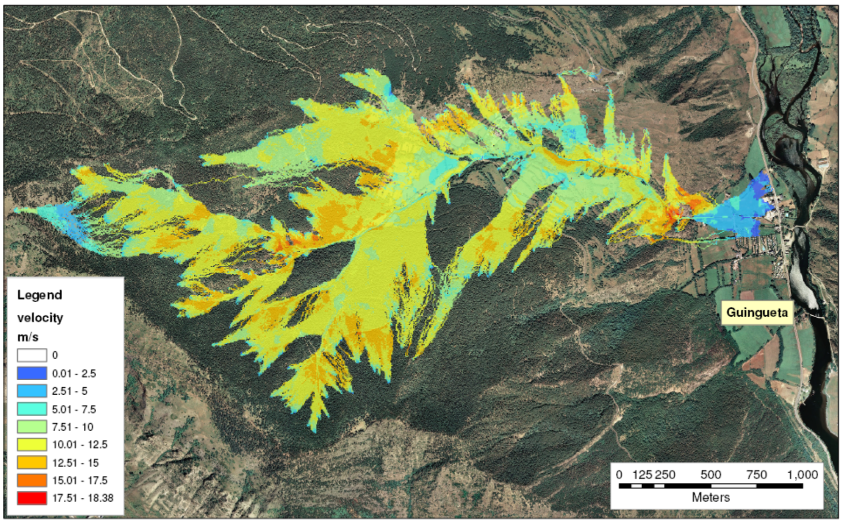

Figure 4: propagation and assessment of velocity of debris flow with a stochastic model in Jou catchment; East Pyrenees, Spain.

3.2.2 2D Model

The model used here is the FLATModel (Medina et al., 2008)[13], a two dimensional finite volume code. It is a complete model that include basal entrainment, stop and go phenomenon, dynamical correction of the evolution of fan slope and different fluid models including laminar rehologies (Bingham, Herschel–Bulkley), granular flows (Coulomb, Voellmy) and turbulent ones (Manning, Chezy). Apart from rheological parameters (from back-analysis), the necessary input data are two raster data sets including a DEM and a raster defining the initial extension and volume of the debris flow. The accuracy of calibration of the rheological parameters and the computational time requirement represent the major drawback of this technique, but the outputs can be directly used to generate intensity maps, since velocity and flow depth are simulated within the entire study area. The computational cost also increase considerably with the number of initiation points.

4 PRELIMINAR RESULTS

The methodology is applied in two catchments with different characteristics of soil. The first one is the Jou's catchment in la Guingueta (East Pyrenees, Spain), affected by a previous events of debris flow in 1982.The debris flow is classified as granular and follow the Voellmy behaviour. The DEM used has a resolution of 5x5 metres (Figure 3 and Figure 4).

The second catchment is in the Amalfi Coast on the Tyrrhenian See in the Southern Italy affected by massive and destructive mud flows in 1954. In that watershed the soil is composed by pyroclastic material with a very cohesive matrix of clay and the debris flow is classified as mud flow following the Herschel–Bulkley behaviour. The DEM used has a resolution of 1x1 metres (Figure 5 and **¡Error! No se encuentra el origen de la referencia.**).

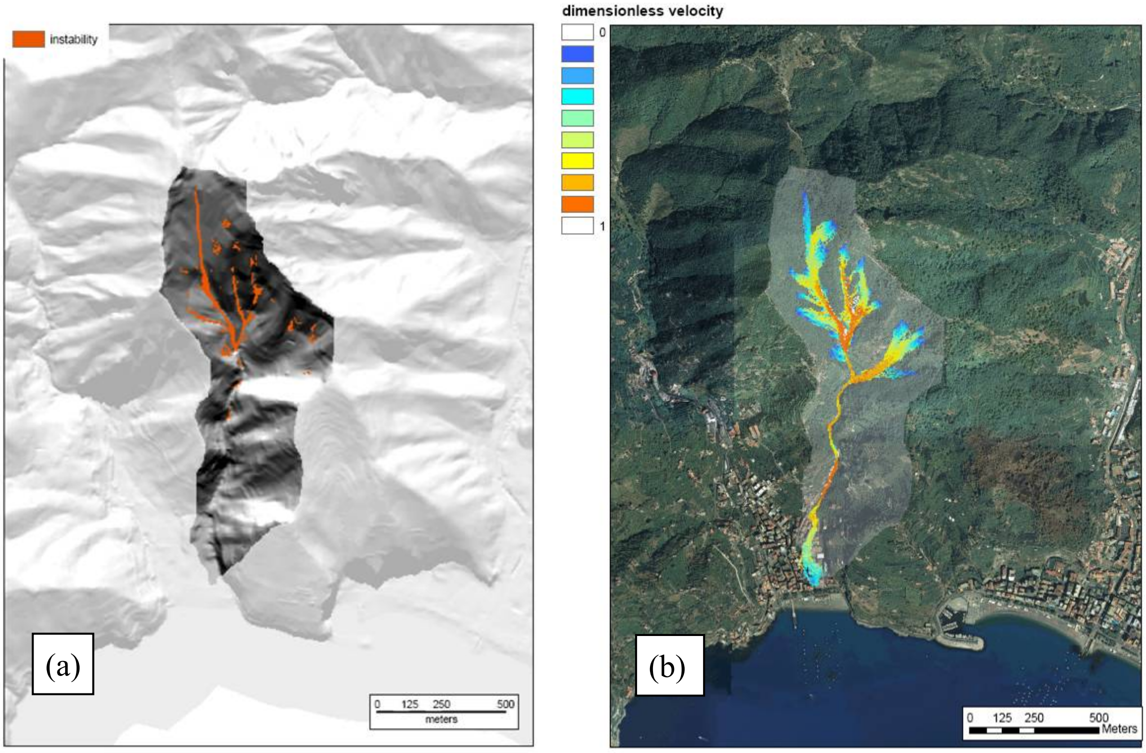

Figure 5: initiation points from shallow landslide (a) and propagation of debis flow (b) in a Amalfi Coast catchment in Southern Italy

5 CONCLUSIONS

A toolbox for debris flow hazard assessment at regional scale, starting from local behaviour of processes is defined. A multilevel approach is proposed, depending on available data. Starting from that point, the method need to be calibrated and applied in different cases and eventually extended to different debris flow behaviour. A 1D model can be incorporated in the future. The effect of DEM resolution on the final result should be investigated.

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