Shallow landslide occurrence and propagation in tropical mountainous terrain with open source models. A case study in the Colombian Andes.

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Introduction

Shallow landslides related to rainfall-triggered translational or rotational failure of saturated slopes are very common in Colombia (Aristizábal, 2013). They can evolve into debris flows (Iverson et al., 1997; Mergili et al., 2012). Various studies have been carried out on slope stability or landslide runout. Few studies, however, consider a combination of both aspects. The possible consequences of shallow landslides represent an important aspect in land use planning programs in mountainous areas (Crosta & Frattini, 2003). In Colombia, the inclusion of a landslide hazard map in land use planning is mandatory.

Aims

In this study, we propose an approach for incorporating landslide release and propagation into a catchment-scale modelling campaign.

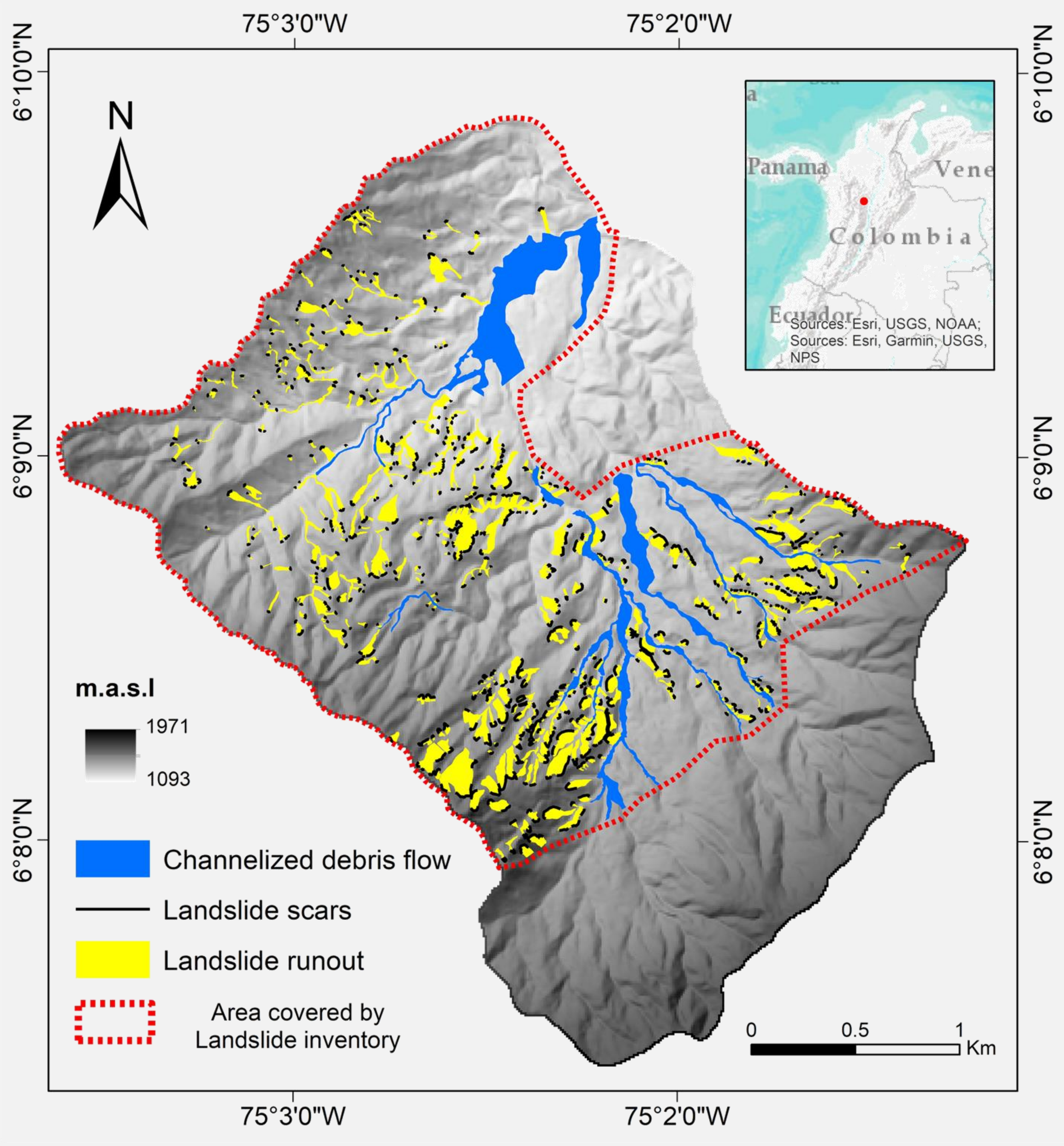
Study area

The study catchment known as La Arenosa (9.9 km^2) is located in the central area of the Colombian Andes (San Carlos – Antioquia). On September 21, 1990, approx. 200 mm of precipitation fell within the study area in less than 3 hours, triggering approx. 700 landslides many of which have converted into hillslope debris flows (Velásquez & Mejía, 1991).

Models

(i) *r.slope.stability* for slope stability assessment, using a limit equilibrium model together with a probabilistic analysis applied to a range of geotechnical parameters (cohesion, internal friction) and surface; **(ii*) r.avaflow*** for landslide propagation, using a Voellmy-type model. The landslide inventory and the zones categorized as high probability of failure (Pf), determined through *r.slope.stability* by Palacio et al. (2020), are applied as the source areas for propagation modelling with *r.avaflow*.

Study area with landslide inventory



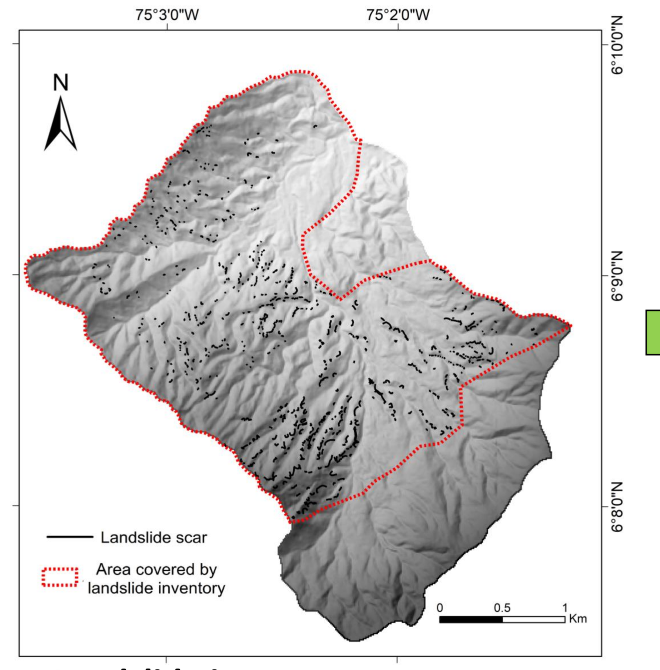
Back-calculation of 1990 event

r.avaflow applied to the 1990 source areas with standard flow parameters

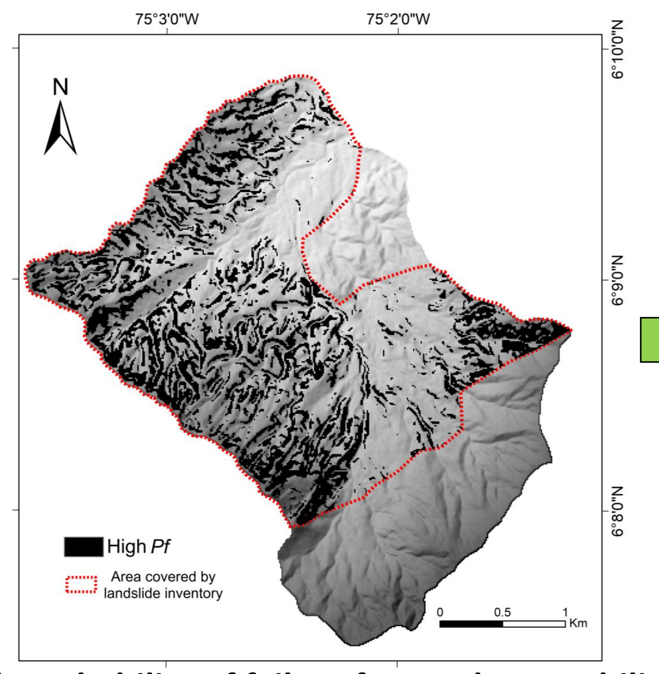
Forward calculation

r.avaflow applied to the areas of high Pf computed with r.slope.stability

Source areas

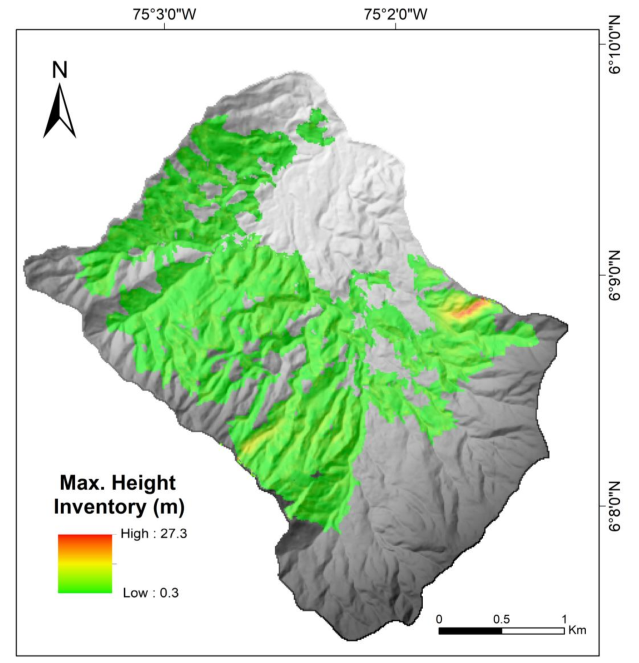


Landslide inventory as source areas

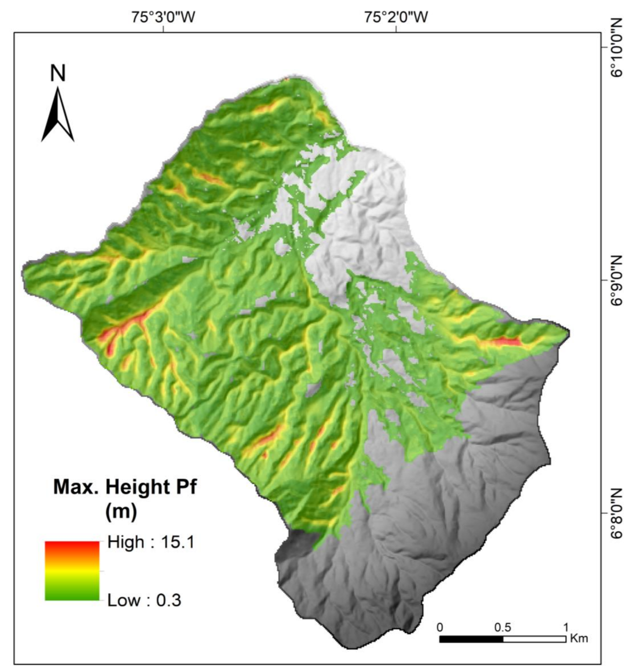


High probability of failure from r.slope.stability as source areas

Impact areas of propagation



Propagation of landslide inventory with r.avaflow



Propagation of High probability of failure with r.avaflow

Factor of conservativeness (FoC)

$$FoC = \frac{TP+FP}{TP+FN} \quad [0,\infty] \quad Optimum\ 1.0$$

	Cut-off flow height (m)	FoC
Back-calculation	1.05	1.02

TP = True positives FP = False positives FN = False negatives

The cutoff-value of flow height (lower flow heights are disregarded) leading to an empirically adequate result in terms of FoC is 1.05 m.

Conclusions

Using the observed landslide source areas as input, the observed runout patterns are best reproduced in terms of FoC when the flow height is cut off at 1.05 m. Considering the difficulty of clearly defining flow boundaries in numerical models such as r.avaflow, this value appears fairly acceptable (though rather high) and therefore indicates a fairly plausible, but rather conservative back-calculation of the 1990 event. Using the areas of high Pf values as source areas, the r.avaflow result reveals a much larger impact area of flow propagation – a result which is not surprising, given that high-Pf-areas are much larger than the source areas observed for the 1990 event. Therefore, it has to be clearly emphasized that the forward calculation represents a worst case scenario, showing what could happen in the unlikely case that all susceptible slopes fail at once.

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