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Regional and detailed multi-hazard assessment of debris-flow processes in the Colombian Andes

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Debris-flow processes are highly destructive phenomena that endanger life and infrastructure located in mountainous areas. The Colombian Andes are especially susceptible to this type of processes. Disaster databases include 1,387 channelized debris flow, debris flood, and flash flood records between 1921 and 2020, causing 3,332 deaths and affecting 1,152,613 people. These statistics show the importance of carrying out a regional debris flow hazard assessment to prioritize resources and actions to reduce risk.

One of the main challenges when evaluating debris-flow processes hazard is their multi-hazard nature: they are understood as part of a concatenated phenomenon at catchment scale, including cascading effects of landslides, flash floods, debris floods and channelised debris flows. In this study, a multi-hazard approach was implemented to assess debris-flow processes susceptibility and hazard on both regional and local scale, combining statistical and physically based models in combination with geomorphological observations.

The study area is located in the central Colombia Andes, with an extension of 63,612 km^2 where 3,039 catchments were analysed for their debris flow-processes susceptibility, using machine learning methods based on morphometric parameters. This analysis was joined with a physically-based slope stability model to estimate potential sediment volumes that might be supplied by intense rainstorms. By combining susceptibility, slope stability, and soil type at the catchment scale, it was possible to understand the magnitude of the potential of different debris-flow processes. Susceptibility analysis allowed to differentiate the catchments into alluvial and torrential and their magnitude level was categorized based on the volume of unstable soil to find hazard and then, used to select critical catchments for a more detailed scale.

A detailed hazard analysis was carried out for those selected areas through hydrological and hydraulic software, along with fluid-dynamic mass routing models. These methodologies were used with a sub- metric resolution and provide detailed information such as flow height, speed, and pressure to categorize more accurate hazard levels, always framed on the torrential geomorphology units.

Traditional hydraulic and hydrological models were insufficient to provide accurate heights and extents of debris-flow processes since they do not consider their multi-hazard nature nor the

volume of sediments from landslides and channel erosion that are added to the flow. As a result, the extent of the flow was smaller than the observed morphological features. The fluid dynamic model r.avaflow considers the rheologic change and fitted better to the type of events. The model was used to simulate different sediment concentrations and flow types. The model results were complemented with the different torrential units mapped through fieldwork. This way, it was possible to establish the events' maximum potential extent linked to their return periods.

This multi-hazard and multi-scale methodology is a useful tool for stakeholders to prioritize and improve urban planning. It grants a perspective from regional to local scale, can be adapted to fit into specific environments and contexts.