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CASCADING EFFECT OF SHALLOW RAINFALL-INDUCED LANDSLIDES, DEBRIS FLOODS AND DEBRIS FLOWS IN THE COLOMBIAN ANDES

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UNIVERSIDAD NACIONAL DE COLOMBIA
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GEOHAZARDS Semillero de Investigación

INTRODUCTION

The Colombian Andean region characterizes for its tropical climate and mountainous topography, where short duration and high intensity rainfall are common. Such rainstorms often trigger progressive hydrometerological hazards caused by concatenated processes. When falling in small and steep catchments, intense rainfalls generate rapid concentration of stream flow as debris floods, a hydrological response where stream-driven process dominates. Since the erosion power of flow increases, it remobilizes sediments of the stream bed and induces small-scale bank slides, which are added to the flow creating debris flood torrents. This phenomenon is a two-phase flow characterized by sediment concentrations that change sediment-transport mechanism. When rainfall events exceed slope stability thresholds, it triggers clusters of landslides, especially on coarse residual soils with high permeabilities, known as Multiple Occurrence Regional Landslide Events (Crozier, 2005).

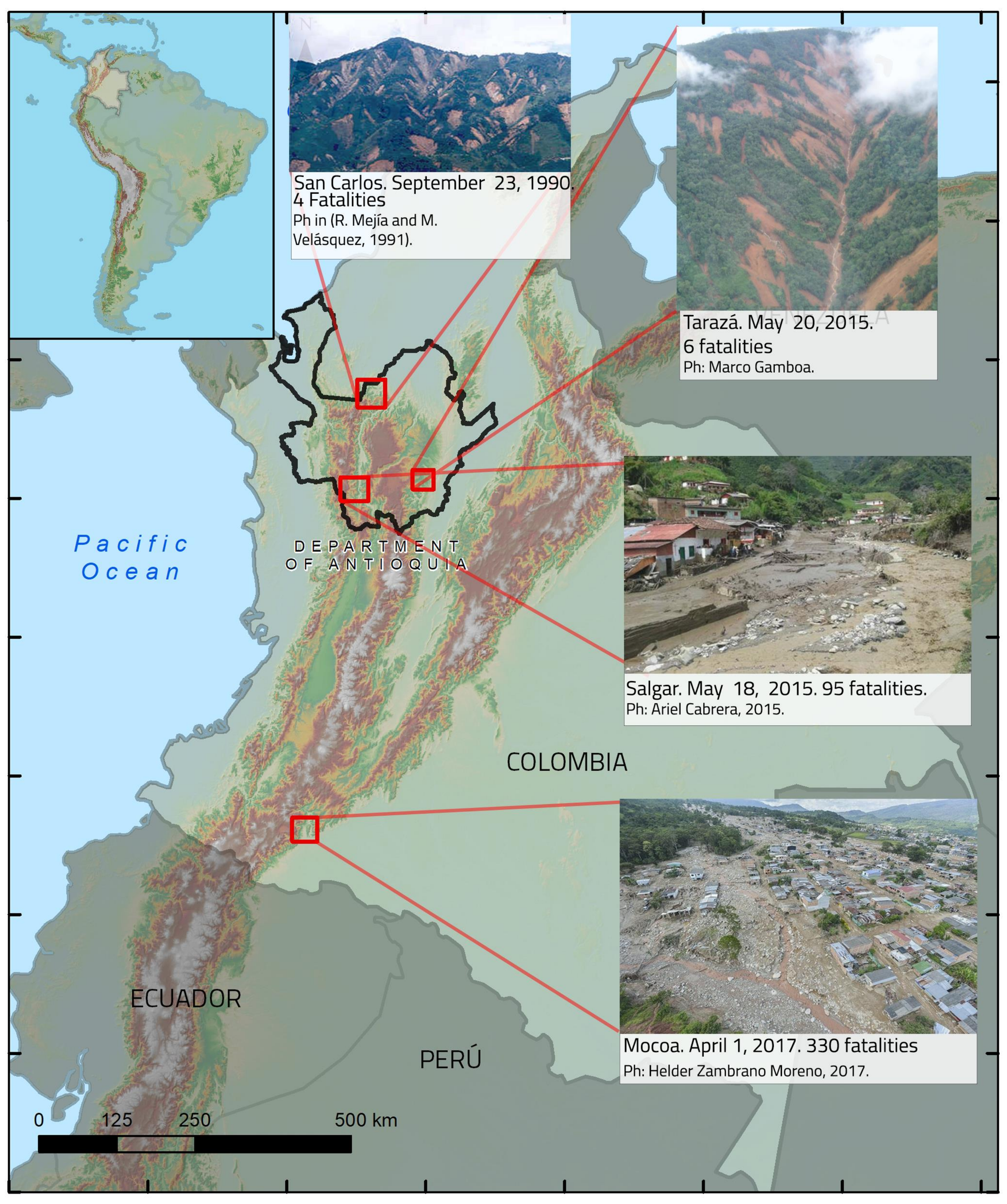


Figure 1. Multiple-occurrence regional landslide events (MORLEs) triggered by rainstorm in the Colombian Andes..

Such landslides supply source material to channel increasing the sediment concentration and altering the fluid properties, changing debris floods into a viscous mass surge of water and sediments that ranges from hyperconcentrated flows to debris flows. The final deposition of these materials is often located in catchment fans that are usually vastly populated resulting in great disasters with high economic losses and fatalities. The most recent reports in Colombia include the events of La Liboriana-Salgar, Tarazá and Mocoa (Figure 1).

According to Desinventar (2018) in Colombia there have been a total of 1,358 reports of channelized debris flows, debris floods and flash floods between 1921 and February of 2018, that caused 3,318 deceases, and left 1,246,705 people affected. Figure 2 shows that the Andean region is where most torrential flows happen, up to 60% of all records.

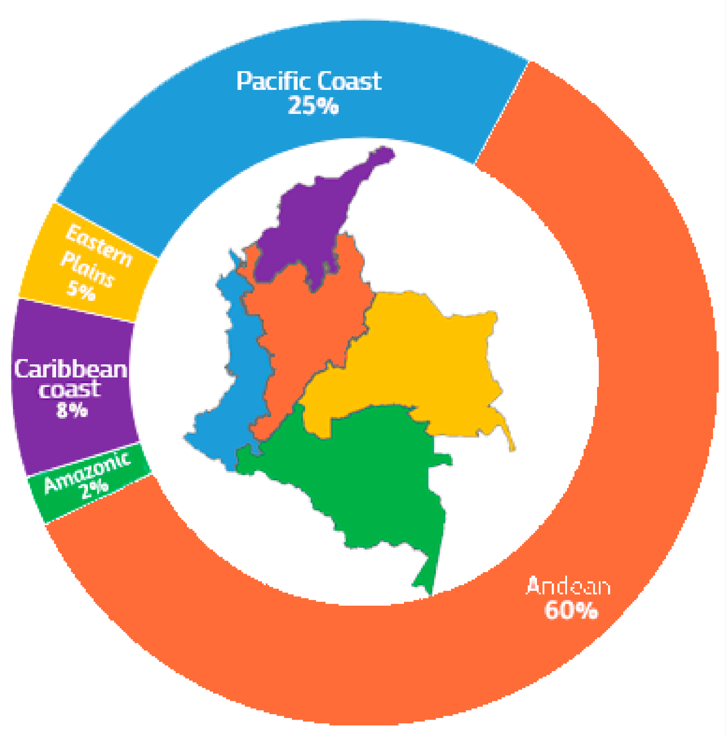


Figure 2. Distribution of torrential flows in Colombian regions.

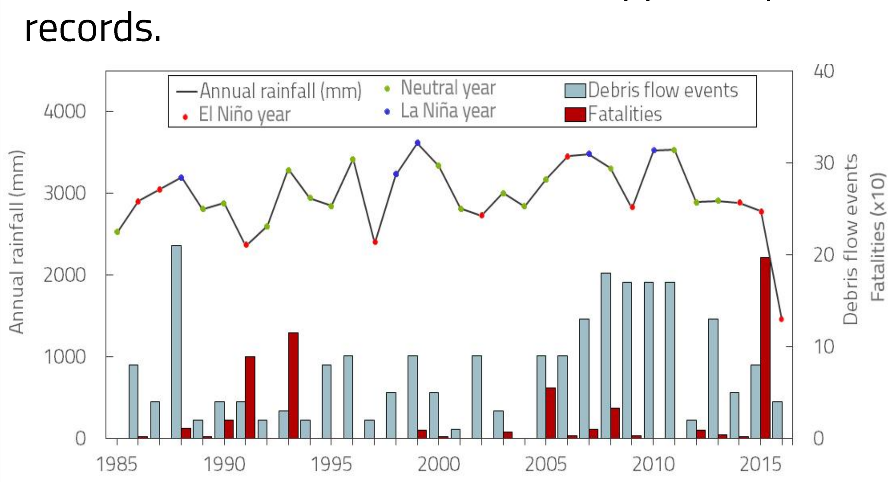


Figure 3. Historical relationship between rainfall, ENSO-phases, torrential events, and fatalities induced by year in Antioquia.

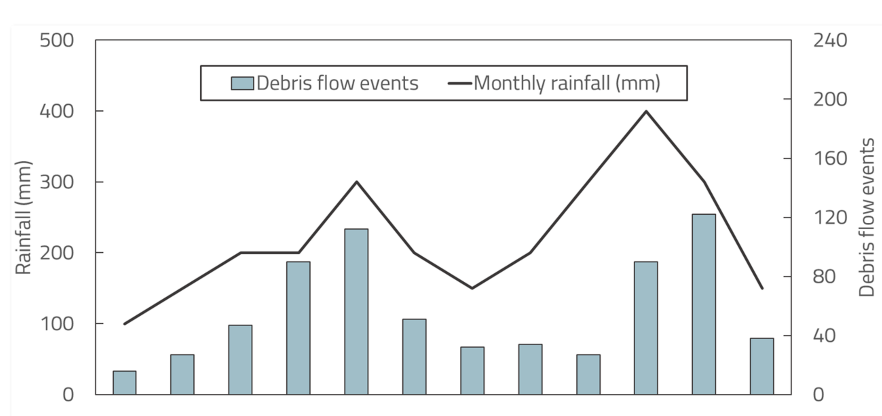


Figure 4. Monthly relationship between rainfall and torrential flow occurrence in the Andean region between 1922 and 2017.

METHODOLOGY

Catchments with areas ranging from 5 to 40 km^2 are delimitated from the DEM (10 m resolution). Then discriminant analysis is carried out to find the hydrological response of the catchments to rainstorms based on its morphometry. Later, lithological units are categorized according to the grain size of the soils generated by weathering. According to Arango-Carmona & García López (2017), around 70% of the historical channelized debris flows in Colombia have occurred on catchments where coarse-grained regoliths, usually from granitic rocks, are found. While catchments where fine-grained regoliths are found often respond to intense rainfall by creating debris floods. According to the hydrological response and the grain size of the regoliths, catchments are classified to be susceptible to: debris floods (torrential hydrological response and fine-grained regolith), or channelized debris flows (torrential hydrological response and coarse-grained regoliths), or fluvial flooding. Finally, hazard is computed from average rainfall intensities distribution along the study area. Results are presented classifying hazard in three ranges: high, medium and low hazard.

The input parameters (Table 1) used for this study include: Digital Elevation Model with resolution of 10 m and basic cartography from the Instituto Geográfico Agustin Codazzi, the geologic map from the Servicio Geológico Colombiano, and daily satellite rainfall data from the CHIRPS database taken from the United States Geological Survey, that collects rainfall information from 1981 to 2016. Historical disaster inventory was taken from the Desinventar database, that gathers all sorts of disasters reports since 1920.

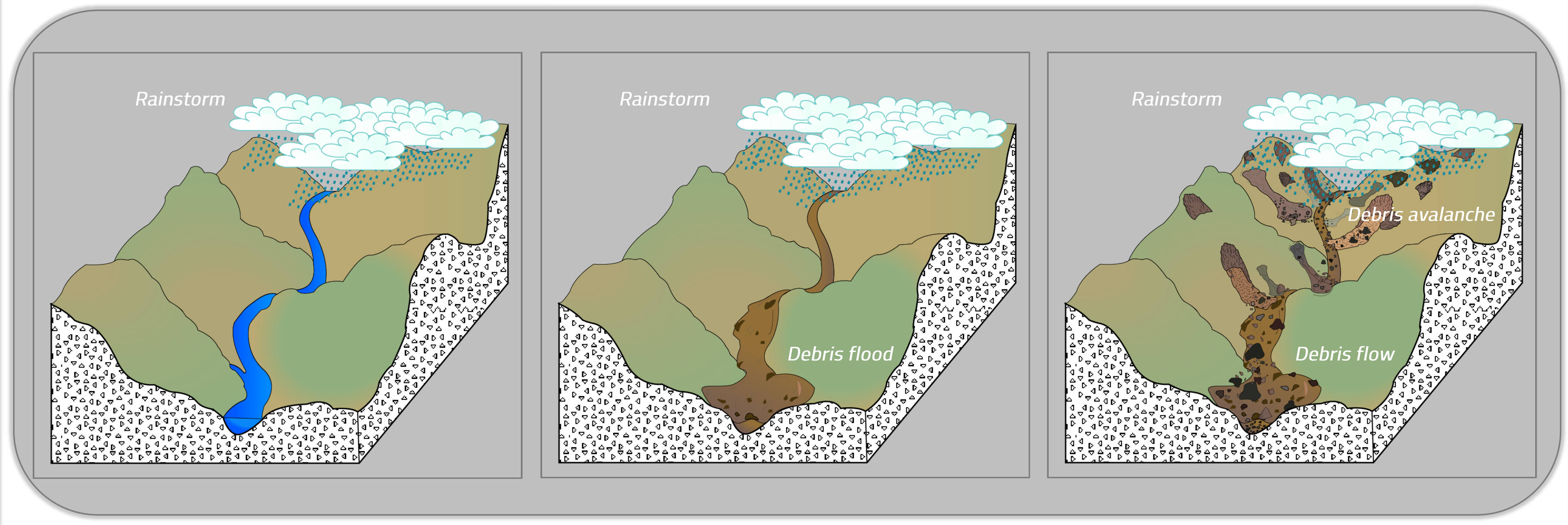
Table 1. Input parameters used for the development of the methodology

Input parameter	Scale	Resolution	Year	Source
DEM	NA	10m	2014	IGAC
Cartographic database	1:10,000	NA	2012	IGAC
Geological cartography	1:100,000/ 1:400,000	NA	2015	SGC
Climate Hazards Group InfraRed Precipitation	NA	0.05°	1981	USGS

CONCATENATED TORRENTIAL PROCESSES

HAZARD ASSESSMENT

SUSCEPTIBILITY ASSESSMENT



TRIGGERING FACTOR	DISCRIMINANT ANALYSIS	SEDIMENT SUPPLY
Rainfall Data base (CHIRPS): Spatial Resolution: 5 km Temporal Resolution: Daily Record: 1981-2016 Source: USGS	Morphometric Parameters: Amount of streams Mainstream sinuosity Constant of channel maintenance Relative relief Melton index	Geological cartography: Scale: 1:400,000 Coarse-grained soils: Regolith of rocks with high silica content. Source: Servicio Geológico Colombiano(SGC).

Figure 5. Sequence of Concatenated torrential processes that take part in the dynamic of a torrential flow.

RESULTS

From the study area 12,658 catchments were delimitated. Based on their morphometry, 35% of the catchments were identified to have torrential hydrological response, most located in steep areas of the Andean region. From which, 49% of the torrential catchments are susceptible to debris floods and 51% are susceptible to channelized debris flows, that is the most critical scenario, due to its destructive power.

After analyzing the rainfall spatial pattern of average intensities, the hazard map was developed. The results show that the catchments with higher hazard to debris floods and channelized debris flows are located on the western, eastern and northern areas of the Andean ranges.

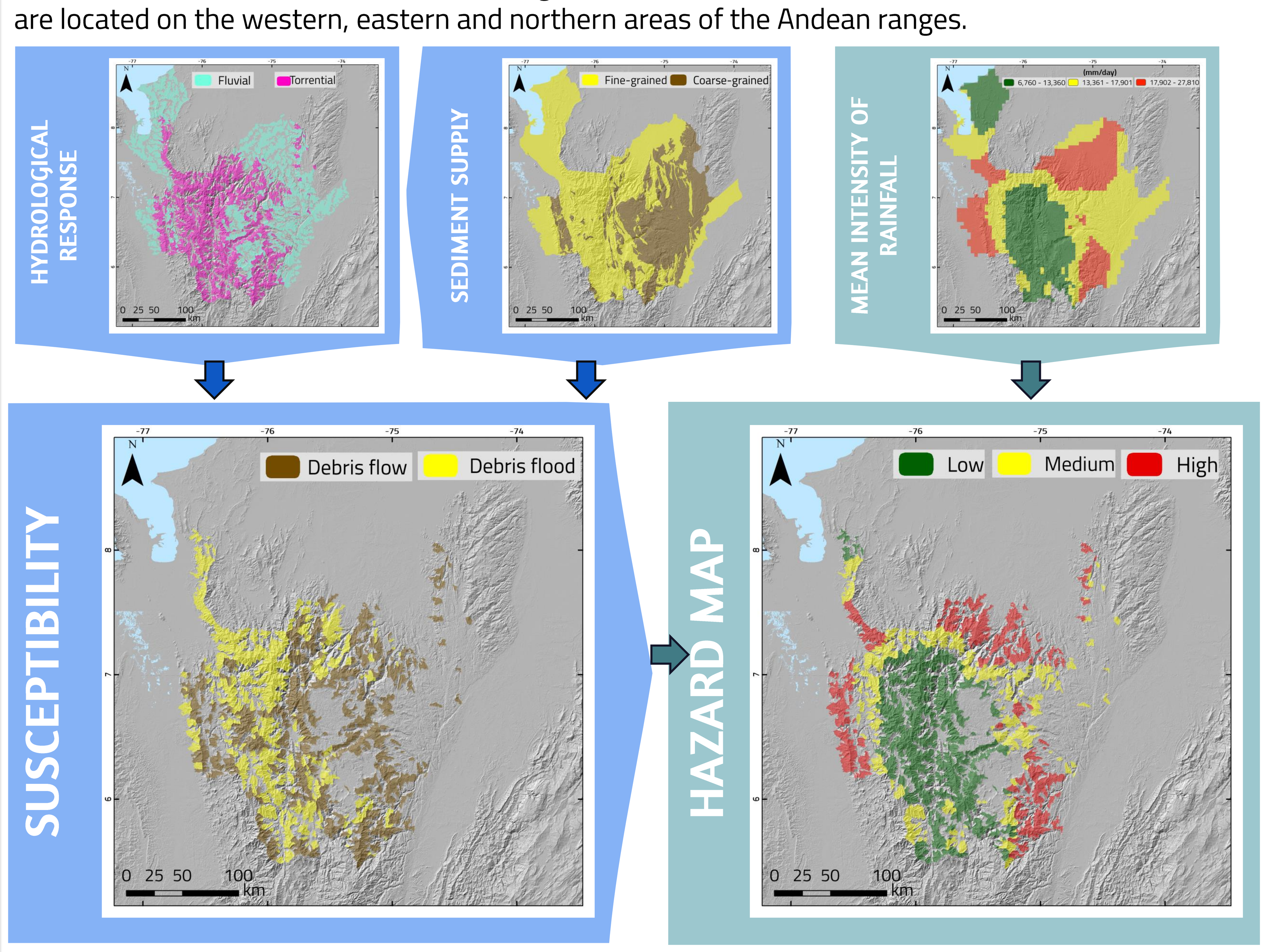


Figure 6. Input maps: Morphometry of the analyzed catchments, sediment supply according to available geological cartography and spatial distribution of rainfall. Resulting maps: Susceptibility map that allows establishing the torrential character of each catchment and hazard map in three categories.

CONCLUSIONS

Debris floods and channelized debris flows are recurrent and destructive phenomena in the Colombian Andes. Nevertheless, given its multi-hazard nature and high destructive capacity, the analysis, evaluation and hazard assessment methodologies of this sort of phenomena are not well developed for tropical environments on a regional scale. Some of the proposed methodologies focus on slope stability analysis and others suggest the use of modified flood hazard assessment, but none include an analysis of the whole phenomena. In this study, a regional hazard assessment methodology is proposed for flash floods, debris floods and channelized debris flows, considering the spatiotemporal variables, basin morphometry, sediment availability and rainfall data using statistical and physical methodologies to assess the susceptibility and hazard at a basin scale, resulting in a key tool for decision-making authorities.

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