



## **Empirically-based rainfall thresholds for debris flows and mud flows occurrence in the North of Portugal**

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The Portuguese North Region (21,287 square kilometres) is frequently affected by different types of landslides, but the most destructive processes are debris flows and mud flows. Landslides of flow type occurred during the last century originated the destruction of houses and roads. Additionally, the social impact of debris flows and mud flows is relevant because these slope movements have been responsible for the majority of fatal cases due to slope instability events (125 .death people in the last 107 years).

The study area is mainly composed by granites and metamorphic rocks (e.g., schist). These rocks are strongly fractured and weathered materials are abundant, namely those resulting from the chemical weathering of granites. From the geomorphological point of view, the study area is characterized by an accidentally landscape, and includes mountain areas (in the NW region), the transmontano plateau (in the NE region), a narrow coastal platform, tectonic depressions, and the deep-incised Douro valley. The elevation ranges from 0 meters (near the Atlantic Ocean) to 1544 meters (in the Gerês Mountain), and the slope is frequently higher than 25 degrees. The NW Mountains and the Douro valley are the most relevant landslide-prone areas of the Portuguese North Region.

Rainfall is the major triggering factor of regional slope instability, and the flow type phenomena are usually associated to very wet winters, as it was observed in 1909-10 and 2000-01. However, little attention has been devoted to this topic until now, and there is no information about critical rainfall characteristics that are able to trigger

slope failures in the study area. In this work, we test different empirical methods to establish the rainfall threshold responsible for the activation of debris flows and mud flows in the study area.

In a first step, descriptions of debris and mud flows events were collected from different sources (e.g., news papers, scientific journals, books, PhD thesis), and a database was compiled containing events dated from 1900 to 2007. The collected data was interpreted and georeferenced, using GPS, aerial photographs (1:5 000 scale) and topographic maps (1:25,000 scale). The database includes 80 flow records, but 5 of them were not georeferenced. The precise day of the occurrence was available only for 54 records. Moreover, our database is certainly incomplete because it does not include non-reported landslides occurred in remote areas without relevant material losses.

In a second step, we analyzed rainfall data from 90 udometric stations, and we selected 2 rain gauges with regional importance: Casal Soeiro located in the NW mountain area, and Amarante located near the Douro valley. The rainfall data was studied both in the spatial and temporal perspectives to test the rainfall regional thresholds obtained using empirical models.

The event rainfall measurements were used to assess intensity - duration thresholds by calculating the cumulative absolute rainfall (for 1, 2, 3, 4, 5, 10, 15, 30, 40, 60, 75 and 90 days) and the calibrated antecedent rainfall (for 3, 5, 10, 15 and 30 days). The Gumbel law was used to compute the return period of each rainfall intensity-duration combination. The obtained results show a very strong correlation between event intensity and duration, in both meteorological stations. In order to compare the rainfall thresholds at the regional scale, the rainfall intensity was normalized dividing the event rainfall intensity by the mean annual precipitation (MAP) for each considered rain gauge. This data was interpolated using the IDW method to obtain the spatial distribution of the critical rainfall responsible for particular debris flow and mud flow events. The antecedent rainfall conditions were evaluated through the combination between the 3-days event rainfall and the previous antecedent rainfall for different periods (e.g., 5, 10, 15, 30, 40, 60, 75 and 90 days). The best result obtained corresponds to the combination between the 3-days event rainfall and the 10 - day antecedent rainfall.

We conclude that both event and antecedent precipitation are important for debris flow and mud flow initiation in the North Region of Portugal. The establishment and validation of critical rainfall thresholds will allow accounting the temporal dimension of slope instability and to improve the landslide hazard assessment methods at the regional scale.