EMPIRICALLY-BASED RAINFALL THRESHOLDS FOR DEBRIS FLOW OCCURRENCE IN THE NORTH OF PORTUGAL

Umbrales de lluvia empíricos para la ocurrencia de corrientes de derrubios en el Norte de Portugal

S. Pereira [(1)], J.L. Zêzere [(1)]

(1) RISKam. Centro de Estudos Geográficos, Instituto de Geografia e Ordenamento do Território, Universidade de Lisboa (Portugal). susana-pereira@campus.ul.pt

Resumen: En la región portuguesa del Norte las corrientes de derrubios provocadas por las lluvias son responsables de la mayoría de los casos de muerte y de daños que se produjeron el último siglo debido a la inestabilidad de las laderas. Se han aplicado métodos empíricos para establecer el umbral de precipitaciones responsable de la activación de corrientes de derrubios, con 80 eventos desde 1900 hasta 2010. Se seleccionaron 2 estaciones meteorológicas de importancia regional: Casal Soeiro (NW zona de montaña), y Vila Real (valle del Duero). Para estas estaciones se calcularon los umbrales de intensidad/duración y los umbrales que combinan la precipitación del evento con la precipitación antecedente. La precipitación del evento y antecedente fueron también normalizadas con la precipitación media anual, para facilitar la comparación de los datos. El mejor resultado obtenido es un umbral combinado entre la lluvia de evento de 72 horas y la lluvia antecedente de 10 días.

Key words: debris flows, rainfall thresholds, intensity/duration, antecedent rainfall
Palabras clave: corriente de derrubios, umbrales de precipitaciones, intensidad/duración, precipitación antecedente

1. INTRODUCTION

Rainfall is considered worldwide as the main triggering factor of landslides (Wieckzorek, 1996; Corominas, 2000).

For landslides triggered by rainfall, empirical thresholds may be established at the regional scale according to specific rainfall conditions (e.g. rainfall intensity/duration). When a threshold is reached or exceeded landslides are expected to occur (Guzzetti et al., 2007).

Thus, different empirical methods to establish the rainfall thresholds responsible for the activation of debris flows in Northern Portugal are evaluated.

2. STUDY AREA

The North of Portugal, covering an area of approximately 21,287 km^2 (Fig. 1) is affected by different types of landslides. Debris flow is the most destructive and damaging process, being responsible for the majority of casualties (43) and damages occurred in over the last century (1900-2010). Bedrock of the study area is mainly composed of granites and metamorphic rocks, such as schists and quartzites. These rocks are strongly fractured and weathered materials are abundant, especially those resulting from the chemical weathering of granites. The study area includes mountainous areas (in the NW sector), a plateau (in the NE sector), a narrow coastal platform, tectonic depressions, and the deep-incised Douro river valley. The elevation ranges from 0m by the Atlantic coast to 1544m in the Gerês Mountain, and the slope angle is frequently above 25°.

The NW mountains and the Douro valley are the most landslide-prone areas (Fig. 1) in Northern Portugal.

Rainfall is the major triggering factor of slope instability in the study area, with debris flows usually occurring during very wet winters (Pereira, 2009).

Mean annual precipitation (MAP) in the study area ranges from 2000–3000 mm in the NW Mountains to 300–500 mm in the Douro river valley. Rainfall has a marked seasonal distribution, with dry months (June to August) contrasting highly with the other months of the year.

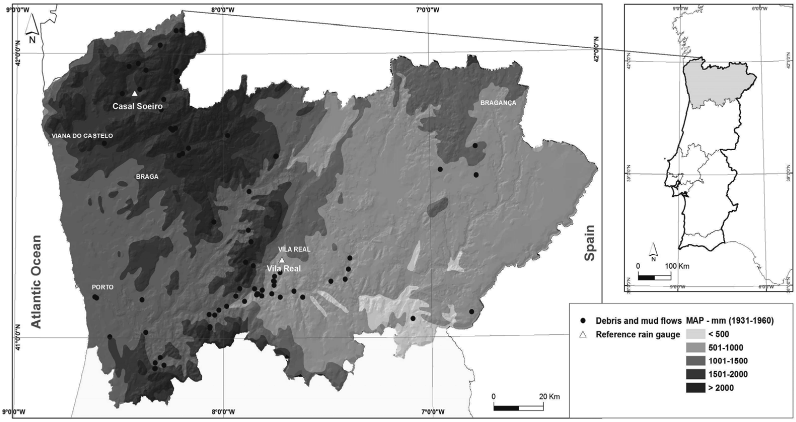

Fig. 1. Mean annual precipitation distribution in Northern Portugal, location of reference rain gauges and distribution of debris flows which occurred between 1900 and 2010.

3. METHODOLOGY

3.1. Debris flows inventory

The record of events of debris flows were obtained from different sources (e.g., newspapers, scientific journals, books, PhD theses), and a database was compiled containing those events dating from 1900 to 2010. Each debris flow record was interpreted and geo-referenced in topographic maps (1:25,000 scale) with a point in the centroid of the rupture zone. The database includes 83 records of debris flows, although 5 of them have not been geo-referenced due to missing data. The exact day of the occurrence was available only for 54 recorded events. Moreover, this database is incomplete because it does not include non-reported debris flows which may have occurred in remote areas without relevant human and material losses.

3.2. Rainfall data

In the study area there are no hourly rainfall data available. Therefore, daily rainfall data from two rain gauges within the area were analysed: one in Casal Soeiro located in the NW mountain area (SNHIR network), and one in Vila Real located near the Douro valley (Meteorological Institute network) (Fig. 1). MAP in Casal Soeiro is 1967.7 mm and in Vila Real is 1104.1 mm. For these rain gauges, the daily rainfall data are available between 1960 and 2001. During this period, 9 debris flow events occurred in the NW mountain area and 8 debris flow events occurred in the Douro valley. These events were used to test the rainfall regional empirical thresholds.

3.3. Regional rainfall thresholds

For both rain gauges of Casal Soeiro and Vila Real two different types of rainfall thresholds were computed: the intensity/duration threshold considering different time periods; and a combined threshold which integrates the rainfall event and the antecedent rainfall for different time periods. The latter was also normalized by the MAP values to allow meaningful comparison of results. For each event date the critical rainfall combinations (i.e. rainfall intensity/duration; event rainfall combined with the antecedent rainfall, both normalized and non-normalized) were assessed and the corresponding return period were calculated using the Gumbel law.

It is assumed that the rainfall combination (intensity-duration) with the highest return period may be considered the critical combination responsible for a particular

debris flow event. This assumption is not physically based, but provides the best discrimination between periods characterized by debris flow activity and those without slope instability (Zêzere et al., 2005).
Thresholds lines were empirically defined by forcing the reduction of both false positive and false negative cases as it was done by Zêzere et al. (2005) in the Lisbon region.

3.3.a. Intensity/duration threshold
The daily rainfall data were used to assess intensity – duration thresholds for debris flow events by calculating the cumulative rainfall for each event (for 1, 2, 3, 4, 5, 10, 15, 30, 40, 60, 75 and 90 consecutive days) and computing the rainfall intensity associated to each period of time.
The maximum rainfall intensity for each period of time was also computed for those years without debris flow occurrence in order to test the accuracy of the threshold.

3.3.b. Combined threshold: rainfall event / antecedent rainfall conditions
The combined threshold assumes that antecedent rainfall is responsible for preparing rock and soil for slope instability while the event rainfall concentrated in just a few hours (24 to 72h) is the trigger for the start of debris flows.
Therefore, the combined threshold integrates the event rainfall ranging from 24 to 72 hours and the previous antecedent rainfall for periods ranging between 5 and 90 consecutive days.

4. RESULTS

4.1. Intensity/duration threshold
Fig. 2 shows the distribution of rainfall intensity *vs*. duration associated with debris flow events. As previously mentioned, the critical combination for each event is the one having the highest return period for the corresponding event date. The power regression line obtained for the debris flow events provides a reliable intensity/ duration rainfall threshold, as the line fits well the points representing debris flow events. At Casal do Soeiro the relationship is as follows (Fig. 2A): $y = 109x^{-0,42}$ (R^2= 0,984) Whilst at Vila Real (Fig. 2B) the relationship is $y = 69,42x^{-0,42}$ (R^2= 0,936), where y is the rainfall intensity (mm/day) and x is the time duration (in days).
Despite the statistically significant relationship, the results are not completely satisfactory because of the long duration associated with some events. The long rainfall episodes should reflect the preparatory role of antecedent rainfall (secondary climatic influence), and not the typical intense short rainfall event (primary climatic influence) that is associated with the triggering of debris flow worldwile (Wieckzorek and Glade, 2005).

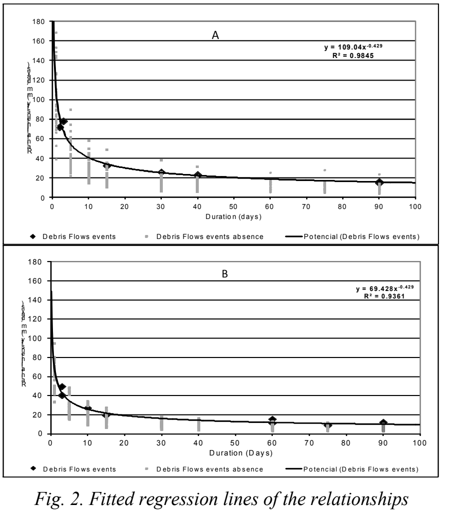

Fig. 2. Fitted regression lines of the relationships between critical rainfall intensity and event duration at Casal Soeiro (A) and Vila Real (B).

4.2. Combined threshold rainfall event / antecedent rainfall conditions
The best result obtained when the rainfall event is combined with the antecedent rainfall, for both rainfall datasets, is the combination between the 72 hours event rainfall and the 10-day antecedent rainfall. Accordingly, if antecedent accumulated rainfall exceeds 75 mm in 10 consecutive days in Casal do Soeiro, the 72 hours-event rainfall needed to trigger debris flow is of 191 mm. For the same amount of

antecedent accumulated rainfall, the 72 hours-event rainfall needed to reach minimum conditions in order to trigger debris flows in Vila Real is only 80 mm.

At first sight, it seems that less rainfall is required to trigger slope failure in Vila Real than in Casal do Soeiro. However, when the rainfall data are normalized by the MAP the results show the opposite tendency. Indeed, as shown in Fig. 3, the triggering conditions require higher rainfall in the Douro Valley (Vila Real), although absolute rainfall values are lower than in NW Mountains (Casal Soeiro). Thus, probability of debris flow initiation is lower in Vila Real than in Casal Soeiro.

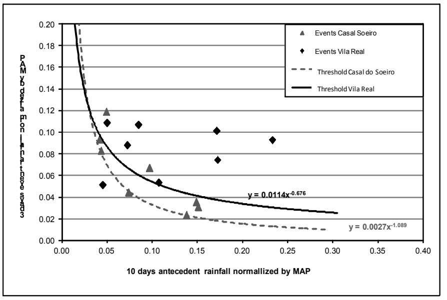

Fig. 3. Comparison between the empirical threshold of 3 days event rainfall and 10 days antecedent rainfall, normalized by MAP.

5. CONCLUSIONS

Event and antecedent rainfall are important factors in debris flow initiation in Northern Portugal. The obtained intensity/duration thresholds were not as good as the ones obtained with a combined threshold between the 72 hours-event rainfall and the 10 days-antecedent rainfall.

It was also shown that MAP is higher in the NW Mountains than in the Douro valley. As mentioned by Pedrozzi (2004) for a different region, slopes tend to an equilibrium state adjusted to the amount of rain which usually occurs at a regional level. Therefore, although less rainfall is required in absolute terms, the triggering condition is more complex and seems to require higher rainfall in the Vila Real area (Douro Valley) as proved by normalizing rainfall data.

The resulting rainfall thresholds need to be further validated with future event data in order to allow accounting for the temporal dimension of slope instability and to improve the landslide hazard assessment methods at the regional scale.

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