

RISK MAPPING FOR EMERGENCY PLANNING IN PORTUGAL –AN EXAMPLE ON SLOPE INSTABILITY

Mapas de Riesgos para la Planificación de Emergencia en Portugal - Aplicación a la Inestabilidad de Laderas

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Resumen: En este trabajo se evalúa la aplicabilidad de la Guía Metodológica para la elaboración de Mapas de Riesgo en los municipios portugueses, utilizando el caso específico de los deslizamientos de ladera de la zona del Alto Douro, situada en el noreste de Portugal. Su objetivo es construir un mapa de susceptibilidad de deslizamientos de ladera para el Plan de Emergencias de la región y cruzarlo con los elementos expuestos al riesgo. El modelo de evaluación de la susceptibilidad está basado en el Método del Valor de la Información. El inventario de inestabilidades fue sometido a una partición aleatoria para permitir la validación independiente de los resultados. Los resultados muestran que algunas laderas en el área de estudio tienen una alta susceptibilidad de ocurrencia de deslizamientos, y en algunas de ellas están presentes elementos humanos y socio-económicos, lo que genera situaciones de riesgo, que deben ser tenidas en cuenta por los agentes de protección civil.

Key words: Emergency Planning, Risk Analysis, Risk Matrix, Landslides, Information Value

Palabras clave: Planificación de Emergencias, Análisis de Riesgos, Matriz de Riesgo, Deslizamientos, Valor de la Información

1. INTRODUCTION

A guide related to risk mapping for Civil Protection and Spatial Planning, which establish general rules for risk mapping in Portugal, was published in 2009. The Methodological Guide for Risk Mapping and for Development of a GIS at the Council Level (Julião et al., 2009) highlights the difficulties encountered in Quantitative Risk Analysis (QRA) for a large set of hazardous phenomena and proposes a methodological approach for susceptibility mapping, applicable from council to national levels, to locate the best areas for future development. Moreover, this guide also recommends the mapping of Exposed Elements, to be combined with susceptibility maps, in order to classify levels of risk. Although the procedure does not quantify potential losses, it indicates where risks are more likely to occur in the future.

In this work the guidelines from the Methodological Guide for Risk Mapping are followed and tested for slope instability assessment in the High-Douro region in NE Portugal, an area with c. 1934 km². The main aim is to produce a landslide susceptibility map as part of the Emergency Plan of the High-Douro region and combine this information with the exposed human and socio-economic elements at risk.

2. STUDY AREA

The High Douro region is located within the Central-Iberian Zone. Metasediments belonging to the Douro Group (mainly schist and greywacke) of Cambrian age, and schist and quartzite of Ordovician age are prevalent in this region. Granitic rocks also occur in small spots in the areas located between the Douro and Sabor rivers.

The study area is characterised by a high plateau with elevation ranging from 650 m to 750 m and small residual mountains resulting from differential erosion (quartzite ridges) where the highest elevation is found (994 m). The upper high plateau is deeply incised by the Douro and Sabor rivers which can present valley slopes reaching up to 600 m and slope gradients usually above 45° (Alves et al., 2004). The study area includes the Vilarica strike-slip fault oriented NNE-SSW which is c. 200 km long and affects the Variscan bedrock (Cabral, 1995). This fault is clearly responsible for a 6.5 km long trench of the Douro River. Other NNE-SSW oriented valleys are also tectonically controlled.

3. METHODOLOGY

A data-driven method was used to assess landslide susceptibility. The rationale is that future slope movements will occur under lithological and geomorphological settings similar to the ones that led to previous movements (Varnes, 1984). As a result, landslide prediction is based on the spatial correlation between previous movements with known location and a set of independent variables (predisposing factors) which control geomorphic instability (van Westen et al., 2008). In this context, the robustness of the inventory of past landslides is absolutely crucial for the quality of the prediction.

Landslide inventory was performed using digital aerial photos with 0.5 m resolution overlapping elevation data. Photo-interpretation was done using geomorphic criteria, such as those that indicate potential slope movements through changes in topography, vegetation or drainage network. Field work was done in order to validate the inventory in some areas.

Six variables were used in the landslide prediction model – three derivatives of elevation data: slope gradient (10 classes), aspect (9 classes) and plan curvature (3

classes); lithology (53 classes), soil type (24 classes) and land use (12 classes).

The landslide susceptibility assessment model used was the Information Value (IV) method (Yin & Yan, 1988), applied to a digital matrix with a 10 m pixel size. The IV method is Bayesian and is based on the natural logarithmic transform of the ratio between the conditioned and the a priori probabilities. The IV was calculated for each class of each of the six variables and the susceptibility value in each *j* pixel is the sum of all IV scores of the classes for each pixel.

Given that the relative age of the landslides is unknown because only one set of aerial photos was used, the inventory data was split randomly into two sets: one for training and one for model validation. Thus, the former was used to weight the classes of the predisposing factors and build the prediction model; and the latter was used as an independent set to validate the model, by plotting prediction-rate curves and computing the Areas Under the Curve (AUC).

Lastly, the structural exposed elements (buildings and roads) as well as the vital and strategic elements were spatially identified and were combined with the susceptibility map in order to locate the risk areas and quantify its spatial extent.

4. RESULTS AND DISCUSSION

Photo-interpretation resulted in the identification of 1295 shallow translational and shallow rotational slides, which in this analysis were considered as a single set. The delineation of the rupture zones of the landslides showed that the average area is 234 m², which corresponds to over 300,000 m² of unstable terrain (Table 1).

The existing landslides in this area tend to be rapid or very rapid and the affected material is frequently moved beyond the rupture zone as debris flow. Table 1 also shows a synthesis of the morphometric characteristics of the training and validation landslide sets.

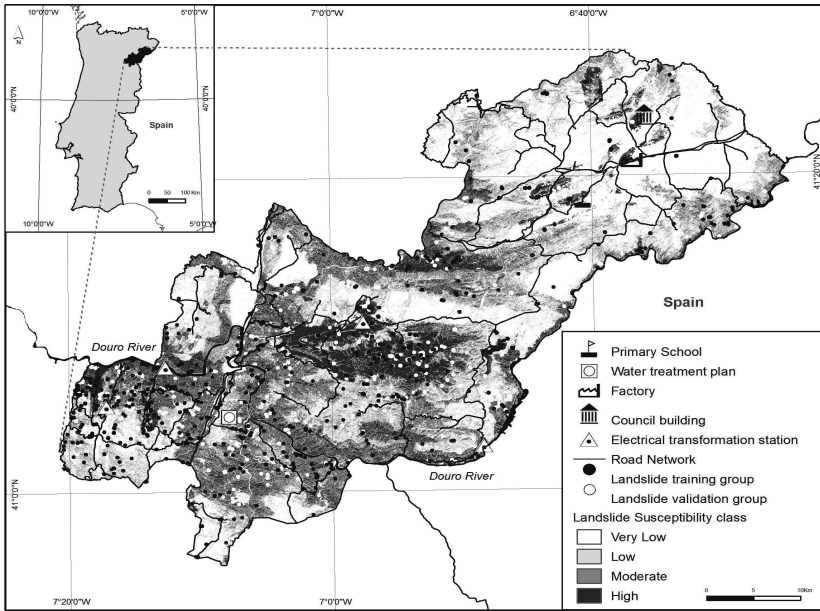


Fig. 1. Landslide susceptibility map of the High Douro Region. Landslides are not represented to scale to ease visualisation.

Table 1. Characteristics of the landslides in the inventory of the High Douro region (area values in meters)

	Landslide training group	Landslide validation group	Total landslide data set
Number of cases	647	648	1295
Min. Area	6	7	6
Max. Area	4,373	6,085	6,085
Mean Area	214	253	234
Std	380	511	451
Total area	139,033	163,914	302,947

Fig. 1 shows the susceptibility map of the study area classified according to final amplitude of variation of the Information Value obtained for each cell and Fig. 2 shows the success and prediction rate curves for the landslide susceptibility model. In the latter it is also indicated the limits of the four classes of susceptibility into which the IV data were split (Table 2). Not surprisingly, the success rate curve, based on the overlapping between the susceptibility model and the landslides in the inventory (training set), has a higher AUC (0.765) than the prediction rate curve (0.749) because the latter expresses the ability of the model to correctly and independently predict landslides in the

validation set. Nevertheless, the values of both AUCs are considered reasonably good.

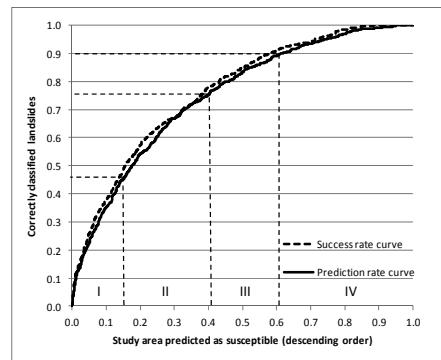


Fig. 2. Success rate and Prediction rate curves of landslide susceptibility model. Susceptibility classes: I – High; II – Moderate; III – Low; IV – Very low.

Table 2 synthesizes the spatial extent and the ability prediction of each susceptibility class. Thus, within an unlimited temporal framework, 46% of future slope movements in the High Douro region shall occur within the areas found to have high susceptibility to landsliding, which represents less than 16% of the total study

area. Similarly, about 30% of future movements are predicted to occur within areas considered to have moderate landslide susceptibility, which represent a quarter of the study area.

Table 2. Landslide susceptibility classes and their spatial extent and predictive power

Susceptibility classes	Information Value scores	Class area (% of total area)	Predictive power
High	> 1.0	15.5	0.462
Moderate	0.0 – 1.0	24.9	0.298
Low	-1.0 – 0.0	20.8	0.140
Very low	< -1.0	38.8	0.100

Table 3. The landslide susceptibility class of buildings and roads in the High Douro Region.

Susceptibility classes	Building Stock (%)	Roads (%)
High	1.6	12.1
Moderate	4.1	17.5
Low	5.2	16.2
Very low	89.1	54.1

In 2004 the High Douro region had 2,662 buildings (inhabited, offices, industrial, agricultural, etc), which correspond to an area of 5,352,000 m² and 751 km of roads, including dual and single carriageways.

The overlap between the built up area (buildings and roads) and landslide susceptibility maps shows that the exposed elements are located mainly on stable terrain, as c. 90% of buildings and c. 54% of roads are found in the very low landslide susceptibility class (Table 3). Nevertheless, almost 6% of the buildings (mainly inhabited) are located in areas classified as having high or moderate landslide susceptibility. Moreover, in those two classes of susceptibility are located ten vital and strategic elements, which should be the target of special planning and surveillance by the Civil Protection Agency: one primary school, one council building, two factories, four electrical transformation stations, and two water treatment plants. Also, almost 30% of the road network (223 km) is located within the two highest susceptibility class areas.

5. CONCLUSIONS

Results clearly showed that some slopes within the study area have high

susceptibility to landslide occurrence, and some of those are built-up areas with important human and socio-economic elements for which actions can now be devised to decrease the losses that may arise from future landslides. In particular, roads are very important in Emergency Planning because landslide-induced road cutting offs can cause major disruption by decreasing the efficiency of emergency responses or stopping entire populations from receiving emergency aid altogether. Thus, the maps produced in this work can be used to identify the extension of roads at high risk of being affected by landslides which could cut off towns.

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