Regional assessment of debris flow impacts on transport infrastructures

Debris flows may have dramatic consequences for the security of transport infrastructures in mountainous regions. Each year in the French Alps, some roads are impacted by debris flows (Fig. 1). The prevention of debris flow hazards along transport infrastructures necessitates the development of tools dedicated to the large-scale prediction of the most exposed infrastructures. In the framework of the Paramount project, Irtsea Grenoble proposed to handle this objective by combining (i) database compilation and statistical analysis, and (ii) regional-scale methodological developments using GIS tools.

Figure 1. An example of traffic interruption following a debris flow event in the Southern French Alps (Hautes-Alpes 2007, photo: Michel Bon ONF-RTM05)

The key issue was to propose a reliable way to recognize debris-flow prone areas for a large territory, where it is impossible to constraint all the physical determinant of debris-flow processes (sediment supply, local relief, sediment size, pore-water pressure). In the literature, this kind of issue is generally apprehended by GIS-based statistical analysis that aimed to obtain empirical relations between spatial occurrences of the phenomena and potential controlling factors.

We know from pioneering regional studies made in the Canadian Rockies in the 1980s that debris flow fans can be recognized by some straightforward morphometrics, such as the Melton index and the fan slope (Kostaschuk et al., 1986; Jackson et al., 1987). The Melton index is the basin relief normalized by the square root of the drainage area, and it corresponds to the mean slope of the catchment above the fan. Early studies revealed that fans subject to debris flows are found above a Melton index of 0.25 and their slope is consistently above four degrees (Fig. 2). Several other regional thresholds like this has been proposed in different mountain ranges of the world (New Zealand, Europe, North America), but all these studies present a limited population of catchments and the validity of the proposed thresholds may be questioned.
In order to get a large sample of catchments, we compiled data from the literature and we obtained a database of 620 catchments with information about the dominant process at the exit (debris flow or fluvial). The two categories occupy very different zones on the “Jackson” diagram and they can be separated using a discriminant function associating the two morphometric parameters (Fig. 3). The slope of the discriminant function revealed that we can not consider a unique threshold for the slope or the Melton index, as generally proposed by previous studies, but that these two parameters must be combined to define a threshold. It is also shown that the threshold slope for debris flow decreases with the slope of the catchment. A logistic regression model was also derived from these data, giving the possibility to calculate the probability for a catchment to generate debris-flow (Bertrand et al., in review). The two proposed models have been tested using the “leave one out” procedure and we obtained high values for both the sensitivity and the specificity ratio, which gives the percentage of true positives and true negatives cases, respectively (these ratios are routinely used to characterize performance of models and they are not sensitive to the prevalence of the dataset). The linear discriminant model shows a sensitivity of 0.90 and a specificity of 0.89. The logistic regression model shows a sensitivity of 0.96 and a specificity of 0.75.
Figure 3. Linear discriminant function obtained to separate debris-flow and fluvial responses from a compiled database of 620 catchments

The next step was to implement these statistical models on a GIS dedicated to the identification of the most exposed roads to debris-flows. The transport network and stream network were obtained from the most accurate vectorial database available in France (BD Topo from IGN) (Fig. 4). The flowchart of the GIS procedure implemented for the automatic extraction of potential debris-flow impact sites is presented in Figure 5.
Figure 4. Transport infrastructure network and stream network used to characterize potential debris-flow impact sites in the Southern French Alps (vectorial data from IGN BD Topo)

![Flow chart diagram](image)

Figure 5. Flow chart of the GIS procedure implemented for the automatic mapping of the most exposed transport infrastructures to debris-flow impacts

A regional map of exposed transport infrastructures is then proposed (Fig. 6). The sum of all potential impact points gave a value of 13 700 points along a 19 700-km transport network. Sixty-five percent of these points have a debris flow probability of occurrence higher than 0.5 according to the logistic regression model. It gave a density of potential debris flow impact points of 4.5 pts/10km of transport infrastructures.
Figure 6. Potential debris flow impact points along transport infrastructures in the Southern French Alps

The regional map has been compared with historical data from the ONF-RTM services (BD événements). The comparison is possible only when the information is integrated at the scale of the municipality (the smallest administrative unit in France). Synthetic indicators can be produced at this scale. We calculated the number of potential debris flow impact sites per km of transport infrastructures for each unit. The historical database from RTM was used to calculate for the same units the number of censed flood events with a known impact on transport infrastructures. Those two maps show a quite similar big picture of the regional hazard assessment, even if some differences are observed locally. This finally confirms that our methodological approach produces relevant information at the regional scale.
Figure 7. (A) The density of potential debris flow impact sites per km of transport infrastructure for each municipality of the Southern Alps, derived from morphometric analysis. (B) Number of censed damaging flood events per km of transport network for each municipality of the French Alps, as recorded by the historical database from ONF-RTM.

References

