A regional landslide warning system based on spatially variable rainfall thresholds

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Rainfall is widely recognized as one of the major causes for landsliding. When studying the conditions of triggering of mass movements at regional scale, a process-based approach is seldom possible because of the complexity in the spatial organization of the involved independent variables (e.g. soil properties). Therefore, empirical methods based on the definition of triggering thresholds are usually employed for the definition of warning systems or for landslide hazard assessments. Such thresholds are defined by observing the characteristics of past rainfall events that have resulted in landslides and selecting the lower bound envelope curve in intensity-duration plots depicting such events. These curves, generally represented by power-law type functions linking, e.g., intensity and duration of the critical rainfall, define the lowest level above which landslides should be expected.

In the present work, concerning the territory of Tuscany (ab. 23,000 km2), a similar approach is adopted and described which presents some improvements with respect to traditional methods.

First of all, the strong variability of environmental, meteorological and geological factors within the study area, together with evidences from available data on triggering conditions, imply that a single general threshold would be affected by a too large degree of overestimation of hazard and suggest the adoption of locally defined thresholds. The studied area was then partitioned in 25 Alert Zones and each of them has been analyzed separately to provide distinct rainfall thresholds.

Secondly, to handle the amount of available data (the analysis regards the period 2000-2007 and involves 408 rainfall events, which were registered by a network of 332 rain-gauges and that caused 2132 landslides), a software has been developed for automatically analyzing rainfall patterns and defining such thresholds. In particular, the automated analysis performs the following tasks:

i) Defining, for every rain-gauge registration, the critical Intensity (I) and Duration (D) of the triggering event, its return time and the amount of antecedent rain;

ii) Designating the most proper rain-gauge to represent every single landslide (the choice is performed combining geographic position and return times of the recorded rainfall);

iii) Plotting the corresponding I\D values on a log-log graph.

iv) Automatic drawing of the rainfall threshold using a geometric criterion (lower-bound line of the plotted points) or a statistical predictor.

By means of this automated procedure, multiple thresholds (differentiated on the basis of the severity of the event or the amount of antecedent rain) can be defined and different alarm levels set up.

Varying the criteria the automated analysis is based upon, different thresholds can be obtained, all of them calibrated only with the past rainfalls that did trigger landslides. To select the most effective one, a calibration based upon rainfalls not connected with landslides was also performed: the 8-years rain-gauges measurements

were compared to the thresholds and the one which minimizes the false positives (rainfall events beyond the threshold without associated landslides) was chosen to represent the rainfall conditions that should trigger landslides in that alert zone.

This procedure allows to balance the thresholds between false positives (occurring when a threshold is too low) and missed alarms (related to excessively high thresholds).

The results have been validated using rainfall registrations and landslides occurred during the period 2008 – 2009. Results were quite satisfactory and therefore the thresholds will soon be combined into a standard open procedure with a high degree of automation for the use of civil protection agencies in Tuscany.