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Probabilistic rainfall thresholds for landslide occurrence using a Bayesian approach

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Landslide rainfall thresholds are commonly defined as the critical value of two combined variables (e.g. rainfall duration and rainfall intensity) responsible for the occurrence of landslides in a given area. Various methods have been proposed in the literature to predict the rainfall conditions that are likely to trigger landslides, using for instance physically-based models or statistical analysis of historical catalogues. Most of these methods share an implicit deterministic view: the occurrence of landslides can be predicted by comparing the input value (rainfall conditions) with the threshold, and a single output (landslide or no-landslide) is only possible for a given input. In practical applications, however, a deterministic approach is not always applicable. Failure conditions are often achieved with a unique combination of many relevant factors (hydrologic response, weathering, changes in field stress, anthropic activity) and landslide triggering cannot be predicted by rainfall alone. When different outputs (landslide or no-landslide) can be obtained for the same input (rainfall conditions) a deterministic approach is no longer applicable and a probabilistic model is preferable.
In this study we propose a new method to evaluate the rainfall thresholds based on Bayes probability. The method is simple, statistically rigorous, and provides a way to define thresholds in complex cases, when conventional approaches become highly subjective. The Bayes theorem is a direct application of conditional probabilities and it allows to computed the conditional probability to have a landslide (A) when a rainfall event of a given magnitude (B) is expected. The fundamental aspect of the Bayes approach is that the landslide probability P(A|B) depends not only on the observed probability of the triggering rainfall P(B|A), but also on the marginal probability of the expected rainfall event P(B). Therefore, both the rainfall that resulted in landslides and the rainfall that not resulted in landslides must be considered in the analysis. The result is a value of landslide probability (from 0 to 1) for each combination of the selected rainfall variables.
The method has been applied to the historical dataset of the Emilia-Romagna Region (Italy). The dataset contains more than 9000 landslide records, for 4141 of which the date of occurrence is reported with a daily accuracy. Among these, 2741 landslides are characterized by a well-defined triggering rainfall (objectively identifiable in terms of duration and intensity) suitable for the analysis. Rainfall that non resulted in landslides account for more than 250000 events. The results clearly show that landslide triggering in the study area is strongly related to rainfall event parameters (duration, intensity, total rainfall) while antecedent rainfall seem to be less important. Moreover, the lines of equal Bayes probability in the rainfall duration- intensity chart are roughly parallel to the regional threshold proposed by Guzzetti et al. (2007), which in our case indicates a landslide probability of about 0.1. The abrupt increase of landslide probability in the duration-intensity plane indicates a radical change of state of the system, proving the existence of a real physical threshold.