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RELIABILITY OF RAINFALL THRESHOLDS FOR LANDSLIDE FORECASTING

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In Early Warning (EW) systems, the prediction of a landslide should be carried out on the basis of the monitoring of movements in the case of slow landslides, or on specific mathematical models for fast phenomena activated by rainfall. Nevertheless, it is not possible to create models for every possible situation and therefore the use of rainfall thresholds, that can be easily defined at the cost of less precision, is widespread. However, with a rigorous approach based on the awareness of the limits of the threshold scheme, acceptable results can be obtained. In this work, authors discuss the main problems related to the use of the rainfall thresholds.

In many applications, a rain indicator I is usually set (for example rainfall intensity of duration D) and a critical value I_{cr} is identified, which divides the range of values for which the landslide is impossible from that for which the landslide is certain.

In an EW system, in many cases, a number of threshold values can be identified; they are typically three, and may have a different meaning, based on the particular scheme adopted, i.e.: a) the occurrence of events with increasing magnitude; or b) an increase of probability associated with the event occurrence. In the former case, different values of I_{cr} are fixed for different expected magnitude, and each one is assumed as a threshold. In the case b), a single critical value is defined and different thresholds are assumed as fractions ξ_i (i = 1, 2, 3) of I_{cr}, with $\xi_i < 1$.

For example, a scheme of the type a) is used in Italy, setting three different thresholds associated with increasing and distinct levels of criticality with a color code (yellow, orange, red), that identifies events with increasing extension, magnitude and consequences. An approach of this type is usually adopted in the forecast phase, when referring to rains that are expected to fall in the next hours, and allows to activate in advance the necessary contrast measures. On the other hand, if the threshold refers to the rains in progress it is more appropriate to use those related to increasing probability of the event (type b).

The thresholds are often applied to large areas that, in the case of Italy, can reach a few thousand km^2. It is clear that passing from the specific case of the single landslide to more and more extensive areas, we bring together very different situations, that include areas with a different degree of vulnerability and therefore with very different thresholds. Fixing values based on the most vulnerable situations implies the proliferation of false alarms, while assuming higher values increases the number of missed alarms. It is evident that the application of single thresholds to large territories, characterized by a very diversified propensity to landslide phenomena, can produce considerable errors. The thresholds should therefore be defined for not extensive areas and for contexts in which the main morphological and lithological characteristics are fairly homogeneous.

A more general issue concerns the essence of the threshold scheme. More correctly, the relationship between I and the probability that the event E could occur is described by a monotone non-decreasing function, indicated as $P[E \mid I]$, with a pattern like that shown in the Figure 1 for a case study (Versace and De Luca 2017). Instead, using a step function like in the usually adopted threshold scheme, a value $P[E \mid I_{cr}]$ equal to 1 is assigned conventionally to I_{cr}. This value is much higher than the effective one (Figure 1). Therefore, when available data allow for, it is necessary to try to reconstruct the function $P[E \mid I]$, in order to also set the thresholds in a much more intuitive way by considering appropriate P values.

It should be emphasized that the estimate of $P[E \mid I]$ is carried out through a back analysis, that associates to each value of I the N / N_{tot} ratio, where N_{tot} is the total number of cases when rain indicator has been greater than or equal to I, and N is a subset of N_{tot} representing the number of cases in which an event occurred. This probability differs from the Hit Rate or Probability of Detection, which considers N_{tot} as the total number of events that have occurred.

The thresholds should be constructed on the basis of observed data, correlating rain indicators and consequences. In the absence of such information, thresholds with assigned return period T are usually adopted, which are assumed invariants when passing from one area to another. However, these areas can have a very different vulnerability: in some situations, landslides can be activated for T values of one or two years and, conversely, in other safer conditions only rains with higher T can be dangerous (10-20 years). To be reliable and effective, therefore, the thresholds must be always based on the analysis of the observed consequences.

When selecting the threshold values based on a back-analysis, false alarms and missed alarms must be taken into account, using optimization criteria based on ROC-like analyses or on objective functions that assign predetermined weights to false and missed alarms.

An Intensity-Duration (ID) scheme is very often used, which identifies a selected threshold curve through a back analysis or by assigning a return period T. In this second case, the probability of exceeding the threshold curve at any point is greater than the probability of exceeding the threshold value for a specific duration D. Therefore, the probability of exceeding a threshold curve with a return period T in a year is greater than 1 / T. This evidence must be taken into account in the assessment of the frequency of the alerts. Another limit of the ID curves is that the average rain intensity is assumed for a specific duration, and not the actual temporal pattern of a rain event. This assumption seems unrealistic in the case of shallow landslides in which the effectiveness of rains decreases rapidly with time.

The considerations above mentioned are also discussed in this work by some case studies

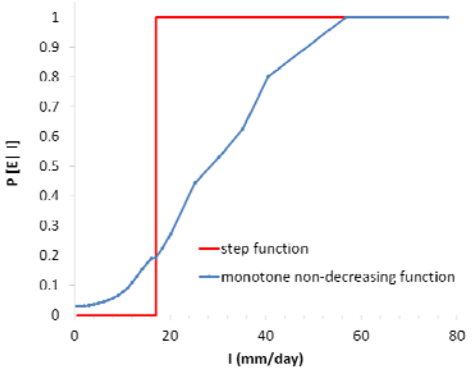

Figure 1. Examples of plot for $P[E \mid I]$ (adapted from Versace and De Luca, 2017).

Keywords: Early warning, rainfall threshold, reliability

References

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