Geophysical Research Abstracts,
Vol. 11, EGU2009-12290, 2009
EGU General Assembly 2009


# A new function for estimating local rainfall thresholds for landslide triggering

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The widely used power law for establishing rainfall thresholds for triggering of landslides was first proposed by N. Caine in 1980. The most updated global thresholds presented by F. Guzzetti and co-workers in 2008 were derived using Caine's power law and a rigorous and comprehensive collection of global data. Caine's function is defined as $I = \alpha \cdot D^{\beta}$, where $I$ and $D$ are the mean intensity and total duration of rainfall, and $\alpha$ and $\beta$ are parameters estimated for a lower boundary curve to most or all the positive observations (i.e., landslide triggering rainfall events). This function does not account for the effect of antecedent precipitation as a conditioning factor for slope instability, an approach that may be adequate for global or regional thresholds that include landslides in surface geologies with a wide range of subsurface drainage conditions and pore-pressure responses to sustained rainfall. However, in a local scale and in geological settings dominated by a narrow range of drainage conditions and behaviours of pore-pressure response, the inclusion of antecedent precipitation in the definition of thresholds becomes necessary in order to ensure their optimum performance, especially when used as part of early warning systems (i.e., false alarms and missed events must be kept to a minimum). Some authors have incorporated the effect of antecedent rainfall in a discrete manner by first comparing the accumulated precipitation during a specified number of days against a reference value and then using a Caine's function threshold only when that reference value is exceeded. The approach in other authors has been to calculate threshold values as linear combinations of several triggering and antecedent parameters. The present study is aimed to proposing a new threshold function based on a generalisation of Caine's power law.

The proposed function has the form $I = (\alpha_1 \cdot A_n^{\alpha 2}) \cdot D^{\beta}$, where $I$ and $D$ are defined as previously. The expression in parentheses is equivalent to Caine's $\alpha$ parameter. $\alpha_1$, $\alpha_2$ and $\beta$ are parameters estimated for the threshold. $A_n$ is the $n$-days cumulative rainfall. The suggested procedure to estimate the threshold is as follows:

(1) Given $N$ storms, assign one of the following flags to each storm: *nL* (non-triggering storms), *yL* (triggering storms), *uL* (uncertain-triggering storms). Successful predictions correspond to *nL* and *yL* storms occurring below and above the threshold, respectively. Storms flagged as *uL* are actually assigned either an *nL* or *yL* flag using a randomization procedure.

(2) Establish a set of values of $n_i$ (e.g. 1, 4, 7, 10, 15 days, etc.) to test for accumulated precipitation.

(3) For each storm and each $n_i$ value, obtain the antecedent accumulated precipitation in $n_i$ days $A_{ni}$.

(4) Generate a 3D grid of values of $\alpha_1$, $\alpha_2$ and $\beta$.

(5) For a certain value of $n_i$, generate confusion matrices for the $N$ storms at each grid point and estimate an evaluation metrics parameter *EMP* (e.g., accuracy, specificity, etc.).

(6) Repeat the previous step for all the set of $n_i$ values.

(7) From the 3D grid corresponding to each $n_i$ value, search for the optimum grid point $EMP_{opti}$(global minimum or maximum parameter).

(8) Search for the optimum value of $n_i$ in the space $n_i$ vs $EMP_{opti}$ .

(9) The threshold is defined by the value of $n_i$ obtained in the previous step and the corresponding values of $\alpha_1$, $\alpha_2$ and $\beta$.

The procedure is illustrated using rainfall data and landslide observations from the San Salvador volcano, where a rainfall-triggered debris flow destroyed a neighbourhood in the capital city of El Salvador in 19 September, 1982, killing not less than 300 people.