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# A tool for the automatic calculation of rainfall thresholds for landslide occurrence

Massimo Melillo*, Maria Teresa Brunetti, Silvia Peruccacci, Stefano Luigi Gariano, Anna Roccati, Fausto Guzzetti

*Istituto di Ricerca per La Protezione Idrogeologica, Consiglio Nazionale Delle Ricerche, Via Madonna Alta 126, 06128 Perugia, Italy*

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ABSTRACT

Empirical rainfall thresholds are commonly used to forecast landslide occurrence in wide areas. Thresholds are affected by several uncertainties related to the rainfall and the landslide information accuracy, the reconstruction of the rainfall responsible for the failure, and the method to calculate the thresholds. This limits the use of the thresholds in landslide early warning systems. To face the problem, we developed a comprehensive tool, CTRL–T (Calculation of Thresholds for Rainfall-induced Landslides–Tool) that automatically and objectively reconstructs rainfall events and the triggering conditions responsible for the failure, and calculates rainfall thresholds at different exceedance probabilities. CTRL–T uses a set of adjustable parameters to account for different morphological and climatic settings. We tested CTRL–T in Liguria region (Italy), which is highly prone to landslides. We expect CTRL–T has an impact on the definition of rainfall thresholds in Italy, and elsewhere, and on the reduction of the risk posed by rainfall-induced landslides.



## Software availability

Name: CTRL–T (Calculation of Thresholds for Rainfall-induced Landslides–Tool)
Developer: Massimo Melillo
Contact Address: CNR-IRPI, via Madonna Alta 126, 06128 Perugia, Italy
Email: massimo.melillo@irpi.cnr.it
Program language: R
Software requirement: R
Integrated Development Environment (IDE) suggest: RStudio
Source code: http://geomorphology.irpi.cnr.it/tools/rainfall-events-and-landslides-thresholds/ctrl-algorithm/ctrl-code/CTRL_code.R/

## 1. Introduction

Landslides are natural and human-induced phenomena that affect all continents, playing an important role in the evolution of landscapes and posing a serious threat to the population (Keefer and Larsen, 2007; Nadim et al., 2006, 2013; Petley, 2012). Rainfall is a recognized trigger of landslides, and this explains why there is a vast scientific literature on the relationship between rainfall and landslide occurrence. At regional and global scales, empirical rainfall thresholds are among the most used tools for the prediction of rainfall-induced slope failures. Several authors have proposed different methods for the calculation of rainfall thresholds through the statistical analysis of empirical distributions of rainfall conditions that have presumably resulted in landslides – including cumulated event rainfall vs. rainfall duration or mean rainfall intensity vs. rainfall duration (e.g., Aleotti, 2004; Guzzetti et al., 2007, 2008; Brunetti et al., 2010; Berti et al., 2012; Giannecchini et al., 2012; Martelloni et al., 2012; Peruccacci et al., 2012; Staley et al., 2013; Segoni et al., 2014; Rosi et al., 2016; Galanti et al., 2017). Some authors have considered both rainfall conditions that have and have not resulted in landslides and have used optimization techniques to define the optimal thresholds (e.g., Berti et al., 2012; Staley et al., 2013; Peres and Cancelliere, 2014). On the other hand, attempts to predict the occurrence of rainfall-induced landslides by means of a physically-based approach are present in the scientific literature (e.g., Lepore et al., 2017; Alvioli et al., 2014; Alvioli and Baum, 2016; An et al., 2016; Peres and Cancelliere, 2016).

Empirical rainfall thresholds are affected by several uncertainties, including: (i) the availability and quality of the rainfall

* Corresponding author.
*E-mail address:* massimo.melillo@irpi.cnr.it (M. Melillo).

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measurements and of the landslide information (Guzzetti et al., 2007; Berti et al., 2012; Peruccacci et al., 2012; Nikolopoulos et al., 2014; Gariano et al., 2015; Marra et al., 2017; Peres et al., 2017); (ii) the characterization of the rainfall event responsible for the landslides (Guzzetti et al., 2007; Iadanza et al., 2016); (iii) the heuristic or statistical methods used to determine the thresholds (Peruccacci et al., 2012, 2017; Vennari et al., 2014). As for the first point, uncertainty exists especially in rainfall series containing large data gaps. Depending on the information source, uncertainty can also affect the geographical and the temporal location of the failure. Gariano et al., 2015 found that even a small (1%) lack of landslide information can result in a significant decrease in the performance of a threshold-based prediction model. Uncertainty in the characterization of rainfall data has a strong impact on the identification of the thresholds, often resulting in their underestimation, leading to a high number of false alarms in early warning system applications (Nikolopoulos et al., 2014; Marra et al., 2017; Peres et al., 2017). Regarding the second point, Melillo et al., 2015 highlighted how standards for measuring landslide-triggering rainfall conditions are still lacking or insufficiently formalized in literature. Indeed, how the rainfall responsible for the landslide occurrence is calculated and whether its definition is reliable it is rarely reported, thus reducing the possibility of comparing different thresholds. Concerning the last point, the majority of empirical rainfall thresholds available in the literature are calculated using subjective and scarcely repeatable methods. Only few attempts were recently made to conceive procedures for an objective and reproducible definition of thresholds (Brunetti et al., 2010; Martelloni et al., 2012; Staley et al., 2013; Segoni et al., 2014; Vessia et al., 2014; Melillo et al., 2015; Piciullo et al., 2017; Peruccacci et al., 2017). We maintain that the quantitative identification of the landslide-triggering rainfall and the definition of reliable thresholds are fundamental steps towards a well-founded landslide prediction.

In this work, we upgraded the algorithm proposed by Melillo et al. (2015, 2016), introducing new criteria to select automatically (i) the representative rain gauge (i.e., the most representative measuring station suitable to reconstruct the landslide-triggering rainfall) and (ii) the rainfall conditions responsible for landslides. The algorithm standardizes the actions performed by an investigator that defines rainfall events starting from series of rainfall records and landslide occurrence dates. In addition, the algorithm, modelling the cumulated event rainfall, identifies the rainfall conditions responsible for the observed failures and calculates rainfall thresholds at different exceedance probabilities (Brunetti et al., 2010; Peruccacci et al., 2012). The algorithm is implemented in a tool (CTRL–T, Calculation of Thresholds for Rainfall-induced Landslides–Tool) written in R open-source software (Appendix A).

The paper is organized as follows. First, we describe the tool and the main upgrades and improvements herein proposed in the algorithm (Section 2), then we describe data and study area (Section 3) and some specific parameters (Section 4). In Section 5, we show the results obtained from its application in the study area (Liguria, northwestern Italy). This is followed, in Section 6, by a discussion on the main advantages of the tool, and its potential application for the reconstruction and assessment of the rainfall conditions that can initiate landslides in wide geographical areas. We conclude (Section 7) summarizing the main findings of the work.

## 2. Description of CTRL–T

CTRL–T contains an improved version of the algorithm proposed by Melillo et al. (2015, 2016). The former version of the algorithm allowed: (i) the reconstruction of distinct rainfall events (by pre-processing and analyzing rainfall measurements and aggregating rainfall sub-events); (ii) the identification of multiple rainfall conditions responsible for the triggering of documented landslides; (iii) the definition of rainfall thresholds for possible landslide occurrence. The former algorithm used pre-defined parameters to account for different seasonal and climatic conditions. CTRL–T includes new criteria to reconstruct automatically the rainfall conditions responsible for landslides and to define rainfall thresholds at different exceedance probabilities. Fig. 1 illustrates the logical framework of the improved algorithm. The "INPUT" data

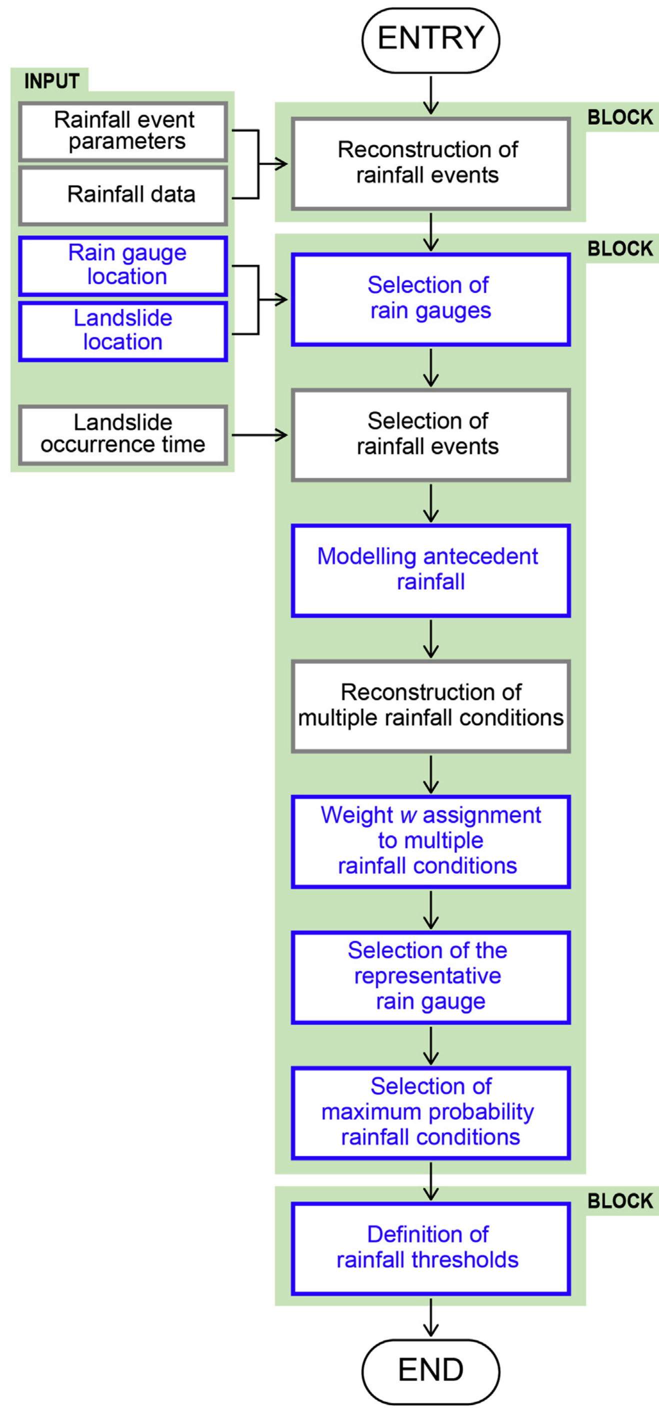


**Fig. 1.** Logical framework of the algorithm in CTRL–T. Grey and blue-bordered boxes represent actions already implemented in the previous release of the algorithm and the new additional actions, respectively. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)