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Real-time stochastic prediction of rainfall for early warning of shallow landslides in a pyroclastic-covered slope

Roberto Greco (1), Luca Comegna (1), Emilia Damiano (1), Massimiliano Giorgio (2), Andrea Guida (1), Lucio Olivares (1), and Luciano Picarelli (1)

(1) Seconda Universita di Napoli, DICDEA, Dipartimento di Ingegneria Civile, Design, Edilizia e Ambiente, Aversa (CE), Italy, (2) Seconda Universita di Napoli, DIII, Dipartimento di Ingegneria Industriale e dell'Informazione Aversa (CE), Italy

The effectiveness of an early warning system, as a means to mitigate the risk of rainfall-induced landslides, relies not only on its reliability (in short, both false alarms and missing alarms should be avoided as much as possible), but also on the lead time separating the launching of the alarm message from the occurrence of the landslide, which should be long enough to allow deploying the procedures required to reduce the exposition of people and/or goods (at least some hours, in the easiest cases). To such aim, the distinction of predisposing causes from the triggering event can be useful. In fact, the predisposing causes are related with the way the slope exchanges water with the larger hydrological system to which it belongs, usually through relatively slow hydrological processes, which can be effectively monitored. In Campania (southern Italy), large mountainous areas often interested by destructive debris flows, are characterized by slopes covered with a shallow loose pyroclastic deposit laying upon a limestone bedrock. In such slopes, the predisposing condition is usually identified with the moisture state of the soil cover, which is controlled by the complex interplay between meteorological forcing (rainfall and evapotranspiration), the attitude of the soil to let water infiltrate and be retained (i.e. the hydraulic functions of the soil), and the mechanisms draining water from the slope (again somehow related with the hydraulic conductivity of the soil, but very much depending on the hydraulic boundary condition at the base of the cover). The triggering, instead, is the rainfall event giving the last push to the slope and make it fail, often characterized by a duration of the order of one day (empirical rainfall thresholds of 200-300mm in 24-48 hours have been proposed to predict landslide initiation in the pyroclastic slopes of Campania).
With such a fast triggering, it looks clear that the real-time monitoring of the rainfall does not allow an early warning system to properly work. In fact, for the civil protection measures to be carried out in due time, the alarm message should be launched when the observed rain is still far from the landslide initiation threshold, and this would lead to a false alarm every time the rain ends before the threshold is actually reached.
To circumvent this problem, a stochastic model of hourly rainfall series has been developed, aimed at carrying out real time conditional predictions of the future evolution of the hyetograph during a storm. The model describes the sequence of rain storms and dry periods as an alternating renewal process. The shape of the normalized cumulative hyetograph of each storm of the sequence is approximated with an incomplete beta function, over which a random fluctuation is superimposed. The properties of the model allow to perform predictions of the future evolution of an ongoing storm, conditional only to the initial part of its hyetograph.
In order to show how such a model is suitable to be implemented as a part of an early warning system, it has been applied to carry out real-time predictions of landslide initiation at the slope of Cervinara, a typical example of the pyroclastic-covered slopes of Campania, for which an hydraulic model of infiltration and a geotechnical model to evaluate the factor of safety (both under the infinite slope hypothesis) were already available from previous research. The rainfall model has been calibrated with hourly rainfall data collected by a rain gauge operating at the slope between 2000 and 2005. The results of the application to the landslide event occurred in 1999 show that the proposed approach would have allowed to launch the alarm several hours before the occurrence of the rainfall.