Hydrogeological Threshold Using Support Vector Machines and Effective Rainfall Applied to a Deep Seated Unstable Slope (Séchilienne, French Alps)

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Abstract

Rainfall threshold is a widely used method for estimating minimum critical rainfall amount which can yield a slope failure. Literature reviews show that most of the threshold studies are subjective and not optimal. For this study, effective rainfall was considered for threshold definition. Support vector machines (SVM) and automatic event identification were used in order to establish an optimal and objective threshold for the Séchilienne landslide. Effective rainfall does significantly improve threshold performance (misclassification rate of 7.08 % instead of 13.27 % for gross rainfall) and is a relevant parameter for threshold definition in deep-seated landslide studies. In addition, the accuracy of the Séchilienne SVM threshold makes it appropriate to be integrated into a landslide warning system. Finally, the ability to make predictions at a daily time step opens up an opportunity for destabilisation stage predictions, through the use of weather forecasting.

Keywords

Infiltration • Landslide • Rainfall threshold • SVM

384.1 Introduction

Rainfall threshold is a widely used method for estimating minimum critical rainfall amount which can yield a slope failure. Rainfall threshold can be defined either with an empirical (statistical) or deterministic (modelled) approach from local to worldwide scale (Terlien 1998). To the best of our knowledge, no attempt at defining an empirical rainfall threshold to a deep seated unstable slope (>100 m) has been successfully undertaken. Literature reviews show that most of the threshold studies are subjective and not optimal, as thresholds are usually drawn visually or with poor mathematical/statistical basis (Guzzetti et al. 2005). Moreover, Effective Rainfall (ER), which is the part of rainfall which recharges the aquifer, is relevant to consider instead of Gross Rainfall (GR) for deep seated landslides involving groundwater flow (Vallet et al. 2014). The aim of this study is to develop a new objective approach, using ER to establish hydrogeological statistical threshold of a deep seated unstable slope. The method has been designed in order to be easily incorporated into a landslide warning system. To do this, Support Vector Machines (SVM) have been used to allow automatic detection of events.

384.2 Monitoring Network and Dataset

The Séchilienne site is located on the external part of the Belledonne crystalline range in the French Alps (south-east of Grenoble city). The Séchilienne site is a deep unstable slope on a micaschist bedrock. Precipitations are recorded at the Mont Sec weather station, including a rain gauge and a snow gauge. ER was computed using a water balance method from precipitation, runoff and evapotranspiration

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with an available water storage of 105 mm in the soil (Vallet et al. 2014). Displacement velocities of the Séchilienne unstable slope are monitored by several extensometers since 1990. The A13, A16 and C2 extensometers were selected as representative of the Séchilienne most active displacement zone. Daily precipitation, recharge, and the displacement time series range from 1st January 1994 to 31 July 2012.

384.3 Hydrological Threshold for Deep Seated Landslide

Hydrological threshold defines the minimal rainfall conditions (rainfall index) prone to trigger slope destabilization. Threshold defines the minimum required amount of rainfall which triggers destabilization. Establishment of rainfall threshold is based on a two-dimensional rainfall index. Literature presents various combinations of rainfall indexes, including the most common: intensity-duration and daily-antecedent (Terlien 1998). Index selection depends mainly on the site settings (e.g. landslide type, climatic conditions, geomorphology, local or global threshold). The Séchilienne unstable slope involves a large scale aquifer with a natural catchment which is much larger than the unstable slope extension. Hydrosystem inertia and buffering properties are significant and smooth-over the properties of any short term events, such as variations in rainfall intensity and duration. Unstable slope aquifer hydrodynamical response is more influenced by antecedent rainfall which considers multiple rainfall events than a single event. Therefore for Séchilienne, threshold definition is based on an antecedent and precedent rainfall index. Antecedent rainfall and precedent rainfall are the accumulated amount of rainfall (sum) over a period of days before an event, and correspond to a long (several weeks) and a short term period (several days) respectively. The two periods do not overlap and are always adjacent. The antecedent period immediately follows the precedent period.

Complex structural geology and induced groundwater hydrodynamics of deep seated landslide generally involve a complicated hydro-mechanical relationship with rainfall (Terlien 1998; Berti et al. 2012). For deep seated landslides, a deterministic threshold approach, based on a hydro-mechanical model, is challenging to implement due to the absence of direct hydrodynamic measurements. Therefore, in the case of a large amount of available data (destabilisation events and rainfall data), definition of a statistical local threshold is preferred as it can implicitly take into account these relationships. Even though Terlien (1998) has shown the importance of period extension selection in threshold definition, in literature, the choice of period extension of antecedent rainfalls is mainly explored empirically, with no optimization to find the best number of days.

Hydrogeological threshold was estimated for all combinations of antecedent and precedent periods varying from 2 to 100 days and from 1 to 10 days respectively. As described in previous works (Vallet et al. 2014), an old rainfall event displays less impact than the most recent one on immediate groundwater hydrodynamics. For this reason, rainfall was cumulated for each landslide event according to a decreasing sum: $DS = \sum_{i=1}^{n} \alpha^{(1-i)} y(i)$ (with α the decay factor, y the rainfall data and n the period length in day). 5 decay factors were tested (1, 0.99, 0.98, 0.95 and 0.9) and combined for the two periods in 15 arrangements (for example 0.99 for precedent and 0.98 for antecedent). SVM performance was used to assess the best combination, among the 14,175 computed permutations, for each dataset (GR and ER), which maximizes the discrimination between stable and unstable events.

384.4 Events Identification

Although deep seated landslide destabilization is controlled mainly by a rainfall trigger (short term component),time-dependent factors (long term component) such as rock weakening, slope groundwater permeability and connectivity modifications, can be significantly influenced by the destabilisation (Berti et al. 2012). Long term displacement monitoring shows that the displacement rate and amplitude follows an exponential trend (Fig. 384.1). This is not the case for the precipitation time series. In Séchilienne, detrended displacement seasonal variations are clearly linked to the groundwater variations and to the recharge amount, whereas exponential trend is independent (Vallet et al. 2014). The observed trend is interpreted as the consequences of a progressive deterioration of rock mechanical properties. For this study, no stable or unstable events have been identified as Séchilienne unstable slope is constantly moving. Furthermore, due to the long term increasing trend, it was not possible to define absolute landslide response from rainfall triggering. Therefore, the choice has been made to define a critical statistical threshold which defines the minimum amount of rainfall (gross or effective) which yields a significant increase in slope destabilization (relative and not absolute variation) independently from the trend. Thus, displacement was removed (by a multiplicative method) and not taken into account for identifying events. Two types of events were defined: low (LDE) and high (HDE) destabilisation events. Because extensometers give a local measurement, an event is considered as being representative of a landslide only if it is simultaneously identified on the three extensometers selected (spatial and temporal coincidence). A method was developed to automatically detect the events. The method is based on a double moving window which was

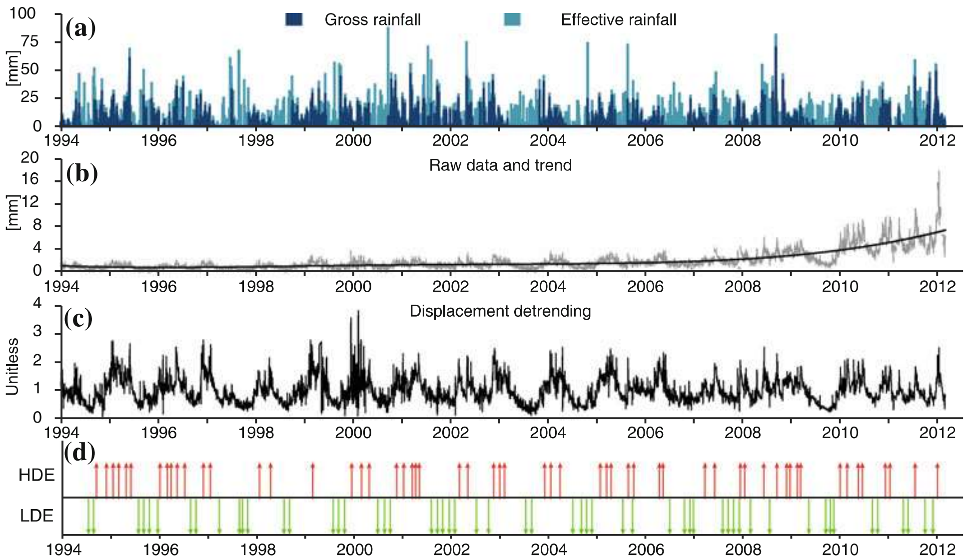

Fig. 384.1 Meteorological dataset (**a**) and displacement of extensometer A13 with (**b**) raw displacement and exponential trend, (**c**) detrended displacement and (**d**) identification of high (HDE) and low (LDE) destabilisation events

tuned on a training period (2001–2004) where events were identified manually (supervised learning). The method was tuned separately for LDE and HDE events detection.

384.5 Objective and Optimal Threshold Definition: SVM

Establishment of a rainfall threshold requires defining a boundary between two categories of two-dimensional points, labelled generally as stable or unstable, where misclassification is authorized for a few data points. There are infinite possibilities of curves which can separate two classes of points. Support vector machines (SVM) are a widely used two-class linear classifier, belonging to supervised learning models and kernel methods (i.e. dot products). Soft margin SVM formulation allows some points to be in the margin or even to be misclassified in order to achieve a greater margin. A soft margin cost parameter (C) needs to be user-specified. Small values of C will produce a classifier with larger margin but will allow a higher proportion of misclassified sample data. The effectiveness of SVM classification depends on calibration of the soft margin parameter. SVM analysis was performed with the Matlab® package LIB-SVM (Chang and Lin 2011). Cross-validation is a statistical method which assesses model performance, specially adapted to SVM (Hsu et al. 2003). Cross-validation assesses the accuracy of the model to predict new data by estimating the average misclassification rate in percent. Cross-validation also avoids model overfitting. For our purpose, 'leave-one-out' cross-validation was chosen.

384.6 Results and Discussions

57 HDE and 55 LDE were identified for the whole studied interval on the extensometers detrended displacement and are plotted on the raw displacement time series (Fig. 384.1). The number of identified events for each class is balanced and the total number of events is sufficient to perform SVM analysis. Among the combinations tested, the hydrogeological threshold misclassification rate is about two times higher for GR (13.27 %) compared to the one obtained with ER (7.08 %) (Fig. 384.2). The other difference is the index antecedent/precedent involved in the two best threshold performances with 10D/5D (short term) for GR and with 34D/8D (long term) for ER. SVM thresholds were defined on discontinuous punctual events. In order to evaluate their forecast ability, an SVM threshold was applied to the ER and GR daily dataset from 1st January 2012 to 31st August 2013 and compared to Expected Destabilisation Stages (EDS) identified visually (Fig. 384.2). The ER and GR thresholds show a large number of false positives, in high and low water periods respectively. The combination of both ER and GR thresholds (composite) identified all the EDS properly with only a few false positives.

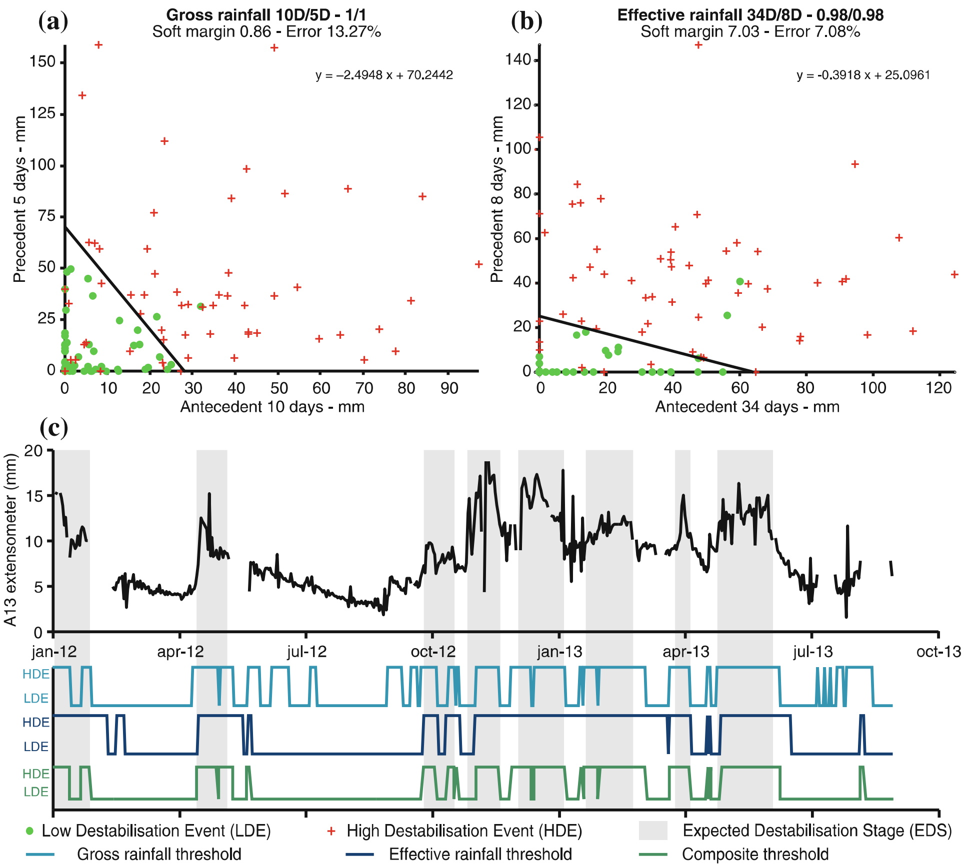

Fig. 384.2 Results of best SVM performance for gross rainfall (**a**) and effective rainfall (**b**). Chart (**c**) shows the prediction ability at a daily time step

384.7 Conclusion

The use of SVM and automatic detection of events has produced good results for the establishment of a hydrogeological threshold. ER does significantly improve threshold performance and is a relevant parameter for threshold definition of deep-seated landslide studies. Destabilisation stages are very well predicted by a high saturation state of the slope aquifer (long term component related to ER threshold) combined with high rainfall events (short term high infiltration amount) which intensify the destabilisation rate. In addition, the accuracy of the ER/GR composite threshold makes it appropriate for use in a landslide warning system. Finally, prediction ability at a daily time step presents the opportunity of destabilisation stage predictions, through the use of weather forecasting.

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