FLASH FLOOD GUIDANCE BASED ON RAINFALL THRESHOLDS: AN EXAMPLE OF A PROBABILISTIC DECISION APPROACH FOR EARLY WARNING SYSTEMS

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Abstract

Early warning systems for flash floods are substantially different from those designed for other types of floods not only in the time scales but in the predicting variables, the data availability and the predictive uncertainty. Therefore the monitored variables, the statistical approach and the data requirements should be specifically selected or designed in order to maximize the skills of the warning systems. In this work is proposed a warning system for flash floods based on critical rainfall thresholds to be compared directly with the quantitative precipitation forecast. Rainfall thresholds are here defined as the cumulated volume of rainfall during a storm event which can generate a critical water stage (or discharge) at a specific river section. It is show how to determine the Flash Flood Guidance (FFG) rainfall depth based on the minimization of a Bayesian Loss Function of the discharge in the target river section conditional upon the state of saturation of the catchment.

1 Introduction

The different approaches of the warning systems based on thresholds assume that there is relationship, physical-mechanical or statistical, between a variable called “predictor” and a variable called “predictand”.

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The distinction between the predictor and the predictand is conceptually important but has also some practical importance for the efficiency of a warning system. By definition the predictor is the variable which can be observed and which shares a certain relationship with the predictand variable which is the variable to be predicted. In the context of the warning system of any natural hazard, usually the predictand is related with the effects of the hazard such as damages which one would reduce or avoid by means of adequate operations which require adequate decisions. The decisions are instead related to, i.e. can be made on the basis of, the predictor.

The thresholds are a simplification of the problem of how to define a decision rule (such as send or not an alarm/warning) and they are necessary applied on the predictor on the basis of a scope (e.g. reducing the damages) and some criteria. The criteria can be expressed coherently with the definition of the risk which is the product of exposure, vulnerability and hazard. Practically a threshold could divide the values of the predictor which result in a acceptable risk from those which result in an unacceptable risk.

In this work the predictand is the discharge in a target river section, the predictor is the rainfall depth at different duration, the relationship between the predictor and the predictand is represented as a joint probability distribution, the damages are function of the discharge and the threshold are defined in terms of rainfall depth based on which can be send or not a flood warning.

Warning systems designed for flash floods have also some differences from the general cases: the time scale is smaller, the relationship predictor-predictand (typically rainfall-discharge) is affected by uncertainty, the predictand often is not monitored. For this reason it is necessary to specifically design the approach in order to maximize the overall skill of the system.

2 The Bayesian Rainfall thresholds methodology

Rainfall thresholds are here defined as the cumulated volume of rainfall during a storm event which can generate a critical water stage (or discharge) at a specific river section. When the rainfall threshold value is exceeded, the likelihood that the critical river level (or discharge) will be reached is high and consequently it becomes appropriate to issue a flood alert; alternatively, no flood alert is going to be is-sued when the threshold level is not reached. In other words the rainfall thresholds must incorporate a "convenient" dependence between the cumulated rainfall volume during the storm duration and the possible consequences on the water level or discharge in a river section. The term "convenient" is here used according to the meaning of the decision theory under uncertainty conditions, namely the decision which corresponds to the minimum (or the maximum) expected value of a Bayesian cost utility function.

There are two possible approaches for the same methodology: (a) using the Monte-Carlo simulations or (2) using the Normal Quantile Transform. The main difference of the two is the requirements in terms of data, i.e. the time series of rainfall and discharge.

2.1 The Bayesian Rainfall Threshold using the Monte-Carlo approach (BRT-MC)

This approach was developed by Martina et al. (2006) and it can be referred to that paper for a more detailed description. In order to ease the description of the methodology, illustrated in Figure 1, two phases are here distinguished: (1) the rainfall thresh-olds estimation phase and (2) the operational utilization phase. The first phase includes all the procedures aimed at estimating the rainfall thresholds related to the risk of exceeding a critical water stage (or discharge) value at a river section. These procedures are executed just once for each river section of interest.

The second phase includes all the operations to be carried out each time a significant storm is foreseen, in order to compare the precipitation volume forecasted by a meteorological model with the critical threshold value already determined as in phase 1.

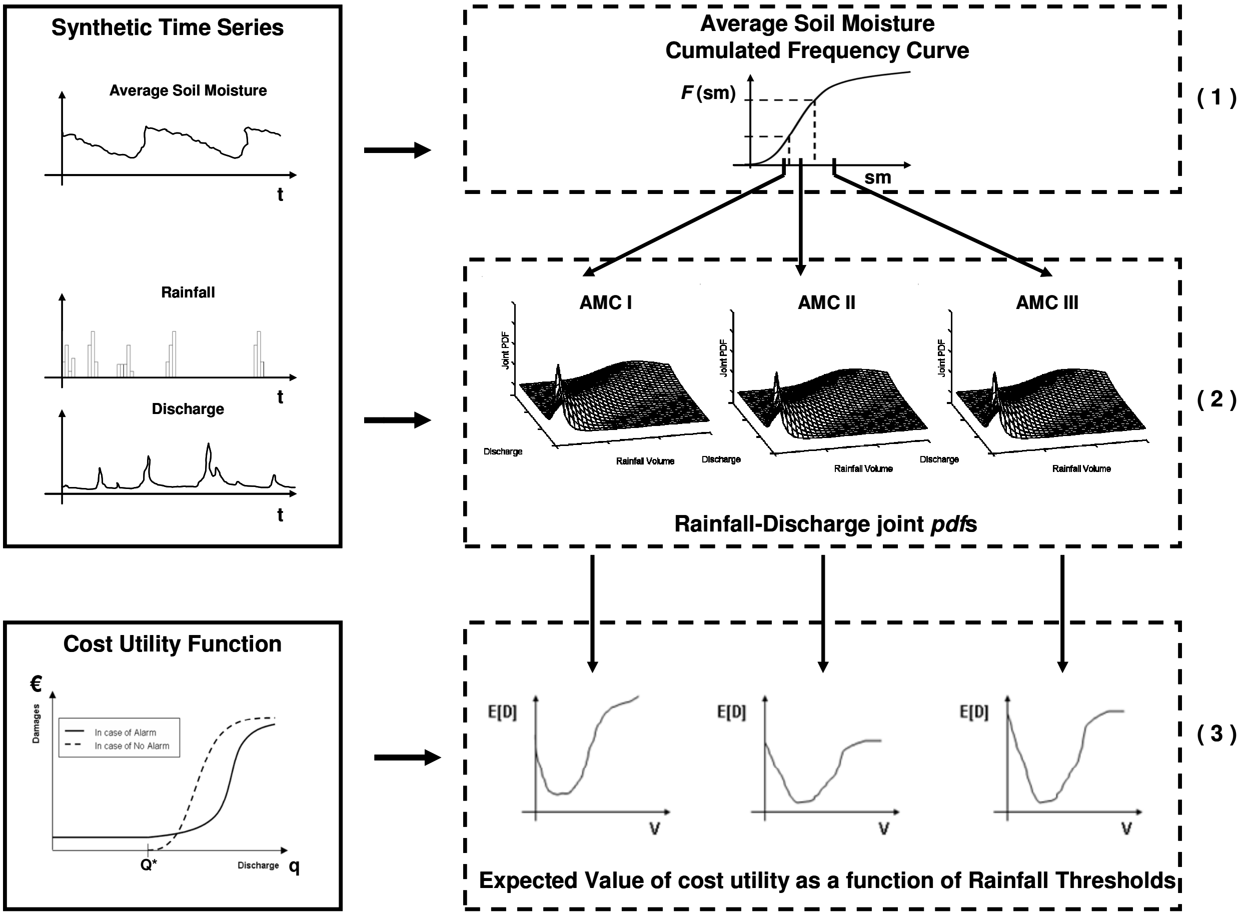

Figure 1. Schematic representation of the proposed methodology. (1) Subdivision of the three synthetic time series according to the soil moisture conditions (AMC); (2) Estimation of the joint pdfs between rainfall volume and water stage or discharge; (3) Estimation of the “convenient” rainfall threshold based on the minimisation of the expected value of the associated utility function.

2.2 The Bayesian Rainfall Thresholds using the Normal Quantile Transform (BRT-NQT)

One of the limits of the method described in Martina et al. (2006) is represented by the excessive data requirement. To overcome the limit of the BRTMC methodology, a second methodology has been recently developed hereafter referred to as BRTNQT (Bayesian Rainfall Threshold using the Normal Quantile Transform). The difference with BRTMC consists in the inference of the joint probability density. Instead of the classical Monte Carlo approach the inference of the joint PDF is performed by trans-forming the two variables, V(T) and Qp, into two standard normally distributed variables by means of the Normal Quantile Transform (NQT). This procedure ensures, by construction, that the marginal distribution of the variables are standard normal, but does not guarantee that the joint PDF is multivariate standard normal distribution. Therefore generally the normality of the joint distribution must be tested by comparing the empirical (based on the data) distribution with the theoretical form or existing goodness of fitting test. The NQT leads to the inference of the meta-Gaussian joint PDF which can be performed using a much smaller amount of data then the BRTMC (e.g. tens of years).

The BRTNQT has been developed and implemented such that the only data requirement is the rainfall and discharge time series (for the joint PDF inference) and the average soil moisture time series which conditions the rainfall thresholds. The average soil moisture conditions, which often necessitates to be simulated by a rain-fall-runoff model, can be substituted with a reliable antecedent conditions index (such as API, AMC, etc..) computed based on the precipitation. A computer program which performs the BRTNQT methodology has been developed and implemented on the pilot basins.

3 Application on a real catchment of the BRT

In order to test the capability of the methodology at reproducing the criteria of the decision maker by means of the Cost/Utility functions, it has be designed an experiment which reproduces different "attitudes" or different decision criteria for the alarm management and the methodology has been applied on the Posina catchment, a medium-sized watershed located in a mountainous region in northern Italy. This could be done by selecting appropriate parameters of the Utility/Cost function. The Utility/Cost function has be defined as (Martina et al., 2006) $U(q, v|V_T, T)$ which if $v \le V_T$ expresses the perception of damages when no alert is issued no costs will occur if the discharge q will remain smaller than a critical value Q^*, while damage costs will grow noticeably if the critical value is overtopped. On the contrary, if $v > V_T$ it expresses the perception of damages when the alert is issued a cost which will be inevitably paid to issue the alert (evacuation costs, operational cost including personnel, machinery etc.), and damage costs growing less significantly when the critical value Q^* is overtopped and the flood occurs. The utility function to be used will differ depending on the value of the cumulated rainfall forecast v and the rainfall threshold V_T. If the forecast precipitation value is smaller or equal to the threshold value, the alert will not be issued; on the contrary, if the forecasted precipitation value is greater than the threshold value, an alarm will be issued.

Three different attitudes of the decision maker have been selected which generated three different cases for the application of the utility/cost function: (a) the "risk-averse" case, (b) the "risk-prone" case, (3) the "real" case. The first two cases have been chosen in order to represent some sort of extreme attitudes of the decision makers, while the third case has been designed on the basis of real experience. It is important to say that, especially for the first two cases, the utility/cost function represents more the "perception" of the costs and of the damages rather than the real costs. This means that not only the real costs are important but also the weights which each decision maker attribute to them. The reasons for that are: (1) there are some costs which are not valuable as the credibility loss; (2) there is a different perception of the costs in terms of social and psychological impacts than only the economic one.

In order to compare the described cases with some references, have been defined also two criteria independent by the cost function.

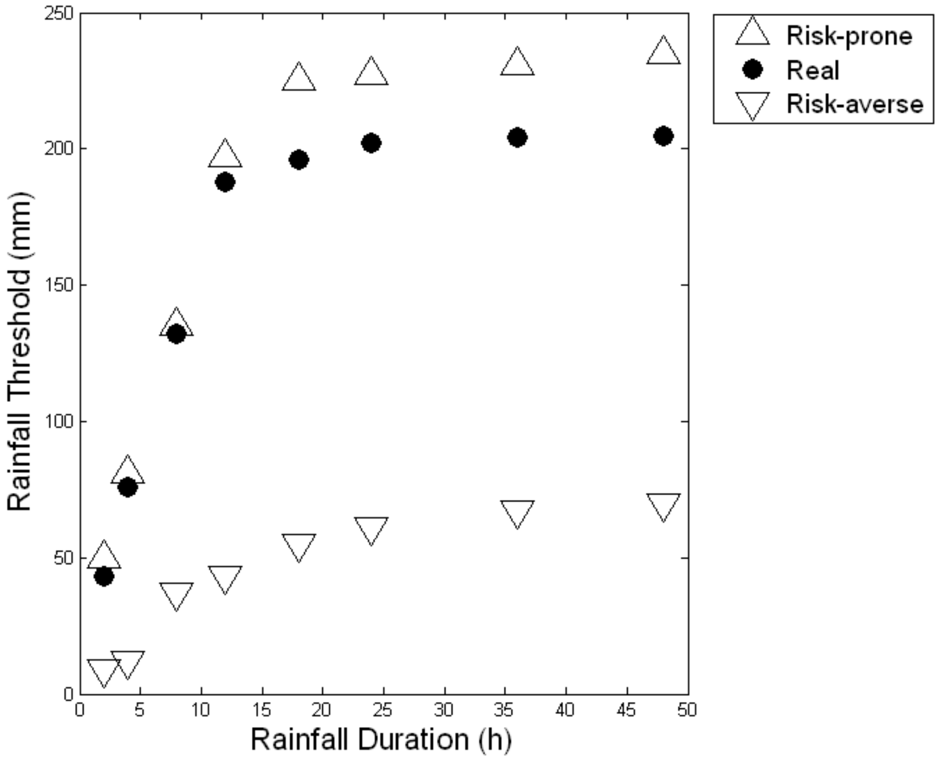

Figure 2. Comparison of the rainfall thresholds for the examined cases.

4 Conclusions

It was here presented a general view on the key concepts of a warning system. In particular it is necessary to clearly define:

- the predictor variable which should be observable (or at last predicted before the predictand)
- the predictand variable on which depends the negative effects of the hazard (damages)
- the relationship, physical or statistical, between predictand and predictor
- the function damages-predictand
- the decision criteria (e.g. threshold) in function of the predictor

It was also presented an example of a FFG (flash flood guidance) based on the rainfall thresholds. Rainfall thresholds seem to be suitable as basis for flash flood warning system.

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