Flash Flood Hazard Assessment in Small Agricultural Basins Coupling GIS-Data and Cellular Automata Modelling: First Experimentations in Upper-Normandy (France)

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ABSTRACT

Flash floods are the most dangerous processes in Seine-Maritime (northern France) due to their sudden onset and rapid rising time. Such floods shortly follow high rainfall, ranging from 50 to up to 100 mm in less than 6 hours, and occur in small (< 20 km²) and dry valleys, in which a surge rushes down through the main valley just a few minutes after rains have peaked. Phenomena currently produce damages to buildings and road infrastructure, but rarely threaten human lives. Anticipating their occurrence, therefore, is crucial. However, such prediction remain delicate, especially at larger scales, due to the quantitative errors of radar disturbing rainfall-runoff simulations, the infrequency of events and the gentle return periods rendering statistical analysis and calibration of models far from obvious. In this study, a susceptibility analysis is then carried out, without depending on the meteorological predictions, by applying RUICELLS, a cellular automaton model driven according to a set of three deterministic hydrological rules of flow pathways. The 2,368 simulations launched for 16 different rainfall intensities on 148 basins of small size (less than 20 km²) permit to simulate the peak-flow discharges (Q), specific peak-flows (Qs) and lag times (T), but also to estimate the critical rains necessitating increased vigilance. The authors’ simulations show that the number of basins susceptible to flash flooding greatly increases with higher rainfall intensity, cultivation of sensitive crops (sugar beet, corn, maize, flax), and basin morphology. Moreover, the authors show that certain valleys are more prone to flash flooding, since several susceptible basins are located in close proximity. The modelling results also question the effectiveness of a specific flash flood alert system for this region.

Keywords: Dry Valleys, Flash Flood, Northern France, Rainfall, Susceptibility Assessment

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1. INTRODUCTION

Over the last two decades, flash floods posed serious risk in sedimentary areas (Boardman et al., 2003; Evrard et al., 2007), especially on several populated outlets in the department of Seine-Maritime (Delahaye et al., 2001; Douvinet et al., 2013). Generated shortly after high rains, ranging between 50 and 100 mm in less than 6 hours, and occurring in small and dry valleys (< 20km²), these flash floods are characterized by a violent onset, a rapid rising time and a surge rushing down the main valley just a few minutes after rainfall have peaked. These floods present features quite similar to others occurring, for example, in western France (Auzet et al., 1995) or in Flanders (Evrard et al., 2007), but are really different to Mediterranean floods (Barrera et al., 2006; Schmitz and Cullmann, 2008; Ortega and Heydt, 2009; Morin et al., 2009). Even though these hazards threaten human lives (11 persons died over the period 1983-2005 in Seine-Maritime) and cause significant damage to infrastructures (from 0.05 to 14 millions of euros; Douvinet, 2008), predicting their time of occurrence and intensity remains delicate at larger scales for several reasons: measurements and field-based experimentations are rarely conducted in dry valleys; these phenomena are insufficiently documented and remain difficult to monitor as they produce destructive effects to measuring devices; the rarity of events and the long recurrence intervals render obvious statistical analysis and calibration of models (Ferraris et al., 2002); the short distances between source areas (runoff production) and risk zones (i.e. settlements) frequently surprises inhabitants in a few minutes; changes in velocity, roughness and water height introduce uncertainties in the estimation of peaks of discharge (Gaume et al., 2009) and hamper classical hydrological approaches.

To anticipate the spatial occurrence and areas at risk, we propose an original approach coupling GIS-data within a cellular automaton (CA) namely RUICELLS (Delahaye et al., 2001; Douvinet et al., 2013). This model is a triangular cellular automaton driven according to a set of simplified and deterministic hydrological rules of flow pathways (Tarboton, 1997). We choose this deterministic approach for two reasons: it is easily transferable to basically any site (Coulthard & Van De Wiel, 2006; Ménard and Marceau, 2006; Van de Wiel et al., 2007), and CA modelling considers common physical characteristics of processes, whereas the statistical models based on inventories of past events are less transferable and only implicitly represent the impacts of processes (rather than the processes themselves) through the reliance on numerous records (Kappes et al., 2012).

By means of a combination of environmental parameters chosen on the basis of previous experiences, water flow speeding (conducted by the slope angle and hydrological height) and recent available land use (influencing the water infiltration capacities) the flash flood susceptibility was calculated for 16 rains on 148 basins (2.386 simulations). The methodology applied in this study simplifies rainfall inputs: indeed, even though the recent efforts in meteorological observations provide relevant details on timing and location of convective storms (Collier, 2007), the forecasters cannot use these estimations coming from existing predictive models (e.g. AROME or PANTHERE) because the rainfall intensities are not precisely established at fine scales (< 10km²) and insufficiently available in advance (1h). Furthermore, the CA modelling approach strongly differs from Soil Erosion Models (SEM) in which a great number of environmental factors are required (Nearing et al., 2005). The major parameter in these SEM is the Manning roughness coefficient, a flow resistant parameter, which is a function of land use criteria in the flooded areas (De Roo, 1999), but information on land practices is usually not available. We also aim at controlling the end-to-end simulation process (Fonstad, 2006), measuring the transformation of input to output data, testing the sensitivity of basins to initial conditions and defining their reactivity to different rainfalls with which we cannot experiment in reality.
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