EXAMINING THE SENSITIVITY OF FLOOD MODELLING IN PERIURBAN AREAS IN RAINFALL INPUTS OF VARIABLE ACCURACY

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ABSTRACT

Flood risk management in periurban catchments is a critical issue, mainly due to the coexistence of different land uses and their frequent interaction, which make flood risk assessment hard. For efficient flood simulations in such areas, the use of accurate and representative rainfall inputs in modelling tools is particularly important. This research focuses on the examination of the impact of rainfall inputs of variable accuracy on both the hydrological and the hydraulic response of a periurban catchment. To this end, representative and efficient models for hydrological and hydraulic simulations were selected and set up for the study area and flood simulations for different rainfall inputs were performed. More specifically, rainfall inputs included rainfall forecasts while available flow measurements from stream flow gauges were used for model calibration. The optimum number of grid points with rainfall forecasts suggested for flood modelling, as well as the impact of the number of grid points used in the hydrological and the hydraulic analysis were further investigated. The study area is the Rafina catchment, a typical Mediterranean periurban catchment located in Eastern Attica, Greece. Hydrometeorological information is retrieved from the Hydrological Observatory of Athens (HOA), operated by the Centre for Hydrology and Informatics (CHI) of the National Technical University of Athens (NTUA), while meteorological information used in the analysis includes daily rainfall forecasts provided by the National Observatory of Athens (NOA). Both organizations operate dense networks in the study area. Flow measurements from HOA are retrieved from three stream flow gauges, while forecasts from NOA are provided in 48 grid points located within the catchment boundaries. The semi-distributed hydrological model HEC-HMS and the 1D hydraulic model HEC-RAS were used for flood modelling and run for selected rainfall events. The research concludes with suggestions on the required accuracy in rainfall inputs in order to achieve reliable hydrological and hydraulic simulations in a complex periurban area.

Keywords: Flood risk management, periurban areas, flood modelling, raingauge network, rainfall forecasts, sensitivity analysis

1. Introduction

Periurban areas are areas exposed to several natural hazards and are particularly prone to floods. Such areas include extended urban zones, which are covered by impermeable soils and are characterized by limited green areas. Therefore, precipitation over these areas is quickly transformed to runoff and when existing hydraulic works are inadequate to safely convey the excessive rainwater to drainage systems, which is quite frequent, flooding occurs. In addition, as defined in Braud *et al*. (2013), these areas are a mixture of natural or agricultural lands and urban areas. In the so-called Wildland-Urban Interface (WUI) which is created at the zone where wildland and urban land uses are intermixed, wildfires are quite frequent (Chas-Amil *et al*, 2013; McGee, 2005; Manzello *et al*., 2010). This is especially true in Mediterranean periurban areas, the coverage of which by flammable forested land and their hydrometeorological and geomorphological regime, renders them particular fire-prone (Darques, 2015). However, wildfires are directly associated with floods, since a recently burnt area is more prone to flooding (Inbar *et al*., 1998; Papathanasiou *et al*., 2013b). Not only is flooding in periurban areas more probable, but also its consequences there are more intense, since increased population and extended infrastructure are affected. For these reasons, flood risk management in periurban areas is an issue of priority and state-of-art flood modelling systems need to use accurate hydrometeorological inputs so as to provide representative simulations of catchment's response. This study examines the impact of rainfall that corresponds to a different number of grid points, on the simulated flood response of a catchment.

2. Study area

The study area of this research is the Rafina catchmnent, a typical Mediterranean periurban area in Eastern Attica, Greece that covers approx. 123 km^2 and extends geographically south of Penteli Mountain and east of Hymettus Mountain. It is a typical periurban area, with mixed land uses, varying from forested areas at its upstream part, agricultural land and a limited industrial zone as we move downstream, which are succeeded by settlements and eventually core urban zones at its downstream parts (Papathanasiou *et al*., 2012). During the last decades the area is characterized by unprecedented population growth, construction of large-scale public works (incl. the new National Airport of Athens in Spata, the developing Rafina port and part of the Attiki Odos Motorway) and intense building activity (Papathanasiou *et al*., 2009). Due to its periurban character and its particular geomorphology (steep upstream slopes, dense upstream hydrographic network *etc.*), Rafina catchment is particularly prone to flooding (Papathanasiou *et al*., 2012). The greater area has a typical subtropical Mediterranean climate, characterized by prolonged hot and dry summers succeeded by mild and wet winters (Papathanasiou *et al*., 2013a). The Hydrological Observatory of Athens (HOA), operated by the Centre for Hydrology and Informatics (CHI) of the National Technical University of Athens (NTUA), monitors the hydrometeorological the regime of the area providing meteorological recordings with a 10-min temporal resolution (Papathanasiou *et al*., 2013a). Also, during the implementation of the FLIRE Project (Papathanasiou *et al*., 2013b), the National Observatory of Athens (NOA) provides daily weather forecasts that refer to the next 24 to 48 hours for an area 80 km X 90 km (40X45 grid points) around the study area, with 1-hour temporal resolution (Figure 1). In total, 48 grid points of the forecast grid are located within the boundaries of the study area.

Figure 1: The study area (in green colour) and NOA weather forecast grid of NOA (blue crosses), as available from the FLIRE platform.

3. Methodology

HEC-HMS 3.5 hydrological model (USACE, 2010a) and HEC-RAS 4.1 (USACE, 2010b) hydraulic model were set up and run for the flood simulations of the study area. HEC-HMS was run in an event based mode, while HEC-RAS was run for steady flow analysis. For the hydrological analysis, the catchment was discretized into 5 subbasins. Six meteorologically representative locations within the catchment were identified and a specific weight for each subbasin was attributed to each location, using Thiessen polygons. Rainfall input was retrieved from properly selected grid points out of the total 48 grid points of NOA's forecast. Stream flows were retrieved from three HOA flow gauges for HEC-HMS calibration purposes. Following a methodology developed for the FLIRE Project (Papathanasiou *et al*., 2013b), the hourly rainfall forecasts were disaggregated to 10min forecasts (the temporal resolution of the flow measurements), so that all datasets refer to the same time-window.

Successive runs of the model chain were performed for variable rainfall inputs. The rainfall input for the base scenario was retrieved from six forecast grid points close to the six selected, representative locations mentioned above. Circles of radius ranging from 5 km to 20 km were drawn around the six locations and the forecasts for the grid points within each circle were isolated. The 1st scenario uses as rainfall input for each subbasin, the mean forecasted value of the grid points located within the 5-km radius around each representative location. Similarly, the 2nd, 3rd and 4th scenarios use the mean forecasted value of the grid points located within the 10-km, 15-km and 20-km radiuses around each location respectively, for each subbasin. The 5th scenario uses the mean value of all forecast grid points located within each subbasin as input for each subbasin. Hydrological simulations for each scenario were followed by the corresponding hydraulic simulations. Results from each scenario were compared against results from the base scenario, so as to identify the optimum range of grid points around the stations for rainfall input, in terms of more representative simulations.

4. Results

In this research, the hydrologic-hydraulic model chain was run for two recent rainfall events that affected the study area: the event of 24-25/10/2014, which had a duration of approx.17 hours and mean areal rainfall equal to 37.1 mm, and the event of 11-12/12/2014, which had a duration of 33.5 hours and mean areal rainfall equal to 14.61 mm. For both events intensive rainfall was forecasted for the north part of the study area and lower rainfall depths for the central and south part of Rafina catchment. In Figure 2, dark blue indicates intense rainfall, light blue indicates moderate rainfall and green indicates low rainfall depths. The boundaries of the 5 subbasins are marked with red line.

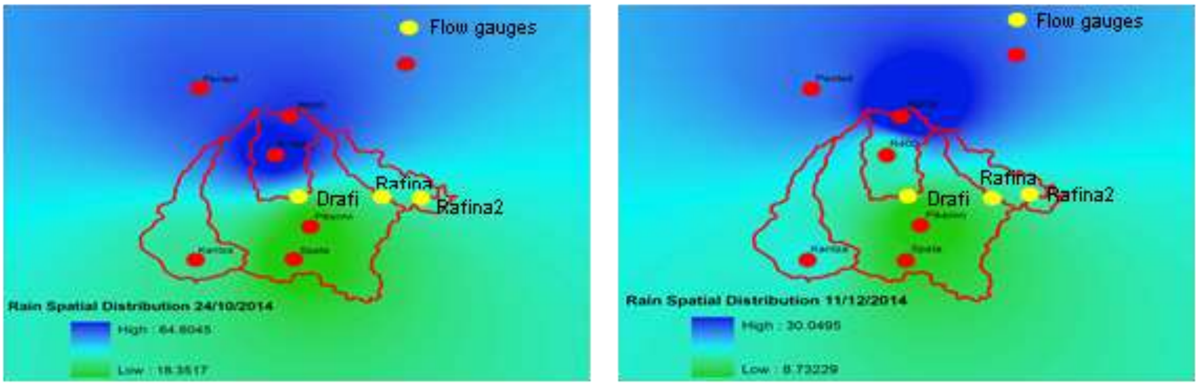

Figure 2: The spatial distribution of rainfall during the selected events (24-25/10/2014 on the left and 11-12/12/2014 on the right).

Flood modelling was performed using rainfall inputs as clarified above and the corresponding results, *i.e.* discharges and water levels were retrieved for the three flow calibration points: Drafi, Rafina and Rafina2. The results of all 5 scenarios run were compared against the corresponding results of the base scenario. The performance of the hydrological model was quantified using the Nash-Sutcliffe (N-S) coefficient (Nash and Sutcliffe, 1970), while a relative difference (%) between water levels for each scenario and water levels for the base scenario, was used as a performance indicator for the hydraulic model. It is expected that the efficiency indicator of the hydraulic model (% difference) will be decreased in comparison to the hydrological model efficiency indicator (N-S), since the first one is retrieved from a comparison of two values for every scenario and the second one is retrieved from a comparison of two timeseries for every scenario.

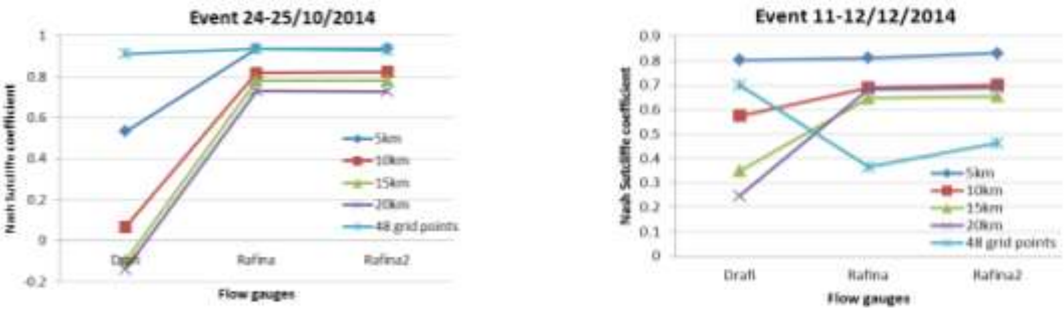

Figure 3: N-S coefficients from the hydrological analysis.

Figure 4: Relative differences (%) between water levels from the hydraulic analysis.

5. Discussion and conclusions

The analysis indicates the optimum number of forecast grid points suggested for flood analyses. Regarding the hydrological modelling, performance (in terms of N-S) is higher for the fine resolution of forecast grid points. Especially for the smaller radius of 5 km, N-S is particularly high, even exceeding 0.9. Therefore, the smaller the radius from which forecast grid points are retrieved, the higher the model performance is. It is noted, that this radius needs to include representative locations for each subbasin; otherwise a limited radius over non-representative areas could lead to significant errors. However, the linear increase in radiuses (from 5-km to 20-km with a 5-km spatial step) around selected locations is followed by a gradual, yet non-linear decrease in N-S. Considering the weather forecast equally accurate in any grid point, this can be attributed to the overlapping of bigger circles and the consequent unrepresentativeness of the used mean values. In this case, the mean areal rainfall per circle cannot be safely considered as representative for the selected locations. Especially when circles extend over areas with significant spatial rainfall distribution (here the central part of the catchment), the corresponding mean rainfall value for each circle is not necessarily representative of the forecast for each subbasin and may be overestimated or underestimated. In this study, rainfall has high spatial distribution around the subbasin upstream Drafi for both events. For this reason, N-S varies significantly for different radiuses, while the results for the 5th scenario are pretty close to the results for smaller radiuses. Therefore, increased radiuses yield poor results for local rainfall events. Also, the rainfall distribution within in the subbasins upstream Rafina and Rafina2 is high, so increased radiuses as well as the consideration of all subbasins' grid points lead to poor results.

Regarding the hydraulic analysis, as expected, the % difference has a lower performance than N-S coefficient used in hydrological analysis, for the reasons discussed above. In general, the best convergence of results is achieved for minimum radius in forecast grids. Again, this radius needs to be around meteorologically representative locations for each subbasin. Unrepresentativeness of rainfall from increased radiuses for the subbasin upstream Drafi, leads to poor hydraulic model performance.

To sum up, the use of accurate rainfall inputs for representative locations within each subbasin is important for accurate flood analyses. When rainfall forecasts grids are available, a study needs to be performed to define the optimum number of grid points to be used for an accurate analysis. For a catchment of 123 km^2, as the study area, circles with a 5 m radius around 6 representative locations yield very good results. Event-specific factors need to be considered, as well. For different rainfall types, *i.e.* events with high spatiotemporal distribution, the range of used grid points for effective analyses may vary. Inherent uncertainties in rainfall forecasts also need to be considered. As a general rule, grid points close to representative locations for each subbasin are the optimum choice.

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