Post-extraction of flood hydrographs under limited and heterogeneous information: Case study of Western Attica event, November 2017

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HS3.6 – Spatio-temporal and/or (geo) statistical analysis of hydrological events, floods, extremes, and related hazards

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1. Introduction

In November 2017, a flash flood occurred in Western Attica, Greece, which led to several human fatalities and severe economical losses. The storm leading up to this flood was intense, but its spatiotemporal evolution remain unknown.

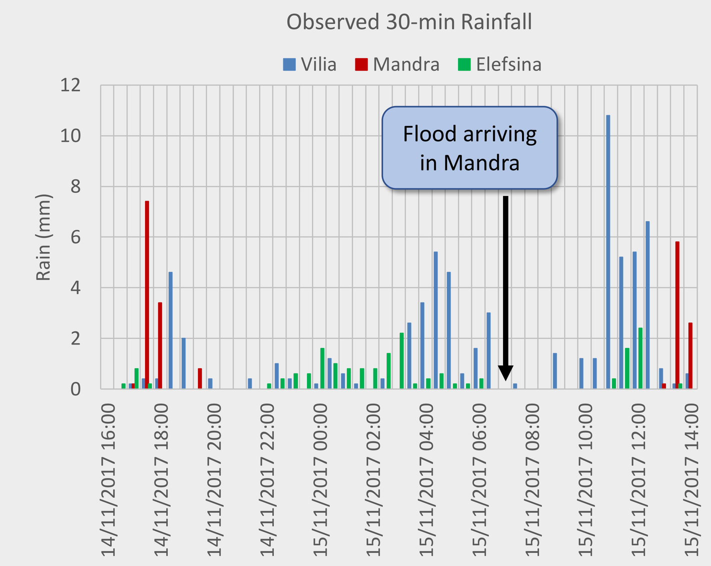
In this study we attempt to take advantage of the **information from the neighbouring catchment** of Sarantapotamos, an ephemeral stream equipped with an automatic stage recorder that partially recorded the event, before it was destroyed by the rising of the flood. Our overall objective is to estimate the rainfall over the broader area of interest through a **reverse rainfall-runoff model**, by utilising several sources of information like hydrometric data, point rainfall measurements and audio-visual material. Monte Carlo simulations are then employed to evaluate the uncertainty embedded in this method and based on these analyses, we provide **probabilistic estimations of the modelled rainfall** along with risk evaluations through the estimation of maximum intensities and the associated return periods across multiple time scales.

2. Background information

At around 7:00 am on November 15th, a large and fast-moving flood wave, carrying heavy debris, arrived at Mandra, a city crossed by two small ephemeral streams (i.e. Soures, Agia Aikaterini) which drain an area of ~75 km². However, during that time and for several hours prior, no major precipitation events were reported in the wider catchment area. This, along with the relatively small catchment size upstream of the city, lead to the assumption that the flood event was due to an unusual storm, of extreme intensity yet very local scale.

This assumption is supported by the observed rainfall at the meteorological stations in Mandra, Elefsina and Vilia, all located in the wider area of Mandra, yet outside of the two catchments of interest (i.e., Soures and Agia Aikaterini). Nevertheless, the amount of the observed rainfall in those stations is not significant enough to explain such a severe flooding.

The most valuable information was found in the neighbouring catchment of Sarantapotamos, a narrow basin located just north of Mandra. The advantage of this catchment is that there are available point rainfall data from the station in Vilia, as well as hydrometric data from an automatic stage recorder near Gyra Stefanis. However, as the flood evolved, the water level rose above the bridge under which the instrument was installed and destroyed it. Due to that, the collected data do not cover the entire flood event.



Observed rainfall at three meteorological stations (top)
CCTV footage from the location of the stage recorder (bottom)

Cross-section of the culvert (left) and the automatic stage recorder (right)

3. Reverse rainfall-runoff procedure

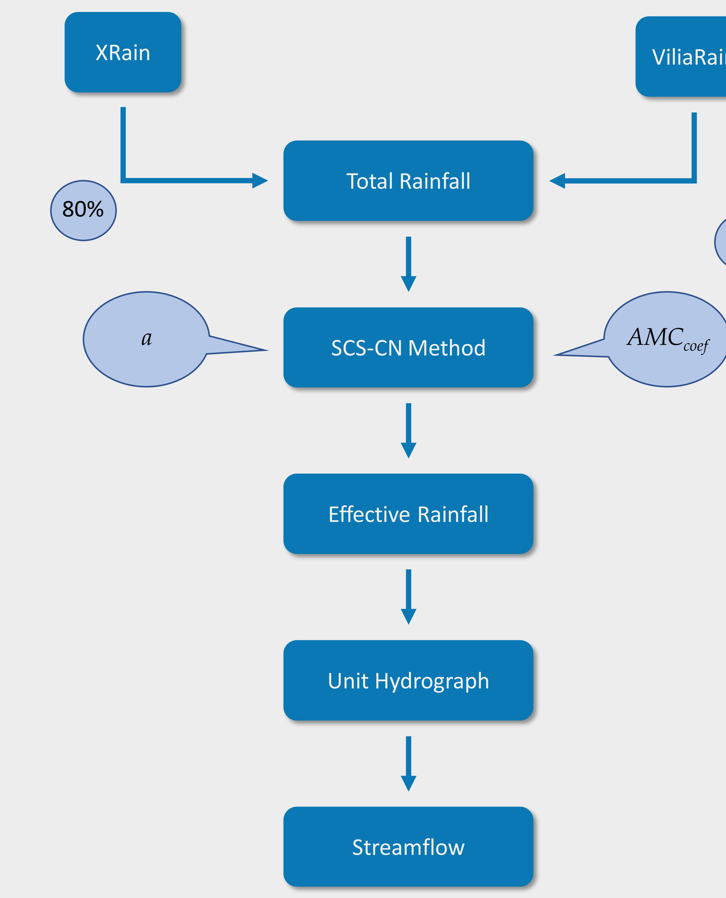
- **Model description:** Estimation of the rainfall 24 hours prior to the storm in 30-min intervals (48 values) at a hypothetical station called X-station, located in the centroid of the catchment that has been effected by the storm but is not covered from other stations.
- **Key assumption:** The point rainfall at X-station (*XRain*) controls 80% of the runoff generated upstream of the stage recorder; the remaining 20% is controlled by the rainfall at the station in Vilia (*ViliaRain*).
- **Effective Rainfall:** Extracted using the SCS-CN method. A revised curve number, CN_{cor}, is used with the reference curve number being set equal to CN_{II} = 48; the antecedent moisture conditions coefficient, AMC_{coef}, and initial abstraction ratio, α, are manually assigned at the beginning of each simulation.
- **Simulated Streamflow:** Use of the Parametric Synthetic Unit Hydrograph of the catchment developed by Michailidi (2018) for propagating the generated runoff to the catchment outlet.
- **Calibration:**
  - **Model I:** The simulated streamflow is calibrated against the observed streamflow by optimising the point rainfall at X-station; generation of peak flow larger than the flow capacity of the culvert, thus integrating the known overtopping of the culvert into the calibration.
  - **Model II:** Two extra flow points are added to the calibration by taking advantage of qualitative information from CCTV footage.
- **Probabilistic analysis:** Use of the given idf curve of the station in Mandra to estimate the return period, *T*, of the simulated rainfall scenarios at X-station, for temporal scales (durations), *d*, from 0.5 to 24 hours; the analytical expression of the idf curve is:

$$i = 213.4\,(T^{0.125} - 0.641)/(1 + d/0.124)^{0.622}$$

where *i* is the rainfall intensity in mm/h, *d* is in hours and *T* is in years.

$$CN_I = \frac{4.2\,CN_{II}}{10 - 0.058\,CN_{II}} \qquad CN_{III} = \frac{23\,CN_{II}}{10 + 0.13\,CN_{II}}$$

$$CN_{cor} = \begin{cases} CN_{II} - \dfrac{CN_{II} - CN_I}{0.4}\left(0.5 - AMC_{coef}\right), & AMC_{coef} < 0.5 \\ CN_{III} + \dfrac{CN_{III} - CN_{II}}{0.4}\left(AMC_{coef} - 0.5\right), & AMC_{coef} \geq 0.5 \end{cases}$$



Revised curve number (top) and sketch of flood simulation procedure (bottom)

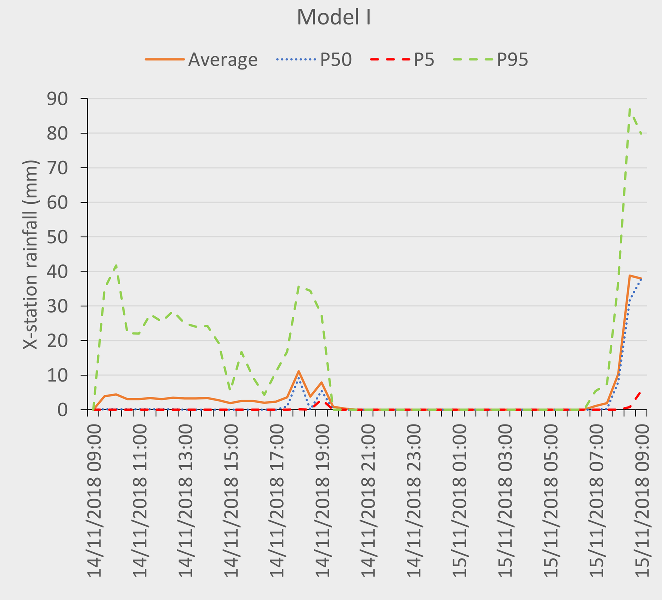
4. Monte Carlo simulation

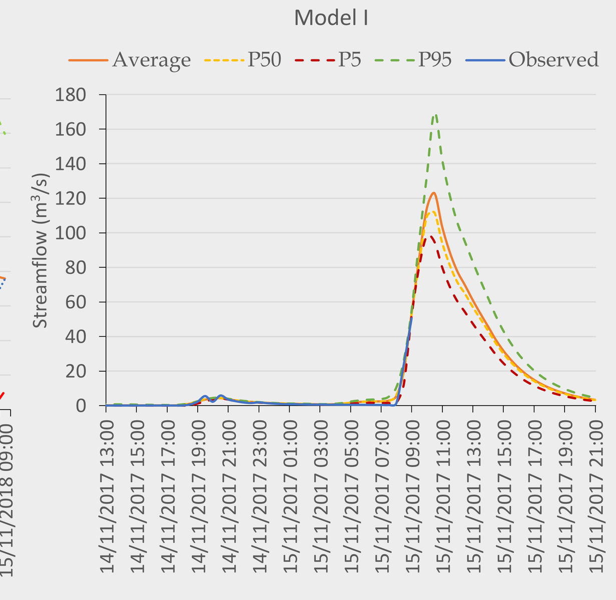
Monte Carlo simulations are employed against the initial abstraction ratio, α, and the antecedent moisture conditions coefficient, AMC_{coef}. The objective is to use randomness to accommodate for the underlying uncertainty of the method, with the goal of probabilistically estimating the quantities of interest i.e. the total rainfall, its temporal evolution, and the peak flow, as well as providing risk evaluations by estimating the maximum intensities and associated return periods of the storm event for several time scales.

- **Initial sampling:** Knowledge from past storm events and weather conditions prior to the storm are used to chose an appropriate distribution for sampling each of the two parameters;
- **Constraints:** The 30-min rainfall intensity for Model II is constrained at a maximum of 100 mm/h; this forces the model to produce the same precipitation volume over a longer time period.

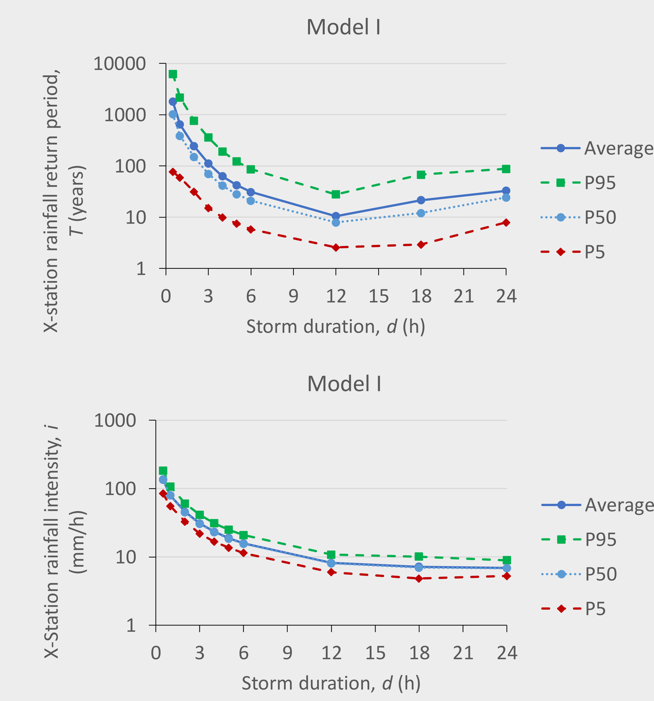
Parameter	Initial abstraction ratio, α	AMC coefficient, AMC_{coef}
Distribution	Log-Normal	Normal
Mean	0.125	0.40
St. Deviation	0.099	0.10

Initial sampling of model parameters for the Monte Carlo simulation

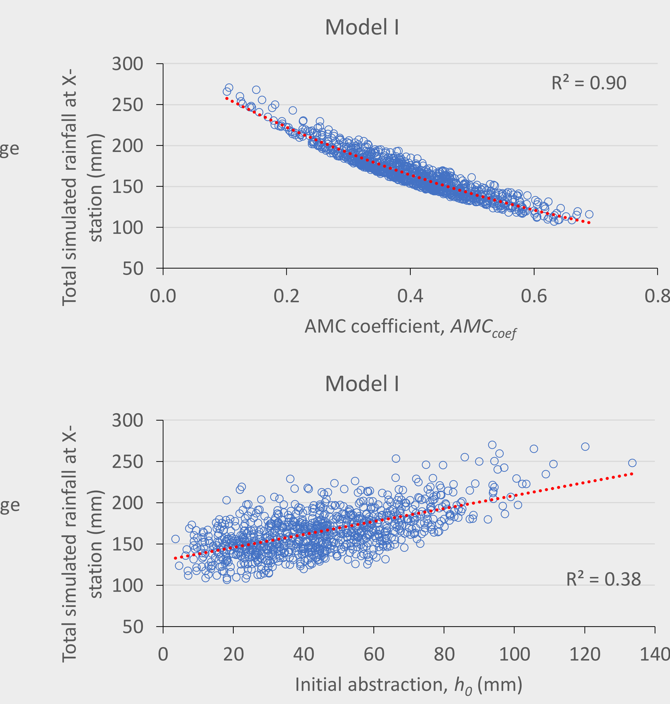




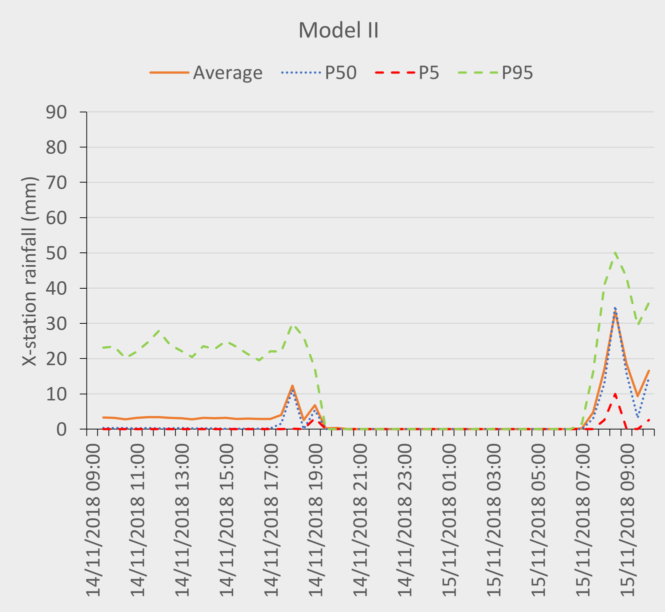
Average simulated rainfall at X-station (left) and average simulated vs. observed flows (right) with confidence intervals for 95%, 50% and 5% non-exceedance probability for Model I

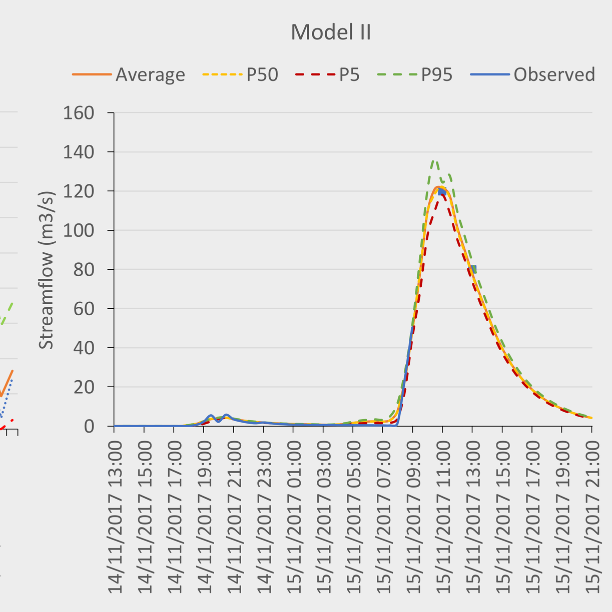


Scatter plots of estimated return periods (up) and simulated rainfall intensities (down) vs. duration for Model II

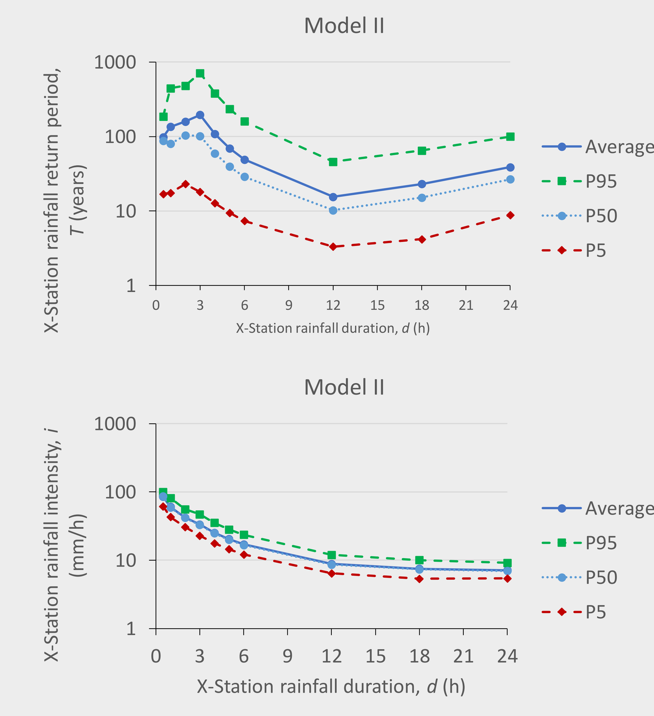


Total simulated rainfall at X-station vs antecedent moisture conditions coefficient (up) and initial abstraction (down) for Model I

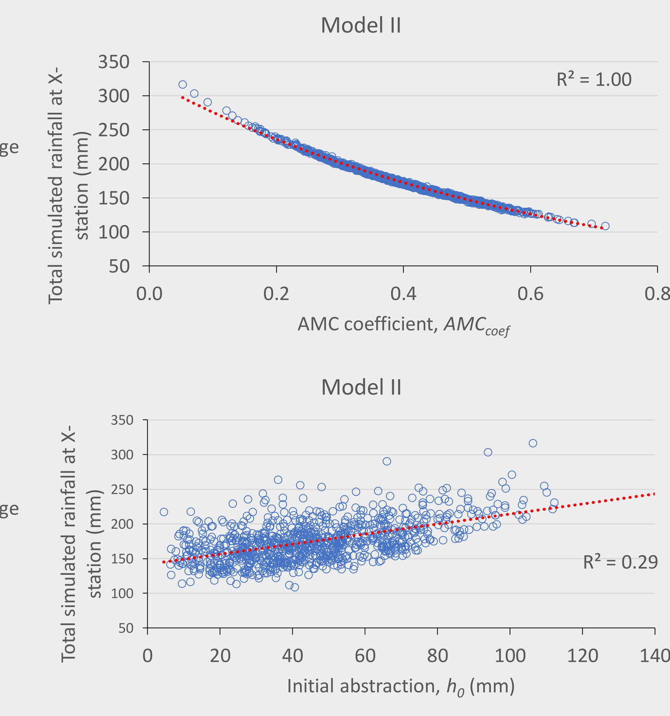




Average simulated rainfall at X-station (left) and average simulated vs. observed flows (right) with confidence intervals for 95%, 50% and 5% non-exceedance probability for Model II



Scatter plots of estimated return periods (up) and simulated rainfall intensities (down) vs. duration for Model II



Total simulated rainfall at X-station vs antecedent moisture conditions coefficient (up) and initial abstraction (down) for Model II

5. Conclusions

- The reverse rainfall-runoff procedure is highly dependant on the sole parameter of the rainfall-runoff transformation (i.e., the initial abstraction ratio) and the initial condition, expressed in terms of the originally introduced AMC coefficient.
- All simulations ensure practically perfect fitting to the observed flows of Sarantapotamos until 9:00 am.
- All simulations agree that the rainfall comprised two distinct clusters, i.e. one during the evening hours of November 14th and a second, more intense cluster during the morning hours of November 15th; this is also supported by witness statements.
- Qualitative and approximate information are undisputedly valuable sources of data; Model II, which encompasses the largest amount of available information, leads to significantly narrower confidence intervals for both rainfall and peak flow estimations.
- The mathematical structure of idf curves makes them substantially sensitive against frequency (return period) for small changes in rainfall intensity; these significantly varying estimations of return periods across multiple time scales make the extraction of safe conclusions about the extremeness of the event highly challenging.

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