RAINFALL - RUNOFF MODELING IN AN EXPERIMENTAL WATERSHED IN GREECE

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ABSTRACT

This research addresses a rainfall-runoff process taking place in a small watershed (17.54 km^2) in Attica, Greece. The case of this particular area was considered as interesting, from a hydrological point of view, due to the intense urbanization and the repeated forest fires that have occurred over the last decades and altered the attributes of the catchment. The rainfall-runoff modeling was performed using the HEC-HMS software. Eight intense rainfall-runoff events were examined. Five of them were used for the calibration process, while the three were used for the verification process. The Soil Conservation Curve Number, the Clark unit hydrograph and the Exponential Recession method were implied for the modeling of losses, direct runoff and base flow procedures respectively. The quantification of the deviation between the modeled and the observed hydrographs was achieved by calculating four fitting criteria: the Nash-Sutcliffe efficiency coefficient, the percentage error in peak flow, the percentage error in volume and the time difference between the peak flows. It was found that the model is capable of performing reasonably well in simulating the different hydrologic procedures taking place in this catchment.

Keywords: watershed, runoff, modeling, HEC-HMS, Attica

1. Introduction

Hydrologic modeling is a simplified representation of a hydrologic system in the sense that it enables the simulation of the interaction between the watershed characteristics and the atmospheric processes (Verma *et al*., 2010). It contributes to the prediction of the hydrologic response of a catchment to various practices associated with anthropogenic interferences, such as land use change, and natural phenomena, such as floods and forest fires (Kotsifakis, 2014; Mostaghimi *et al*., 1997; Rao *et al*., 2000; Gosain and Rao, 2004).

The HEC-HMS model is a widely-spread tool which serves the above purpose. It is designed to simulate the surface runoff response of a catchment to precipitation by representing the attributes of the catchment with interconnected hydrologic and hydraulic components (Oleyiblo and Li, 2010). In the current study, HEC-HMS was used in order to examine the watershed response in eight intense rainfall episodes, which occurred during 2010-2013. Three basic hydrological processes were simulated: the losses, the direct runoff and the base flow.

2. Study Area and Data used

The study area is an experimental watershed (Fig. 1) which is located approximately 15 km east of the city of Athens, on the eastern side of Penteli Mountain, in the prefecture of Attica, Greece. The total area of the basin is 17.54 km^2, its geometric shape is oblong in the North–South direction and the mean, minimum and maximum altitudes are 420, 140 and 950 respectively. The steep slopes constitute another characteristic, with the maximum slope being equal to 59^o and the mean equal to 17^o.

The main vegetation type is pasture. A small share of residential area (Drafi) is included in the southern part of the basin. The land use types and the corresponding shares are shown in Table 1. The geological texture of the basin consists of the formations of schists (60%), conglomerates

(23%), marls (9%) and marbles (8%). A karstic aquifer contributes significantly to the baseflow of the watershed. There are cohesive conglomeratic formations with varying participation of clay and sand thus varying infiltration capacity. Additionally, there is a low percentage of impervious formations (Baltas *et al*, 2007).

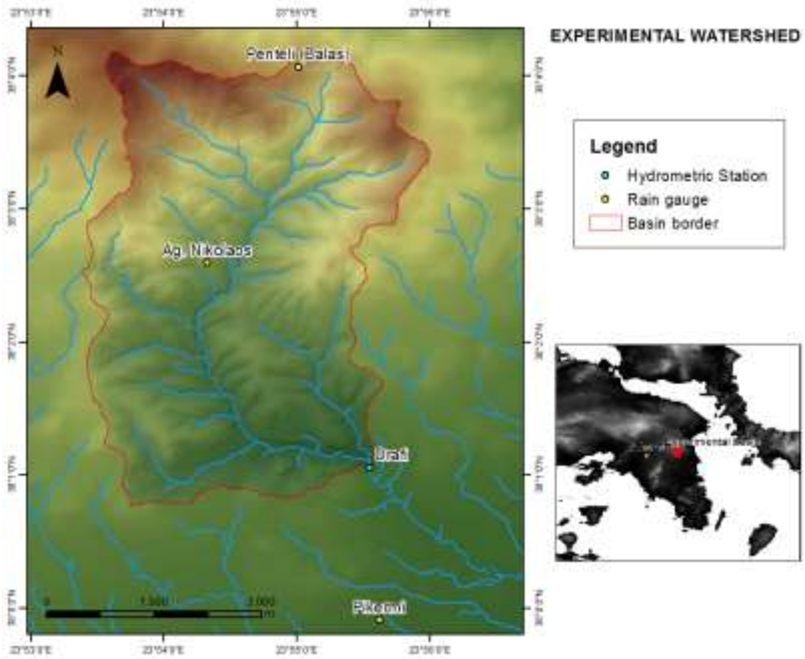

Figure 1: Study area

The necessary input of meteorological and observed flow data have been acquired by the Hydrological Observatory of Athens (HOA), developed and operated by the Laboratory of Hydrology and Water Resources Management of NTUA. The raingauge network has been installed in altitudes 383 m, 630 m and 133 m and has operated since October 2003, with ten-minute time step intervals. The hydrometric station, which provides stage measurements, is located at the outlet of the watershed, and has operated since December 2010.

Table 1: Study area land use

Land use	Area (km^2)	Share (%)
Pasture	12.313	70.2
Wood	0.132	0.75
Residential area (Drafi):		
Residences	1.293	7.37
Roads (impervious surface)	0.579	3.3
Pasture among residences	3.224	18.38

3. Methodology

Three major tasks were performed: (i) simulating the geomorphological features in ArcGIS environment, mainly by using the HEC-GeoHMS toolbar (ii) importing the processed data to HMS and combining the historical data with the processed DEM (iii) model processing.

At the first step the watershed DEM was modified in order to fill the depressions and pits appeared in the original DEM. These pits are recognized as errors, resulting in the stagnation of water. The direction of the steepest descent for each terrain was defined and in combination with the accumulated upstream draining cells to each separate cell, the stream flow path was determined. The final product of this procedure was the hydrographic network, which was introduced in HEC-HMS, along with other required calculated elements, for the model application.

The loss components were used to determine the interception and infiltration processes in the catchment, while the transform component was used to compute the runoff processes as pure surface routing. Groundwater contributions are represented by the baseflow component. The correspondent methods which were selected for parameterization were the following: SCS-CN, Clark Unit Hydrograph and Exponential Recession.

The meteorological model is the component used for setting the meteorological boundary conditions of the basin. The Thiessen Polygons method was applied for the interpolation point rainfall measurements. The weight for each of the three gages used (from N to S: Balas, Ag. Nikolaos, Pikermi) was calculated in AcrGIS Env.

For the application of the model, eight intense rainfall-runoff events were examined. Five of them were used during the calibration process, where the parameterization of the applied functions was achieved and three during the validation process, were the efficiency of the model was verified. During the model calibration, the objective was to match simulated volumes, peaks and timing of the hydrographs with the observed ones. The calibrated parameters were the initial abstraction (Ia) and the curve number (CN) for the losses (SCS-CN Method), the time of concentration (Tc) and the storage coefficient (R) for direct runoff (Clark Unit Hydrograph) and the recession constant (k) for the baseflow (Exponential Recession Method). A trial and error method was followed for parameter estimation, until a reasonable match between the observed and computed hydrographs was obtained. After each parameter adjustment and corresponding simulation run, the simulated and observed streamflow hydrographs were visually compared and several fitting criteria where estimated, with the aim to improve the simulation results. A sufficient number of runs was performed in order to optimize the values of the parameters. The fitting criteria were the Nash-Sutcliffe efficiency coefficient (E_f) (Nash and Sutcliffe, 1970), the percentage error in peak flow ($PEPF$), the percentage error in volume (PEV) and the time difference between the peak flows of the simulated and observed hydrographs (ΔT_{PF}).

4. Results and discussion

The calibration results (Table 2) indicate noticeable variability among the different events. The variability of the SCS-CN method parameters has been previously highlighted in a number of studies, which have confirmed that more than one set of parameters may characterize the same watershed (Ponce and Hawkins, 1996; Mishra and Singh, 2004; Mishra *et al*., 2004, 2005, 2006; Baltas *et al*., 2007).

Table 2: Calibrated parameter values

Model Component	Parameter	Event (dd/mm/yy)				
		02/01/11	03-04/02/11	12/06/11	06-07/02/12	29-30/11/12
Losses	Initial abstraction (mm)	2	3	8	6	4
	Curve Number	77	54	52	60	62
Transform	Time of Concentration (hr)	2.7	1.3	0.4	1.2	1.1
	Storage Coefficient (hr)	0.9	0.27	0.1	0.3	0.3
Baseflow	Recession Constant	0.9	0.05	0.05	0.9	0.1

There is remarkable goodness of fit between the observed and the simulated hydrographs (Table 3, Figure 2) during the calibration process. More specifically, the range of the Nash-Sutcliffe efficiency coefficient (0.78-0.95) is considered as very satisfactory. The same applies for the results of the time difference and the percentage error in peak flows indicators, for which the deviation in values is negligible. The percentage error in flow volumes indicator is within acceptable limits, although an overestimation can be noted in the (29-30)/11/2012 event.

Table 3: Calibration and verification results

Performance Indicator	Calibration events					Verification events		
	2/1/11	3-4/2/11	12/6/11	6-7/2/12	29-30/11/12	24-25/2/11	29-30/12/12	22/2/13
E_f	0.91	0.95	0.78	0.95	0.80	0.79	0.57	0.73
PEPF (%)	-3.88	-3.38	-1.28	-2.22	-3.58	5.00	10.04	-0.13
PEV (%)	6.80	3.40	19.73	5.03	31.66	-12.88	69.08	14.03
ΔT_{PF} (min)	20	-20	10	10	0	10	-10	40

The three verification results confirm the model adjustment in the value and timing of the peak flow in all examined events (Table 3, Figure 3). It is evident that the model simulation capacity reaches acceptable level of accuracy and therefore the calibrated parameters are representative of the hydrologic attributes of the watershed.

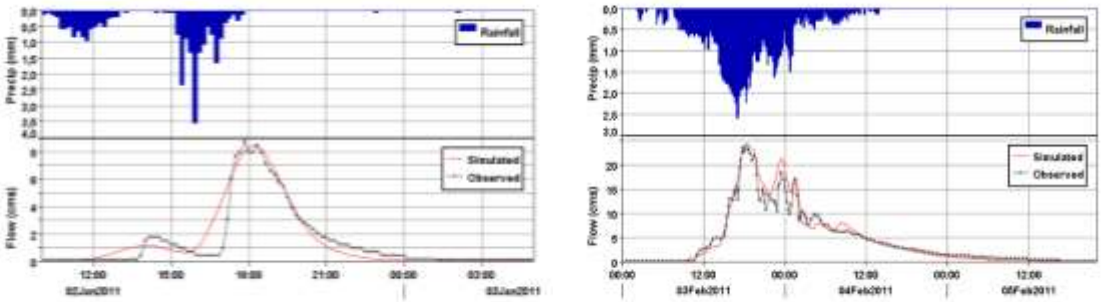

Figure 2: Two indicative calibration events

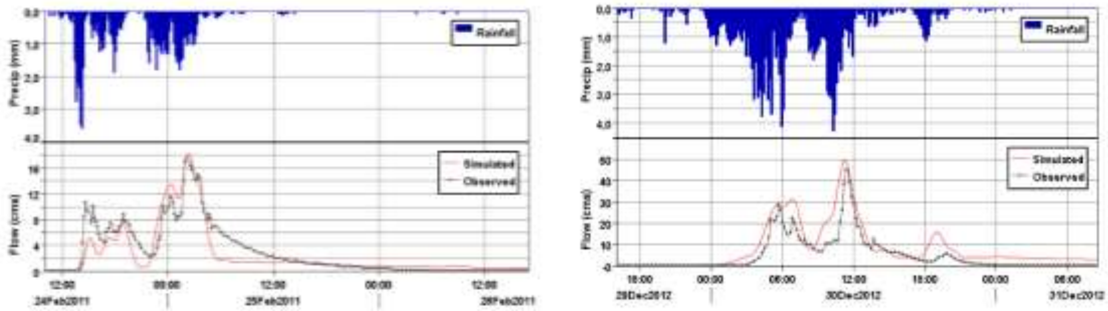

Figure 3: Two indicative verification events

5. Conclusions

Four rainfall-runoff events were used during the calibration and three during the validation process. The goodness of fit was achieved by performing four fitness criteria. It was found that the HEC-HMS model is capable of representing accurately the different hydrological processes taking place in the watershed and replicating the entire shape of the observed streamflow hydrographs. The simulation of both the value and timing of the peak discharge was remarkable. The simulation of the discharge volumes was generally very satisfactory, but in two cases there was notable overestimation. Overall, we may conclude that the HEC-HMS model developed for the studied catchment is a robust tool for the prediction of runoff from rainfall data. Moreover, the low complexity of the model structure proves it a user-friendly, effective and efficient tool for hydrologic modeling.

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