Comparison of WBNM and HEC-HMS for Runoff Hydrograph Prediction in a Small Urban Catchment

Fares Laouacheria · Rachid Mansouri

Abstract The Azzaba City located in the North East of Algeria has undergone rapid urbanization during the past few years. Infrastructure development has further enhanced the land use change process in the area. Bad land use management practices are thought to be the cause of increased flooding. While the characteristics of the precipitation are tied to the climatology of the region, and can change only over the long term, the urbanization, an antropic factor, changes more rapidly and plays a non negligible role in modifying the land use. It is thus very important to assess the runoff changes due to land-use changes. Moreover, the knowledge of the rainfall runoff relationship is an essential tool in modelling and design of urban drainage networks. In this paper two hydrological models, namely WBNM and HEC-HMS, and a GIS procedure are used to predict runoff hydrographs of a small urban catchment located in Azzaba city. The aim was to test the effect of catchment size and time steps on runoff hydrograph shape, and to evaluate the catchment reaction to a given rainfall event obtained from the established IDF Curves. Furthermore a sensitivity analysis of the parameters of the models is carried out. In addition the results of the models are compared with the observed runoff data, measured during a storm event that occurred in 11th of Mars, 2014. This calibration is performed by applying different situations of catchment size and time steps. Then, characteristics of calculated hydrographs were compared with the same characteristics of the same observed hydrographs and analyzed statistically. The results indicate that HEC-HMS provide acceptable simulations in the flood events, which WBNM fail to simulate. Finally, hydrographs simulated by the HEC-HMS model have the best fit with the real situation. It is necessary to generalize this study and build up the data base for the further application of rainfall runoff model in Algeria.

Keywords Catchment size · GIS · Runoff hydrograph · IDF Curves · HEC-HMS · WBNM · Sensitivity analysis

F. Laouacheria · R. Mansouri
Department of Hydraulic, Badji Mokhtar Annaba University, P.O. Box 12, 23000 Annaba, Algeria

R. Mansouri
e-mail: rmansouri2001@yahoo.fr

F. Laouacheria (✉)
Laboratory of Hydraulic and Hydraulic Construction, Badji Mokhtar Annaba University, P.O. Box 12, 23000 Annaba, Algeria
e-mail: fares.laouacheria@gmail.com

1 Introduction

Accurate understanding of rainfall-runoff modeling is an important precondition for flood management, and serves various purposes such as overall assessment of the catchment response as a part of strategic and master planning to detailed network and ancillary elements design,. The biggest challenge facing modelers is choosing a rainfall-runoff model which can correctly simulate a wide range of floods. During the last decades, many efforts have been made to accurately estimate runoff within ungauged watersheds. Runoff prediction in ungauged catchment remains a difficult task in hydrology (Sivapalan et al. 2003). In addition to the quest for better prediction methods in ungauged basins, a capital of environmental observations noted considerable change in the hydrological cycle (Costa and Foley 1999; Groisman et al. 2004). These changes were most likely driven by the combined effects of a climate change (Alcamo et al. 2007, Seager et al. 2007, Molini et al. 2011), land use changes due the large increase in population or economic pressures (Ye et al. 2003, DeFries et al. 2010). Flood hydrograph prediction becomes difficult due to the increasing complexity of the physical nature of the catchment as a result of urbanisation growth. As process based hydrologic modelling is a data demanding process and contains large degree of uncertainty (Leimer et al. 2011) in data sparse areas, predicting flood hydrograph becomes even more difficult if the site under consideration is ungauged. The most recent studies, which aimed to simulate the rainfall-runoff response of small catchments in semi-arid regions, used semi-distributed models. These models require many parameters, representing specific catchment characteristics. Due to the relative scare data in these Regions, lumped parameters are used to simplify the hydrological processes. Limited availability of hydrologic data is a major hurdle for implementation of detailed hydrologic models. In cases where available data is limited, simple hydrologic models consisting of a minimum number (one or two) of model parameters are more desirable (Ahmad et al. 2009).

This study focused on Azzaba watershed in order to test the effect of catchment size and time steps on runoff hydrograph shape, and to evaluate the catchment reaction to a given rainfall event obtained from the established IDF Curves. Two models were chosen for the simulation of rainfall-runoff namely WBNM and HEC-HMS. In both models, the initial and constant loss methods are used to determine the direct runoff from the rainfall input. The two rainfall-runoff models were used to estimate direct runoff volume, peak discharge and to construct hydrographs. Furthermore the intensity of rainfall was obtained from the Intensity-Duration-Frequency (IDF) curve of Azzaba rainfall station for a selected return period of 50 years. For each duration time, the corresponding precipitation depth was computed as the product of intensity and duration. Furthermore a comparison the WBNM (Watershed Bounded Network Model) based on a quasi-distributed hydrologic model, and the HEC-HMS (Hydrologic Engineering Center-Hydrologic Modeling System) model for computing the watershed hydrologic response has been made. Using four statistical indexes (mean absolute error (MAE), the Nash-Sutcliffe coefficient (E), the coefficient correlation of linear regression (R), and root mean square error (RMSE)) simulated and observed hydrographs were compared. In Addition sensitivity analysis and model performance due to various sources such as wrong data input, incorrect model parameterizations are also highlighted in this study.

2 Materials and Methods

2.1 Study Area

Azzaba catchment which is located between (36° 44$'$42.58$''$ and 36° 45$'$08.64$''$ N latitude; 7° 6$'$48.75$''$ to 7° 08$'$ 06.69$''$ E longitude) with an elevation ranging from 25 to 250 m was selected

for this study. The study area is located in the eastern part of Seybouse Region of Algeria, with a drainage area of 57.44 ha (Fig. 1). The watershed receives an average annual rainfall of 641.07 mm. The overall climate of the area can be classified as Mediterranean type. The soil is mainly sandy loam type occupying the maximum area with a land slope varying from 0 to 1 %.

2.2 Use of the CatchmentSim

CatchmentSIM is a stand-alone GIS based terrain analysis program that is designed to help setup hydrologic models. The program is used to automatically delineate sub-catchments and calculate their associated spatial and topographic characteristics.

Prior to using the two models, namely WBNM and HEC-HMS, Digital Elevation Model (DEM) was used to create the stream network and to delineate the whole watershed. This step is made by using CatchmentSim, the GIS pre-processor for WBNM coupled with ESRI's Arcview GIS program. The whole catchment was divided into 3 sub-catchments (Figs. 2 and 3), for which the corresponding drainage networks were also delineated. Then the topographic attributes (Tables 1 and 2) for each sub-catchment (e.g., slope, area and impervious...ect) were derived.

The model structure including land use information, hydrologic soil groups and rainfall events, all of which were allowed to vary in space, and rainfall was allowed to vary in time. Land use data was obtained by digitizing the satellite image, and was reclassified into seven types including administrative buildings, green space, sidewalk, roadway, residences, agricultural and forest land with poor cover (Fig. 4) .
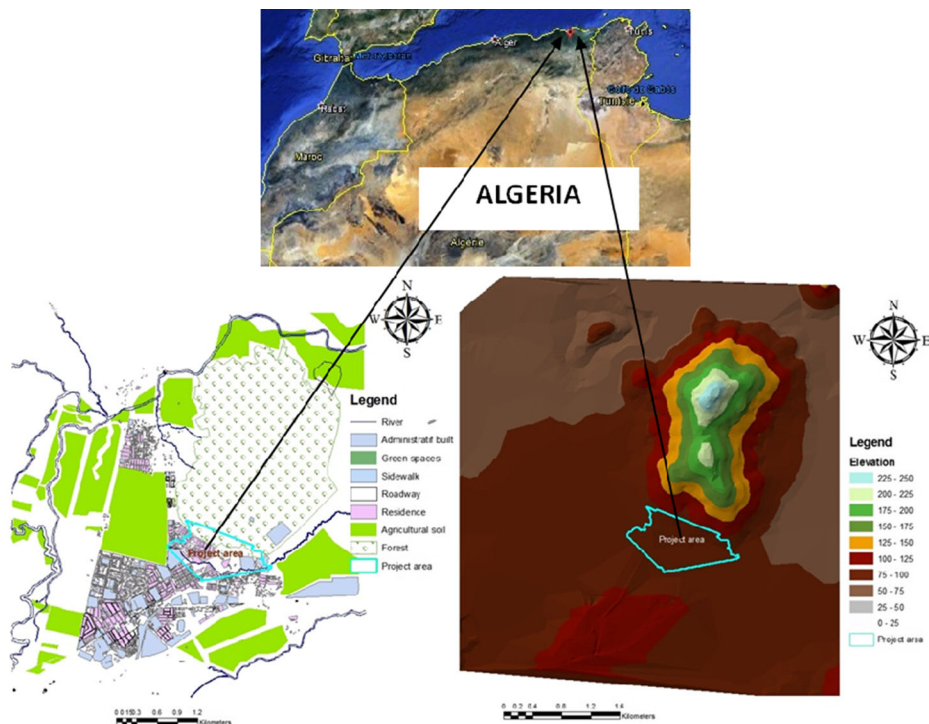

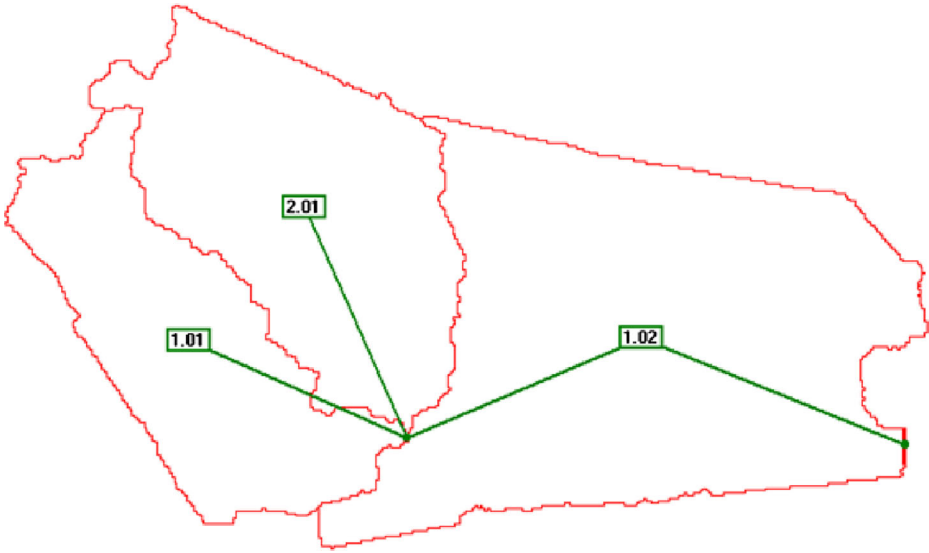**Fig. 1** Location of the study area

Fig. 2 Sub-catchments of the study area

The CN is a hydrologic parameter used to describe the storm water runoff potential for drainage area. The CN is a function of land use, soil type, and antecedent soil moisture condition (AMC). The information needed to determine a CN is the hydrologic soil group (HSG), which indicates the amount of infiltration the soil will allow. There are four hydrologic soil groups (USDA, 1986). The hydrologic soil group of Azzaba catchment corresponds to the soil class B (sandy loam). Soil Conservation Service (SCS) curve numbers are assigned for each possible land use-soil group combination. The AMC is defined as an indicator of catchment wetness and the initial moisture condition of the soil prior to the storm event.
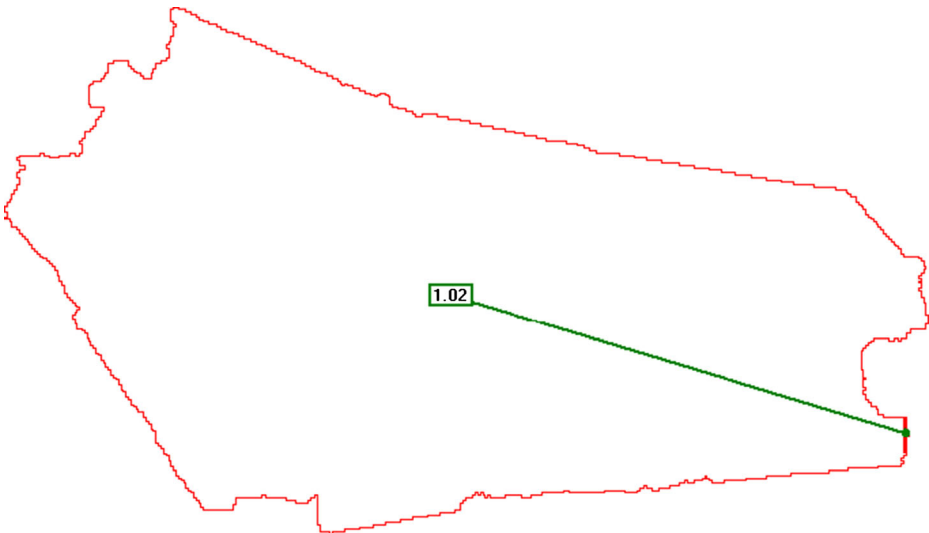

Fig. 3 Whole catchment of the study area

Table 1 Whole catchment characteristics

Total Area (ha)	Slope %	Impervious (ha)	Impervious %	Perimeter (km)	Main stream length (km)	Main stream slope %
57.44	0.7	31.247	54.40	4.56	1.97	0.4

SCS methodology expresses this parameter as an index based on seasonal limits for the total 5-day antecedent rainfall, as follows: AMC I conditions represent dry soil with a dormant season rainfall (5-day) of less than 12.70 mm and a growing season rainfall (5-day) of less than 35.56 mm. AMC II conditions represent average soil moisture conditions with dormant season rainfall averaging from 12.70 to 27.94 mm and growing season rainfall from 35.56 to 53.34 mm, and AMC III conditions represent wet soil with dormant season rainfall of over 27.94 mm and growing season rainfall over 53.34 mm. In general, CN are calculated for AMC II, then adjusted up to simulate AMC III or down to simulate AMC I. The values of CN shown in Table 3 corresponds to AMC II

2.3 Model Structure

HEC-HMS model components and WBNM Software were used to simulate the hydrologic response in the watershed. HEC-HMS model components and WBNM model components include basin models, meteorological models, control specifications and input data. The control specifications included the time period and the time step of the simulation run. Input data components were required as boundary condition in the basin and in the meteorological models. The initial and constant loss method for HEC-HMS as well as the initial and continuing loss method for WBNM was used in this study.

2.3.1 WBNM

The Watershed Bounded Network Model (WBNM) was originally developed to be a physically realistic representation of the catchment as it transforms storm rainfall into a flood hydrograph (Boyd et al. 2007). WBNM model has been used extensively for urban and rural flood investigations. WBNM is an event-based hydrologic model that calculates flood hydrographs from either recorded storm rainfall hyetographs or design storm rainfall parameters. It is a lumped conceptual model. It needs a single parameter and realistically represents the catchment structure and flow of water on the catchment surface. The stored volume is related to the outflow discharge as shown below (Boyd et al. 2007):

$$S = 60.K.Q \tag{1}$$

Table 2 Characteristics of the subareas

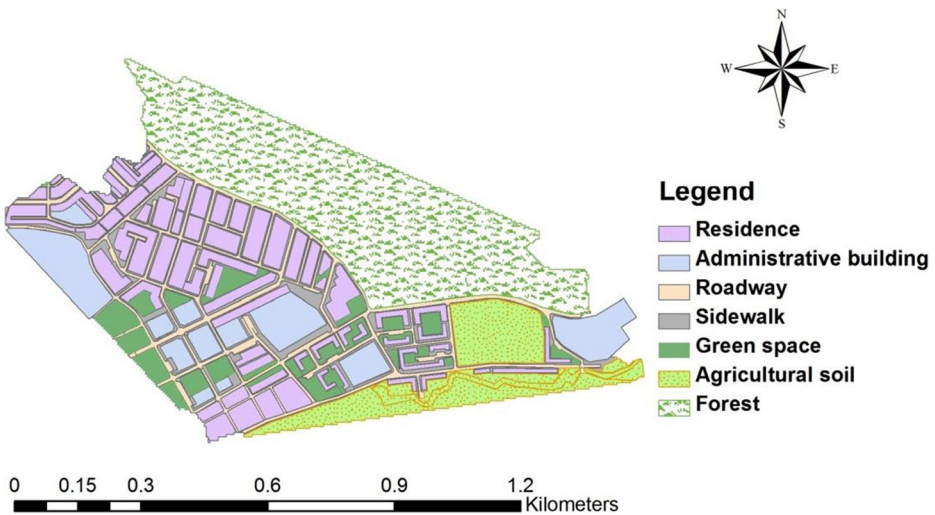| Name	Area (ha)	Outflow basin	Slope %	Impervious (ha)	Impervious %	Perimeter (km)	Main stream length (km)	Main stream slope %
1.02	29.08	Outlet	0.6	12.797	44	3.36	0.86	0.3
1.01	12.4	1.02	0.4	8.566	69.1	2.44	1.1	0.5
2.01	15.97	1.02	1	9.885	61.9	2.5	0.93	1

Fig. 4 Land use of the study area

Where, Q (m³/s) is the outflow rate at time t, S (m³) is the volume of water stored on catchment surface at time t and K (min) is the lag time between centroids of inflow and outflow hydrographs. The lag time K, depends on the size of the catchment. If it remains constant for this subarea for all size floods, the model would be linear. However, based on recorded rainfall and flood hydrograph data (Askew 1968, 1970), and also on hydraulic considerations, WBNM allows K to decrease as flood discharges increase, and it thus would be nonlinear. WBNM uses lag relations developed by Askew (1968, 1970):

$$K = C.A^{0.57}.Q^{-0.23} \qquad (2)$$

Where, A (km²) is the area and C is the lag parameter. This equation contains a nonlinear component (lag decreases as discharges increase), and an area component. WBNM proposes a global value of the lag parameter near 1.6, unless there is good evidence for varying it.

Table 3 Land use categories and associated CN

Land use	Curve Number by Hydrological Soil			
	A	B	C	D
Residence	77	85	90	91
Administrative Building	77	85	90	92
Roadway	98	98	98	98
Sidewalk	98	98	98	98
Green space	67	78	85	89
Agricultural Soil	67	78	85	89
Forest	36	60	73	79

WBNM is using m - 1 as its measure of nonlinearity (m is a storage-discharge nonlinearity coefficient). It uses the value of $m - 1 = -0.23$ (m=0.77) for nonlinearity and recommends it as a global value for all watersheds. However, it allows it to be varied if there is strong evidence that it is different than this value. If m - 1 is less than -0.23 (e.g., -0.30) the nonlinearity is greater and lag times decrease even more as discharges increase. If $m - 1 = 0$ the flood response is linear and lag times remain constant over the range of discharges.

2.3.2 HEC-HMS

HEC-HMS (Hydrologic Engineering Center-Hydrologic Modeling System) is hydrologic modeling software developed by US Army Corps of Engineers Hydrologic Engineering Center. HEC-HMS model adopts a concept of semi-distributed modeling by using sub-catchments and channel routing components. It includes many of the well-known and well applicable hydrologic methods to be used to simulate rainfall-runoff processes in river basins (USACE-HEC 2010).

HEC-HMS includes a soil moisture accounting algorithm, thus qualifying it for consideration. HEC-HMS conceptualizes the watershed into a network of subareas connected by channel links. Basins of all sizes may be modeled. Automatic calibration algorithms are included with the new model version (Feldman 2000), and an Arcgis extension, HEC-GeoHMS, expedites input file creation if proper GIS data layers are available. An urban hydrology option exists where in each subarea contains two plane surfaces (one impervious, and one pervious), and two levels of collector channel. Another option allows each subarea to be represented as a raster (grid), accounting for spatial variation of both rainfall and hydrologic parameters (Feldman 2000). Basin model in HEC-HMS is set up for each subbasin using two hydrologic elements: subbasin and junction. The Subbasin element handles the infiltration loss and rainfall runoff transformation process. The Junction element handles the observed flow data. Among the available hydrologic methods (USACE-HEC 2010) the initial and the constant loss method is used to handle the infiltration loss. Besides the spatial distribution of the rainfall, the temporal distribution pattern has always been a major problem in hydrologic studies. There are several different methods suggested for the temporal distribution of a rainfall in a specified period. A general classification of these methods is given by Veneziano and Villani (1999). Castronova and Goodall (2013) successfully employed the HEC-HMS to test the performance of the Open Modeling Interface Software Development Kit (SDK), where infiltration, surface runoff, and channel routing processes are each implemented as independent model components.

2.4 Catchment Model

The catchment model represents the physical watershed. In this study, the catchment model was developed in CatchmentSim as described earlier. This catchment model was than imported into the HEC-HMS and WBNM.

2.5 Meteorological Model

The meteorological model calculates the precipitation input required by a sub-basin element. The meteorological model can use both point and gridded precipitation. In the study, frequency storm data were used for both the HEC-HMS model and WBNM model.

2.6 Sensitivity Analysis and Calibration

Model calibration is an important process needed to assure that the simulation outputs are close to real observations. It is the phase that determines the credibility of modelling. The model HEC-HMS and the WBNM model include a certain number of parameters. Calibrate these parameters would be very difficult. Sensitivity analysis is used to identify the parameters that have most influence on the performance of the model for the study site and thus reduce the number of parameters to be optimized. The sensitivity analysis, set up by the users of the model HEC-HMS and WBNM model is done by varying certain parameters while keeping the other parameters fixed. The purpose of this process is to identify the parameters whose variation causes significant changes in the outputs of the model. In our case we have chose the CN, Impervious and Lag time parameters for the HEC-HMS model and initial loss (IL), Impervious and Lag Parameter C parameters for WBNM model influence the flow. A sensitivity analysis has been carried out, enhancing the comprehension on how the model works and also to identify the influence of each parameter on simulated discharge. The model is tested under different situations so that we could study the impact of catchment size and time step in the simulated processes. Furthermore, the study evaluates the model capability of simulating and providing a hydrological analysis to compare different situations. Sensitivity analyses were conducted to determine the relative importance of parameter CN, Impervious and Lag time of the HEC-HMS model and IL, Impervious and Lag parameter C of the WBNM model. This was done by using formula for calculating relative sensitivity given below (James and Burges 1982 and Kati and Indrajeet 2005):

$$Sr = \left(\frac{x}{y}\right) \cdot \left(\frac{y_2 - y_1}{x_2 - x_1}\right) \qquad (3)$$

Where Sr is relative sensitivity with units of objective function units divided by units of hydrologic parameter whose sensitivity is being measured, x is hydrologic parameter and y is the predicted output. $x_1 = x + \Delta x$ and $x_2 = x - \Delta x$ are parameter values that result in output of y_1 and y_2 respectively.

The performance of the HEC-HMS model and the WBNM model are evaluated using the coefficient correlation of linear regression, R, in Eq. 4. A high number of R=1.0 means perfect statistical correlation. The success measurement of sensitivity analysis for choosing the input variables is based on the Root Mean Square Error (RMSE), given by Eq. 5, which measures the level of fitness between the HEC-HMS model output and the observed data and measures the level of fitness between the WBNM model output and the observed data. The mean absolute error (MAE), given by Eq. 6, measures the global goodness of the fit of the simulated error (the difference between the observed data and the model predicted output). The correlation between the simulated hydrograph and the observed hydrograph is evaluated using the Nash-Sutcliffe coefficient by Nash and Sutcliffe(1970), E, given by Eq. 7, which ranges from negative infinity to 1.0. An E value of 1.0 means a good agreement between the observed and predicted hydrographs.

$$R = \frac{\sum_{i=1}^{N} \left(Q_{i,Obs} - \overline{Q}_{Obs}\right)\left(Q_{i,sim} - \overline{Q}_{sim}\right)}{\sqrt{\sum_{i=1}^{N} \left(Q_{i,Obs} - \overline{Q}_{Obs}\right)^2 \left(Q_{i,sim} - \overline{Q}_{sim}\right)^2}} \qquad (4)$$

$$RMSE = \left(\frac{\sum_{i=1}^{N} (Q_{i,Obs} - Q_{i,Sim})^2}{N} \right)^{\frac{1}{2}} \tag{5}$$

$$MAE = \frac{\sum_{i}^{N} |Q_{i,Obs} - Q_{i,Sim}|}{N} \tag{6}$$

$$E = 1 - \frac{\sum_{i=1}^{N} (Q_{i,Obs} - Q_{i,Sim})^2}{\sum_{i=1}^{N} (Q_{i,Obs} - \overline{Q}_{Obs})^2} \tag{7}$$

where $Q_{i,Sim}$ is the simulated discharge at time t=i, $Q_{i,Obs}$ is the observed discharge at time t=i, $\overline{Q}_{Obs}$ is the average observed discharge; N is the number of observations.

3 Results and Discussion

The comparison of model results was performed on two levels: the runoff hydrographs were compared visually to assess differences in the hydrograph shape and timing, however the peak flow rates were analyzed for statistically significant differences.

3.1 Model Situations

The following section describes different model situations that were developed to test the influence of the catchment size and the time step on the differences between WBNM and HEC-HMS models.

3.2 Sub-Catchment and Time Step Situations

Based on the topography, the catchment was divided into several smaller sub-catchments. Two different situations were considered. In the first situation, the catchment was divided into 3 sub-catchments (Fig. 2). The second scenario had only one single catchment (the whole catchment), (Fig. 3).

Table 4 Results of simulated and observed hydrographs for Three Sub-catchments (HEC-HMS model)

Time	Measure	Simulated	Observed	Difference	Percent Difference
10 min	Volume (mm)	40.95	34.70	6.25	18.01
	Peak Flow (m3/s)	4.04	4.20	−0.16	−3.81
	Time of Peak	01 :10	01 :20		
20 min	Volume (mm)	41.14	34.70	6.44	18.56
	Peak Flow (m3/s)	3.45	4.20	−0.75	−17.86
	Time of Peak	01 :20	01 :20		

Table 5 Results of simulated and observed hydrographs for Whole catchment (HEC-HMS model)

Time	Measure	Simulated	Observed	Difference	Percent Difference
10 min	Volume (mm)	42.40	34.70	7.70	22.19
	Peak Flow (m3/s)	5.18	4.20	0.98	23.33
	Time of Peak	01 :10	01 :20		
20 min	Volume (mm)	41.80	34.70	7.10	20.46
	Peak Flow (m3/s)	4.86	4.20	0.66	15.71
	Time of Peak	01 :20	01 :20		

The Sub-catchment size has indeed an effect on differences between WBNM and HEC-HMS peak discharge rates. From Table 4 to Table 7 it can be observed the occurrence of large differences between whole catchment and three sub-catchments. It could also be noted that the sub-catchment size does not affect the routing calculations in WBNM or HEC-HMS. However, it has a direct impact on the unit hydrograph. Both in WBNM and HEC-HMS, the shape of the unit hydrograph for each sub-catchment is determined by one parameter, namely the lag parameter in WBNM and lag time in HEC-HMS. Lag parameter in WBNM and lag time in HEC-HMS should be responsible for the observed differences.

The (Figs. 5 and 6) illustrated the differences between simulated and observed hydrographs for the event of 11th Mars, 2014, obtained for different situations of catchment size and time steps. The HEC-HMS and WBNM models for the whole catchment indicate that the simulated hydrograph overestimates the peak discharge, and underestimates the peak discharge in the case of the three sub-catchments. From the simulated hydrographs given by the Fig. 5, in the case of three sub-catchments and time step of 10 min, it can be observed that simulated peak discharge, obtained by the HEC-HMS model and WBNM model are respectively about 4.04 m3/s and 3.97 m3/s, however the observed peak discharge is about 4.20 m3/s. In the case of a time step of 20 min, the simulated peak discharge obtained by the HEC-HMS model is about 3.45 m3/s, the observed peak discharge is about 4.20 m3/s, and the peak discharge resulting from the WBNM model is about 3.82 m3/s (Tables 4 and 6) . In the case of the whole catchment and for different time steps, the simulated hydrographs (Fig. 6) show that simulated peaks discharge obtained by using the HEC-HMS model is about 4.86 m3/s, the calculated observed peak discharge is about 4.20 m3/s, and the peak discharge from the WBNM model is about 5.93 m3/s (Tables 5 and 7). It can be concluded that results obtained by using the WBNM model (40.67 mm and 40.30 mm) are more closer to the observed value (34.70 mm)

Table 6 Results of simulated and observed hydrographs for Three Sub-catchments (WBNM model)

Time	Measure	Simulated	Observed	Difference	Percent Difference
10 min	Volume (mm)	40.67	34.70	5.97	17.20
	Peak Flow (m3/s)	3.97	4.20	−0.23	−5.48
	Time of Peak	01 :00	01 :20		
20 min	Volume (mm)	40.30	34.70	5.60	16.14
	Peak Flow (m3/s)	3.82	4.20	−0.38	−9.05
	Time of Peak	01 :00	01 :20		

Table 7 Results of simulated and observed hydrographs for whole catchment (WBNM model)

Time	Measure	Simulated	Observed	Difference	Percent Difference
10 min	Volume (mm)	46.72	34.70	12.02	34.64
	Peak Flow (m3/s)	5.93	4.20	1.73	41.19
	Time of Peak	01 :00	01 :20		
20 min	Volume (mm)	48.18	34.70	13.48	38.85
	Peak Flow (m3/s)	6.01	4.20	1.81	43.09
	Time of Peak	01 :00	01 :20		

rather than those obtained by using the HEC-HMS model (40.95 mm and 41.14 mm), as illustrated in Table 4 and Table 6.

For the whole catchment and by using different time steps (10 min and 20 min), it can be seen from the Table 5 and the Table 7 that the results of both models are relatively above the observed values. Finally it could be concludes that the obtained time to peak from the HEC-HMS model for time step of 20 min is relatively closer to the observed time to peak (1:20 h), and greater than the values obtained from both models in the case of time step of 10 min.

3.3 Sensitivity Analysis

In the present study, the relative sensitivity coefficients for the parameters of both models have been computed, the corresponding parameters for each model are listed below:

1) For the HEC-HMS model : CN, Impervious and Lag time
2) For the WBNM model: IL, Impervious and Lag parameter C.

In the case of using the HEC-HMS model the estimated values of the parameters are:CN= 82, Impervious=54.40 %, Lag time=26.40 min.

In the case of using the WBNM model the values of the corresponding parameters are:IL= 14.80 mm, Impervious=54.40 %, Lag parameter=1.90.

Using the above mentioned parameters for each model the peak of the unit hydrograph is estimated, and the corresponding values are given below:
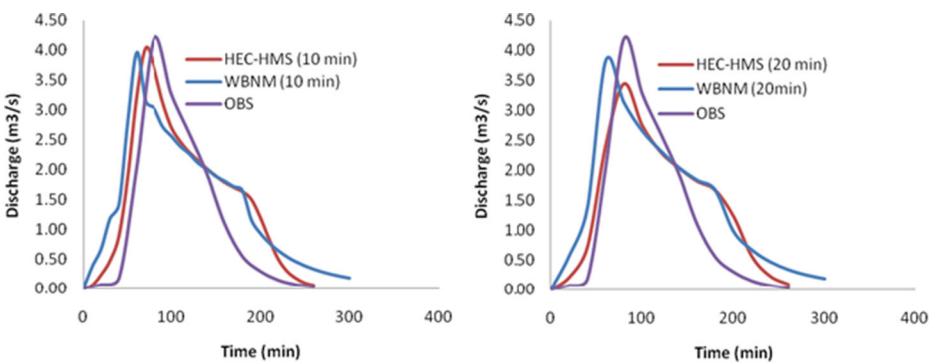

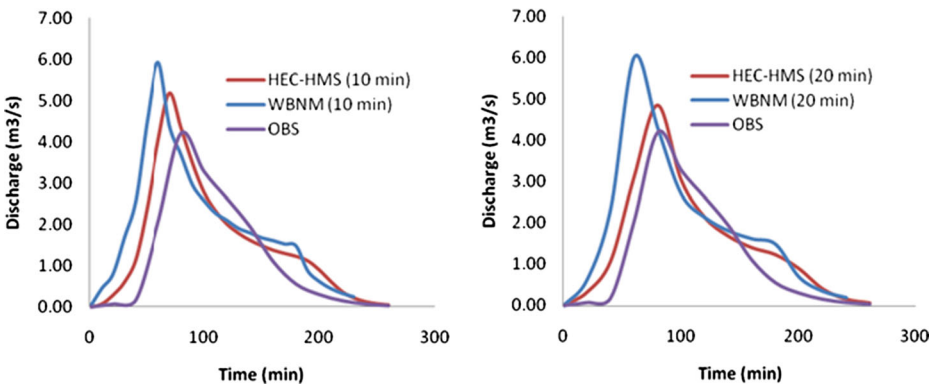Fig. 5 Observed and simulated hydrographs for the three sub-catchments

Fig. 6 Observed and simulated hydrographs for the whole catchment

- For the HEC-HMS model

  – In the case of whole catchment: 5.18 m3/s and 4.86 m^3/s respectively for time steps of 10 min and 20 min.
  – In the case of the three sub-catchments: 4.04 m^3/s and 3.45 m3/s respectively for time steps of 10 min and 20 min.

- For the WBNM model

  – In the case of whole catchment: 5.93 m^3/s and 6.01 respectively for time steps of 10 min and 20 min.
  – In the case of the three sub-catchments: 3.97 m^3/s and 3.82 m^3/s respectively for time steps of 10 min and 20 min.

To lead the relative sensitivity analysis for both models model, the peak of the unit hydrograph and the time to peak are computed for various values of the three mentioned

Table 8 Variation of peak discharge and time to peak with de CN for HEC-HMS model

Element	Time step	CN	Peak discharge (m3/s)	Time to peak (hr)
Whole catchment	10 min	73.80	4.85	1:10
		82	5.18	1:10
		90.20	5.70	1:10
	20 min	73.80	4.54	1:20
		82	4.86	1:20
		90.20	5.34	1:20
Three sub- catchments	10 min	73.80	3.56	1:10
		82	4.04	1:10
		90.20	4.80	1:10
	20 min	73.80	2.88	1:20
		82	3.45	1:20
		90.20	4.32	1:20

Table 9 Variation of peak discharge and time to peak with de impervious for HEC-HMS model

Element	Time step	Impervious (%)	Peak discharge (m3/s)	Time to peak (hr)
Whole catchment	10 min	48.96	4.95	1:10
		54.40	5.18	1:10
		59.84	5.40	1:10
	20 min	48.96	4.67	1:20
		54.40	4.86	1:20
		59.84	5.05	1:20
Three sub- catchments	10 min	48.96	3.91	1:10
		54.40	4.04	1:10
		59.84	4.17	1:10
	20 min	48.96	3.38	1:20
		54.40	3.45	1:20
		59.84	3.51	1:20

parameters. This step is realized by varying only one of these parameters for a given time. The procedure and the results are summarized in the Tables 8, 9, 11, 12 and 13.

The computed values of relative sensitivity (Sr) coefficient for peaks of discharges for each model are given in Table 14 and Table 15. It could be observed that the CN-parameter and the lag time are more sensitive comparing to the impervious, which is relatively less sensitive in computing peak of discharge by the HEC-HMS model, except in the case of the whole catchment and three sub-catchments for the time step of 20 min.

It could be also observed that the CN-parameter is more sensitive comparing to the impervious and the lag time, which are less sensitive in computing peak of discharge.

When the WBNM model is used, it could be also concluded that the IL and Lag parameter C are more sensitive comparing to the impervious, which is relatively less sensitive in computing peak of discharge, except in the case of the whole catchment for time steps of 10 min and 20 min, where the impervious and the Lag parameter C are less sensitive in computing peak of discharge. Further, in the sensitivity analysis, the time to peak values

Table 10 Variation of peak discharge and time to peak with the Lag time for HEC-HMS model

Element	Time step	Lag time (min)	Peak discharge (m3/s)	Time to peak (hr)
Whole catchment	10 min	23.76	5.46	1:10
		26.40	5.18	1:10
		29.04	4.84	1:10
	20 min	23.76	4.95	1:20
		26.40	4.86	1:20
		29.04	4.65	1:20
Three sub- catchments	10 min	23.76	4.28	1:10
		26.40	4.04	1:10
		29.04	3.79	1:20
	20 min	23.76	3.53	1:20
		26.40	3.45	1:20
		29.04	3.28	1:20

Table 11 Variation of peak discharge and time to peak with the initial loss for WBNM model

Element	Time step	Initial loss (mm)	Peak discharge (m3/s)	Time to peak (hr)
Whole catchment	10 min	13.32	6.23	1:00
		14.80	5.93	1:00
		16.28	5.50	1:00
	20 min	13.32	6.23	1:00
		14.80	6.01	1:00
		16.28	5.65	1:00
Three sub- catchments	10 min	13.32	4.37	1:00
		14.80	3.97	1:00
		16.28	3.63	1:00
	20 min	13.32	4.19	1:00
		14.80	3.82	1:00
		16.28	3.39	1:00

doesn't change, except in the case of the HEC-HMS model for the three sub-catchments in time step of 10 min (Table 10).

3.4 Model Performance

The only available observed discharge to assess the quality of the simulation was a runoff measurement made by the Hydraulic Service of Skikda department (Algeria) in 11th Mars, 2014. For the calibration of the generated simulation, the measured peak flow of 4.20 m^3/s was used to enhance the difference between the simulated and observed discharge hydrograph.

The HEC-HMS model, as showed in Table 16, presents the most accurate discharge values for three Sub-catchments obtained for a time step of 20 min with. In this case the MAE is about 0.453 m3/s; the value of E slightly higher up to 0.830, and a perfect fit of the observed discharge with R greater than 0.930.

Table 12 Variation of peak discharge and time to peak with the impervious for WBNM model

Element	Time step	Impervious (%)	Peak discharge (m3/s)	Time to peak (hr)
Whole catchment	10 min	48.96	5.75	1:00
		54.40	5.93	1:00
		59.84	6.11	1:00
	20 min	48.96	5.90	1:00
		54.40	6.01	1:00
		59.84	6.12	1:00
Three sub- catchments	10 min	48.96	3.91	1:00
		54.40	3.97	1:00
		59.84	4.04	1:00
	20 min	48.96	3.76	1:00
		54.40	3.82	1:00
		59.84	3.88	1:00

Table 13 Variation of peak discharge and time to peak with the Lag parameter C for WBNM model

Element	Time step	Lag parameter C	Peak discharge (m3/s)	Time to peak (hr)
Whole catchment	10 min	1.70	5.96	1:00
		1.80	5.95	1:00
		1.90	5.93	1:00
	20 min	1.70	6.04	1:00
		1.80	6.03	1:00
		1.90	6.01	1:00
Three sub- catchments	10 min	1.70	4.94	1:00
		1.80	4.42	1:00
		1.90	3.97	1:00
	20 min	1.70	4.71	1:00
		1.80	4.23	1:00
		1.90	3.82	1:00

The performance measures for the WBNM model for all situations (Catchment size and time step) are not good comparing with those for the HEC-HMS model: larger MAE between 0.692 and 0.832 m3/s; very low value of E between 0.054 and 0.083 for the whole catchment for time step of 20 min and 10 min and value of R than 0.840. Furthermore, from Figs. 5 and 6, it could be concluded that the simulated discharge hydrograph obtained using the HEC-HMS model is matched by the observed discharge hydrograph with the correlation coefficient value of 0.939. This value is higher than all the correlation coefficient of the WBNM model for different situations.

These performance measures clearly indicate that the HEC-HMS model performs better than the WBNM model.

Table 14 Value of relative sensitivity coefficient for HEC-HMS model

Element	Time step	parameter	Parameter value	Relative sensitivity (Sr)
Whole catchment	10 min	CN	82	0.805
		Impervious	54.40 %	0.435
		Lag time	26.40 min	−0.602
	20 min	CN	82	0.809
		Impervious	54.40 %	0.391
		Lag time	26.40 min	−0.313
Three sub-catchment	10 min	CN	82	1.48
		Impervious	54.40 %	0.322
		Lag time	26.40 min	−0.607
		CN	82	2.00
	20 min	Impervious	54.40 %	0.189
		Lag time	26.40 min	−0.367

Table 15 Value of relative sensitivity coefficient for WBNM model

Element	Time step	parameter	Parameter value	Relative sensitivity (Sr)
Whole catchment	10 min	IL	14.80 mm	−0.622
		Impervious	54.40 %	0.303
		Lag Param C	1.90	−0.045
	20 min	IL	14.80 mm	−0.488
		Impervious	54.40 %	0.183
		Lag Param C	1.90	−0.044
Three sub-catchment	10 min	IL	14.80 mm	−0.925
		Impervious	54.40 %	0.163
		Lag Param C	1.90	−1.959
		IL	14.80 mm	−1.055
	20 min	Impervious	54.40 %	0.157
		Lag Param C	1.90	−1.878

4 Conclusion

The accuracy of results from hydrologic models depends on the underlying hypothesis and the availability of data. In this study the HEC-HMS model and WBNM model coupled with a GIS- procedure are used to predict the surface runoff of a small catchment located in Azzaba city. The obtained hydrographs, as responses of the catchment to rainfall events of return period of 50-years are estimated. Both models were calibrated against measured runoff event of 11th Mars, 2014. From the calibrated models new parameters were estimate for the catchment. The comparison, between simulated and observed discharge hydrograph, indicates how the calibrated model fits the observed runoff data. The relative sensitivity coefficients computed for three selected parameters of each model were computed. In the case of using the HEC-HMS model, it can be concluded that parameters CN and Lag time are more sensitive and impervious is relatively less sensitive in computing the peak hydrograph. By using the WBNM Model, it was found that The IL and the Lag parameter are more sensitive and impervious is relatively less sensitive while computing the peak hydrograph. Then, characteristics of calculated hydrographs including peak discharge, and time to peak were compared with the same characteristics of the same observed hydrographs and analyzed statistically.

Table 16 The performance simulation between the HEC-HMS model and the WBNM model

Time Step	Sub-basin scenario	Mean flow (m3/s)	Simulated model	RMSE (m3/s)	MAE (m3/s)	E	R
10 min	3 Sub-basin	1.73	HEC-HMS	0.663	0.530	0.767	0.917
	1 Sub-basin	1.75	WBNM	0.911	0.744	0.560	0.799
		1.83	HEC-HMS	0.812	0.567	0.650	0.887
		1.91	WBNM	1.314	0.832	0.083	0.644
20 min	3 Sub-basin	1.45	HEC-HMS	0.556	0.453	0.832	0.939
	1 Sub-basin	1.66	WBNM	0.836	0.692	0.619	0.838
		1.69	HEC-HMS	0.612	0.464	0.796	0.949
		1.85	WBNM	1.319	0.779	0.054	0.703

Statistical analysis of the effect of mentioned three parameters on characteristics of hydrographs using mean relative error, coefficient of determination (R^2) and root mean square error, showed the relative better performance of the HEC-HMS model than the WBNM model. In Algeria most of catchments are not equipped with surface water gauges. Therefore, we believe that the presented methodology could be allowed an acceptable estimation of the runoff in areas with similar conditions.

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