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Beht Watershed (Morocco) Rainfall-Runoff Simulation with the HEC-HMS Hydrological Model

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ABSTRACT

This research aimed to prepare for spatial hydrological modeling using the Hydrologic Modeling System (HEC-HMS) by integrating different spatial technologies to study the Beht catchment area, which covers 4560 km^2 and also has a perimeter of 414 km. Firstly, the approach was to extract automatically the sub-basins and the drainage network. Then, these data were edited using the HEC-GEO-HMS extension, whereas the land use and land cover data were prepared for the generation of a Curve Number (CN) map of Beht watershed; lastly, the basin model was imported into the Hydrologic Modeling System (HEC-HMS) to simulate the surface runoff. The findings indicated a good match between the calculated and measured values and revealed also that the model is valid, good and performed well in terms of assessment criterion, with average values of Relative Error in peak: REP = 9.6%, Relative Error in volume: REV = 1.69%, Nash-Sutcliffe Efficiency: NSE = 0.63, coefficient of determination: R2 = 0.870, and Ratio of standard deviation of observations to root mean square error: RSR = 0.36.

Keywords: spatial hydrological modeling, remote sensing, Geographic Information Systems (GIS), Curve Number (CN), HEC-GEO HMS; HEC-HMS.

INTRODUCTION

Morocco has experienced a number of severe flood events in recent years, that have generated flooding in several regions of the country due to population growth and urban, agricultural, industrial and tourism development on the one hand, which led to an increasing occupation of vulnerable areas and, on the other hand, to the aggravation of extreme conditions (drought and floods) as a result of climate change (PDAIRE 2011). In order to deal with this flood risk, a set of tools has been developed to understand the hydrological functioning of basins. In this context, hydrological modeling is the most adequate tool to understand the water cycle on small and large scales.

The Soil Conservation Service (SCS) curve number (CN) method is one of the popular methods for computing the runoff volume from a rainstorm (Mishra and Singh, 2003). It is popular because it is simple, easy to understand and apply, stable, and accounts for many characteristics of the runoff producing watershed, like soil type, land use, hydrologic condition, and antecedent moisture condition (Mishra and Singh 2003; Ponce and Hawkins 1996). The SCS-CN method was first designed for small agricultural watersheds and has since been expanded and used to rural, forest and urban ones (Hawkins et al. 2009). Because of its low input data needs and GIS implementation, it has been integrated into many hydrological models in wide use. In recent years, the approach has received much attention within the hydrologic literature. The SCS-CN method was initially published in 1956 in Section-4 of the National Engineering Handbook of Soil Conservation Service (now called the Natural Resources Conservation Service), U. S. Department of Agriculture. The publication has since been revised several times (Mishra and Singh 2003). In spite of several limitations of the method and even questionable credibility at times, it has been in continuous use for the reason that it simply works fairly well at the field level (Mary 1995; Banasik 2010; Xiao and Qing-Hai 2011; Mishra et al. 2012; Ji-Hong et al. 2014; Giridhar and Viswanadh 2014).

The HEC-HMS model (U.S. Army Corps of Engineers, 2015) was selected for this study. It is a distributed model that allows a watershed to be subdivided into several sub-basins, each considered to have homogeneous characteristics. It simulates the rainfall-runoff relationship adequately for different types of watersheds. Because of its capacity to simulate runoff during short and extended duration events, as well as its ease of use, the HEC-HMS model has been highly helpful and has been used in many hydrological studies (Mishra and Singh, 2002). It is particularly well adapted to simulate the hydrological behavior of non-urbanized watersheds. HEC-HMS also allows the simulation and incorporation of reservoirs and diversions (USACE, 2015).

The objective of this study was to apply GIS software and remote sensing to determine Curve Number for the Beht watershed to study a rainfall-runoff model based on the HEC-HMS, to calculate the runoff volume and peak discharge.

MATERIALS AND METHODS

Study area

The Beht catchment area is located in northwestern Morocco and covers an area of approximately 4560 km^2 in the southwestern part of the Sebou basin. It is bounded to the north by the Gharb plains and the Meknes shelf, to the south by the Oum-Erbia basin, to the west by the Bouregregreg basin and to the east by the Middle Atlas. Its boundaries are located between the meridians 5° and 6° west and the parallels 33° and 34° north.

This basin is located between the Lambert coordinates (X1 = 430347.24; Y1 = 281864.43) and (X2 = 529704.23; Y2 = 386110.82).

The Beht watershed has an elongated shape following a SW-NE direction. The Gravelius index of compactness, calculated for this basin, is

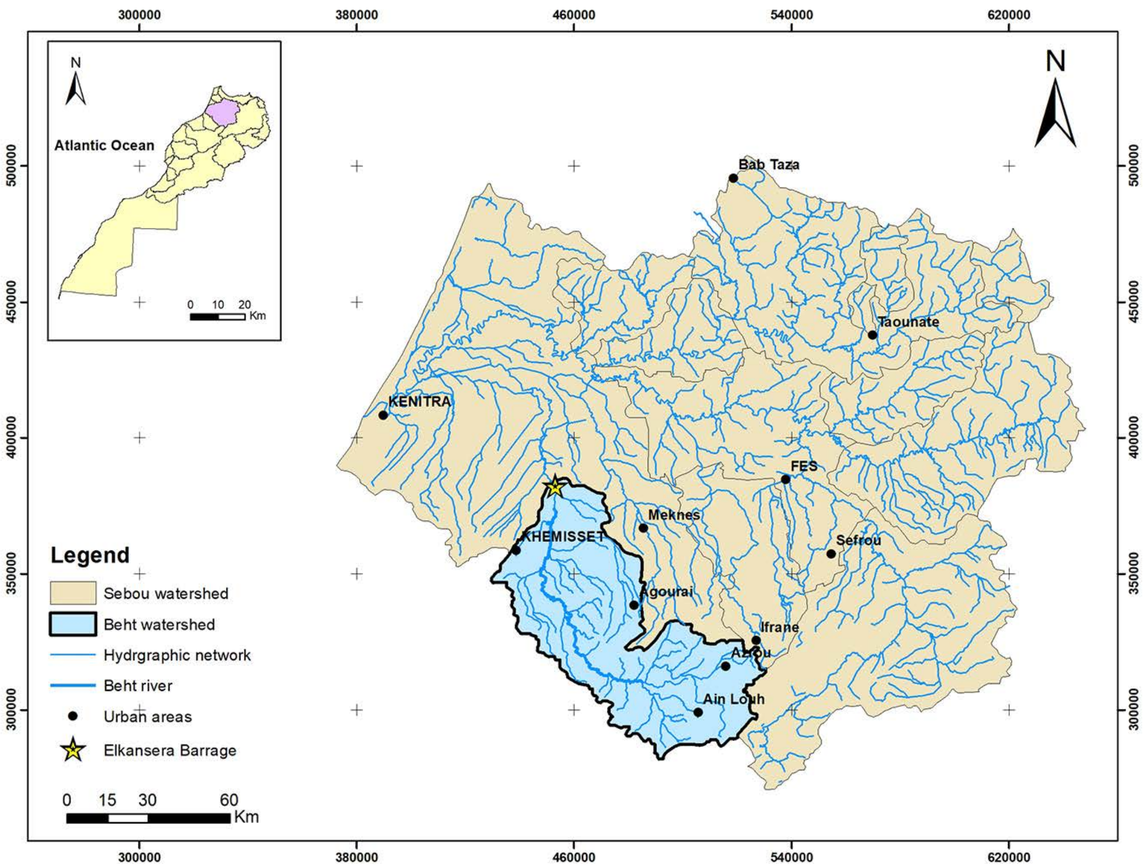

Figure 1. Geographical location of the catchment area of Beht

about 1.86. It is therefore eight times longer than it is wide, which allows a rapid collection of water towards the outlet. It can also be assimilated to a rectangle of the same surface area, which is 202.5 km long and 22.5 km wide. The Beht catchment area has a Mediterranean climate (semi-arid to humid). It presents a double gradient of decreasing intensity from south to north and from east to west. This climate is marked by frequent summer droughts and violent stormy rainfall. Rainfall is marked by annual fluctuations. They vary from 550 mm in the North-West of the basin to about 900 mm in the South-East. Temperatures show a clear variation in space and time. High altitudes are characterized by low temperatures, ranging from -0.9°C in winter to 25°C in summer. In contrast, low altitude regions record temperatures of around 15°C in winter and 34°C in summer.

The hydrological regime is characterized on the one hand by floods recorded mainly during wet periods and which ensures 80% of the annual liquid flow. On the other hand, low water levels during the dry season, when liquid flows are very weak at around 20%.

Data processing

The work methodology focuses on the preparation of the data necessary for the spatial hydrological modeling of the basin, from Arc Hydro and HEC-GeoHMS; extensions of a geographic information system (GIS), as well as the elaboration of land use and soil maps and the calculation of the Curve Number grid, then the import of the basin model into HEC-HMS.

Delimitation of the watershed

The traditional method used to delineate a watershed area from the topographic map takes time and is inaccurate; thus, it has been replaced by the automatic extraction from a digital Terrain Model (Gyozo 2003).

The first step consists in the automatic delimitation of the Beht watershed based on the digital terrain model, derived from the ASTER sensor, which is characterized by its 30 m spatial resolution. Then, the drainage network was extracted from the basin DTM (USACE 2010). Nine operations were carried out to obtain the schematization of the basin model (Okirya et al. 2012).

Land use map

It is determined through a supervised classification on satellite images "ASTER" using an image processing tool (ENVI: Environment for Visualizing Images). There are six main types of land use in the Beht watershed: pastures covering almost 1/3 of the area, which is equivalent to an area of 1471 km^2. They are geographically dispersed throughout the basin. This natural vegetation develops according to the type of soil conditions and climate. It is followed by bare land, which represents 23% of the total surface area, i.e. 1052 km^2. They are mainly located upstream. Forests represent 20.6% of the surface area. They are grouped in two lots, located on the middle and the southern extremity of the basin. The agricultural lands represent 18% of the land; they are mainly located up-stream of the basin. Matorrals appear in the extreme northwest of the study area representing 5.6% of the surface area. (Fig. 2)

Because of the specific requirements of the chosen modular combination, specifically the NRCS CN (Natural Resources Conservation Service Curve Number) method as a production function, the elaboration of a land use map over the entire study area was a necessary step.

This map's information should be accurate according to the NRCS categorization (Natural Resources Conservation Service) (USDA 1986), so connections between the NRCS classes and the map prepared by the satellite image classification method had to be made. Then, the thematic classes defined above were reclassified, as shown in the Table 1.

Soil map

The nature of the soil affects the rate of flood rise and volume, as well as, the infiltration rate, moisture content, storage capacity, initial losses, runoff coefficient (Cr) are all related to the soil type.

The soil map was recovered from the National Institute of Agronomic Research (INRA) (published in 2001) (Fig. 3), and digitized in order to obtain a standard soil map. The main classes

Table 1. Land use class reclassification

First classification		Reclassification	
Class Number	Class Name	Class Number	Class Name
1	Water	1	Water
2	Forest	2	Forested area
3	Reforestation		
4	Bare Soil	3	Non-forested area
5	Built		
6	Low vegetation	4	Low vegetation

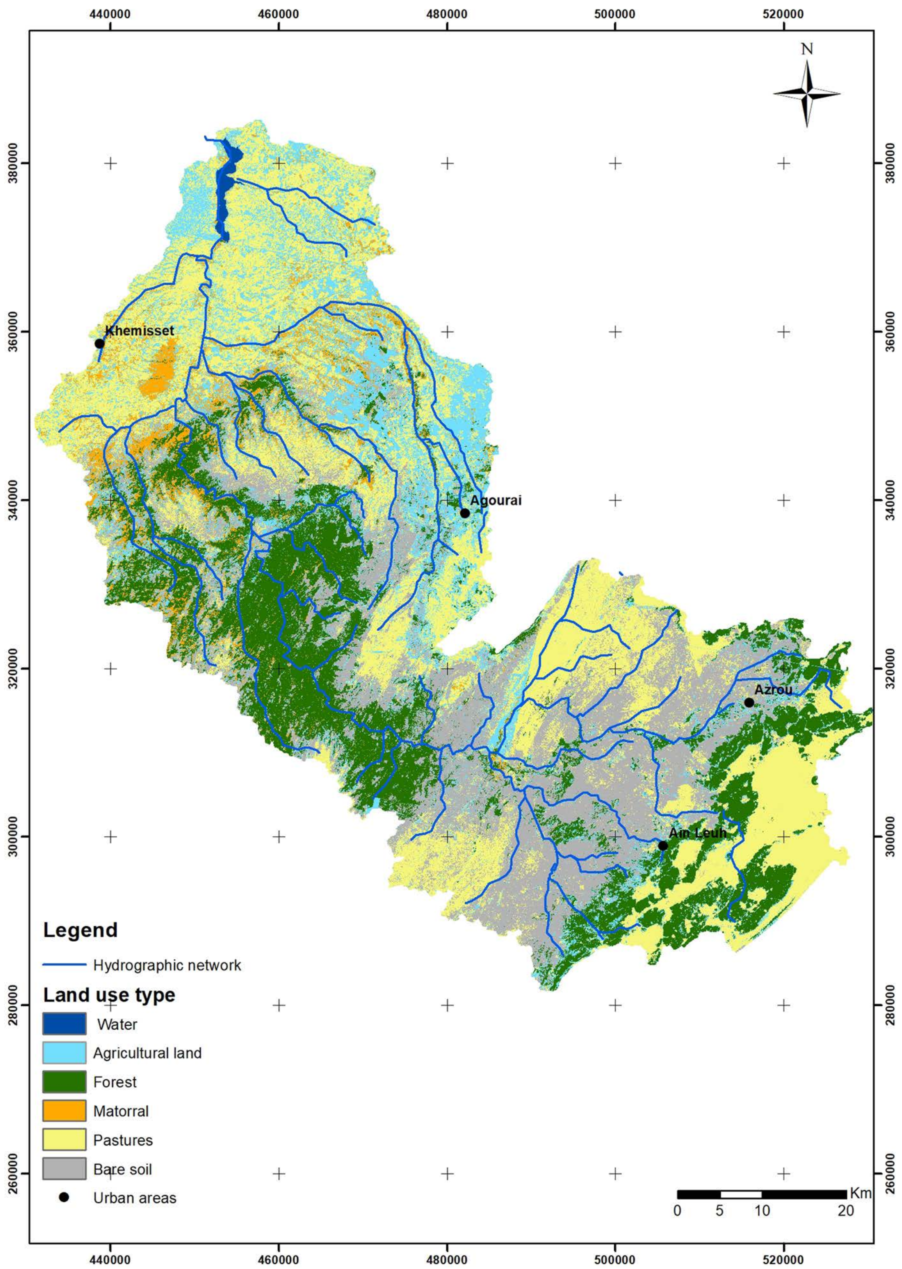

Figure 2. Land use map

of soils outcropping in the Beht catchment area: Calcimagnesic soils (CAL.S), Isohumic soils (ISO.S), Crude mineral soils (CM.S), Poorly developed soils (PD.S), Vertisols and assimilated soils (VA.S), Fersiallitic soils (FER.S), Hydromorphic soils (HYD.S), Brown soils (BR.S).

The soil cover for the entire watershed shows a significant dominance of poorly developed soils, which can form associations with crude mineral and calcimagnesic soils (33.1%). The poorly developed soils as well as the "poorly developed soils and raw mineral soils" association are located in the upstream part of the watershed; they are mainly associated with alluvial deposits. The "poorly developed soils and calcimagnesic soils" association is present mainly on the right bank downstream of the basin.

Approximately 30% of the watershed is covered by brown soils as well as associations of brown soils and hydro-morphic or poorly developed soils. These soils are mainly present in the middle of the watershed, although they can also be found further south in the upstream part of the watershed.

In the northeast and southwestern extremities, vertisols and assimilated soils are present, with a percentage around 11%. Isohumic soils as well as the isohumic and calcimagnesic soil association downstream of the watershed, have a proportion of 11.2%.

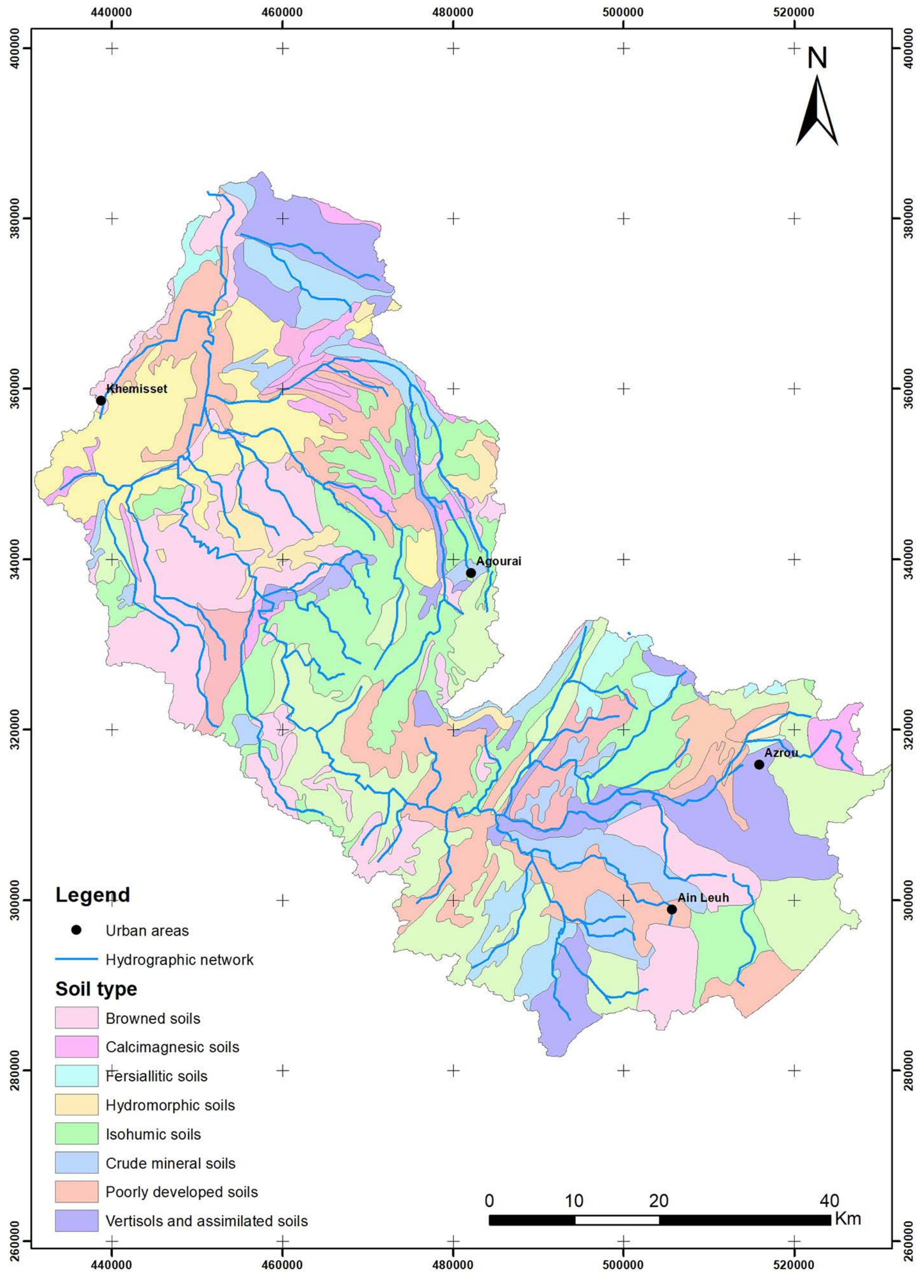

Figure 3. Soil map of the study area (INRA, 2001: digitized)

The basin has other types of soil and soil association, such as: hydromorphic soils, fersiallitic soils, the association of raw mineral soils, poorly evolved soils and hydromorphic soils, the association of fersiallitic and poorly evolved soils, the association of brown soils and raw mineral soils etc., but in small or even very small proportion.

The soil classification used by the Soil Conservation Service method is the hydrological classification. It is a classification that consists of grouping soils into four hydrological groups (A, B, C, D), (USACE 2009), based on their estimated infiltration potential. As a result, soils are assigned to the following groups: A; soil having high infiltration rates, B; soils having moderate infiltration rates, C; soils having slow infiltration rates, and D; soils having very slow infiltration rates (USDA 1986).

The transition from soil classification to hydrological classification is made by providing the information on soil texture according to the composition of sand(S), silt (St), clay(C) and organic matter (O), because the Soil texture information is essential to determine the runoff coefficient (Shadeed and Almasri 2010). The values of these components are given in the Table 2.

According to the map (Fig. 4), the class C is the most prevalent one, indicating that the soils have slow infiltration rates, therefore a relatively high runoff.

Table 2. Textural classes of soils and their associations according to their correspondence in hydrological class

Soil name	Hydrological grp	Texture
Poorly developed & Crude mineral	C	S_tSC
Brown	A	S_tSC
Poorly developed	B	S_tSC
Brown & Hydromorphic	D	C
Vertisols	D	CS_tO
Calcimagnesic & Isohumic	C	S_tSC
Crude minerals	A	S_tSC
Calcimagnesic & Poorly developed	A	S_tSC
Isohumic	C	S_tSC
Calcimagnesic	B	S_tSC
Brown & Poorly developed	C	S_tSC
Hydromorphic	C	S_tSC
Fersiallitic	B	S_tCS
Crude mineral & Poorly developed & Hydromorphic	B	S_tSC
Fersiallitic & Poorly developed	A	S_tSC
Brown & Crude minerals	B	S_tSC
Brown & Calcimagnesic	D	S_tSC
Brown & Isohumic	C	S_tSC
Vertisols & Hydromorphic	B	C
Vertisols & Poorly developed	B	C

GENERATION OF THE CURVE NUMBER MAP

Calculation of the CN grid

The SCS has developed a soil characterization system based on the hydrology and land use group called the Curve Number (CN). Values range from 0 to 100; A CN value of 0 indicates no runoff potential, while a value of 100 indicates that all precipitation runs off (USACE 2009). In other words, a value of 100 is assigned directly to the water surface and 0 for highly permeable soils with a high infiltration potential.

Preparation of the CN-Lookup table

The look-up table contains the Curve Number for different combinations of land use and soil groups. The purpose of this table is to define the CN values for each land use/hydrology group combination. In this case the SCS curve numbers that are available from the literature (SCS reports, or SCS tables) were used. The Table 3 summarizes the CN-Lookup table created from the land use classes and their correspondence in hydrological groups while following the TR-55 standard and the NRCS land use table.

Table 3. Attribute table of correspondence between land use and soil type

Class Number	Class Name	A	B	C	D
1	Water	100	100	100	100
2	Wooded land	45	66	77	83
3	Unforested land	77	86	91	94
4	Low vegetation	60	71	78	81

Creating the CN grid

HEC-GeoHMS was used to create the CN grid. It combines the union result between type and land use, the CN-Lookup table and the DTM of the basin. Before proceeding, it is necessary to add a new field named "LandUse" in the union table. This field will contain the land use category information, and will link the union table to the CN-Lookup table.

The final map of curve number of the Beht watershed (Fig. 5) shows an average CN of 78 indicating that the basin has a moderate high runoff, and this is due to the clay type soil dominated by poorly developed soils, brown soils and vertisols assimilated soils and also, the vegetation cover that is marked by a significant presence of pasture lands. These results are nearly similar to the study realized by (Chadli et al. 2016) who found that the average curve number in the Sebou basin is 82.

The choice of the Curve Number depends, in addition to the soil type and land use, on the antecedent soil moisture conditions (AMC). These can be dry (I), moderate (II) or wet (III) (Mishra and Singh 2003). The values provided in the Attribute Table (Table 3) are representative of average initial moisture conditions (CNII) (Fig. 5) and the Curve Number CNI and CNIII are calculated directly using the (USDA 1985) equations below:

$$CN(I) = \frac{4.2 \times CN(II)}{10 + 0.058 \times CN(II)} \quad (1)$$

$$CN(III) = \frac{23 \times CN(II)}{10 + 0.13 \times CN(II)} \quad (2)$$

The soil moisture status is determined based on precipitation in the watershed during the last five days before the event in question, and by season (low and rainy seasons). The curve number in the conditions I and III are 51 and 89 respectively.

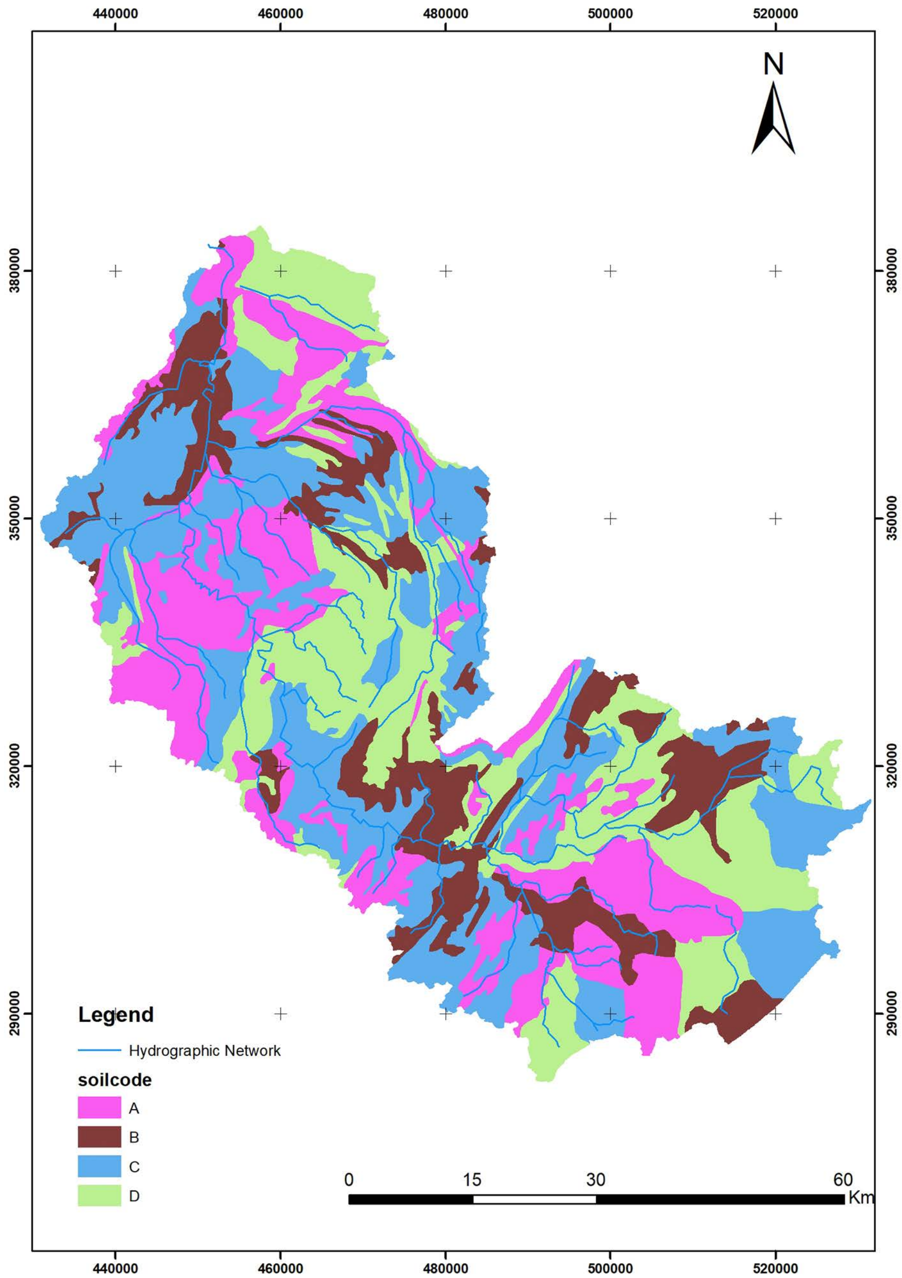

Figure 4. Pedology of the Beht Watershed according to hydrological classification

HMS MODEL

The deterministic and conceptual hydrological model HEC-HMS (Hydrologic Modeling System) is essentially applied to the simulation of specific rainfall runoff events. This makes it easy to perform huge tasks related to hydrological studies, including losses, runoff transform, open channel routing, weather data analysis, rainfall-runoff simulation and parameter estimation (USACE 2000; USACE 2008). In addition, the models developed in HEC-HMS are based on three main functions: models to calculate rainfall, runoff volume, direct runoff and models for calculating groundwater flow (USACE 2000, USACE 2002). There are six formalisms to represent the loss technique that allow transforming the rainfall by subtracting all possible losses caused by interception (obstacles, vegetation, ponds, etc.), infiltration and evapotranspiration (in case of continuous simulations), six transformation methods, like the Clark Unit Hydrograph Banitt methods (Banitt 2010), to determine the hydrograph resulting from the rainfall, and the routine methods that are used to calculate a hydrograph downstream of the watershed, based on the upstream hydrograph (USACE 1994).

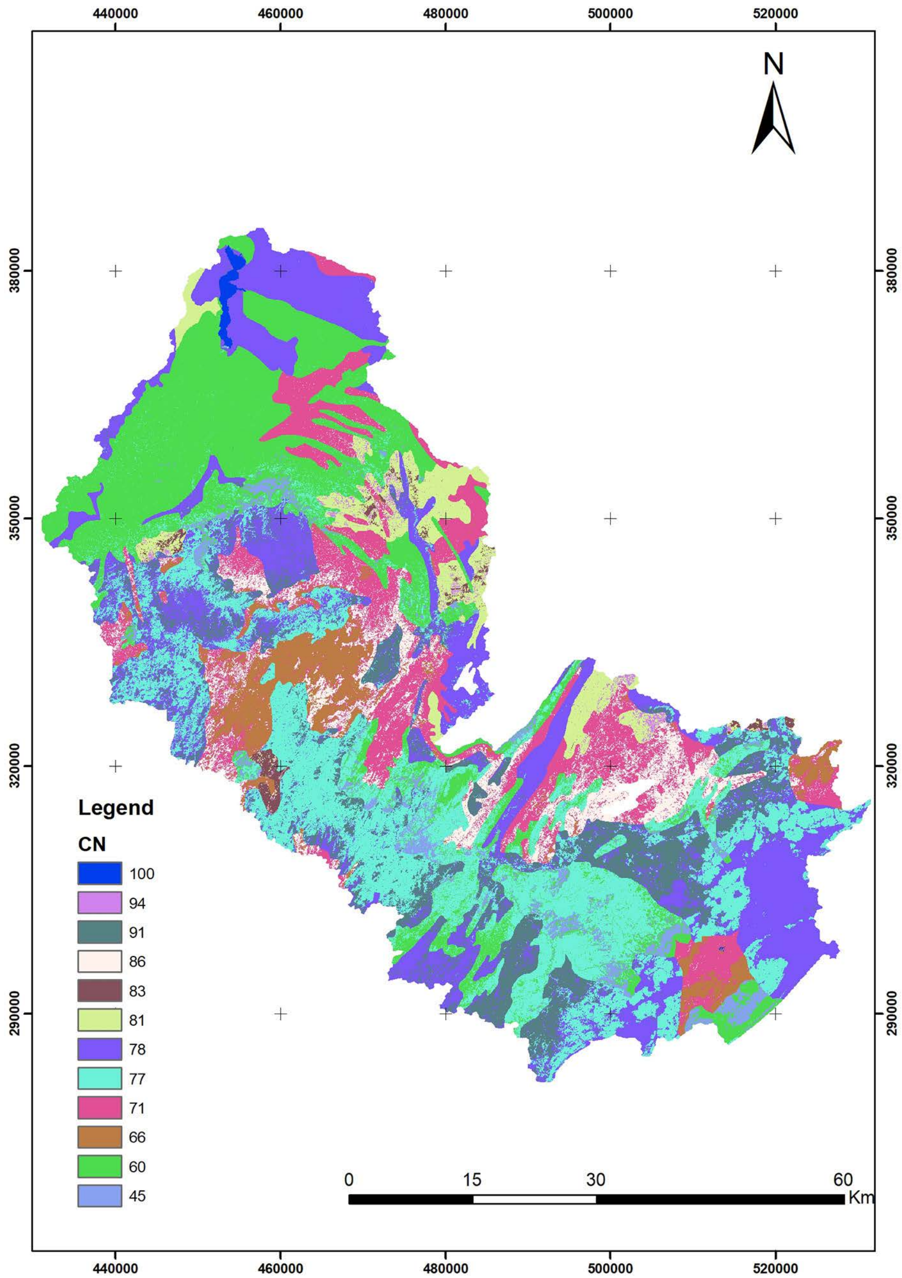

Figure 5. Curve number map of the Beht watershed

In this study, the loss method chosen was the Soil Conservation Service Curve Number, it is used to estimate direct runoff from a specific or design rainfall (Hawkins et al. 2009).

The implementation of this function was carried out by the NRCS in cooperation with three private consultants: Horner, Horton and Sherman (Musy and Higy 1998). This method, which appeared in 1950 is the result of more than two decades of analysis of the rainfall-runoff relationships in small basins. It relates the cumulative rainfall to runoff to three basic factors: land cover, soil type, and antecedent moisture (Mishra and Singh 2003), according to the equation below (USACE 2000):

$$Pe = \frac{(\mathrm{P} - \mathrm{Ia})^2}{\mathrm{P} - \mathrm{Ia} + \mathrm{S}} \quad (3)$$

where: Pe – accumulated precipitation excess (mm); P – Accumulated rainfall depth (mm); Ia – Initial abstraction (mm); S – the potential maximum retention (mm).

The influence of the first two factors mentioned above is estimated by the CN parameter which is related to S by the equation below:

$$S = 25400 - \frac{254 \times CN}{CN} \quad (4)$$

Regarding the transform method, the SCS Unit Hydrograph model was selected to transform excess precipitation into runoff. This method is based on the normalized unit hydrograph (which is the average of many unit hydrographs calculated for different watersheds). The only parameter of this method is TLag. The following empirical relationships are also given as:

$$Tlag = 0.6Tc \quad (5)$$

where: *Tc* – the concentration time of the basin (min).

The Muskingum method was selected for the routing technique (McCarthy 1938). The model calculates the storage of water in a reach by the following equation:

$$S = KOt + KX(It - Ot) \quad (6)$$

where: S – storage in the reach; K – travel time; X – constant; I and O – inlet and outlet flow of the reach; t – time.

It calculates a volume of water from the flood wave by computing storage in the reach. The only parameters of this method are the travel time (K) and the constant weight (X). They are often calibrated from observed flow hydrographs (Birkhead and James 2002).

For each of the methods presented, the model requires parameters that had to be calibrated, i.e., adjusted, in order to reproduce the observed hydrograph. Some of the parameters were calculated from the digital terrain model (DTM) and land use layers using the geographic information system.

Model calibration and validation

HEC-HMS has an internal optimization function to calibrate the hydrological model, the initial values of the parameters to be calibrated are calculated via the spatial data of the study area. Once the hydrological models have been calibrated, we move to the validation step. Its objective is to validate the models by simulating a real event different from the one used for the calibration, in order to observe the model's response.

The model was calibrated using the Univariate Gradient optimization function that adjusts only one parameter at a time, while keeping the others constant and the objective function Peak-Weighted Root Mean Square Error (Hawkins et al 2009), that measures the quality of the adjustment of the simulated hydrograph to the observed hydrograph, whether in terms of flow, volume or time and it gives greater importance to the flows above the average and lesser to those below.

For this study, the events were chosen in the period between 2001 and 2014. It remains to be noted that the different parameters of the basin can be calibrated in order to have a good match between the calculated and measured values.

In order to assess the performance of the simulation, statistical and graphical parameters were used. These methods compare the observed values to the ones simulated by the model. The parameters selected are the relative bias error functions (Najim et al. 2006), Nash–Sutcliffe Efficiency (NSE) by Nash and Sutcliffe (1970), Ratio of standard deviation of observations to root mean square error (RSR) by Moriasi et al. (2007) and coefficient of determination (R^2) as described in Neter et al. (1990).

The events were selected based on the available data, as shown in the following Table 4:

RESULTS AND DISCUSSION

Calibration

From the results displayed in Figure 6, it is evident that the model has accurately represents the general shape of the hydrographs and the simulated peak discharge always occurs at the same time as the observed discharge for all the events. This factor is very important when estimating floods (Ramirez, 2000) (Fig. 6).

Table 5 shows the results of the relative errors for the volume and peak flow.

Regarding the total volume and peak flow, their relative percent error was significant. In this case, a test of sensitivity was conducted to determine which parameter was more sensitive. It consists in varying the different parameters of the model to find out which ones have the most influence on the simulation results. It was found that the initial abstraction and curve number

Table 4. Characteristics of the events used for the model

Events	Function	Start time	End time
1	Calibration	01/12/2001	31/12/2001
2	Calibration	01/12/2003	31/12/2003
3	Calibration	01/12/2009	31/12/2009
4	Calibration	21/11/2010	21/12/2010
5	Validation	01/03/2013	31/03/2013
6	Validation	13/01/2014	09/02/2014

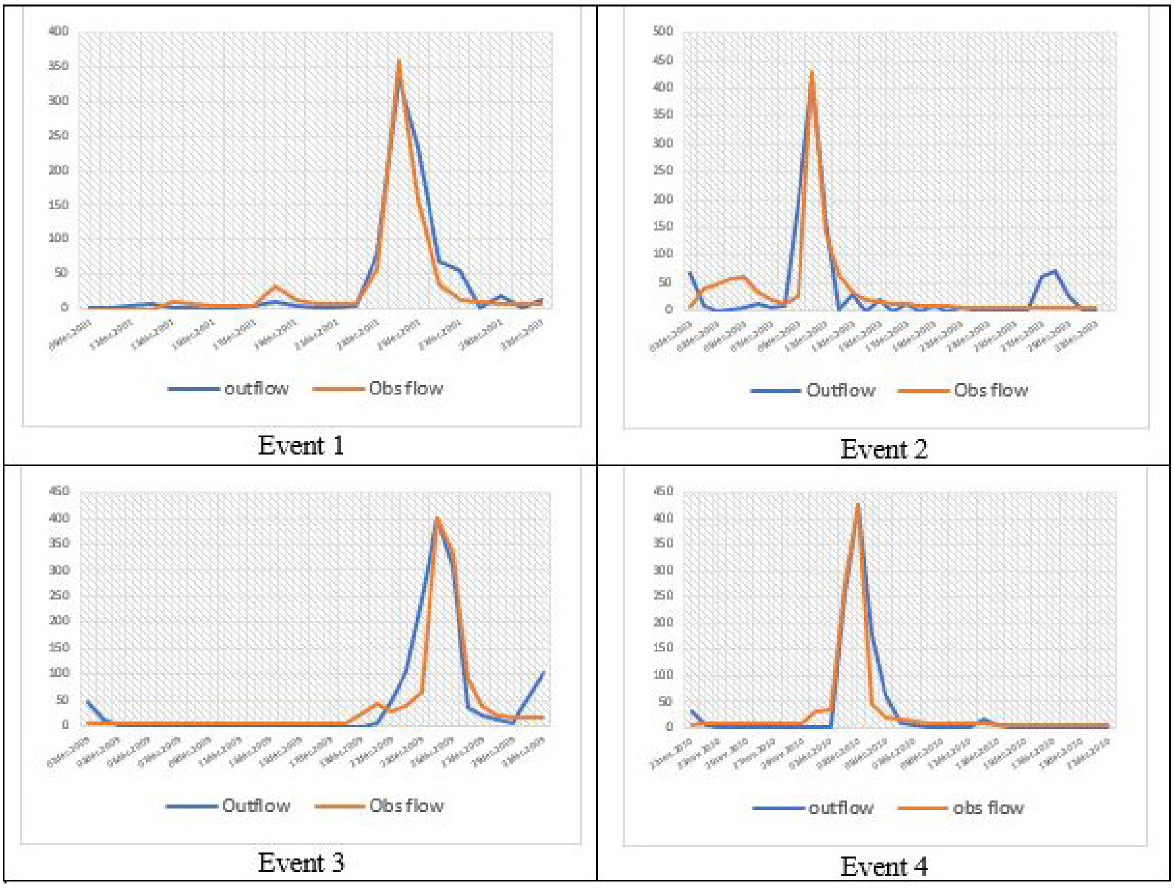

Figure 6. Simulated and observed hydrographs during calibration

were more sensitive, travel time K less sensitive, and lag time insensitive.

The results of the relative errors during optimization were decreased for the peak flow and total volume by 2.5% and 4.8%, respectively. A negative value indicates an underestimation by the model and a positive value an overestimation. Moriasi et al. (2007) and Cheng et al. (2002) state that a performance of ±25% is an indication of a satisfactory simulation.

Regarding the NSE criteria, its value is 81.5% (Table 6). This value indicates that the HEC-HMS model simulations perform very well (Moriasi et al., 2007; Benett et al., 2013; Chatterjee et al., 2014).

The mean value of ratio of standard deviation of observations to root mean square error (RSR) obtained was 0.1, so according to Moriasi et al. (2007), the model can be said as satisfactory if RSR<=0.7.

The results of the linear regression study showed that the correlation between simulated and observed flows is very good for all four events (R^2 = 0.842) (Fig. 7). On the basis of the classification cited in Zou et al. (2003), the results can be judged as strong (>0.8).

During calibration, the statistical assessment criteria revealed good agreement between calculated and measured values (REP = 2.5%, REV = 4.8%, NSE = 0.815, R2 =0.842, RSR=0.1).

Table 5. Simulated and observed peak flows and volumes

Events	Peak flow(m^3/s)				Volume (mm)			
	Simulated		Observed	REP	Simulated		Observed	REV
	B.O	A.O			B.O	A.O		
Event1	379.9	334.3	359	-6.9	19.86	17.58	14.98	17.5
Event2	382.6	416.4	430	-3.2	22.51	22.24	22.4	-0.86
Event3	400.5	400.7	400	0.2	26.74	26.49	26.64	7.51
Event4	395.1	427.6	428	-0.1	17.88	20.07	21.05	-4.69
Mean	389.525	394.75	404.25	-2.5	21.74	21.59	20.76	4.82

Table 6. Evaluation criteria during calibration

Event No.	NSE	RSR	R2
Event1	0.903	0.097	0.918
Event2	0.691	0.309	0.739
Event3	0.773	0.227	0.81
Event4	0.893	0.107	0.903
Mean	0.815	0.185	0.842

Following all these results, it can be concluded that the HEC-HMS model was able to reproduce flood hydrographs for daily rainfall events for the watershed very satisfactorily. Moreover, despite an underestimation of the peak flows (Fig. 8), the results indicate a good performance of the model. The HEC-HMS model can therefore be used to simulate the flood hydrographs for daily rainfall events. The relative error percentage is 9.6% and 1.69% for the volume and peak flow respectively.

In relation to the coefficient of determination there is a quite close match between the measured and calculated peak flow values $R^2 = 0.807$ (Fig. 9). Regarding the (NSE) and (RSR) criteria, the values obtained are 63.4% and 36%, respectively.

Validation

A model is validated, if the parameters obtained by calibration allow reproducing the validation events. The results seem to be satisfactory in terms of the relative errors and the different assessment criteria (Table 7).

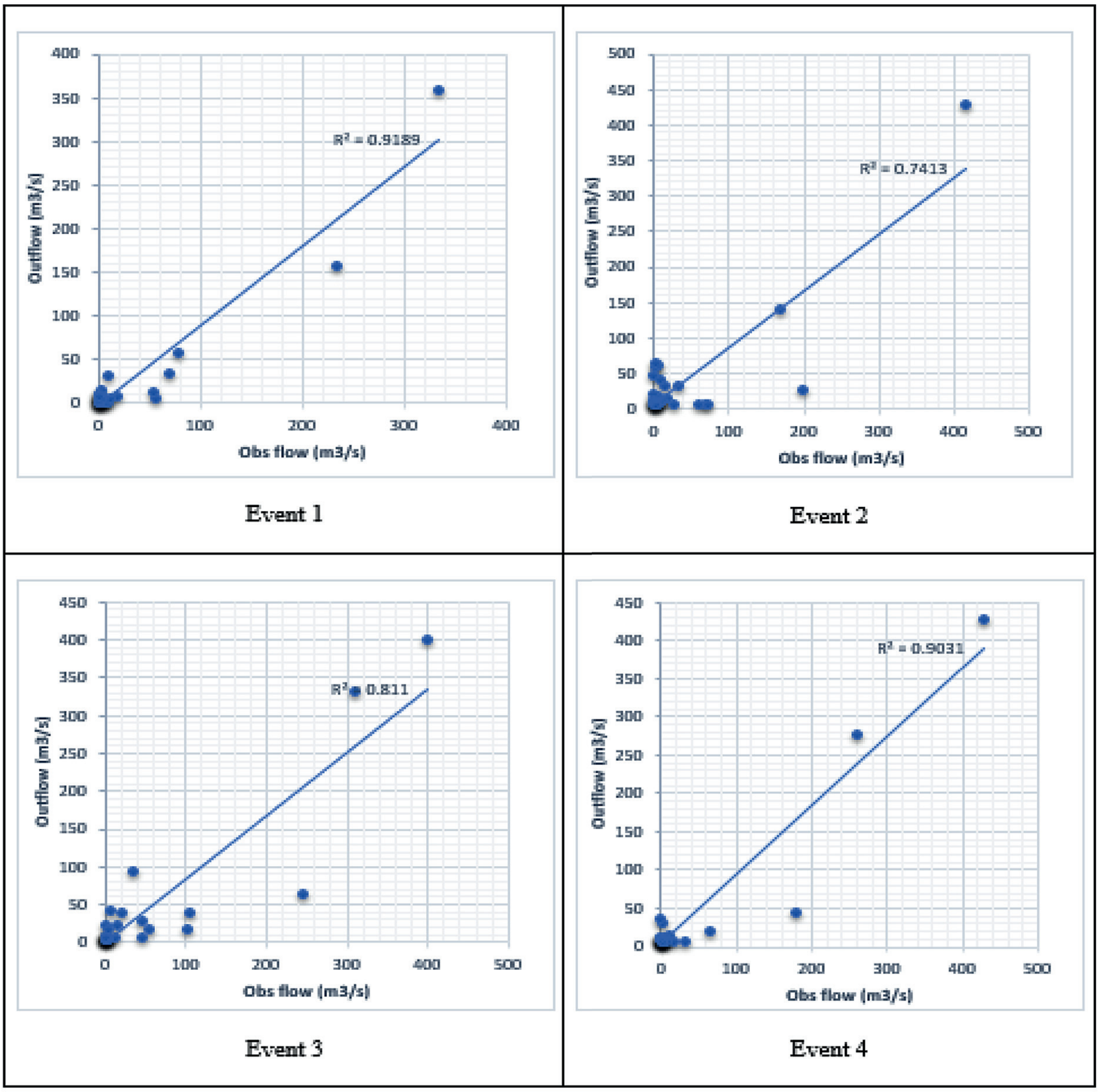

Figure 7. Linear regression during calibration

Table 7. Calculated and measured peak flows and volume and their evaluation criteria

Events	Peak flow(m^3/s)			Volume (mm)			NSE	R2	RSR
	Simulated	Observed	REP	Simulated	Observed	REV			
Event5	235.1	214	9.8	13.59	16.62	-18.2	0.711	0.867	0.28
Event6	169.5	155	9.3	12.31	10.72	-14.8	0.557	0.874	0.44
Mean	202.3	184.5	9.6	12.95	13.67	-1.69	0.634	0.807	0.36

These NSE values are highly indicative of the performance of the simulations (Moriasi et al. 2007). Usually, the statistical assessment criteria demonstrate a good simulation between the calculated and measured values as shown in the Table 7.

The SCS techniques used in this study for the simulation produced good results of validation events, and the statistical assessment criteria revealed that the HEC-HMS model performed well in forecasting peak flow and total volume in the Beht watershed. To improve the model's efficiency, more rain gauge stations are recommended in the basin, because the use of 3 stations is not sufficient, in order to reduce the effect of spatio-temporal heterogeneity in precipitation, also for the flow data which are not enough to perfectly estimate the flows at the outlet, it is necessary to set up more

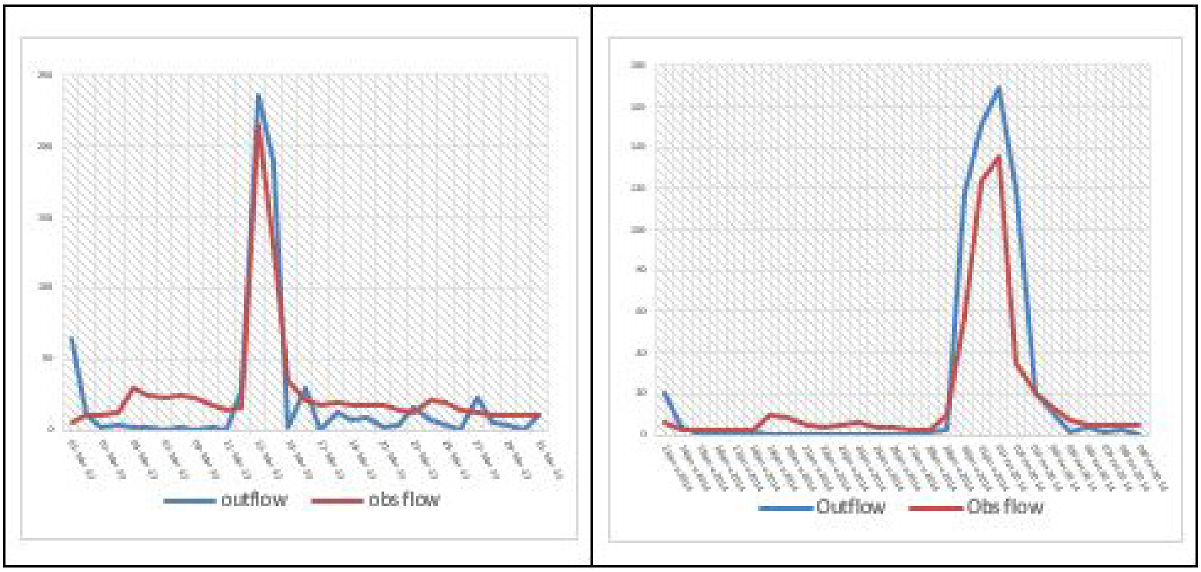

Figure 8. Hydrographs for validation events

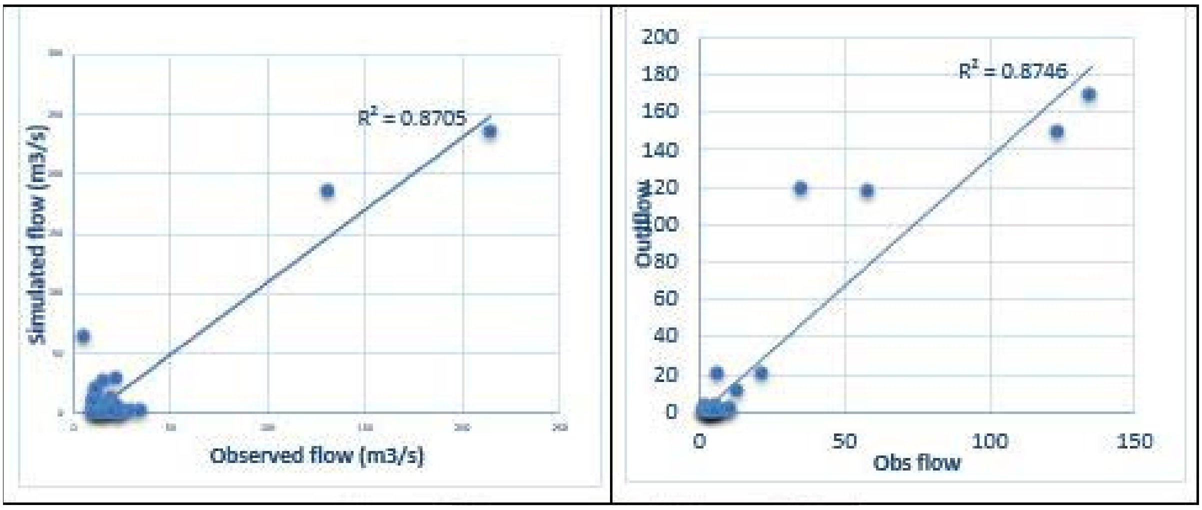

Figure 9. Linear regression during validation

hydrometric stations in the upper areas of the catchment, as well as to determine appropriate hydrographs and curve number, as recommended by Hawkins (1993).

CONCLUSIONS

The initial phase of the conducted research was to provide the data required for hydrological simulation by using the HEC-HMS model. Subbasins delimitation, hydrographic network extraction and the development of the soil and land use databases were very important steps in this study. These were performed with ArcGIS and HEC-GeoHMS to estimate the curve number in three states (CNI (dry), CNII (medium) and CNIII (wet)), and to determine a curve number map that has been widely used in the simulation for the Beht watershed. The results demonstrate that the watershed is characterized by the clay soil type, dominated by poorly developed soils, brown soils and vertisols assimilated soils and a vegetation cover that is marked by significant presence of pasture lands which occupy more than 32%, followed by forests, agricultural land and bare land. The CN of the Beht watershed is medium to high, with an average value of 78, which means that the basin has a moderate runoff potential, the most runoff-producing areas have a high runoff coefficient.

All of the events peak flow and total volume are highly comparable to the measured data. The initial abstraction and the curve number were found to be the most sensitive parameter in the simulation during calibration. After the simulation of the rainfall-runoff system of the watershed, it can be concluded that the result expected is encouraging. In fact, significant values for the different performance criteria (relative errors, NSE, R2 and RSR) in calibration and validation were obtained, based on the selected methods.

The model adopted from the HEC-HMS software is effectively able to reproduce the reality of the flows observed at the outlet of the watershed.

Finally, the results obtained revealed that the model is valid and good and is effectively able to reproduce the reality of the flows observed at the outlet of the watershed; however more meteorological and hydrometric stations should be installed in order to create more information and improve the model's performance in simulations.

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