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# RAINFALL-RUNOFF PROCESS SIMULATION USING HEC-HMS MODEL: STUDY CASE OF RHUMEL SMEDOU WATERSHED

**Abstract**: Hydrological modeling is a critical and decisive technique for estimating hydrological processes and the availability of water resources. In our research, we used Hydrologic Modeling System (HEC-HMS), a 4.4 version, to achieve the affected goals, and a watershed in the east of Algeria, known as Rhumel Smedou watershed, was chosen as a case study which covers an area of 1,083 km$^2$. A Geographic Information System (GIS) was used to analyze and process the Digital Elevation Model 30-meter resolution data accompanied with Landsat of Land Use Land Cover 10-meter resolution with accuracy to extract and deduce the basic inputs of the simulation model, which are: curve number (%), lag time (mn), impermeability (%), and rainfall (Ia) (mm). The research purpose is to compute runoff depth and volume rate for four extreme events. Two events are chosen for model calibration and two for model validation. The results of the statistical tests [NSE (%) RMSE_PBIAS (%)] proved the success and ability of the model to achieve the research objectives, and their averages were as follows: [82%_0.45_32.55%] for calibration phase, and [77%_ 0.45_30.95%] for validation phase. After calibrating and validating the effectiveness of the model, the volume and flow were predicted for different return periods (2y, 10y, 50y, and 100y).

**Key words:** Rhumel Smedou watershed, HEC-HMS, runoff depth, extreme events, calibration, validation.

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## Introduction

Hydrological modeling plays a significant role in studying the hydrological processes and water resources in the river basins in various areas (Abdelkebir et al., 2021). It entails simulating hydrological response, which can be affected by variables like precipitation and other basin parameters such infiltration and evaporation (Mokhtari et al., 2023). Hydrological processes, forecast water availability, and hydrological estimates have frequently been provided for watersheds by using hydrological models (Moradkhani & Sorooshian, 2009) These models are crucial for evaluating water resources availability, and establishing strategies to effectively manage them in light of changing environmental conditions (Lenhart et al., 2002). Among the key components of hydrological modeling is rainfall-runoff modeling, which explores the relationship between rainfall and direct runoff while considering various physical parameters of the watershed (Salwa & Wardah, 2015; Kishor et al., 2014).

Recent years marked notable progress in simulating the streamflow resulting from precipitation events across diverse water resource conditions (Todini, 2007; Ramly & Tahir, 2016). The structure, complexity, data requirements, and application scale of these simulation models vary (James & Zhi-Jia, 2010), ranging from low small-scale field plots to large-scale analyses. They serve multiple purposes, including the analysis of floods and droughts and the management of water resources and water quality. These models offer valuable insights into hydrological processes, such as runoff and sediment transport, under the influence of environmental changes and human activities (Karabörk et al., 2007)

Rainfall-runoff modeling plays a crucial role in countries like Ethiopia, where hydrological data may be scarce. This modeling approach enables the examination of the complex connections between rainfall, physical characteristics of the watershed, and surface runoff generation in regions with limited data availability. For example, in the Awash Bello sub-catchment located in the upper part of the Awash River Basin, flood damage is frequently observed from June to September (Geyisa Namara et al., 2020). Understanding the extent of flood inundation in this area relies on an accurate estimation of peak flood values at the sub-catchment outlet. However, directly measuring these flood peaks is challenging, costly, and time-consuming. To overcome these limitations, rainfall-runoff modeling becomes indispensable as it allows for the estimation of peak flows at the outlet and investigates the intricate relationships between rainfall and runoff volume.

Traditionally, the manual representation of rainfall-runoff relationships in mathematical equations has been a complex and time-consuming task (Rathod et al., 2015). However, the development of computer-aided hydrological modeling technologies has revolutionized this process and provided compelling solutions to these challenges. One such technology is the Hydrologic Engineering Center-Hydrologic Modeling System (HEC-HMS) (Halwatura & Najim, 2013). HEC-HMS is a semi-distributed, physically-based model that incorporates various methods for modeling precipitation losses, transforming excess precipitation into a direct runoff, simulating base flow, and routing floods (Todini, 2007; Majidi & Shahedi, 2012). It has been widely used by worldwide researchers and has consistently demonstrated satisfactory results. For instance, Abdessamed et al. (2018) applied HEC-HMS to model rainfall-runoff in the Ain Sefra watershed in Algeria and obtained close agreement between the computed and observed flows. Similarly, Mokhtari et al. (2016) used HEC-HMS to simulate rainfall-runoff in the Wadi Cheliff-Ghrib watershed in Algeria, achieving favorable model performance.

Hydrological modeling is essential for comprehending basin hydrological processes and assessing water resource availability. Rainfall-runoff modeling allows us to examine the connection between rainfall and direct runoff, considering various physical characteristics of the watershed. Even in regions with limited data, rainfall-runoff modeling is valuable in investigating precipitation-runoff relationships and supporting water resource management. HEC-HMS has become a popular tool in rainfall-runoff modeling due to its simplicity, physical foundation, flexibility, and minimal data requirements. It provides an efficient approach for representing the hydrological response of watersheds, particularly in areas with limited data availability.

This investigation aims to apply the HEC-HMS model to simulate the rainfall-runoff process in the Rhumel Smedou watershed. The primary objectives included calculating the depth and peak rate of runoff for four extreme events and implementing flow routing methods such as the SCS curve number and SCS unit hydrograph. To obtain the necessary inputs for the simulation model, the research used Geographic Information System (GIS) techniques to analyze and process digital elevation models and land use/land cover data. The Rhumel Smedou watershed in Algeria was selected as the study area.

The HEC-Geo HMS tool, which integrates HEC-HMS and GIS functionalities, was utilized to process and analyze the data. The study involved developing a basin model, meteorological model, control specifications, and time series data using the HEC-HMS model. Infiltration losses were simulated using the SCS curve number method, while flow routing applied various techniques, including the SCS unit hydrograph and lag routing. The model parameters were calibrated and optimized using observed data from rainfall and hydrometric stations in the study area.

## Materials and methods

### *Study area*

The Oued Rhumel Smedou watershed is located on Algeria's eastern coast, situated between the latitudes of 36° 19' 33" N and 36° 35' 26" N and the longitudes of 6° 12' 23" E and 6° 47' 28" E. It covers an area of 1,083 km$^2$ and has a 158 km perimeter, with an elevation ranging from 144 to 1,362 meters (Figure 1). The study area has a climate that ranges from semi-arid in the south to Mediterranean in the north. It has extremely variable thermal amplitudes, notably in the south, with an annual average air temperature of 14.1 C (10 C in January and 26.4 C in August) and an average rainfall range of 410 to 600 mm traveling south to north (ANRH 2008).

### *Hydrographic network*

A GIS was used to extract the hydrographic network, by processing and analyzing the digital elevation model (DEM) with resolution of 30 meters. Through our analysis, we found the study area is a 5th order with Drain density (Dd) of 0.81 km/km$^2$, while the Torrentiality coefficient is 0.54 (Figure 2).

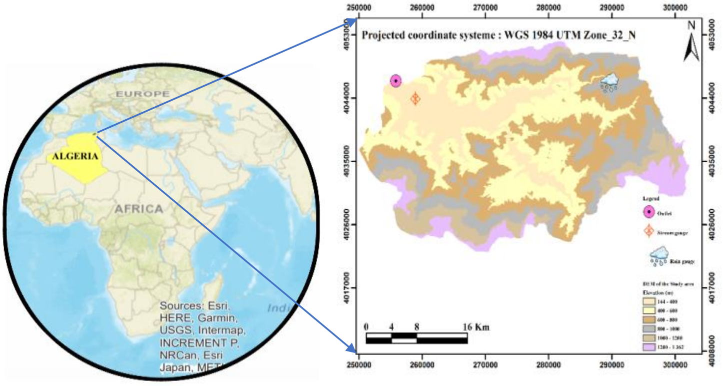

*Fig. 1 Geographical location of the Oued Rhumel Smedou watershed*

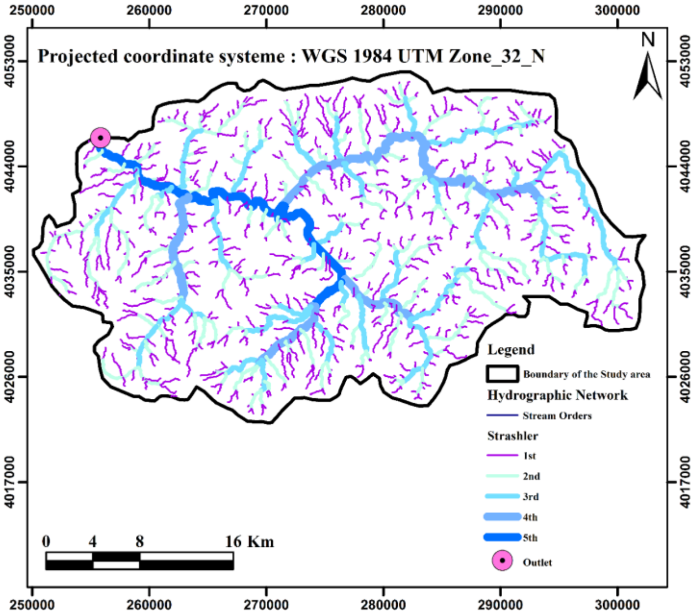

*Fig. 2 Hydrographic network of the Oued Rhumel Smedou watershed*

## *Data acquisition*

### *Rainfall and hydrometric station*

Daily rainfall data and stream flow data were obtained from Zighoud Youcef Station (100608) and Grarem station (100601). The location and main characteristics of station are shown in Table 1.

*Tab. 1. Identification of hydrologic station of the study area*

| **Identification** | | | | **Geographical coordinate** | | |
|---|---|---|---|---|---|---|
| Type | Code | Name | Distance to the outlet (km) | X (m) | Y (m) | Z (m) |
| Rainfall gauge | 100608 | Zighoud Youcef | 33 | 289.791 | 4.046.330 | 554 |
| Streamflow gauge | 100601 | Grarem | 3.2 | 258.911 | 4.043.973 | 172 |

*Land Use Land Cover (LULC)*

The LULC (Figure 3) of the Qued Rhumel Smedou watershed was derived from ESA Sentinel-2 imagery at 10-meter resolution for the year 2021 (from: https://www.arcgis.com/home/item.html?id=d3da5dd386d140cf93fc9ecbf8da5e31).

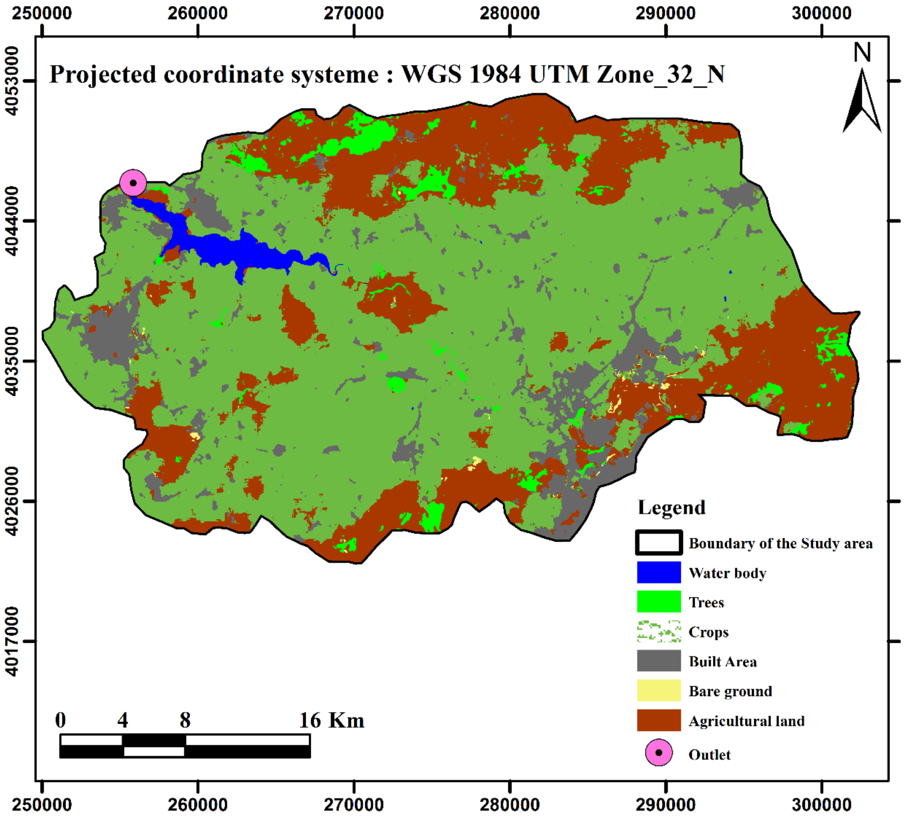

*Fig. 3 LULC of the Oued Rhumel Smedou.*

Usage of deep learning model resulted in classification of LULC map on six categories as follows: trees, crops, built area, bare ground, agricultural land and water body. The proportions of land uses varied in relation to the total area, as shown in table 2.

*Tab. 2. Distribution of LULC at the Oued Rhumel Smedou watershed*

| LULC Classes | Percent at watershed (%) | Partiel area (km²) | Total area (km²) |
|---|---|---|---|
| Water body | 1.68 | 18.2 | 1083 |
| Trees | 2.98 | 32.31 | |
| Crops | 60.94 | 659.93 | |
| Built Area | 9.07 | 98.24 | |
| Bare ground | 0.21 | 2.25 | |
| Agricultural land | 25.12 | 272.05 | |

### Model HEC-Geo HMS

DEM and GIS are used to extract physical basin properties, and HEC-Geo HMS is a tool for merging HEC-HMS and GIS, a spatial hydrology tool in ArcGIS 10.2.2 that generates input for the HEC-HMS model 4.0. It establishes a river network and defines the basin and sub-basins. Analyzing digital topographical data is also used to build the drainage network (Ramly & Tahir, 2016)

### HEC-HMS

The US Army Corps of Engineers created the Hydrologic Engineering Center-Hydrologic Modeling system (Chea & Oeurng, 2017; Choudhari et al., 2014). The model is suitable for simulation of the watershed's dendritic pattern. The model output is peak flow in $m^3/s$ and volume in mm, and it is also interpreted as a hydrograph (US Army Corps of Engineers, 2016). The hydrologic model result is utilized as an input to the hydraulic model to calculate flood spread area. The configuration includes four main models: the basin model, the meteorological model, control requirements, and time series data. The basin model consists of a basin, sub-basin, and the connectivity and runoff component. Precipitation, evapotranspiration, and snowmelt are all part of the meteorologic model (Kaffas & Hrissanthou, 2014). The research plan methodology is illustrated in Figure 4.

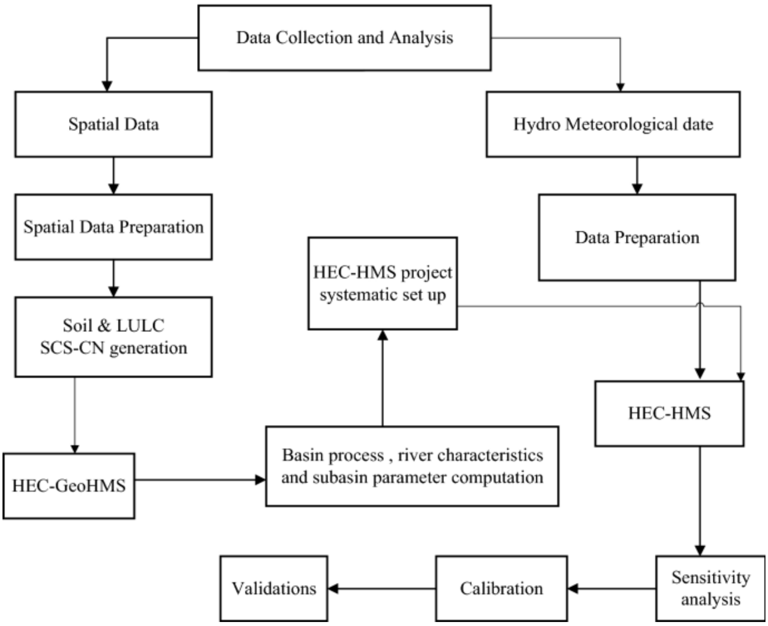

*Fig. 4 HEC-HMS model flow chart*

### Basin modeling process

The basin was divided into three sub-basins, as shown in Fig. 5. The basin model includes subbasins, junctions, reaches, and sinks. The Soil Conservation Service (SCS) curve number (CN) is used as a loss method to determine the hydrologic loss rate. The CN of the basin is considered a valuable indicator of soil type, antecedent soil moisture state, and land use. The range of CN values is 100 to 30. Water bodies takes a value of 100, and porous soils with high infiltration rates a value of 30. The SCS-CN model is provided by Eq. 1 (Wang et al., 2016):

$$Q = \frac{(P - I_a)^2}{(P - I_a)} + S \tag{1}$$

where:

Q is the runoff value in millimeters,
P is the precipitation in millimeters,
Ia is the initial abstraction in millimeters,
S is the potenial maximum retention in millimeters.

The potential maximum retention (S) of a catchment is an assessment of its ability to abstract and hold storm precipitation. As indicated in Eq. 2, there will be no precipitation surplus until the accumulated rainfall surpasses the initial abstraction.

$$I_a = 0.2 * S \tag{2}$$

The preceding equation's parameter S is changed into a dimensionless parameter CN that varies in a more conceptually understandable range of 0-100, as indicated in Eq. 3.

$$\mathrm{S} = \frac{25400}{\mathrm{CN}} - 254 \tag{3}$$

where:

P is the total rainfall (mm),
Q is the direct runoff ($m^3/s$),
Ia is the Initial abstraction (mm),
S is the potential maximum retention.

SCS Unit Hydrograph developed a direct flow model that combines precipitation translation into surface runoff. The base flow module was not used because there was no base flow in the study area. As an input, the transform technique requires a lag time determination. The SCS identified a link between concentration time (Tc) and lag time (Tlag). Topography and reach length in the subbasin can approximate the concentration-time (Kirpich's formula):

$$Tc = \frac{0.0078 * L^{0.77}}{S^{0.385}} \tag{4}$$

where:

L is the reach length (m),
S is the slope (%).

The hydrological and morphological inputs necessary for the runoff simulation of the study catchment are shown in Table 3.

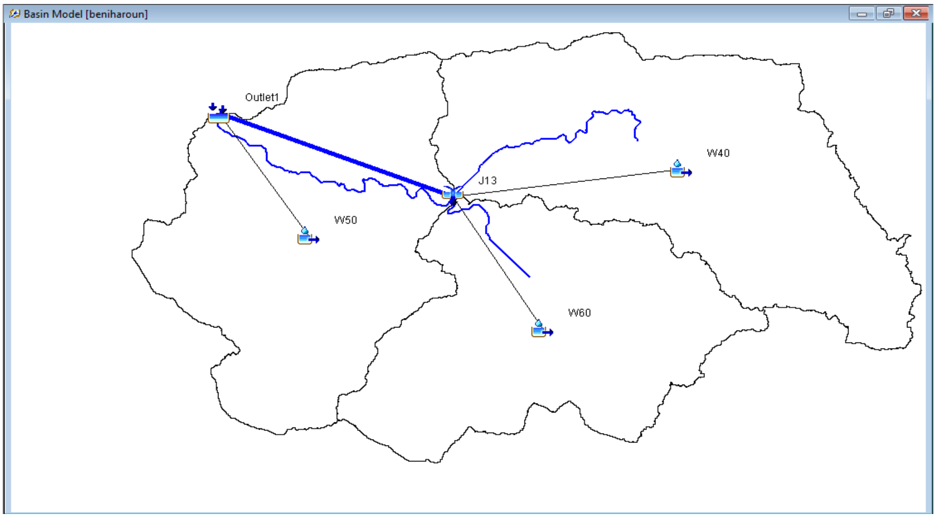

*Fig. 5 HEC-HMS model of the watershed of Oued Rhumel Smedou*

*Tab. 3. Hydrological and morphological inputs of the study research.*

| **N°** | **Sub-basin** | **Area (km$^2$)** | **Slope (%)** | **Ia(mm)** | **Lag time (mn)** | **CN (%)** | **Impermeability (%)** |
|---|---|---|---|---|---|---|---|
| 1 | W40 | 387.64 | 1.59 | 27.35 | 130 | 65 | 44 |
| 2 | W50 | 358.52 | 1.2 | 28.58 | 108 | 64 | 44 |
| 3 | W60 | 333.86 | 1.84 | 18.79 | 97 | 73 | 44 |

### *Model calibration and model validation*

The HEC-HMS watershed model has been tuned for event-based simulation. The goal of model calibration is to match observed simulated runoff quantities, runoff peaks, and hydrograph timing with observed ones. Tables 5 and 6 list the events used for the phase of calibration and validation, respectively.

The model was calibrated and validated using rainfall-runoff data collected in the Oued Rhumel Smedou watershed. At the time of calibration, the parameter values required for calibration were calculated and delivered as initial values. These parameters were improved using HEC-HMS's optimization tools. Table 4 shows the initial and optimized parameter values.

*Tab. 4. Initial and optimized parameters of Rhumel Smedou watershed*

| **N°** | **Parameter** | **Initial Value** | **Optimized Value** |
|---|---|---|---|
| 1 | CN | 67 | 79 |
| 2 | Lag time (min) | 335 | 310 |
| 3 | Ia (mm) | 24.91 | 19 |
| 4 | Impermeability (%) | 44 | 60 |

### *Model evaluation*

The HEC-HMS model, like any hydrological model, must perform statistical tests to judge the credibility of the simulation output (flow and volume). Equations 5, 6, and 7 show the statistical test applied to the Rhumel Smedou watershed.

$$\text{NSE}=1- \frac{\sum_{i=1}^{N}(Q_{i.Sim}-Q_{i.Obs})^2}{\sum_{i=1}^{N}(Q_{i.Obs}-\bar{Q}_{Obs})^2} \tag{5}$$

$$RMSE = \left(\frac{\sum_{i=1}^{N}(Q_{i,Obs} - Q_{i,Sim})^2}{N}\right)^{1/2} \tag{6}$$

$$\text{PIBAS}=\frac{\sum_{i=1}^{n}(Q_{i.Obs} - Q_{i.Sim}).100}{\sum_{1=1}^{n} Q_{i.Obs}} \tag{7}$$

where:

Qi.Sim is the simulated flow at time t = I,
Qi.Obs is the observed flow,
Q¯.Obs is the average observed discharge,
N is the number of observations.

To assess the performance of the model used in our study, the settings recorded in Table 5 must be followed.

*Tab. 5. Model assessment criterion (Coffey et al., 2004).*

| **Performance Rating** | **NSE** | **PBIAS (%)** | **RMSE** |
|---|---|---|---|
| Very good | NSE ≥ 0.7 | \|PBIAS\| ≤ 25 | 0 to ∞: The closer the score is to 0 the better performing |
| Good | 0.5 ≤ NSE < 0.7 | 25 < \|PBIAS\| ≤ 50 | |
| Satisfactory | 0.3 ≤ NSE < 0.5 | 50 < \|PBIAS\| ≤ 70 | |
| Unsatisfactory | NSE < 0.3 | \|PBIAS\| > 70 | |

## Result and discussion

### *Calibration results*

The estimated initial parameter values (Table 4) are used firstly to calibrate the HEC-HMS model, and simulated variables included peak discharge and runoff depth. These parameters were compared to the observed values (Table 6), and it identified that there are significant disparities between the observed and simulated values of all parameters for the calibration events. With a mean of 16.52, the percentage of variation in runoff depth ranged from 10.2 to 22.83. Likewise, the peak discharge percentage variation between observed and simulated values (simulated using beginning values) ranged between 94.3 and 162, with a mean value of 128.15. These improved parameters were used to simulate the hydrograph parameters including runoff depth and peak discharge (Table 6). It shows that the optimized values for the different hydrograph parameters were close to the observed values.

Figures 6 and 7 show the variation for two calibrated events: event 1 (17th April 2000) and event 2 (11th January 2002). According to these two figures, the optimized parameters in the HEC-HMS model produced values of multiple runoff hydrograph parameters that were closer to the observed values than the unoptimized (before optimization) parameters.

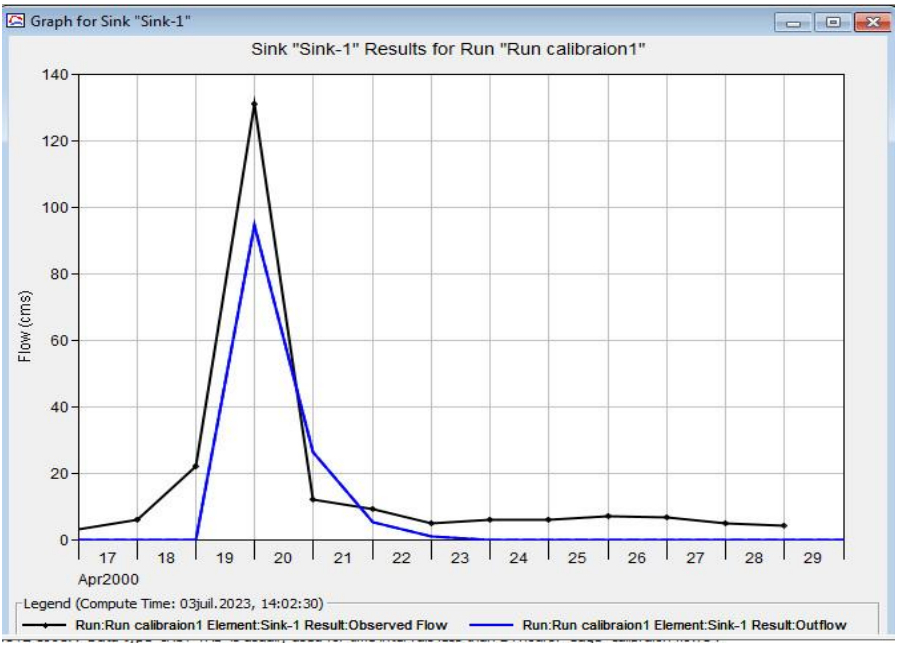

*Fig.6 Runoff hydrograph comparison for the first event (17th April, 2000)*

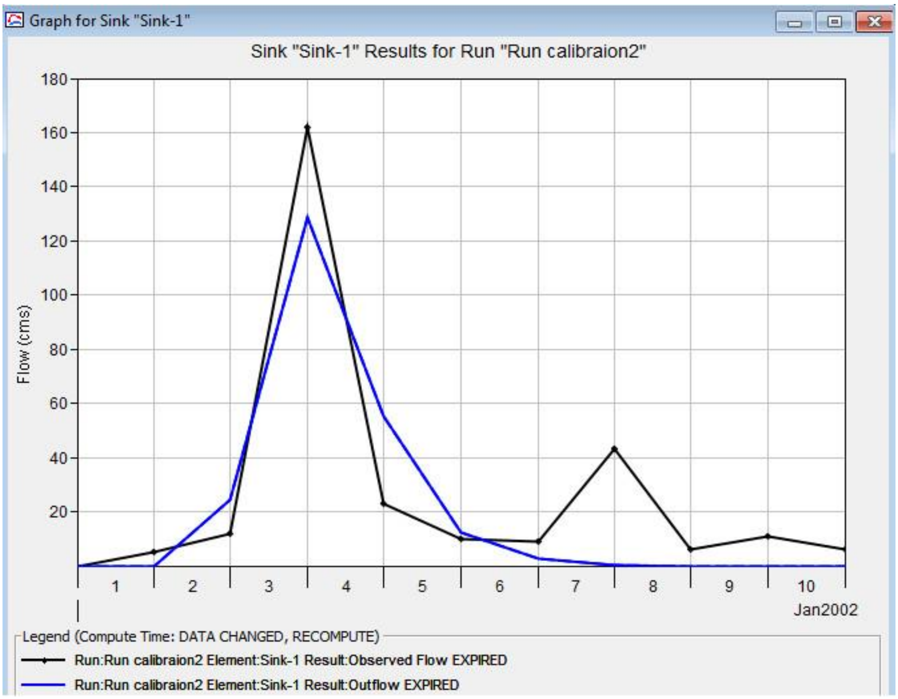

*Fig.7 Runoff hydrograph comparison for the first event (11th January, 2002)*

*Tab. 6. Simulated and observed runoff depth and peak discharge of calibration phase*

| **Events** | **Runoff depth (mm)** | | | **Peak discharge ($m^3/s$)** | | |
|---|---|---|---|---|---|---|
| | Simulated | | Observed | Simulated | | Observed |
| | Before optimisation | After optimisation | | Before optimisation | After optimisation | |
| 17 April 2000 | 7.58 | 10.2 | 17.6 | 70 | 94.3 | 131 |
| 11 January 2002 | 11.34 | 17.96 | 22.83 | 92.54 | 128.7 | 162 |

### *Validation results*

Before advising its use, the calibrated model must be validated. The simulated data must be compared to the observed data to validate the model, and statistical tests of error functions must be run. If the error function values are reasonably small, the model is considered validated. The validity of the model was checked using two events.

The two selected events are listed in Table 7. The values of different runoff hydrographs, including peak discharge and runoff depth, that were simulated by the calibrated model with the addition of optimized parameters are shown in Table 7. For the two events, it is discovered that the simulated values of these parameters are relatively close to the observed values (Table 7).

Runoff depth and peak discharge have estimated mean percentage differences of 4.79 and 4.99 between observed and simulated values, respectively. Actual and simulated hydrographs for events (21 May 2005) and (03 October 2004) are compared in Figure 8 and Figure 9. These graphs demonstrate how closely the simulated runoff hydrograph matches the observed one for each event. The model's validation for the simulation of runoff hydrographs in the investigated watershed is supported by statistical tests of error functions.

The mean percentage of difference in runoff depth and peak discharge between observed and simulated values is calculated to be 14.98 and 129.3, respectively. Figures 8 and 9 compare observed and simulated hydrographs for events 21 May 2005 and 03 October 2004, respectively. These figures show that for all of the events, the simulated runoff hydrograph is very close to the observed one. The statistical tests of error functions support the model's validation for the simulation of runoff hydrographs in the studied watershed.

*Tab. 7. Simulated and observed runoff depth and peak discharge of validation phase.*

| **Events** | **Runoff depth (mm)** | | **Peak discharge ($m^3/s$)** | |
|---|---|---|---|---|
| | Simulated | Observed | Simulated | Observed |
| 21 May 2005 | 21 | 15.71 | 165.5 | 121 |
| 03 October 2004 | 9.6 | 13.64 | 88.7 | 142 |

The obtained statistical tests shown in Tab.8 reveal that the HEC-HMS model has proven its ability and effectiveness to simulate runoff and flow hydrography in the calibration and validation phases.

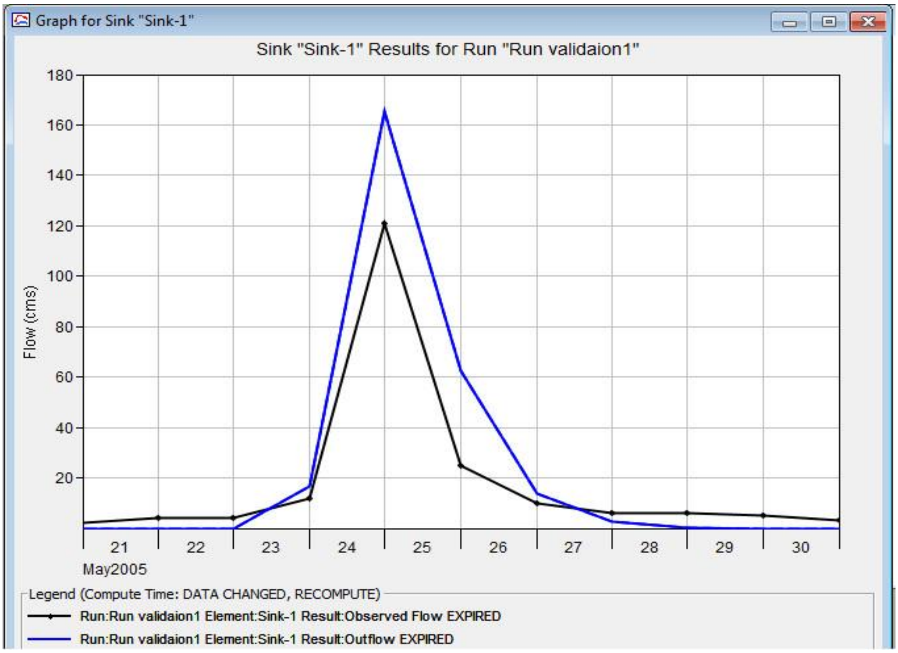

*Fig. 8 Runoff hydrograph comparison for the first event (21 May 2005).*

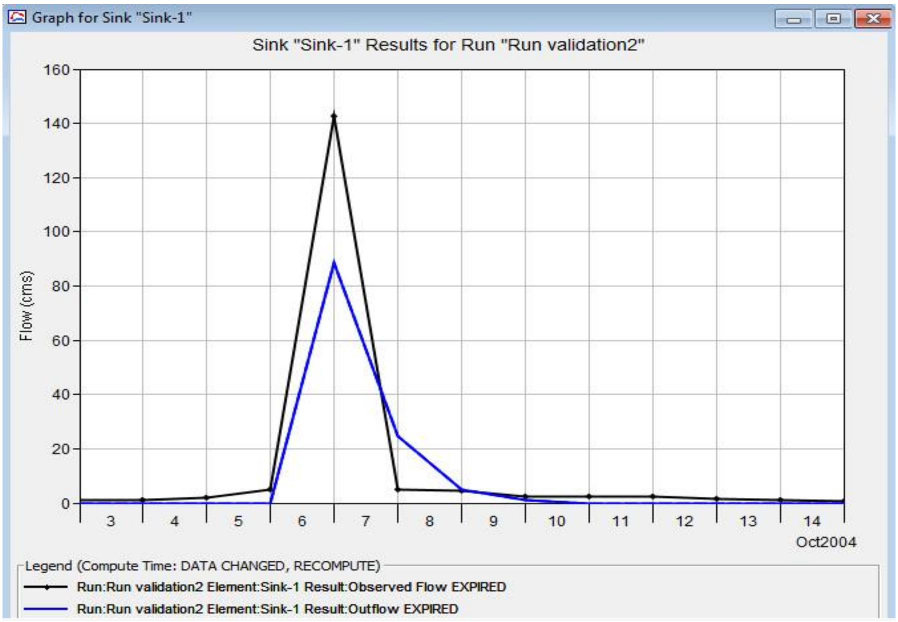

*Fig. 9 Runoff hydrograph comparison for the first event (03 October 2004).*

*Tab. 8 Evaluation the performance of the HEC-HMS model.*

| **Events** | **a- Phase of Calibration** | | |
|---|---|---|---|
| | **NSE (%)** | **RMSE** | **PBIAS (%)** |
| 17 April 2000 | 84 | 0.4 | -42.96 |
| 11 January 2002 | 79 | 0.5 | -22.14 |
| **Events** | **b- Phase of Validation** | | |
| | **NSE (%)** | **RMSE** | **PBIAS (%)** |
| 21 May 2005 | 71 | 0.5 | 31.96 |
| 03 October 2004 | 82 | 0.4 | -29.94 |

### *Simulation of the prediction LULC and climate change of the Rhumel Smedou watershed*

The disruption of the natural flow balance and the impact of climate and LULC changes on hydrological processes cannot be disputed. Planners and decision-makers must therefore be aware of the effects of anthropogenic activities carried out upstream of the watershed, such as urban development, deforestation, and reforestation.

In light of this, the current section makes an effort to reuse the HEC-HMS model fitted to the Rhumel Smedou watershed to forecast its response to both positive and negative scenarios. The 11 January 2002 event, for which the model was able to reproduce the peak discharge, was used to test all of these scenarios. We'll compare the flood volume to what the model predicted, and then to what was seen at the outlet station.

### *Scenario of climate change*

Based on these modifications, we used the composite CN of the watershed, which is 79%. The percent of impermeability is equal to 60%.

Table 9 summarizes the estimated rainfall values for return periods as input data for the first scenarios.

*Tab. 9 Estimated rainfall OF RHUMEL SMEDOU WATERSHED for different return periods.*

| **Return period T (years)** | **Pj max (mm)** |
|---|---|
| 2 | 44.63 |
| 10 | 78.93 |
| 50 | 111.29 |
| 100 | 125.64 |

*Tab. 10 Peak flow and volume for different return periods.*

| **Return period (year)** | **T=2** | **T=10** | **T=50** | **T=100** |
|---|---|---|---|---|
| **Qp ($m^3/s$)** | 143.00 | 259.30 | 524.10 | 708.60 |
| **V (103m³)** | 4708.60 | 10140.30 | 20808.40 | 26945.30 |

Due to these findings, those in charge must take additional precautions to protect the flow-measuring equipment at the outlet from impending floods and put in place structural modifications that can handle the enormous volumes predicted.

Table 10 shows an increase in flow and volume values from (Qp ($m^3/s$)= 143.00; V ($10^3m^3$)= 4708.60) to (Qp ($m^3/s$)= 708.60; V ($10^3m^3$)= 26945.30), for 2 year to 100 year respectively.

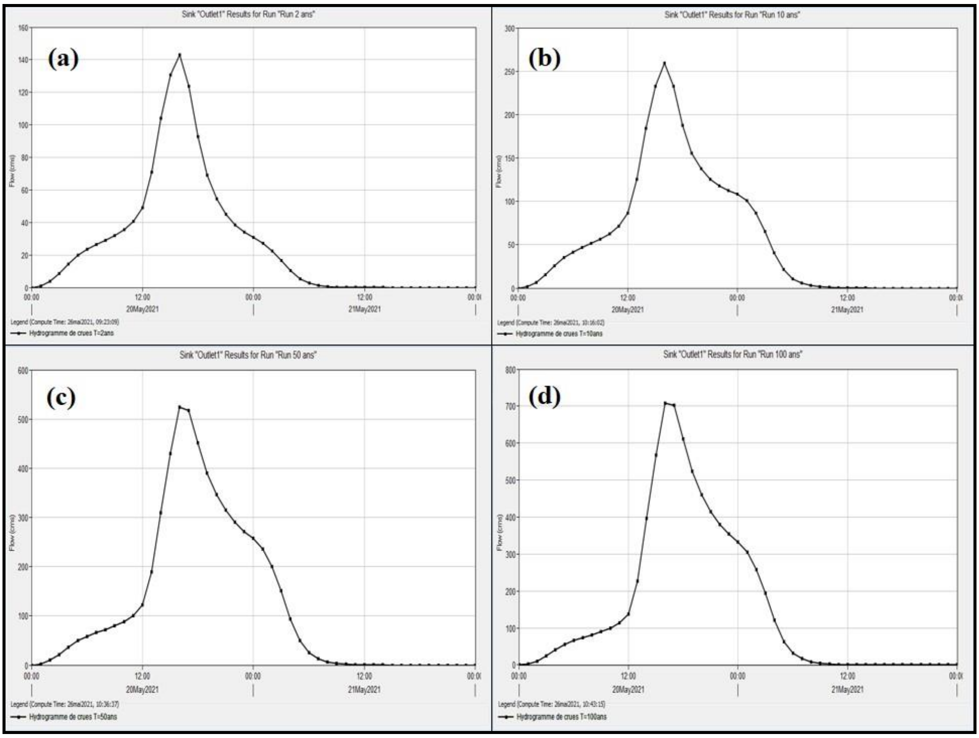

*Fig. 10 Flow hydrographs for different return periods: (a) 2 years; (b) 10 years; (c) 50 years; (d) 100 years.*

### *Scenario of negative land-use change*

In this scenario, we attempt to simulate the effect of deforestation and urbanization on flood flows and volumes. The scenario concern:

- An increase in the surface area of the urbanized zone;
- The disappearance of low-density forest cover;
- An increase in the percentage of bare land in favor of cleared land;
- An increase in the percentage of impervious land due to urbanization.

Based on these modifications, we have recalculated the new composite CN of the basin, which increases from 79 to 88. The percentage of impervious is estimated at 70%.

These CN and imperviousness values will replace the old ones in the optimized parameter set, and the simulation is then run.

Table 11 shows the peak flow and volume values for different return periods obtained in the second scenario.

Table 11 shows an increase in flow and volume values from (Qp ($m^3/s$)= 286.40; V ($10^3 m^3$)= 9960.00) to (Qp ($m^3/s$)= 1666.70; V ($10^3 m^3$)= 53735.40), for 2 year to 100 year respectively.

*Tab. 11 Predicted peak flow and volume values*

| Return period (year) | **T=2** | **T=10** | **T=50** | **T=100** |
|---|---|---|---|---|
| **Qp ($m^3/s$)** | 286.40 | 689.30 | 1330.00 | 1666.70 |
| **V($10^3m^3$)** | 9960.00 | 24648.80 | 43986.00 | 53735.40 |

### *Scenario of positive change in land use*

For the third scenario, the focus is on assessing the impact of urbanization in the basin on the same scale as scenario 2, but in parallel actions are undertaken to reforest bare soil and reinforce low-density forest cover, thus:

- Bare soil will become open forest;
- Open density will become medium;
- The urbanized area is identical to scenario 2.

Based on these modifications, we have recalculated the new composite CN of the basin, which is equal to 65. The percentage of impervious is set at 20%.

The following table shows the results obtained for this scenario, i.e. the peak flow and volume resulting from the scenario simulation and those resulting from substituting the rainfall of the January 11, 2002 event with rainfall of different return periods.

*Table 12 Predicted peak flow and volume values*

| | **T=2** | **T=10** | **T=50** | **T=100** |
|---|---|---|---|---|
| **Qp ($m^3/s$)** | 286.10 | 506.10 | 791.50 | 974.00 |
| **V($10^3m^3$)** | 94177.10 | 17386.00 | 29163.6 | 35625.00 |

We can therefore understand the negative effect of the sealing of watershed surfaces, through urbanization for example, on its hydrological regime. Furthermore, we note that the two variables flow and volume show lower values than in the case of scenario 2, which proves that reforestation, although modest, cushions the effects of planned urbanization.

Finally, the reduced influence of land use on flows and volumes for extreme downpours is also valid for this scenario.

On the basis of the above, we are able to recognize the positive and negative effects of a number of situations likely to occur in the field in the coming decades, and which those responsible are expected to take into consideration in their development plans for the Rhumel Smedou watershed. In addition, we were able to reconfirm that the cause-effect relationship between changes in land use on the one hand and flows and volumes on the other is less and less close the more extreme the downpours.

## Conclusion

One of the best techniques that have proven to be both easy and effective is the usage of modeling as a tool for understanding the hydrological functioning of watersheds as an aid in decision-making. In light of this, one of the Rhumel Smedou watersheds was the first to receive a suitable modular combination of the HEC-HMS model in the current study. The study then concentrated on using this model to forecast future hydrological behavior of the basin under climate change scenarios and land-use modification after it had been validated on at least one of the previously selected events.

Once the HEC-HMS model is validated in the study area, it can be used for flood protection, using what is known as real-time modeling, based on the principle of reconstructing the discharge at the outlet for each time step for which rainfall data is measured so that the flood hydrograph can be reconstructed as the rainfall height recorded. This alarm system is more effective than the one based on measuring the water level in the river upstream of the watershed. The HEC-HMS model is used to simulate runoff hydrographs in the Rhumel Smedou watershed in Algeria. The initial calibration parameter was determined using geomorphologic parameters.

Final validation parameters were determined using an optimization technique and used as global values for the model. The NSE for the calibration and validation phases of the HEC-HMS model used for rainfall-runoff simulation in the specified watershed is 79% and 84%, respectively. These validated model results show that the HEC-HMS model performs well in simulating runoff hydrographs.

After calibrating and validating the efficiency of the model, the volume and flow were predicted for different return periods (2y, 10y, 50y, and 100y). The scenarios were as follows: Climate change, negative land-use change, positive land-use change. Such predictions are essential for decision-makers to develop strategies to confront extreme phenomena such as drought and floods. However, the study area should be covered with stations monitoring more to increase the credibility of the simulation outputs in our research flow and volume.

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## References

Abdelkebir, B., Maoui, A., Mokhtari, E., Engel, B., Chen, J., & Aboelnour, M. (2021). Evaluating Low-Impact Development practice performance to reduce runoff volume in an urban watershed in Algeria. *Arabian Journal of Geosciences, 14*(9), 1–10. https://doi.org/10.1007/s12517-021-07178-0

Abdessamed, D., Abderrazak, B., & Kamila, B. (2018). Modelling rainfall runoff relations using HEC-HMS in a semi-arid region: Case study in Ain Sefra watershed, Ksour Mountains (SW Algeria). *Journal of Water and Land Development, 36*(1-3), 45-55. https://doi.org/10.2478/jwld-2018-0005

Chea, S., & Oeurng, C. (2017). Flow simulation in an ungauged catchment of Tonle Sap Lake Basin in Cambodia: Application of the HEC-HMS model. *Water Utility Journal, 17*, 3-17.

Choudhari, K., Panigrahi, B., & Paul, J. C. (2014). Simulation of rainfall-runoff process using HEC-HMS model for Balijore Nala watershed, Odisha, India. *International Journal of Geomatics and Geosciences, 2*(5), 253-265.

Coffey, M. E., Workman, S. R., Taraba, J. L., & Fogle, A. W. (2004). Statistical procedures for evaluating daily and monthly hydrologic model predictions. *Transactions of the American Society of Agricultural Engineers, 47*(1), 59–68. https://doi.org/10.13031/2013.15870

Geyisa Namara, W., Adugna Damise, T., & Gudu Tufa, F. (2020). Rainfall Runoff Modeling Using HEC-HMS: The Case of Awash Bello Sub-Catchment, Upper Awash Basin, Ethiopia. *International Journal of Environment, 9*(1), 68-86. https://doi.org/10.3126/ije.v9i1.27588

Halwatura, D., & Najim, M. M. M. (2013). Application of the HEC-HMS model for runoff simulation in a tropical catchment. *Journal Environmental Modelling & Software, 46*, 155-162. https://doi.org/10.1016/j.envsoft.2013.03.006

Hydrlogic Engineering Center. (2016). *Hydrologic Modeling System HEC-HMS User's Manual*. Institute for Water Resources.

James, O. O., & Zhi-jia, L. (2010). Application of HEC-HMS for flood forecasting in Misai and Wan'an catchments in China. *Water Science and Engineering, 3*(1), 14-22. https://doi.org/10.3882/j.issn.1674-2370.2010.01.002

Kaffas, K., & Hrissanthou, V. (2014). Application of a continuous rainfall-runoff model to the basin of kosynthos river using the hydrologic software HEC-HMS. *Global Nest Journal, 16*(1), 188-203. https://doi.org/10.30955/gnj.001200

Karabörk, Ç., Kahya, E., & Komuscu, A. U. (2007). Analysis of Turkish precipitation data: homogeneity and the Southern Oscillation forcing on frequency distributions. *Hydrological Processes, 21*(23), 3203–3210. https://doi.org/10.1002/hyp.6524

Kishor, C., Balram, P., & Jagadish, C. (2014). Simulation of rainfall-runoff process using HEC-HMS model for Balijore Nala watershed, Odisha, India. *International Journal of Geomatics and Geosciences, 5*(2), 253-265.

Lenhart, T., Eckhardt, K., Fohrer, N., & Frede, H. G. (2002). Comparison of two different approaches of sensitivity analysis. *Physics and Chemistry of the Earth, 27*, 645–654.

Majidi, A., & Shahedi, K. (2012). Simulation of Rainfall-Runoff Process Using Green-Ampt Method and HEC-HMS Model (Case Study: Abnama Watershed, Iran). *International Journal of Hydraulic Engineering, 1*(1), 5-9. https://doi.org.10.5923/j.ijhe.20120101.02

Mokhtari, E. H., Remini, B., & Hamoudi, S. A. (2016). Modelling of the rain–flow by hydrological modeling software system HEC-HMS-watershed's. The case Cheliff-Ghrib, Algeria. *Journal of Water and Land Development, 30*(7-9), 87-100. https://doi.org/10.1515/jwld-2016-0025

Mokhtari, E., Mezali, F., Abdelkebir, B., & Engel, B. (2023). Flood risk assessment using analytical hierarchy process: A case study from the Cheliff-Ghrib watershed, Algeria. *Journal of Water and Climate Change, 14*(3), 694-711. https://doi.org/10.2166/wcc.2023.316

Moradkhani, H., & Sorooshian, S. (2009). General Review of Rainfall-Runoff Modeling: Model Calibration, Data Assimilation, and Uncertainty Analysis. In: S. Sorooshian, K-

l. Hsu, E. Coppola, B. Tomassetti, M. Verdecchia & G. Visconti (Eds.), *Hydrological Modelling and the Water Cycle* (pp. 1-24).

Ramly, S., & Tahir, W. (2016). Application of HEC-GeoHMS and HEC-HMS as Rainfall–Runoff Model for Flood Simulation. In: W. Tahir, P. Abu Bakar, M. Wahid, S. Mohd Nasir & W. Lee (Eds.), *Proceedings of the International Symposium on Flood Research and Management* (pp. 181-192). https://doi.org/10.1007/978-981-10-0500-8_15

Rathod, P., Borse, K., & Manekar, V. L. (2015). Simulation of Rainfall Runoff Process Using HEC-HMS: Case Study on Tapi River, India. *20th International Conference on Hydraulics, Water Resources and River Engineering*.

Todini, E. (2007). Hydrological catchment modelling: Past, present and future. *Hydrology and Earth System Sciences, 11*, 468-482. http://dx.doi.org/10.5194/hess-11-468-2007

Wang, M., Zhang, L., & Baddoo, T. D. (2016). Hydrological Modeling in A Semi-Arid Region Using HEC-HMS. *Journal of Water Resource and Hydraulic Engineering, 5*(3), 105–115. https://doi.org/10.5963/jwrhe0503004