Evaluation and Calibration of the HEC-HMS/WMS model in Mahabad dam’s basin

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ABSTRACT
Lack of water which Iranians have faced it from the old times, it has created such a technical, cultural and socio-economical complications that even the scientific exploitation of these resource are affected, hence before any decision making, the hydrological dimensions of these should be explored. Using of empirical relation of the rainfall - runoff is known as one of the simplest way in calculating the outlet runoff volume of the basins. By the development of the computers and their calculating and logical decision abilities, researchers have developed more accurate and more efficient methods for different problems and phenomena. In this research rainfall- runoff process of Mahabad dam basin is simulated by the HEC-HMS conceptual model. The simulating process is done by using the SCS curve number and Initial and Constant Loss methods for calculating the loss rate, and Clark unit hydrograph and Snyder unit hydrograph for calculating the runoff rate, and their performance was evaluated using statistical criteria, Peak-weighted Root Mean Square Error (PRMSE) and correlation coefficient (R2). Reviewing the Simulation results indicate a better adaptation of the SCS Curve Number method in compare to Initial and Constant Loss method.

INTRODUCTION
Understanding the dynamic behavior of rainfall – runoff process is one of the most fundamental and complex process in designing the water projects [1]. This process has a special role in estimating the river flows, producing energy, flood controlling, adjusting the water and irrigation needs, drainage recycling, and aquaculture and so on [2]. None of the statistical and conceptual models are not exact modeling of rainfall – runoff with nonlinear relations, uncertainty and temporal and spatial variant features in water circulation systems could not be known as a prominent model [1]. From the old times, there have done broad researches on modeling the rainfall process in the basin and changing it to the runoff and outlet flow. In this paper, only the researches have been considered that simulated the rainfall- runoff process by HEC-HMS model [3]. This model has expressed by the US Army in 1988 which make conceptual models of the rainfall- runoff process.

Ghaderi et al. [4] simulated the rainfall- runoff process in Mahabad basin by the use of Adaptive Neuro-Fuzzy Inference System and comparing it with 666Artificial Neural Network and HEC-HMS conceptual model. This research has shown that HEC-HMS model simulated the happened flood in the basin very accurately, and this model can be used in the initial design and overview of the water resources in the Mahabad basin. Nouri et al. [5] has used WMS/ HES-HMS model in flood estimating of the basins without any statistics. These models have been used for extracting the flood hydrograph especially in the basins without statistic. In this paper by using WMS/ HEC-HMS model, Qorveh basin in Kurdistan province is estimated. In this respect four storm which have symmetric hydrograph and hyetograph were chosen and the basin flood hydrographs were simulated with the HEC-HMS model by using the SCS empirical method and the Curve number, lag time and the loss rate were also calibrated. The results have shown that the mentioned software is a useful tool for estimating the peak flow in the statistic less areas of the basin. Kasmin [6] has used HEC-HMS for evaluating the lag effects of the basin over the outlet hydrograph. Motiei and Barbod [7] have used GIS software and HEC-HMS model for forecasting and modeling the hydraulic behavior of Sefidrood River against the probable floods and their zoning.
**MATERIALS AND METHODS**

**HEC-HMS Model:**

HEC-HMS software is the developed version of HEC-1 and one of water engineering software that used for simulating the rainfall-runoff processes in the basins. This software is useful in solving different problems in the water fields as the water resources and hydrology, great floods and the natural or small urban basins runoff. The generate hydrographs by this software directly or in merging with other software are used in studies and water projects like water resources, urban drainage, flow forecasting, reservoir spillway design, Operation of water resources systems and Etc. In the HEC-HMS model, for calculating the runoff several methods like Snyder unit hydrograph, SCS unit hydrograph and Clark unit hydrograph and for routing some methods like kinematic wave of flood are used. In the figure (1) the principles of HEC-HMS model in simulating the rainfall-runoff process are presented, the HEC-HMS model for simulating each one of the components of the fig. 1 uses a different model which consists of runoff volume calculating model, direct runoff calculating model, base flow models and river flow models.

![Fig. 1: The principles of the HEC-HMS model in simulating rainfall-runoff process.](image)

The resulted hydrographs from the HEC-HMS software analyses either directly are used in designing matters or can be used in conjunction with other software for complementary studies of water availability, urban drainage, flow forecasting, reservoir spillway design, and flood damage reduction. This model shows the basin as a lumped system with hydrologic and hydraulic components, and each part of the model simulates one aspect of the rainfall-runoff process inside one part of the basin that is usually considered as sub basin. In other word, different elements are combined for simulating the basin physical system and each element represents one of the transformation factors of rainfall to runoff in the basin and the final flood hydrograph will results from dual effect combination of the above factors.

**Calculating methods of the basin components:**

All calculations of subbasins in the HEC-HMS model can be classified into the following three groups:

a) **Calculating methods of the basin or subbasin loss rate:**

In the HEC-HMS, the loss rate calculating methods in the basins are eleven methods, the user can calculates the loss rate by choosing just one of them. In these research two methods, SCS curve number and Initial and Constant loss are used.

- **SCS curve number method:**

  The U.S. soil conservation service (now the Natural Resources Conservation Service) for calculating the runoff rate presented the SCS method which is a function of Cumulative precipitation, vegetation cover, basin soil moisture and land use, by using the following equation:

  \[
  R = \frac{(P - 0.2S)^2}{(P + 0.8S)}
  \]  

  (1)
Where:
R: the height of runoff in inches
P: the height of precipitation at time t in inches
S: the factor related to surface storage of the soil moisture in inches and metric unit.

- **Initial and Constant loss method:**

  Basically, the Initial (indicating previous condition of the basin) and Constant loss method means that maximum loss rate of the basin ($f_c$) is constant through all the stages, in this condition if $P_t$ be assumed as the average height of the surface precipitation during a certain time interval $t$ and $t+\Delta t$, the excess precipitation ($P_{et}$) during this period equals to equation (2):

  $$
P_{et} = \begin{cases} 
P_t - f_c & \text{if } P_t > f_c \\
0 & \text{if } P_t \leq f_c 
\end{cases}
$$

  (2)

  In penetrable part of the basin until the cumulative precipitation does not exceed than loss rate and wouldn’t be made the excess loss volume, the runoff would not appear. Therefore the excess precipitation is defined as equation (3):

  $$
P_{et} = \begin{cases} 
P_t - f_c & \text{if } \Sigma P_t < I_a \\
0 & \text{if } \Sigma P_t > I_a \text{ and } P_t > f_c
\end{cases}
$$

  (3)

  In this equation:
  $I_a$: is the initial loss rate or initial infiltration
  $P_t$: is the precipitation rate during time $t$
  $f_c$: is the intensity of loss during the rainfall duration or the steady infiltration rate, in inches per hour (in/hr)

b) **Calculating methods of the basin or subbasin runoff rate:**

  In HEC-HMS software seven methods are introduced for calculating the runoff caused by excess precipitation which includes the empirical and the conceptual models like the unit hydrograph, implementation of the kinematic wave, and the linear quasi-distribution method. For calculating the runoff rate we can use different methods in each one of the subbasins or can choose a similar method for all the subbasins. In this research the SCS unit hydrograph and the Clark unit hydrograph are used for calculating the runoff rate.

- **The SCS unit hydrograph method:**

  This model was introduced in 1986 by the US Soil Conservation Service, was originally developed from observed data in small, agriculture watersheds in the US. In this method the coordinate of the unit hydrograph points are obtained based on a non-dimensional table in which the values are recorded in proportion to the time ($t_p$) against the hydrograph discharge proportion ($Q/Q_p$). To get the coordinate of the hydrograph points from $t_p$ and $Q/Q_p$ it’s necessary that the $t_p$ and $Q_p$ be presented till based on them and the table values, the amount of $t$ and $Q$ be obtained. $t_p$ and $Q_p$ are calculated by the equation (4) and (5):

  $$
Q_p = \frac{0.208A}{t_p}
$$

  (4)

  $$
t_p = \frac{D}{2} + t_l
$$

  (5)

  That, in this equations:
  $Q_p$: the unit hydrograph peak flow in cube meters ($m^3$)
  $t_p$: time of peak flow in hours (hr)
  D: the desired rainfall duration in hours (hr)
  $t_l$: the basin lag time in hours (hr)

  In the SCS method the rainfall duration (D) which the unit hydrograph is made for, depends on the time of concentration and gets by the equation (6):
The Clark unit hydrograph method:
The Clark unit hydrograph is an artificial unit hydrograph method that the user does not need to evaluate the previous observed unit hydrographs for creating a unit hydrograph. In transforming the excess precipitation to the runoff, the short-term rainfall storage is very effective; the structure of this model begins with the Continuity equation (equation (7)):

\[
\frac{ds}{dt} = I_t - Q_t
\]  

(7)

Where:
- \( s \): the storage changes with respect to time
- \( I_t \): the average inflow to the storage at time \( t \)
- \( Q_t \): the average outflow of the storage at time \( t \)

In the linear reservoir model, the storage at time \( t \) is expressed as equation (8):

\[
S_t = R \cdot Q_t
\]  

(8)

Where:
- \( S_t \): the storage at time \( t \)
- \( R \): the constant parameter of linear reservoir

The equation (9) is obtained by combining and solving equations (7) and (8):

\[
Q_t = C_A \cdot I_t + C_B Q_{t-1}
\]  

(9)

In this equation, \( C_B \) and \( C_A \) are the routing coefficients that are obtained from the equations (10) and (11):

\[
C_A = \frac{\Delta t}{R + 0.5 \Delta t}
\]  

(10)

\[
C_A = 1 - C_A
\]  

(11)

The average outflow at time \( t \) is (equation (12)):

\[
Q_t = \frac{Q_{t-1} + Q_t}{2}
\]  

(12)

In the equation (9) if we consider the width of the inflow as runoff resulting from a unit of excess precipitation, the outflow width of this reservoir gets the unit hydrograph. In the HEC-HMS the calculations of hydrograph widths continue till the outflow volume value exceeds 0.995 inches, then the hydrograph widths by using the corrected weighted height to the height of equivalent to one, became unit.

c) Calculating methods of the basin or subbasin base flow:
The Surface flow hydrograph has two independent parts of the baseflow and runoff transformed from precipitation. The base flow is a steady flow which caused by previous precipitations, delayed and subsurface flows in the basin. There are many conceptual models that are able to simulate and calculate the storage rate and subsurface flow stream in the basin, this models are called base flow models. In HEC-HMS, three models presented for calculating the base flow which in this research the Constant Monthly method has been used.
General information of Mahabad basin and data used in this research:

Mahabad basin is located in west Azerbaijan province and the south of Urmia lake in northwest of Iran which is one of the Urmia lake basins. This basin is located between the 45° 35’ to 45° 46’ Eastern longitude and between 36° 26’ to 36° 46’ Northern latitude. The area of this basin is 841 square kilometers and the length of its main river is 61 kilometers. Kowtar and Beytas are two important rivers of this basin that both finally enter to the Mahabad dam reservoir and after the dam they join together and make Mahabad River and after passing Mahabad plain, enter into the Urmia Lake. This basin has two important hydrometric station before the Mahabad dam named Beytas and Kowtar and one station in the outlet of the basin named Gerde Yaqub. In this paper, all the daily events and their corresponding discharge in Beytas and Kowtar hydrometric stations in 2001 to 2010 has been analyzed and their models have been developed. After analyzing the data, it has been cleared that the final data series has a high accuracy and 80 percent of these data have been used for training and calibration and 20 percent for testing.

RESULTS AND DISCUSSION

The HEC-HMS model results in calibration phase:

For calibration of the model, the recorded data of flood and rainfall in the region has been used, therefore, two floods were used for calibration of the model and determining the optimum amounts by using of three modeling combination to estimate the runoff and loss rate. In figures 2 to 7, the model results in calibration phase and in comparison to the observed floods are shown. The three modeling combination include:

a) The SCS Curve Number method for calculating loss rate and the SCS Unit Hydrograph method for estimating the runoff rate
b) The SCS Curve Number method for calculating loss rate and the Clark Unit Hydrograph method for estimating the runoff rate
c) The Initial and Constant method for calculating loss rate and the Clark Unit Hydrograph method for estimating the runoff rate

![Fig. 2: Comparing the simulated results in the combined model (a) with the observed data in the first flood (May 02-08, 2001).](image)

![Fig. 3: Comparing the simulated results in the combined model (a) with the observed data in the 2nd flood (Feb 06-12, 2011).](image)
Fig. 4: Comparing the simulated results in the combined model (b) with the observed data in the first flood (May 02-08, 2001).

Fig. 5: Comparing the simulated results in the combined model (b) with the observed data in the 2nd flood (Feb 06-12, 2011).

Fig. 6: Comparing the simulated results in the combined model (c) with the observed data in the first flood (May 02-08, 2001).
Comparison of the results of three combined models:

In order to evaluate the performance of the three used combination models in this paper, the calculated discharge of two floods which were simulated by the HEC-HMS model are compared with the observed discharge in tables (1) and (2) and the fig. (8) and (9):

Table 1: Comparing the results of the three combined models in the first flood.

<table>
<thead>
<tr>
<th>Year-Month</th>
<th>Day</th>
<th>Observed discharge (CMS)</th>
<th>Simulated discharge (CMS)</th>
<th>Difference (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Model (a)</td>
<td>Model (b)</td>
</tr>
<tr>
<td>2001-05</td>
<td>2</td>
<td>35.64</td>
<td>30</td>
<td>30.7</td>
</tr>
<tr>
<td>2001-05</td>
<td>3</td>
<td>32.08</td>
<td>35.447</td>
<td>33.5</td>
</tr>
<tr>
<td>2001-05</td>
<td>4</td>
<td>53.77</td>
<td>55.712</td>
<td>56.6</td>
</tr>
<tr>
<td>2001-05</td>
<td>5</td>
<td>40.5</td>
<td>42.34</td>
<td>44.6</td>
</tr>
<tr>
<td>2001-05</td>
<td>6</td>
<td>32.59</td>
<td>32.865</td>
<td>30.36</td>
</tr>
<tr>
<td>2001-05</td>
<td>8</td>
<td>29.21</td>
<td>30.058</td>
<td>31.93</td>
</tr>
</tbody>
</table>

Table 2: Comparing the results of the three combined models in the 2nd flood.

<table>
<thead>
<tr>
<th>Year-Month</th>
<th>Day</th>
<th>Observed discharge (CMS)</th>
<th>Simulated discharge (CMS)</th>
<th>Difference (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Model (a)</td>
<td>Model (b)</td>
</tr>
<tr>
<td>2011-02</td>
<td>6</td>
<td>13.65</td>
<td>2</td>
<td>8.3</td>
</tr>
<tr>
<td>2011-02</td>
<td>7</td>
<td>63.45</td>
<td>55.2</td>
<td>70.3</td>
</tr>
<tr>
<td>2011-02</td>
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<td>80.2</td>
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<tr>
<td>2011-02</td>
<td>9</td>
<td>45.03</td>
<td>33.118</td>
<td>58.2</td>
</tr>
<tr>
<td>2011-02</td>
<td>10</td>
<td>25.99</td>
<td>11.4</td>
<td>32.4</td>
</tr>
<tr>
<td>2011-02</td>
<td>11</td>
<td>19.4</td>
<td>4.6</td>
<td>14.4</td>
</tr>
<tr>
<td>2011-02</td>
<td>12</td>
<td>16.37</td>
<td>1.8</td>
<td>7.5</td>
</tr>
</tbody>
</table>
As can be observed from the above comparisons, modeling the rainfall-runoff process by using the combined model c (the Initial and Constant loss method and Clark unit hydrograph method for estimating the runoff rate) in comparison to other combinations, presents unexpected results, also the model b (the SCS curve number for loss and the Clark unit hydrograph method for calculating the runoff rate) is more accurate for simulating and the calculated results are more compatible to the observed results.

**Conclusion:**

What is the most obvious from considering the graph results, hydrographs and tables is the high dependency of the results and simulated data resulted by the model to the inputs data and information which are defined to the model by the user. Therefore if these data are more accurate and more correctness the output simulated results be more accurate and have less faults and finally are more compatible to the observed results. On this basis it can be said that the model compound of the SCS curve number loss method with the SCS unit hydrograph and Clark unit hydrograph for calculating the runoff rate presents a better and more accurate results.

**REFERENCES**


