Application of the HEC-HMS Model for Monthly Runoff Simulation over the Upper Gauged Catchments of a Timah-Tasoh Reservoir

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ABSTRACT

Hydrological modelling plays a pivotal role in understanding and managing water resources and flood forecasting. This study focuses on the calibration and validation of the HEC-HMS to assess its effectiveness in simulating rainfall-runoff processes and peak flow. The study utilized the Soil Conservation Service-Curve Number (SCS-CN) method to calculate the loss rainfall, while the Soil Conservation Service-Unit Hydrograph (SCS-UH) technique was applied to convert excess rainfall into a direct runoff hydrograph. For routing purpose, lag routing was used and the analysis included a constant monthly baseflow. The calibration phase resulted in commendable R-values ranging from 0.6898 to 0.7954, indicating a strong agreement between simulated and observed data. During validation, the model consistently demonstrated its accuracy, with R-values failing within the range of 0.6495 to 0.6695. These results affirm the capability of the HEC-HMS model to reliably represent hydrologic processes, establishing it as a valuable tool for hydrological studies and flood forecasting.

Keywords: HEC-HMS, modelling, calibration, validation, Timah-Tasoh.

1. INTRODUCTION

Water stands as the most crucial natural resource on our planet, and the existence of human life depends on it. The calculation of stream flow or runoff from a given catchment area is vital for various purposes [1]. These purposes include evaluating flood peaks, ensuring an adequate water supply for municipal use, designing storage facilities for diverse needs, planning irrigation strategies for agriculture and industrial applications, and forecasting reliable future water sources for power generation.

In the field of water resources engineering, hydrological modelling serves as an essential tool, offering valuable insights into the behavior of river systems and catchments. HEC-HMS is a software application created by the Hydrologic Engineering Center (HEC) of the US Army Corps of Engineers. It is designed to simulate how water movers through river systems and making it easier to understand water behavior in catchments area [2]. Moreover, it is a robust software application specifically designed for simulating rainfall-runoff processes. Ensuring the precision and reliability of its forecasts, the calibration and validation of HEC-HMS model are integral components of the modelling process. Model calibration and validation are assessed using statistical methods, including the utilization of the R.

The main aim of this study is to utilize the HEC-HMS hydrologic model to assess the calibration and validation of the rainfall-runoff model when applied to the Timah-Tasoh reservoir. The subsequent sections will cover data and methodology, followed by the analysis of results, discussions, and a conclusion.

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2. EXPERIMENTAL PROCEDURE

Description of The Study Area

Perlis situated in the northern region of Peninsular Malaysia, is geographically bordered by Thailand in north, Kedah in the South, and its western coastline meets the Straits of Malacca [3]. As shown in Figure 1, the study specifically focuses on the upper sub-catchments within the Timah-Tasoh reservoir, the largest reservoir in Perlis and covering an area of 183.34 km². In particular, it focuses on four sub-catchments (brown) for J8 and three sub-catchments (yellow). The others sub-catchments not being focused in this study due to ungauged catchment. Additionally, it is worth noting that the surrounding land in the Timah-Tasoh catchment area is predominantly devoted to agriculture, with rice, sugar, herbs, and fruits as primary crops, and these agricultural activities can influence the inflow discharge within this region [4].

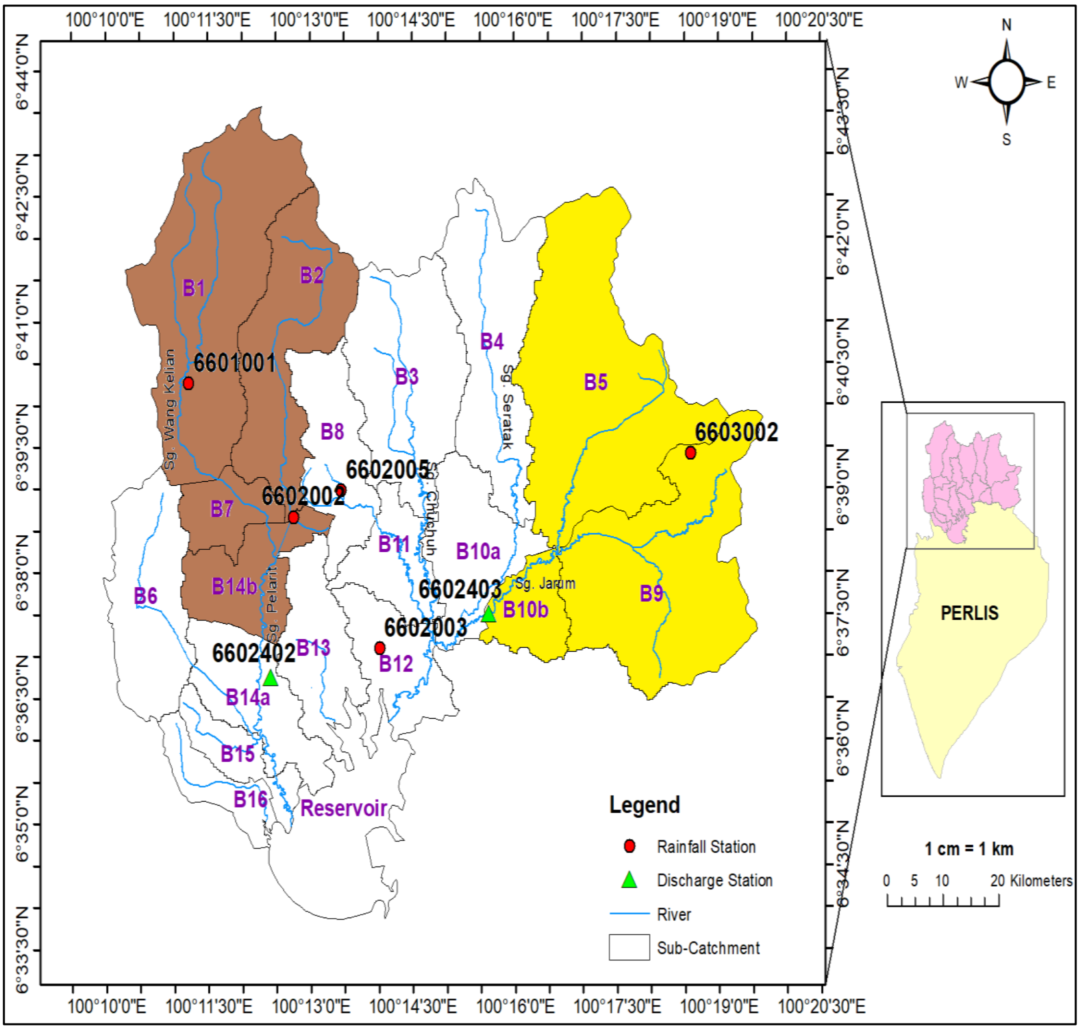


Figure 1. Location of study area.

HEC-HMS Model Set-Up

The hydrological analysis model setup employed the HEC-HMS software. Table 1 presents the rainfall and discharge stations utilized in this study, while Table 2 details the parameters and methods implemented within the model.

Table 1 Rainfall and discharge stations used for HEC-HMS model

Station	Station ID	Station Name
Rainfall	6601001	Wang Kelian
	6602002	Kaki Bukit
	6602003	Tasoh
	6602005	Lubok Sireh
	6603002	Padang Besar
Discharge	6602402 (J8)	Sg.Pelarit di Kg. Bukit
	6602403 (J18)	Sg. Jarum di Kg. Masjid

Table 2 Parameter and method used for HEC-HMS

HMS Processes	Method Applied
Loss Method	SCS Curve Number
Transform Method	SCS Unit Hydrograph
Baseflow Method	Constant Monthly
Routing	Lag

3. RESULTS AND DISCUSSION

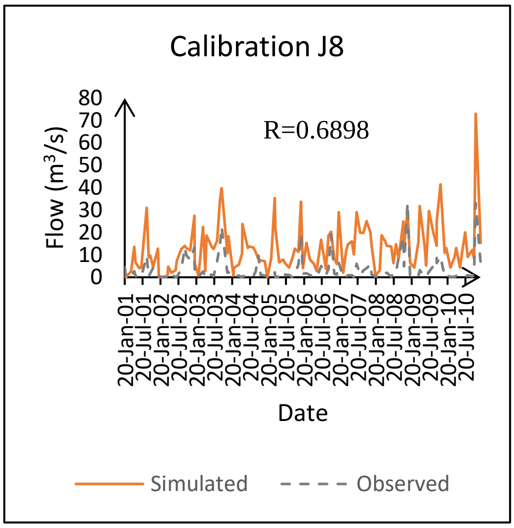
The calibration was performed for the continuous process, and results have been presented. The monthly flow of the model is generated using rainfall and streamflow data for each month. Throughout the process of calibrating and validating J8 (6602402) and J18 (6602403) for the monthly model, the simulated and observed monthly flow is represented in Figures 2-3. As can be observed, the comparison reveals a close correlation between simulated and observed data.

In the calibration for J8, monthly simulated discharged consistently exceeded monthly observed discharge throughout the year. The highest simulated peak flow for J8 was 73.0 m^3/s in November 2010, while the lowest was 20.4 m^3/s in October 2006. Similarly, during calibration at J18, the simulated flow exceeded observed flow for the entire month, with the highest simulated peak flow reaching 111.0 m^3/s in November 2010 and the lowest flow recorded at 25.70 m^3/s in December 2001.

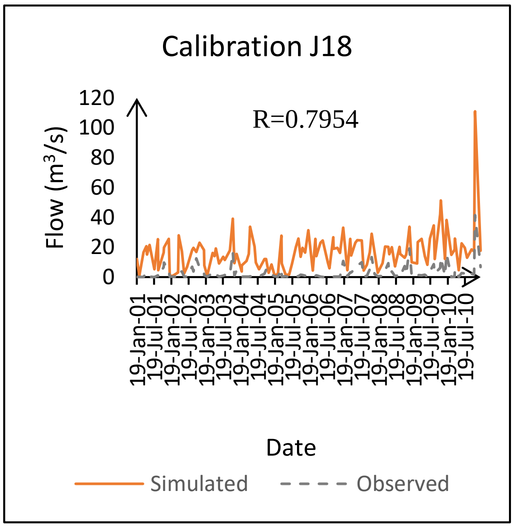
For the validation at J8, the monthly simulated flow was higher than the observed flow. Figure 3a illustrates that, in the middle of 2015, the monthly simulated and observed data were closely aligned compared to other months. Additionally, the highest peak flow during the validation occurred in September 2011, reaching 62.30 m^3/s, while the lowest was observed in December 2016 at 20.0 m^3/s.

In the case of J18, the data indicates that for a few years (2014-2017), the monthly simulation was lower than the observed values, suggesting that the simulation unable to accurately reflect the observed data. The highest peak flow in this validation was 51.80 m^3/s in September 2011, with the lowest recorded at 19.60 m^3/s in March 2013. Tables 3-4 summaries the peak flow for each junction during calibration and validation.

Table 5 shows the model performance during calibration and validation. Calibration results for monthly observations indicate that the model performs satisfactorily, with the R-values ranging from 0.6898 to 0.7954. These finding reveal that the R-value for J18 increased after calibrated parameters were adjusted, except for J8 which dropped compare to the initial simulation. During validation, the specified R-value range of 0.6495 to 0.6695 suggests that the model performs satisfactorily in terms of monthly time series data. When R-value between 0.4 – 1.0, it is considered acceptable [5]. These findings also align with other studies, such as those conducted by [6-7].

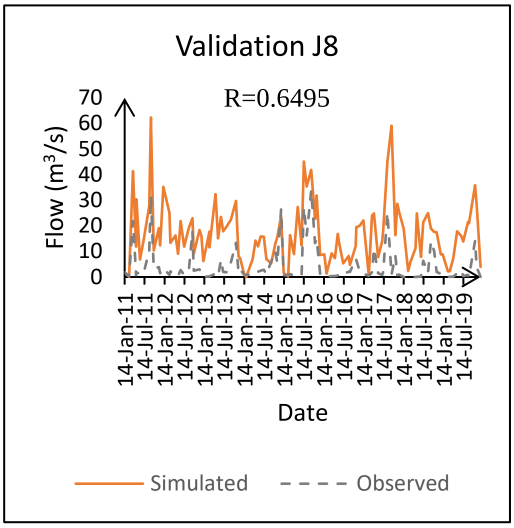


(a)

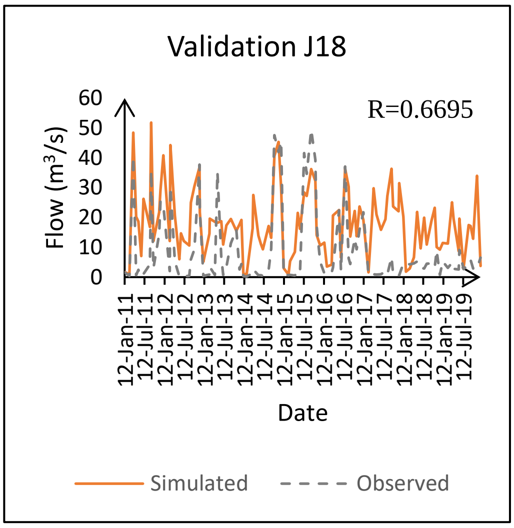


(b)

Figure 2. Simulated and observed monthly discharge during calibration (2001-2010) at (a) J8 and (b) J18.



(a)



(b)

Figure 3. Simulated and observed monthly discharge during validation (2011-2019) at (a) J8 and (b) J18.

Table 3 Simulated and observed peak flow for calibration.

Junction	**Observed**		**Simulated**	
	Peak flow (m^3/s)	**Time of peak flow**	**Peak flow (m^3/s)**	**Time of peak flow**
J8	50.90	03 Oct 2008	73.00	02 Nov 2010
J18	56.90	01 Nov 2010	111.00	02 Nov 2010

Table 4 Simulated and observed peak flow for validation

Junction	Observed		Simulated	
	Peak flow (m^3/s)	Time of peak flow	Peak flow (m^3/s)	Time of peak flow
J8	35.90	11 Sept 2011	62.30	12 Sept 2011
J18	71.70	28 Jan 2017	51.80	12 Sept 2011

Table 5 Performance of the model calibration and validation.

Junction	Calibration	Validation
J8	0.6898	0.6495
J18	0.7954	0.6695

4. CONCLUSION

The utilization of the HEC-HMS hydrologic model proved effective in identifying peak discharge through the simulation of rainfall-runoff processes. The calibration outcomes revealed satisfactory R-values falling between 0.6898 to 0.7954, signifying a strong match between the simulated and observed data in the calibration phase. Furthermore, the validation phase satisfactorily validated results with the R-values in the range of 0.6495 to 0.6695, affirming the model's ability to accurately represent the hydrologic processes. This suggests that the HEC-HMS model is a valuable tool for hydrological studies and flood forecasting.

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