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Preliminary Study on Flood Simulation using the HEC-HMS Model for Muda River, Malaysia

Z Hassan[1,2,*], N H Mohd Razali[1], A N Kamarudzaman[1], M Z M Salwa[1], N A S Nordin[1]

[1]Faculty of Civil Engineering Technology, Universiti Malaysia Perlis (UniMAP), Kompleks Pusat Pengajian Jejawi 3, 02600 Arau, Perlis, Malaysia.
[2]Centre of Excellence Water Research and Environmental Sustainability Growth (WAREG), Universiti Malaysia Perlis (UniMAP), Kompleks Pusat Pengajian Jejawi 3, 02600 Arau, Perlis, Malaysia.

[*]Email: zulkarnainh@unimap.edu.my

Abstract. Flooding poses a severe threat to human beings and causes significant damage to property, infrastructure, and agricultural production. The flood also has severe consequences for socio-economic activities and can lead to the loss of human life. One of the significant factors that cause the flood is rapid development, especially in the floodplain area. This study estimates the flood discharge along the Muda River, Malaysia using Hydrological Modelling System (HEC-HMS). The finding shows that the HEC-HMS model performed well during the validation period, in which the coefficient determination (R^2) between observed and simulated discharge during the validation process ranges from 0.51-0.84. In terms of design flood, the model simulated the peak flow with 1247-1448.8 m^3/s and 1798.5-3662.5 m^3/s for 50 and 100-year ARIs, respectively. The results obtained from this study can be used as fundamental data for advanced studies of flood control and management for better sustainable flood risk management.

Keywords: Hydrological Modelling, HEC-HMS, Muda River, Design Flood

1. Introduction

Generally, Malaysia is blessed with abundant rainfall, with an annual rainfall average of 2000 mm to 4000 mm. The annual average may exceed the above average except for extraordinary occasions. The consequences are that during the monsoon periods, several areas are inundated [1]. Seasonal floods usually occur between November and March during the North-East Monsoon season, while Southwest Monsoon occurs between May and September. In April and October, the two inter-monsoon periods are generally characterized by variable afternoon winds and thunderstorms [2]. Flood risk management is a non-structural flood mitigation action that could significantly reduce the impact of flooding. The estimation of floods involving the development of hydrological models is one of the non-structural measures that can help reduce the number of damages that have occurred.

Malaysia's Muda River experiences flooding each year, and three major floods occur within the 15 years: 1988, 1998, and 2003. On 6th October 2003, Ladang Victoria was hit by floods with a peak discharge of 1,340 m^3/s and 45,000 people in Kedah were adversely affected [3].

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This study aims to find the best hydrological parameters of the Muda River catchment during the calibration process in the HEC-HMS model. Next, evaluate the HEC-HMS model's performance during the validation process. This paper also covers the design of storm and flood events for 50 and 100-year-ARI.

2. Methods

This study uses the hydrological modelling system to develop the flood simulation for the Muda River catchment. HEC-HMS is being utilized in this study. The data that will be used as the input of the model were obtained from the Department of Irrigation and Drainage Malaysia (DID). The results from the HEC-HMS model will determine the best hydrological parameters of the Muda River catchment, and flood events for 50 and 100-year-ARI will be designed.

2.1. Study area

Muda river is located in Kedah, Malaysia, and the catchment area for the Muda River is 4,219 km^2, as shown in Figure 1. The river is Kedah's longest river, about 180 km away. Located in Sik District, the river provides a water supply to Kedah and Penang through the Beris Dam. The dam, completed at a value of RM 360 million in 2004, is being used to control water flows along the Muda River basin to increase the water available for paddy or upland crops, domestic and industrial water supply, and other uses. The network of the Muda River flows through several areas, such as Baling, Sik and Kulim, before it flows through the Kuala Sungai Muda area to the Straits of Malacca. Some of the Muda Riverbanks become boundaries between Kedah and Penang. Among the major rivers in the Muda River basin are the Ketil River, Lahar Endin River, Tembus River, Sedim River, Chepir River, Sok River, Teliang River, and Baho River [4].

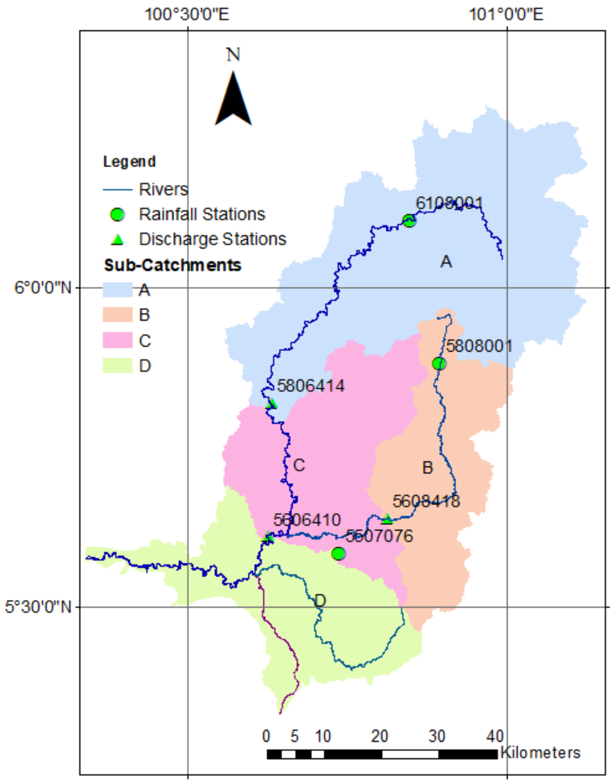

Figure 1. Location of the study area

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For this study, the catchment area of Muda River is divided into Sub-Catchments A, B, and C. The description and the location of rainfall and discharge stations are detailed in Table 1 and Figure 1, respectively.

Table 1. Location of rainfall and discharge stations

Sub-Catchments	Station No.	Station Name	Type of Data	Latitude (N)	Longitude (E)
A	6108001	Kompleks Rumah Muda Kedah	Hourly Rainfall	6.105556	100.8472
	5806414	Sg. Muda at Jeniang, Kedah	Hourly Discharge	5.819444	100.6319
B	5808001	Bt.61 Jln.Baling, Kedah	Hourly Rainfall	5.880556	100.8944
	5608418	Sg. Ketil at Kuala Pegang, Kedah	Hourly Discharge	5.638889	100.8125
C	5507076	Bt.27 Jln.Baling, Kedah	Hourly Rainfall	5.583333	100.7361
	5606410	Sg. Muda at Jam. Syed Omar, Kedah	Hourly Discharge	5.609722	100.6264

2.2. Development of the HEC-HMS model

The schematic diagram of the model set-up in the HEC-HMS model is shown in Figure 2. In this study area, the basin model consisted of three (3) sub-basins, three (3) junctions, and three (3) reaches. For model development, the hydrograph was constructed from 1st January 1975 until 16th January 2013 to identify the selected events, which consisted of five days of maximum runoff for calibration and validation. After data were inserted, the model parameters were calibrated until the results were favourable with the closeness of the observed hydrograph and the simulated hydrograph. For this study, the SCS Curve number method is chosen as a loss method, while SCS Unit Hydrograph method for the transform method is the basis of the flood simulation in HEC-HMS. In this study, the curve number (CN), percentage of imperviousness (I), and lag time (t_c) values are estimated by calibration-trial and fitting errors, as shown in Table 2.

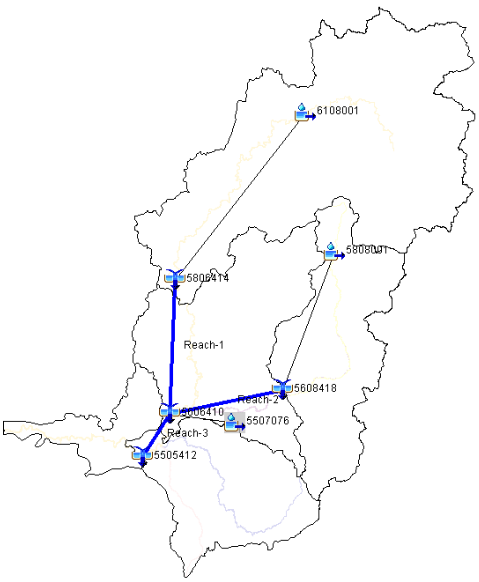


Figure 2. Basin model of the Muda River catchment build in HEC-HMS

Table 2. Optimized parameters for the HEC-HMS model

Parameters	Sub-Catchments		
	A	B	C
Curve Number, CN	40	40	28
Impervious, I (%)	35	30	30
Lag Time, T_c (min)	1500	900	1400

The performance of the model is evaluated by using the correlation of determination (R^2), and it is written as:

$$R^2 = \sqrt{\frac{\Sigma(x-\bar{x})(y-\bar{y})}{\sqrt{[\Sigma(x-x)^2\Sigma(y-y)^2]}}}$$

where, x is the observed discharge, y is the simulated discharge, $\bar{x}$ is the mean observed discharge, and $\bar{y}$ is the mean simulated discharge. The R^2 value close to one indicates a better performance of the HEC-HMS model.

2.3. Design Flood using the HEC-HMS model

In this study, frequency storm data for 50 and 100-year ARI are used for the input to the calibrated HEC-HMS model to simulate the design storm events. The frequency data are obtained from the Malaysian Hydrological Procedure No. 1 [6] and can be tabulated in Table 3.

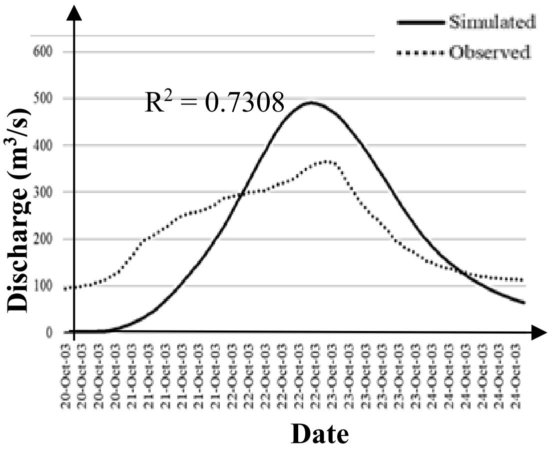
Table 3. Rainfall intensities for 50 and 100 years-ARI (in mm)

Catchment	**Return Period (Years-ARI)**	**Duration (hours)**							
		1	**2**	**3**	**4**	**5**	**6**	**12**	**24**
A	50	91	111.93	137.7	169.3	208.3	256.2	315.1	91
	100	131	161.13	198.2	243.8	299.8	368.8	453.6	131
B	50	72.5	89.2	109.7	134.9	165.9	204.1	251	308.7
	100	99	121.8	150	184.2	226.6	278.7	342.8	421.6
C	50	84	103.3	127	156	192.3	236.5	290.9	84
	100	112	137.8	169.4	208.4	256.4	315.3	387.8	112

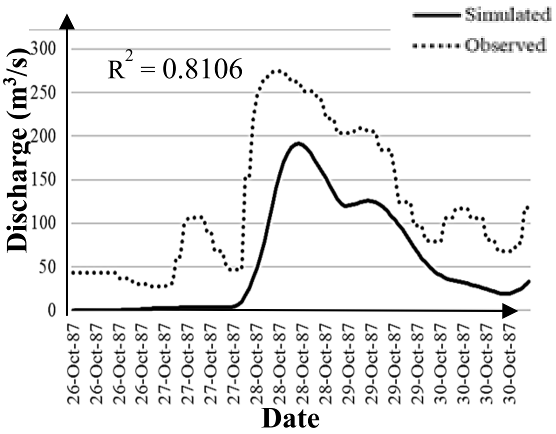
3. Results and Discussions

3.1. Performance of the HEC-HMS model during the model development

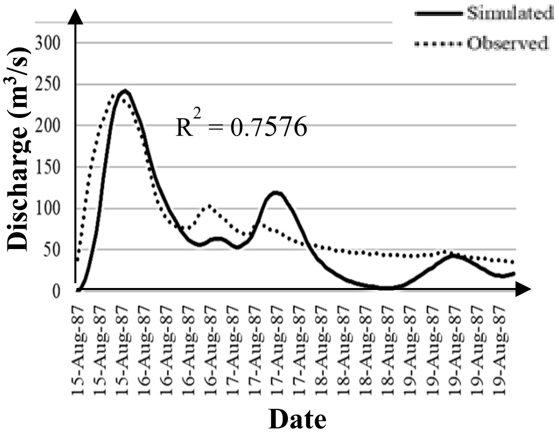
After identifying the optimized parameters during the calibration period, the HEC-HMS model is validated during the validation period, as shown in Figure 3. In general, the model's performance is satisfactory, with an R^2 value ranging from 0.7308 to 0.8106, as recommended by Moriasi et al. [7]. In terms of the graphical representation of observed and predicted hydrographs, it is found that the simulated hydrograph can capture well the peak and pattern of the observed hydrograph for Sub-Catchment C (Figure 3c). For Sub-Catchments A and B, the model can simulate the same pattern as the observed hydrograph, but the model cannot estimate the peak discharge, as shown in Figures 3a and b.



(a)



(b)



(c)

Figure 3. Hydrograph comparisons simulated by the HEC-HMS model at Sub-Catchments **(a)** A, **(b)** B, and **(c)** C during the validation period

3.2. Design flood using the HEC-HMS model

The HEC-HMS is applied to design the flood event of 50 and 100-year-ARI, as shown in Figures 4 and 5. As shown in the figure, it can see that the peak discharge of 50 and 100 years ARI for Sub-Catchment A are 1,278 m^3/s and 2,141.9 m^3/s, respectively. For Sub-Catchment B, the peak discharge of 50 years-ARI simulated by the HEC-HMS model is 1,2471 m^3/s, and the peak discharge of 100 years-ARI is slightly higher than at Sub-Catchment A, in which 3,662.5 m^3/s. The same pattern of the design flood is shown at Sub-Catchment C, in which the design flood for 50 and 100 years ARI are 1301.1 m^3/s and 1798.5 m^3/s, respectively. This finding is slightly different from Julien et al. [4], in which this study underestimates the peak discharge for both return periods at Sub-Catchment B. However, the finding from this study overestimates the peak discharge for Sub-Catchments A and B, as compared to Julien et al. [4]. The differences between the model result from previous research, such as Julien et al. [4], due to the different methods deployed to run the model. The large variability and tendency to over-predict the hydrologic modelling results is a source of concern for river engineering applications.

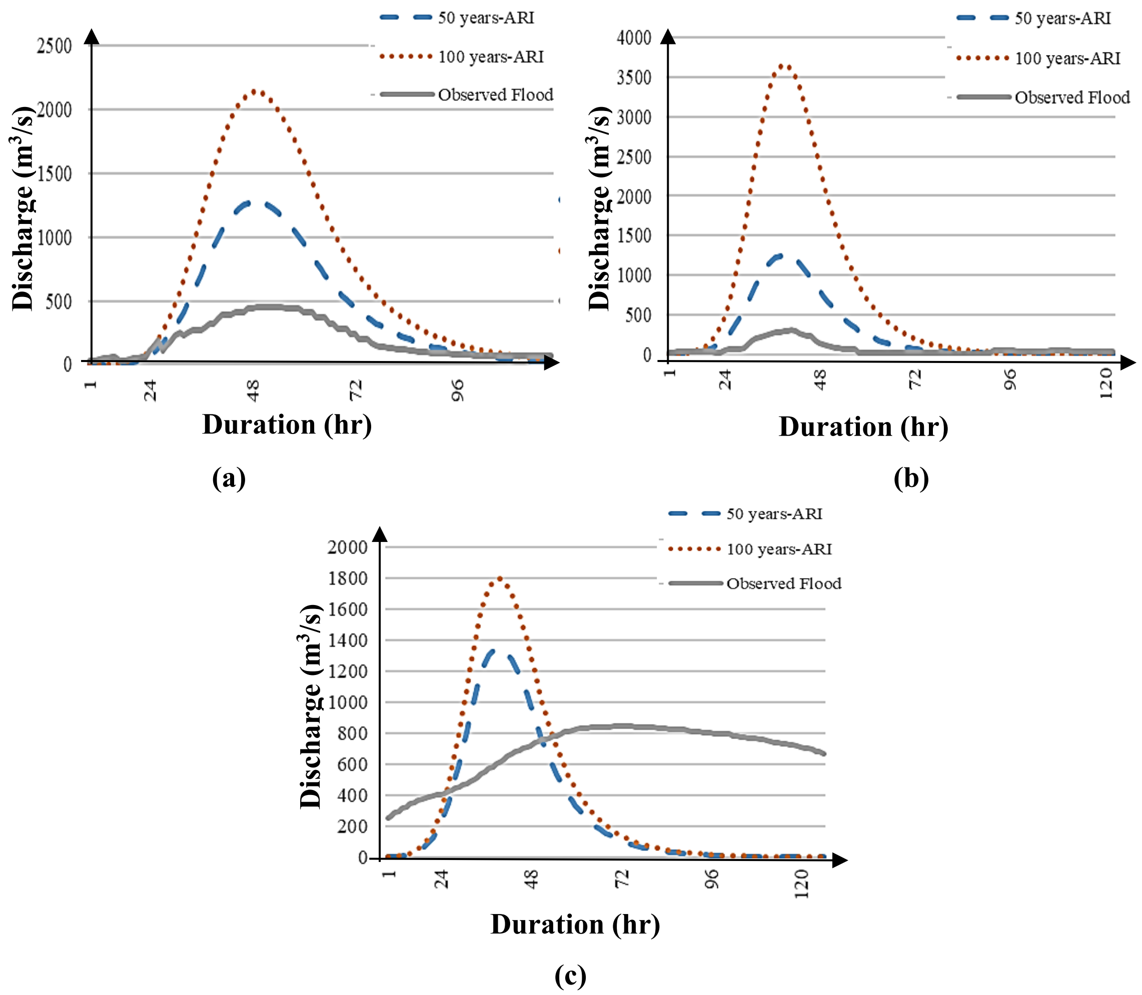


Figure 4. Hydrograph comparisons between observed and design flood at Sub-Catchments **(a)** A, **(b)** B, and **(c)** C using the HEC-HMS model

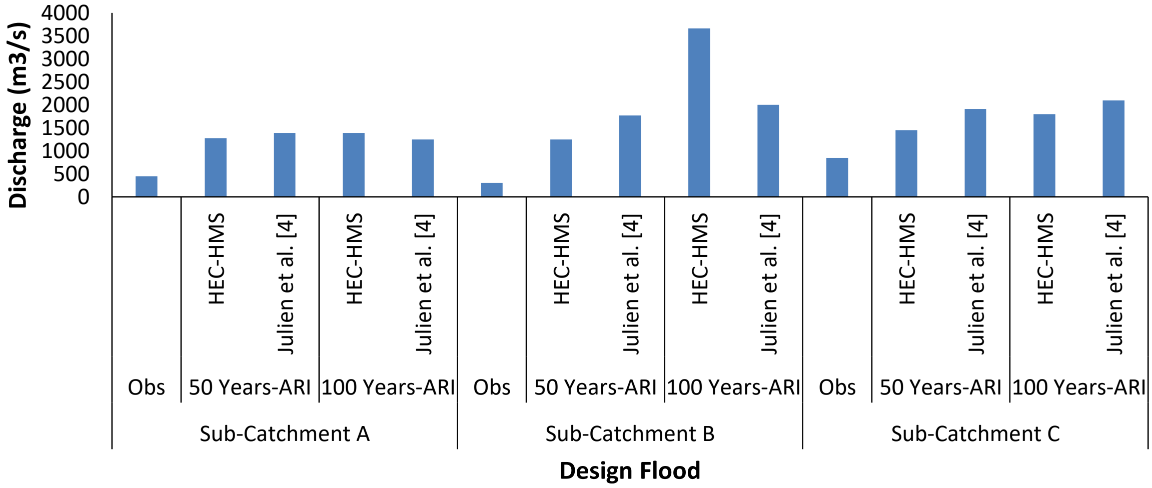


Figure 5. Peak discharges of flood event 50 and 100 year- ARI for the Muda River catchment

4. Conclusion

The hydrological data obtained from the Muda River catchment after the model development shows that the HEC-HMS can investigate the hydrological parameters of the Muda River catchment. In terms of design flood, the HEC-HMS model simulated the peak flow with the values of 1247-1448.8 m^3/s and 1798.5-3662.5 m^3/s for 50 and 100-year ARIs, respectively. The results obtained from the validation process give high correlation coefficient (R^2) values in the range of 0.51 to 0.84, which indicates that for each catchment, the values of curve number, lag time and percentage of imperviousness were very satisfactory.

Generally, the results obtained from this study can be used as fundamental data for advanced studies of flood control and management projects for better sustainable flood risk management.

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