Calibration and validation of hydrological model using HEC-HMS for Kuantan River Basin

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Abstract. Hydrological modeling is a commonly used tool to estimate the basin’s hydrological response due to precipitation. This study aims to calibrate and validate the rainfall-runoff transformation model for Bukit Kenau Station in Kuantan River Basin (KRB) using HEC-HMS (Hydrologic Engineering Centre Hydrology Modeling System). For the loss rate, SCS Curve Number method was selected while Clark Unit Hydrograph was used for the transform method. The model calibration and validation efficiency were verified using the Nash-Sutcliffe model efficiency (ME). As a result, the model calibration and validation were found to be satisfactory with ME between 0.5 to 0.8. The model can be used to forecast the river flow and helps in the flood mitigation works to reduce the impacts along with the cost use. Besides, the result obtained from this study can be used as a guideline for future flood risk assessment works in the study area.

1. Introduction
Hydrology is a branch of science that describe the occurrence, distribution and circulation of global water resources including its physical and chemical characteristics and how the surroundings responds to them [1]. Generally, by applying related engineering and geographical principles, hydrology provides guidance for water resource planning and management, as well as for the water resource control. A proper estimation of water availability is essential in the climate change impacts assessment on the water resources in river basin. These can only be attained by hydrological modelling [2]. Hydrological modeling can be established by the use of small-scale physical models, mathematical analogues, and computer simulations to describe a real hydrologic features and system [3]. Hydrological modelling, however is a complex task and hydrologic models should be well-calibrated to enhance user confidence in its predictive ability which makes the application of the model effective [2]. The purpose of conducting hydrological modeling is to estimate flow hydrograph from tributary catchments where the estimated flow hydrograph serves as an input to hydraulic modelling [4]. The use of mathematical hydrological modelling is compelling in order to clearly understand the reality and forecast the future water supply of various catchment [1].

Physically-based hydrological modelling is the most used modelling work in Malaysia where a few models such as HEC-HMS, SWAT, MIKE-SHE, MIKE 11 and MIKE 22, Infoworks RS, TREX and IFAS had been utilized. From the physically-based model, most of the researchers preferred an open-access model that is the HEC-HMS for their modelling works [1]. The Hydrologic Engineering Center–Hydrologic Modeling System or HEC-HMS is an open-access hydrologic model developed by the
United States Army Corps of Engineers Hydrologic Engineering Center (HEC). HEC-HMS is designed to model the precipitation-runoff processes of dendritic watershed systems. The program enables implementation in a wide variety of geographical areas to solve different problems, including large river basin water supply and flood hydrology, and urban or natural watershed runoff. The watershed model is built by dividing the hydrological cycle into manageable sections and building boundaries across the watershed of interest [5].

Calibration and validation is a critical process in a model simulation. During the process, the model parameters are modified to provide a good outcome of the reproduction of historical field measurements. It is then presumed that this is ample evidence is enough to use the model to make predictions with a reasonably good prediction [6]. Model calibration and validation are evaluated by using statistic measurement tools such as R, R², NSE, RMSE and MAE. These calibrations of hydrological models are an interactive procedure for the evaluation and improvement of parameters. It plays a crucial role in hydrological modelling by reducing ambiguity in model predictions.

With the aim to assist in the flood risk assessment of the Kuantan River Basin, an attempt has been made to calibrate and validate a hydrological model using HEC-HMS. This paper presents the applicability of the hydrological results to be used for further flood modelling works in the study area.

2. Methodology

2.1. Description of the study area
The study area only included the upper part sub-basins from Bukit Kenau Station. The sub-basin covers an area of 423 km² and length 18.6 km. The location starts from Chereh Dam to downstream in Bukit Kenau streamflow station as shown in Figure 1.

Figure 1. Location of the study area
2.2. HEC-HMS model set-up
The HEC-HMS software was used for the model set up of the hydrological analysis. Table 1 shows the rainfall and streamflow station adopted in this study while in Table 2, the element parameter and method applied in the HEC-HMS setup is presented. Only one station i.e. Bukit Kenau has been used for this study. Meanwhile, the SCS Curve Number had been applied for loss method, while Clark Unit Hydrograph and Constant Monthly had been used for transform and baseflow method respectively.

Table 1. Rainfall and streamflow stations used for hydrological modeling.

| Station | Station ID  | Station name |
|---------|-------------|--------------|
| Rainfall| 3930013     | Bukit Kenau  |
| Streamflow | 3930401   | Bukit Kenau  |

Table 2. Element parameter and method set up in the HEC-HMS model.

| Model Parameter       | Station ID    |
|-----------------------|---------------|
| Loss Method           | SCS Curve Number |
| Transform Method      | Clark Unit Hydrograph |
| Baseflow Method       | Constant Monthly |

2.3. Model calibration and validation
Calibration is the process to reduce the difference between the observed and simulated hydrograph. The parameters was adjusted until the observed and simulated hydrograph are almost fitted well. The parameters depend on the transform method that has been selected. While validation is the process that carried out the test for the robustness of the calibrated model. In order to validated, statistical tests of error function should be carried on. Each calibrated model should be validated before it is proposed for use. The model parameter obtained will be used to validated by using different sets of events. The simulated hydrograph is compared with the observed hydrograph. The validation of a model is depended on the results of the error function where if the error functions is small, the model is validated.

In this study, the Nash-Sutcliffe model efficiency coefficient is applied for the verification of both calibration and validation model. The model efficiency (ME) was calculated using equation (1):

\[ ME = 1 - \frac{\sum_{i=1}^{n}(Q_{Oi} - Q_{Si})^2}{\sum_{i=1}^{n}(Q_{Oi} - Q_{a})^2} \]  

Where \( ME \) is the model efficiency (efficiency index), \( Q_{Oi} \) is the observed flow at time \( i \), \( Q_{Si} \) is simulated flow at time \( i \), \( Q_{a} \) is an average observed flow, and \( n \) is the number of data points.

3. Results and discussion

3.1. Model calibration and validation
The HEC-HMS model was calibrated using rainfall and flow data of Bukit Kenau gauging station from 12th October 2013 event while the validation process used the event of 4th September 2010, 20th March 2011 and 12th November 2011. The adjusted model parameter values for the model calibration and validation process is shown in Table 3. On the other hand, Table 4 presents the results of the model efficiency (ME) for the calibrated and validated model. The comparison between simulated and observed peak flow shows a difference of 7% for the calibrated model. Meanwhile, the validation model
resulted a difference of 0.8%, 1.1% and 9.3% for 4th September 2010, 20th March 2011 and 12 November 2011 event respectively. The performance of the calibrated and validated model is satisfactory where the ME is 0.85 and 0.76, 0.83 and 0.81 respectively.

Table 3. Tested model parameters for calibration and validation processes.

| Parameter             | Unit     | Value |
|-----------------------|----------|-------|
| SCS Curve Number:     |          |       |
| Curve Number          |          | 60    |
| Imperviousness        | %        | 17    |
| Clark Unit Hydrograph:|          |       |
| Time of concentration | Hour     | 6.4   |
| Storage coefficient   | Hour     | 7.5   |

Table 4. Observed and simulated peak flow for model calibration and validation.

| Run       | Date             | Peak flow (m^3/s) | ME  |
|-----------|------------------|------------------|-----|
|           |                  | Observed | Simulated |     |
| Calibration | 12th October 2013 | 99.8    | 92.7      | 0.85|
| Validation | 4th September 2010 | 60.6    | 60.1      | 0.76|
|           | 20th March 2011  | 82.1    | 81.2      | 0.83|
|           | 12th November 2011 | 93.1    | 84.4      | 0.81|

Figure 2. Observed and calibrated hydrograph for the 12th October 2013

The results of calibrated hydrograph are presented in Figure 2 while Figure 3, Figure 4 and Figure 5 are the resulted calibrated hydrographs. Comparison was made with the observed hydrograph. An outstanding results was obtained where from Figure 2, it can be seen that the simulated peak flow for the calibration event is 92.7 m^3/s, which is close to the observed peak flow of 99.8 m^3/s. A similar trend of result is observed in Figure 3 where the simulated peak flow for the 4th September 2011 validation
event is 60.1 m³/s, which is adjacent to the observed peak flow of 60.6 m³/s. For validation event, 20th March 2011 in Figure 4 the simulated peak flow is 81.2 m³/s compared to 81.2 m³/s observed peak flow. While for the 12th November 2011 event, the simulated peak flow is 84.4 m³/s compared to 93.1 m³/s observed peak flow in Figure 5.

Figure 3. Observed and calibrated hydrograph for the 4th September 2010

Figure 4. Observed and validated hydrograph for the 20th March 2011
4. Conclusion
A calibrated and validated hydrological model for Kuantan River Basin was established using HEC-HMS. The calibration result shows an acceptable model efficiency (ME) of 0.85 which is in agreement with observed data while the ME of 0.76, 0.83 and 0.81 are satisfactorily validated with HEC-HMS model. Hence, the hydrologic model can be used for future flood risk assessment works of the study area. The information is appropriate as the input for the hydraulics modeling and mapping.

5. References

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Acknowledgments
The authors acknowledged the Ministry of Education of Malaysia (MOE) and Universiti Malaysia Pahang (UMP) for financial supports through the Fundamental Research Grant Scheme (FRGS): FRGS/1/2019/TK01/UMP/02/2 (RDU1901155).