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Original Research Article

Development of HEC-HMS Model for Flow Simulation at Dungun River Basin Malaysia

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Abstract: The uncertainty in climate can result in droughts, extreme floods and an imbalance in agriculture, natural resources and ecosystem. Special attention should be given to operations management, reservoirs and water catchment to address water-related issues arising from climate change. The purpose of this study is to evaluate a rainfall-runoff model and to assess the runoff potential for the catchment, to calibrate and validate the model, and to use the calibrated values for future hydrological research. The Hydrological Modelling System (HEC-HMS) is used to simulate rainfall-runoff processed in the watershed. The rainfall data for this study were obtained from the Department of Irrigation and Drainage (DID) Malaysia, covering from the year 2007 to 2018. There are three rainfall gauging stations and one stream-flow data stations in the study area. The rainfall-runoff simulation has been conducted using different data set for calibration and validation. Preliminary data shows that there is a clear difference between the observed and simulated peak flows. Model calibrations with the optimization process and sensitivity analysis were performed to obtain the optimal parameters for this watershed. The values of the parameters obtained and model validation using optimized parameter values from the calibration curve show a reasonable difference in peak flow. Generally the results of the study showed a good simulation between observed and estimated value with NSE = 0.85, R^2 = 0.86, relative error peak = -4.14% and relative error volume = -22.5%. This study intended to help managers of the river basin and related agencies to forecast and analyze management options for conducting planning and potential measures of the river basin.

Keywords: Model development, HEC-HMS, Flow simulation, Dungun River Basin

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1. Introduction

In the 21st century and the coming years, climate change contributes to global warming and affects life on earth (Jaybhaye, 2014). The consequences of climate change and global warming are now in the form of high temperatures and weather patterns that are unpredictable. Droughts and extreme flooding can be triggered by weather instability. Agriculture, natural capital and habitats can be extremely affected (Yener, 2008). In most cases, however, land use planning and inadequate soil management practices can adversely affect the amount and quality of surface runoff by decreasing the covering of the soil, resulting in water absorption and consequently increasing the amount of surface runoff.

There are various methods available for estimating river flows from catchments, using as much data as possible, or using empirical and statistical techniques to estimate river discharge. The Hydrology Modeling System HEC-HMS, developed by the US Army Corps of Engineers Hydrologic Engineering Center (HEC) as an integrated modeling tool for water flow hydrological processes. The system includes losses, runoff transform, open-channel routing, meteorological data analysis, rainfall-runoff simulation and parameter estimation. HEC-HMS has become very popular and adopted in many hydrological studies because of its ability to simulate and run both in short and long time events, its simplicity to operate and use the usual method (Halwatura, 2013). Hydrographs developed by HEC-HMS either directly or together with other software is used for urban drainage studies, water availability, future urbanization effects, flow forecasts, flood mitigation, flood regulation, and system operation (US Army Corps, 2015).

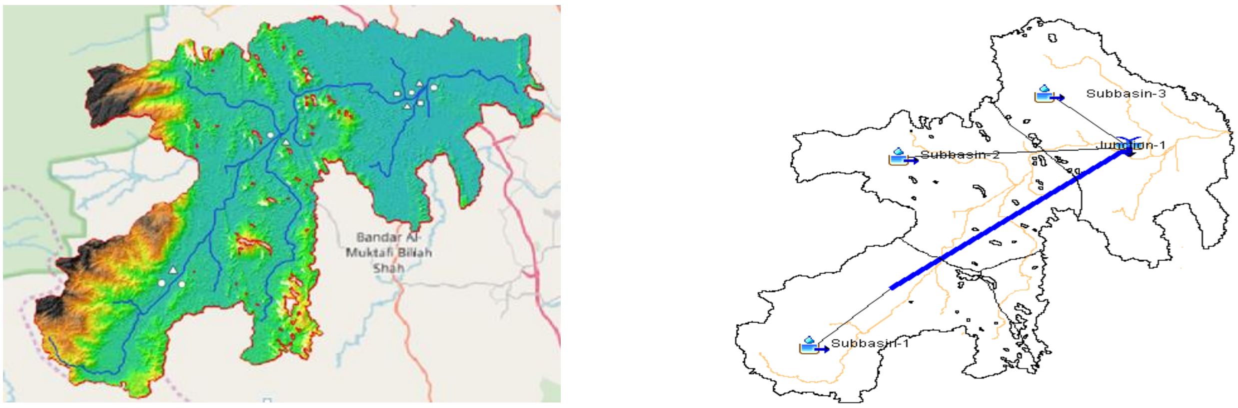
Previous studies on HEC-HMS have proven its ability to simulate and predict flows based on different datasets and capture types (Chu & Steinman, 2009). Almost all of these studies explicitly demonstrate that the outcomes of the model simulation are in specific locations and various combinations of a set of models that were comprising of loss methods, runoff method and basic flow separation techniques (Zelelew & Melesse, 2018). Nuramidah *et al.* (2011) using the HEC-HMS model to simulate river flow in the Kurau River sub-basin, Perak. Nadiatul & Nuramirah (2014) using HEC-HMS for Estimating discharge in gauged and ungauged stations in Kuantan river basin using Clark method. Majidi and Shahedi (2012), using HEC-HMS and Green-Ampt Method to Simulate of Rainfall-Runoff process in Abnama Watershed, Iran. Many fields of study have used the HEC-HMS model and the results obtained were satisfactory. The HEC-HMS software was used in this study, since it has been used extensively for rainfall-runoff modeling. Without denying other applications, HEC-HMS is easier available for free and easily accessible from the internet.

The HEC-HMS model has been tested and calibrated worldwide, but each catchment area requires its calibration to determine the exact parameters for a catchment. Each catchment area has different conditions such as land cover, different soil types and so on. These differences will cause the value of the parameter to be different for each place. The agricultural area of the Dungun River Basin is not spared from undetermined flood disasters, especially in the lowlands. Therefore, the precise estimation of the peak flow and the volume of the discharge from storm events are very important to control soil erosion, water conservation and provide appropriate measures for future flood protection. This study aims to develop a rainfall-runoff model, to evaluate the catchment runoff potential and to calibrate and validate the model than to use the calibrated parameter values for future hydrological research.

2. Materials and Methods

2.1 Study Site

Dungun River Basin is in the district of Dungun at Terengganu State in Peninsular Malaysia. The basin covers an area of 1463.34 km^2 of catchment areas with a river length of about 75 km, starting from a reserved forest area in Kuala Berang via agricultural land in Jerangau, Dungun town, towards the South China Sea. The Dungun River Basin is divided into three sub-basins, which are around 405.54 km^2 in sub-basin 1, 444.53 km^2 in sub-basin 2 and 613.27 km^2 in sub-basin 3. Each sub-basin has a one rainfall gauge. These rivers flow through major rural, agricultural, urban and industrial areas in the Dungun District and flowing into the South China Sea**.** Figure 1(a) below shows the Dungun River basin.



(a) (b)

Figure 1. Location of (a) Dungun river basin and (b) Basin Model of Dungun catchment with hydro meteorological stations. (R1 = rain gauge id no. 4529001), (R2 = rain gauge id no. 4730002), (R3= rain gauge id no. 4832011 and (SF1 = stream flow gauge id no. 4832441)

2.2 Data Pre-processing

Version 2.18 of the combined QGIS with the GRASS program was used to pre-process the data collected for the study area. From the raw data for digital elevation models, several processes were carried out in software to extract information to obtain the path of river basins. Several hydrological parameters were calculated such as river length, longest flow path, curve number slope and sub-basin area based on the geometric algorithm's elevation. Once information on the river basin has been obtained, it was imported into the HEC-HMS software as this file serves as the background map to facilitate the process of component construction, such as the sub-basins, reaches and even junctions. The configuration of HEC-HMS for the Dungun River Basin is shown in Figure 1(b).

2.3 Rainfall Runoff Model: HEC-HMS

The Hydrological Modeling System (HEC-HMS) was designed to simulate surface runoff processes as a result of rainwater in a watershed. It was designed to be used in various geographical areas to solve a wide range of potential problems. These included the river water supply, flood hydrology, urbanization and natural water runoff. Hydrographs generated by the program were used directly or together with other software for study on water availability, urbanization drainage, water flow forecasts, latest urban impacts, design of water reservoir overflow, damage reduction of flood, flood policies and system operators. Most of the watersheds can be represented using this program. The watersheds model was built by dividing the hydrological cycle into controlled parts and creating boundaries within the attractive watersheds (Scharffenberg & Fleming, 2006). For each portion of the runoff process, the initial and constant loss method, the Clark unit hydrograph transform method, and the lag routing method selected for this study were selected as runoff depth, direct runoff, channel routing and canal routing, respectively. These methods have been chosen based on applicability, limitations of each system, data availability and suitability for the same hydrological situation.

2.4 Loss Method (Initial And Constant)

The loss method in HEC-HMS models typically calculated the amount of surface runoff by calculating the volume of water lost during the infiltration, evaporation, transpiration and subtracting it from the rainfall event. The initial and constant loss methods have been selected for this study to estimate the direct runoff from the rainfall events. For some catchment areas that do not have detailed soil information, the initial constant loss method can be used. It is possible to specify the proportion of the sub-basin that was directly connected to the impermeable area. No loss calculations were carried out on the impervious area; all precipitation on that portion of the sub-basin became excess precipitation and subject to direct runoff. In this studies the initial loss and constant rate were set to be zero refer to hydraulic procedure no. 27 (DID HP 27, 2010) issued by the Department of Irrigation and Drainage (DID) for Sungai Dungun catchment.

2.5 Transform method (Clark Unit Hydrograph)

Translation and attenuation processes dominate the water movement through the catchment area. The movement of water in the catchment area is due to gravity force and the process called translation. Attenuation is the result of the ability of channel storage to receive the amount of rainfall excess and it also depends on the friction force in the catchment area. As defined by Clark (1945), the translation of water movement can be interpreted using the time area curve. Actual rainfall or effective rainfall is the amount of rainfall not lost due to infiltration or stagnation in small ponds. The Clark's Unit Hydrograph parameter is time concentration, Tc that is derived from the time area curve. For ungauged catchment areas, equations relating and catchment characteristic were required to estimate time of concentration (Tc) and storage coefficient (R) values.

In general, Tc and R correlated with catchment size, slope and stream length, slope, and stream length only. The overall Tc and R correlated significantly with stream length catchment size and stream slope. In this study, the estimated Tc and R values were depending on Hydraulic Procedure No. 27 (DID HP 27) published by DID. The Tc and R values for this study were 31.10 and 30.0.

2.6 Routing Method (Lag)

As the flow of water flows through the channel, the water flow decreases as a result of the storage effect. In this study, the lag routing method was used and the value was in minutes. The lag parameters value can be obtained from the equation (1).

$$Tlag = 0.6\mathrm{Tc} \tag{1}$$

Inflow to the reach was delayed in time by an amount equal to the specified lag and then became outflow.

2.7 Model Calibration

The calibration process was achieved by varying each input parameter and running the model within a specified range. The model was calibrated to improve the agreement between the simulated and observed data (Majidi & Shahedi 2012) for the specified sensitive parameters. The calibration method is an important method for matching the simulated and observed peak, length, and timing of the hydrograph.

2.8 Model Validation

The generate hydrograph from the simulation was compared to the observed discharge graph for validation. The calibrated model parameters were validated using different rainfall and streamflow data. The Nash-Sutcliffe index (NSE) and the determination coefficient (R^2) were used in this study to compare the result between the observed and simulated. The Nash Sutcliffe model efficiency coefficient was between 0 and 1. The closer the Nash Sutcliffe model efficiency coefficient to one was, the better the performance of the model. The data sets used for the calibration and validation process are shown in Table 1.

Table 1. Data for calibration and validation

Data set	Date start	Time start	Date end	Time end	Process
1	02 Jan 2007	00:00	31 Dec 2011	00:00	Calibration
2	01 Jan2012	00:00	31 Dec 2017	00:00	Validation

3. Results

3.1 Sensitivity Analysis

In general, sensitivity analysis was performed to understand how the results of the model respond to changes in model parameters. Some parameters are more sensitive than others on the results of the model, so the task here is to find sensitive parameters. In model calibration, knowledge of sensitive parameters is useful in trying to align model performance with observed results.

In this study, there were five main parameters that were applicable for sensitivity analysis. In the loss method, two parameters (initial and constant rate) were involved in the sensitivity analysis. The time concentration and storage coefficient involves in the transform method, while the lag parameter was involved in the routing method in the sensitivity analysis. Each parameter was altered in ranges of ±10, ±20, and ±50% and then simulated and allowed the other parameters to be constant since the effect of each parameter on the outputs (runoff peak discharge) was predicted.

It appears from the results of the sensitivity analysis that the hydrological modeling outputs were not sensitive to the initial loss parameter. Initial loss was indirectly related to runoff volume and runoff peak discharge, as the runoff peak discharge remained constant with a rise in the initial loss to 50%. When the constant rate parameter rises by 50%, the outcome of the sensitivity analysis indicated a 7.72% reduction in runoff peak discharge. The runoff peak discharges were elevated to 8.96%, when the constant rate parameter was reduced to 50%.

The time concentration and storage coefficient parameters were involved in sensitivity analysis for the transformation process. When the time concentration rised to 50 %, the outcome of the sensitivity analysis indicated a 4.33 % decrease in runoff peak discharge and a 6.12 % rise in runoff peak discharge, when the parameter decreased to 50%. When the value increased by 50%, the sensitivity analysis result indicated a 16.96% decrease in the runoff peak discharge for the storage coefficient parameter. The runoff peak discharges were elevated to 25.92%, when the value of the storage coefficient was reduced to 50%.

The lag parameter was also involved in sensitivity analysis for the routing method. The sensitivity analysis result exhibited that the runoff peak discharge decreased by 0.034%, when the lag time increased to 50%, while the runoff peak discharge increased by 0.04, when the parameter decreased to 50%. Figure 2 shows the result of the sensitivity analysis for this study.

Based on the results of the HEC-HMS sensitivity analysis in the Dungun River Basin, the most sensitive parameters (more than 5% change) were the constant rate, time concentration and storage coefficient. During the calibration process, these parameters could be considered and focalized.

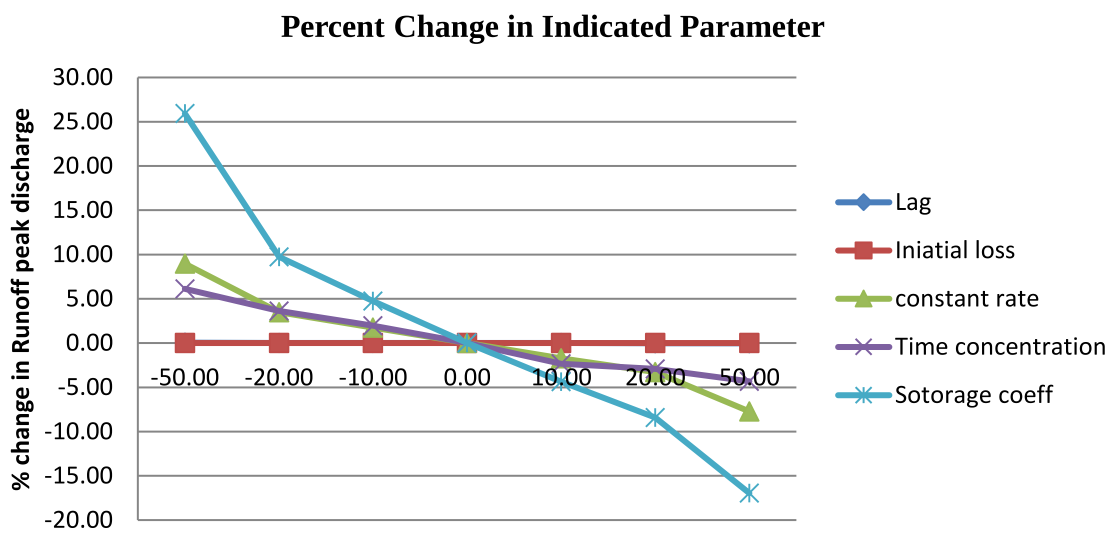


Figure 2. Sensitivity Analysis of HEC-HMS for Runoff Peak Discharge with selected value percent change parameter.

3.2 Model Calibration

Some parameters, such as initial abstraction and imperviousness, should be assumed during this calibration process. The assumed parameter varies within a given range while retaining other constants and running the model. The simulated and observed hydrographs were compared and where a high similarity between the two has been obtained, then only the assumed values of the parameters were considered good and further work can be carried out. In this study, the loss method assumed to be zero and for the transform method were referring to Hydraulic procedure no. 27 (DID HP 27, 2010) issued by Department of Irrigation and Drainage (DID) for Sungai Dungun catchment. The value for time concentration was set to 31.1 hr and 30 hr for storage coefficient. The lag value for routing method was calculated using 0.6Tc and the value was set to 18.66 min for the initial value.

The trial and error method is used in the calibration and validation process (Dinor, 2009). The method used is to define the optimized parameter and obtain a strong correlation between the simulated and observed value. Observed daily rainfall and streamflow data from 2 January 2007 (00:00) to 31 December 2011 (00:00) were used in this calibration process. The data set chosen to carry out the calibration and validation process depends on the availability of the data and also for the same time range to ensure its effectiveness. Modelling performance and model accuracy were measured using the Coefficient of Determination (R^2) and Nash-Sutcliffe Coefficient (NSE). The accuracy of the model can be measured by considering the R^2 values as well as the NSE values. R^2 and NSE values approaching 1 indicate a better model and values closer to 0 consider a worse model.

The results obtained during the calibration process for peak flow at the Jambatan Jerangau discharge station exhibited R^2 values of 0.693 and NSE of 0.691. This result indicates a good correlation between simulations and observations. Table 2 shows the model results include NSE and R^2 efficiency, peak flow, and total volume value before and after optimization and relative error during the calibration process. The runoff hydrograph results from the calibration process shown in Figure 3. The correlation between simulation and observed flow during the calibration process at Jambatan Jerangau station shown in Figure 4.

The value of R^2 obtained at 0.693 after optimization exhibited a good agreement between observed and simulated peak flow. As shown in Table 3, the NSE value obtained was 0.691. This obtained value can be considered a strong correlation (> 0.6) between simulation and observation (Sugiyono, 2013). According to Moriasi *et al.* (2015), the model simulation could be considered acceptable, if the NSE value obtained is above 0.5, good if it exceeds 0.65, and very good if it exceeds 0.75. Therefore the model performs in this study can be considered as good with an NSE value of 0.69. Relative error peak and relative error volume were recorded at 5.66% and 21.7%.The calibration process is using the initial parameter values given in Table 3. Then the optimization process took place to get the optimized parameter that can fit the model. The optimization parameter value showed in Table 4. These optimized parameter values were used when conducting the validation process.

Table 2. Performance of the model after optimization during calibration (peak flow total volume and error function).

Station	**Peak flow (m^3/s)**				**Total volume (mm)**				**NSE**	***R^2***
	Simulated		Observed	Relative error peak	Simulated		Observed	Relative error volume		
	Before Optimize	After Optimize			Before Optimize	After Optimize				
4832441	2,432.90	1,688.80	1,598.40	5.66	20,923.11	9,616.90	7,902.18	21.70	0.691	0.693

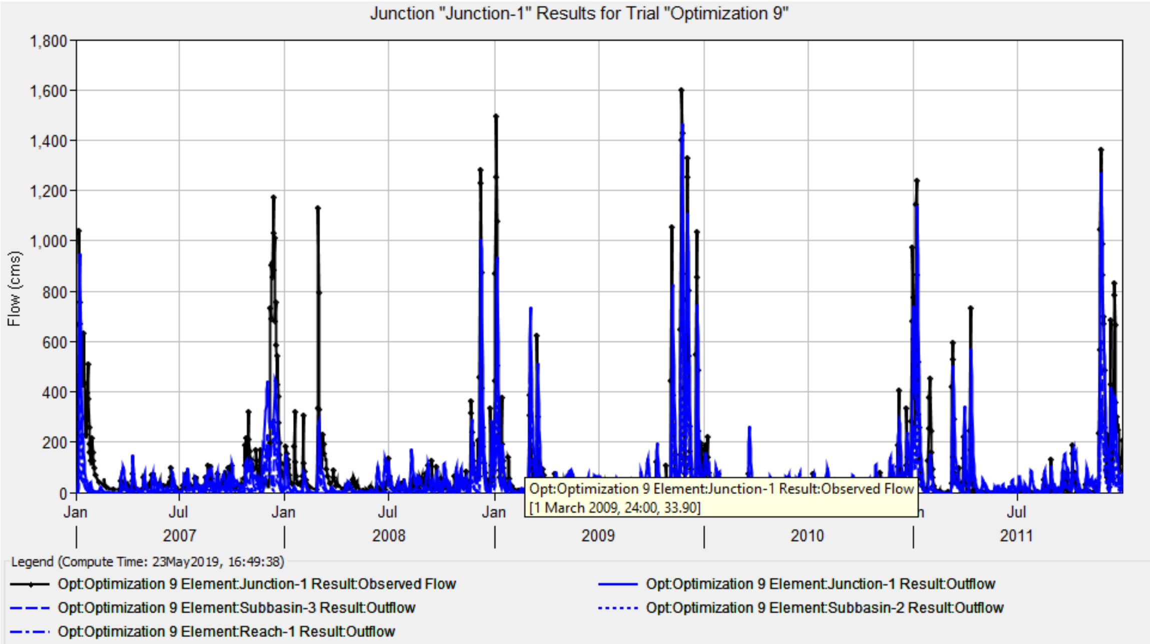


Figure 3. Runoff hydrograph for Jambatan Jerangau discharge station (Calibration).

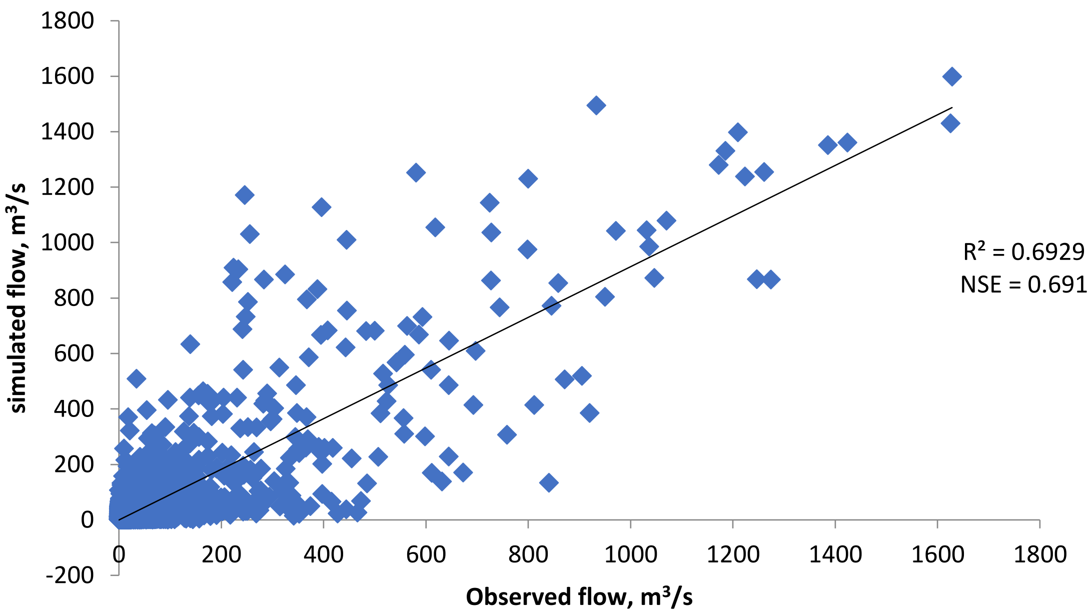


Figure 4. Correlation between simulated and observed flow during calibration at the Jambatan Jerangau station.

Table 3. Estimated parameters for the watershed

	Initial parameter		**After optimizing**	
Loss method (Initial and constant)	***Initial loss (mm)***	***Constant rate (mm/hr)***	***Initial loss (mm)***	***Constant rate (mm/hr)***
Sun-basin 1	0	0	0.96675	0.93278
Sub-basin 2	0	0	0.84186	0.93887
Sub-basin 3	0	0	0.48813	0.73219
Transform method (Clark unit hydrograph)	***Time concentration, Tc (Hr)***	***Storage coef. (hr)***	***Time concentration, Tc (Hr)***	***Storage coef. (hr)***
Sun-basin 1	31.1	30	57.723	49.335
Sub-basin 2	31.1	30	62.612	58.909
Sub-basin 3	31.1	30	49.5	51.757
Reach 1 Routing (method) (Lag) (min)	18.66		23.214	

Table 4. Calibrated parameter values used for validation.

Element	**Method**	**Parameter**	**Parameter Value**
Sub-basin 1	Loss Method	Initial loss (mm)	0.96675
		Constant rate (mm/hr)	0.93278
	Transform method	Time concentration (Tc) (hr)	57.723
		Storage coefficient (R) (hr)	49.335
Sub-basin 2	Loss Method	Initial loss (mm)	0.84186
		Constant rate (mm/hr)	0.93887
	Transform method	Time concentration (Tc) (hr)	62.612
		Storage coefficient (R) (hr)	58.909
Sub-basin 3	Loss Method	Initial loss (mm)	0.48813
		Constant rate (mm/hr)	0.73219
	Transform method	Time concentration (Tc) (hr)	49.5
		Storage coefficient (R) (hr)	51.757
Reach 1	Routing method	Lag (min)	23.214

3.3 Model Validation

The parameters generated from the calibration process validated using rainfall datasets from 01 January 2012 until 31 December 2018. The validation results showed in Figure 5 for the discharge station at Jambatan Jerangau (4832441). Validation results obtained were better than the calibration results.

The results obtained during the validation process for simulated peak flow at the Jambatan Jerangau discharge station showed R^2 values of 0.86 and NSE of 0.85. The model simulation from the validation process in this study can be judged as very good (NSE >0.75) (Moriasi *et al*. 2015). These results indicated that simulations of peak flow at the Jambatan Jerangau station were closely fit with the observed peak flow. Relative error peak and relative error volume record at -4.14% and -22.5%, respectively.

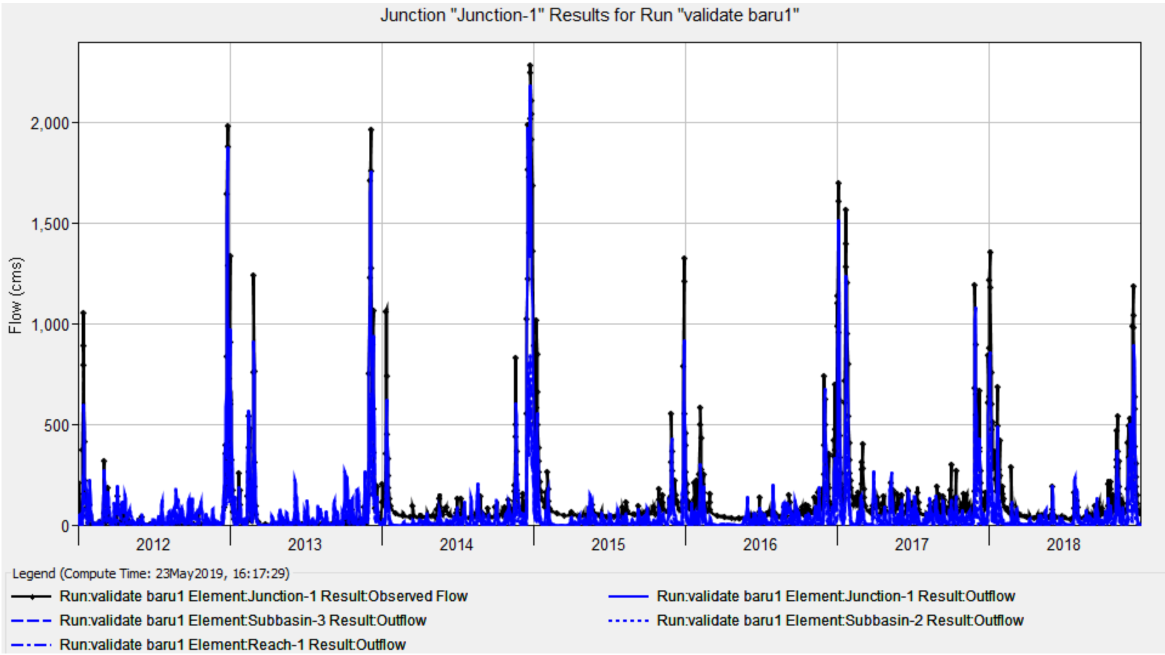


Figure 5. Runoff hydrograph for the Jambatan Jerangau discharge station (Validation).

The results obtained during the validation process for simulated peak flow at the Jambatan Jerangau discharge station showed R^2 values of 0.86 and NSE of 0.85. The model simulation from the validation process in this study can be judged as very good (NSE >0.75) (Moriasi *et al*. 2015). These results indicated that simulations of peak flow at the Jambatan Jerangau station were closely fit with the observed peak flow. Relative error peak and relative error volume record at -4.14% and -22.5%, respectively.

The performance of the model and comparison between peak flow and predicted peak flow during the validation process showed in Table 5. The correlation between simulation and observed flow during the validation process at the Jambatan Jerangau station showed in Figure 6. Generally, during this validation process, a good simulation was made between the estimated and observed values.

The results of the validation process are much better than the calibration process. The model performance also exhibited better NSE and R^2 values for the validation process. The study conducted by Tassew *et al.* (2019) also gives similar results, which was the result from validation was better than the calibration, when using HEC-HMS model in simulating rainfall-runoff model in the Lake Thana basin.

Table 5. Performance of the model during validation (peak flow of total volume and error function).

Station	Peak flow (m3/s)			Total volume (mm)			NSE	R^2
	Simulated	Observed	Relative Error Peak	Simulated	Observed	Relative Error Volume		
Jambatan Jerangau	2,185.60	2,280.10	-4.14	12,861.61	16,595.76	-22.50	0.85	0.86

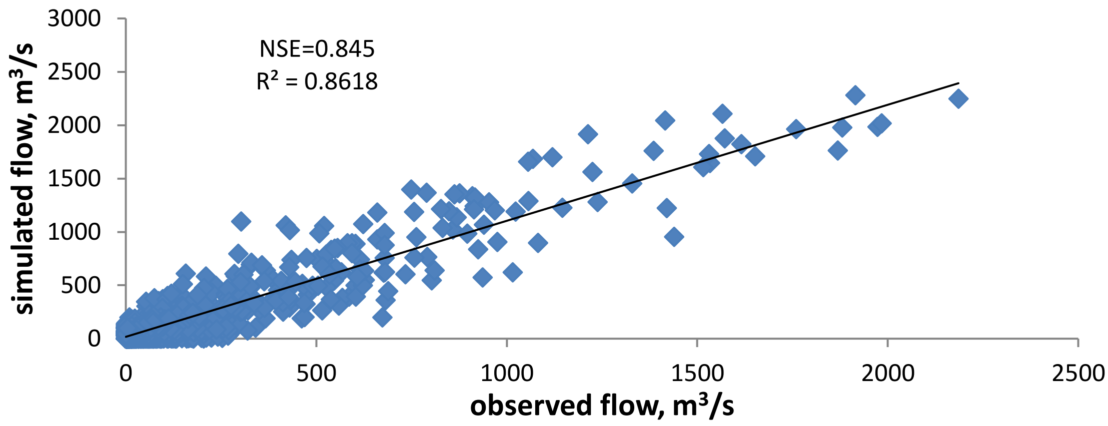


Figure 6. Correlation between observed and simulated flow during validation at the Jambatan Jerangau station.

4. Discussion

Based on the results of the statistical evaluation, the HEC-HMS model performed well in simulating peak flow and total volume. Initial and constant loss method, Clark unit hydrograph transform method, and lag routing method selected for this study yielded an acceptable result. The model efficiency could be enhanced by using a suitable combination of the parameter value, during the calibration process.

The performance and accuracy of the model depended on the coefficient of determination (R^2) value. The value of R^2 measures how well the correlation between simulations compared to the observations with ranges from 0 to 1. A value of 0 indicated no correlation, and a value of 1 implied that the prediction equals the measured. In this study, the R^2 value is 0.693 for calibration and 0.86 for validation. These showed the performance and accuracy of the model are good because it was close to 1. The peak flow prediction produced in the model simulation was almost equal to the peak flow from observation.

The results of this study provided an estimate of the peak flow resulting from precipitation that falls in a catchment area. This knowledge is useful for those responsible for planning and handling various activities. The results of this study also can be used to examine and conduct hydrological studies of neighboring areas using the optimized parameters obtained during the calibration process (Jin *et al.*, 2009).

5. Conclusions

The HEC-HMS model performs well in terms of Nash-Sutcliffe Efficiency (NSE) and the coefficient of determination (R^2) based on the loss, transform, and flow routing system chosen. Comparison of the measured peak discharge using Clark's Unit Hydrograph model, Initial and Constant model and Lag routing model exhibited that the HEC-HMS model proves to be good for runoff estimation despite limited data availability. The optimized parameters obtained from the calibration process could be used for other similarly featured catchment areas or for neighboring areas. The results show that the use of GIS and other modelling tools is an efficient way to evaluate river basins and hydraulic model integration, and will play an important role in making the decision-making process more realistic.

Geographic Information System (GIS) is usually used for generated maps for a large and small-scale watershed. The map created by the GIS contains details about the catchment area, the length of the river and the catchment perimeter. For knowing the position of the rain gauge as well as the streamflow gauge, this mapping and information are essential. The rainfall-runoff simulation was carried out using different data sets for calibration and validation. Optimized parameter values showed substantial variations in peak discharge during validation. The outcomes of this study indicated that the results of the validation process were better than calibration.

Therefore, we conclude that there are a relatively unique input-output relationship and the formation of surface runoff. The findings obtained from this study could be used in other ungauged catchment areas with similar characteristics for future hydrological investigations. The results also help the hydrologic agencies in basin management make predictions and evaluate management options in conducting planning for the catchment and future river basin studies. We propose further research in this study to use and produce more detailed information for modeling work and use calibrated parameter values for modeling runoff in other catchment areas.

Author Contributions: Conduct the experiment, data collections, and analyzing, prepared and edited the manuscript.

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Conflicts of Interest: The authors declare no conflict of interest.

References

Chu, X., Steinman, A. (2009). Event and continuous hydrologic modeling with HEC-HMS. *J. Irrig. Drain. E-Asce*. 135, 119–124. https://doi.org/10.1061/(ASCE)0733-9437(2009)135:1(119)

Clark, C. O. (1945). “Storage and the unit hydrograph.” Trans. *American Society of Civil Engineering*, 110, 1419–1488.

Dinor, J. (2009), *The Effect of Deforestation on Catchment Response in the Tropical Climate Region: Case Study for Sungai Padas Catchment*. Master Thesis, River Engineering and Urban Drainage Centre, USM Engineering, Penang. http://eprints.usm.my/41529/1/Joseph_Dinor24.pdf.

Government Of Malaysia. (2010) *Hydrological Procedure No. 27 ESTIMATION OF DESIGN FLOOD HYDROGRAPH Hydrological Procedure No. 27.” no. 27*. https://www.water.gov.my/jps/resources/PDF/Hydrology%20Publication/Hydrological_Procedure_No_27_(HP_27).pdf

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

Jaybhaye, P. U. (2014). “*Event Based Rainfall-Runoff Simulation Using Hec-Hms Model* A Thesis Submitted to the Maharashtra State (India) In the Partial Fulfillment of the Requirements for the Degree of Master of Technology (Agricultural Engineering) In By,” 68–159. http://krishikosh.egranth.ac.in/displaybitstream?handle=1/90136

Jin, X., Xu, C.Y., Zhang, Q., *et al.. (*2009 *Regionalization study of a conceptual hydrological model in Dongjiang basin, south China*. Quat. Int., 208, 129–137. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.595.8837&rep=rep1&type=pdf

Majidi, A., Shahedi, K. (2012). *"Simulation of Rainfall-Runoff Process Using Green-Ampt Method and HEC-HMS Model (Case Study: Abnama Watershed, Iran)"* 1 (1): 5–9. McCuen, H. R. (1989), *Hydrologic Analysis and Design (2nd Edition).* Prentice Hall Inc. doi: 10.5923/j.ijhe.20120101.02.

Moriasi, D. N., Arnold, J. G., Van Liew, M. W., *et al.* (2015). Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. *Trans. ASABE*, 50, 885–900. DOI: 10.13031/2013.23153.

Nadiatul, A., Nuramirah, S. (2014) . IOP Conf. Ser.: Earth Environ. Sci. 244 012014. *"Estimating Flow Rate in Gauged and Ungauged Stations in Kuantan River Basin Using Clark Method in Hec-HMS*" 0–8. https://iopscience.iop.org/article/10.1088/1755-1315/244/1/012014/pdf

Nuramidah, H, Zulkeflee, A. H., Sobri, H. (2011). "*Integrated River Basin Management (IRBM): Application of HEC-HMS and SWAT2005 for Kurau River Sub-Basin, Perak,*" no. December: 100–109. http://redac.eng.usm.my/html/publish/2011_22.pdf

Scharffenberg, W. A., Fleming M. J. (2006), *Hydrologic Modelling System HEC-HMS User's Manual*, US Army Corps of Engineers.

Sugiyono. (2013), *Metodelogi Penelitian Kuantitatif, Kualitatif dan R&D.* (Bandung: ALFABETA)

Tassew, B. G., Belete, M. A., Miegel, K. (2019). Application of HEC-HMS Model for Flow Simulation in the Lake Tana Basin: The Case of Gilgel Abay Catchment, Upper Blue Nile Basin, Ethiopia. *Hydrology*, 6(1), 21. https://doi.org/10.3390/hydrology6010021

U.S. Army Corps of Engineers, (2015). Hydrologic Modeling System (HEC-HMS) Applications Guide: Version 4.1.0. Institute for Water Resources, Hydrologic Engineering Center, Davis, CA.

Yener, M. K., Sorman, A. U., Sorman A. A., *et al*. (2008). Modeling studies with HEC-HMS and runoff scenarios in Yuvacik basin, Turkiye. *International Congress on River Basin Management*. pp. 621-634. http://redac.eng.usm.my/v2/images/lecture_notes/ead513/HEC-HMS_paper.pdf.

Zelelew, D., Melesse, (2018) A. Applicability of a Spatially Semi-Distributed Hydrological Model for Watershed Scale Runoff Estimation in Northwest Ethiopia. *Water 2018*, 10, 923. https://doi.org/10.3390/w10070923