RAINFALL RUN OFF MODELLING OF SUNGAI PAHANG BY USING HEC HMS

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Abstract

Flash flood happens when the drainage or river could not cope with the sudden increase in rainfall volume. In Malaysia, flash flood often occurs in the developed cities such as Kuala Lumpur and Kuantan. Water yield or reservoir storage is the collection and storing of water during high-water period and to be used during low-water period. It preserves the excess water where or else it will result in water wastage and potentially cause a flood disaster to happen. The capacity of the water yield has to be sufficiently large to sustain the amount of increasing rain water without overflowing. The study aims to investigate the rainfall runoff relationship of Sungai Pahang River. Study period of this hydrological modelling was selected from year January 2013 to December 2017. The hydrological modelling using HEC-HMS of Sungai Pahang resulted with a correlation of 0.65 and Nash-Sutcliffe coefficient of 0.41. Clark unit hydrograph in transform method and recession constant in baseflow method have great impact on the simulation result.

Keywords: HEC HMS, rainfall runoff relationship, Sungai Pahang River

I. Introduction

Flood is a common phenomenon that occurs in Malaysia due to its geographical location with hot wet equatorial climate. Season monsoon wind that affects the east coast of peninsula Malaysia covering states such as Terengganu, Pahang and the eastern of Johor will have higher amount of precipitation. The effect of the monsoon wind on the west coast of Malaysia has been reduced due to the presence of Mountain Titiwangsa.

Frequent flood that occurs in bring massive impact that disrupt the overall economy of the affected area and cause costly repair bills on water damaged vehicles or
housing properties. Moreover, when there is an occurrence of flooding, temporary relief centers, subsequent flood clean-up and emergency response team will be deployed to assist the citizen affected which in result costing a hefty bill to the government.

River discharge is greatly dependent on the amount of rainfall that falls on the mountainous areas where it has high rainfall intensity and the rainfall quickly converted to runoff due to the steep slopes [II].

To counter this issue, this study applied the Hydrologic Engineering Center Hydrologic Modelling System, (HEC-HMS) to interpret the hydrological aspects and the rainfall-runoff relationship of the Sungai Pahang River based on historical data of 2008 to 2017 data. HEC-HMS allows input of hydrological parameter for analysis of rainfall trend, infiltration and hydrologic routing. After describing the computer models HEC-HMS that are used in the study, a description of part of the Pahang river watershed used in the case study is presented, including its representation in HEC-HMS. The simulated runoffs produced by the HEC HMS were evaluated to access the goodness of the model performance and are discuss in the result. The study presents the flood level characteristics and results of hydrograph modeling for the study area catchment.

II. Study Area and Data Description

Sungai Pahang River is the longest river in Malaysia spanning 440 km in length. The Pahang river basin is located at longitude of 103’30’ E to 103’ 30’ E with latitude of 3’00’ N to 4’45’ N. It has a total area of 25600 km2. Fig.1 shows the location of the river basin in Pahang state. The catchment receives an average annual precipitation of 2014.39 mm and the temperature in the basin ranges from 23°C and 32 °C except for highland area [I]. The river is a main river system in state of Pahang that and outlets to South China Sea.

Pahang Basin receives high total rainfall during the northeast monsoon period amounting to almost 40% of Pahang’s total annual rainfall [XII]. The consequence of the extreme rainfall has an impact on Pahang River where it results in higher river flow and water level and finally contributing to serious flood events along the river in the basins [V].

In this study, five years of rainfall data (2013 - 2017) were used to simulate the catchment. The rainfall data were collected from Department of Irrigation and Drainage (DID). The raw rainfall data from 10 stations obtained was analysed and determined as the best set of data used to run the modelling. Rainfall was measured by a manual tipping bucket rain gauge which records daily rainfall. The water level was measured continuously using automatic streamflow recorder. Table 1 showsthe name and station number of both rainfall stations and streamflow station.
The raw rainfall data obtained was analysed and determined the best set of data used to run the modelling. The rainfall inputs from the 10 stations were then regionalized using the method of Thiessen-Polygon. Analysis of rainfall data is usually based on linear combinations of available data and performed to fill in any missing rainfall data. The spatial variability of rainfall is analysed at different stations with respect to distance between each rainfall station.

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**Table 1: Rainfall and Streamflow Stations near Sungai Pahang Area**

| Station No | Station Name | Latitude   | Longitude  |
|------------|--------------|------------|------------|
| 3524080    | Kg. TebingTinggi, Sanggang | 03°31’05’’  | 102°25’50’’ |
| 3717052    | LLN Sempan   | 03°36’35’’  | 101°46’50’’ |
| 3723077    | Kuala Krau   | 03°42’40’’  | 102°22’05’’ |
| 3824001    | PayaGintong di Jerantut | 03°51’30’’ | 102°26’40’’ |
| 3924071    | PeriJerantut | 03°57’45’’  | 102°25’40’’ |
| 3924072    | Rumah Pam PayaKangsar | 03°54’15’’ | 102°26’00’’ |
| 4020001    | PayaTampin   | 04°02’20’’  | 102°02’15’’ |
| 4219001    | Bukit Betong | 04°14’00’’  | 101°56’25’’ |
| 4223115    | Kg. Merting  | 04°14’35’’  | 102°23’00’’ |
| 4319048    | Sek. Keb. Kg. AurGading | 04°21’05’’ | 101°55’10’’ |
| 4324001    | Kuala Tahan  | 04°23’10’’  | 102°24’10’’ |
| 4414037    | Ldg. Boh (Bhg. Boh) | 04°26’30’’ | 101°26’40’’ |
| 4414040    | Mardi C Highlands | 04°27’00’’ | 101°25’12’’ |
| 4419047    | Stn. KeretapChegarPe | 04°25’30’’ | 101°56’00’’ |
| 3424411    | Sg. Pahang di Temerloh | 03°26’40’’ | 102°25’45’’ |
Fig. 2 shows the graph of average daily precipitation data for year 2017, the highest of mean daily rainfall fell on 15th of January 2017 which is 46 mm for Station Kg. TebingTinggi, Sanggang. While the highest monthly rainfall received on December 2013 with the amount of 363.80 mm. The analysis result reveals the fact that the inner region receives relatively small amount of rainfall than the highlands because the topographic barrier appears to block the monsoon winds. The rainfall produced in the lowlands of Peninsula Malaysia is due to local convection caused by intense heating of land surface.

![Average Daily Precipitation Data for Year 2017 for Station Kg. TebingTinggi, Sanggang](image)

**Fig. 2:** Average Daily Precipitation of Year 2017 for Station Kg. TebingTinggi, Sanggang

### III. Model Setup

The HEC-HMS model is a physically based and conceptually semi-distributed model developed to simulate rainfall-runoff processes such as precipitation, evapotranspiration, infiltration, interflow, overland flow, percolation, baseflow, recharge of aquifer and streamflow. However, some of the process was simplified. In this study, the catchment was divided into 5 subbasins. Basically, HEC HMS routines separate several sub models to represent different component of rainfall runoff that are model of runoff volume, models of direct runoff, model of baseflow and models of channel flow. It consist of nine different loss methods that are developed primarily for simulating events, while others are intended for continuous simulation. While for transformation sub model, it has seven different methods. Examples of the methods are the Snyder Unit Hydrograph Yilma and Moges [XIII] and Clark Unit Hydrograph Banitt [IV] methods which have been applied successfully to simulate long-term stream flows globally.

#### A. Model of Runoff Volume (Loss Model)

The loss model in HEC-HMS is designed to calculate the runoff volume by computing the volume of water that is intercepted, infiltrated, stored, evaporated, or transpired and subtracting it from the precipitation. In this study, the Initial Loss and Constant loss method was selected to calculate direct runoff from a specific or design rainfall [VII]. It has several advantages compare to other methods because it is a simple conceptual method and parsimonious which it includes only a few necessary
parameters to explain the variation of runoff volume. Likewise, it is also suitable for the study area with observed hydrological data.

**B. Model of Direct Runoff (Transform Model)**

The transform prediction model in HEC-HMS is designed to simulate the process of the direct runoff of excess precipitation on the watershed, and they transform the precipitation excess in point runoff. In this study, the Clark’s Unit Hydrograph model was chosen to transform excess precipitation into runoff. The Clark’s Unit Hydrograph model considers the short term storage of water throughout the watershed, in the soil, on the surface and in the channel which plays an important role in the transformation of precipitation excess to runoff. The linear reservoir model is a common of rainfall excess to runoff. In addition, the Clark Model accounts for the time to require for water to move to the watershed outlet.

This delay is represented implicitly with a time area histogram which defines the watershed area contributing to flow at the outlet as a function of time. If the area is multiplied by unit depth and divides by the computation time step, the result is inflow to the linear reservoir. The parameters required to be estimated in this model are time of concentration, $t_c$ (hr) and basin storage coefficient, $R$ (hr).

The time of concentration can be projected based on basin characteristics including topography and the length of the reach by Kirpich’s formula [IX].

$$t_c = 0.0078 \times (L^{0.77}S^{0.385})$$

(1)

where $L$ is the reach length in feet, and $S$ is the slope in (ft/ft).

The basin storage coefficient is an index of the temporal storage of precipitation excess in the watershed as it drains to the outlet. Both parameters were calibrated using the observed data as summarized in Table 2.

**C. Model of Baseflow (Recession Model)**

Baseflow or return flow is used to model the return of infiltrated precipitation to the channel. In this study, Recession Curve method was selected to estimate baseflow from the initial flow and recession ratio. Initial flow is the initial baseflow for each subbasin at the beginning of the simulation. The Recession Ratio is the ratio of the current flow to the flow one day earlier. This method is particularly suitable when there is observed streamflow data at the outlet of the subbasin for determining the initial flow in the channel.

The recession curve can be represented by an exponential decay function as:

$$q_t = q_0Kt$$

(2)

where $q_t$ is the flow at time (m$^3$/s) ; $q_0$ is the initial flow at time zero(m$^3$/s)and $Kt$ is the recession ratio $< 1$

Table 2 summarizes total of 8 the parameters being applied in the Sungai Pahang basins based on the selected method of each submodel as explain in the previous chapter. In this study, the model was only calibrated by using the daily data for the period of 5 years (January 2013 to December 2017).
Table 2: HEC-HMS Calibrated Parameters Applied on the Study Area

| Parameter                        | Value  |
|----------------------------------|--------|
| **Loss: Initial and Constant**   |        |
| Initial Loss (mm)                | 5      |
| Constant Rate (mm/hr)            | 3      |
| Impervious (%)                   | 10     |
| **Transform: Clark Unit Hydrograph** |       |
| Time of Concentration (hr)       | 48     |
| Storage Coefficient (hr)         | 24     |
| **Baseflow: Recession**          |        |
| Initial Discharge (m$^3$/s/km$^2$) | 0.10   |
| Recession Constant               | 0.77   |
| Ratio                            | 0.90   |

IV. Model Calibration

A sensitivity analysis is usually undertaken in most modeling studies [XIV, III]. It is a necessary process to determine the sensitivities of the model to various parameters and parameter precision required for calibration. The most fundamental sensitivity analysis technique utilizes partial differentiation, whereas the simplest method involves perturbing parameter values one at a time [VIII]. In this study, the sensitivity analysis was performed by changing the parameter values in the range of ±15% with 5% intervals. The sensitivity parameters were then selected based on their impact on the computed peak discharge and total volume.

A statistical method was used to evaluate the performance of the model. The aim of this statistical method is to find the best values of the model parameters that used to run the simulation. In this study, the objective functions Nash–Sutcliffe Efficiency (NSE) by Nash and Sutcliffe [X], which is equal to one minus the ratio of the mean square error and standard deviation of measured data time series [VII], root mean squared error (RMSE), which depends on the units of the predicted variable and varies on the interval [0.0 to inf], and correlation coefficient(r) as described in Neter et al. [XI] were applied to evaluate the performance of the model and the selected loss and transform methods. The equations are:

\[ NSE = 1 - \frac{\sum_{i=1}^{n}(Q_{obs} - Q_{sim})^2}{\sum_{i=1}^{n}(Q_{obs} - Q_{avg})^2} \]  
\[ RMSE = \left[ \frac{\sum_{i=1}^{N}(Q_{obs} - Q_{sim})^2}{N} \right]^{1/2} \]

Where Qobs is the observed discharge (m$^3$/s); Qsim is the simulated discharge (m$^3$/s) and Qavg is the average observed discharge at time i (m$^3$/s).

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where $Q_{obs}$ is the observed discharge (m$^3$/s); $Q_{sim}$ is the simulated discharge (m$^3$/s) and $n$ is the number pairs of data.

**V. Results and Discussion**

The most important aspect in analyzing a flood event of the hydrograph is the peak flow. Peak flow corresponds to the maximum downstream flooding. For the calibration purpose, observed streamflow were compared with the simulated streamflow for the whole set period of January 2013 to December 2017. The results of the hydrological model in this study showed a reasonable fit between the model and observations after optimization where the hydrograph shape and time to peaks matched well, although the model tended to overestimate or underestimate the runoff before optimization. From Fig. 3, it is noticeable that the simulated flow rate, $Q_{sim}$ matches observed flow rate, $Q_{obs}$ generally in terms of overall pattern throughout January 2013 to December 2017. The peak of simulated flow rate, $Q_{sim}$ recorded at 7621.0 m$^3$/s on the 26th of January 2017 whereas for the observed flow rate, $Q_{obs}$ peaks at 9819.2 m$^3$/s during 30th December 2014. The two peaks of rainfall in green lines match the two peaks of simulated flow rate, $Q_{sim}$ in red lines.

Objective functions of the simulation are shown in Table 3 by applying HEC-HMS parameters in Table 2. For the loss method applied on the sub-basins, the initial and constant approach was used. Most sensitive parameter among the loss method would be the percentage of impervious. Impervious percentage depends on the land use or land cover of the study area. Percentage of impervious taken as 10% based on the minimal land use for urban development whereas a large area remained as virgin forest or plantation.

| Objective Function | Values |
|--------------------|--------|
| Correlation        | 0.65   |
| Nash-Sutcliffe Coefficient | 0.41   |
| Mean Absolute Error (%) | 4.82   |
| Root Mean Square Error (%) | 8.52   |

For the transform method Clark unit hydrograph parameters, 48 hours of time of concentration and 24 hours of storage coefficient was set to obtain optimum results for simulation. A combination of various time of concentration and storage coefficient as shown in Table 3.4 above were used to generate the sensitivity analysis results for transform method parameters of Clark unit hydrograph as illustrated in Figure 5. It is noticed that starting from time of concentration of 24 hours and 12 hours of storage coefficient, the Nash-Sutcliffe coefficient drops below negative to a value of -0.174. As the time of concentration decreases to 12 and storage coefficient of 12 hours, the Nash-Sutcliffe coefficient recorded a value of -1.225. As observed in
Figure 3.13, Nash-Sutcliffe coefficient stays above zero as positive value from 96 hours of time of concentration and 96 hours of storage coefficient until 48 hours of time of concentration and 12 hours of storage coefficient.

From fig. 4, the correlation and Nash-Sutcliffe coefficient ranges from 0.49 to 0.66 and 0.20 to 0.42 respectively from recession constant 0.1 to 0.8. The correlation peaks at 0.70 when the recession constant is 0.9 and a Nash-Sutcliffe coefficient turns negative to -0.06 at this point. When it reaches recession constant of 0.95, its correlation decreased to 0.65 whereas the Nash-Sutcliffe coefficient drops to -3.01.

The efficiency and accuracy of the model were determined from the result from HEC-HMS output. The equations mentioned earlier were used to calculate the data obtained from the model to get the control functions.

VI. Conclusion

The hydrological modeling is completed that with the use of ArcGIS and HEC-HMS software. The area of watershed delineation using ArcGIS is larger than expected but due to the use of snap pour point function in the software. In HEC-HMS
software, with the correct use of various parameters, the result of simulation was satisfactory.

Fig. 3 shows the peak of observed flow rate, Qobs is 9819.2 m$^3$/s during 30th December 2014 whereas the peak of simulated flow rate, Qsim is 7621.0 m$^3$/s during 26th January 2017. At the 30th December 2014, the simulated flow rate, Qsim obtained is 3172.2 m$^3$/s. The shift of peak flow occurrence date were due to the removal of extreme data where hourly rainfall data more than 20 mm.

From the rainfall analysis, it is observed that rainfall stations recorded a higher annual rainfall in 2017 compared to other years especially from 2014 to 2016. This is due to the amount of missing rainfall data was significant lesser in 2017 in comparison to year 2014 to 2016. With the minimal missing rainfall data in 2013 and 2017, it can be concluded that the rainfall trend is on an increasing trend.

Among the parameters used, it is found that Clark unit hydrograph in transform method and recession constant in baseflow method have made significance impact on the simulation result. Parameters such as time of concentration, storage coefficient, and recession constant are very sensitive that when it reaches certain values it made the simulation gone worst in terms of correlation and Nash-Sutcliff coeffcients. As for the initial and constant parameters such as percentage of impervious, initial loss and constant loss doesn’t affect the simulation result too much due to the constraint are somewhat restricted in this particular section.

It is advisable that to delineate a smaller watershed so that the usage and analysis of rainfall or streamflow raw data can be more manageable also will increase the accuracy of the hydrological modeling results.

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References

I. Ab. Ghani, A., Chang, C. K., Leow, C. S., & Zakaria, N. A. (2012). Sungai Pahang digital flood mapping: 2007 flood. International Journal of River Basin Management, 10(2), 139–148. https://doi.org/10.1080/15715124.2012.680022

II. Aminuddin AB. G., A., Chang, C. K., Leow, C. S., & Zakaria, N. A. (2012). Sungai Pahang digital flood mapping: 2007 flood. International Journal of River Basin Management, 10(2), 139–148.

III. Azam, M.; San Kim, H.; Maeng, S.J. Development of flood alert application in Mushim stream watershed Korea. Int. J.Disast. Risk Re. 2017, 21, 11-26.

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IV. Banitt, A. Simulating a century of hydrographs e Mark Twain reservoir. In Proceeding of 2nd Joint Federal Interagency Conference, Las Vegas, NV, USA, 27 June–1 July, 2010

V. Department of Irrigation and Drainage (DID) (2009). Retrieved from https://www.water.gov.my/#?mid=209

VI. Environmental and Water Resources Instit. Curve number hydrology: State of the practice. Hawkins, R.H., Ward, T.J., Woodward, D.E., Van Mullem, J.A., Eds; American Society of Civil Engineers: Reston, VA, USA, 2009.

VII. Gupta, H.V.; Kling, H.; Yilmaz, K.K.; Martinez, G.F. Decomposition of the mean squared error and NSE performance criteria: Implications for improving hydrological modelling. J. Hydrol.2009, 377, 80–91.

VIII. Hamby, D. A review of techniques for parameter sensitivity analysis of environmental models. Environ. Monit. Assess. 1994, 32, 135–154.

IX. Kirpich, Z. Time of concentration of small agricultural watersheds. Civil Engineer. 1940, 10, 362.

X. Nash, J.E.; Sutcliffe, J.V. River flow forecasting through conceptual models part I—A discussion of principles. J. Hydrol. 1970, 10, 282–290.

XI. Neter, J.; Wasserman, W.; Kutner, M.H. Applied statistical models. Richard D. Irwin, Inc.: Burr Ridge, IL, 1990.

XII. Suhaila, J., S. MohdDeni, W.Z. Wan Zin & A.A., Jemain. (2010). Trends in Peninsular Malaysia Rainfall Data during The Southwest Monsoon and Northeast Monsoon Seasons: 1975-2004. SainsMalaysiana, 39:533-542.

XIII. Yilma, H.M.; Moges, S.A. Application of semi-distributed conceptual hydrological model for flow forecasting on upland catchments of Blue Nile River Basin, a case study of GilgelAbbay catchment. Catchment Lake Res. 2007, 6, 1–200.

XIV. Yusop, Z.; Chan, C.; Katimon, A. Runoff characteristics and application of HEC-HMS for modeling stormflow hydrograph in an oil palm catchment. Water Sci. Technol. 2007, 56, 41–48.