Event-based rainfall-runoff modelling of the Kelantan River Basin

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Abstract. Flood is one of the most common natural disasters in Malaysia. According to hydrologists there are many causes that contribute to flood events. The two most dominant factors are the meteorology factor (i.e climate change) and change in land use. These two factors contributed to floods in recent decade especially in the monsoonal catchment such as Malaysia. This paper intends to quantify the influence of rainfall during extreme rainfall events on the hydrological model in the Kelantan River catchment. Therefore, two dynamic inputs were used in the study: rainfall and river discharge. The extreme flood events in 2008 and 2004 were compared based on rainfall data for both years. The events were modeled via a semi-distributed HEC-HMS hydrological model. Land use change was not incorporated in the study because the study only tries to quantify rainfall changes during these two events to simulate the discharge and runoff value. Therefore, the land use data representing the year 2004 were used as inputs in the 2008 runoff model. The study managed to demonstrate that rainfall change has a significant impact to determine the peak discharge and runoff depth for the study area.

1. Introduction

Flood is a common natural disaster that exists in almost every part of the world. Flood contributed to many losses in socio-economic aspects of human life. In Malaysia, there are three large basins namely Kelantan River basin, Pahang River basin and Terengganu River basin. These three basins are under monsoon catchment which is affected by the heavy rainfall during Northeast monsoon. Northeast monsoon occurs in November to March while Southwest monsoon occur from May to September[1]. The Kelantan River is known as the flood prone area in Malaysia. The heavy rainfalls increase the water inundation area and affected economic and agriculture sector. There are several factors contributing to flood such as unmanaged drainage system, unpredictable regional weather condition and unplanned development by human activities. Land use and climate change have significant impact on the hydrologic conditions and ecological process of watershed. For example, land use change will cause modification in hydrological processes over the year in range of temporal and spatial scales such as interception, infiltration and evaporation. Thus, it will lead to changes in rainfall intensity([2],[3],[4]) . In Malaysia, two major factors contributed to flood are natural monsoon effect and human factor (i.e urbanization, deforestation). The hardest hit areas are along the East coast of peninsular Malaysia in the states of Kelantan, Terengganu and Pahang by which Kelantan hold the highest frequency of flood catastrophe.

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2. Site description

Kelantan River basin is one of the major basins in Malaysia. It is located at the North Eastern part of Peninsular Malaysia at latitudes 4° 40' to 6° 12' North and longitude 101° 20' to102° 20' East .The maximum length and breadth of the catchment are 150 km and 140 km respectively. The river is about 248 km long and drains an area of 13,100 km2, occupying more than 85% of the State of Kelantan. There are six sub-basins in Kelantan River basin namely Galas, Nenggiri, Pergau, Guillemard Bridge, Kuala Krai and Lebir. The entire basin contains large areas of tropical forested mountains, lowland forest and limestone hills. Currently, there are many activities involving land use changes from lowland forest to vegetation and urban area.



Figure 1. Study Area of Kelantan Basins

3. HEC-HMS model

In order to come out with the hydrology model of study area, there are a few steps that need to be done. Preparation of hydrology networks was made using ArcGIS. Sub-basin was delineated using HEC GeoHMS which can be freely downloaded from the internet through this website address (*http://www.hec.usace.army.mil/software/hec-geohms/download.html*). It is an embedded tool built in ArcGIS. The most important role of HEC-GeoHMS is to derive a watershed data structure under the platform of GIS that can be imported directly to HEC-HMS. Due to this, the topographic information supplied by HEC-GeoHMS, HEC-HMS works more readily and exactly. The HEC HMS model was developed by US Army Corp to simulate the precipitation runoff processes of watershed systems [5]. The unit of hydrograph produced by the programme is later used directly together with asoftware (i.e ArcMap) for studies such as the flood forecasting, urbanization impact and flow forecasting. Many studies have integrated the HEC-HMS programme with the Geographical Information System (GIS) ([4],[6],[7],). There are several steps involved prior to HMS model. Figure 2 and Figure 3 show the process which was done using ArcGIS environment. All data needs in this study should be compiling in geodatabase (ie. river.shp, dem). Then the further process can be done.

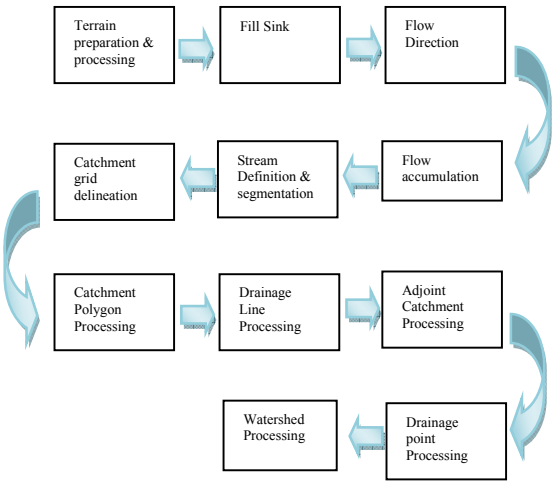


Figure 2. Sub-basin preparation.

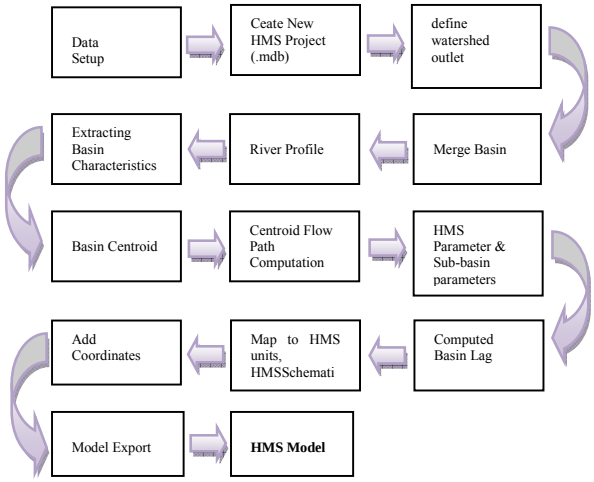


Figure 3. HEC-GEOHMS procedure.

4. Data

The historical rainfall data of year 2008 and 2004 are selected as the models using HEC HMS software. A semi-distributed hydrologic model was used for runoff estimation at Kelantan River basin. The rainfall data for 2008 were considered as newest event modelled, while rainfalls data for 2004 are considered as the previous event. The 15 minutes of time interval of rainfall data was selected to run the HEC HMS model for both year 2004 and 2008. Two sets of data were used for data collection process which is five days and one day for 2008 and 2004 respectively. The dates from 24 to 29 November have been selected based on the heavy rainfalls event and the suitability of data. While for 2004 two days event was selected starting from 11 until 12 of December. The dates of the event were selected based on the heavy rainfalls event and suitability of data. The parameters used in this study were lag time (Lt), Impervious (Imp), Curve Number (CN), Initial abstraction (Ia). For derivation and delineate the sub-basin, digital elevation model (DEM) for spatial resolution 25m have used. DEM data was obtained from Department of Mapping and Surveying Malaysia. The land use parameter of 2004 was applied as an land use input to the runoff model. The land use values were considered as constant as the meteorology data (i.e rainfall) was only changed in 2008.

5. Results and discussion

As reported by Adnan *et al*,[4], rainfalls intensity is the main reason of flooding in Kelantan. This preliminary study shows that sub-basin Guillrmard Bridge, Nenggiri, Galas have better enhancement model after calibrated while sub-basin Kuala Krai, Lebir and Pergau have difficulty to make the simulated model similar to the observed model. Pergau basin is unpredictable water flows because it regulated by the hydroelectric dam located at upstream of study area. In this study, analyses were performed using root mean square error (RMSE). The RMSE method was also used as one of the methods to measure the efficiency of the model by Adnan [8]. This method is also highly concentrated on the high flow peak and flows sensitivity of the hydrograph [9].

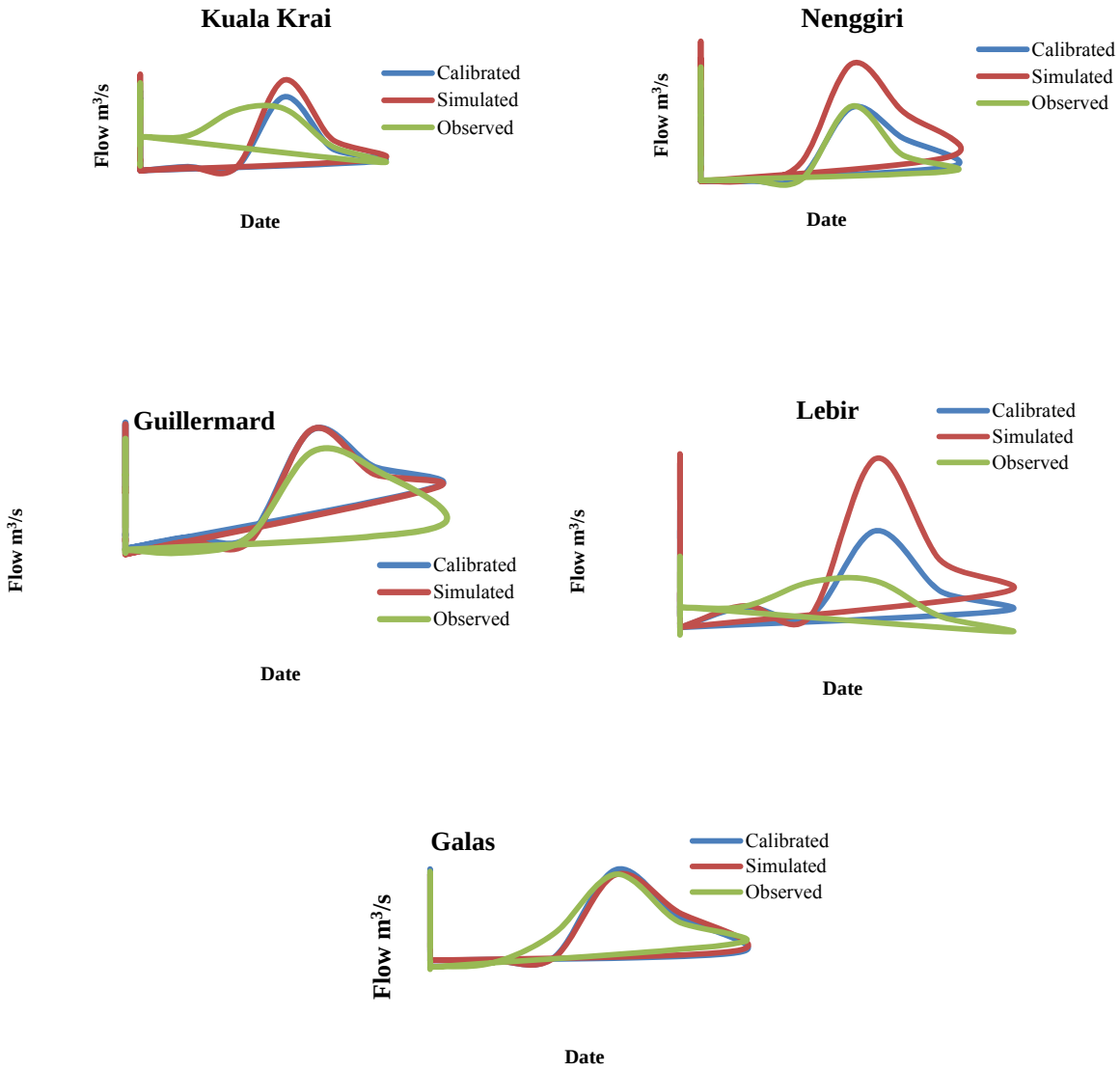


Figure 4. Comparison of simulated, calibrated and observed hydrograph for six sub-basins for year 2008

Table 1. Results of sub-basin year 2008.

Details	Guillermard	Lebir	Nenggiri	Pergau	Galas	K.Krai
RMSE -Sim	103.26	195.00	170.80	38.34	75.64	108.63
RMSE-Cal	101.54	96.49	95.68	38.29	68.13	99.35
R^2	0.9188	0.3701	0.6128	0.0312	0.9255	0.1985
PQobs	1648.00	386.80	616.60	7.50	1260.80	386.80
PQcal	1769.6	540.00	529.6	163.00	1279.2	360.3
RVobs	448.60	43.52	25.21	1.79	157.04	83.68
RV cal	478.68	50.12	30.63	12.39	156.59	65.36
PERV(%)	6.71	15.17	21.50	-	0.29	21.89

Note: PQ=Peak Discharge, RV= Runoff Volume, Obs=Observed, Sim= Simalated Cal=Calibrated

Table 2. Results of sub-basin year 2004.

Details	Guillemard	Lebir	Nenggiri	Pergau	Galas	K.Krai
RMSE -Sim	347.18	470.16	170.80	151.65	361.49	190.38
RMSE-Cal	267.48	100.80	255.58	151.77	415.42	167.21
R^2	0.99	0.96	0.93	0.62	0.85	0.91
PQobs	12117.00	1647.70	1643.2	787.52	3158.5	1647.70
PQcal	12586.20	1665.60	2055	863.7	3010.2	1336.00
RV obs	3321.63	268.45	120.17	468.41	713.38	516.14
RV cal	3420.71	253.46	145.36	359.44	595.85	494.68
PERV(%)	2.98	5.58	20.96	23.26	16.47	4.16

Note: PQ=Peak Discharge, RV= Runoff Volume, Obs=Observed, Sim= Simalated Cal=Calibrated

The results of calibration hydrographs for all sub-basins for both years 2004 and 2008 have better result enhancement compared to the runoff result before calibration (i.e simulated). It can be proven by results of RMSE for each sub-basin. The comparisons of RMSE for both simulated and calibrated results have shown differences with the improvement of RMSE value for the calibrated model. The derivation of model performance (R^2) coefficient value for each sub-basin year 2008 has close to 1.0 as presented in Table 1. Figure 4 shows the results of calibration hydrographs for Guillemard Bridge sub-basin for 24 to 29 November 2008 yield the maximum observed and calibrated flow rates of 1648.0m^3sec^{-1} and 1769.6 m^3sec^{-1} respectively. For Nenggiri sub-basin, the observed and calibrated flows are 616.6 m^3sec^{-1} and 529.6 m^3sec^{-1} respectively. However for the year 2004, calibrated peak discharge have slightly differences value compared to observed peak discharge. While, runoff volumes in 2004 indicated lower volume compared to 2008. For example, the runoff volume of the Guillemard Bridge sub-basin in 2004 indicated 3420.71mm, yet runoff volume for 2008 indicated 478.68mm. Again, the percentage error of runoff volume (PERV) also showed the satisfactory agreement between the calibrated and observed values which are for all sites (except for Pergau sub-basin 2008) being less then ±25% for both years. The lowest error was represented by the Guillemard Bridge sub-basin of 2.98% for year 2004 and 0.29% at the Galas sub-basin for year 2008. The study by Cheng *et al*,[10] indicate that runoff model is considered good if the percentage error of runoff volume is less than 20% according the criteria for flood forecasting in China. Consequently, the study was performed in satisfactory hydrograph.

6. Concluding remark

As a result, HEC HMS can be used to model the runoff events in a monsoon catchment in Malaysia. In comparison, the result from rainfall intensity in the year 2004 and 2008 showed that the peak discharge and runoff volume in 2008 has decreased compared to 2004. Table 1 and Table 2 clearly show that the calibration results were enhanced in the model performance. For this preliminary study, validation

process is not performed yet. For future research land use changes parameter will be associated. The future study will focus on land use changes and their impact on the hydrograph.

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