Natural Hazards (2022) 112:2053–2081
https://doi.org/10.1007/s11069-022-05256-4

ORIGINAL PAPER

Effect of the tide on flood modeling and mapping in Kota Tinggi, Johor, Malaysia

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Received: 6 September 2021 / Accepted: 28 January 2022 / Published online: 7 March 2022

Abstract

This study aimed at mapping the Kota Tinggi flood event in 2006/2007 that had caused massive damages to properties and the environment. The flood was associated with unusually high intensity and continuous rainfall, and high tide. Therefore, a reliable technique of floodplain mapping is crucial for the improvement of flood control strategies and for preparing an evacuation plan. The main objective of this study is to incorporate the effect of tide on flood modeling analysis. The inundated areas were mapped for various annual recurrent intervals (ARI) using peak flow data from 1965 to 2010. The study used Light Detection and Ranging data for flood modeling using HEC-HMS, HEC-RAS, and HEC-GeoRAS. The Generalized Extreme Value model was found to be the best fit for the annual flood simulation. The HEC-HMS hydrologic model was calibrated and validated using observed hydrographs in September 2002 and January 2003, respectively. Due to riverbank overflow, the level-discharge rating curve during flood events is not valid which causes underestimation of the peak flow in the observed flow. Therefore, the simulated hydrographs which model the actual peak flow provide more reasonable results of 625.3 m^3/s for the December 2006 flood and 743.9 m^3/s for the January 2007 flood. The modeling took into account the tidal effect. When the tidal effect was not considered, the simulated flood depth was 43% lower than the observed flood. However, the inclusion of the tidal effect has reduced the simulation error with an average similarity with the observed flood at 91.4% based on site verification. The simulation results show that the river flow starts to over bank for ARIs exceeding 25 years.

Keywords Flood modeling · GEV: HEC-GeoRAS · HEC-HMS · HEC-RAS · Johor River · Kota Tinggi flood

1 Introduction

Flood has been recognized as the number one disaster in many parts of the world mainly affecting Asia and South America and causing tremendous damages to the properties, environment, and losses of life (Adikari et al. 2010; Marengo et al. 2013). Due to global

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warming, future rainfall is predicted to be more intense, resulting in increased flood peak, volume, and duration (Westra et al. 2014; Wang et al. 2014). In addition, the rate of sea-level rise is expected to be higher in the future which further amplifies the impacts of the flood (Nijland 2005). Significant damage from floods also happens due to the people living in high flood risk areas which are unsuitable for settlement (Elsheikh et al. 2015; Ghorbani et al. 2016).

Throughout history, Malaysia has faced several major floods. In particular, during the 2006/2007 flood event, Kota Tinggi town in the State of Johor has recorded the highest, worst, and costliest flood in history of the Johor River since 1950 and a declared emergency curfew (Hamzah et al. 2012). Many flood structures that were meant to safeguard public properties and agricultural lands were damaged although it was designed to withstand a 25-years return period since the area used to be rural with scattered residential (Shafie 2009). The return period for urban areas is 100 years. However, the 2006/2007 flood event was more than a 100-years return period. The estimated total loss due to these disasters was RM 1.5 billion of which RM 237.1 million was for damaged infrastructure alone (Hamzah et al. 2012; Tam et al. 2014). A total of 11,724 victims in the December 2006 flood event and 7915 victims in January 2007 were evacuated (Hamzah et al. 2012; Tam et al. 2014; Karki 2019). In some cases, flood victims had to move to another relief center as the evacuation centers were also flooded.

It was found that the main cause of the flood was due to a large amount of rainfall, geographically low-laying area, rapid land use changes, inadequate drainage facilities, and tidal effect (Shafie 2009; Tam et al. 2014; Karki 2019). The flood started on December 19, 2006, until January 16, 2007, where the first wave had inundated most of the Kota Tinggi town. Malaysia Meteorological Department (MMD) reported high rainfall intensities from December 19, 2006, to January 12, 2007. The second wave continued on January 11, 2007, and this caused a huge disaster within a short period. The rainfall total during the first wave doubled compared to the average monthly rainfall, and during the second wave, the rainfall was about 5 times higher compared to the average monthly rainfall in December and January at Kota Tinggi. It has been reported that the water level was up to 5.45 m during the second wave compared to 4.9 m during the first wave. The disaster was compounded by the low infiltration rate of the soils in the area (Adib et al. 2011). At the same time, the Department of Irrigation and Drainage (DID) reported that a high tide of about 2 m occurred at the river mouth causing a backwater phenomenon and saline intrusion up to Kota Tinggi town and Rantau Panjang station (Tam et al. 2014; Lee et al. 2015; Karki 2019). Consequently, the outflow of stormwater in tidal reach, creeks, and rivers was blocked by the increasing sea water level. The problem with the outflow of stormwater is expected to recur year after year.

Kota Tinggi is the largest district in the State of Johor with an area of 3489 km^2 (18.34% of the state area) acting as one of the main catchment areas for Johor River basin. Urbanization in Kota Tinggi with its administrative town also named Kota Tinggi is a growing and densely populated area with a growing population of more than 200,000 people (Othman et al. 2013; Tam et al. 2014). The Kota Tinggi sits on the low-lying areas along the Johor River heading to the sea, with average elevation of 6 m above the mean sea level (Karki 2019). Thus, it is highly flood-prone. Although flood has recurred almost annually in the area, the 2006/2007 flood was a big surprise for most of the residents as they did not believe that the flood surge would rise so high. This spelled the need for better flood modeling in the area to forecast and to better anticipate the occurrence of flood. About 60% of the district land in Kota Tinggi is used for agriculture purposes, mainly oil palm and rubber. A few major projects have been outlined in the area such as the systematic replanting of oil palm trees and integrated village industries, as well as modern cultivation programs. During the flood event of 2006/2007, it was observed that this plantation area has caused massive sheet erosion to happen and it also turned into an open field for the floodwater to flow freely with extremely strong currents which channel the water to lower areas. This spells the need for a better storm design to protect the agricultural area from future massive floods.

Kota Tinggi has a pool of nature and man-made attractions to offer the local and regional tourists' demand. The district of Kota Tinggi is renowned for its historical attractions, valuable artifacts, and historical sites, especially from the era of Malacca Malay, Johor-Riau, Singapore, and Linggi (Hamzah et al. 2012). Historically, Kota Tinggi has its historical importance as a center for the Old Johor Sultanate. Kota Tinggi Museum, built in 1997, portrays the history of Johor Sultanate. Desaru, a destination of beach tourism, Kota Tinggi waterfall, and Panti Recreational Forest, among others, are always a preferred destination for both local and international tourists, especially during weekends, public holiday, or school holiday. Other than that, firefly offered eco-tourism hot spots in Kota Tinggi, especially along Johor River. Hamzah et al. (2012) disclosed that the catastrophic flood in Kota Tinggi had not just jeopardized the basic facilities like hospital, police department, and fire department but also affected the tourism industry. Due to the importance of Kota Tinggi as outlined above, more research is needed to better understand the climatic circumstances of extreme rainfall and the hydrologic model to simulate flood events in Kota Tinggi amid increasing deforestation and urban expansion (Abdullah et al. 2018).

Flood modeling is an important tool in predicting the magnitudes of floods which provides useful information in managing the potential risks caused by flooding (Nkwunonwo et al. 2020). To cater to the needs to further understand the present and the future flood events, there is an increasing interest to develop a new hydrologic and hydrodynamic model in order to achieve better flood modeling results in terms of visualization and characterization. Typically, a model needs to be chosen based on appropriate catchment characteristics, model input parameters, and boundary conditions. Previous study by Abdullah et al. (2018) employed Two-dimensional Runoff, Erosion, and Export (TREX) model, to simulate 2006/2007 flood event in Kota Tinggi, and found that multi-day rainfall, resulting in significant amount of accumulated rainfall, is identified as the main cause of flooding for both events. Heydari et al. (2013) employed one-dimensional model HEC-RAS to simulate the flood zoning and flood risk in Kota Tinggi and found the volume and upstream surface runoff area and stream or flood conditions and physical characteristics of the area as the most significant factors that can affect the flood severity and recurrence. Tam et al. (2014) used hydrodynamic modeling, 1D2D Sobek to simulate different flood scenarios to produce flood risk map for Kota Tinggi. Adib et al. (2011) used a combination of InfoWorks River Simulation (RS) and flood mapping approach and shows that the water spread out through the Kota Tinggi catchment with the maximum inundation depth above 10 m during flood event on January 12, 2007. Similarly, Othman et al. (2013) utilized geographic information system (GIS) and InfoWorks RS in modeling the flooding events in Kota Tinggi and found a reasonable agreement between simulated flood depth and observed flood depth. Razi et al. (2010) used HEC-HMS as a tool to estimate the peak discharge in Kota Tinggi for a period of 1997–2006 with 4% percentage of error R^2 value of 0.905. Various aspects of the 2006/2007 flood event in Kota Tinggi have been investigated. All previous studies determine the extreme multi-day rainfall event as the cause for flood to happen, with a brief note on the concurrent high tide event at the downstream area that reaches up to Kota Tinggi town and Rantau Panjang station. None of these studies take into account the cascading tidal effect in their model. Besides, previous studies also rely heavily on the observed flow at Rantau Panjang station without taking into consideration the invalidity of the stage-discharge rating curve when the riverbank overflow happens. This can only be confirmed through site verification in the flooded area. Therefore, this study will incorporate the tide effect that was observed at the time to improve the flood event simulation in Kota Tinggi. Given that this extra risk is ignored in previous study, flood frequency and severity may be higher than understood during design.

HEC-HMS is one example of a semi-distributed and integrated hydrological modeling system which is applicable for a wide variety of applications including hydrological and flood modeling. In Malaysia, HEC-HMS was frequently used by consultancy projects and employed by DID Malaysia for the Kelantan River Flood Forecasting program (Ramachandra Rao and Hamed 2019).

In flood modeling, the tide level became one of the important elements especially when the area affected is close to the sea. HEC-RAS is one of the most widely used models, offering a known water surface as model input for tide level (Fan et al. 2012; Romali et al. 2018; Muñoz et al. 2021). This model computes water surface profiles and energy grade lines in 1D, steady-state, and gradually varied flow analyses. It has been applied extensively in studying the hydraulic characteristics of rivers (Thakur et al. 2017; Ogras and Onen 2020). Natale et al. (2007) and El-Naqa and Jaber (2018) used HEC-RAS and HEC-GeoRAS as hydraulic model software to run the flood modeling with the contribution of tidal effect. Their analysis of floodplain showed the effect of floodplain modeling is much better in terms of flood extent and depth. A previous study by Shabri et al. (2011) showed high accuracy of the HEC-RAS model in simulating unsteady tidal flow under natural conditions. Adib et al. (2011) reported that several downstream areas along Sungai Johor were inundated and this is attributed to the reverse tidal flow. The magnitude of flooding was its maximum when heavy rainfall coincides with the upsurge of tides (Karki 2019). Therefore, flood modeling for the Kota Tinggi 2006/2007 flood event will be more significant with consideration taken on the tidal effect at downstream boundary conditions. In addition, the integration of HEC-GeoRAS into the hydrologic and hydraulic modeling provides detailing on flood mapping in the form of flood depth and flood extent.

To complement the flood model, flood frequency analysis has been primarily used to analyze annual peak flow for large and mid-size catchments (Shiau and Shen 2001). Flood frequency analysis is usually applied for model validation of the observed and simulated hydroclimatic variables such as rainfall and streamflow (Ramachandra Rao and Hamed 2019). The present study will examine the performance of five probability distribution models, namely GEV, Lognormal, Pearson 5, Weibull, and Gamma for modeling the annual flood of the Johor River basin (JRB). These models were chosen because they are commonly recommended by many researchers (Kim et al. 2017; Langat et al. 2019).

As mentioned above, flood mapping at Kota Tinggi town is important to predict the possibility of flood occurrences and formulate an emergency action plan, insurance policy, and development planning. 2D numerical hydraulic models are considered advanced enough for the prediction of flood depth and extent (Romali et al. 2018; Muñoz et al. 2021). Thus, the present analysis develops 2D flood mapping using the hydrodynamics model in order to estimate the present and future floods. One of the common practices in hydrology is estimating the Annual Exceedance Probability (AEP) and ARI (Ramachandra Rao and Hamed 2019). ARI refers to the return period in time between the events that have the same magnitude, volume, and duration (Zakaria et al. 2017). Information on ARI derived from frequency analysis is crucial for hydrologic analysis and designing hydraulic structures. This study concerned with developing an appropriate method for flood mapping by estimating the ARI of an annual flood using flood frequency analysis, examining the effect of the tide on flood modeling results, and mapping the 2006/2007 flood and the simulated floods for 25-, 50-, 100-, and 200-year return periods.

2 Study area

The study area was in the JRB as shown in Fig. 1. The basin covers 6319 km^2 and lies in the eastern part of the State of Johor with 122.7 km in length of the main river. The basin is exposed to the northeast (NE) monsoon which brings heavy rain from November to March (Wong et al. 2009). The average rainfall is 2470 mm per year. The average slope degree of the Johor River basin is about 0.1%, which means the basin is a low-lying and flat area. About 65% of the land use in the JRB is covered by various crops, mainly oil palm and rubber plantation (23%), residential and commercial areas (8%), and water bodies (4%). Based on the land use pattern, the JRB has a high impervious area due to the bigger coverage of vegetation land use type. Kota Tinggi is a district in Johor State. The distance

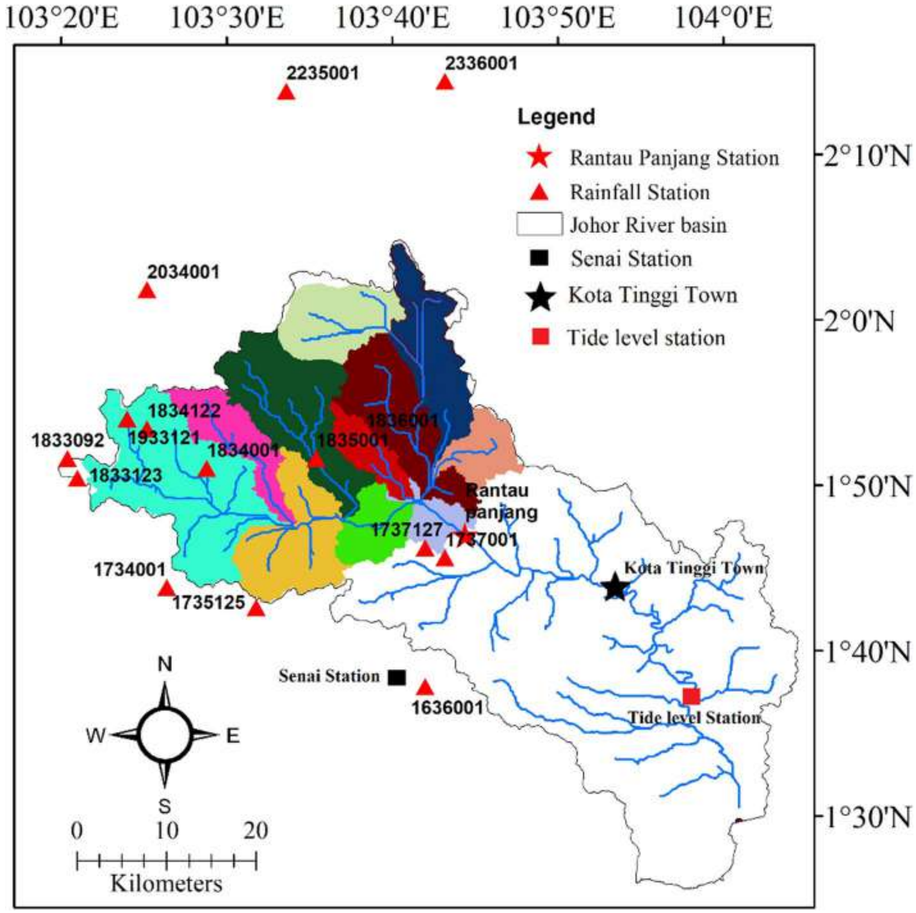


Fig. 1 The 11 lumped re-delineate sub-catchments of the Rantau Panjang catchment for HEC-HMS modeling. The location of 15 rainfall stations (red triangle) and Rantau Panjang gauging station as outlet (★)

between Kota Tinggi town and Rantau Panjang gauging station is about 12 km along the river. The area upstream of this station is about 3489 km^2, which consists of several small towns and villages, surrounded by various types of agricultural and mining activities.

For HEC-HMS hydrological modeling, a catchment is defined as a lump at a particular area. For this purpose, the Rantau Panjang catchment was re-delineate, whereas the Rantau Panjang gauging station acts as the basin outlet. The Rantau Panjang catchment consists of two reaches, Sungai Ulu Sebol and Sungai Sayong. The Rantau Panjang catchment was then divided into a total of 11 sub-catchments as shown in Fig. 1 which represented the sub-basin in the HEC-HMS model. A digital elevation model (DEM) based on LiDAR data with 1 m and 15 cm accuracy of horizontal and vertical positioning was collected from DID Malaysia for this study. Based on the ground verification in Kota Tinggi town, the LiDAR data were good to be used in flood modeling. The verification point was at the riverbank at Kota Tinggi town. During ground observation, the reading of the cross section was about 4.29 m compared to 4.13 m from the LiDAR data. It has been found that the topography is rather flat with an elevation between 0 and 50 m. The elevation becomes steeper toward the northeast up to 150 m where the Linggiu dam is located.

3 Data

Hydrometeorological information used in this study consisted of rainfall, evapotranspiration, streamflow, and tide level collected from DID Malaysia. Fifteen rainfall stations fairly distributed with sufficient periods were selected, and the location and details are shown in Fig. 1b and Table 1. The hourly data for the period of 1965–2010 were used. The percentage of area rainfall in 11 sub-catchments in the Rantau Panjang catchment was computed based on Thiessen Polygon Method as shown in Table 2.

This study used evapotranspiration data from the Senai Meteorological station, which was the closest to the JRB. The hourly streamflow data from 1965 to 2010, recorded at

Table 1 List of 15 rainfall stations for hydrological modeling

Sub-catchment	St. no.	St. name	River	Lat	Lon
1	1,636,001	Balai Polis Kg. Seelong	Tebrau	1.63	103.70
2	1,735,125	Ldg. Sedenak	Skudai	1.71	103.53
3	1,734,001	Loji Pembersih Bkt. Batu	Pontian Besar	1.73	103.44
4	1,834,122	Ldg Rengam	Sayong	1.89	103.42
5	1,933,121	Ldg. Getah See Sun	Sayong	1.90	103.40
6	1,833,123	Ldg. Benut	Benut	1.84	103.35
7	1,833,092	Ldg. Simpang Rengam	Benut	1.86	103.34
8	2,034,001	Felda Kahang Barat	Kahang	2.03	103.42
9	2,235,001	Sek. Men. Kahang	Kahang	2.23	103.56
10	2,336,001	Felda Nitar	Tambang	2.24	103.72
11	1,737,001	Sek. Men. Bkt. Besar	Johor	1.76	103.72
12	1,737,127	Bkt. Besar Felda	Linggui	1.77	103.70
13	1,836,001	Rancangan Ulu Sebol	Sebol	1.88	103.64
14	1,835,001	Ldg. Pekan Layang Layang	Sayong	1.86	103.59
15	1,834,001	Stesen Tele. Ulu Remis	Sayong	1.85	103.48

Table 2 The percentage (%) of area rainfall for each sub-catchment in the Rantau Panjang catchment

St. no.	Sub-basin										
	1	2	3	4	5	6	7	8	9	10	11
1,833,123	0	0	0	0	0	0	0	0	10.9	0	0
1,734,001	0	0	0	0	0	0	0	0	17.4	0	0
1,834,122	0	0	0	0	0	0	6.9	47.5	33.5	0	0
1,735,125	0	29.6	0	0	0	0	0	0	21.8	0	0
1,835,001	0	68.9	6.9	0	0	7.8	70.4	52.5	9.8	1.2	0
1,833,092	0	0	0	0	0	0	0	0	0.2	0	0
1,933,121	0	0	0	0	0	0	0	0	6.4	0	0
2,034,001	0	0	0	0	0	12	5.6	0	0	0	0
1,836,001	80.5	1.5	93.1	100	90.9	80.2	17.1	0	0	98.8	88.3
2,336,001	0	0	0	0	4	0	0	0	0	0	0
2,038,001	0	0	0	0	5.1	0	0	0	0	0	6.3
1,739,003	19.5	0	0	0	0	0	0	0	0	0	5.4
Sum (%)	100	100	100	100	100	100	100	100	100	100	100

Rantau Panjang gauging station (latitude: 01° 46′ 50’’, and longitude: 103° 44′ 45’’) located about 12 km upstream of Kota Tinggi town, were used in this study. There are about seven water years of missing data in 1967, 1968, 1972, 1975, 1993, 2003, and 2007 (Table 3), which was defined as three or four months of continuously missing data. This is partly due to technical problems such as the failure of the data logger. As a result, 38 out of 45 annual maximum data were used in this study. Estimation of annual maximum streamflow for the selected water year is shown in Table 3.

At the downstream boundary condition, the hourly tide level was used from 00:00 to 24:00, starting from December 11, 2006, to January 20, 2007. Figure 2 shows the highest tide level at 1.45 m during the 2006/2007 flood event at Kota Tinggi. The phenomena occurred twice, which was on December 11, 2006, and January 20, 2007. The highest tide that occurred during that flood event was 1.90 m.

Table 3 The annual maximum discharge from 1965 to 2010

Year	Q (m^3/s)	Year	Q (m^3/s)	Year	Q (m^3/s)	Year	Q (m^3/s)	Year	Q (m^3/s)
1965	98.666	1975	–	1985	363.301	1995	724.734	2005	234.605
1966	310.024	1976	204.320	1986	203.149	1996	192.824	2006	361.213
1967	–	1977	141.708	1987	204.276	1997	86.800	2007	–
1968	–	1978	263.037	1988	173.175	1998	166.181	2008	90.186
1969	587.903	1979	336.451	1989	511.985	1999	165.053	2009	135.495
1970	281.363	1980	118.434	1990	105.950	2000	231.291	2010	200.350
1971	134.950	1981	278.257	1991	246.903	2001	186.729		
1972	–	1982	539.315	1992	220.555	2002	140.284		
1973	79.055	1983	549.600	1993	–	2003	–		
1974	109.343	1984	301.118	1994	255.875	2004	226.472		

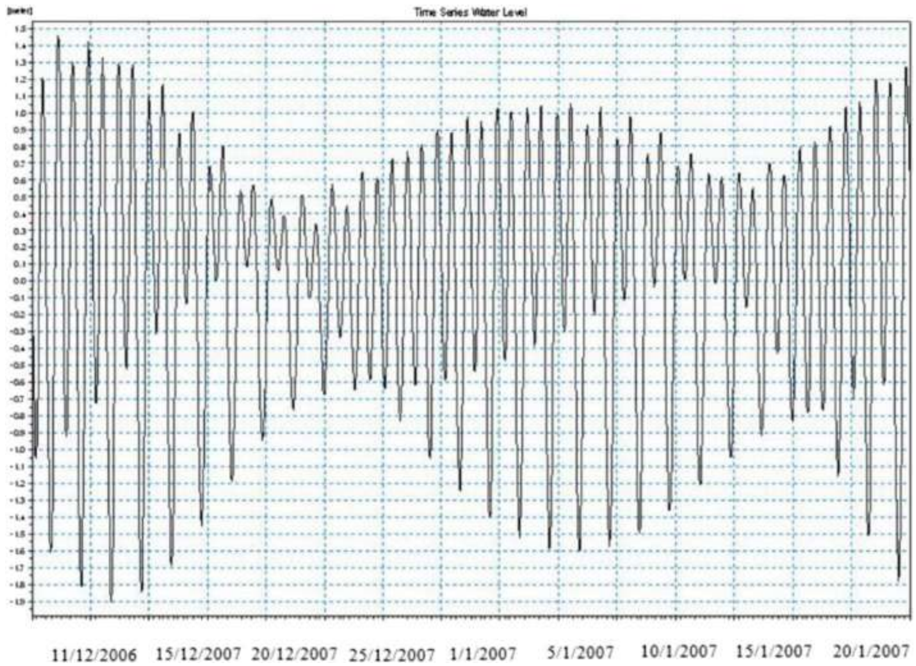


Fig. 2 Observed tidal cycle between December 11, 2006, and January 20, 2007, at the estuary of JRB

4 Methods

4.1 Procedure

1. Initially, the land use, DEM, river sub-catchment, river profile, rainfall, streamflow, and tide level data were collected and compiled.
2. Then, several distribution models, namely GEV, Gamma, Lognormal, Pearson 5, and Weibull were used for the analysis of annual maximum flow from 1965 to 2010 to determine the flow for 10, 25, 50, and 200 years. EasyFit software was used to select the best-fitted model based on the goodness-of-fit (GOF) performance by using Kolmogorov–Smirnov (K–S) test.
3. After that, the HEC-HMS hydrological model was used to simulate the flood hydrograph in Rantau Panjang catchment. The model calibration and validation used rainfall and flow data from September 7–12, 2002, and January 19–31, 2003, respectively. The minimum relative error (MRE) and model efficiency (ME) were also used to assess the performance of the calibrated and validated model.
4. The model was then optimized and corrected by considering the riverbank overflow during the 2006/2007 flood event. Site verification was done to inspect the flood mark in Kota Tinggi town to assess the actual flood depth due to riverbank overflow.
5. Based on the optimized model, simulation was run for the 2006/2007 flood event in Rantau Panjang. Then, the simulated hydrograph was routed downstream to Kota Tinggi

town by using the Muskingum routing method to simulate the 2006/2007 flood event in Kota Tinggi town.
6. After that, the simulated hydrographs were used as the main input for HEC-RAS hydraulic modeling and HEC-GeoRAS for flood mapping, respectively, by considering the tidal and without tidal effect. The flood depth and extent were verified with the existing flood marks.
7. Finally, the study simulated floodplains for 25, 50, 100, and 200 ARIs.

4.2 Distribution model

Distribution models such as GEV, Gamma, Lognormal, Pearson 5, and Weibull were run accordingly for 38 years of available dataset. The best-fitted model was analyzed by using EasyFit software and then tested by using GOF to estimate the flow of 10, 25, 50, and 200 years.

4.3 Hydrological model

The purpose of HEC-HMS hydrological modeling in this study was to route the flow of hydrograph from the upstream of Rantau Panjang gauging station to downstream of Kota Tinggi town. Then, the hydrograph in Kota Tinggi was used for HEC-RAS hydraulic modeling. The basic input requirements for the HEC-HMS consist of the hydrological model parameter, initial soil moisture condition (Table 4), meteorological data (evaporation and rainfall), and streamflow data for model calibration and validation. The options for rainfall excess transformation include kinematic wave Unit Hydrograph (U-H) methods. The synthetic U-H and quasi-U-H methods that are available include Snyder, Clark Time Area, Soil Conservation Service (SCS), and Santa Barbara U-H. The SCS Hydrograph was selected in this model as it is also recommended by the Urban Stormwater Management Manual for Malaysia (MSMA) and suit to Malaysian condition (Takaijudin and Ghazali 2011). Soils Moisture Accounting (SMA) was used for losses method to suit the type of environment and land use in the JRB. The SMA method was selected after a few comparative studies, especially on the landuse. Basically, landuse in the study area has bigger storage and impervious area. The infiltration, losses, impervious, and storage are good parameters for tropical countries. Therefore, it seems that SMA is the best technique to estimate runoff. SMA was calculated based on the soils, canopy, roughness, and groundwater storage. Since field measurement was not carried out, the hydrological parameters were estimated based on MSMA (DID 2011). The soil moisture accounting was selected using loss method, simple canopy for canopy method, and simple surface for surface method.

For modeling, the catchment was divided into eleven sub-catchments (nodes in HEC-HMS) as shown in Fig. 1, assumed as a lumped model for SMA parameters. The selections of nodes are based on the consideration of certain aspects of the catchment characteristics and locations where the determination of flow is required. Meanwhile, the transform method used Clark Unit Hydrograph and linear reservoir for the baseflow method. The simulated hydrograph was calibrated in September 2002 and validated in January 2007. The model efficiency was estimated by using the Nash–Sutcliffe method. Rainfall-runoff simulations were run for every sub-catchment, and the results were then combined to produce the main hydrograph.

Table 4 Model parameter values for soils moisture accounting technique in HEC-HMS based on MSMA (DID 2011)

SMA	Canopy (%)	Surface (%)	Soil (%)	GW1 (%)	GW2 (%)	Canopy storage (mm)	Surface storage (mm)	Max. infiltration (mm/hr)	Imper. (%)
	50	10	40	30	25	4.9	5	15	25
	Soil storage (mm)	Tension storage	Soil perc. (mm/hr)	GW1 storage (mm)	GW1 perc. (mm)	GW1 coeff. (hr)	GW2 storage (mm)	GW2 perc. (mm/hr)	GW2 coeff. (hr)
	150	50	3	1000	2	5	1000	2	25
Baseflow (linear reservoir)		Initial type		GW1 initial (m^3/s)	GW1 coeff. (hr)	GW1 reserv	GW2 initial (m^3/s)	GW2 coeff. (hr)	GW1 reserv
		Discharge		5	4	1	0	0	1
Clark transformation		Time of concentration (hr)			Storage coeff. (mm)				
		102.2			9.8				

coeff. coefficient, *GW* Groundwater, *Imperv*. Impervious, *Max*. maximum, *perc*. percolation, *reserv*. reservoir

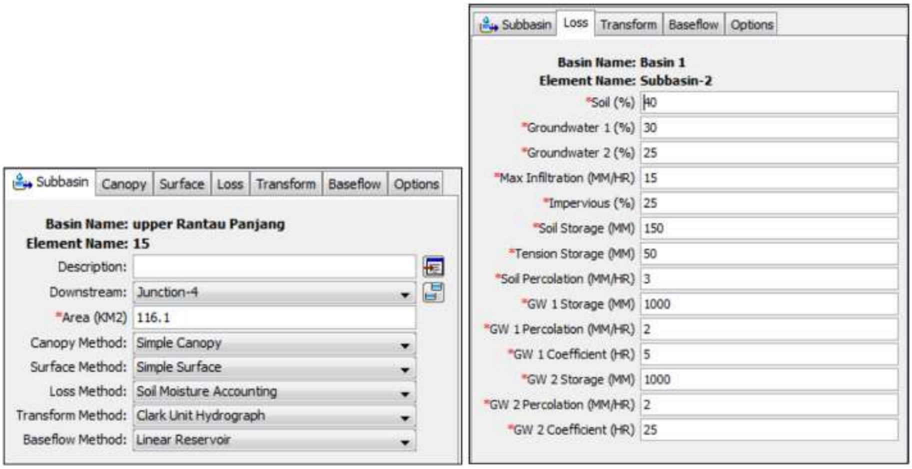
4.3.1 Hydrological model parameter

The input for method setup and properties of hydrological losses are shown in Fig. 3. The input for percent of soil loss was based on *Harimau Malay* soil characteristics, and the groundwater movement depends on the geological condition of the area. *Harimau Malay* soil is derived from older alluvium of granitic materials, brownish in color (hue 7.5–10 YR), clayey, few plinthite, well-drained, and have a deep soil profile (Department of Standards Malaysia 2004). The maximum infiltration is 15 mm/hr. The impervious area is 25% as an agricultural area. Soil storage is 150 mm and tension storage is 50 mm. Meanwhile, soil percolation is 3 mm/hr, Groundwater 1 storage is 1000 mm, Groundwater 1 percolation is 2 mm/hr, and GW 1 coefficient is 5 h. However, Groundwater 2 storage is 2 mm/hr and GW 2 coefficient is 25 h. All the properties of losses were set to all sub-catchments.

On the hydrological transform method, the candidate parameters of time of concentration (T_c) and storage coefficient (S_c) in the hourly unit were calculated. The two parameters were used for the development of a synthetic unit hydrograph. The T_c is estimated by using the Barnsby–William formula. The resulting hydrographs were then compared with the observed hydrographs. If the match is not satisfactory, the parameters are tuned until the best match is obtained. The T_c and S_c for the Rantau Panjang catchment were found to be 102.2 h and 9.8 h. The linear reservoir method for baseflow models was used to assess the overall retention capacity of the catchment in terms of both peak response and baseflow. The GW 1 initial was defined as 5 m^3/s, with the GW 1 coefficient of 4.

4.3.2 Routed flow from Rantau Panjang gauging station to Kota Tinggi town

Five junctions were installed in the HEC-HMS model for hydrologic flow routing (Fig. 4). The flow at the upstream (Rantau Panjang gauging station) can be observed but not the downstream (Kota Tinggi town). Therefore, the flow downstream has to be estimated by routing the observed flow from the upstream. This was carried out by routing the flow using the Muskingum routing method, which uses a simple conservation of mass approach to route flow through the stream and reaches. The distance from Rantau Panjang to Kota



Basin Name: **upper Rantau Panjang**
Element Name: **15**
Description:
Downstream: Junction-4
*Area (KM2) 116.1
Canopy Method: Simple Canopy
Surface Method: Simple Surface
Loss Method: Soil Moisture Accounting
Transform Method: Clark Unit Hydrograph
Baseflow Method: Linear Reservoir

Basin Name: **Basin 1**
Element Name: **Subbasin-2**
*Soil (%) 40
*Groundwater 1 (%) 30
*Groundwater 2 (%) 25
*Max Infiltration (MM/HR) 15
*Impervious (%) 25
*Soil Storage (MM) 150
*Tension Storage (MM) 50
*Soil Percolation (MM/HR) 3
*GW 1 Storage (MM) 1000
*GW 1 Percolation (MM/HR) 2
*GW 1 Coefficient (HR) 5
*GW 2 Storage (MM) 1000
*GW 2 Percolation (MM/HR) 2
*GW 2 Coefficient (HR) 25

Fig. 3 The interface and input of HEC-HMS method setup and loss parameter in this study

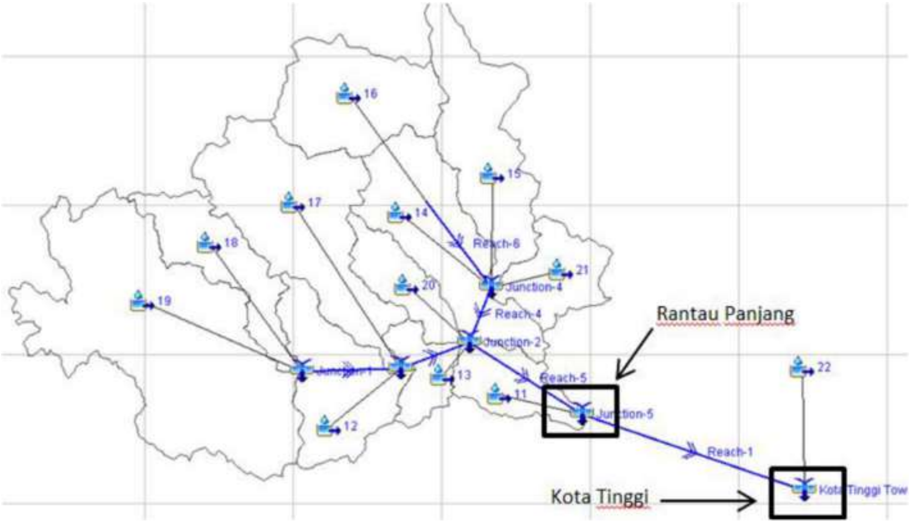


Fig. 4 Routing model from Rantau Panjang gauging to Kota Tinggi town

Tinggi town is about 15 km. By adding the travel time for each reach and a weighting between the influence of inflow and outflow, it is possible to approximate the flow attenuation.

4.4 Hydraulic modeling

For the HEC-RAS hydrodynamic model, additional data on river cross sections, river basin maps, sub-catchment maps, and tidal data were computed. The purpose of hydraulic modeling is to estimate the water level in relation to flow discharge. In this study, a tide level was inserted at the downstream boundary condition, while a flow hydrograph was set at the upstream. The tide level was based on the 2006/2007 flood event. Figure 5a shows the geometrical model setup for flood simulation at Kota Tinggi town. Cross sections gathered from LiDAR data are located at relatively short

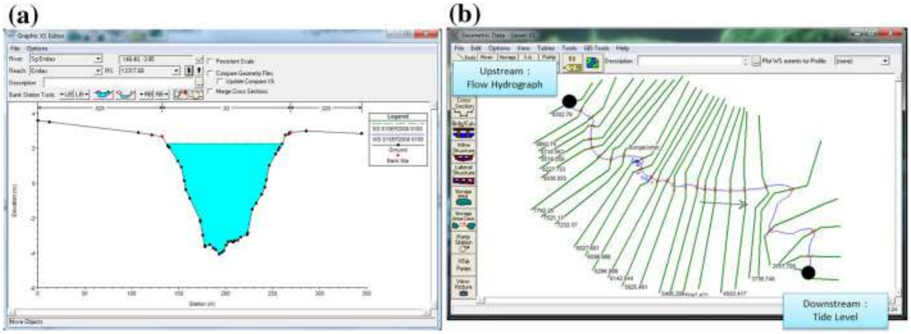


Fig. 5 **a** The cross-section editor in HEC-RAS. **b** The geometry model setup in HEC-RAS at Kota Tinggi

intervals along the stream to characterize the flow carrying capacity of the stream and its adjacent floodplain. Cross sections are obtained at selected locations throughout the stream and at locations where changes occur in discharge, slope, shape, and roughness at locations. The cross sections were perpendicular to the riverbank and were identified from a topographic map. This is compulsory for stability of HEC-RAS modeling. In addition, the cross section has been filtered in order not to exceed 400 points or nodes because this is the maximum requirement in the HEC-RAS model as shown in Fig. 5a. In order to verify the accuracy of LiDAR data, ground verification was carried out at the riverbank across Kota Tinggi town. During ground observation, the reading of the cross section was about 4.29 m compared to 4.13 m from the LiDAR data. Based on the ground verification, the LiDAR data were good to be used in flood modeling. All the cross sections were adjusted and corrected based on ground verification, in terms of the location of banks and points of the cross section. Meanwhile, a setup of manning roughness for each cross section was made based on landuse. However, the coefficient of manning was standardized into one value ($n=0.035$) reflecting the similar landuse cover in the area.

Based on important parameters marked in Fig. 5a, the inlet was determined as the upstream boundary condition, with main input data being hourly flow and tide level derived from downstream boundary condition. The selected cross section was perpendicular to the river channel to ensure stability of HEC-RAS modeling. Additionally, flow can be changed at any location within the river system. This analysis used unsteady flow because the upstream boundary condition during the flood event was high velocity which caused flooding. The study used a subcritical flow regime for the downstream boundary conditions and an open free-flow method for the upstream. Previous study by Sholichin (2019) used a subcritical flow analysis of flood characteristics in Ciliwung River, Indonesia, and the majority of analysis conducted using HEC-RAS for downstream cross section is done in the subcritical regime (Thomas and Williams 2007). Connections to junctions are considered internal boundary conditions, which are automatically listed based on how the river system is defined in the geometric data editor. For the downstream boundary condition, the tidal cycle was considered in order to make an effect of tidal during flood simulation.

4.5 Flood mapping with HEC-GeoRAS model

The 2006/2007 floodplain was simulated in 1D result and then converted into 2D by using HEC-GeoRAS. The HEC-GeoRAS mapping tool generates the flooding extents, by intersecting the water surface elevations at each cross section with the digital terrain surface. The HEC-RAS hydraulic model's goal was to provide accurate flood plain maps based on the hydrologic model's flows. The geospatial data in ArcGIS were processed by using the Geospatial Extension tool in HEC-GeoRAS and to create the geometry file for the HEC-RAS model. Geometric data were then prepared for import into HEC-RAS. The flood boundary was computed by maximizing the cross-section extent for inundation after running the model. The geographical representations of floodplain depths and extents provide great insight into the model response and ideally the behavior of the natural system. In the end, the simulated 2006/2007 floodplain was verified with the observed flood marks at the actual site.

4.6 Average recurrent interval (ARI)

Once the simulated floodplain is verified, the model will simulate the inundated area based on the ARI. An ARI represents an average number of years between similar events over a very long period of record. It can be determined by using Eq. 1;

$$P = 1 - \left(1 - \frac{1}{T_r}\right)^N \tag{1}$$

where P is the probability of a returning value, and T_r is the return period, occurring at least once in N successive years. The ARI refers to the return period of discharge value, where the average length of the time between events has the same magnitude, volume, and duration. Specifically, the return period, T_r, is given by

$$T_r = \frac{1}{P} \tag{2}$$

where T_r is in years and P is the AEP in percent. Hence, 1% of AEP has ARI for 100 years. A design flood is a probabilistic or statistical estimation being generally based in some form of probability analysis of flood and rainfall data. In hydrology, a design is not only for routine flow design, but more important is for maximum flood estimation or maximum peak flow for several calculated years. The design is intended to obtain the value with an extremely low probability of exceedance. Here, the GEV distribution function of x was written in the inverse form by substituting $F=1–1/T$ where T is the return period, as follows (Ramachandra Rao and Hamed 2019);

$$x = u + \frac{a}{x_{\text{avg}}}\left[1 - (-\log F)^K\right] \tag{3}$$

Then, the probability of a flood to occur in any year is given by;

$$P_x = 1 - \frac{1}{T_r} \tag{4}$$

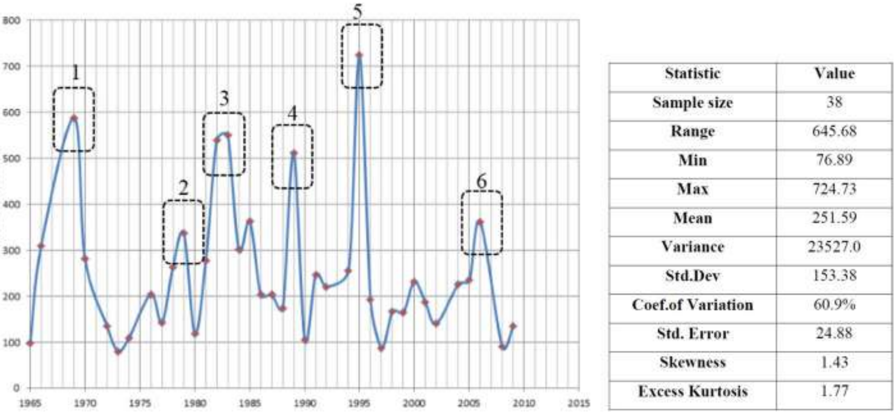
where T_r is the return period, and the T-year quantile can be estimated by Eq. 2.

In Malaysia, a 100-year ARI is a standard design flood protection for channels and bridges (Romali et al. 2018). Given the more frequent and extreme occurrence of flood events in the recent decades, and rapid urbanization in the area, it was suggested that the design standard is extended to 200-year return periods for urban drainage construction and flood control design (Deni and Jemain 2008). Therefore, in this study, 25, 50, 100, and 200 ARIs were considered.

5 Results and discussion

5.1 Hydrological distribution model

Figure 6 shows the annual flood variation from 1965 to 2010. The highest flow of 724.7 m^3/s was recorded in 1985 and the lowest in 1973, which was 76.4 m^3/s. There are six biggest floods over the 45-years’ period, which occurred in 1969, 1979, 1982, 1989,



Statistic	Value
Sample size	38
Range	645.68
Min	76.89
Max	724.73
Mean	251.59
Variance	23527.0
Std.Dev	153.38
Coef.of Variation	60.9%
Std. Error	24.88
Skewness	1.43
Excess Kurtosis	1.77

Fig. 6 The annual peak flow and descriptive statistics of annual flood at Rantau Panjang gauging station from 1965 to 2010

1995, and 2006/2007. In the 2006/2007 flood event, one of the major contributors to the flood was the tidal effect downstream. The data were positively skewed with a coefficient of variation of 61%.

Table 5 presents the performance ranking of the distribution models based on the Kolmogorov–Smirnov GOF tests. The parameters are shape parameter (∝, *k*), continuous scale parameter (σ, β), and continuous location parameter (μ, γ). GEV is ranked first, followed by Pearson 5, Lognormal, Weibull, and Gamma. A closer *P*-value to one indicates a better-fit distribution. In this analysis, the GEV with a *P*-value of 0.99 emerges as the best distribution model. In addition, based on the results of the probability difference and probability–probability (P–P) plots for the five models, the GEV model is the closest to the line and selected as the best-fitted model distribution.

Table 6 shows the simulated peak discharge for 25, 50, 100, and 200 ARIs which were 595, 691, 786, and 852 m^3/s, respectively. The flood depth was simulated to 3.8, 6.0, 7.0, and 7.8 m, respectively, for 25, 50, 100, and 200 ARIs.

5.2 Hydrological model calibration and validation

A set of single-storm event data was used to calibrate the optimized HEC-HMS hydrological parameters for the Rantau Panjang catchment. The model calibration used rainfall and

Table 5 Fitting results and goodness-of-fit test ranking for the probability distribution of annual flood

Distribution	Parameters	Kolmogorov–Smirnov	
		P	Rank
Gen. extreme value	$k=0.19646$, $\sigma=93.782$, $\mu=175.09$	0.99010	1
Pearson 5	$\sigma=3.8871$, $\beta=762.79$, $\gamma=-8.3373$	0.98806	2
Lognormal	$\sigma=0.74468$, $\mu=5.0606$, $\gamma=46.792$	0.97408	3
Weibull	$\alpha=1.0908$, $\beta=178.53$, $\gamma=78.521$	0.97101	4
Gamma	$\alpha=1.091$, $\beta=158.6$, $\gamma=78.569$	0.90748	5

Table 6 Estimated peak flow and flood depth for 25, 50, 100, and 200 ARIs

ARI	Estimated peak flow (m^3/s)	Flood depth (m)
25	595	3.8
50	691	6.0
100	786	7.0
200	852	7.8

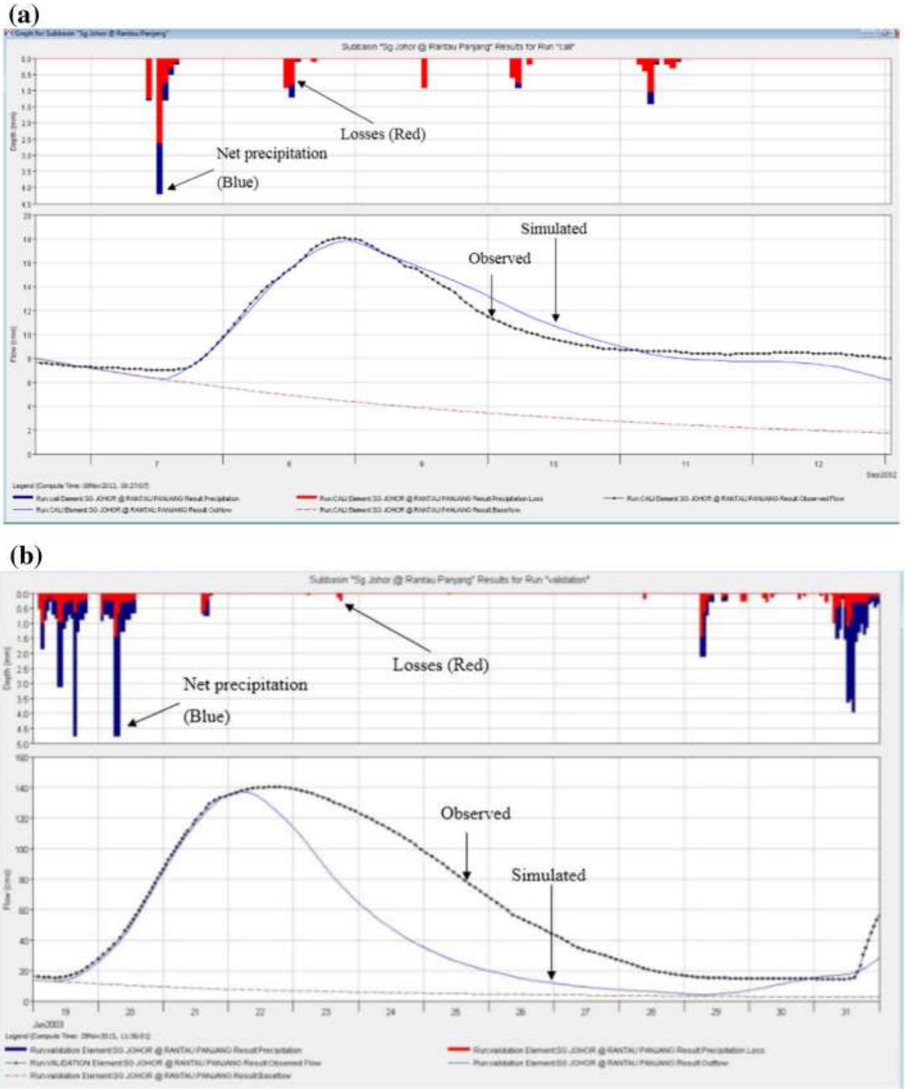


Fig. 7 **a** Calibrated and **b** validated hydrographs in September 2002 and January 2003, respectively, for HEC-HMS hydrological model

flow data from September 7–12, 2002. The results in Fig. 7a showed the losses (in red) and net precipitation (in blue) during model calibration. The losses are defined as the loss of water from a river channel due to leakage, seepage, evaporation, and others. The simulated peak flow for the event in September 2002 was 17.9 m^3/s, which was close to the observed peak discharge of 18.10 m^3/s. For this event, the total precipitation was 15.20 mm; the total loss was 9.47 mm, and the base flow 1.58 m^3/s. The validation set of storm event data was used to validate the HEC-HMS model based on the optimized model parameters obtained during calibration. The model validation used rainfall and flow data from January 19–31, 2003. In Figure 7b, the observed peak discharge (140.28 m^3/s) was close to the observed peak discharge (137.2) m^3/s. The total area precipitation during this event was 78.50 mm, of which 25.60 mm was losses and 5.35 m^3/s as baseflow. Initially, the results show a similar pattern, but after the hydrograph started to decrease, the simulated pattern was slightly different compared to the observed one. It seems that the water from the upstream traveled faster to downstream compared to the observed hydrograph. A similar pattern was also observed by Razi et al. (2010) although with a different degree depending on the simulated event. The calibration and validation result in Table 7 based on MRE showed the value of 0.1 and 0.2, respectively, and ME of 87.34 and 73.00%, respectively, which is generally acceptable for flood models.

5.3 Hydrological model optimization

For optimization, the study adjusts the time of concentration and storage coefficient. The peak flows for calibration and validation phases were more than 70% accurate. However, the peak flows during the 2006 and 2007 floods were about double the observed values. This happens due to the river flow having spilled over the banks, and the water level-flow rating curve is no longer valid. Site verification was made at the riverbank, bridge, and building at the immediately flooded downstream area in Kota Tinggi town for confirmation as shown in Fig. 8. The details on full site verification can be found in Table 7. These underestimations of peak flow were corrected by simulating the hydrograph using the model coefficients during the calibration and validation stages.

5.4 Simulation of 2006/2007 flood event

The result of the simulation at Rantau Panjang is shown in Fig. 9. It was found that the simulated hydrograph was much higher than the observed hydrograph. This was due to flood overflows on the riverbank; thus, the stage-discharge rating curve during a flood event is

Table 7 The average observation (Obs.), MRE, ME, and peak flow for the calibration and validation of the HEC-HMS hydrological model in September 2002 and January 2003, respectively

	Average (Obs.)	MRE	ME (%)	Peak flow (m^3/s)	
				Simulated	Observed
Calibration	10.4	0.1	87.34	17.90	18.90
Validation	75.2	0.2	73.00	137.20	140.28
Storm event 2006				625.30	314.20
Storm event 2007				743.90	361.21

Fig. 8 Site verification on flood marks at the riverbank, bridge, and building at the flooded area in Kota Tinggi town

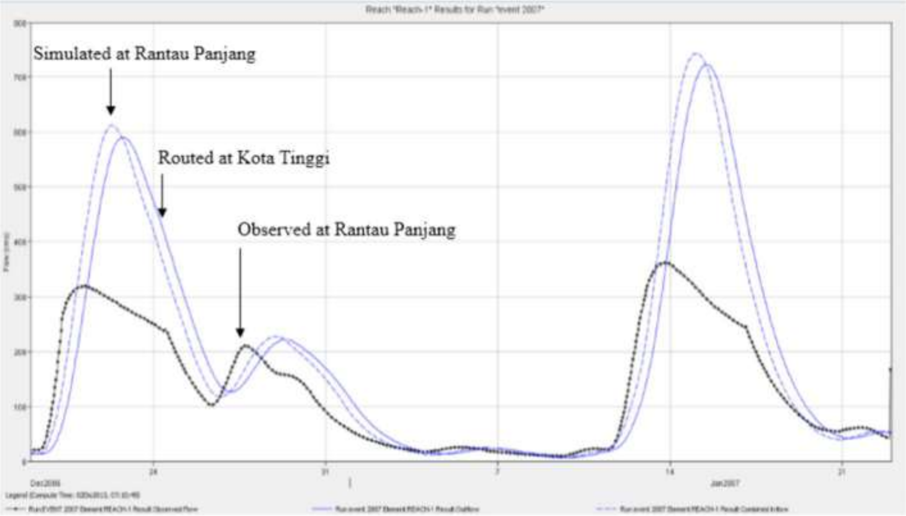


Fig. 9 The simulated and observed hydrograph data from December 19, 2006, to January 23, 2007, at Rantau Panjang and comparison with the routed flow at Kota Tinggi town

not valid (Fig. 8). Simulation of hydrograph using hydrological model using rainfall as the main input data provides an opportunity to correct the data. Despite having 3 days of heavy rainfall of 366 mm during floods in December 2006 and 416 mm in January 2007, the observed peak discharges were low, 314, and 361.21 m^3/s, respectively. The simulated hydrographs provide more reasonable results of 625.3 m^3/s for the December 2006 flood and 743.9 m^3/s for the January 2007 flood. Out of 573.23 mm total precipitation in December 2006, 98.18 mm was lost and 7.93 m^3/s appeared as base flow. The results of the model calibration and validation closely follow the same pattern with the observed hydrographs as far as the water level does not exceed the river bank. This suggests that the optimized hydrological parameters for hydrological losses, runoff transformation, and baseflow could be used for filling in missing hydrograph records during the large flood.

Figure 10 shows the 1D Water Level Simulation for the 2006/07 Flood Event. The second wave caused a deeper flood with a wider inundated area. Besides, there is slightly

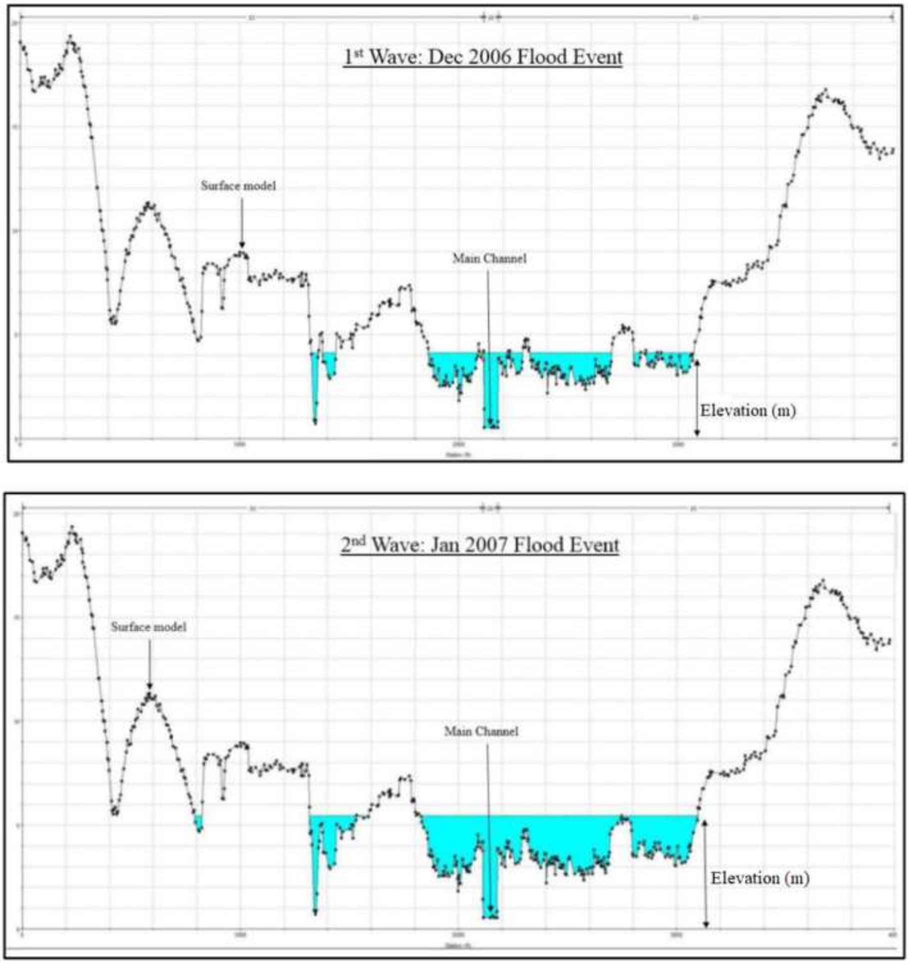


Fig. 10 The 1D cross-section profile for peak flow during the 1st and 2nd wave in December 2006 flood event at Kota Tinggi

higher total rainfall during the second wave where the water storage in terms of soil moisture, pond, and depressions is already filled up by the first event. As such, a larger portion of the rainfall appeared as storm flow.

5.5 Routed flow from Rantau Panjang to Kota Tinggi town

Figure 9 shows the simulated hydrograph at Rantau Panjang station and the routed hydrograph at the Kota Tinggi town based on the Muskingum routing method. The Muskingum routing method uses a conservation of mass approach to route an inflow hydrograph. The travel time of a flood wave moving through a reach was estimated by taking the difference between a similar point on inflow and outflow during the time of peak for both Rantau Panjang station and Kota Tinggi town hydrographs. This parameter ranges between 0.0 (maximum attenuation) and 0.5 (no attenuation). From the initial estimate of 0.25, we have refined the value to 0.40 through model calibration. The highest simulated peak flow at Kota Tinggi town was 590 m^3/s in December 2006 (1st event) and 723 m^3/s in January 2007 (2nd event). Previous study by Abdullah et al. (2018) did not take into account the underestimation of the peak flow due to the riverbank overflow in their TREX model. Therefore, it is pertinent that future modeling works to simulate the actual hydrograph of the peak flow before subsequent analysis, to avoid underestimation of the flood risk in Kota Tinggi town.

5.6 Tidal effect on flood modeling

Figure 11a, b compares 1D cross-section profile with tidal and without tidal effect. Figure 11a shows the maximum simulated water level (5.3 m) when the tidal effect was factored in, which is quite close to the observed maximum level (flood mark) of 5.45 m. However, when the tidal effect is not considered, the simulated maximum flood level is only 3.3 m as shown in Fig. 11b. Therefore, it is crucial to consider tidal in any flood modeling especially when the affected area is flat or close to river mouth which can cause backwater phenomena. Figure 12a shows the simulation of the inundated area with and without tidal effect. Figure 12b shows that the difference in flood coverage with and without tidal effect was 43.16%.

5.7 Kota Tinggi town flood mapping for 2006/2007 flood event

The result of the HEC-RAS model was exported to HEC-GeoRAS to map the flood extent. The 1D cross-section profile for water level was converted to 2D flood using shallow water equation. Figure 13 shows the flood progression from December 12 to 28, 2006. Between 21st and 23rd December, the heavy rainfall had caused water overflow to as far as 1.5 km from the river bank. The peak flow of 625 m^3/s occurred on 23rd December consequently resulting in a maximum depth of 5 m above the ground. The river started to overflow on 11th January, by first inundating Kampung Kelantan, which is located in a tributary catchment as shown in the dash line box. Within 2 days, the flood has inundated the whole of Kota Tinggi town. The time to peak during the second wave took only 2 days compared to 5 days during the first wave.

The flashier flood during the second wave suggests a smaller capacity of the catchment to store additional water as the storage has been filled up by the first wave. The flood

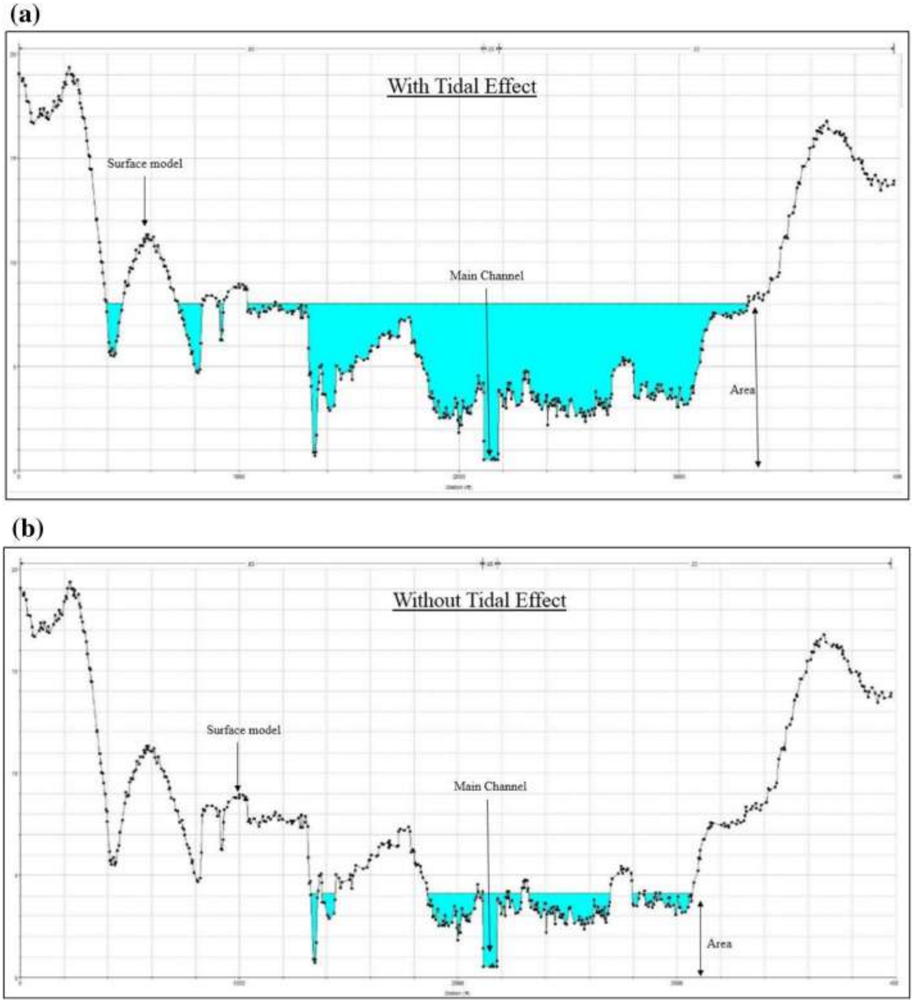


Fig. 11 Simulated flood level with (**a**) and without (**b**) tidal effect at cross-section AB

chronology started with the overbank flow on the tributary, especially at Sungai Kundang. The simulated floodplain is very similar to the actual flood in terms of flood boundary and depth. To demonstrate more clearly the differences between the two flood waves, their flood layers were overlaid as shown in Fig. 14. An additional 3.83 km^2 was affected by the second wave or equal to 7.3% bigger compared to the first event.

5.8 Flood mark for 2006/2007 flood event

To check the model's approximation in the real world, it is necessary to calibrate and verify the model against a set of observed flood data or flood evidence (Howe Lim and Melvin Lye 2003). Figure 15 shows the water spilled from the main channel and flooded the areas up to 1.3 km from the riverbank. The red triangles are observed flood marks in the study

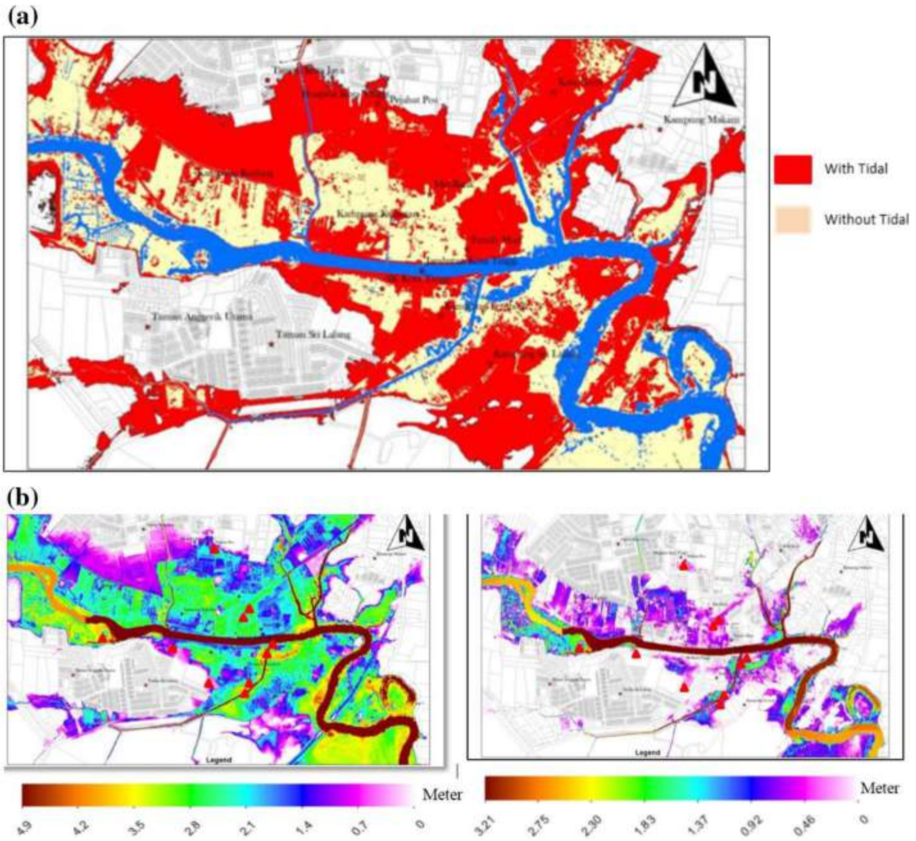


Fig. 12 **a** The differences in the simulated inundated area at Kota Tinggi during the 2006/2007 flood event with (red) and without (cream) considering tidal effect. **b** Inundated area during the 2006/2007 flood event with and without tidal effect

area. The study was validated by comparing the simulated flood against the observed value at 12 stations for the January 2007 flood event (Fig. 8). The simulated flood boundary was also found to be close to the actual flood boundary. Table 8 provides a detailed comparison in terms of flood depth between the observed flood mark and simulated flood level. The simulated flood depth was compared with and without tidal effects. The results showed that the difference with tidal effect is more than 90% and without tidal is more than 40%.

5.9 Flood maps for 25, 50, 100, and 200 ARIs with tidal effect

Figure 16 shows the water level of various ARIs derived from the simulated hydrographs. The simulated flood depths are 3.8, 6.0, 7.0, and 7.8 m for 25, 50, 100, and 200 ARIs, respectively. The simulated peak flows were used in HEC-RAS to model water level and the inundated area. In the HEC-RAS model, the discharge values used for 25 ARI, 50 ARI, 100 ARI, and 200 ARI were 595, 691, 786, and 852 m^3/s, respectively.

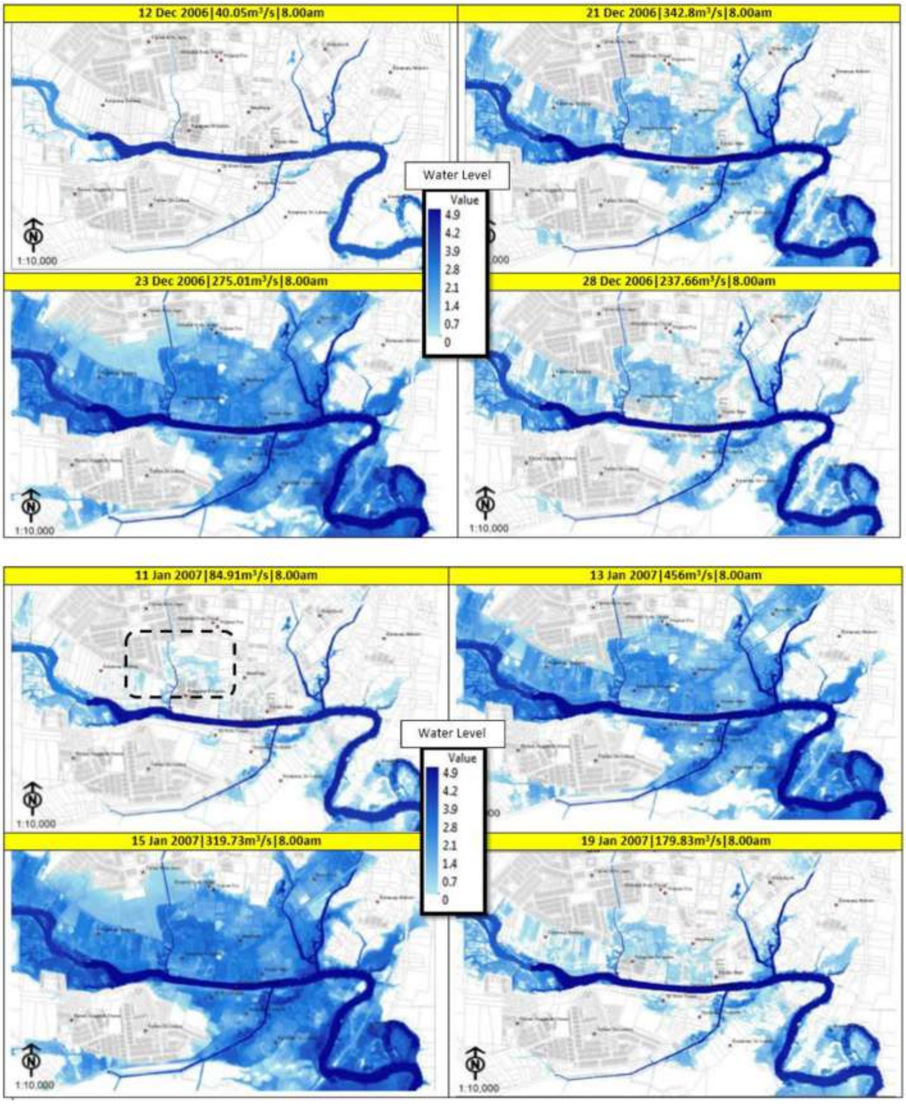


Fig. 13 The simulated inundated areas as the floods progress and recede during the 1st and 2nd flood waves in December 2006 and January 2007, respectively

The flood maps for 25, 50, 100, and 200 ARIs are shown in Fig. 17. The result indicates that the numerical model gives a realistic detection of the flow of floodplain together with a good calibration data model. It was found that the simulated 100-year flood has very similar coverage and depth with the January 2007 flood event at Kota Tinggi. For 25 ARI, the total inundated area was covered for about 654.09 ha, while the water level above 3 m was about 15.15 ha. Based on the flood simulation, the water level started to overflow at the tributary. In summary, the flood map for 25, 50, 100,

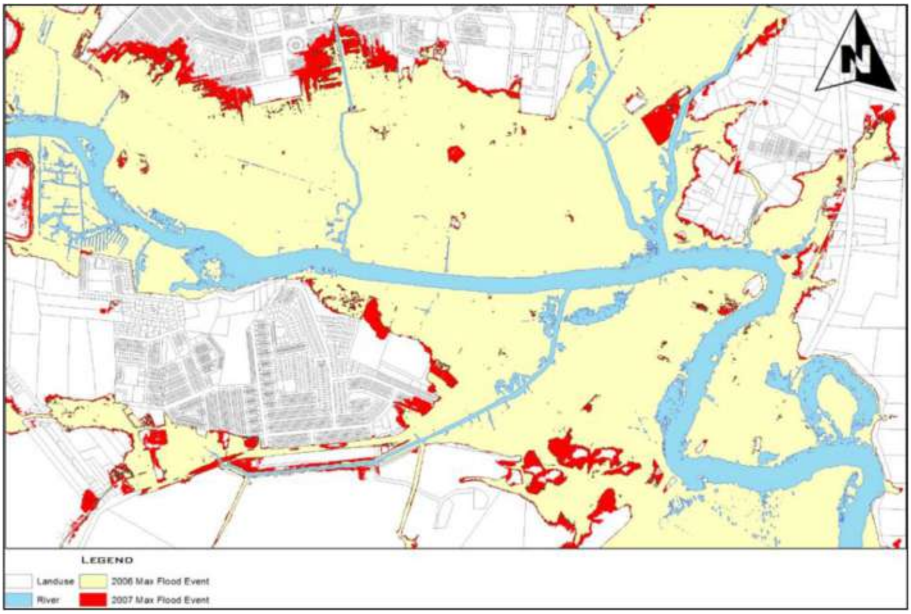


Fig. 14 Simulation of the additional flooded area in January 2007 (red) compared to flood coverage in December 2006 (cream)

Fig. 15 The location of flood marks (triangle) for the 2007 flood event over the simulated flood coverage

Table 8 The percentage differences between observed (Obs.) and simulated (Sim.) inundated area at Kota Tinggi town during the January 2007 flood event

St. no.	Location	Obs. WL (m)	Sim.WL with tidal effect (m)	Sim.WL without tidal effect (m)
1	Kota Tinggi bridge	5.5	4.9	4.7
2	Family Mart	2.12	2.08	1.05
3	TNB Family Mart	2.5	2.37	1.9
4	Maybank	2.15	2.28	1.5
5	Kg. Kelantan	1.88	1.7	0
6	Big Clock	2.33	2.32	1.65
7	Kota Tinggi hospital	0.88	0.95	0
8	Kota Tinggi High School	2.4	2.22	1.92
9	Football field 1	3.74	2.25	0
10	Football field 2	2.8	2.1	0
Accuracy			91.37%	43.16%

WL Water level

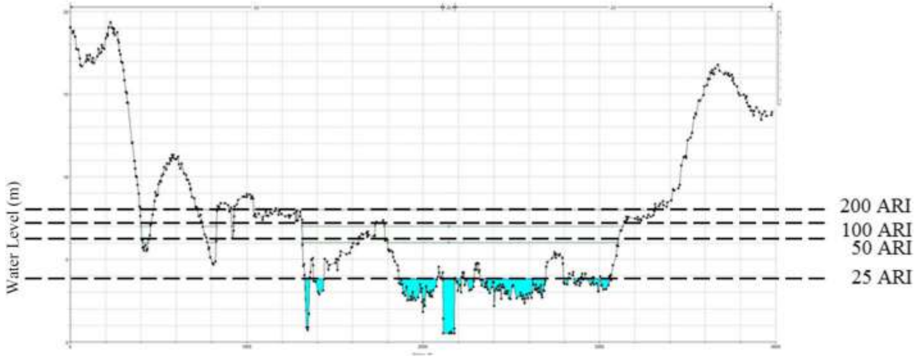


Fig. 16 Simulated water levels for various ARIs (Kota Tinggi town)

and 200 return periods is useful for flood mitigation strategy, especially for determining flood structure design.

6 Conclusion

The study provides knowledge and understanding of the use of HEC-HMS, HEC-RAS, and HEC-GeoRAS for hydrological and flood modeling. The study helps in understanding the components and characteristics of tidal on flood modeling. The result showed that the GEV gave the best fit for distribution to estimate the return period for the JRB. The estimated peak flows for 25, 50, 100, and 200 ARIs were 595, 691, 786, and 852 m^3/s, respectively. The hydrological modeling using HEC-HMS gave 73% model efficiencies for calibration and 83% for validation. From this result, the hydrological model is considered reliable for simulating hydrographs. The observed

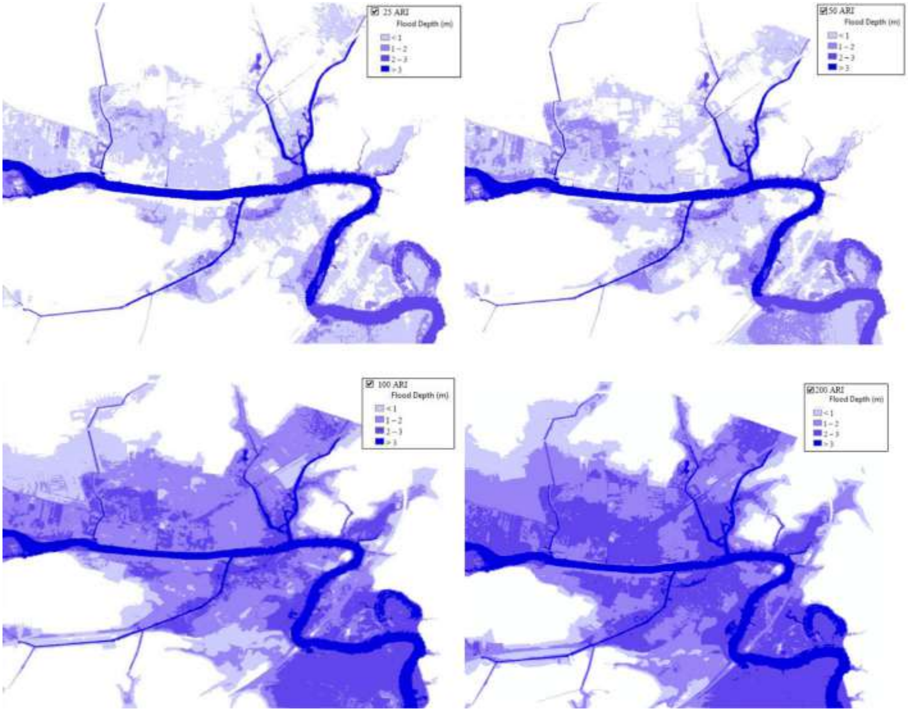


Fig. 17 Inundated area for 25, 50, 100, and 200 ARI. The darker blue indicates a deeper level and is very much related to the elevation profile

peak flow in 2006 was only 314.20 m^3/s, which is about half of the simulated peak flow of 625.3 m^3/s. Meanwhile, in the 2007 flood event, the observed peak flow was 361.21 m^3/s, and the simulated peak flow was 743.9 m^3/s. The much lower observed peak flows were due to overbank flow, and under such a situation, the stage-discharge rating curve is not applicable.

The simulated flood coverage for the 2006/2007 flood event closely matches the actual flood at Kota Tinggi. In addition, the simulated water levels for the second wave show more than 90% similarities at 11 flood marks when the tidal effect is considered in the modeling. Based on the flood map, the 2006/2007 flood event is quite similar to the simulated flood map for 50-year ARI. In addition, results of frequency analysis, hydrological modeling, flood routing, and flood mapping are useful as a basis for improving strategies to manage the future flood. In addition, local authorities could have better planning for flood mitigation and flood evacuation strategies.

Author contributions All authors contributed to the study conception and design. Material preparation, data collection, and analysis were performed by AZI, ZY, ZS, and ZMY. ZS wrote the first draft of the manuscript. All authors commented on previous versions of the manuscript. All authors read and approved the final manuscript. AZI, ZY, ZMY conceptualized the study; ZS, AZI helped in data curation, formal analysis, software, validation, and visualization; ZY acquired the funding; AZI, ZY, ZS investigated the study; AZI, ZY were involved in methodology; ZY administrated the project; ZY, ZMY helped in resources and supervision; ZS wrote the original draft; ZS, ZY contributed to writing—review and editing.

Funding This work was supported by the Water Security and Sustainable Development Hub funded by the UK Research and Innovation's Global Challenges Research Fund (GCRF) [Grant No.: ES/S008179/1] Universiti Teknologi Malaysia under High Impact Research Grant [Grant No.: Vot No 04G46].

Declarations

Conflict of interest The authors declare that they have no known competing financial interest or personal relationships that could have appeared to influence the work reported in this paper.

Consent to publish We (Zulfaqar Sa'adi, Ahmad Zuhdi Ismail, Zulkifli Yusop, Zainab Mohamad Yusof) hereby declare that we participated in the study in the development of the manuscript titled (Effect of the tide on flood modeling and mapping in Kota Tinggi, Johor, Malaysia). We have read the final version and give our consent for the article to be published in Natural Hazards.

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