

APPLICATION OF HEC-RAS AND ARC GIS FOR FLOODPLAIN MAPPING IN SEGAMAT TOWN, MALAYSIA

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ABSTRACT: Nowadays, a risk-based flood mitigation concept has received more attention rather than the conventional flood control approach in reducing the impacts of flooding. With the intention to assist in the management of flood risk, flood modeling is useful in providing information on the flood extent and flood characteristics. This paper presents the application of HEC-RAS model to the development of floodplain maps for an urban area in Segamat town in Malaysia. The analysis used Interferometric Synthetic Aperture Radar (IFSAR) as the main modeling input data. Five distribution models, namely Generalized Pareto, Generalized Extreme Value, Log-Pearson 3, Log-Normal (3P) and Weibull (3P) were tested in flood frequency analysis to calculate extreme flows with different return periods. Using Kolmogorov-Smirnov (KS) test, the Generalized Pareto was found to be the best distribution for the Segamat River. The peak floods from frequency analysis for selected return periods were input into the HEC-RAS model to find the expected corresponding flood levels. Results obtained from HEC-RAS model were used in ArcGIS to prepare floodplain maps for different return periods. The results indicated that most of the inundated areas in the simulated 100 year return period were also affected by 2011 historical floods. For 100 years flood simulation, the inundated area was almost 5 times larger than the simulated 10 years' flood.

Keywords: Floodplain Mapping, HEC-RAS, ARC GIS, Frequency Analysis, Segamat

1. INTRODUCTION

Flood is a common natural disaster that occurs frequently and caused a severe impact on people, infrastructures, and properties, as well as indirectly impact the country's economy [1]-[2]. In recent years, the conventional flood control approach than focusing on structural flood mitigation measures have been shifted to a risk-based flood mitigation concept [3]-[5]. Flood risk is related to two elements i.e. flood hazard and flood vulnerability [6]. Flood hazard is the probability of a flood event to take place, while flood vulnerability is the potential flooding impacts to community and assets which is normally associated with the assessment of property damages [6]-[7]. In most studies i.e. [4], [5], [8], [9], the estimation of flood damage was obtained using the combination of flood characteristics, flood exposure, and flood damage function curve.

Flood modeling is important for the assessment of flood hazard to show the magnitude of the flood to a certain exceedance probability [6], while its function in vulnerability assessment is to provide hydrological characteristics for damage modeling. The existing literature on flood hazard assessment is extensive and focuses particularly on flood mapping (for example, [10]-[13]). Montane et al. [10] developed a numerical floodplain model to

map extreme flood of Meurthe River in France. The model used hydro-geomorphological observations and LiDAR DEM data to produce water depth mapping. Meanwhile, Cunha et al. [11] applied land morphology approach to mapping the flood risk of mainland Portugal. There is also a considerable volume of published studies describing the role of flood modeling in the flood vulnerability assessment. In literature [14]-[16], flood modeling is used to provide hydrological and hydraulics information for flood damage modeling.

HEC-RAS is one of the most widely used models to analyze channel flow and floodplain delineation [12]. Khattak et al. [12] applied HEC-RAS and ArcGIS in their study to map a floodplain of Kabul River that lies in Pakistan. Similarly, Ullah et al. [11] in their flood forecasting study of Kalpani River, Pakistan used a combination of remote sensing, geographical information system (GIS), HEC-RAS (1D), and HEC-Geo RAS. HEC-RAS model was found to give a good performance where the simulated results for both studies showed a close agreement with observed water surfaces. Several other applications of HEC-RAS model can be observed in [17]-[19].

In Malaysian, the implementation of flood risk management approach that is supported by modeling tools is still new [20], [21]. However, several flood modeling studies have been carried

out during the last few years. Ab. Ghani et al. [21] had developed a flood mapping of 2007 Pahang River flood. In the study, a digital elevation model (DEM) was produced using a combination of digital topography maps and satellite image. A few studies have applied HEC-RAS and GIS techniques in flood modeling (e.g. [22]-[24]). Shahiriparsa et al. [22], [24] had applied HEC-RAS to simulate flood zoning in Kota Tinggi district in Johor state and Maka River district in Kelantan state.

Flood modeling is an important tool in the assessment of flood risk for both hazard and vulnerability. Hence, this study aimed at developing a floodplain map showing the extent of flood and providing related flood characteristics information for flood risk assessment purpose. The application of HEC-RAS modeling for the selected study area in Malaysia is presented.

2. METHODOLOGY

2.1 Study Area

The study area is Segamat River Basin, Johor which is located in the southern part of Peninsular Malaysia. The aim is to provide flood mapping for frequently flood-affected areas in the Segamat town. Segamat town is a medium size town located at the center of the Segamat district with an approximate area of 12,875 hectares and 80,000 residents.

The town center is divided into two, which is Bandar Atas (uptown) and Bandar Seberang (Crosstown). Both neighborhoods are separated by Segamat River. Bandar Atas is the original town center of Segamat while Bandar Seberang is located at the other side of Segamat River [25]. Fig. 1 shows the Segamat River that flows through the Segamat town. Segamat River is located in 102° 49' E and 2° 30.5' N. With a length of 23 km, the average width of Segamat River is 40 m and is 14 m above sea level. Segamat River is the tributary of Sungai Muar that flow in Segamat town [26].

A series of major floods have occurred in the last few decades along the Segamat river. According to historical records, Segamat experienced flooding during the 1950s, 1984 and more recently in 2006 and 2011. The flood disaster had caused serious damages to infrastructures, threatening human lives and affecting the local community.

2.2 Research Methodology

The research methodology generally follows the steps shown in Fig. 2. The flood model is a combination of four elements i.e., hydrologic model, hydraulic model, a tool for floodplain mapping and visualization and the extraction of geospatial for use in the model [11]. A digital elevation model (DEM) was applied to provide the essential information. The DEM refers to a topographic map which contains terrain elevation properties. The DEM was used in order to set up 2D models for processing the results of flood progression. DEM can be represented by a raster map (grid) or as a triangular model network (TIN). The DEM data used in this study was the Interferometric Synthetic Aperture Radar (ISFAR) obtained from the Drainage and Irrigation Department (DID) Malaysia.

The determination of peak flow is essential in natural disaster management and flood mitigation structures design [27]. Hence in this study, the estimation of peak discharge is the initial step in the development of floodplain maps for selected flood event and different return periods [10]. The peak flows for 10, 25, 50, 100, 200, 500 and 1000 average recurrence interval (ARI) were obtained by conducting flood frequency analysis. While the peak flood of 2011 flood used in this study is 1238.2 m³/s, obtained from hydrological modeling analysis using HEC-HMS. The steps followed with the hydraulics modeling to translate the discharges into water levels, and the final step is the determination of the inundated extent areas for discharges corresponding to different return periods.

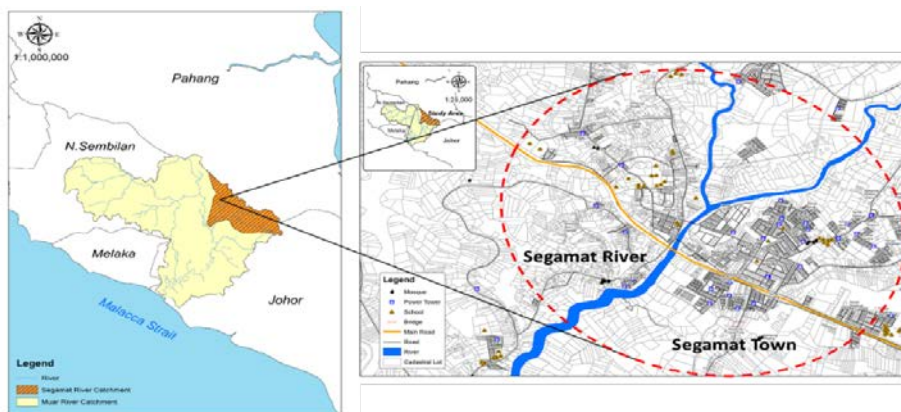


Fig. 1 Location of the study area

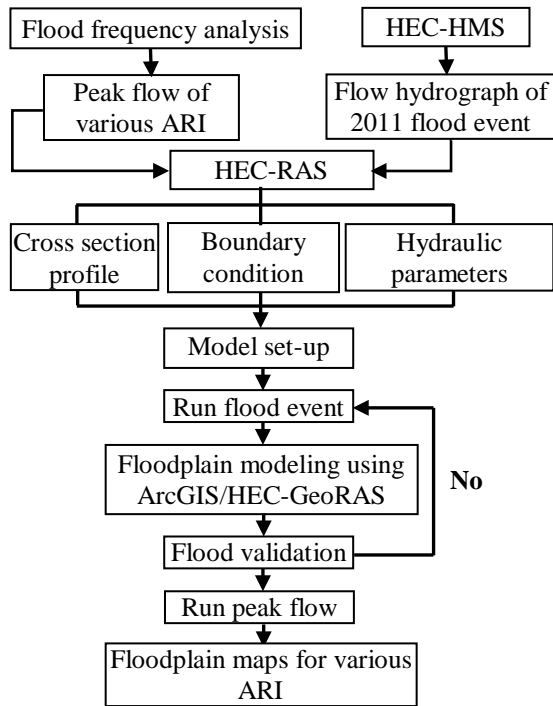


Fig. 2 Methodology flowchart of floodplain mapping

2.2.1 Flood Frequency Analysis

The EasyFit software was used to select the best flood distribution model to calculate peak flows of various ARIs. We used 52 annual maximum flow data of Sg. Segamat gauging station (Site 2528414) for the water years between 1960 and 2011, provided by DID.

Five flood distribution models were tested, namely Generalized Pareto (GP), Generalized Extreme Value (GEV), Log-Pearson 3 (LP3), Log-Normal (LN) (3P) and Weibull (3P). The goodness of fit test (GOF) of Kolmogorov-Smirnov (K-S) was used to evaluate and estimate the best-fitted distribution. K-S at 5% level of significant (p<0.05) was used to define the best fit ranking. The detailed description of flood frequency analysis is described in [28].

2.2.2 HEC-RAS Modeling

As illustrated in Fig. 2, a schematic geometry model that consists of river cross-section profile and banks is required in an HEC-RAS model set up. The hydraulic parameters required manning n values for the land cover. Then the boundary condition was set up to a condition of the river. In the next step, the year 2011 floodplain was simulated in the 1D result. The 1D result was converted into 2D using HEC-GeoRAS software. The simulated floodplain was verified with the 15 observed floodmarks at various location. Once the simulated floodplain is verified,

the HEC-RAS was applied to simulate flood inundated area for various return periods [29].

In HEC-RAS, the data input requirement consists of three main parts which are plan data, geometry data and flow data. Those requirements have to be fulfilled before running the simulation. The plan data is the first step in performing a simulation. The plan data will identify which geometry and flow data to be used as well as provide a description and short identifier for the simulation. If the geometry and flow data do not exist, the simulation will not run. It also includes the flow regime in the simulation option. Cross sections are required at representative locations along the stream and at locations where changes occur in discharge, slope, shape, and roughness [29].

3. RESULT AND DISCUSSION

3.1 Flood Frequency Analysis

The peak flows for 10, 25, 50, 100, 200, 500 and 1000 return periods, calculated using GP, GEV, LP3, LN (3P) and Weibull (3P) distributions are shown in Table 1. It's found that the predicted maximum flood using GEV is the highest, followed by LP3 and GP. The smallest values were obtained by Weibull distribution.

Table 1 Maximum flood for various return periods based on GP, GEV, LP3, LN (3P) and Weibull (3P) distributions

| Return Period (Years) | Estimated flood discharge (m ³ /s) | | | | |
|-----------------------|---|------|------|---------|--------------|
| | GP | GEV | LP3 | LN (3P) | Weibull (3P) |
| 10 | 541 | 830 | 616 | 666 | 176 |
| 25 | 943 | 1415 | 1099 | 1375 | 297 |
| 50 | 1362 | 2071 | 1563 | 2195 | 404 |
| 100 | 1914 | 2997 | 2112 | 3342 | 523 |
| 200 | 2642 | 4308 | 2755 | 4917 | 653 |
| 500 | 3971 | 6915 | 3280 | 6624 | 840 |
| 1000 | 5354 | 9861 | 4651 | 10877 | 993 |

Table 2 GOF K-S ranking results for GP, GEV, LP3, LN (3P) and Weibull (3P) distributions

| Distributions | Kolmogorov Smirnov | |
|---------------|--------------------|---------|
| | the p-value | Ranking |
| GP | 0.832 | 1 |
| GEV | 0.678 | 2 |
| LP3 | 0.673 | 3 |
| LN (3P) | 0.452 | 4 |
| Weibull (3P) | 0.294 | 5 |

Table 2 shows the performance ranking based on K-S GOF test. GP is ranked the first in terms of performance, followed by GEV, LP3, LN (3P), and

the least for Weibull (3P). The ranking is based on the p-value. A p-value closer to one indicates a better-fit distribution. The highest p-value is 0.832 for the Generalized Pareto and the lowest is 0.294 for Weibull (3P). Based on the results, the estimation of peak flows using GP distribution was used as the input into HEC-RAS model. The estimated peak flows for 10, 25, 50, 100, 200, 500 and 1000 years ARI are 541 m³/s, 943 m³/s, 1362 m³/s, 1914 m³/s, 2642 m³/s, 3971 m³/s and 5354 m³/s respectively.

3.2 Floodplain Mapping

An HEC-RAS hydraulic modeling set-up was created to generate the water level due to the 2011 flood and subsequently the flood map for various return periods. The comparison between the simulated 2011 flood and the simulated 10 and 100 years return periods are presented. The cross-section of water surface elevation for 2011 flood is shown in Fig. 3. The blue line shows the level of water surface (WS), while the dotted black line indicates the ground level. The purple and blue dotted line represents the left of the bank (LOB) and

right of the bank (ROB) respectively. The water level produced by 2011 flood is higher than those simulated for 10 and 100 years return period floods, as shown in Fig. 4(a) and Fig. 4(b) respectively. This indicates the extreme situations of 2011 flood.

The results of HEC-RAS model were then exported to HEC-GeoRAS for flood map generation. The simulated inundated areas for 2011 flood, 10 and 100 years return period are shown in Fig. 5, Fig. 6 and Fig. 7 respectively. The blue color shows the extent of the flooded area for depth between 0 to more than 1.2 meters. Fig. 5 shows that almost 45% of Segamat town was affected during 2011 flood where 66% of the area is inundated with more than 1.2 meters' depth (dark blue area). Most of the affected area were located at Bandar Seberang (crosstown) which is on the other side of Segamat river. The residential and commercial properties located at the center of the crosstown area i.e. Bandar Seberang, Jalan Sia Her Yam, Jalan Ros and Jalan Genuang experienced flood depth up to 2 meters. Kampung Abdullah and Kampung Jawa were severely affected during 2011 flood with flood depth more than 3 meters.

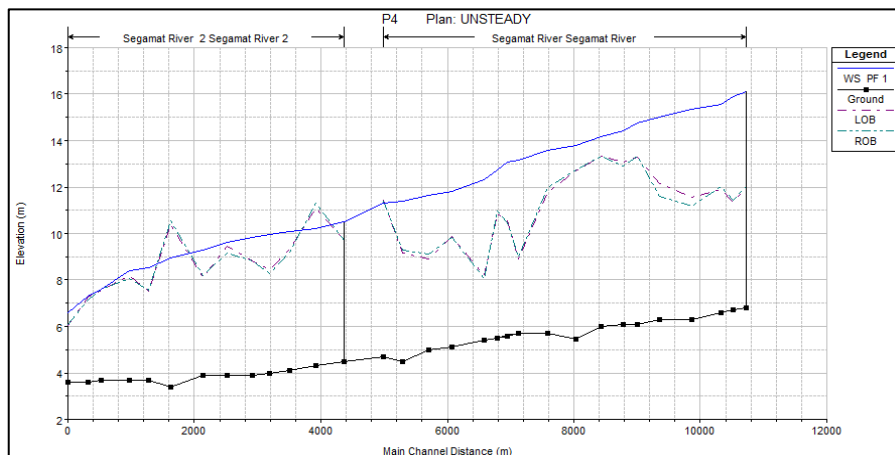
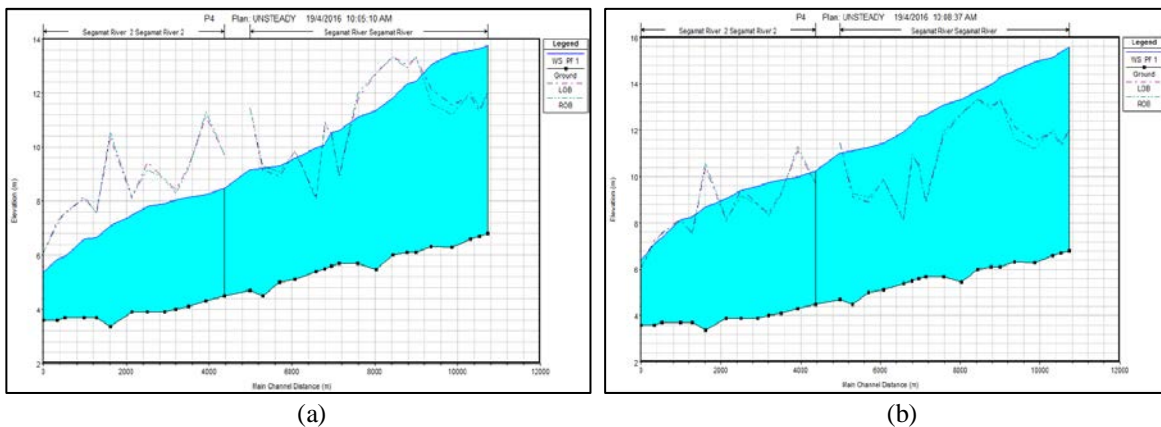


Fig. 3 Water surface profile for 2011 flood



Note: — = WS PF 1, · · · · = Ground, · · · · = LOB, · · · · = ROB

Fig. 4 Water surface profile for return period (a) 10 years (b) 100 years

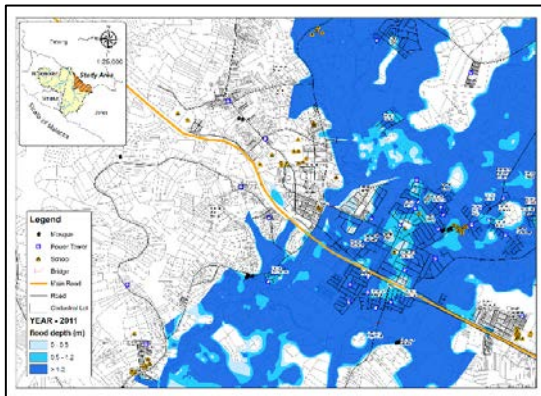


Fig. 5 Floodplain map of 2011 Segamat flood event

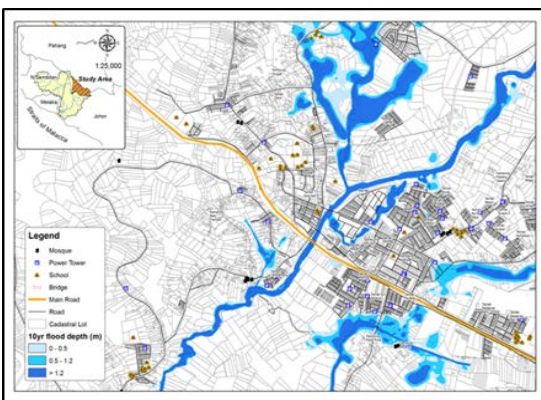


Fig. 6 10 years' floodplain map of Segamat town

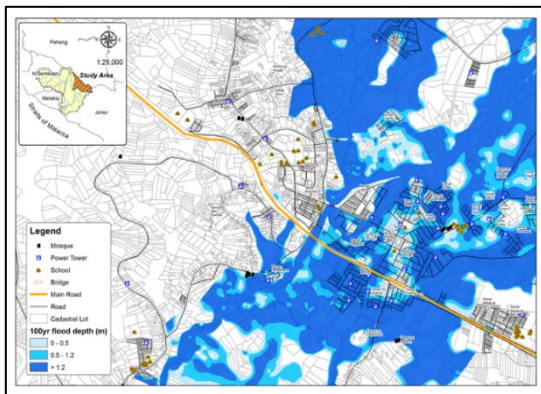


Fig. 7 100 years' floodplain map of Segamat town

The simulation results for 10 years return period (Fig. 6) indicate that only 7.43 km² of the Segamat town area were affected by the flood. The most affected area with flood depth more than 1.2 meters was Kampung Chabong, Taman Pawana, and Taman Pemuda. On the other hand, the simulation of 100 years return period (Fig. 7) shows that almost 40 km² of the area was affected by flood, which is 5 times larger than the simulated 10 years' flood. The results also indicate that most of the areas inundated by the 100 years' flood were also affected

by 2011 historical floods. Kampung Abdullah and Kampung Tengah were most affected with flood depth more than 4 meters in certain parts of the area.

The results were validated by comparing the simulated flood against the observed value at 15 stations for 2011 flood event. As shown in the 1:1 graph in Fig. 8, flood simulated flood depths are acceptable with more than 91% accuracy compared to the observed values. The simulated flood boundary is also close to actual flood boundary.

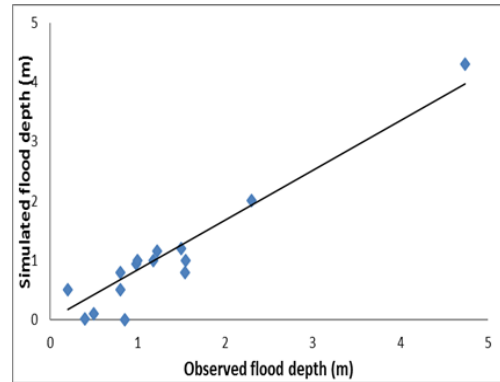


Fig. 8 Observed and simulated flood depth of 2011 Segamat flood

4. CONCLUSION

HEC-RAS model was applied to map the inundated area of Segamat town during the 2011 flood and simulate flood map under various return periods. The modeling accuracy was validated against observed flood marks of 2011 event. The simulated flood depth is acceptable with more than 91% accuracy. It's found that Generalized Pareto is the best-fit distribution model for peak discharge. The estimated peak flows of Segamat River for 10, 25, 50, 100, 200, 500 and 1000 ARIs are 541 m³/s, 943 m³/s, 1362 m³/s, 1914 m³/s, 2642 m³/s, 3971 m³/s and 5354 m³/s respectively.

The simulation suggests that most of the inundated areas of 100 years' flood were also affected by the 2011 historical floods. For 100 years flood simulation, the inundated area was almost 5 times larger than the simulated 10 years' flood.

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