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MAPPING THE FLOOD INUNDATION AREAS USING HEC-GEORAS AT BATANG MAHAT RIVER

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ABSTRACT: The Batang Mahat region in Lima Puluh Kota Regency is highly prone to flooding, with significant events recorded in 1961, 1968, 1972, 1978, 1984, 1991, 1998, 2005, 2017, 2019, 2020, and 2021. The most catastrophic flood occurred in March 2017, inundating public areas and residential zones in the Pangkalan Koto Baru district. This study aims to simulate a flood inundation map for Batang Mahat using HEC-GeoRAS 10.8, ArcGIS, and HEC-RAS 6.2. HEC-GeoRAS is an ArcGIS extension designed for pre-processing geospatial data for HEC-RAS. For hydrological analysis, the study employed the Log Pearson Type III and Nakayasu Synthetic Unit Hydrograph models within HEC-RAS. The simulation covered a 9.26 km² area in Batang Mahat, from Batu Kisok upstream, analyzing discharge return periods of 2, 5, 10, 25, 50, and 100 years. The findings showed that flooding commenced at the Q5-year discharge return period and increased substantially at the Q25-year level, with an 84.44% rise in flood area compared to the Q10-year period. The 2017 flood was classified as a Q50-year event (2003.07 m³/s), affecting 2.47 km² of the 9.26 km² area studied. Validation through community surveys and interviews in Pangkalan Koto Baru yielded a data correlation value of 0.98, confirming the accuracy of the results.

Keywords: Flood Map, Batang Mahat, Hec-GeoRAS.

1. INTRODUCTION

Batang Mahat, situated in Lima Puluh Kota Regency, is administratively located in two provinces. The upstream section of Batang Mahat is located at the Pangkalan Bridge in Lima Puluh Kota Regency, West Sumatra Province. In contrast, the downstream section is the Koto Panjang hydropower weir intake in Kampar Regency, Riau Province. Within this region, there are various tributaries of Batang Mahat, including Batang Bulu Kasok and Batang Malagiri, which possess a tributary known as Batang Samo, as depicted in Fig.1.

The occurrence of flooding in Batang Mahat is an almost annual phenomenon. Noteworthy flood events occurred in 1961, 1968, 1972, 1978, 1984, 1991, 1998, 2005, 2017, 2019, 2020, and 2021 [1]. The flood incident in March 2017, which submerged the land and settlements in Pangkalan Koto Baru, stands as the most significant flood in Batang Mahat. According to Mukmin et al. [2], the flood's peak discharge of 2,345 m^3/s inundated Pangkalan Koto Baru and Bukit Barisan Districts, resulting in substantial casualties and material losses. The highest inundation level in March 2017 was approximately +93.40 meters [3]. The most recent floods occurred on 3 February, 11, and 20 December 2019 (resulting in 2 victims) and on 11 February 2020, leading to the inundation of national roads, residential areas, and schools.

The flood events observed in Batang Mahat have been classified as significant occurrences that require immediate attention. These floods are caused by various factors, such as the insufficient capacity of the channel to accommodate the discharge of floodwater and the narrowing location of the river channel, which can cause a “bottleneck” in Batu Kisok [4]. It is worth noting that the government has not taken any action to control these flood incidents. Flood management solutions can be structural or nonstructural, depending on the specific problem, conditions, time, and space [5]. Both structural and nonstructural measures are necessary for integrated flood risk management. However, implementing structural measures requires substantial funding, which may only be feasible for certain countries. Therefore, instead of solely relying on structural measures, it is advisable to consider some nonstructural measures as they can help reduce costs and prove more effective [6]. One possible nonstructural measure is creating a flood hazard map to forecast future flood damage.

The development of flood inundation mapping forms the basis for conceptual flood mitigation measures. Identifying the extent of the flooded area is crucial for proper flood risk management and flood damage rehabilitation, and this can be achieved through flood inundation mapping [7]. The U.S. Army Corps of Engineers (USACE) has developed a Geographic Information System (GIS) extension for ArcMap known as HEC-GeoRAS, which has been utilized to prepare geospatial information for hydraulic modeling and processing the results [8]. Integrating hydrological models with GIS has proven valuable in evaluating flood hazard spatial variability [9]. HEC-GeoRAS is a collection of ArcGIS tools designed explicitly for processing geospatial data for use with HEC-RAS (Hydrologic Engineering Centers River Analysis System) [10]. Additionally, results obtained from HEC-RAS can also be processed. HEC-GeoRAS can handle water surface profiles and velocity data exported from HEC-RAS simulations for GIS analysis, which many researchers employ for flood inundation mapping, flood damage computations, ecosystem restoration, and flood warning response and preparedness [11-14].

Therefore, this study aims to simulate the flood inundation map of Batang Mahat in Lima Puluh Kota regency, West Sumatera, covering an area of 9.26 km^2 using the HEC-GeoRAS 10.8 interface with GIS and HEC-RAS 6.2.

2. RESEARCH SIGNIFICANCE

The flood phenomenon can be one of the costliest hazards, leading to loss of life, displacement of individuals, ecological harm, and substantially adverse effects on economic progress [15] if not addressed through appropriate flood management strategies. The flood event in Batang Mahat has been identified as a significant incident that necessitates immediate attention, as the government has failed to undertake substantial measures to mitigate the situation. Consequently, using HEC-GeoRAS for flood mapping could yield advantageous outcomes for the government and other stakeholders in determining effective flood management strategies while also serving as a decision-making tool for matters concerning flood control in Batang Mahat.

3. METHODOLOGY

The flood inundation map of Batang Mahat is created by the following steps below:

3.1 DTM data

The Digital Terrain Model (DTM) is synonymous with the DEM. The DTM encompasses not only the DEM but also incorporates terrain features that offer a more precise depiction of topographic surface attributes [16]. To generate a Flood inundation Map of Batang Mahat using the Hec-GeoRas Software, a high-resolution DTM is necessary. However, the maximum resolution of DTM or DEM accessible on the government website (DEMNAS) is a mere 8m. Nevertheless, Junaidi and Diva [17] found that the most optimal and efficient data for flood inundation analysis is the DEM data provided on the government website (DEMNAS), which possesses a resolution that is adequately accurate for flood simulation, as they compared it with the DTM data from DEMNAS with an 8m resolution, obtained through terrestrial survey and photogrammetry using DJI Phantom 4 RTK.

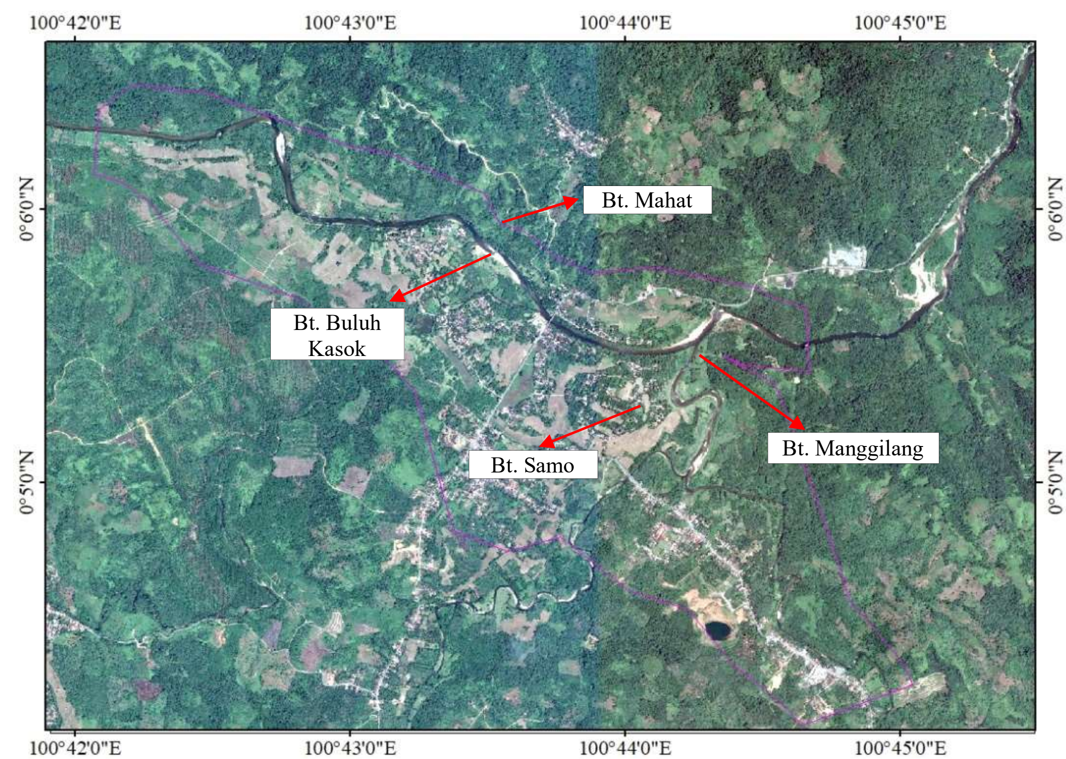

Fig.1 Location of Batang Mahat and its tributaries in Pangkalan Koto Baru District of Lima Puluh Kota Regency of West Sumatera Province

3.2 Hydrology Analysis

A hydrological investigation is conducted to acquire data on the discharge of design floods. The hydrological analysis, which was carried out in this particular study, involved employing the Log-Person Type 3 frequency analysis and the Nakayasu Synthetic Unit Hydrograph for return periods of 2, 5, 10, 25, 50, and 100 years. In this particular examination, the hydrology analysis will utilize 16 years of Rainfall Data obtained from the rainfall stations Sontang and Suliki, as presented in Table 1.

Table 1 Maximum Rainfall Data from Sta. Sontang and Sta. Suliki

Year	Max Rainfall		AVRG Max
	Sta. Suliki	Sta. Sontang	(mm)
2020	68	39	54
2019	79	80	80
2018	94	160	127
2017	80	108	94
2016	82	125	104
2015	79	93	86
2014	73	90	82
2013	67	71	69
2012	68	32	50
2011	140	94	117
2010	65	60	63
2009	72	89	81
2008	107	100	104
2007	67	100	84
2006	74	250	162
2005	62	82	72

Table 2 Flood discharge (m^3/s) at Batang Mahat (Upstream), Batang Malagiri (tributary), and Batu Kisok (downstream)

Return Period	Q Batang Mahat (Upstream)	Q Batang Malagiri (Tributary)	Q Batu Kisok (Downstream)
	1	2	1+2
2 year	610.73	410.89	1021.62
5 year	795.32	534.13	1329.44
10 year	919.50	617.03	1536.54
25 year	1084.73	727.34	1812.07
50 year	1199.27	803.80	2003.07
100 year	1322.34	885.97	2208.31

This research examines the inundation caused by flooding in the narrowing area of Batu Kisok up to the upstream section of Batang Mahat. Within this area, a tributary of Batang Mahat is known as Batang Malagiri. In order to analyze the flood inundation using HEC-GeoRAS, it is imperative to consider the flood discharge for each river branch. Consequently, calculating the design flood discharge involves selecting two sub-watersheds located at the confluence of the Batang Mahat (upstream) and Batang Malagiri (tributary) rivers. By doing so, the design flood discharge for both rivers can be obtained. Subsequently, the design flood discharge for Batu Kisok (downstream) is determined by combining the flood discharges from both Batang Mahat and Malagiri, as depicted in Eq. 1 below:

$$Q_{Batu\ Kisok} = Q_{Batang\ Mahat} + Q_{Batang\ Malagiri} \quad (1)$$

The result of each flood discharge at Batang Mahat (upstream), Batang Malagiri (tributary), and Batu Kisok (downstream) shown in Table 2.

3.3 Flood Inundation Mapping Using HEC-GeoRAS

The flowchart of working with HEC-GeoRAS software to create a flood inundation map can be seen in Fig.2. The fundamental approach to producing flood inundation maps for a watercourse through the utilization of HEC-GeoRAS encompasses three primary phases: Pre-processing, processing, and post-processing of the data.

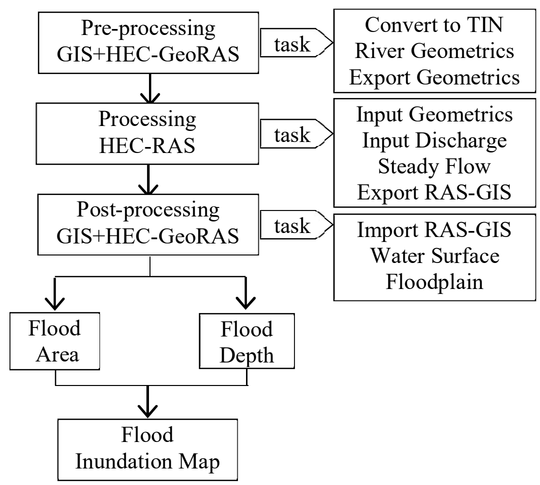

Fig.2 The general method for modeling floodplains using ArcGIS, HEC-GeoRAS, and HEC-RAS

3.1.1 Pre-processing Stage

In this case, the river geometrics were generated using the HEC-GeoRAS 10.8 tools. The initial phase requires converting the DTM data to a TIN format, which can be accomplished by using the converting tools found in the Arctoolbox menu. This conversion is necessary because HEC-GeoRAS demands DTM data in TIN format to analyze flood inundation. Once the TIN is established, the geometric data of the river can be constructed using the RAS geometry menu. This step will yield the geometric data of Batang Mahat, including stream centerlines, main channel banks (both left and right), flow paths, and cross sections. A 3D stream centerline and cross-section layer was also generated to acquire the cross-section and stream centerline attribute table.

The outcome of this process can be observed in

Fig.3. Following the creation of the geometric data, export the data to generate an RAS GIS import file, which will subsequently be utilized during the processing step in HEC-RAS.

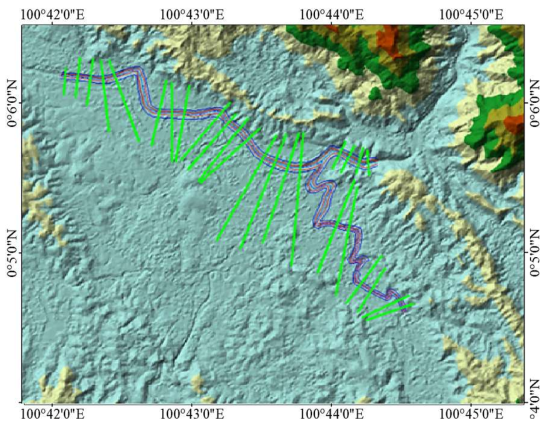

Fig.3 Batang Mahat geometric data using HEC-GeoRAS tools in ArcGIS.

3.1.2 Processing Stage

The processing stage involves the utilization of HEC-RAS 6.2 software to carry out the Hydraulic analysis. The outcome will be exported to HEC-RAS upon completion of the geometric data. Each station is assigned an automatic designation from the primary channels (upstream and downstream) to the branch (tributary), as depicted in Fig.4.

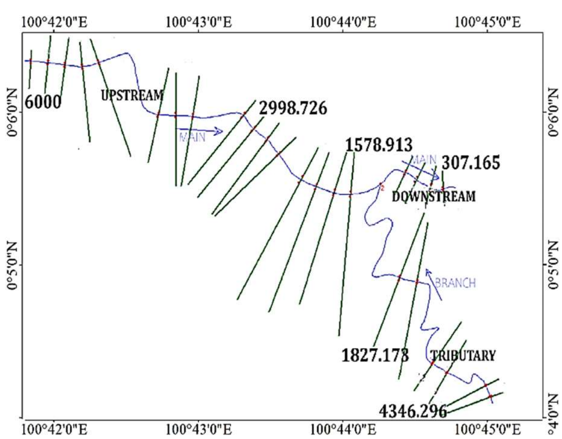

Fig.4 The result of RAS imported Geometric data from HEC-GeoRAS to HEC-RAS.

All necessary adjustments and edits were executed within the geometric data editor, such as determining the manning value and filtering points for the cross-section. The steady flow data recorded the flood discharge for return periods of 2 years, 5 years, 10 years, 25 years, 50 years, and 100 years. Subsequently, within the steady flow analysis, the water surface profiles were calculated. The cross-section profile after the simulation can be observed in Fig.5.

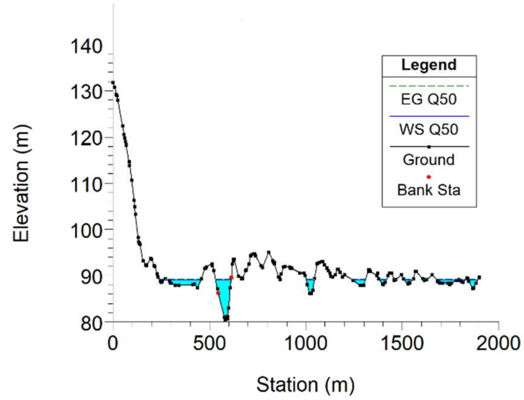

Fig.5 The Cross-section Profile for Sta. 1578.913 with Q50 discharge after the steady flow simulation.

3.1.3 Post-processing Stage

In this stage, the examination returns to the tools of HEC-GeoRAS. The outcome of the submerging of the flood is carried out in this stage. The RAS GIS export file is brought into ArcGIS using HEC-GeoRAS RAS Mapping tools. Following the completion of "Theme Setup" and "Read RAS GIS Export File," the outcomes from the export file will be examined, and initial data collections will be formed.

The networks of streams, data on cross-sections, data on bank stations, and data on bounding polygons will be examined, and the shape files will be automatically generated. Subsequently, based on the elevations of the water surface in the cut lines of the cross-sections and the theme of the bounding polygon, the TIN of the water surface was produced for each profile of the water surface (Q2, Q5, Q10, Q25, Q50, and Q100).

After the generation of Water surface TIN, the next step is the delineation of the floodplain. This process entails the creation of a thematic representation of the floodplain in the form of a poly-line, as well as developing a grid indicating the depth of the floodwaters. The water depth grid is derived by subtracting the rasterized TIN representing the water surface from the TIN encompassing the terrain. Through this particular stage, the flood inundation map can be formulated.

4. RESULT AND DISCUSSIONS

Fig.6-Fig.11 shows the result of the flood inundation map for each water discharge of Q2-year, Q5-year, Q10-year, Q25-year, Q50-year, and Q100-year, respectively.

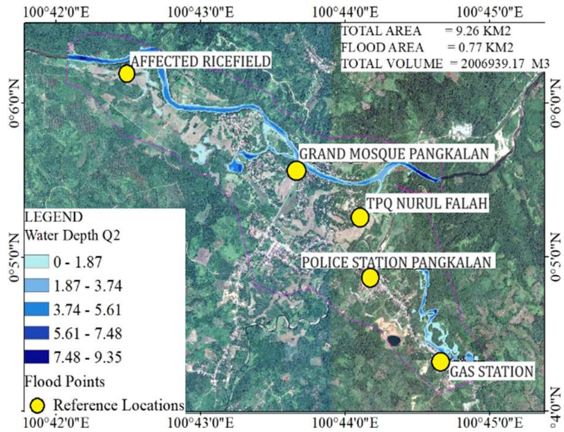

Fig.6 Flood Inundation Map for Q2-year.

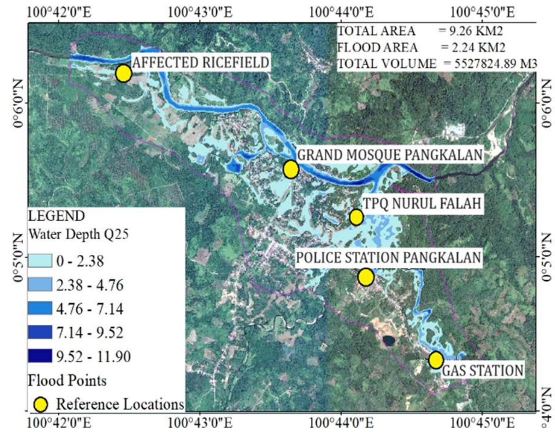

Fig.9 Flood Inundation Map for Q25-year.

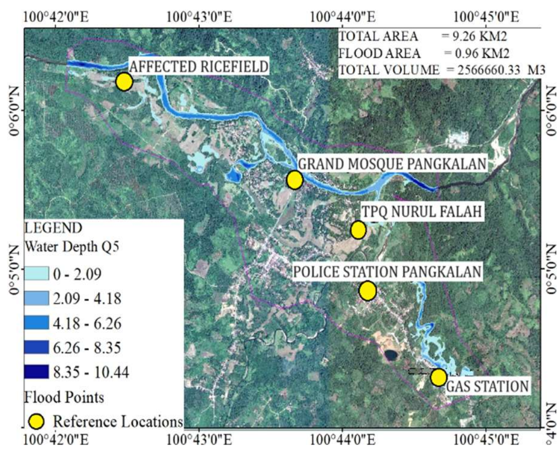

Fig.7 Flood Inundation Map for Q5-year.

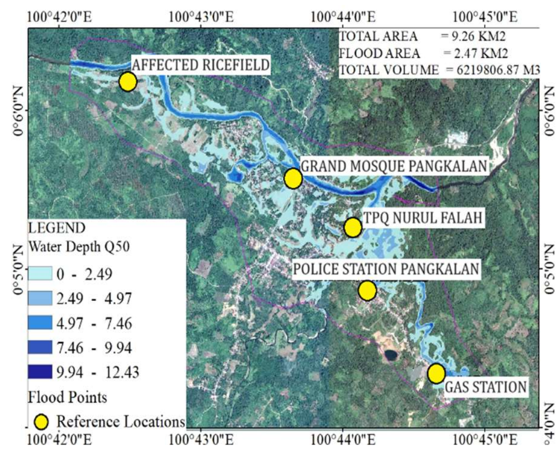

Fig.10 Flood Inundation Map for Q50-year.

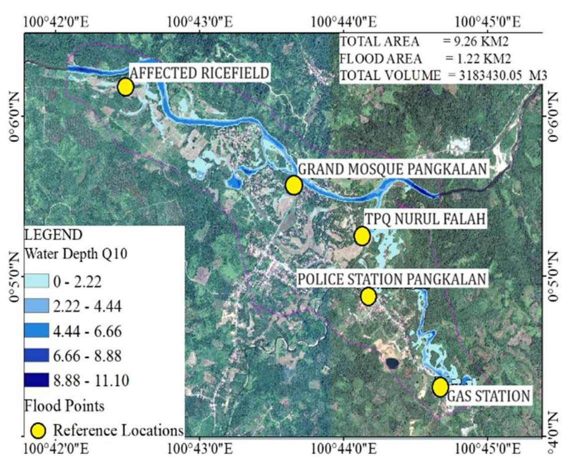

Fig.8 Flood Inundation Map for Q10-year.

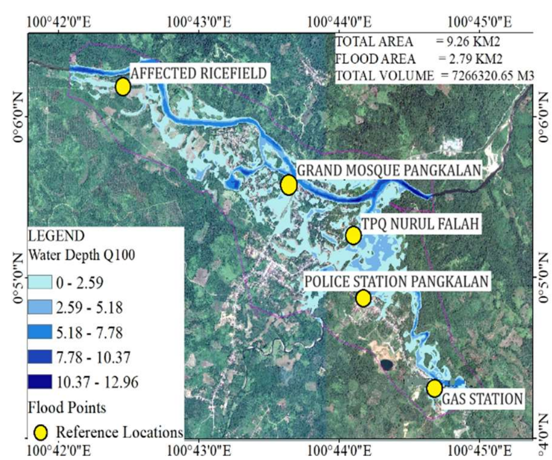

Fig.11 Flood Inundation Map for Q100-year.

According to the map findings, the inundated region has a discernible expansion in every design flood discharge. Table 3 exhibits the percentage growth in flood area for each discharge, indicating the significant increase in flood area.

Table 3 Percentage of Increasing in Flood Area for Each Discharge.

Q-year	Inundation Areas (Ha)	Increase in Flood Area (%)
Q_2 year	77	0
Q_5 year	96	24.66
Q_{10} year	122	26.43
Q_{25} year	224	**84.44**
Q_{50} year	247	10.23
Q_{100} year	279	12.86

From Table 3, it is observable that there is a surge in the extent of flooding by approximately 24.66% at the Q5-year return period discharge. Nonetheless, the inundation of land and settlements became more widespread during the Q25-year discharge, as the expansion of the flood area amounts to 84.44% compared to the Q10-year discharge. Subsequently, we proceed to examine the Q50-year discharge and Q100-year discharge. Furthermore, the mean water elevation, submerged areas, and return periods data can be employed to construct a visual representation that illustrates the correlation among these three variables [18]. This study presents Fig.12, which depicts the correlation among the mean water elevation, submerged areas, and return periods of Batang Mahat. By observing Fig.12, it becomes evident that there is an escalation in the flood elevation at each return period and an increase in the extent of inundation. Additionally, it demonstrates that as the water level rises during each return period, the inundation area in Batang Mahat experiences a corresponding augmentation.

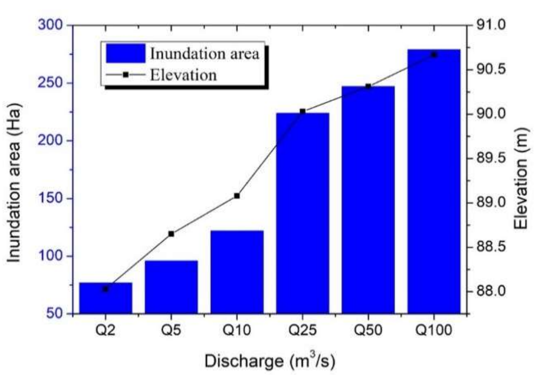

Fig.12 The correlation between Inundation areas (Ha) and Average Water Elevation (m).

The present study examines the outcome of HEC-GeoRAS software in displaying the flood occurrence in Batang Mahat during March 2017, which constituted the most significant inundation ever witnessed in the Pangkalan Koto Baru district.

However, it is imperative to authenticate these findings by cross-referencing them with the data obtained in the field. The data is procured through direct interviews conducted with the affected community residing in the area and extensive research encompassing news articles of the flood incident and various other credible sources. In this context, numerous locations that were adversely impacted by floods in 2017 have been selected as pivotal reference points.

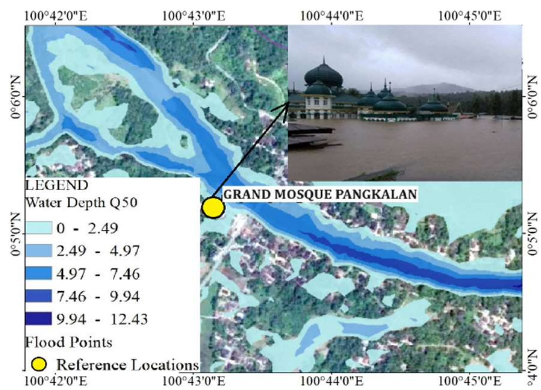

Fig.13 Flood Height at Grand Mosque Pangkalan is ±3.69 m (Hec-GeoRAS simulation) and ±4.00 m (Flood height during 2017 event)

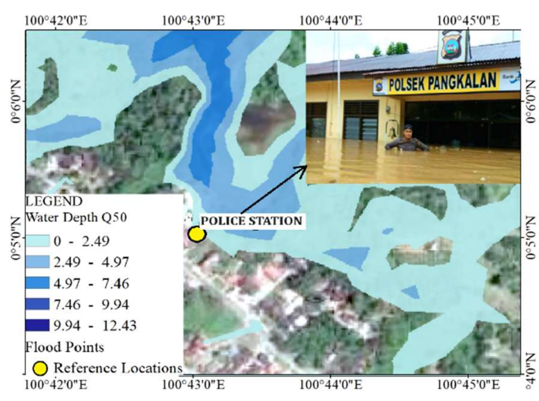

Fig.14 Flood Height at Police Station Pangkalan is ± 1.24 m (Hec-GeoRAS simulation) and ±1.50 m (Flood height during 2017 event)

The field data that has been meticulously gathered for this study encompasses a comprehensive analysis of seven specific locations, namely Rice field, Grand Mosque Pangkalan, TPQ Nurul Falah, Police station Pangkalan, gas station Pangkalan, Restaurant Ombak, and SRC Iswandi Mart. The data extracted from the community interviews and the analysis of articles effectively corroborates the flood elevation as determined by the flood simulation using HEC-GeoRAS. Fig.13 and Fig.14 shows samples on the flood that occurred in 2017 with the simulation result.

The findings reveal that the community's depiction of the area and flood height aligns with the flood inundation observed during the Q50-year return period in HEC-GeoRAS. Additionally, Table 5 presents the outcome of the correlation examination conducted in Excel, which compares the flood height from the simulation result with the community interview. The results indicate a robust correlation between the two datasets, with a correlation coefficient 0.98.

Table 5 Comparison of Flood Height from Field Interview and HEC-GeoRAS (Q50 = 2003.07m^3/s).

Reference location	Coordinate	Flood Height (Interview)	Flood Height (HEC-GeoRAS)
Ricefield	100°42'30.583"E 0°6'12.903"N	±1.00 m	1.03 m
Grand Mosque Pangkalan	100°43'41.006"E 0°5'35.98"N	±4.00 m	3.69 m
TPQ Nurul Falah	100°44'7.344"E 0°5'16.484"N	±1.50 m	1.49 m
Police Sta. Pangkalan	100°44'12.683"E 0°4'54.339"N	±1.50 m	1.24 m
Gas Station Pangkalan	100°44'41.853"E 0°4'18.811"N	±2.00 m	2.00 m
SRC Iswandi Mart	100°44'43.749"E 0°4'18.743"N	±2.00 m	1.90 m
Restaurant Ombak	100°44'43.621"E 0°4'18.538"N	> 1.50 m	1.80 m
Correlation value		0.98	

5. CONCLUSIONS

In this study, flood inundation mapping was conducted using the HEC-GeoRAS 10.8 interface in combination with GIS and HEC-RAS 6.2. High-resolution Digital Terrain Model (DTM) data was essential for generating accurate flood inundation simulations. The resulting flood inundation map showed significant flooding at the Q25 return period discharge (1812.07 m^3/s), with the flood area increasing by approximately 84.44% compared to the Q10 return period. The flood simulation results for Batang Mahat closely matched actual flood events, validating the model's accuracy. Notably, the 2017 flood corresponded to the Q50 discharge (2003.07 m^3/s) in the simulation, affecting about 2.47 km^2 of the 9.26 km^2 study area.

The use of HEC-GeoRAS for flood mapping is beneficial for governmental authorities and stakeholders, aiding in the formulation of effective flood management strategies and serving as a decision-making tool for flood control in Batang Mahat. Based on the research findings, one recommended flood management strategy involves normalizing the riverbank in the upper sections of Batang Mahat and widening the river at the bottleneck area in Batu Kisok to increase channel capacity. The cross-sectional analysis revealed a broader and relatively shallow riverbed in the upstream section, whereas the riverbed narrows and reaches depths of about 17 meters at Batu Kisok.

6. ACKNOWLEDGEMENTS

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