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Analysis of Cross-section Capacity of Jambi River at Muaro Jambi Temple About Various Flood Return Period Using HEC-RAS Software

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Abstract. Jambi River is one of the rivers located in the Muaro Jambi Temple Complex Area, Muaro Jambi Regency, Jambi Province. Muaro Jambi Temple is one of the tourist attractions in Jambi Province. This study aims to find the capacity of Jambi River tested by planned flood discharge utilizing (synthetic unit hydrograph) HSS Nakayasu method for a return period of two, five, ten, twenty-five, fifty and hundred years. HEC-RAS software used to analyse the water level in the Jambi River towards the flood potential that causes the submerging of the Kedaton Temple building. This research used the log Pearson type III method to calculate the planned rain return period and used the Nakayasu synthetic unit method to calculate the planned flood discharge. The analysis showed that the Jambi River could not load the flood discharge in the five, ten, twenty-five, fifty, and one hundred years return period at several measurement points: river sta-1, river sta-2 and river sta-5. The floodwater level did not cause the Kedaton Temple building to be flooded from the simulation result.

Keywords: Cross-section Capacity, Design Flood Discharge, HEC-RAS, Hydraulic Analysis, Hydrology Analysis, Water Level

1. Introduction

Floods are a type of natural disaster caused by water and interfere with human activities. Floods are the most frequent natural disaster that happened in Indonesia and caused losses to human life and the environment that occur due to overflowing rivers, reservoirs, and lakes that inundate the lowlands. Floods also occur because rainwater is trapped in a cavity and becomes a puddle, changes in land use that trigger sedimentation/silting in the cross-sectional area of the river [2]. Floods also occur because

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the water flow rate/volume in a river or drainage channel exceeds its flowing capacity [1]. Floods usually occur during the rainy season or when it rains [8].

Floods happened at Jambi Province in 2003 and brought on several districts flooded. One of them is Muaro Jambi Regency [3]. Floods involved most of the houses around Muaro Jambi Temple Complex were flooded, Muaro Jambi Regency was flooded, but the floods did not inundate Kedaton Temple around the Jambi River.

Jambi River is one of the rivers located in Muaro Jambi Temple Complex Area, more precisely in Muaro Jambi Regency, Muara Jambi Village, Jambi, Jambi Province.

Muaro Jambi Temple is one of the tourist attractions and cultural reserve in Jambi Province and needs to be preserved. This study analyses the cross-section capacity and water level of floods in Jambi River towards design flood discharge for the return period of two years, five years, ten years, twenty-five years, fifty years, and one hundred years. Furthermore, this study also analyzes the water level in the Jambi River based on the simulation results of HEC-RAS software towards the flood potential that causes the submerging of the Kedaton Temple building.

2. Materials and Methods

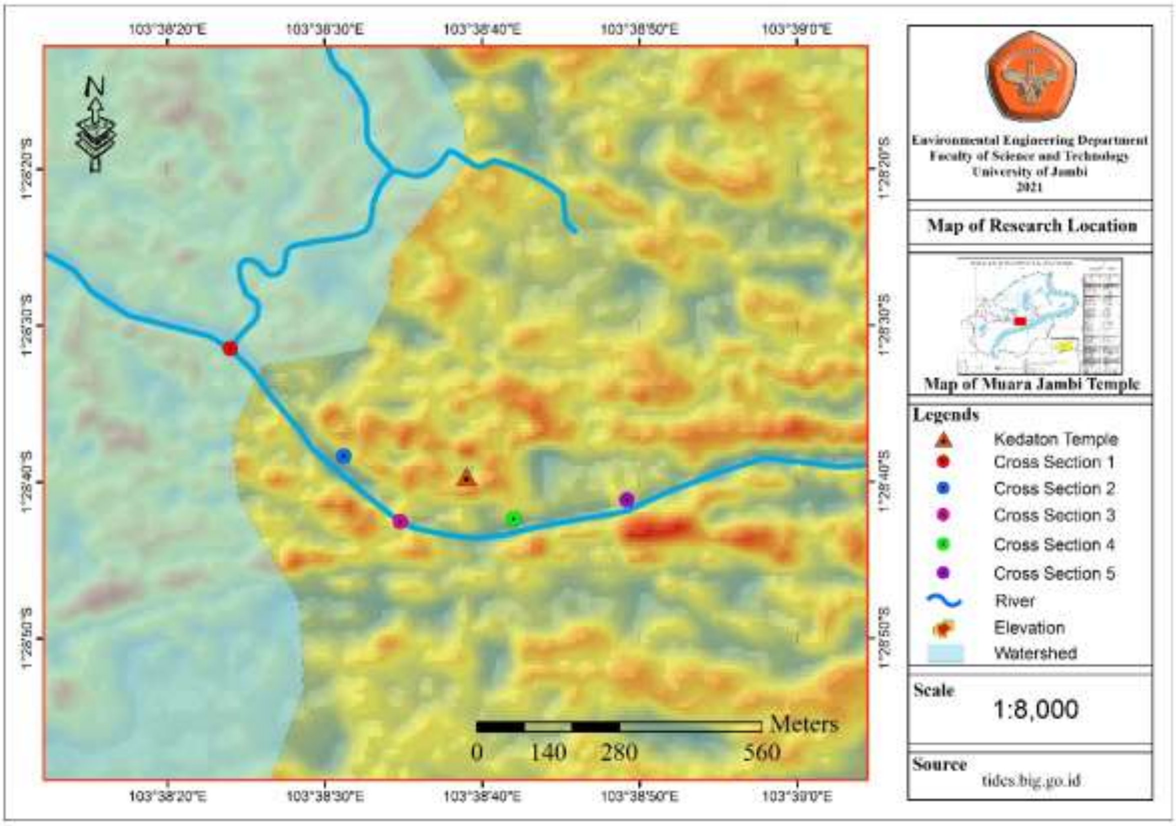

Figure 1. The Map of Research Location and Cross-section Measurement Point

2.1 Materials

2.1.1 Research Location

This research is located in Jambi River, Muaro Jambi Temple Complex Area around Kedaton Temple, Muaro Jambi Regency and geographically located in latitude 1° 28.723'S and longitude 103° 38.634'E (Figure 1). The research began by conducting a preliminary survey in the Jambi River area along with Kedaton Temple, Muaro Jambi Temple. Then, collect the rainfall data as secondary data from Sumatra Rivers Regional Office VI and Meteorology, Climatology, and Geophysics Agency of

Muaro Jambi Regency. Then cross-sectional measurements were carried out in the Jambi River as primary data.

2.1.2 Data Collection Technique

This research used primary data and secondary data. Primary data collection is the photos of the condition of the Jambi River and measuring the cross-section of the river along 1024 meters. The secondary data in this research are daily rainfall data from 2009 until 2019 sourced from Sumatra Rivers Regional Office VI (BWSS VI) and daily rainfall online data from 2009 until 2019 sourced from Meteorology, Climatology, and Geophysics Agency (BMKG).

2.2 Methods

The analysis in this research is divided into two types, the first is the hydrological analysis and the second is hydraulic analysis. The hydrological analysis is divided into several calculation steps; (1) calculating the empty rainfall data, (2) calculating the consistency test of the rain data using the RAPS methods, (3) calculating the area average rainfall using the arithmetic methods, (4) calculating the design rain using the Log Pearson type III methods and (5) calculating the amount of rain design used the Nakayasu Synthetic Unit Hydrograph (HSS Nakayasu) methods. The methods used in this research are as follows.

2.2.1 The Calculation of Planned Rain

In this research, the calculation of planned rain used the Log Pearson type III methods for return period 2-years, 5-years, 10-years, 25-years, 50-years, and 100-years. Most of the distribution Log Pearson Type III used in hydrology calculation analysis, especially in maximum data analysis. The equation used in calculating the amount of rain using the Log Pearson type III method is as follows:

$$\log(X_t) = \overline{\log(X)} + k * \left(S\bar{d}\right) \tag{1}$$

Information:

Log (X_t) : The value of x in the log that expected to occur in the return period t years
Log (X) : Mean of the log values (X)
K : The value from the table is a function of the return period and the coefficient of variation.
Sd : Standard deviation

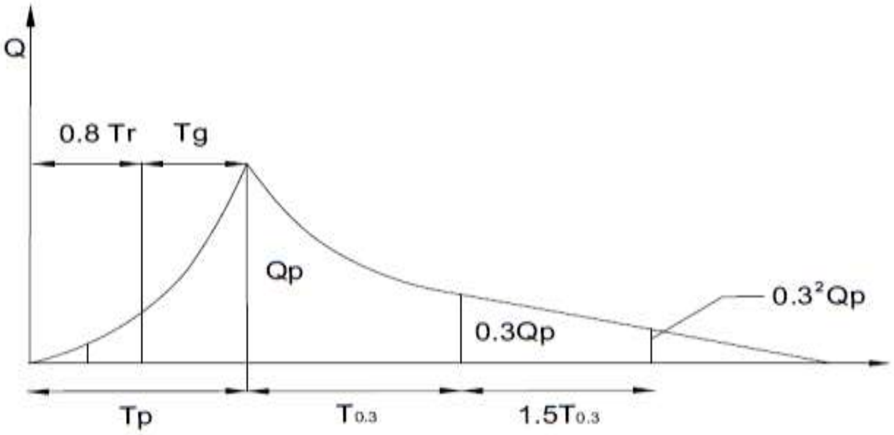

Figure 2. Nakayasu Synthetic Unit Hydrograph

2.2.2 The Calculation of Design Flood Discharge

The calculation of design flood discharge used the Nakayasu Synthetic Unit Hydrograph methods. The Nakayasu Synthetic Unit Hydrograph methods are the hydrograph was developed based on several rivers in Japan. This method only used two parameters; they are the river catchment area and the river length. The equations used in the Nakayasu Synthetic Unit Hydrograph methods are (Figure 2)

$$Q_P = \frac{1}{3.6}\left(\frac{ARe}{0.3Tp+T_{0.3}}\right) \quad (2)$$

$$T_p = t_g + 0.8\,T_r \quad (3)$$

$$t_g = 0.4 + 0.058\,L \text{ for L > 15 km} \quad (4)$$

$$t_g = 0.21\,L^{0.7} \qquad \text{for L < 15 km} \quad (5)$$

$$T_{0.3} = \acute{a}t_g \quad (6)$$

$$tr = 0.5\,t_g\,up\ to\ t_g \quad (7)$$

The hydrograph form can be seen from the following equation:

a Rising Limb (QN) ($0 < t < T_p$)

$$Q_t = \left(\frac{t}{T_p}\right)^{2.4} \quad (8)$$

b Recession Limb 1 ($T_p < t < T_p + T_{0.3}$)

$$Q_r = Q_p \times 0.3^{(t-T_p)/T_{0.3}} \quad (9)$$

c Recession Limb 2 ($T_p < T_{0.3} < t < T_p + T_{0.3} + 1.5T_{0.3}$)

$$Q_t = Q_p \times 0.3^{[(t-T_p)+(0.5T_{0.3})]/(1.5T_{0.3})} \quad (10)$$

d Recession Limb 3 ($t > T_p + T_{0.3} + 1.5\,T_{0.3}$)

$$Qt = Q_p \times 0.3^{[(t-T_p)+(1.5T_{0.3})]/(2T_{0.3})} \quad (11)$$

Information:

Q_p = Peak flood discharge
A = watershed area (km^2)
R_e = effective rainfall (1 mm)
T_p = duration from the beginning of flood until the top of the hydrograph (hour)
$T_{0.3}$ = duration from peak flood to 0.3 times peak discharge (hour)
T_g = concentration time (hour)
T_r = time unit of rainfall (hour)
á = the coefficient of watershed characteristic usually taken 2
L = the length of the main river (km)

After doing hydrological analysis, the next step is to calculate using hydraulic analysis to find the cross-section capacity of the Jambi River and the floodwater level using the HEC-RAS software.

2.2.3 HEC-RAS Software

HEC-RAS Software is an application that used for modelling the flows in the river. HEC-RAS is an acronym from Hydrologic Engineering Centers River Analysis System (RAS), made by Hydrologic Engineering Center (HEC) and one division in Institute for Water Resources (IWR), under the auspices of U.S. Army Corps of Engineers (USACE) (Istiarto,2010). HEC-RAS is software for modelling a dimension of steady or unsteady flow. HEC-RAS Software has four components for one dimension model, they are:

- Steady Flow Water Surface Component
- Unsteady Flow Simulation
- Sediment Transport/movable boundary conditions

- Water Quality Analysis

The Calculation of the Basic of Cross-section

The bottom of a cross-section of the water level can be estimated from one cross-section to the next by using the energy equation using an iteration procedure with an iterative procedure called the standard step method. Rivers usually have a changing cross-section area and non-prismatic shape. The energy loss in the channel is a loss of energy due to basic friction or changes in the cross-section shape.

The energy loss can be formulated as follows:

$$Y_2 + Z_2 + \frac{á_2 v_2^2}{2g} = Y_1 + Z_1 + \frac{á_{1} v_1^1}{2g} + he \qquad (12)$$

which is:

Y_1. Y_2 = Pressure Height (m)
Z_1. Z_2 = Height (m)
$\frac{V_1^2}{2g} . \frac{V_2^2}{2g}$ = High Height (m)
á1. á2 = Velocity coefficient
he = energy loss (m)

3. Results and Discussion

3.1 Hydrology Analysis

3.1.1 The Maximum Rainfall Data

The first step for hydrology analysis is selecting the maximum rainfall data for each rain station to find design rainfall amount and design flood discharge. The researcher used the maximum rainfall data for 11 years from 2009-2019 sourced from Sumatra Rivers Regional Office VI (BWSS) and daily rainfall online data from 2009 until 2019 sourced from Meteorology, Climatology, and Geophysics Agency (BMKG) and can be seen in Figure 3.

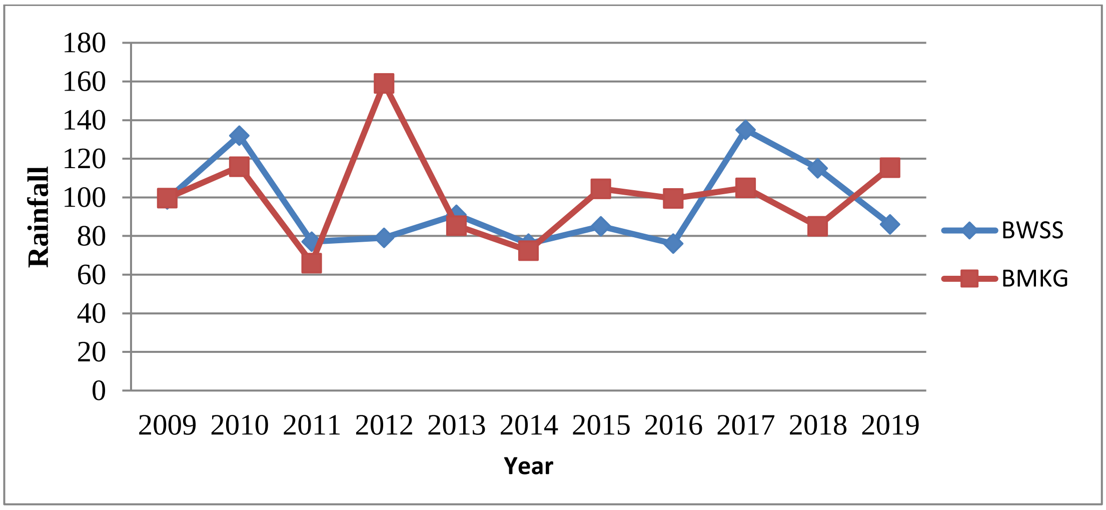

Figure 3. The Maximum Rainfall Data

3.1.2 Data Consistency Test

Data consistency test is a hydrology analysis for finding the correctness of field data influenced by several factors such as the location of rain gauge stations changes and rain measurement procedures changes (Figure 4).

One of the methods of data analysis is the RAPS method. The RAPS method is a data resilience check or a data consistency check that uses the cumulative value of the deviation from the rain data series to the average rainfall value. The results of data consistency test calculations using the RAPS method at the BMKG and BWSS VI rain gauge stations can be seen in Table 1.

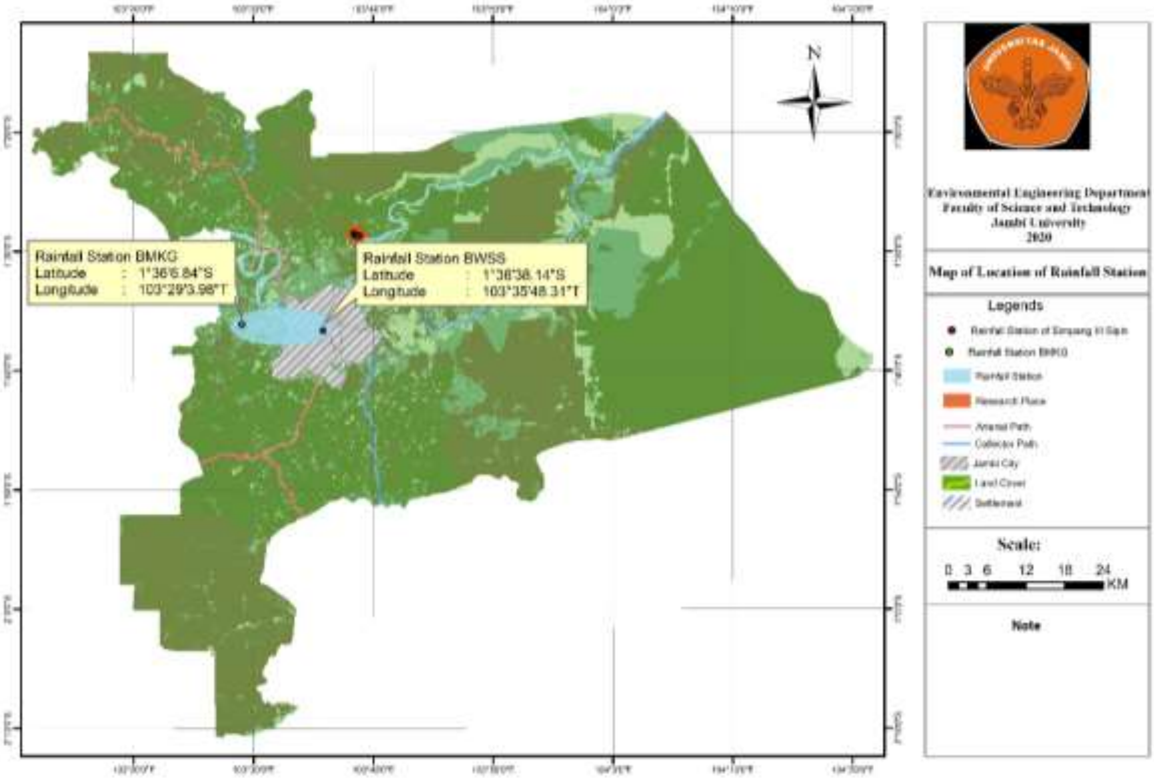

Figure 4. The Map of Rainfall Gauge Station Location

Based on Table 1. The consistency result test of rainfall using RAPS method in the Rain Gauge Station BWSS VI and BMKG Muaro Jambi obtained Q count> Q table and the value of R count> R table the rainfall data is consistent.

Table 1. RAPS Test Recapitulation Results

No	Rain Gauge Station	RAPS Test Results				Information
		$Q/n^{0.5count}$	$Q/n^{0.5table}$	$R/n^{0.5count}$	$R/n^{0.5table}$	
1	Simpang III Sipin Stations BWSS VI	1.786	3.807	1.630	4.295	Data are consistent
2	Climatology Stations Muaro Jambi BMKG	2.313	3.807	2.270	4.295	Data are consistent

3.1.3 Regional Rainfall Analysis

Regional rainfall analysis in this research used the arithmetic method because only use two rainfall gauge stations which are quite close. The calculation of rainfall in the Muaro Jambi area using the arithmetic method can be seen in Figure 5.

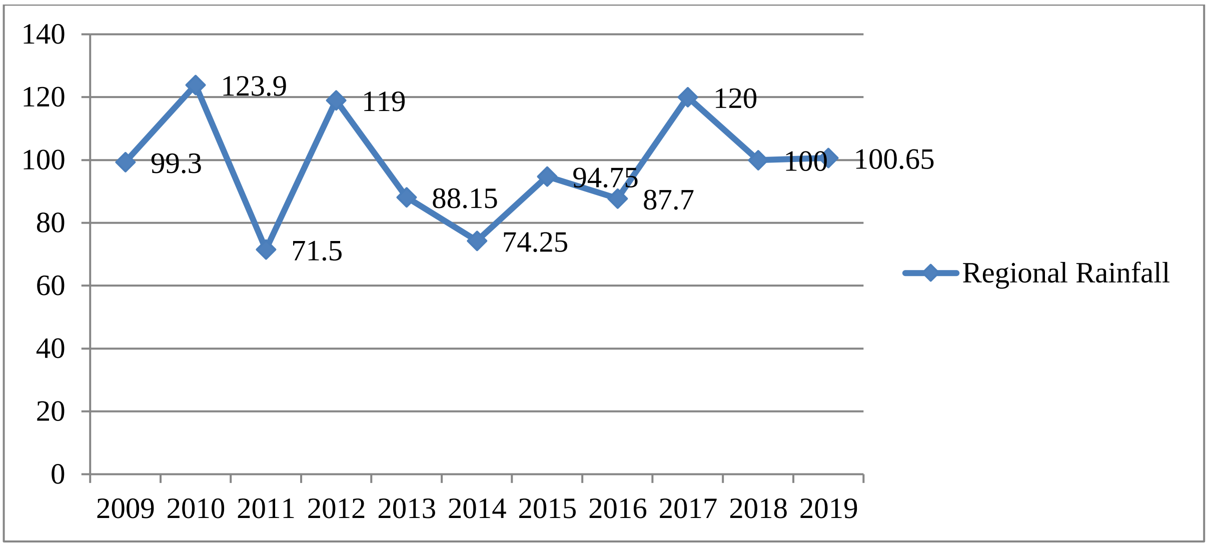

Figure 5. Regional Rainfall

3.1.4 The Planned Rain

The planned rainfall is rain with a certain return period (T) expected to occur in a drainage area. Meanwhile, the return period is a hypothetical time where an event with a certain value, for example, is planned rainfall. The calculation of the rain plan in this research uses several return periods, they are 2-years, 5-years, 10-years, 25-years, 50-years, and 100-years. The first step to calculate the planned rainfall is counting the statistical parameters consisting of several parameters. They have calculated the average rain, standard deviation, skewness coefficient (Cs), Kurtosis coefficient (Ck), Coefficient of Variation (Cv) to determine the type of distribution following the characteristics of the rainfall data. The calculation of the rainfall data statistical parameters shows that the rainfall data is not tied to any parameter, so the most suitable distribution is the log Pearson type III method. The calculated, planned rainfall results for the return period of 2-years, 5-years, 10-years, 25-years, 50-years, and 100-years using the Log Pearson type III method can be seen in Figure 6.

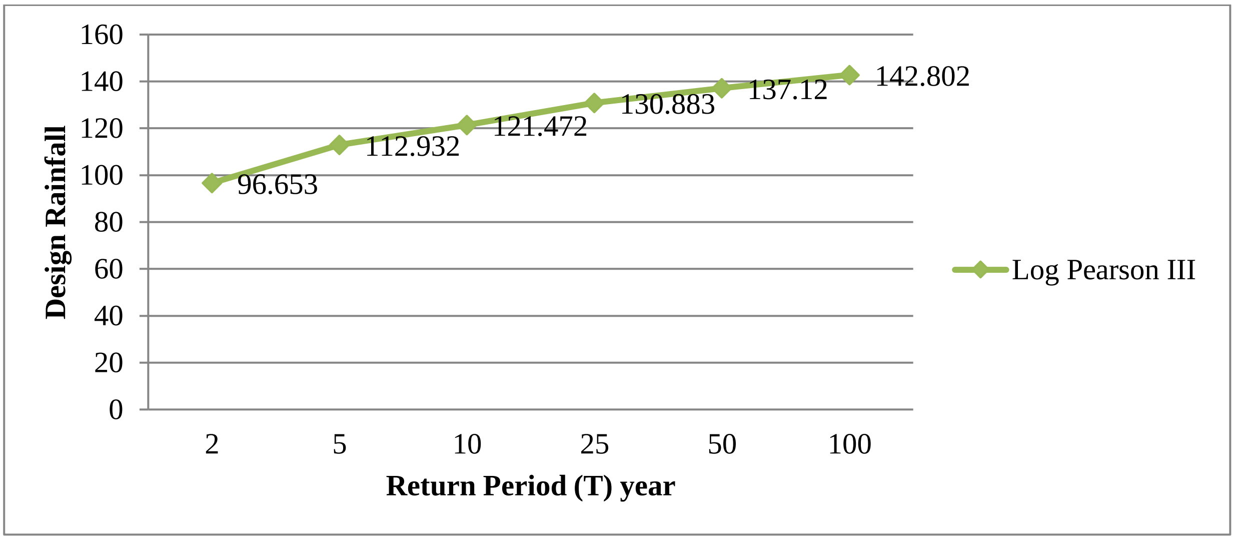

Figure 6. Maximum Design Rainfall of Log Pearson type III Method

3.1.5 Distribution Compatibility Test

The distribution compatibility test in this study used the Chi-Square test and the Smirnov Kolmogorov test. The distribution suitability test aims to describe the relationship between the depth of rain or discharge and the probability value. The calculation of the distribution fit test using the chi squared test shows that all distributions follow the rainfall data because the calculated X^{2cr} value is smaller than the X^2 table so that the Pearson III log distribution is suitable for analyzing the planned rainfall. To test the distribution compatibility using the Smirnov Kolmogorov test, all distributions follow the rainfall data because the D max value is smaller than the critical value (Do) obtained from the table so that the Pearson III log distribution is suitable for analyzing the planned rainfall.

3.1.6 Net Rain

Net rain is the component of total rain that produces direct runoff, which is also influenced by the C value (runoff coefficient). The calculation of net rain or effective rain is one of the hydrological analysis to determine the flood discharge using the unit hydrograph method. To determine the runoff coefficient in this study, Suyono's flow coefficient was used. The flow coefficient is a value or quantity used to determine the amount of surface runoff, which is determined based on a drainage area condition characteristic of the rain that falls in the area. The results of the calculation of net rain can be seen in Table 2.

Table 2. Hourly Net Rain

Number	Hour	Ratio	Cumulative	Hourly Rain (mm)					
		(%)	(%)	2	5	10	25	50	100
1	0.50	43.679	43.679	17.955	23.102	25.86	28.935	30.995	32.884
2	1.00	11.353	55.032	4.667	6.005	6.72	7.521	8.056	8.547
3	1.50	7.964	62.996	3.274	4.212	4.71	5.276	5.651	5.996
4	2.00	6.340	69.336	2.606	3.353	3.75	4.200	4.499	4.773
5	2.50	5.354	74.690	2.201	2.832	3.17	3.547	3.799	4.031
6	3.00	4.680	79.370	1.924	2.475	2.77	3.100	3.321	3.523
7	3.50	4.185	83.555	1.720	2.213	2.48	2.772	2.970	3.151
8	4.00	3.803	87.358	1.563	2.011	2.25	2.519	2.699	2.863
9	4.50	3.498	90.856	1.438	1.850	2.07	2.317	2.482	2.633
10	5.00	3.248	94.104	1.335	1.718	1.92	2.151	2.304	2.445
11	5.50	3.038	97.141	1.249	1.607	1.80	2.012	2.156	2.287
12	6.00	2.859	100.000	1.175	1.512	1.69	1.894	2.029	2.152
Design Rain (mm)				96.65	112.93	121.47	130.88	137.12	142.80
Flow Coefficients				0.43	0.47	0.49	0.51	0.52	0.53
Effective Rain (mm)				41.11	52.89	59.20	66.24	70.96	75.28

3.1.7 Analysis of Watershed Area

Analysis of watershed area for finding the large of watershed area that would be inputted data in calculation of design flood discharge. Watershed Area Determination is using the help of Google Earth software. Based on the results of the analysis, it was obtained that the watershed area was 10 km2 and the length of the main river was 5.61 km. The results of the delineation of the watershed can be seen in Figure 7**.**

Figure 7. Watershed Area of Jambi River

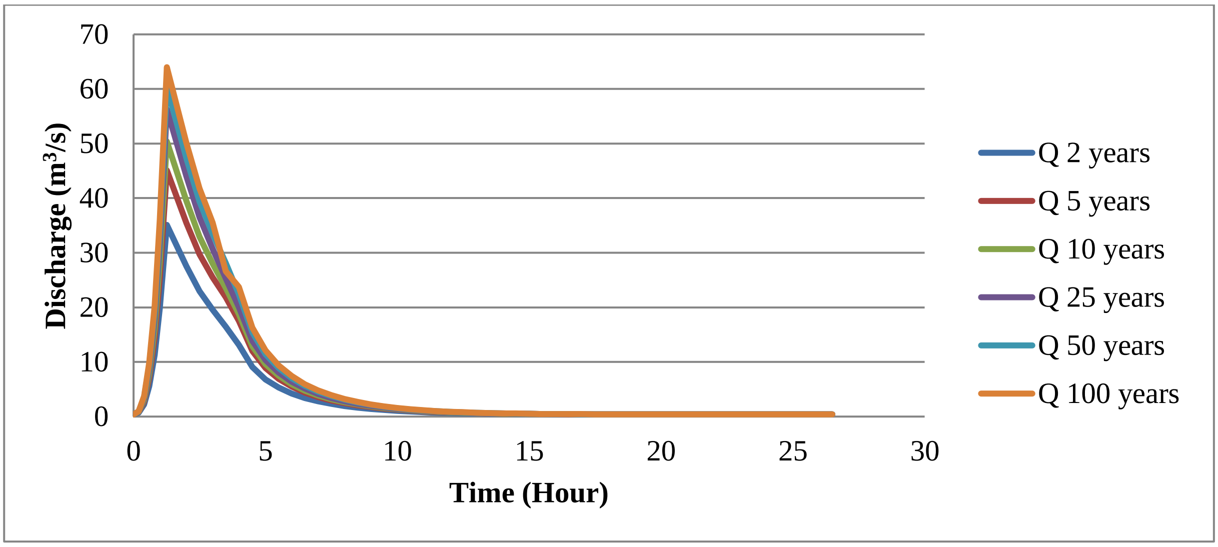

Figure 8. Nakayasu Synthetic Unit Hydrograph

3.1.8 Planned Flood Discharge Analysis (Nakayasu Synthetic Unit Hydrograph Method)

The calculation of flood discharge in this research uses the synthetic hydrograph unit method, because the watershed area is <2.5 km^2. The synthetic hydrograph method used in this research is the Nakayasu method, because it only uses physical data of the watershed, where the length of the river and the area of the river basin. The results of the planned flood discharge calculations using the Nakayasu method can be seen below

a. Watershed Physical Input Parameters

The Large of Watershed Area	: 10 km^2
River Length	: 5.61 km
Effective Rain	: 1.000 mm.

Hydrograph Parameters (α) : 2.

b. Nakayasu Synthetic Unit Hydrograph Parameters

Time Lag (Tg) $= 0.21\ L^{0.7} = 0.21 \times 5.61^{0.7}$ = 0.702 hours

Time Reduced (Tr) $=1^{*}Tg = 1^{*}0.702$ = 0.702 hours

Time Peak (Tp) $= t_g + 0.8\,T_r = 0.702 + (0.8 * 0.702)$ = 1.264 hours

T0.3 $= \alpha^{*}tg = 2^{*}0.702$ = 1.405 hours

Peak Discharge (Qp) $= \frac{1}{3.6}\left(\frac{ARe}{0.3Tp+T_{0.3}}\right) = \frac{1}{3.6}\left(\frac{10^{*}1.000}{0.3^{*}1.264+01.405}\right)$ = 1.557 m^3/s

The flood discharge plan uses the Nakayasu method for a 2-year return period of 35.106 m^3/s, for a 5-year return period of 45.101 m^3/s, for a 10-year return period of 50.396 m^3/s, for a 25-year return period, amounting to 56.298 m^3/s, for the 50-year return period of 60.332 m^3/s and for the 100-year return period of 63.987 m^3/s. The results of the calculation of the flood discharge using the Nakayasu Synthetic Hydrograph method can be seen in Figure 8.

3.2 Hydraulics Analysis

3.2.1 Analysis of Cross-section Capacity and Water Level of Flood Using HEC-RAS Software

Hydraulics analysis in this research aims to find the capacity of Jambi River tested by flood discharge Nakayasu Synthetic Unit Hydrograph for return period 2-years, 5-years 10-years, 25-years, 50-years, and 100-years using HEC-RAS software. The result is there is runoff at several measurement points for return period 2-years, 5-years, 10-years, 25-years, 50-years, and 100-years. Simulation result from HEC-RAS software for a return period of 100-years can be seen in Figure 9, Figure 10 dan Figure 11.

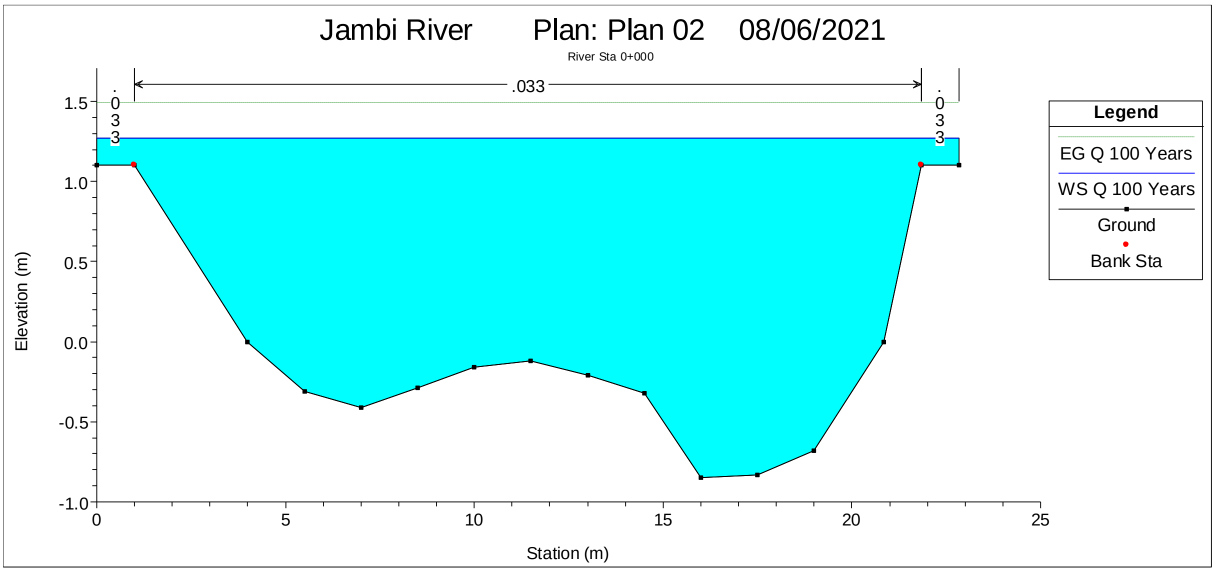

Figure 9. River Sta 5 (Measurement Point 1)

According to Figure 9, Figure 10 and Figure 11 can be seen the figure of Jambi River cross-section at river sta-5 (measurement point 1), river sta-4 (measurement point 2) and river sta-1 (measurement point 5) for return period 100 years that the water level exceeds the elevation of the left and right cliffs of the river so that runoff occurs at several measurement points. This is due to differences in elevation in the upstream and downstream of the river, causing backwater to flow. In addition, this is due to differences in the shape of the river cross-section at each measurement point. The three-dimensional cross-section shape of the simulation results of the HEC-RAS software can be seen in Figure 12.

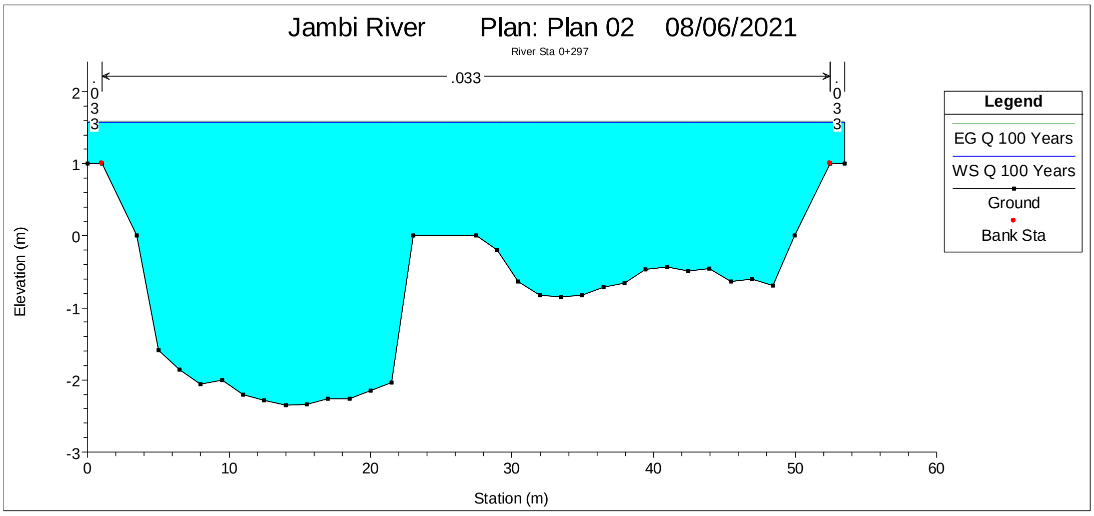

Figure 10. River Sta 2 (Measurement Point 4)

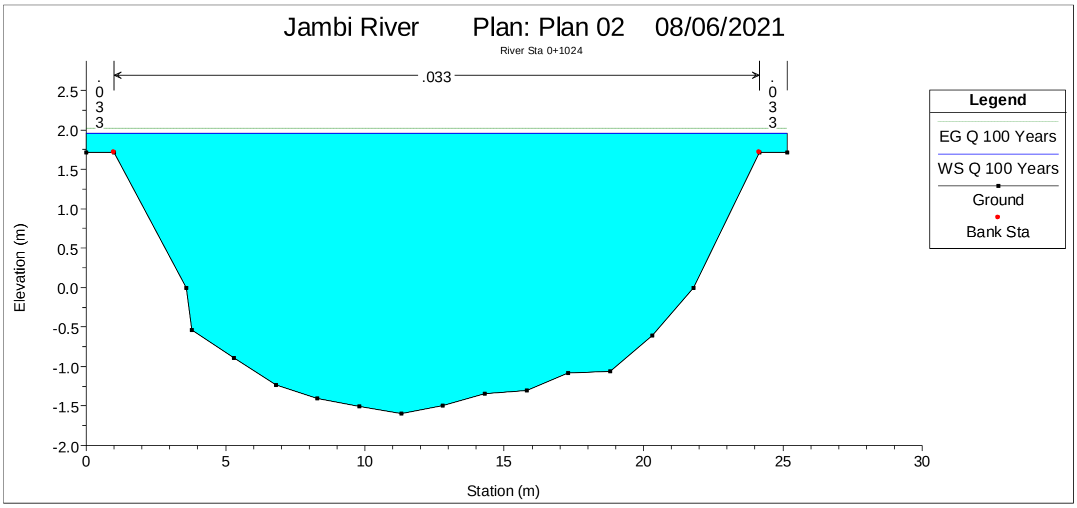

Figure 11. River Sta 1 (Measurement Point 5)

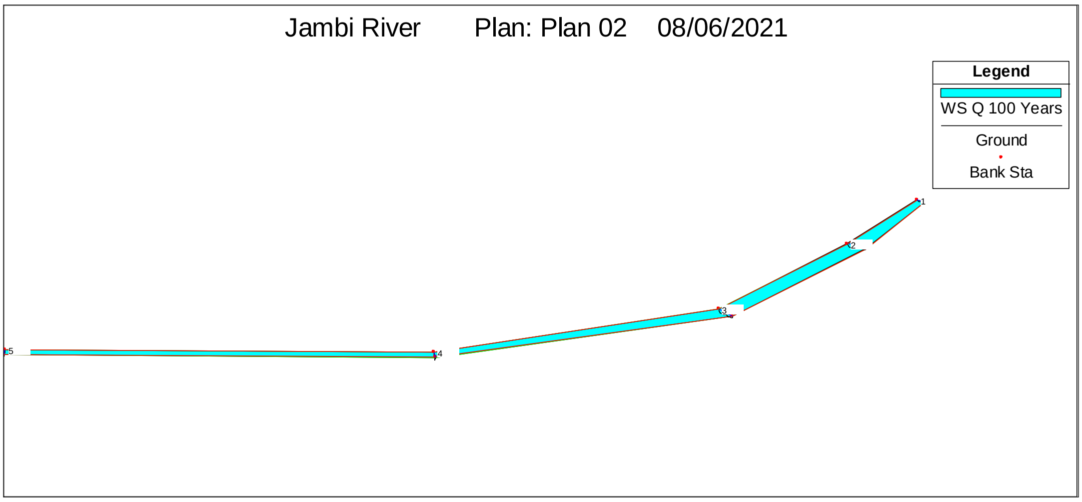

Figure 12. 3 Dimension Cross-section (perspective xyx)

3.2.2 Water Level Analysis in Jambi River Based on Simulation Result Using Hec-Ras Software towards Flood Potential that Causes Submerging of Kedaton Temple

HEC-RAS software simulation results show that the cross-section capacity of the Jambi River and the water level of each return period. Furthermore, it is necessary to compare the elevation of the Kedaton Temple building using the help of Google Earth software with the flood water level at the measurement point in front of Kedaton Temple. They are the third measurement point (river sta-3), the fourth measurement point (river sta-2) and the fifth measurement point (river sta-1). The results of elevation measurements can be seen in Figure 13.

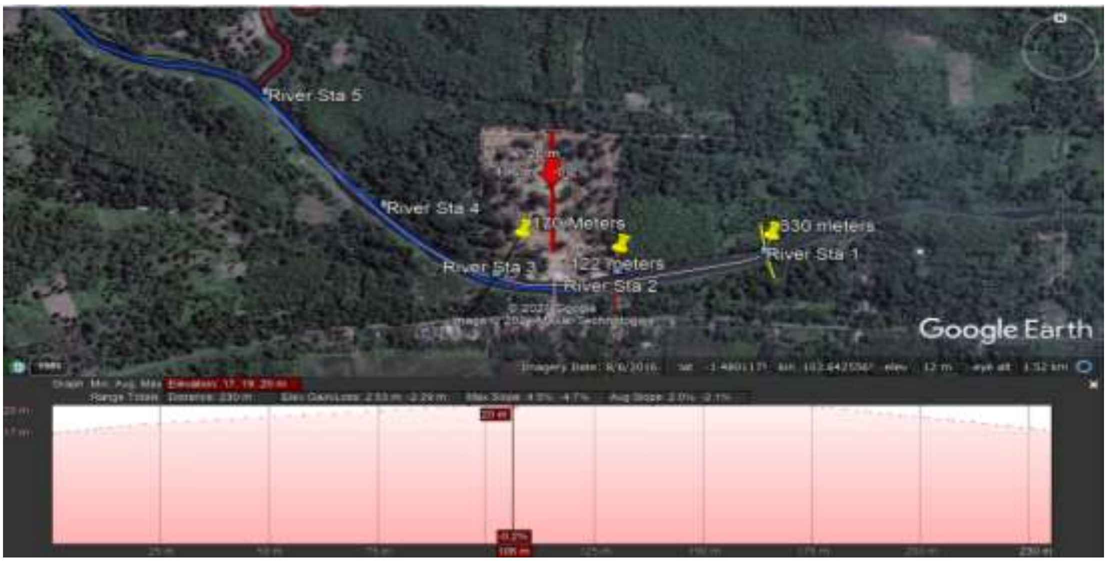

Figure 13. Elevation Comparison Measurement Results

The comparison shows that the elevation of the temple building is higher than the elevation of the flood water level so that it does not cause the Kedaton Temple building to be flooded. The results of the elevation comparison for the 100-yearreturn period on river sta-3 (measurement point 3), river sta-2 (measurement point 4) and river sta-1 (measurement point 5). can be seen in Table 3.

Table 3. Comparison of temple elevation with water level

River Sta	*Profile*	*W.S. Elevation (m)*	Temple Elevation (m)	Information	Distance from Segment to Temple (m)
3	Q 100 Years	1.610	20	Not Submerged	107
4	Q 100 Years	1.570	20	Not Submerged	122
5	Q 100 Years	1.270	20	Not Submerged	330

4. Conclusion

The results show a runoff in the 5 year and 10-yearreturn period at the fourth measurement point (river sta-2). Furthermore, in the 25 year, 50-yearand 100-yearreturn period, runoff occurs at the first measurement point (river sta-5), the fourth measuring point (river sta-2) and the fifth measuring point (river sta-1). Based on the analysis of the flood water level obtained from the HEC-RAS software compared with the results of comparing the elevation of Kedaton Temple using Google Earth software, it does not cause the Kedaton Temple building to be flooded. In the future, conduct further research using data on the effect of the Batanghari River discharge on all ancient tributaries or canals found in the Muaro Jambi Temple complex with analysis using unsteady flow in the HEC-RAS software as an analysis tool and including several variables. Other to produce countermeasures that need to be carried out on ancient tributaries or canals in the Muaro Jambi Temple complex.

5. Acknowledgements

Acknowledgements are addressed to the Sumatra Rivers Regional Office VI (BWSS VI), Cultural Heritage Conservation Center (BPCB), Public Works and Public Housing (PUPR) Office of Jambi Province, Youth Community of Environmental Lovers in Muaro Jambi and Friends at Environmental Engineering, and Jambi University who have helped a lot in conducting research, support and data collection used in research both primary data and secondary data.

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