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Effect of Water Level Elevation in Madiun River on Flooding in Jeroan River

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Abstract. Jeroan River is one of sub-basin of Madiun River which located in Madiun Regency. Every year, the area around the Jeroan river experiences flooding caused by heavy rainfall, influence of full bank capacity, changes in land use and the presence of backwater from Madiun River. The study examines one of the causes of flooding, namely backwater from Madiun River. The effect of the Madiun River water level elevation on the flooded area that occurred around Jeroan River was analyzed by using the hydrological and hydraulics approach of the HEC-HMS 6.1 and HEC-RAS 4.1 programs. The area of Jeroan basin is ± 620 km2 with a length of ± 36 km of the main river. The Jeroan basin modeling is divided into 5 sub-basins, namely Upstream Jeroan sub-basin, Mejayan sub-basin, Klitik sub-basin, Piring-Sono sub-basin and Muneng sub-basin. The modeling uses unsteady flow modeling, with the upstream boundary is the return period discharge of each sub-basin and the downstream boundary is the highest water level and the average water level in the Madiun River. The results of the study show that the highest water level in the Madiun River causes a rise in the water level in the Jeroan River in the conditions of Q2, Q5, Q10 and Q25. The rise in the river water level ranges from 0.3-1.6 meters on the cross section with the worst conditions. Length of affected by backwater (until change in elevation of 5 cm) in various discharge around 15 km. Meanwhile, the average water level of Madiun River does not affect the flooding of Jeroan River.

Keywords: *jeroan river; flood; backwater madiun river; HEC-HMS; HEC-RAS.*

1 Introduction

Flood occur several times in the Madiun Basin (DAS) caused by the overflow of the Madiun River. Madiun River overflows caused by heavy rainfall and land use change in basin area that causes the flood discharge that occurs bigger from Madiun River capacity. Madiun Watershed is part of the Bengawan Solo River [1].

Jeroan River is one of the tributary streams of Madiun River located in Madiun Regency, East Java. Problems in the Jeroan River is flood occurs several times that affect facilities and infrastructure area, affect land agriculture, and submerge settlement population especially in downstream area of Jeroan River. Flood caused by land use change and *backwater* effect from Madiun River [2].

Herlina (2011) analyzes the Factors of Jeroan River flood on 26 December 2007 are highest rainfall or high outliers, insufficient fullbank capacity, and land use change [3].

Recorded in last decades, The largest flood in Jeroan River happened in 2019 until inundated Ngawi-Kertosono Toll Road section throughout 400 meters on sections +603,600 to +604,000 and inundated National Road for 100 meters in the Garon Village, 500 meters in the Babadan Lor Village, inundated settlement as many as 4,317 households, and innundated thousand hectares of fields [4].

Based on problem above, then it will be analyzed one of the causes flooding in Jeroan River that is affected by Madiun River backwater based on Kali Jeroan discharge conditions with return periods of 2 years, 5 years, 10 years and 25 years.

In this study, simulation using the HEC-HMS software. The HEC-HMS model was designed for simulate the process of rainfall becomes runoff on a watershed system. HEC-HMS or *The Hydrologic Engineering Center's Hydrologic Modeling system* was developed by USACE-HEC. For imitate behavior flow inside watershed system, the HEC-HMS model requires adjustment of the so-called model parameters with calibration. The calibration conducted to the model parameters with evaluate similarity results simulation with observational data [5]. Whereas for simulation backwater effect to Jeroan River flood, carried out modeling using *unsteady flow* in HEC-RAS 4.1 software.

2 Materials and Methods

2.1 Study Area

Study area is located in the Jeroan Basin in Madiun Regency with a basin area of ± 620 km^2 consisting of of 5 Subbasin that is Jeroan Upstream Subbasin, Mejayan Subbasin, Klitik Subbasin, Piring-Sono Subbasin and Muneng Subbasin. Jeroan River through from Caruban area (Mejayan District) through Balerejo Subdistrict, Madiun Regency. The Upstream Jeroan is in the area of the slopes of Mount Wilis and Mount Pandan and the downstream is Madiun River.

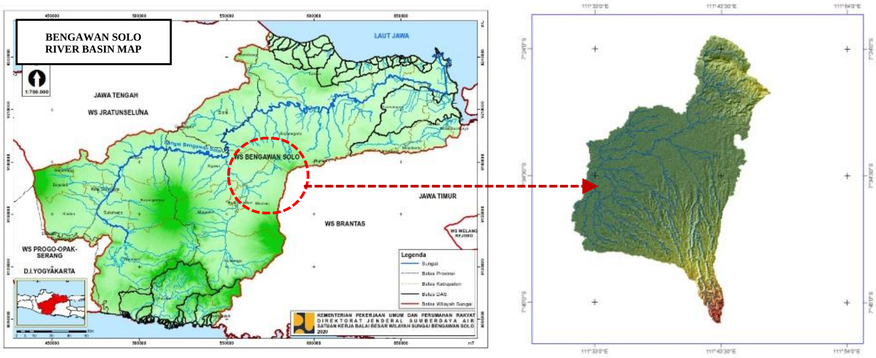

Figure 1 Location of the Jeroan Basin

2.2 Data Collection

Collection of necessary data in this study is secondary data. Required data is rainfall data, observation discharge data, water level elevation, land use map, geometric data and topography maps.

10 years rainfall data supprorted from the BBWS Bengawan Solo and the PUSDA East Java Government. Rainfall data originated from Sta Cermo, Sta Gemarang, Sta Pilangkenceng, Sta Saradan, Sta Kuwu, Sta Muneng, Sta Notopuro, Sta Jiwan, Sta Sooko, Sta Telaga Ngebel, Sta Tawang Mangu and Sta Pondok.

Observation discharge data, water level elevation data, and geometry data river suppoted from BBWS Bengawan Solo. Discharge data from Ketonggo control point and Madiun River elevation sourced from A. Yani control point.

Land use map from webgis Indonesia-geospatial.com sourced from the Ministry of the Environment and Forestry. Topographic map sourced from DEMNAS.

2.3 Data Analysis

On this styudy will be calculated data analysis on systematic includes:

2.3.1 Rainfall Analysis

Maximum daily rainfall from each rainfall sta will processed becomes rainfall area. The Formulation of rainfall area use method polygon *Thiessen* according to Eq. (1) [6].

$$d = \frac{A_1 d_1 + A_2 d_2 + A_3 d_3 \ldots + A_n d_n}{A} = \frac{\sum A_n d_n}{A} \quad (1)$$

Where:

A	=	area (km^2)
D	=	average rainfall data (mm)
$d_1, d_2, .. dn$	=	Rainfall in each sta (mm)
$A_1, A_2, .. An$	=	Effected Area of sta 1,2,… n

Rainfall distribution analysis in this study use *Generalized Extreme Value* (GEV) method by using *hydrognomon software* 4. GEV distribution probability is distribution probability continuously developed based on theory score extremes that include the Gumbel, Frechet, and Weibull distributions. The GEV distribution is the only one normalizing distribution score maximum on a distributed set of identical and independent data in a manner random [7].

Hydrognomon is application device for analysis and processing of hydrological data especially in form *time series*. This program also supports application hydrology special, includes evapotranspiration models, stages *discharge* and analysis of sediment discharges, tests homogeneity, method water balance, and hydrometry [8].

2.3.2 Flood Discharge Analysis

On this research, flood discharge is analyzed by using HEC-HMS. The runoff calculation is modelling by using *Soil Conservation Service* (SCS) *Curve Number* (CN) method. The SCS CN method is considered the easiest applied in calculation for estimate precipitation excess as cumulative function from rainfall, cover land, land use, and humidity (antecedent moisture) using Eq. (2) and Eq.(3) [9].

$$Pe = \frac{(p-Ia)^2}{P-Ia+S} \tag{2}$$

$$Ia = 0.2\ x\ S \tag{3}$$

Where:

Pe	=	Rainfall cumulative at time t
P	=	Depth of rainfall cumulative at time t
He	=	Initial abstraction
S	=	Storage maximum capacity

Initial abstraction is all lose water before happening rainfall started. The initial abstraction value is variable depending on land use. Empirical formula S in Eq. (4) [9].

$$S = \frac{25400 - 254\,CN}{CN} \text{ (SI units)} \tag{4}$$

Where

S	=	Maximun retention value
CN	=	Curve Number

CN (Curve Number) values vary from 100 (for waterlogged surface up to around 30 for impermeable surface with high infiltration rate. The CN value represents function of land use, type land, plant cover and humidity. For the land consists of some type land and land use accordingly the CN value is $CN_{composite}$ in accordance Eq. (5) [9].

$$CN_{\text{composite}} = \frac{\sum A_i CN_i}{\sum A_i} \tag{5}$$

Where

$CN_{composite}$	=	Land use composite value
Ai	=	Subbasin Area

On this research will use Snyder's hydrograph method. F.F. Snyder from the United States in 1938 made use of basin parameters for obtain hydrograph unit synthetic. A number of the watersheds studied by Snyder are on plains Appalachian height with watershed area ranges between 30 and 30,000 km^2 [10].

Snyder developed the model with connecting empirical coefficients elements hydrograph unit with basin characteristics. It is based on thought that conversion rainfall becomes runoff influenced by the basin system [11].

Hydrograph unit determined with element among Qp (m^3/sec), T_b (hours), and t_b (hours) and t_r (hours). The hydrograph element connected with basin area (km^2), main river length (km), and length river main be measured from the place measurement up to the point in the main river with basin weight point (km). With those elements, Snyder created a hydrograph unit synthetic model with Eq (6) – Eq (7) [10].

$$t_{\text{p}} = 0.75\,.\,Ct\,(L.\,Lc)^{0.3} \tag{6}$$

$$\text{Qp} = 2.75\,\frac{Cp.A}{tp} \tag{7}$$

where:

t_p	=	Time lag (hours)
Qp	=	Peak Discharge (m^3/sec)

Ct and Cp are coefficients that depend on the unit and features of the basin [12]. The Ct and Cp coefficients should be determined empirically, because magnitude capricious among one area _ with the others. In the metric system, Ct ranges between 0.75 to 3.00, while Cp ranges between 0.9 to 1.4 [13].

3 Results and Discussion

3.1 Basin and Subbasin Delineation

The watershed delineation was carried out in the Madiun Basin for necessity calibration and Jeroan Basin as study location. Madiun Basin have watershed area of ± 3,828 km^2 and Jeroan Basin have watershed area of ± 620 $km^{2.}$ and with using the HEC-HMS program, the mapping process is carried out for determine the subbasin of Jeroan Basin so that 5 subbasin were obtained, namely the Upstream Jeroan subbasin with area of 111.95 km^2, Mejayan subbasin with area of 182.25 km 2, Klitik subbasin with area of 67.20 km^2, Piring-Sono with area of 198.46 $km^{2,}$ Muneng subbasin with area of 60.17 $km^{2.}$ The Delineation of Madiun Basin dan Jeroan Basin can be seen on Figure 2.

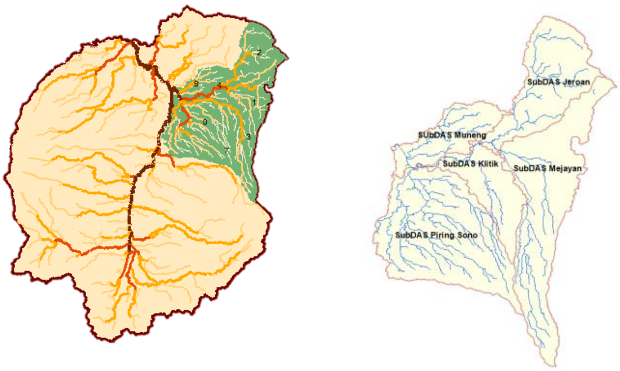

Figure 2 The Delineation results of Madiun Basin, Jeroan Basin and Subbasin’s

3.2 Land Use Analysis

Land use of Madiun Basin consists of some classes that is shrubbery, dry land secondary forest, forest crops, settlements, plantations, mining, agriculture dry land, mix agriculture land, rice fields, open field and waters. From the land use map determined type soil from each cover land based on grouping criteria of Hydrological Soil Group (HSG) ie class B and class D so that obtained $CN_{composite}$ of 76.79. The $CN_{composite}$ values of the Upstream Jeroan Subbasin was 80.58, the Mejayan Subbasin of 76.96, Klitik Subbasin of 64.51, Piring-Sono Subbasin of 70.78, and the Muneng SUbbasin of 84.83.

3.3 Hydrology Analysis

3.3.1 Rainfall Analysis

Annually Maximum Rainfall (HHMT) analyzed to regional rainfall in each Subbasin using Polygon Thiessen method. Then it analyzed to return period rainfall by using GEV method then multiplied with ARF. The Rainfall Anlyasis shown on Table 1.

Table 1 Rainfall Frequency Analysis

Return Period	Rain Plan X ARF (mm)				
	Upstream Jeroan Subbasin	Mejanyan Subbasin	Klitik Subbasin	Piring-Sono Subbasin	Muneng Subbasin
2	116	100	104	97	178
5	139	113	115	105	201
10	151	121	121	110	213
25	163	130	128	114	225
50	171	136	132	117	232

3.3.2 Calibration

calibration conducted with comparing 3 events of flood discharge maximum events recorded on Ketonggo control point. The results of discharge from the rainfall on the same day of the 3 events using the HEC-HMS 4.10 program. Ct and Cp values were obtained with *trial-and-error* method so that obtained less than 10% error between calculation discharge and observed data on Ketonggo control point in 3 different years (Figure 3). Simulation use *SCS CN* loss method and *transform HSS Snyder*.

Duration used 12 hours rainfall distribution considering the Jeroan Basin including large Basin with time base hydrograph estimated less than 12 hours so that recommended for use 12 hours rain duration as base calculation. hourly rainfall distribution conducted using PSA-007 based Technical Instructions for Calculation of Flood Discharge at Dams 2017 [9]. Ct and Cp values obtained of the calibration process is 1.15 and 0.7 closest to observed data in 2014, 2017 and 2018.

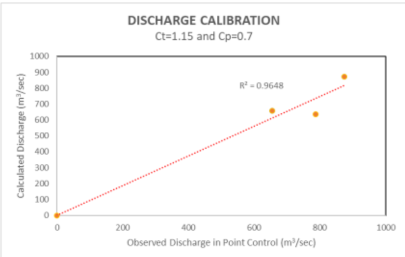

Figure 3 Discharge Calibration Results

The calibration parameters can be applied for discharge calculation in each subbasin in the location study with data input as in Table 2.

Table 2 Loss and Transform Parameters in HEC-HMS

No	Subbasin	CN	Initial Abstraction	Ct	Peaking Coefficient (Cp)	River Length(L)	Lc	Time Lag	Impervious
						(km)	(km)	(o'clock)	(%)
1	Upstream Jeroan	80.58	12.2	1.15	0.7	34.16	17.70	7.86	2.19
2	Majayan	76.96	15.2	1.15	0.7	40.28	13.03	7.53	2.00
3	Klitik	64.51	27.9	1.15	0.7	32.69	16.73	7.62	5.00
4	Piring-Sono	70.78	21.0	1.15	0.7	36.18	22.3	8.57	4.49
5	Muneng	84.83	9.1	1.15	0.7	24.98	14.43	6.73	5.23

3.3.3 Flood Discharge Analysis

Flood discharge analysis on this study use *Snyder* 's Hydrograph method with the HEC-HMS 4.10 program. Based on simulation results using HEC-HMS was obtained flood discharge hydrograph return period for each subbasin as shown in Figure 4. Peak discharge Flood could be seen in Table 3.

Table 3 Return Period Discharge

Return Period	Peak Discharge (m^3/sec)				
	Upstream Jeroan	Mejayan	Klitik	Piring-Sono	Muneng
2	161.7	199.1	47.2	153	213.1
5	221.8	242.1	57.2	165.2	247.7
10	253.7	269.1	63.9	177.6	265
25	275.5	302.8	73.8	293.2	285.2
50	292.1	329.3	79.4	213.9	296

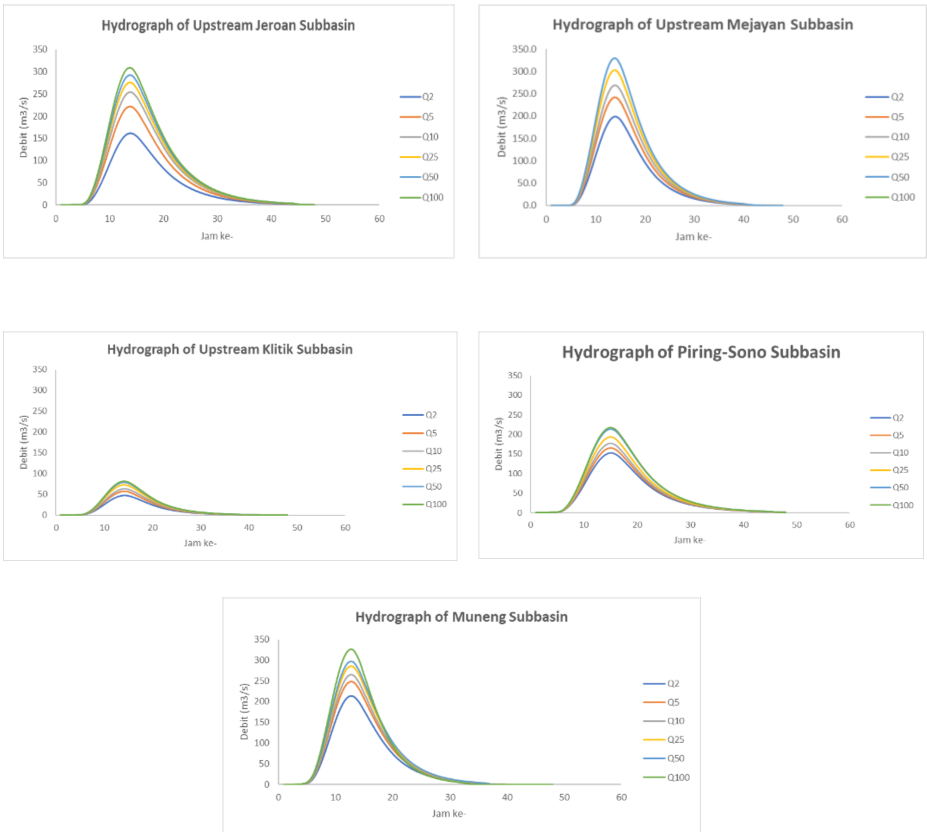

Figure 4 Hydrograph of Each Subbasin

3.3.4 The Water Level Elevation of Madiun River

The water level Elevation of the Madiun River at the junction between Jeroan River and Madiun River in Q25 was obtained from A. Yani control point. A. Yani control point was ± 8 km away from downstream of Jeroan River. So Q25 calculation based on comparison between basin area with A.Yani control point as an outlet (± 2202.42 km ^{2}) with basin area of Madiun River and Jeroan River meeting point as an outlet. The water level elevation is analyzed using rating curve graph on the segment of cross section in junction of two river. *Rating curves* obtained from cross-sectional in measurement 2009 that simulated using HEC-RAS. Water level elevation used in this simulation could be seen in Table 4.

Table 4 The Water Level Elevation of Madiun River at the Downstream of the Jeroan River

Outlets	Basin area (km ^{2})	Discharge (m ^{3}/sec)		Elevation (mdpl)	
		Q25	Qaverage	Q25	average
Junction of Madiun and Jeroan River	2837	1029.25	168.22	56.43	49.34

3.1 Model Simulation

Modeling in this study is running on HEC-RAS 6.1.0 by implementing unsteady flow with the modeling scheme in Figure 5 and modeling scenario can be seen in Table 5.

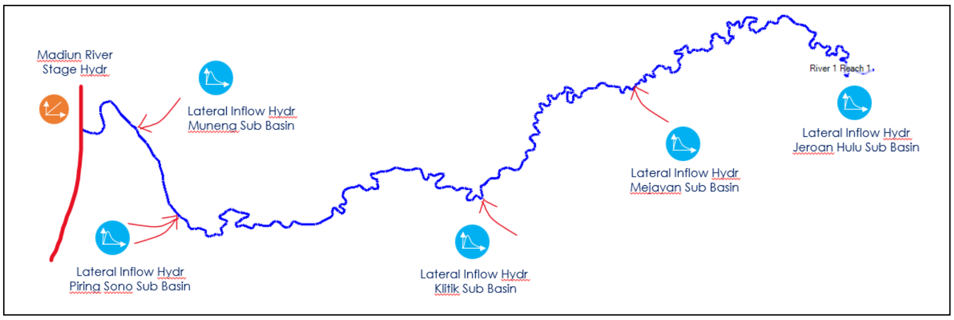

Figure 5 modeling scheme

Table 5 modeling scenario on HEC-RAS

Skenario	Upstream (Jeroan Basin)	Downstream (Madiun Basin)
1	Q2, Q5, Q10, Q25, Q50	Normal depth (slope 0.00077)
2	Q2, Q5, Q10, Q25, Q50	The highest water level elevation
3	Q2 dan Q25	The average water level elevation

In the upstream boundary scenario, Q2 hydrograph discharge is calculated from upstream toward Mejayan River (sta 327) as large as 161.7 m3/sec, section (sta 328–sta 212) along Mejayan River until Klitik River as large as 347.35 m3/sec, section (sta 213–sta 49) after Klitik River till Plate-Sono River as large as 383.33 m3/sec, section (sta 50-sta 27) along Plate-Sono River until Muneng River as large as 511.73 m3/sec, and section (sta 28–sta 0) after Muneng River confluence calculated discharge as large as 643.94 m3/sec. On the normal depth as a downstream boundary, the Jeroan River has experienced overflow along sta 300 – sta 490. This shows that the bankful capacity of the Jeroan River is no longer able to accommodate discharge that occurs without the influence of the backwater from the Madiun River.

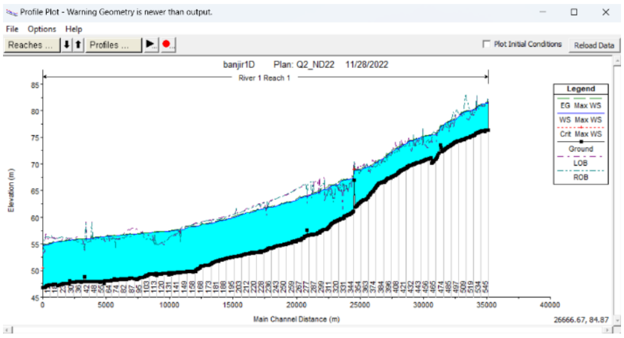

Figure 6 Simulation Result of Q2 (Upstream Boundary) and Normal Depth (Downstream Boundary)

In the simulation scenarios Q2, Q5, Q10, and Q25 as the upstream boundary and the highest TMA Madiun River as the downstream boundary, it is found that increasing water elevation in Jeroan River. This shows that there is backwater from Madiun River which has an effect on flooding in Jeroan River. The rise in Jeroan River water level can be seen in Figure 7 until Figure 9.

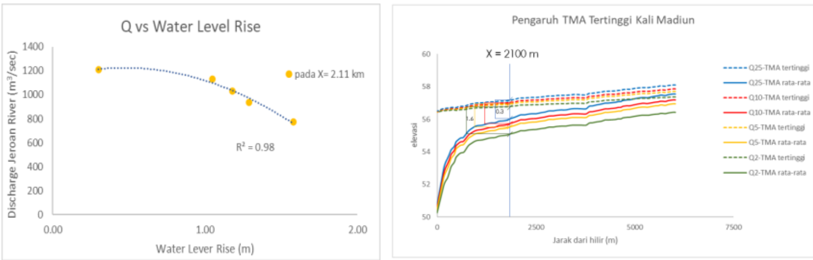

Figure 7 Elevation Changing of Jeroan River affected of Backwater from the Madiun River.

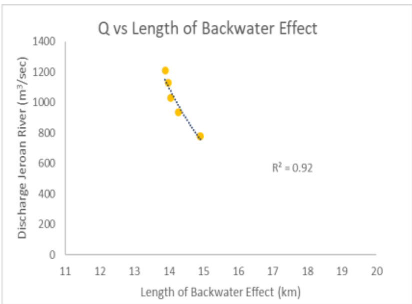

Figure 8 The Length Effect of Backwater

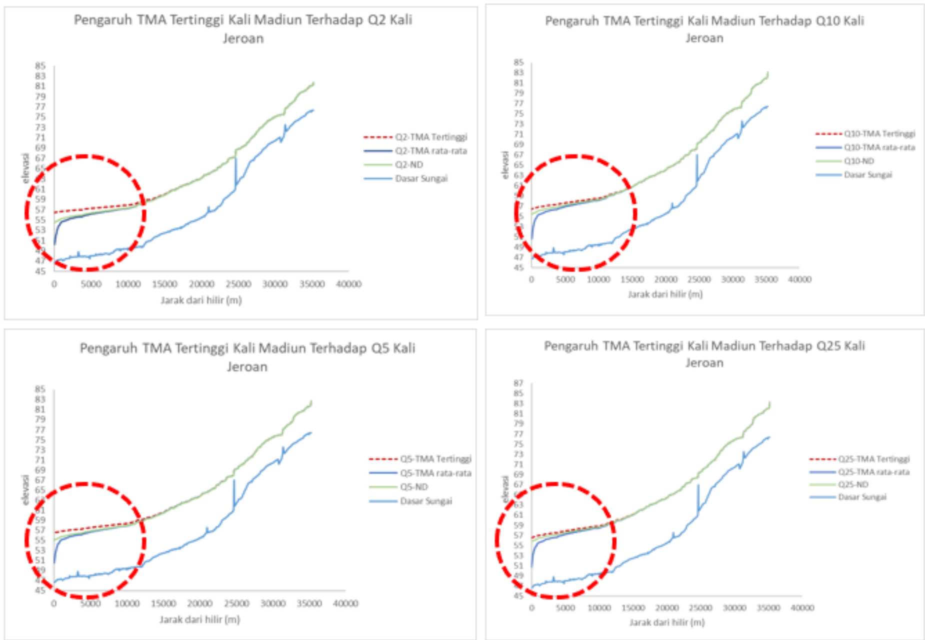

Figure 9 Elevation Changing of Jeroan River affected of Backwater from the Madiun River in Each Discharge Return Period

Based on scenario using average TMA Madiun River as the downstream boundary, it is found that Average TMA Madiun River does not affect water level of the Jeroan River. This shows that the condition of the Madiun River with an average water level does not cause backwater into Jeroan River. So, it can be concluded that the flooding that occurs is influenced by the amount of discharge from the sub-basin of Jeroan River.

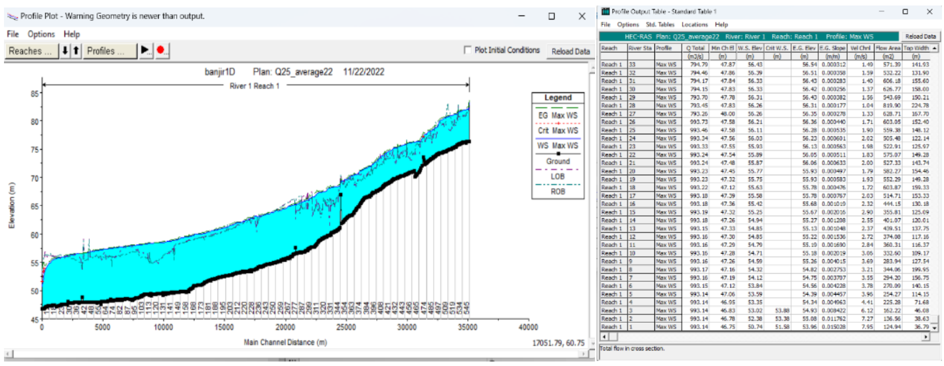

Figure 10 The Simulation Result of Q2 as Upstream Boundary and Average Water Level of Madiun River as Downstream Boundary

However, based on scenario Q25 as the upstream boundary and average water level of Madiun River as the downstream boundary, there is increasing velocity as much as 12% and critical flow occurs at downstream Jeroan River. This increasing velocity of water can be related to natural conditions of the Jeroan River which tend to experience degradation and frequent cliff slides, especially on the cliffs on the outer bend.

4 Conclusion

Based on the analysis result and discussion, it can be concluded as follows:

1. The Calibration result on Ketonggo point control, obtained the parameters Ct = 1.15 and Cp = 0.7 which can be used to calculate flood discharge design in each Jeroan sub-basin.

2. Based on hydrological analysis, the peak discharge during Q25 period in Upstream Jeroan sub-basin is 275.5 m3/sec, in the Mejayan sub-basin is 302.8 m3/sec, in the Klithik sub-basin is 73.8 m3/sec, in the Piring-Sono sub-basin is 293.2 m3/sec, and in the Muneng sub-basin is 285.2 m3/sec.

3. In the simulation uses Q2, Jeroan River has overflowed at several points along sta 300 to sta 490. This shows that the bankful capacity of the Jeroan River is no longer able to accommodate flow-discharge that occurs even without impact of backwater from Madiun River.

4. In the highest water level elevation conditions exists in Madiun River, it was found that highest conditions effects of rising water level from normal conditions, ranged from 0.3 to 1.6 meters with affected length around 15 km. This explains that Kali Madiun affects increasing of flood volume into Kali Jeroan.

5. In the average water level conditions occurs in Madiun River, it is found that there was no effect on rising of the water level to Jeroan River. It can be concluded that in this condition the Jeroan River flooding is caused by flow-discharge from its sub-basins that come from high rainfall or land use change in subbasin.

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