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# MODELING BENGAWAN SOLO RIVER TO PREDICT THE AREA INUNDATION OF FLOOD

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**ABSTRACT**

Bengawan Solo River is the longest river in Java Island. The river have length is approximately 600 km and 16.100 km$^2$ in area of watershed. Bengawan Solo watershed is divided into three zones that are Upper Solo River, Middle Solo River, and Lower Solo River. In this case, The Middle Solo River is represented by Kali Madiun Catchment Area. Bengawan Solo River is often flooded. A flood is an unusually high stage in a river. Discharge exceed than full bank capacity can be flood in the river. The damages caused by floods are loss of life, property and economic due to disruption of economic activity. There are many solutions to minimize of effect of flood. In this study make a model of Bengawan Solo River to analysis of Hydraulics River. The results of hydraulics analysis are used to create map of flood inundation. The map of flood inundation is used as information for peoples who stay in Bengawan Solo Watershed as warning of flood. If information could be known early then it can help people to be careful and minimize of damages. Model of Bengawan Solo River is produced from hydraulic analysis of HEC-RAS. HEC-RAS process is using flow hydrograph from hydrological analysis. HEC-HMS is software is used to hydrological analysis in Bengawan Solo Watershed. Input data needed to process of HEC-HMS is average of rainfall data, return periods of rainfall at 2 years, 5 years, 10 years, and 25 years. The area rainfall is determined by Polygon Thiessen methods. The return periods of rainfall data is determinable using Gumbel's method. The last result of this process is discharge data, elevation of surface water, and prediction of flood inundation. In this study produced a map of flood inundation. This map is referring of flood and non-inundation area at Bengawan Solo Watershed. It is a benefit to minimize of flood damages.

**Keywords:** modeling of river flow, bengawan solo**,** map ofinundation, flood.

## INTRODUCTION

Bengawan Solo River is the longest river in Java. The length of river approximately 600 km with area is 16.100 km$^2$. Bengawan Solo River divided in to three zones that is Upper Solo River, Middle Solo River, and Lower Solo River. In this case, The Middle Solo River is represented by Kali Madiun Catchment Area. The problems in Bengawan Solo Watershed are caused by Upper Solo River and Middle Solo River. The flood in Lowes Solo River is a flood flow from Upper Solo and Middle Solo River. The length of Upper Solo River more than length of Middle Solo River until if Upper Solo River experience rain and Middle Solo River some times after it, then flood flow will be very high to Lower Solo River. The next problem in Lower Solo River has superficial elevation of surface land until the flood inundation will be long time to be here. A flood is an unusually high stage in a river. Discharge exceed than full bank capacity can be flood in the river. The damages caused by floods are loss of life, property and economic due to disruption of economic activity. There are many solutions to minimize of effect of flood. In this study make a model of Bengawan Solo River to analysis of Hydraulics River. The results of hydraulics analysis are used to create map of flood inundation. The map of flood inundation expected the minimizing of damage of flood. Therefore, the map of flood inundation is needed to predicting the area of flood inundation.

## METHOD

In this study is using many methods to create a map of flood inundation in Upper Solo River. The method of Polygon Thiessen can be used to determine average of rainfall data. The some equation from Polygon Thiessen that is:

$$\bar{P} = \frac{\sum_{i=1}^{M} P_i A_i}{A} = \sum_{i=1}^{M} P_i \frac{A_i}{A} \quad (1)$$

Where:
$\bar{P}$ =Average of rainfall data
$P_i$ =The rainfall data from staion-i
$A_i$ =The area from station-i
$A$ =The total area of watershed
(HEC-HMS Manual, 2015)

The result of Polygon Thiessen is used to determine return periods of rainfall in Upper Solo River, Middle Solo River, and Lowes Solo River. The Gumbel's Method can be used to determine return periods of rainfall. The some equation from Gumbel's Method that is:

$$x_T = \bar{x} + K\sigma_{n-1} \quad (2)$$

$$\sigma_{n-1} = \sqrt{\frac{\Sigma(x-\bar{x})^2}{N-1}} \quad (3)$$

$$K = \frac{y_T - \overline{y_n}}{S_n} \quad (4)$$

$$y_T = -\left[ln.\,ln\frac{T}{T-1}\right]$$ (5)

$$y_T = -\left[0.834 + 2.303\log\log\frac{T}{T-1}\right]$$

= frequent factor
$y_T$ = reduction variant
$S_n$ = from table
$\bar{y}_n$ = from table

The confidence limit of Gumbel's method can be calculation with equation 6.

$$X_{1/2} = X_T \pm f(c)S_e$$ (6)

Where:
$S_e$ = Probable eror = $b\frac{\sigma_{n-1}}{\sqrt{N}}$
$b$ = $\sqrt{1 + 1.3K + 1.1K^2}$
$K$ = Equation 4
$\sigma_{n-1}$ = Standard deviation of the sample
$N$ = Sample size
(Subramanya, 1995)

There are the other methods to determine the return period of rainfall. Log Pearson type III is the other method to calculate the return period of rainfall. In this study the calculation of the return period of rainfall is do with two methods that is the Gumbel method and The Log Pearson type III method. The use of these methods is aimed to determining the right method in use calculation of the return period rainfall. The formula of Log Pearson type III is:

$$Z_T = \bar{Z} + K_T S_Z$$ (7)

Where:
$Z_T$ = log x
$\bar{Z}$ = the average of log x
$K_T$ = coefficient Log Pearson type III
$S_Z$ = standard deviation
(Subramanya, 1995)

In this study is using the return period of rainfall data that is 2 years, 5 years, 10 years, and 25 years. To determine time of concentration at river flow can using Kircprich's equation.

$$t_c = 0.0078L^{0.77}S^{-0.385}$$ (8)

Where:
$t_c$ = Time of concentration (Minute)
$L$ = Length of channel (ft)
$S$ = Average watershed slope, (ft/ft)
(VenTeChow,Dkk, 1994)

In this study the calibration of hydrologic model is using the Nash method and the correlation test. The Nash method explaining about the model is good if the Nash value approaching zero (0). While, the correlation test is good if the correlation value approaching one (1). The formula of The Nash method and the correlation test is:

$$Nash = 1 - \frac{(Q_{sim} - Q_{Obs})^2}{(Q_{obs} - \overline{Q_{obs}})^2}$$ (9)

Where:
$Q_{sim}$ = the discharge of model ($m^3$/s)
$Q_{Obs}$ = the discharge of AWLR station ($m^3$/s)
$\overline{Q_{obs}}$ = the average of the discharge of AWLR station ($m^3$/s)
Then, the formula of the correlation test is:

$$r^2 = \frac{\sum(\hat{y} - \bar{y})^2}{\sum(y - \bar{y})^2}$$ (10)

$$r^2 = \frac{a(\sum y) + b(\sum xy) - n(\bar{y})^2}{\sum(y)^2 - n(\bar{y})^2}$$ (11)

$$r = \pm\sqrt{r^2}$$ (12)

Where:
$\hat{y}$ = the estimate value of the independent variable
$\bar{y}$ = the average y
$x$ = the

$$a = \bar{y} - b\bar{x}$$ (13)

$$b = \frac{n(\sum xy) - (\sum x)(\sum y)}{n(\sum x^2) - (\sum x)^2}$$ (14)

$y$ = the data
$r$ = the correlation value
(Harilnaldi, 2005)

The analysis of hydrological is using HEC-HMS. The Capabilities HEC-HMS is the program has an extensive array of capabilities for conducting hydrologic simulation. Many of the most common methods in hydrologic engineering are included in such a way that they are easy to use. The program does the difficult work and leaves the user free to concentrate on how best to represent the watershed environment. Every simulation system has limitations due to the choices made in the design and development of the software. The limitations that arise in this program are due to two aspects of the design: simplified model formulation, and simplified flow representation. Simplifying the model formulation allows the program to complete simulations very quickly while producing accurate and precise results. Simplifying the flow representation aids in keeping the compute process efficient and reduces duplication of capability in the HEC software suite.

The analysis of hydraulically is using HEC-RAS. The HEC-RAS software can use to determine hydraulic condition from the flow of one dimension of river. The HEC-RAS software in this study used for shown of the change of water surface elevation in each cross section data. The schematic from this study can be shown at flow chart in Figure-1.

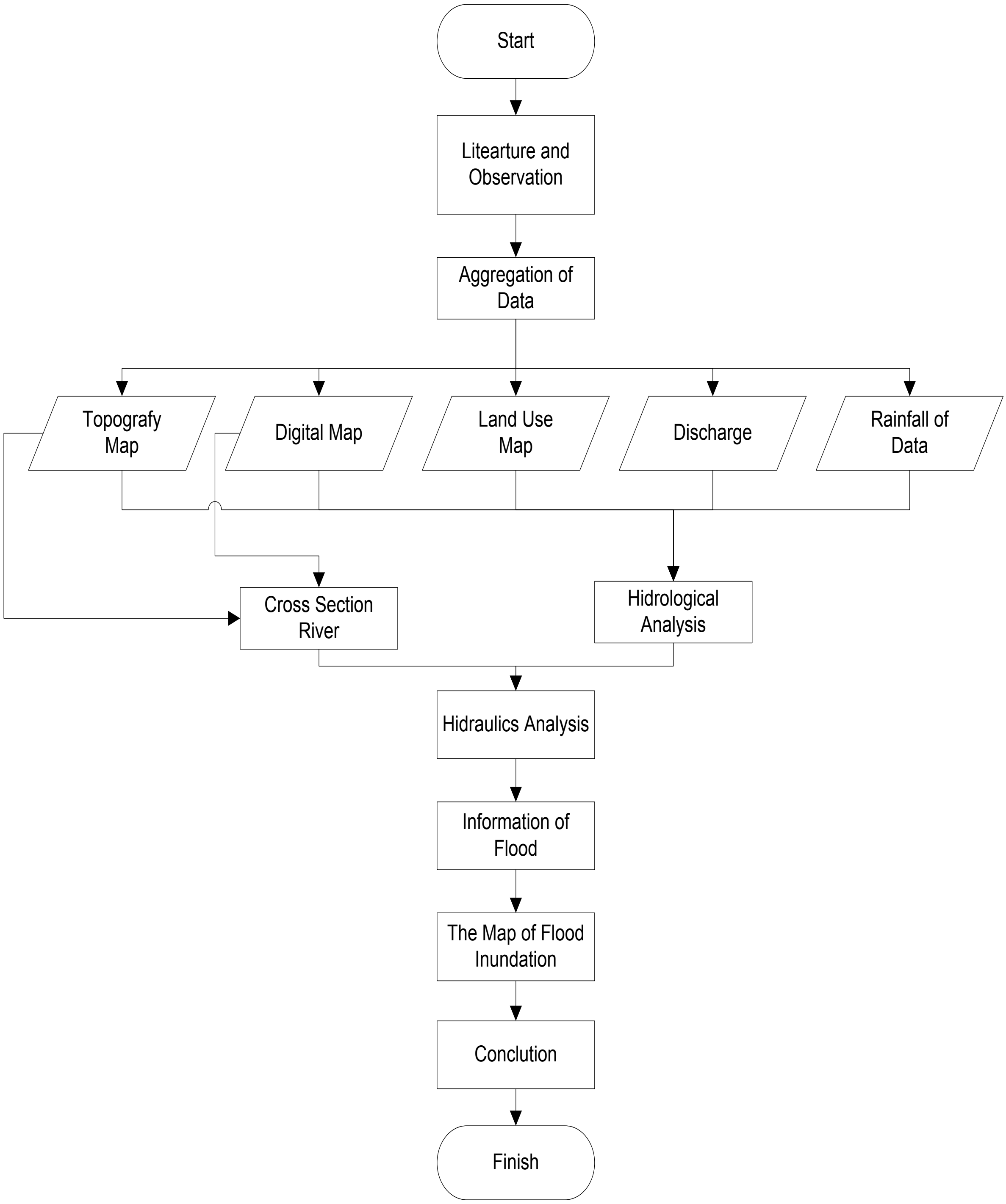


**Figure-1.** Flow chart of study (2015).

**RESULT**

Based on hydrological analysis be found results of calculation of rainfall data to discover return period of rainfall in Bengawan Solo Watershed. The return periods of rainfall are 2 years, 5 years, 10 years, and 25 years is used in this study. Before the calculation of return period of rainfall, the polygon Thieesen is needed to determine the factor influence from rainfall station. The location of rainfall station in Bengawan Solo Watershed with the polygon of each rainfall station can be shown in Figure-2.

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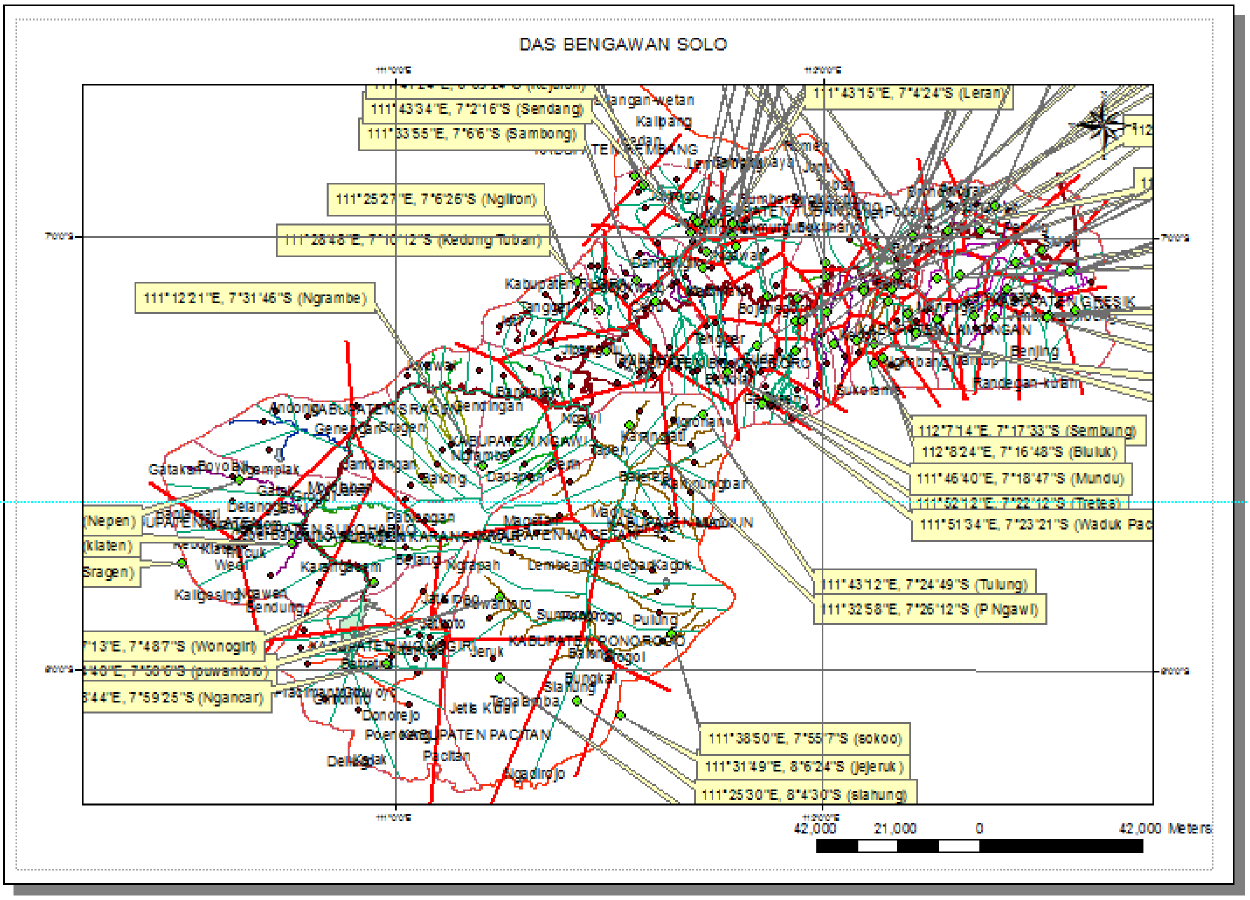


**Figure-2.** Map of rainfall station and the polygon Thieesen (2015).

Based on Figure-2 can be calculation of average rainfall in Bengawan Solo with method of Polygon Thieesen. Then, the return period of rainfall can be calculated with Gumbel's method. Based on the result can be known the return period of rainfall as the following Table-1.

The confidence limit from Gumbel's method is 95 percent used in this study. The confidence limit is the limit of value from the forecasting calculation of the Gumbel. The confidence limit of Gumbel is calculated is using equation 6. The confidence limit of Gumbel's method can be shown in table 2, 3, and 4.

Based on the table 2, 3, and 4 is showed CL (Confidence Limit) in Upper Solo, Middle Solo, and Lower Solo. $X_1$ is the maximum variable of forecast rainfall and $X_2$ is the minimum variable of forecast rainfall. Thus, the value of rainfall for each watershed is 1.25 – 10.97 for the return period 2 years; 6.10 – 25.36 for the return period 5 years; 11.22 – 38.11 for the return period 10 years; and 15.82 – 52.69 for the return period 25 years in Upper Solo. The value of rainfall in Middle Bengawan Solo is 1.23 – 12.33 for the return period 2 years; 6.56 – 28.57 for the return period 5 years; 12.26 – 42.98 for the return period 10 years; and 17.41 – 59.53 for the return period 25 years. The value of rainfall in Lower Bengawan Solo is -0.07 – 9.97 for the return period 2 years; 3.55 – 23.48 for the return period 5 years; 7.84 – 35.65 for the return period 10 years; and 11.86 – 50.00 for the return period 25 years. Based on the calculation of Gumbel's method is resulting forecast of rainfall on return period. If the calculation of rainfall is using Log Pearson type III as a comparison then the result can be shown in table 5.

**Table-1.** The return period of area rainfall from the calculation of the Gumbel method.

| Return period | The Rainfall | | |
|---|---|---|---|
| | Upper Solo | Kali Madiun | Lower Solo |
| 2 year | 6.422045 | 7.125678 | 5.210532 |
| 5 year | 14.23037 | 15.57886 | 11.87509 |
| 10 year | 23.07102 | 24.69813 | 20.17626 |
| 25 year | 29.49748 | 31.29980 | 26.27838 |

Source: The result of study, 2016

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**Table-2.** Confidence limit in the upper Bengawan solo (2015).

| Tr | K | B | Se | $R_B$ | C | Rn | f(c)Se | $X_1$ | $X_2$ |
|---|---|---|---|---|---|---|---|---|---|
| 2 | -0.14314 | 0.914581 | 2.478791 | 40.78415 | 0.15 | 6.117622 | 4.85843 | 10.97605 | 1.259192 |
| 5 | 0.967411 | 1.813038 | 4.913884 | 52.44155 | 0.30 | 15.73246 | 9.631213 | 25.36368 | 6.101251 |
| 10 | 1.702692 | 2.530331 | 6.857965 | 60.15976 | 0.41 | 24.66550 | 13.44161 | 38.10711 | 11.22389 |
| 25 | 2.631721 | 3.469840 | 9.404319 | 69.91174 | 0.49 | 34.25675 | 18.43246 | 52.68922 | 15.82429 |

Source: The result of study, 2016

**Table-3.** Confidence limit in the middle Bengawan solo (2015).

| Tr | K | b | Se | $R_B$ | C | Rn | f(c)Se | $X_1$ | $X_2$ |
|---|---|---|---|---|---|---|---|---|---|
| 2 | -0.14314 | 0.914581 | 2.832447 | 45.2404 | 0.15 | 6.78606 | 5.551595 | 12.33766 | 1.234465 |
| 5 | 0.967411 | 1.813038 | 5.614961 | 58.56091 | 0.30 | 17.56827 | 11.00532 | 28.5736 | 6.562948 |
| 10 | 1.702692 | 2.530331 | 7.836409 | 67.38033 | 0.41 | 27.62593 | 15.35936 | 42.9853 | 12.26657 |
| 25 | 2.631721 | 3.46984 | 10.74606 | 78.52368 | 0.49 | 38.47661 | 21.06227 | 59.53888 | 17.41433 |

Source: The result of study, 2016

**Table-4.** Confidence limit in the lower Bengawan solo (2015).

| Tr | K | b | Se | $R_B$ | C | Rn | f(c)Se | $X_1$ | $X_2$ |
|---|---|---|---|---|---|---|---|---|---|
| 2 | -0.14314 | 0.914581 | 2.564905 | 32.99101 | 0.15 | 4.948652 | 5.027214 | 9.975865 | -0.07856 |
| 5 | 0.967411 | 1.813038 | 5.084594 | 45.05332 | 0.30 | 13.51599 | 9.965805 | 23.4818 | 3.55019 |
| 10 | 1.702692 | 2.530331 | 7.096213 | 53.03969 | 0.41 | 21.74627 | 13.90858 | 35.65485 | 7.837694 |
| 25 | 2.631721 | 3.46984 | 9.731028 | 63.13049 | 0.49 | 30.93394 | 19.07282 | 50.00675 | 11.86112 |

Source: The result of study, 2016

**Table-5.** The result of calculation from the log pearson type III.

| Return period | The Rainfall | | |
|---|---|---|---|
| | Upper Solo | Kali Madiun | Lower Solo |
| 2 year | 6.422045 | 7.125678 | 5.210532 |
| 5 year | 14.23037 | 15.57886 | 11.87509 |
| 10 year | 23.07102 | 24.69813 | 20.17626 |
| 25 year | 29.49748 | 31.2998 | 26.27838 |

Source: The result of study, 2016

Based on the result from Gumbel method and Log Pearson type III method can be calculated the calculation of normal distribution. The test of Kormogorov-Smirnov and correlation test is the method to determine the different than two methods of forecasting of rainfall. Based on the result can be shown in the table 6,7, and 8.

**Table-6.** The calculation of statistic in upper solo.

| No. | Variable | Gumbel Method | Log Pearson type III Method |
|---|---|---|---|
| 1 | Standard Deviation | 20.53 | 8.14 |
| 2 | KS | 0.13 | 0.17 |
| 3 | P-Value | 0.15 | 0.15 |

Source: The result of study, 2016

**Table-7.** The calculation of statistic in Kali Madiun.

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| No. | Variable | Gumbel Method | Log Pearson type III Method |
|---|---|---|---|
| 1 | Standard Deviation | 20.81 | 6.94 |
| 2 | KS | 0.114 | 0.114 |
| 3 | P-Value | 0.15 | 0.15 |

Source: The result of study, 2016

**Table-8.** The calculation of statistic in lower solo.

| No. | Variable | Gumbel Method | Log Pearson type III Method |
|---|---|---|---|
| 1 | Standard Deviation | 21.14 | 8.70 |
| 2 | KS | 0.089 | 0.107 |
| 3 | P-Value | 0.15 | 0.15 |

Source: The result of study, 2016

Based on the Table-6, 7, and 8 there are a difference between the two methods. The Deviation standard from Gumbel method is bigger than Log Pearson type III, but KS from Gumbel method is smaller than Log Pearson type III. P-Value is showning value 0, 15. This value bigger than the alpha value (0.05), then the conclusion from this case is the distribution is normal. In this study using the Gumbel method to determining the extreme value of rainfall plan.

The Table-9 is referring all of return periods of rainfall at Bengawan Solo Watershed. The rainfall is assumed to be centralized for 8 hours.

**Table-9.** The return period of area rainfall data (2015).

| Time (Hour) | Ratio | Upper Bengawan Solo | | | | Middle Bengawan Solo | | | | Lower Bengawan Solo | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2 | 5 | 10 | 25 | 2 | 5 | 10 | 25 | 2 | 5 | 10 | 25 |
| 1 | 0.5 | 3.06 | 12.68 | 12.33 | 17.13 | 3.39 | 14.29 | 13.81 | 19.24 | 2.47 | 11.74 | 10.87 | 15.47 |
| 2 | 0.13 | 0.8 | 3.3 | 3.21 | 4.45 | 0.88 | 3.71 | 3.59 | 5 | 0.64 | 3.05 | 2.83 | 4.02 |
| 3 | 0.09 | 0.55 | 2.28 | 2.22 | 3.08 | 0.61 | 2.57 | 2.49 | 3.46 | 0.45 | 2.11 | 1.96 | 2.78 |
| 4 | 0.072 | 0.44 | 1.83 | 1.78 | 2.47 | 0.49 | 2.06 | 1.99 | 2.77 | 0.36 | 1.69 | 1.57 | 2.23 |
| 5 | 0.063 | 0.39 | 1.6 | 1.55 | 2.16 | 0.43 | 1.8 | 1.74 | 2.42 | 0.31 | 1.48 | 1.37 | 1.95 |
| 6 | 0.051 | 0.31 | 1.29 | 1.26 | 1.75 | 0.35 | 1.46 | 1.41 | 1.96 | 0.25 | 1.2 | 1.11 | 1.58 |
| 7 | 0.053 | 0.32 | 1.34 | 1.31 | 1.82 | 0.36 | 1.51 | 1.46 | 2.04 | 0.26 | 1.24 | 1.15 | 1.64 |
| 8 | 0.041 | 0.25 | 1.04 | 1.01 | 1.4 | 0.28 | 1.17 | 1.13 | 1.58 | 0.2 | 0.96 | 0.89 | 1.27 |

Based on Table-9 can be known there are increase of rainfall any increase in the return period of rainfall. On the return period of rainfall in upper, middle, and lower of Bengawan Solo occur slope of intensity rainfall on time. This incident can be shown in Figure-3, 4, and 5.

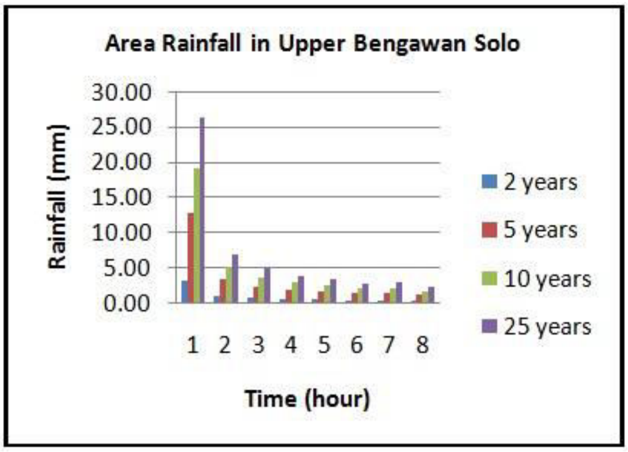


**Figure-3.** Area rainfall in upper solo.

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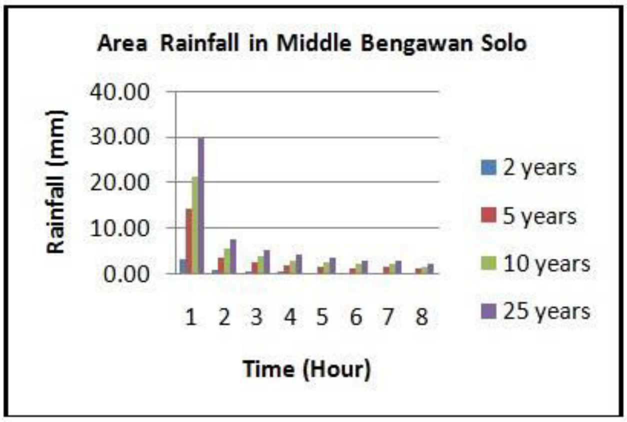


**Figure-4.** Area rainfall in middle solo.

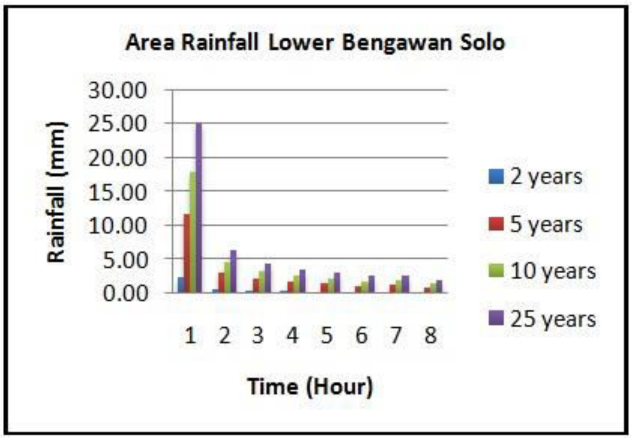


**Figure-5.** Area rainfall in lower solo.

Therefore, based on the results can be maked a model of Bengawan Solo Watershed at HEC-HMS to take flow hydrograph. Based on the results can be create the model of Bengawan Solo Watershed. The model of Bengawan Solo Watershed at HECHMS is shown in Figure-6

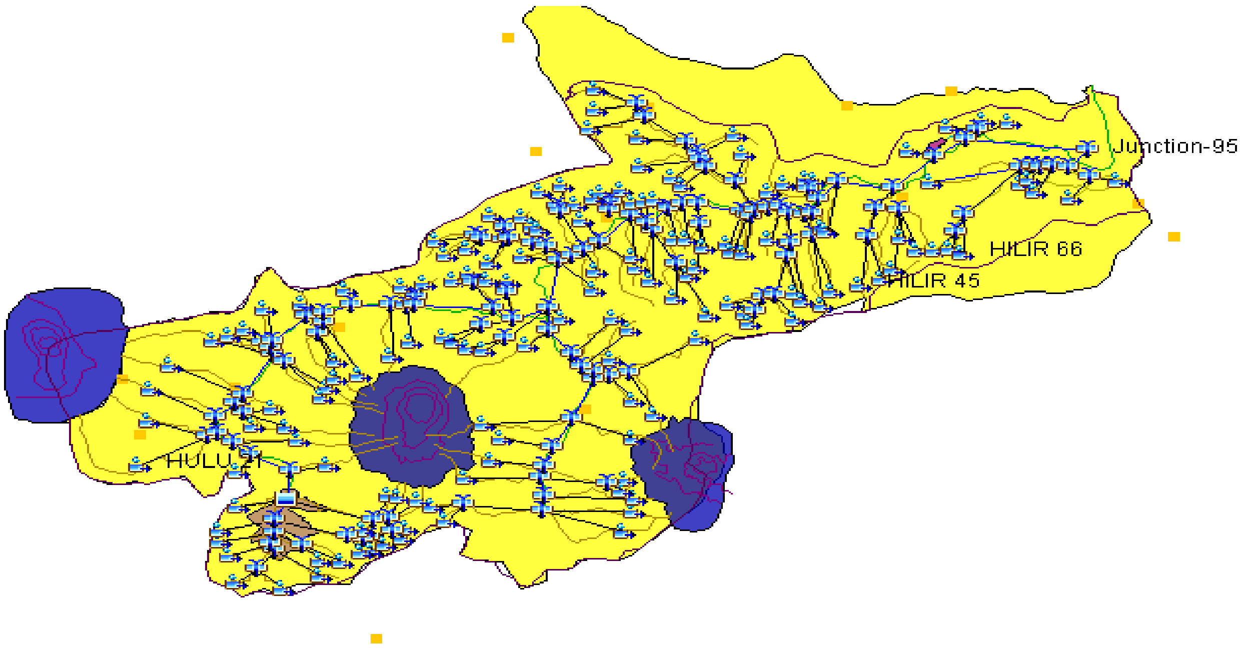


**Figure-6.** Bengawan solo watershed modeling at HEC-HMS (2015).

The hydrological calculations for Bengawan Solo Watershed are using HEC-HMS produce the flow hydrograph in rivers. The determining of subbasin area, time lag, curve number and impervious is needed to found the hydrological result. Based on the result can be found the hydrograph of rivers in Bengawan Solo Watershed. The hydrograph is the response of a given catchment to a rainfall input. The hydrograph is showing the level of discharge in river. The flow hydrograph in rivers can be shown in Figure-7, 8, 9, and 10.

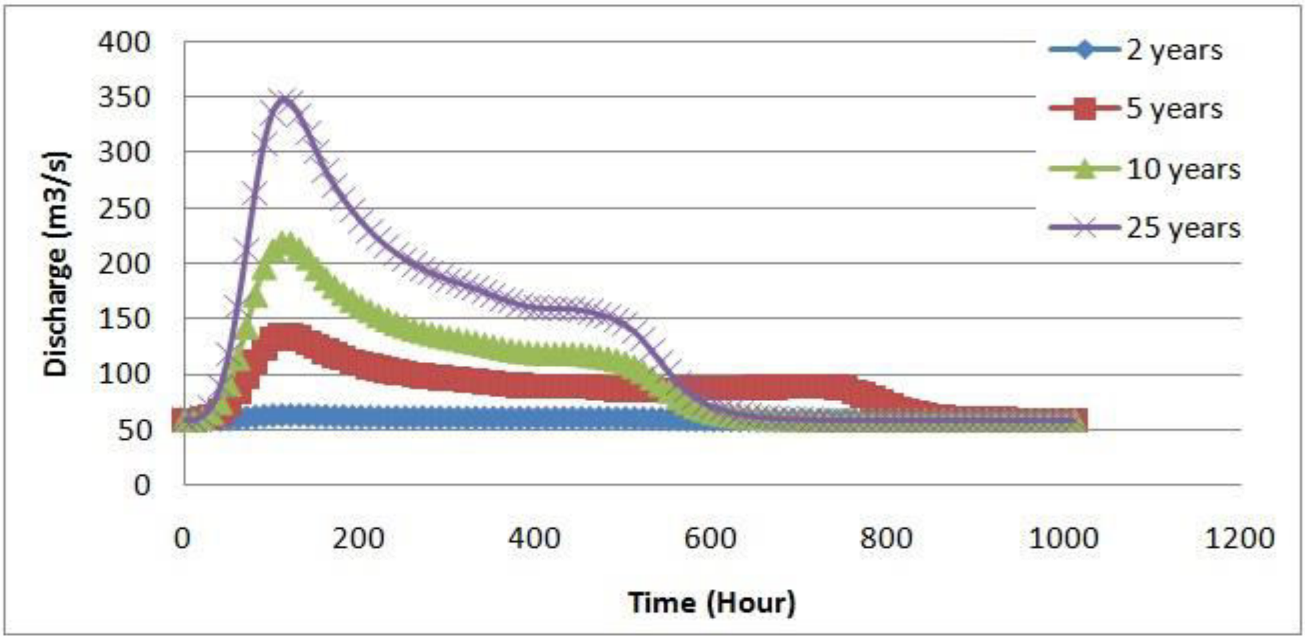


**Figure-7.** Hydrograph of Ampel river (2015).

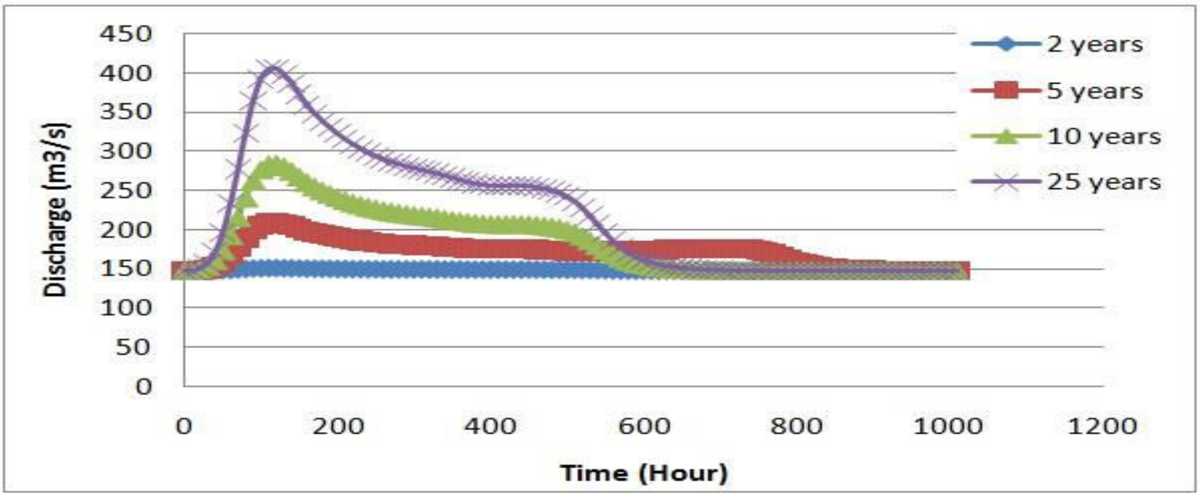


**Figure-8.** Hydrograph of Batokan river (2015).

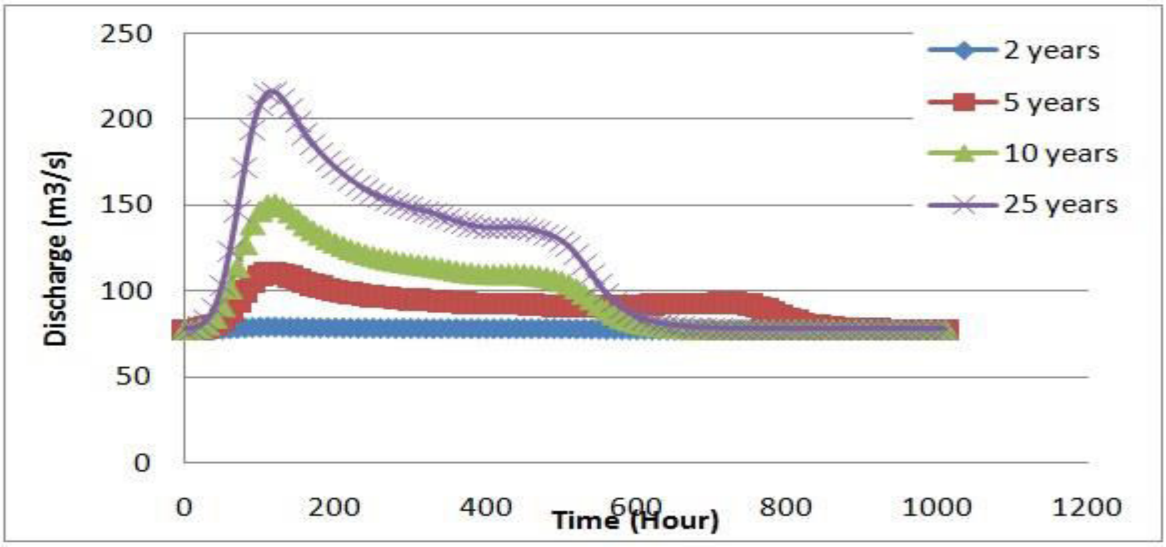


**Figure-9.** Hydrograph of Bendo river (2015).

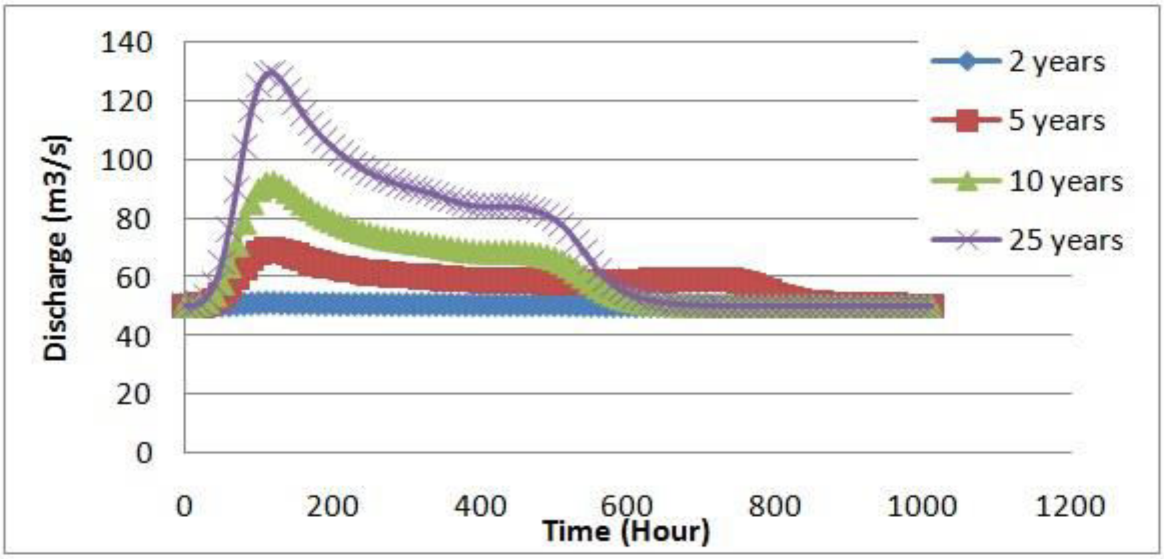


**Figure-10.** Hydrograph of Besuki river (2015).

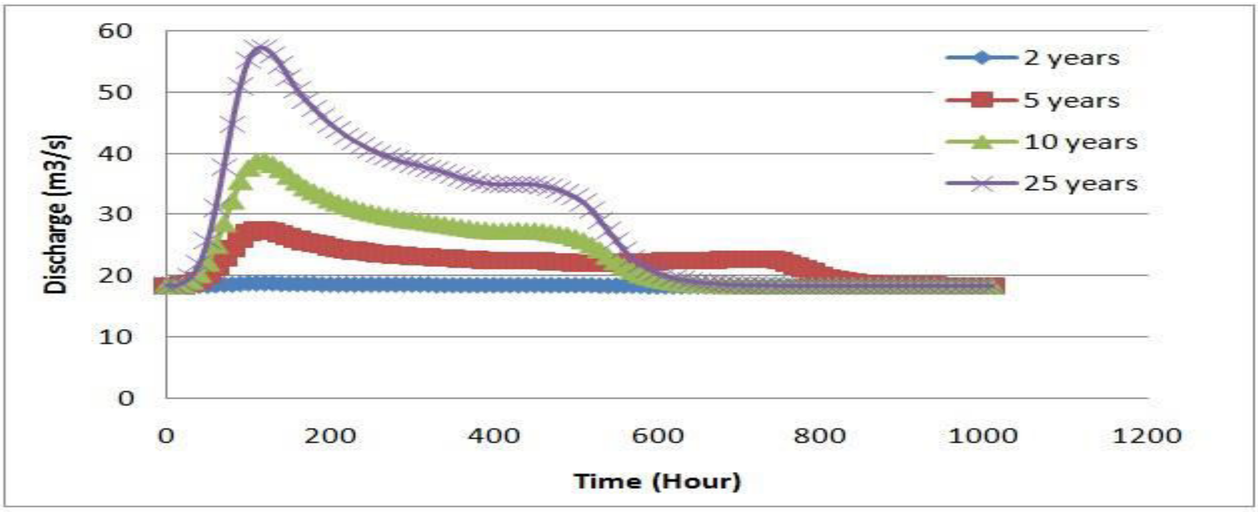


**Figure-11.** Hydrograph of Gandong river (2015).

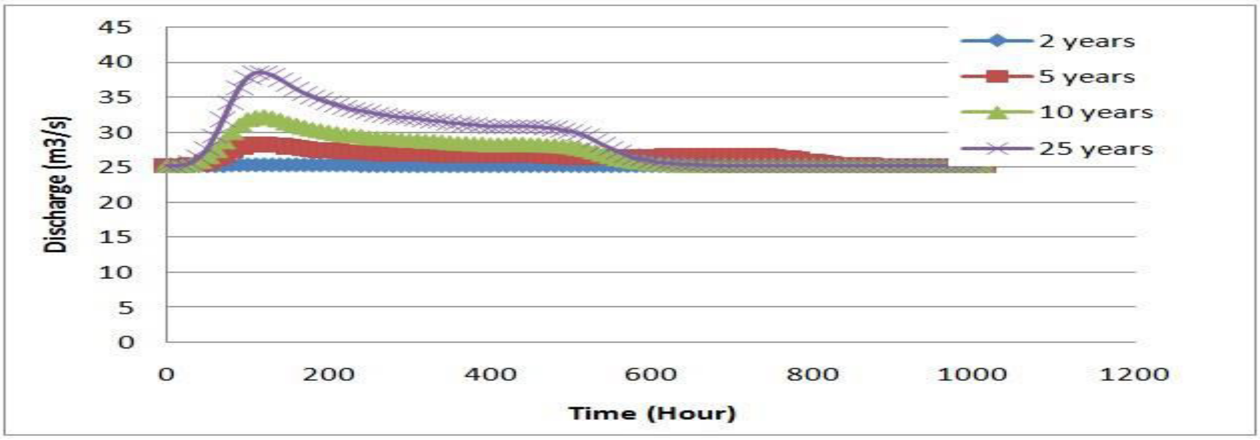


**Figure-12.** Hydrograph of Grogol river (2015).

In the flow hydrograph had shown the values of discharge at the rivers in Bengawan Solo Watershed. The accurate of the hydrograph can be known with compare the data than the existing data in AWLR station. The AWLR station is used in this study that is Napel. The accuration of the model HEC-HMS can be shown in Figure-13 at time in 2005.

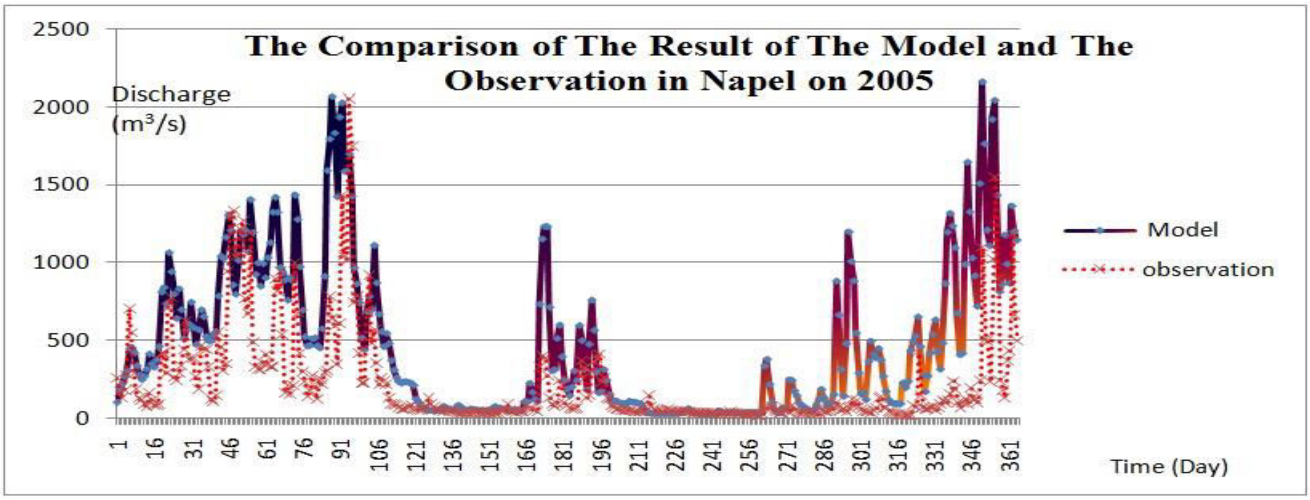


**Figure-13.** The discharge of model versus the discharge of existing data (2016).

Based on the graph can be known the discharge of model approximately equal with the discharge of existing data from the AWLR station of Napel. The calibration of model can be calculated with the Nash method and correlation test.

**Table-10.** The calibration of model.

| No. | Method | Result | Theory |
|---|---|---|---|
| 1 | Nash | 0.74 | Getting closer to zero (0) the better |
| 2 | Correlation | 0.751 | Getting closer to one (1) the better |

Source: The result of study, 2016

Based on the Table-10 can be known the model of HEC-HMS is good. The result of the calibration test shown is the model having correlation is strong.

Therefore, input of flow hydrograph into unsteady data at HEC-RAS can do. The first to using HEC-RAS needed to make Geometry of Bengawan Solo River. The geometry of Bengawan Solo River was produced by the input process of cross section at each river and reach in Bengawan Solo Watershed. The geometry of Bengawan Solo River have the cross section data approximately 3118 data and Semardemen River (39 data), Serning (47 data), Cawak (15 data), Brangkal (28), Ngabon (25 data), Mekuris (27 data), Besuki (15 data), Pacal (39 data), GG0 (16 data), Grogol (20 data), Gebang (25 data), Kening (35 data), Tidu (20 data), Bendo (20 data), Ampel (10 data), Pendong (15 data), Gandong (11 data), Puter (13 data), Batokan (15 data). The geometry of

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Bengawan Solo River in Lower Solo can be shown in Figure-14.

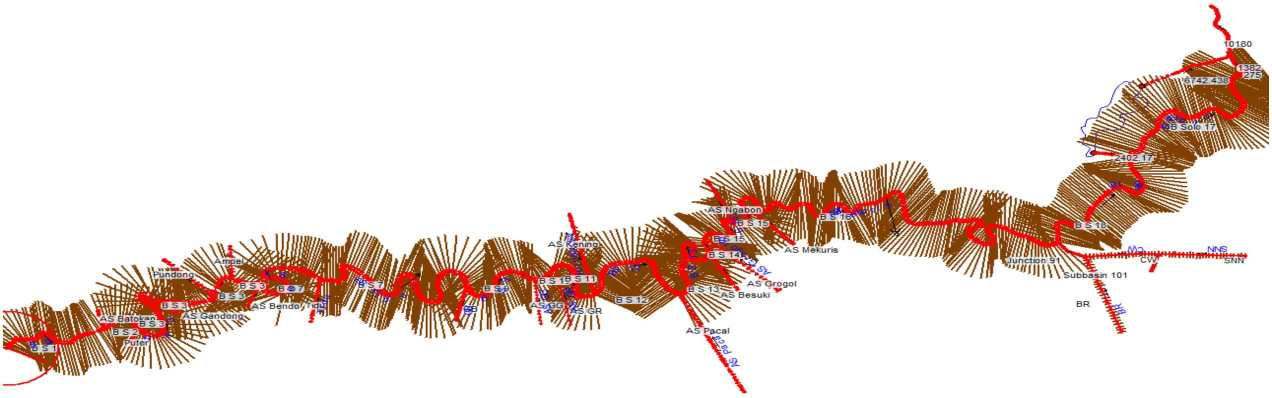


**Figure-14.** Geometry of the lower Bengawan solo river (2015).

Based on Figure-12 can be seen shape of Bengawan Solo River in Lower Solo. The hydraulic calculation of Bengawan Solo River can be started to determine flood condition. The first of the process of HEC-RAS is to input data of flow hydrograph in each river at return period. The after success of running HEC-RAS can be found elevation of water surface in Bengawan Solo River. The result of HEC-RAS can be shown in Table-3, 4, 5, and 6. The map of flood inundation area can be shown in Figure-11, 12, 13, and 14.

**Table-11.** The flood inundation at the return period 2 year.

| Section of River | Deph (m) | | | Range (m) | | |
|---|---|---|---|---|---|---|
| | left | channel | right | left | channel | Right |
| BS 1 | 0.00 | 7.23 | 0.00 | 0.00 | 131.43 | 0.00 |
| BS 2 | 0.00 | 6.24 | 0.00 | 0.03 | 213.43 | 0.04 |
| BS 3 | 0.00 | 5.21 | 0.38 | 0.00 | 211.09 | 40.76 |
| BS 4 | 0.03 | 5.67 | 0.00 | 8.30 | 211.31 | 0.00 |
| BS 5 | 0.00 | 5.21 | 0.00 | 0.00 | 280.87 | 0.00 |
| BS 6 | 0.41 | 6.60 | 0.10 | 297.46 | 155.01 | 247.52 |
| BS 7 | 0.29 | 4.62 | 0.19 | 157.76 | 340.39 | 47.01 |
| BS 8 | 0.89 | 6.32 | 1.04 | 367.47 | 228.65 | 2564.95 |
| BS 9 | 0.81 | 6.68 | 1.01 | 849.27 | 376.18 | 666.02 |
| BS 10 | 0.47 | 6.96 | 1.06 | 2913.14 | 202.58 | 409.82 |
| BS 11 | 0.58 | 7.29 | 1.20 | 1855.21 | 171.60 | 441.15 |
| BS 12 | 0.72 | 5.16 | 0.82 | 2077.11 | 365.94 | 179.67 |

Based on table 11 can be known the flood condition in Lower Solo River at return period 2 year. The high of flood is approximately 0.0 cm - 106cm. The map of flood inundation can be shown in Figure-15.

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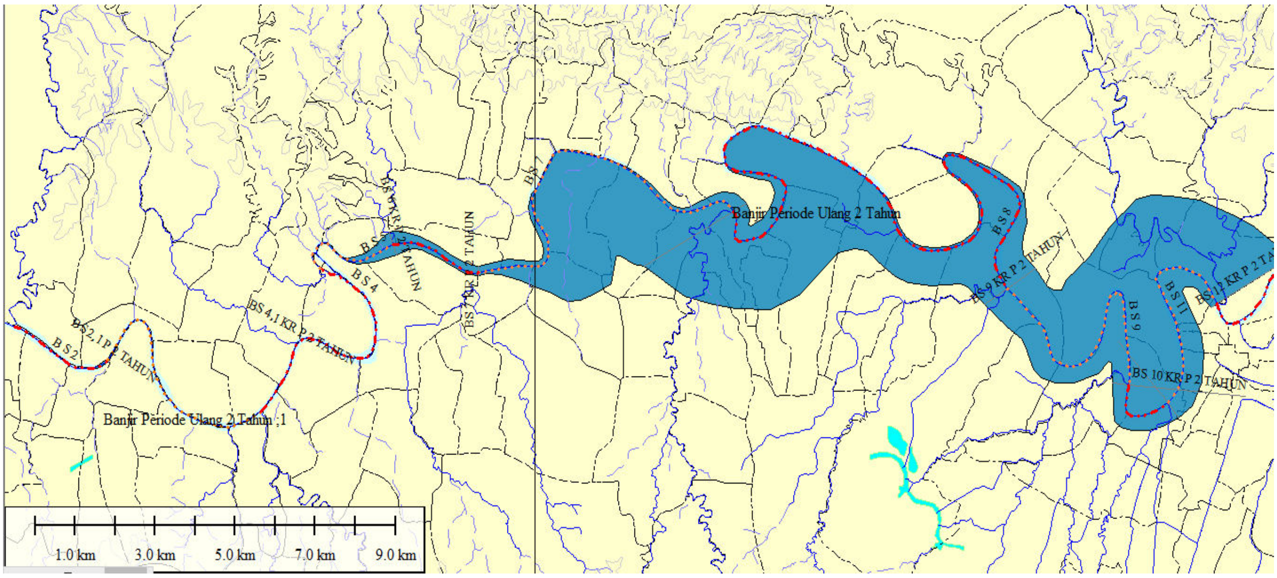


**Figure-15.** Flood inundation area in return periods 2 year.

Based on Figure-15 can be seen flood inundation in Lower Bengawan Solo. The flood inundation is shown in blue color. The map of flood inundation is limited because the data of cross section area can't describe of water flow. While for the return period 5 year, the result can be shown in Table-12.

**Table-12.** The flood inundation at the return period 5 year.

| Section of River | Depth (m) | | | Range (m) | | |
|---|---|---|---|---|---|---|
| | left | channel | right | left | channel | right |
| BS 1 | 0.00 | 7.91 | 0.00 | 0.00 | 134.61 | 0.00 |
| BS 2 | 0.16 | 6.96 | 0.24 | 147.67 | 213.43 | 273.86 |
| BS 3 | 0.31 | 5.26 | 0.67 | 194.56 | 238.71 | 99.22 |
| BS 4 | 0.43 | 6.01 | 0.10 | 38.23 | 219.79 | 30.05 |
| BS 5 | 0.05 | 5.43 | 0.14 | 86.10 | 300.36 | 17.96 |
| BS 6 | 0.77 | 7.13 | 0.33 | 399.9 | 155.01 | 1802.19 |
| BS 7 | 0.59 | 5.11 | 0.09 | 246.71 | 340.39 | 1028.08 |
| BS 8 | 1.22 | 6.8 | 1.47 | 418.63 | 228.65 | 2647.28 |
| BS 9 | 1.01 | 7.04 | 1.17 | 1011.18 | 376.18 | 799.09 |
| BS 10 | 0.93 | 7.47 | 1.32 | 3269.37 | 202.58 | 508.18 |
| BS 11 | 0.86 | 7.88 | 1.51 | 3205.46 | 171.60 | 541.37 |
| BS 12 | 1.08 | 5.85 | 1.16 | 3010.91 | 365.94 | 254.97 |

Based on Table-12 can be known the flood condition in Lower Solo River at return period 5 year. The high of flood is approximately 0 cm - 151cm. In this condition the depth of flood is greater and more extensive than the return period of 2 years. Thus, the map of flood inundation on return period of 5 years can be shown in Figure-16.

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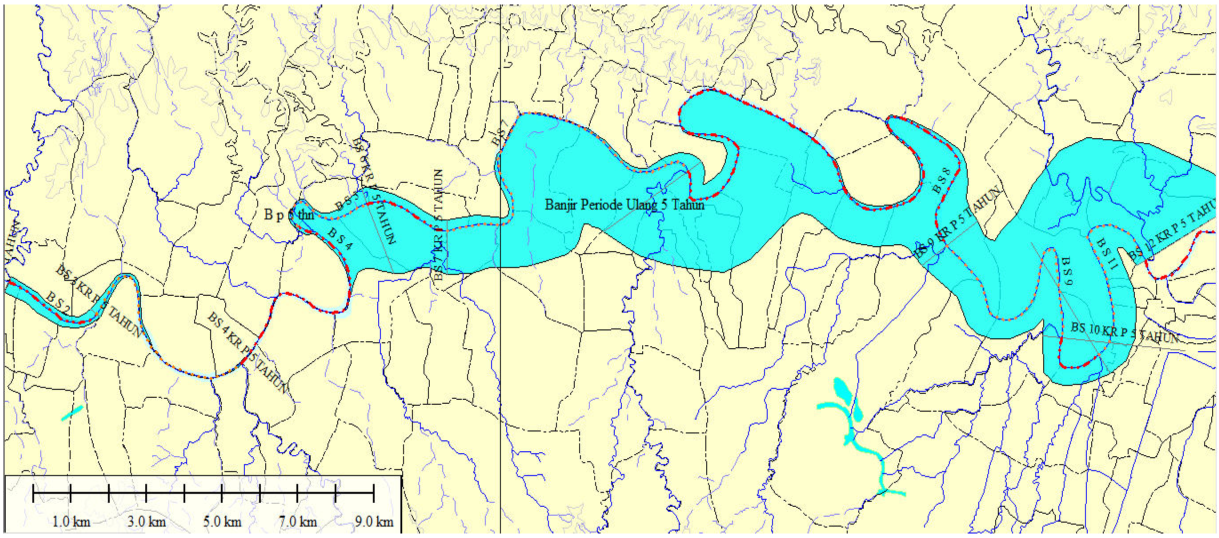


**Figure-16.** Flood inundation area in return periods 5 year.

Based on Figure-16 can be seen the flood inundation in Lower Bengawan Solo. The flood inundation is shown in red color. Then, the flood inundation in return period 10 years can be shown in Table-13.

**Table-13.** The flood inundation at the return period 10 year.

| Section of River | Depth (m) | | | Range (m) | | |
|---|---|---|---|---|---|---|
| | left | channel | right | left | channel | right |
| BS 1 | 0.08 | 7.88 | 0.10 | 7.36 | 141.46 | 39.04 |
| BS 2 | 0.33 | 7.30 | 0.42 | 313.80 | 213.43 | 463.20 |
| BS 3 | 0.51 | 5.64 | 0.75 | 297.32 | 238.71 | 141.08 |
| BS 4 | 0.16 | 6.28 | 0.11 | 333.05 | 219.79 | 154.27 |
| BS 5 | 0.19 | 5.71 | 0.17 | 381.32 | 300.88 | 170.81 |
| BS 6 | 0.98 | 7.47 | 0.55 | 465.99 | 155.01 | 2356.98 |
| BS 7 | 0.76 | 5.42 | 0.34 | 304.03 | 340.39 | 1832.26 |
| BS 8 | 1.40 | 7.06 | 1.73 | 446.90 | 228.65 | 2661.62 |
| BS 9 | 1.12 | 7.25 | 1.27 | 1104.70 | 376.18 | 875.95 |
| BS 10 | 1.22 | 7.76 | 1.26 | 3269.37 | 202.58 | 664.76 |
| BS 11 | 1.19 | 8.21 | 1.54 | 3205.46 | 171.60 | 654.04 |
| BS 12 | 1.49 | 6.26 | 1.37 | 3010.91 | 365.94 | 300.25 |

Based on Table-13 can be known the flood condition in Lower Solo River at return period 10 years. The high of flood is approximately 8 cm - 173 cm. In this condition the depth of flood is greater and more extensive than the return period of 2 and 5 years. Thus, the map of flood inundation on return period of 5 years can be shown in Figure-17.

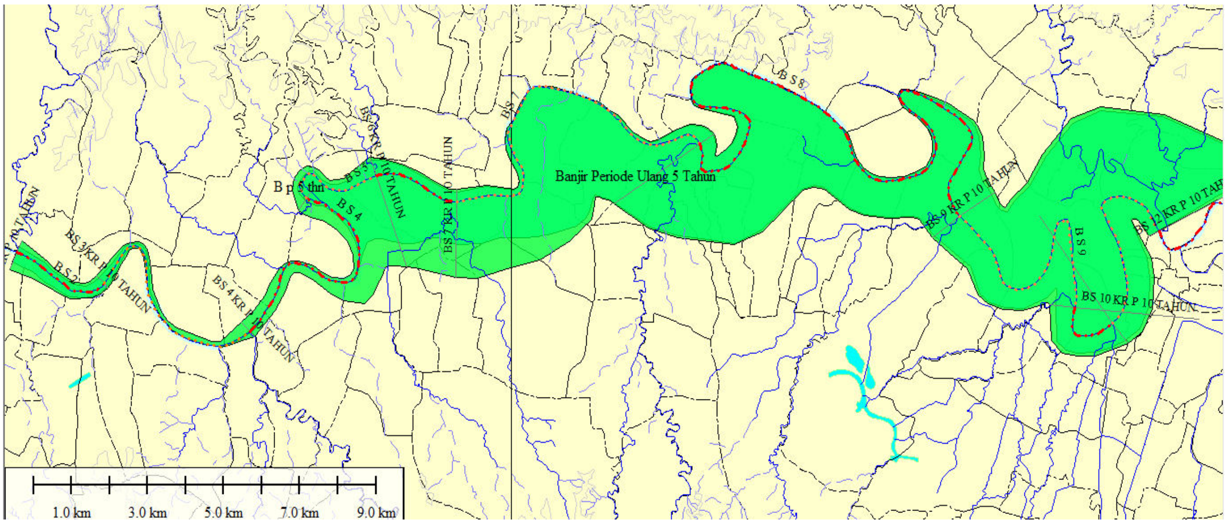


**Figure-17.** The flood inundation area in return periods 10 year.

Based on Figure-17 and 18 can be seen the flood inundation in Lower Bengawan Solo at return period 10 years. The flood inundation is shown in green color. Then, the flood inundation in return period 25 years can be shown in Table-14.

**Table-14.** The flood inundation at the return period 25 year.

| Section of River | Depth (m) | | | Range (m) | | |
|---|---|---|---|---|---|---|
| | left | channel | right | left | channel | right |
| BS 1 | 0.15 | 8.55 | 0.44 | 188.63 | 141.46 | 159.87 |
| BS 2 | 0.62 | 7.87 | 0.75 | 576.01 | 213.43 | 701.78 |
| BS 3 | 0.78 | 6.15 | 0.58 | 438.81 | 238.71 | 449.31 |
| BS 4 | 0.43 | 6.70 | 0.29 | 688.35 | 219.79 | 1683.86 |
| BS 5 | 0.37 | 6.05 | 0.33 | 704.59 | 300.88 | 356.46 |
| BS 6 | 1.23 | 7.91 | 0.91 | 550.49 | 155.01 | 2691.08 |
| BS 7 | 0.99 | 5.85 | 0.60 | 381.67 | 340.39 | 2611.77 |
| BS 8 | 1.62 | 7.40 | 2.06 | 484.21 | 228.65 | 2680.54 |
| BS 9 | 1.24 | 7.46 | 1.37 | 1201.65 | 376.18 | 955.63 |
| BS 10 | 1.48 | 8.02 | 1.27 | 3269.37 | 202.58 | 810.65 |
| BS 11 | 1.46 | 8.49 | 1.50 | 3205.46 | 171.60 | 808.83 |
| BS 12 | 1.80 | 6.56 | 1.23 | 3010.91 | 365.94 | 420.15 |

Based on Table-4 can be known the flood condition in Lower Solo River at return period 25 years. The high of flood is approximately 15 cm - 206 cm. In this condition the depth of flood is greater and more extensive than the return period of 2, 5, and 10 years. Thus, the map of flood inundation on return period of 5 years can be shown in Figure-18.

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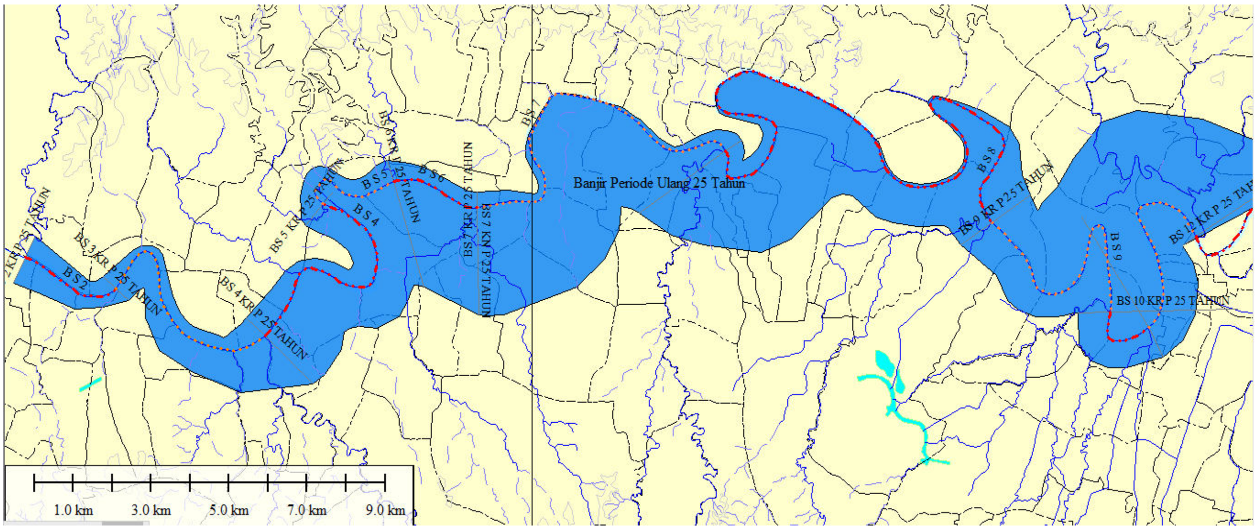


**Figure-18.** The flood inundation area in return periods 25 year.

Based on the results of the map of the flood inundation in return period of 2, 5, 10, and 25 years concluded there increase of area in the area of inundation. In addition, in this simulation is all of discharge in each tributary into the main river simultaneously. The area of flood inundation can be shown in Table-15.

**Table-15.** Area of flood inundation (2015).

| Return Period | Area of Inundation ($Km^2$) |
|---|---|
| 2 year | 50.928 |
| 5 year | 64.714 |
| 10 year | 75.306 |
| 25 year | 94.927 |

Based on Table-15 can be known of area inundation. The area of inundation is increase approximately 27% at the return period 5 year, 48% at the return period 10 year, and 86% at the return period 25 year. The data of flood is limited to create the complete map of flood. The result of the calculation model of the hydraulics can be compared against the results of digitized map from historical of flood every village. The map of flood from the historical of flood can be shown in Figure-19.

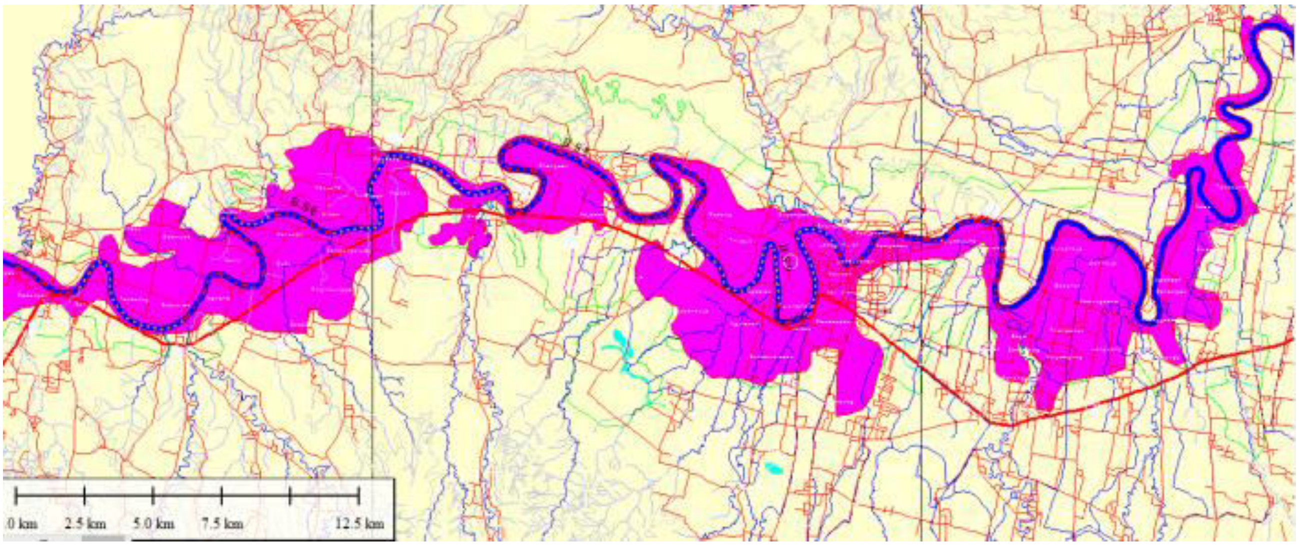


**Figure-19.** The map of flood from historical flooding (Syahdinar, 2016).

Based on Figure-19 can be known that there are similar pattern occurring flood inundation area in Lower Bengawan Solo on the map of flood by the model with the map of flood on the historical of flood. Based on map can be known the condition of flood area then the society can be wary about flood. The prospects of this study are the minimum of loss of flood and the map of flood inundation can be used on other sector. Based on this map can be known the villages of flood in Bengawan Solo Watershed.

## CONCLUSIONS

Based on the result of this study can be concluded that the flood condition in Bengawan Solo River has a flood inundation is great. Based on results have occurred an increase in area of flood inundation than an increase the return period of time. The area of inundation in Bengawan Solo Watershed should be minimized because the damage of flood is dangerous for society.

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