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ANALYSIS OF DRAINAGE CAPACITY AS A FLOOD CONTROL EFFECTS IN LAWEYAN SUB-DISTRICT

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ABSTRACT: Laweyan sub-district is located in the Laweyan sub-district, Surakarta City, and passes by a Premulung river. Flooding is often causing inundation around the riverbank area. Due to the high rainfall intensity, the discharge at the confluence of the two rivers is causing overtopping of embankment in many sites. It happened to the Premulung River and the Brojo River. As an effort to control floods, it must analyze the existing drainage system. It is an effective way to determine the performance of a drainage system. The drainage system depends on the contour maps of the Laweyan sub-district on the flood-affected area. The capacity of the drainage system is calculated by Hec-Ras. Reducing the volume of runoff is analyzed based on the Manning's formula. The result shows that the drainage channel has ability to reduce flooding. The flash flooding volume of the Premulung rivers due to Q_{10} is 3750 m^3/hr. Based on Q_{25}, 4272.5 m^3/hr, based on the maximum of two-consecutive days rainfall, 5722.8 m^3/hr, the flooding caused inundation in 3 sites with duration for a long 23 hours. The existing drainage in normal conditions with a capacity of 118653.26 m3 / hour can reduce water runoff from rivers.

Keywords: Laweyan, Drainage capacity,Flood control, Maximum rainfall

1. INTRODUCTION

According to the number of population, Surakarta is the third-largest city on the southern island of Java in Indonesia, after Bandung and Malang. Surakarta is located at 105 m above sea level while in the city center it is 95 m above sea level. The land characteristics in Surakarta and around it, have classified as fertile land. It is caused by many tributary rivers of the Bengawan Solo River. In the south of the city, there is Bengawan Solo river, the longest river in Java. The Anyar river, Pepe river, and Premulung river are flowing across the Surakarta city.

Bengawan Solo River is a source of life for the people of Surakarta and surrounded it. The length of the Bengawan Solo River is 600 km with a watershed area of 16,100 km2. Since 1863 the Bengawan Solo River always causes flooding. Even today, floods are a disaster in the downstream area [1]. Drainage means to drain, throw away, or divert water. The drainage system, in general, can be defined as an action to reduce excess water from rainwater, seepage, or excess irrigation water from an area so that the function of the land is not disturbed [2].

Flooding is the event of the sinking of land (which is usually dry) because of the increasing volume of water. Floods have two conditions; the first is flooding or inundation that occurs in municipal areas. Second, flooding that occurs in around the embankment. It is caused by the overtopping from rivers [3,4] because the river flow or flood discharge is greater than the existing river capacity [2]. The site one of the sub-districts in Surakarta often floods and create inundation on the Laweyan sub-district. This location is lying at the confluence of the Premulung River and Brojo River [5].

2. MATERIALS AND METHODS

This research is conducted in the Laweyan Sub-District while map of the location is presented as in the Fig. 1. Analysis of drainage systems intends to determine the ability of the drainage channel for reducing the runoff and inundation water at the research location. The aim of this research is to control flooding and inundation in the Laweyan sub-district based on the drainage system. Runoff simulation was analyzed by using HEC-RAS. HEC-RAS is one of the software for analysis in the field of hydraulics. This software is also capable for performing the flood routing analysis based on the review of flood discharge boundaries. This simulation can present how much the volume and length of inundation occurs due to the river flow. The flood routing is calculated based on the return period of discharge such as Q_{10}, Q_{25}, and the maximum of two-consecutive day's rainfall. It is as the input to calculate the inundation area

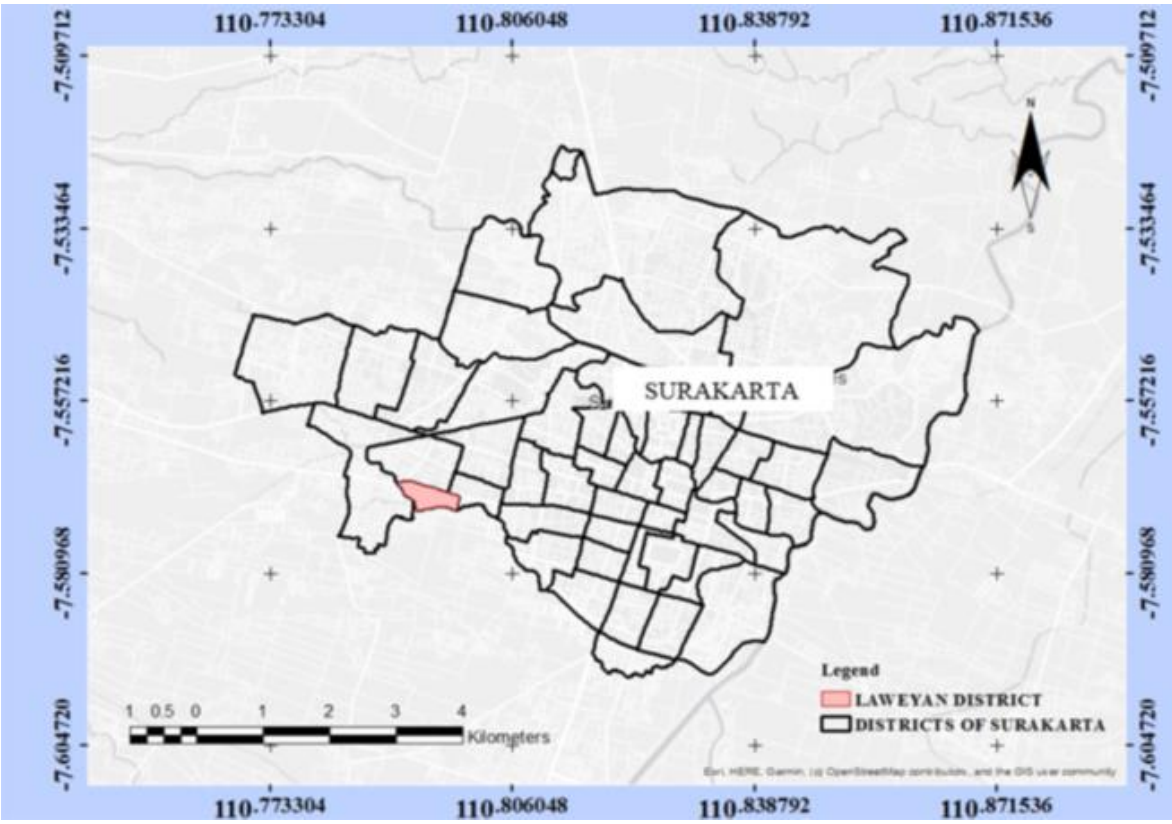

Fig. 1 Location Map Overview
Source: Geo-spatial Information Institution of Indonesia

2.1 Hydrological Characteristic and Analysis

2.1.1 Consecutive of two-days maximum rainfall

Two daily rainfall is the two consecutive days of rain. The analysis in this research is based on the maximum rainfall that ever happens along with the series of study. The calculation uses an algebraic method. The algebraic is a simple calculation, summing the amount of rainfall and then divided by the number of rainfall stations. Then there is chosen the maximum rainfall intensity in each station as the maximum rainfall of the area [5].

2.1.2 Rainfall distribution analysis

Analysis of rainfall distribution is using The Log-Pearson Type III method as follows:

$$C_s = \frac{n\sum_{i=1}^{n}(\log xi - log\bar{x})^2}{(n-1)(n-2)S^3} \quad (1)$$

$$\log X_T = log\bar{x} + slog\bar{x} \quad (2)$$

Distribution analysis of the data is using the Log Pearson Type III (SNI 2415-2016, 2016). Then the Smirnov-Kolmogorov test is conducted to know the data deviations in the horizontal direction. It is to find out the data according to the type of a theoretical distribution chosen or not [6,7].

From the analysis of rainfall distribution that is using The Log-Pearson Type III method, the results of the inclination coefficient are equal to 0.0394.

2.1.3 Rainfall return period

Rainfall return period is calculated by returning the logarithmic value of rainfall distribution:

$$Log\ X_r = \log X + K.S \quad (3)$$

2.1.4 Distribution match test

To find out the compatibility between the rainfall distribution method and the existing rainfall data, the distribution match test is using the Smirnov-Kolmogorov method. The Log-Pearson Type III distribution of rainfall has an accuracy rate with the level of significant of 5%.

Table 1 Summary of the return period rainfall

Rainfall return period	K	K.Sd	Xt+K.Sd	Qt (mm/hr)
10	1.29	0.14	2.00	100.48
25	1.77	0.20	2.06	113.72

2.1.5 Runoff coefficient analysis

The runoff coefficient is a value that indicates the amount of ability of the land cover to drain water, or how small the capacity of the land covers to absorb rainwater. Runoff coefficients are often called as Curve Numbers (CN). This value is strongly affected by land use in a region. Runoff coefficient is decided based on the type of land use as presented in the Table 2.

The result shows that the runoff coefficient value was 83.01%. It is the same in the Brojo river and Premulung rivers due to the similarity of land use.

2.1.6 Effective rainfall analysis

The effective rainfall is the rainfall that is as a river flow. The runoff coefficient value is very influential in the effective rainfall calculation. The calculation of effective rainfall analysis for the ten years, 25 year return period, and the maximum of two consecutive days of rainfall as in the Table 3.

Table 2 Runoff coefficient value

Types of Land Use	CN	Area	%	CN*%
Rice fields	81	22.58	43.70	35.40
Field	71	0.98	1.90	1.35
Coarse grass	79	0.88	1.70	1.35
Garden	81	1.70	3.29	2.66
Industry	88	0.10	0.19	0.17
Settlement	85	24.43	47.28	40.19
Street	98	1.00	1.94	1.90
Sum		51.67		83.01

The time of concentration is the duration of rainfall starting from when the rainwater falls in a location in the river upstream until downstream. It is calculated by using the Kirpich equation. The results show that the time of concentration of the Premulung River and Brojo River is the same that is 4 hours (as presented in the Fig.2).

Table 3 Effective rainfall

Rainfall	P	P x Cn
Q_{10}	100.48	57.12
Q_{25}	113.72	68.74
Two days max of rainfall	176.50	126.51

2.1.7 Rainfall intensity

A method to analyze rainfall intensity is the Mononobe method as follow.

$$I = R_{24}/tc\ [tc/t]^{2/3} \quad (5)$$

The analysis of Mononobe method were verified by observed rainfall data through the official website of The Bengawan Solo River Region (BBWS). The verification results showed that the rainfall distribution time for Surakarta city was no longer than 4 hours. Analysis of the intensity of the 10-year return period of the Premulung and Brojo Rivers is shown as in the Table 4.

2.1.8 Time rainfall distribution

The pattern of hourly rainfall creates by the Alternating Block Method (ABM) method. ABM analysis is the value of rainfall intensity per-hour that is arranged by putting the maximum rainfall intensity value in the middle of the analysis time. This analysis produces bell-shaped blocks

Table 4 Rainfall intensity

T	Tc	R24	I	
			Premulung	Brojo
1	3.30	57.12	38.33	39.03
2	3.30	57.12	48.30	24.59
3	3.30	57.12	18.43	18.76
4	3.30	57.12	15.21	15.49

2.1.9 Hydrograph analysis

Flow discharge was analyzed based on the Synthetic Unit Hydrograph of Soil Conservation Service (SUH SCS). It conducted on the both rivers that are Premulung River and Brojo River. SCS parameters of the Premulung River are presented as in the Table 5.

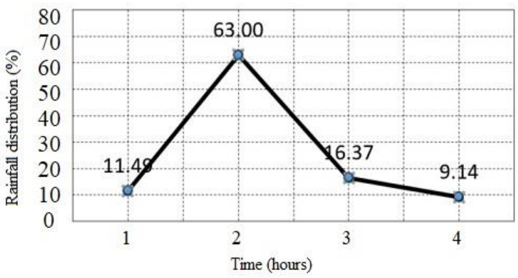

Fig.2 Daily Rainfall Distribution by ABM Method

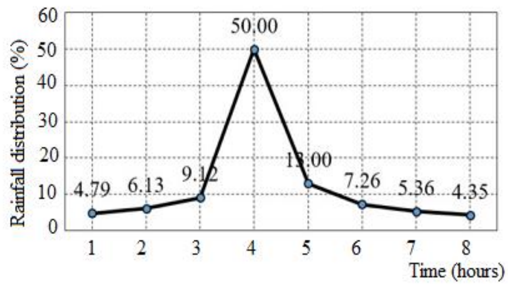

Fig.3 Two-consecutive Days Rainfall Distribution by ABM Method

Table 5 SUH SCS parameter of Premulung River

No	Parameter	Notation	Value		Unit
			Premulung	Brojo	
1	Watershed area	A	7.3	1.60	km^2
2	Main river length	L	22.7	9.70	km^3
3	Riverbed slope	S	0.01	0.01	m/m
4	Curve number	CN	83.0	83.00	
5	Maximum iinfiltration	S	2.05	2.05	
6a	Depth of daily rainfall	P	5.26	5.26	
6a	Depth of daily effective rainfall	P_{eff}	3.41	3.41	
7a	Depth of two days of rainfall	P	6.95	6.95	Inch
7a	Depth of two days effective rainfall	P_{eff}	4.99	4.98	Inch

Based on the Table 5, it can be determined the hydrograph for 10-year return period, 25 year return period, and hydrograph of the maximum two consecutive days of rainfall. It will be as the input on the HEC-RAS as a hydrology boundary condition.

The hourly rainfall distribution for maximum daily rainfall is 4 hours (as in the Fig.2). On 2 consecutive days rainfall can reach 7 hours (as in the Fig.3).

Flow discharge was calculated by using the Synthesis Unit Hydrograph of Soil Conservation Service (SUH SCS). The Premulung River and Brojo River use the SUH parameters of SCS in Premulung River as presented in the Table 5.

2.2 Description of Model

2.2.1 Flood routing with HEC-RAS

Flood routing is a method to track the river flows through a hydrological system. It is defined as a hydrograph forecast at a point in streamflow or part of a river flow based on the observation of the hydrograph in another site. Flood routing aim is to forecast the flood-term at any point in this river. It also finds the unit hydrograph along the river. Flood routing is also interpreted as a procedure to determine the time or magnitude of floods in a river or regional point [8]. Before carrying out the analysis by using HEC-RAS, there are some data that are needed to be prepared. These data included the Map of Surakarta DEM in TIFF format, Surakarta Administrative Map, and Surakarta Hydrological Map in SHP format.

2.2.2 Unsteady flow based on rainfall data

The flood analyzes is based on the unsteady flow conditions. The discharge data included Q_{10}, Q_{25}, and the maximum two days of rainfall discharge of Premulung and Brojo rivers as the input data. The flood analysis is carried out with the interval of 1 hour during the hydrograph time and 24 hours or one day simulation times.

From the results of running, HEC-RAS there is obtained the height of the inundation depth in each cell, inundation area, and inundation time. The flooded areas simulation is presented as in the Figs.7 to 9.

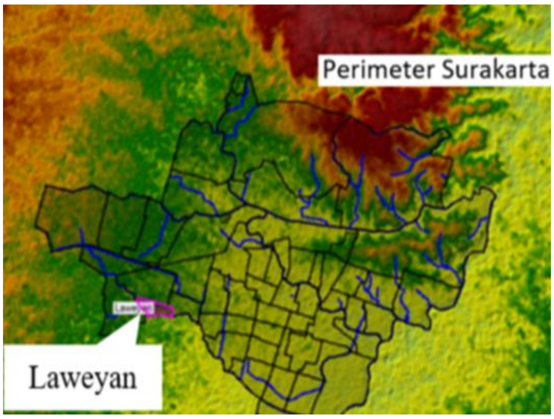

Fig.4 Perimeter

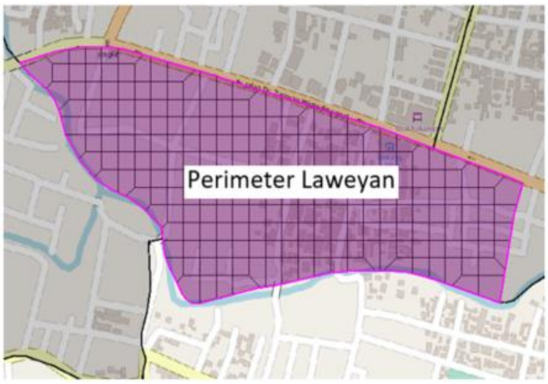

Fig.5 The Perimeter is divided into several cells

3. RESULTS AND DISCUSSION

3.1 Inundation Volume

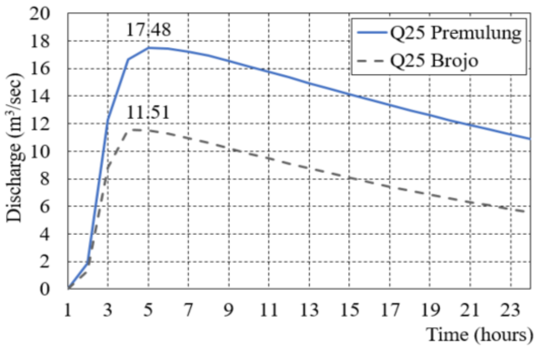

Fig.6 Unsteady Flow Data

In the Fig.7, The depth is described by gradations of color. The darker the color, it indicates the deeper the puddle. Fig.9 shows that if there are 2 consecutive days of rain, there will be inundated in all areas with varying duration.

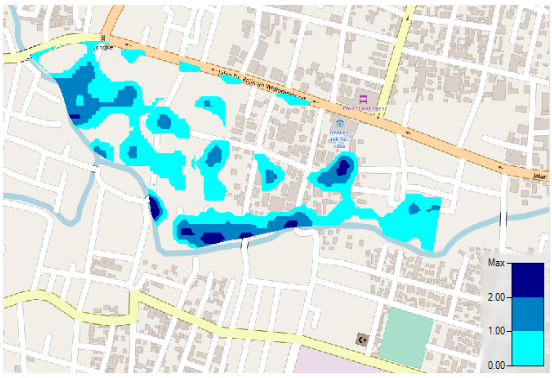

Fig.7 Inundation due to rainfall Q_{10}

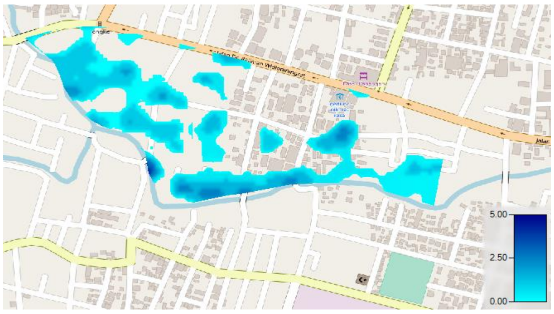

Fig.8 Inundation due to rainfall Q_{25}

The inundation volume of each review point is calculated based on the graph of depth area for each cell.

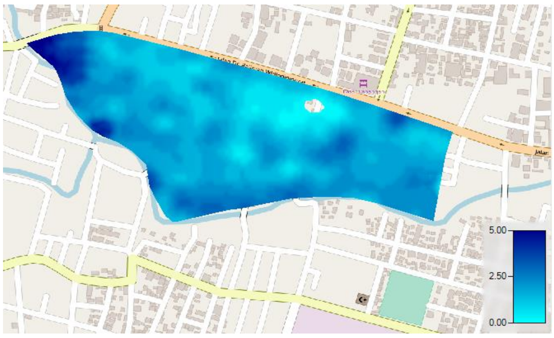

Fig.9 Inundation due to a maximum of two days of rainfall

The sum of the area is used to get the total inundation volume.

Table 6 Inundation volume

Rainfall	Inundation Volume (m^3/hr)
Q_{10}	3,750.17
Q_{25}	4,272.46
2 cons-days	5,722.80

3.2 Drainage Capacity

The drainage channel that is already in the review location is a type of square channel made of concrete with different dimensions. The inundation area was determined by analyzing the drainage capacity of the drainage channel. The volume of channel storage capacity is calculated by using the Manning's formula [9,10].

3.3 Graph of Correlation between Depth and Velocity

The results of HEC-RAS running can be known as the depth graph and also of the water flow velocity. From both of these graphs, we can analyze the points that are most vulnerable to inundation. Then maximizing the performance by evaluating the drainage channel at that point.

Table 7 Volume Capacity of Drainage Chanel

Channel	Dimension (m)		Length	Mannings	Slope	Velocity	$Q_{cappacity}$	Volume
	Height	Width	(m)	Coefficient		(m/sec)	(m^3/sec)	(m^3/hr)
C	0.50	0.50	771.65	0.012	0.130	9.10	2.27	8,189.65
C1	0.50	0.50	771.65	0.012	0.004	1.58	0.39	1,418.48
D1	2.00	1.50	106.00	0.013	0.009	5.28	15.83	56,999.29
D2	2.00	1.50	122.00	0.013	0.008	4.65	13.95	50,211.84

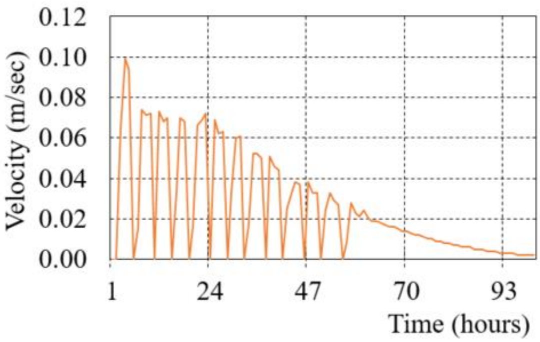

Fig.10 Velocity graph

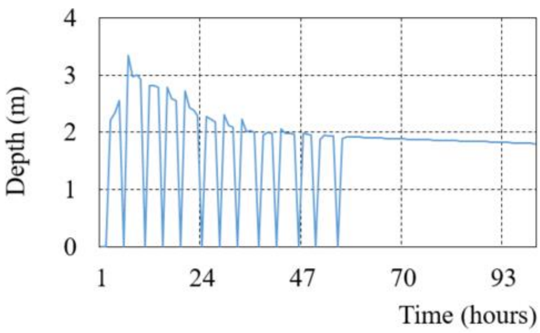

Fig.11 Depth graph

From the table above, it can be seen that the total capacity of the drainage channel in the Laweyan sub-district is 112,434.72 m^3 / hour.

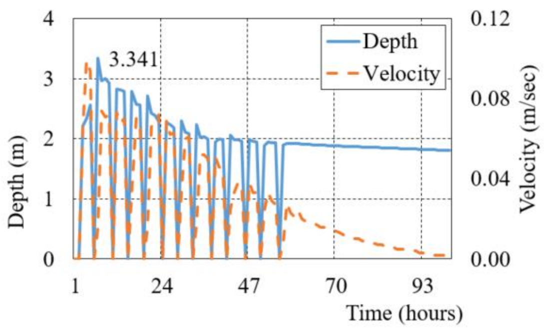

Fig.12 Pattern depth and velocity in a graph

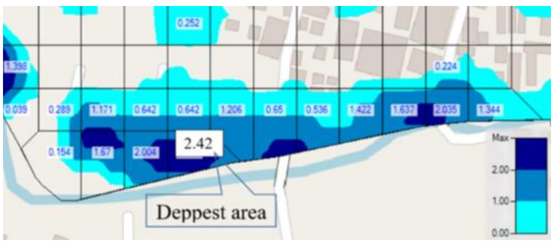

Fig.13 The example of deepest area
(Part of Fig.7)

4. CONCLUSION

Based on the flood analysis and tracing with HEC-RAS, the volume of runoff due to Q_{10} is 3,750.1705 m^3/hour. It means that the inundations caused Q_{10}, can be reduced by the existing drainage. Also, from the graphical analysis of the relationship between depth and speed, it can be seen that inundation characteristics at several points are high velocity and have inundation height. But when going down, the decrease of inundation height does not stable until the reaches 0 m^3/hour. It means that at that time, there was an inundation. So, at these points, further analysis of the existing drainage system is needed to either redesign or normalize the channel.

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