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Inundation Numerical Modeling in the Eastern Part of Surabaya

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Abstract— *Inundation in Surabaya is a problem year after year, especially in the eastern part of Surabaya. The river which is located in eastern Surabaya direct to the sea. East Surabaya has varying inundation heights ranging from 0.10 to 0.80 meters. One of the causes of inundation in eastern Surabaya is land use change. In addition, the eastern part of Surabaya is relatively low and close to the sea. When sea level is higher than water level from river so that water cannot flow to downstream and that one of the causes of inundation in eastern Surabaya. Inundation simulation are made with 1D and 2D models on HEC-RAS. Ananlysis of the inundation model in eastern Surabaya using the upstream boundary condition as return period flood discharge and the condition of the downstream boundary condition as water level. Then process map data and do a model descritization. Then do calibration so that the model get near to existing condition. There are 4 inundation simulation scenario in this research. The fourth difference in the scenario is the upstream boundary conditions. The upstream boundary conditions used for the four scenarios are 2, 5, 10, and 25 years return period flood discharge. In addition, pump are also used as existing conditions. The result of the four scenarios are then made inundation maps based on area and depth. Flood discharge with 2, 5, 10, and 25 years return peiod for inundation simulations are 33.28 m^3/s, 39.71 m^3/s, 43.765 m^3/s, and 48.68 m^3/s. The result of inundation simulation based on depth are 0.05 to 0.82 meters. The result of inundated area by simulation is 0.20 to 8.5 ha. This map is used as reference in determining the priority scale of inundation handling in Eastern Surabaya. It can be concluded from the result of simulations with inundation impacts based on the area and depth of inundation in Mulyorejo District.*

Keywords— *Inundation, HEC-RAS, Pump, East Surabaya.*

I. INTRODUCTION

Indonesia has a tropical climate so its has high rainfall. Problems arise when rainfall cannot flow well to downstream, so some areas are flooded. This is a problem also in the eastern part of Surabaya. Inundation that occur in eastern Surabaya are as high as 0.10 to 0.85 meters[1]. One of the causes of inundation is the change in land use so that water absorption is reduced there is a large surface run-off. In addition to change in land use, the eastern part of Surabaya has a relatively low tophography so that the influence of tides could be occurrence of inundation.

The research location is on two rivers in eastern Surabaya, namely Kalidami and Kalibokor, figure 1. During high tides conditions, sea level is higher than the river water level. To still be able to drain water from upstream to downstream a pump is needed. Pump that used on Kalidami and Kalibokor are Kalidami Screw Pump, Kalidami I pump, Kalidami II pump, Kali, Mulyosari pump, and Kalibokor pump. There are more than one watershed that included on Kalidami and Kalibokor' system, figure 2.

Fig. 1. Kalidami and Kalibokor as a research loacation

The inundation map owned by Surabaya is based on depth and area of the inundation. Inundation maps obtained based on the result of the survey, so that the shape of the inundation map only lists the points as a sign inundated areas. In addition, the limited of surveyor that caused some areas can'y be surveyed. Therefore modelling is needed to determine the depth of inundation and the inundated area use HEC-RAS 1D/2D[2].

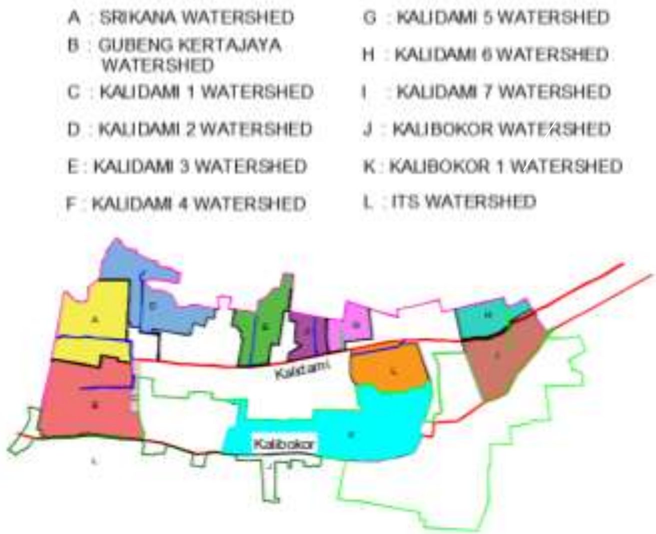

Fig. 2. Watershed on Kalidami and Kalibokor's System

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II. METHODOLOGY

The method used for this research will be explained through a flowchart, figure 3.

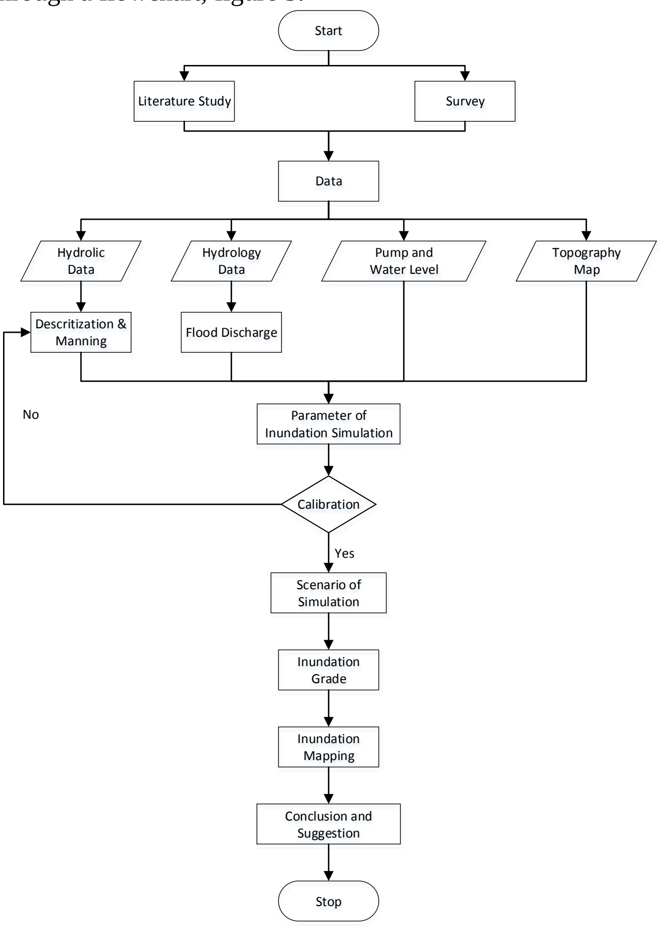

Fig. 3. Flowchart of research method

A. *Hydrolic and Hidrology Data*

Hydraulics data used for inundation simulations are cross section of rivers and manning values. Cross section of the river is obtained from DEM (Digital Elevation Model) data. In addition to hydraulic data, hydrology data is also needed in the form of rainfall data. Rainfall data from 2001 until 2015 in Surabaya that can be use on this research. Rainfall is processed using Log Pearsonn type III distribution[3]. The rainfall that has been obtained, then carried out the distribution test using Chi-Square and Smirnov Kolmogorov test.

The design rainfall data that has been obtained then processed into a return period flood discharge. Flood discharge is calculated using two methods, nakayasu method and Rational method[4]. This return period flood discharge will be used as an upstream boundary in modelling using the HEC-RAS program.

B. *Pump*

The pumps used in the research location site are 5 pumps, namely Kalidami I pump, Kalidmai II pump, Mulyosari pump, Kalidami Screw pump, and Kalibokor pump. Pumps are needed when modelling a scenario. The capacity and number of pumps can be seen in table 1.

TABLE 1. Kalidami and Kalibokor watershed pump capacity

No.	Pump	Unit	Pump Capacity
1	Kalidami I	1 unit 4 units	250 liter/s 1500 liter/s
2	Kalidami II	3 units 2 units	1500 liter/s 250 liter/s
3	Kalidami Screw	1 unit	1000 liter/s
4	Mulyosari	3 units 2 units	1500 liter/s 250 liter/s
5	Kalibokor	2 units 3 units	250 liter/s 1500 liter/s

C. *Calibration*

At each modelling calibration is needed, so that the meodeling results get near to conditionexisting condition. The function of calibration to determine the initial condition, by selecting on of the cross section in the model. Than the cross section is measured the velocity of the stream. So that the velocity and water level is obtained. Both of these parameters are used to calibrate the manning value so that the water level in the model get near to water level in existing condition of measurement result[5]. Calibration was carried out on both research location.

D. *Scenario Simulation*

Modeling flood scenario aims to determine the inundation that occurs with different scenarios. The scenarios carried out also continue to included existing conditions, only the upstream and downstream data are changed. The four scenarios use the flood discharge eith return period 2, 5, 10, and 25 years as the upstream boundary conditions. Meanwhile, the scenario for the downstream boundary conditions are same that used water level.

E. *Inundation Mapping*

Determination of flood parameters using Minister of Public Works Regulation Number 12/PRT/M/2014, table 2[6]. In the regulation, flood parameters have been described with low, medium and high risk level. After the flood parameters are made, the next stape is to make inundation map. Inundation map is made by Arc-GIS.

TABLE 2.Criteria for inundation parameter

No.	Inundation parameter	Grade	Grade Percentage
1	Depth of inundation > 0.50 m 0.30 m – 0.50 m 0.20 – < 0.30 m 0.10 – < 0.20 m < 0.10 m	35	 100 75 50 25 0
2	Area of inundation > 8 ha 4 – 8 ha 2 – < 4 ha 1 – < 2 ha < 1 ha	25	 100 75 50 25 0

III. RESULT

A. *Rainfall*

The watershed that has to be calculated is 13 watersheds. There are 4 rain station used, Wonkromo, Gubeng, Laranagn and Keputih rain stations. Determination of rain areas using Thiessen polygons, so that the maximum rainfall is obtained. Next the data is carried out by Chi-Square test and Smirnov Kolmogorov test to find out which distribution method is suitable. The result of design rainfall with return period will be used to calculate discharge, table 3.

TABLE 3. Design Rainfall in all watershed

No.	Watershed	Rainfall Return Period (mm)			
		2 years	5 years	10 years	25 years
1	Kalidami & Kalibokor	84.88	103.33	115.22	130.06
2	ITS	81.23	104.67	119.57	138.33
3	Srikana	90.65	114.37	131.04	153.30
4	Gubeng Kerrtajaya	102.45	120.98	132.05	145.23
5	Kalidami 1	90.65	114.37	131.04	153.30
6	Kalidami 2	90.65	114.37	131.04	153.30
7	Kalidami 3	90.65	114.37	131.04	153.30
8	Kalidami 4	77.75	102.64	121.74	149.17
9	Kalidami 5	77.75	102.64	121.74	149.17
10	Kalidami 6	81.23	104.67	119.57	138.33
11	Kalidami 7	81.23	104.67	119.57	138.33
12	Kalibokor Cut	84.03	101.35	111.66	124.23
13	Kalibokor 1	81.23	104.67	119.57	138.33

B. Flood Discharge using Nakayasu Method

The watershed calculated by the flood discharge using the Nakayasu Method is only KalibokoR watershed with a return period of 2, 5, 10, and 25 years, figure 4.

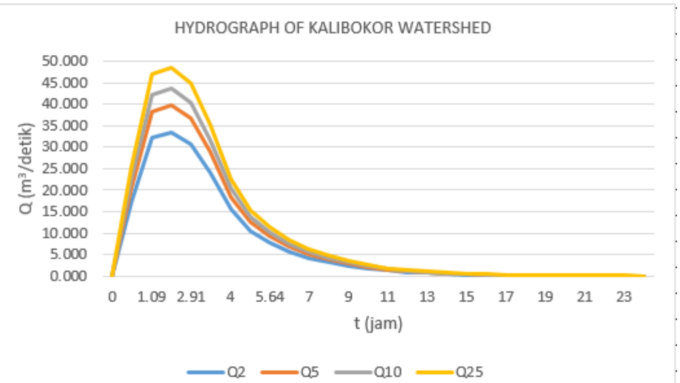

Fig. 4. Hydrograph of "Kalibokor Cut" watershed

C. Flood Discharge using Rational Method

Watersheds that discharge is calculated using the rational method are ITS, Srikana, Gubeng Kertajaya, Kalidami 1, Kalidami 2, Kalidami 3, Kalidami 4, Kalidami 5, Kalidami 6, Kalibokor 1 and Kalidami 7 watersheds. Some parameters needed are time concentration, catchment area, and the value of land use[8]. The result of flood discharge with return period can be seen in table 4. At the time of modelling, hydrograph is needed so that it takes a long time to rain (td). The sape of hydrograph adjusts the length of rain in each watersheds.

D. Calibration

Calibration is needed to adjust the manning value so that the simulation results are obtained that are clos to existing condition. The calibration location in Kalidami and Kalibokor. Measurements are made directly to the drainage using currentmeter. From the current meter obtained velocity. Furthermore, the water level in the downstream is also measured. The result of manning validation can be seen in table 5 and 6.

TABLE 4. Flood discharge using rational method

Watershed	Q2 (m^3/s)	Q5 (m^3/s)	Q10 (m^3/s)	Q25 (m^3/s)
ITS	1.748	2.904	2.298	2.557
Srikana	1.255	2.086	1.650	1.836
Gubeng Kertajaya	0.901	1.076	1.185	1.318
Kalidami 1	0.647	0.772	0.851	0.947
Kalidami 2	0.465	0.555	0.611	0.680
Kalidami 3	0.334	0.398	0.439	0.488
Kalidami 4	0.240	0.286	0.315	0.351
Kalidami 5	0.172	0.205	0.226	0.252
Kalidami 6	0.124	0.148	0.163	0.181
Kalidami 7	0.089	0.106	0.117	0.130
Kalibokor 1	0.017	0.020	0.022	0.025

TABLE 5. Validation of manning in Kalidami

No.	Location	Manning (n)	H_{survey} (m)	$H_{simulation}$ (m)	ΔH (m)
1	Upstream Kalidami	0.015	0.88	0.8156	0.0646
		0.016	0.88	0.8483	0.0317
		0.0169	0.88	0.8771	0.0129
		0.01699	0.88	0.8799	0.0001
		0.016992	0.88	0.8799	0.0001
		0.016994	0.88	0.88	0
		0.017	0.88	0.8802	0.0002
2	Downstream Kalidami	0.025	1.33	1.1208	0.1192
		0.027	1.33	1.1883	0.1117
		0.03	1.33	1.2536	0.0464
		0.031	1.33	1.2791	0.0209
		0.032	1.33	1.3043	0.0257
		0.033	1.33	1.3287	0.0013
		0.03305	1.33	1.33	0
		0.0331	1.33	1.3312	0.0012

TABLE 6. Validation of manning in Kalibokor

No.	Location	Manning (n)	H_{survey} (m)	$H_{simulation}$ (m)	ΔH (m)
1	Upstream Kalibokor	0.0136	0.33	0.3292	0.0008
		0.0138	0.33	0.3295	0.0005
		0.01362	0.33	0.3299	0.0001
		0.013631	0.33	0.33	0
		0.0139	0.33	0.3323	0.0077
		0.014	0.33	0.3313	0.0087
		0.0142	0.33	0.34	0.01
2	Downstream Kalibokor	0.03	1.00	0.9452	0.0548
		0.032	1.00	0.9837	0.0163
		0.0326	1.00	0.9950	0.0050
		0.0328	1.00	0.9988	0.0012
		0.03284	1.00	0.9995	0.0005
		0.03286	1.00	0.9999	0.0001
		0.032862	1.00	1.00	0
		0.033	1.00	1.0026	0.0026

E. 1D an 2D Modeling

1D and 2D models are assisted with the HEC-RAS. 1D modelling is a simulation without connecting the area aroung research location. Model 1D is only the main river and lateral flow in the river. The required parameters are cross section, manning value, and existing pump. If only 1D modelling cannot be known which areas are inundated. Therefore, 2D modelling is required by making 2D areas on HEC-RAS,

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figure 5. In addition to 2D area, the amount of land use value can be entered as shown in figure 6. Making 2D area in HEC-RAS must be connected to the nearest channel. Connectors from reach and 2D area using lateral structure, figure 7.

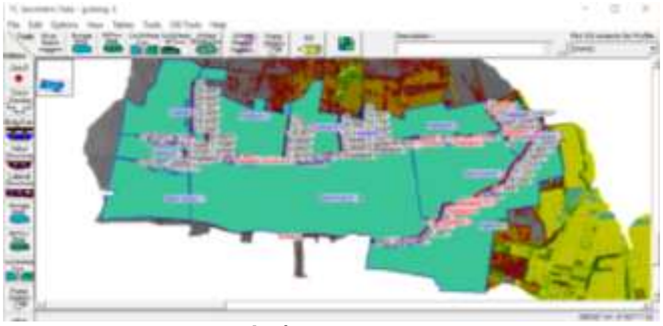

Fig. 5. Result of 2D Area using HEC-RAS

Fig. 6. Land use of Bokor and Dami watershed

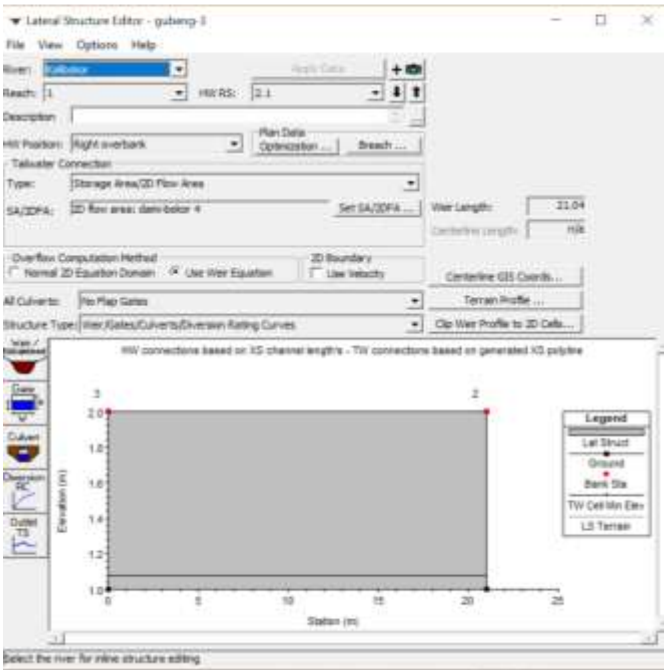

Fig. 7. Lateral structure editor using HEC-RAS

F. Simulation Result and Innundation Mapping

One of simulation result using the HEC-RAS for the four scenarios can be seen in figure 8. The HEC-RAS simulation results can be seen from 0 to 24 hours. The mapping is done using Arc-GIS. Maps are made based on the depth and inundated area, figure 9 and 10. The depth of the inundation mapped is the maximum depth. Inundation is based on Minister of Public Works Regulation Number 12/PRT/M/2014 attachment 1. One of the results that will be shown is the simulation results in 10 years return period. For the return period the other is done in the same way.

Fig. 8. Simulation result of 2 years return period

IV. CONCLUSION

The conclusion obtained in this research are based on the analysis that has been done, including:

1. The flood discharge in East Surabaya is calculated using two methods are Nakayasu method and rational method. Nakayasu method is used in Main River, while the rational method is used in lateral flow. The recalculated period is the return period 2, 5, 10, and 25 years. The amount of peak flood discharge for each return period 2, 5, 10, and 25 years in a row, start from 0.50 until 48.679 m^3/s.
2. The value of manning is obtained by calibration. The function of calibration to get simulation result approach existing condition. The value of manning after calibration are :
   a. Upstream of Kalidami, n = 0.016994
   b. Downstream of Kalidami, n = 0.03305
   c. Upstream of Kalibokor, n = 0.013631
   d. Downstream of Kalibokor, n = 0.032862
3. The depth inundation in Dami and Bokor watersheds in various parts of the downstream area, ranging from 0.05 to 0.822 meters. The inundation area in the Dami and Bokor watersheds is diverse, ranging from 0.30 to 8.5 ha.
4. Parameter for making inundation maps are inundation parameters with a range 0.10 to more than 0.50 meters. In addition to the depth parameters of inundation, the parameters of the inundated area from 1 to more the 8 ha are used. The area that has highest risk of inundation in Mulyorejo District.

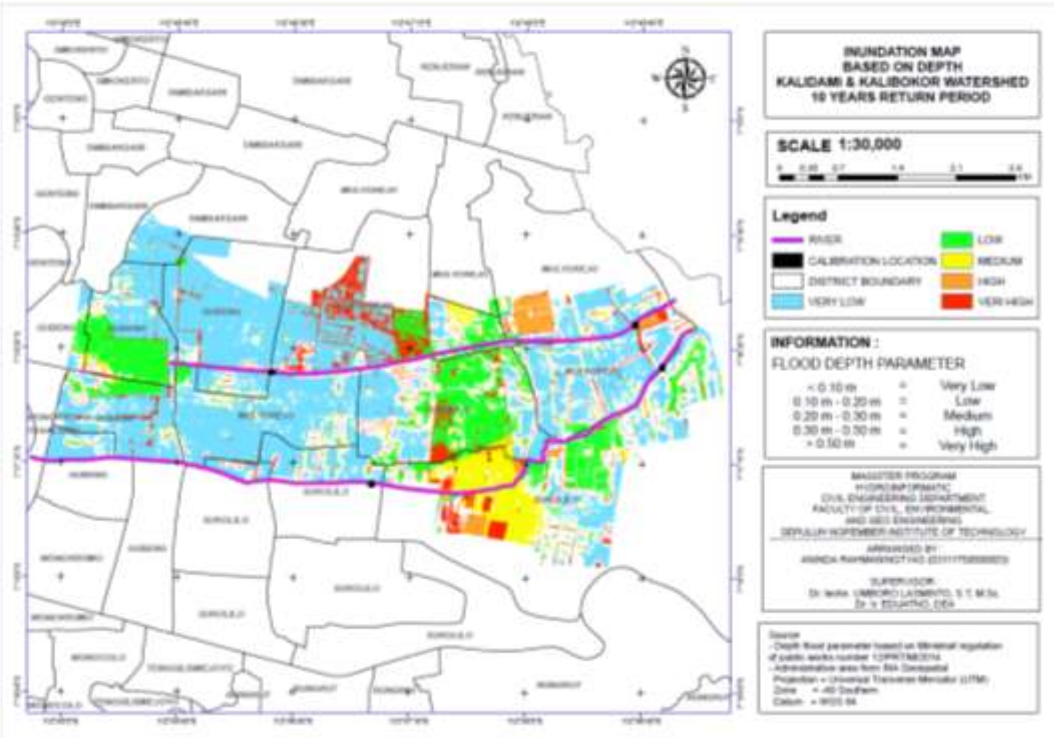

Fig. 9. Depth inundation map in Kalidami and Kalibokor watersheds with 10 years return period

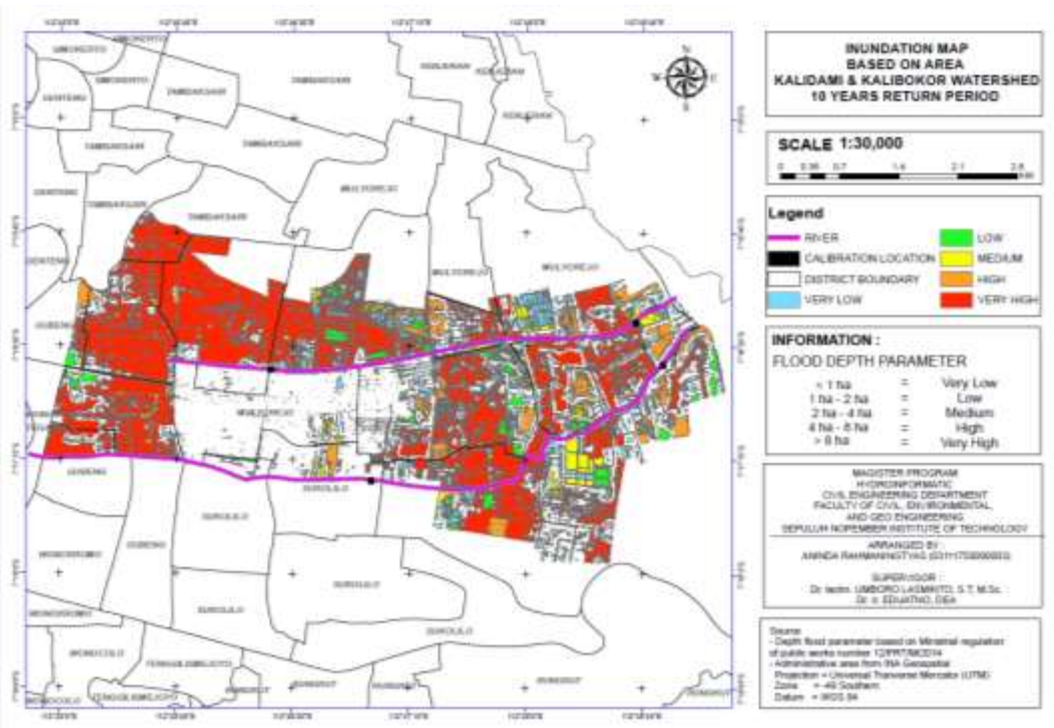

Fig. 10. Area inundation map in Kalidami and Kalibokor watersheds with 10 years return period

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