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RESEARCH PAPER

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Flood analysis in Kali Lamong Watershed

Diah Susilowati[1*], M. Bisri[2], Kliwon Hidayat[3], Arief Rachmansyah[4]

[1]*Doctoral Program of Environmental Studies, Graduate School, University of Brawijaya, Indonesia*

[2]*Department of Water Resources Engineering, University of Brawijaya, Indonesia*

[3]*Department of Social Economic Agriculture, University of Brawijaya, Indonesia*

[4]*Department of Civil Engineering, University of Brawijaya, Indonesia*

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Abstract

Sub-watershed of Kali Lamong is includes in parts of downstream Bengawan Solo Watershed that flooded every year. The risk of flood lead to the disadvantage of various aspects of life, e.g. properties, facilities and infrastructure, socio-economy factors, decreased land productivity and environmental quality. The aims of this study were: (1) to determine the integrated spatial model of land use with river hydrodynamic model towards the flood potential by GIS method; (2) to know the watershed responses for the flood risk valuation; (3) to determine the flood risk analysis model regards to controlling land functions in the area of Kali Lamong Watershed. First, we used problem identification method, continued by area assessment and model development. Area assessment consisted of demands, data collection and data processing. Data development includes Hydrology Integrated Model and Dynamic GIS. Data processed by model testing and model application and result the Decision Support System (DSS) Model. Results obtained the total flooded area in Q5 is 15,805.284 ha, Q10 16,632.930 ha, Q5-50 17,359.265 ha, and Q100 17,956.701 ha. The flood (input debit 300 m^3/s) expands along the Districts of Sambeng to Mantup, Balongpanggang to the north Benjeng, Kebomas, Menganti, and Benowo which passed by Kali Lamong. The land use areas which affected most are rainfed paddy field and ponds for all distance period. Thus we concluded that if the average rainfall on Kali Lamong is more than 100 mm/s, then the area surround Kali Lamong will be overflooded.

***Corresponding Author:** Diah Susilowati ✉ diah.susilo60@gmail.com

Introduction

Annual flood in East Java Province, especially in the downstream area of Bengawan Solo Watershed was flash floods, flooding and tidal inundation. The sub-watershed area, namely Kali Lamong also received this annual flood phenomenon, which recently expanded. Efforts to overcome the flood already conducted. However, it is still hard to avoid the flood because the several primary causes, e.g. high intensity of rainfall, the decrease on watershed quality, sedimentation, tides' back water. The prevention of these causes was hard due to the characteristics of Kali Lamong itself. In rainy season, the flood overflowed the carrying capacity, while in dry season the watershed was shortages for water.

Yet, in the facts, the efforts program in managing flood in Kali Lamong was not optimal. Thus, the flood created loss for community around the Kali Lamong which is the risk of flood impact. Policy in managing the flood completely should consider the flood risk based on its fundamental problems from upstream to downstream of Kali Lamong. Therefore the concept of *One River One Plan* for the river management should be run to realize the comprehensive policy and meet the demand of community along the watershed of Kali Lamong. The aims of this study were to determine the integrated spatial model of land use with river hydrodynamic model towards the flood potential by GIS method; to know the watershed responses for the flood risk valuation and affecting factor to the economic disadvantage; and to determine the flood risk analysis model regards to the controlling land functions in the area of Kali Lamong Watershed.

Materials and methods

The phases in the research was used as procedural steps to answers the purpose of the study. The procedure for this research described as follows. Identification of problems as initial phases was conducted in the study area and model development. In the study area, we record the demand, collect and process the data. Otherwise, we also develop the integration model of hydrology and dynamic Geographic Information System (GIS).

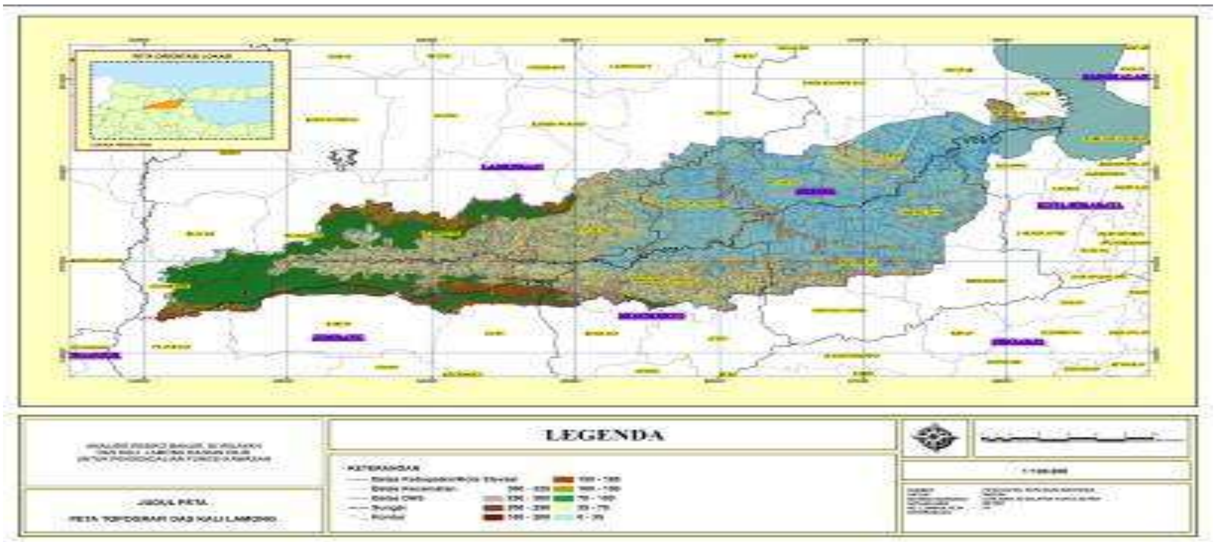


Fig. 1. Topography Map.

The next phase, we conduct the model testing included correction, calibration, and verification. The tested model then applied the simulation and risk assessment of flood. As results, we obtained the DSS model and the map of flood risk.

Study site

he sub-watershed area of Kali Lamong is part of Bengawan Solo River Area Unit, administratively located in the Regencies area of Lamongan, Jombang, Mojokerto, Gresik and Surabaya City. It's estuary end in the Gulf of Lamong and Strait of Madura. Kali Lamong with 720 km^2 watershed areas and 103 km river length has 7 sub-streams. It is located 15 km away from the border between Gresik and Surabaya City.

The upstream of Kali Lamong is mountainous area with wavy topography, surrounded by limestone ridges and clay, with fertile land area. Its wavy contour functioned as rain water reservoir. Middle area of Kali Lamong was relatively flat, mostly teak forest, and the rest is used for seasonally rainfed paddy field.

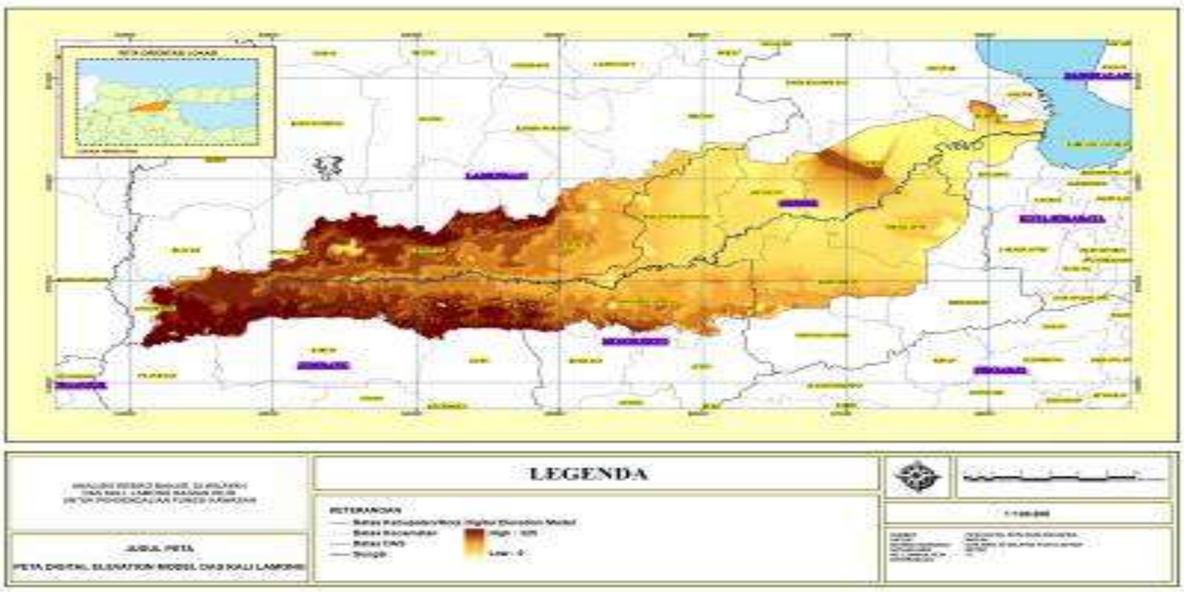


Fig. 2. DEM map of Elevation Zone around Kali Lamong Watershed.

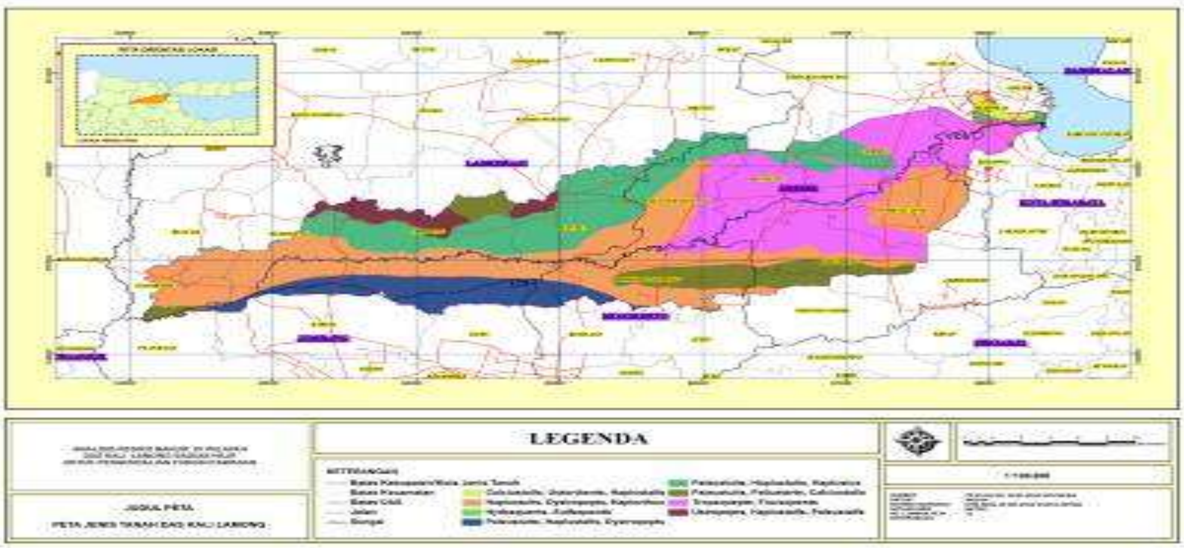


Fig. 3. Map of Soil Types in Kali Lamong Area.

Site selection was based on the unique characteristics of Kali Lamong watershed which end in Lamong Gulf, as strategic area for the development of central port and trading in the Madura Strait. Besides due to its annual flood, Kali Lamong become concern for government to develop its land use coastal area regards to the climate changes that lead to backwater to Kali Lamong stream.

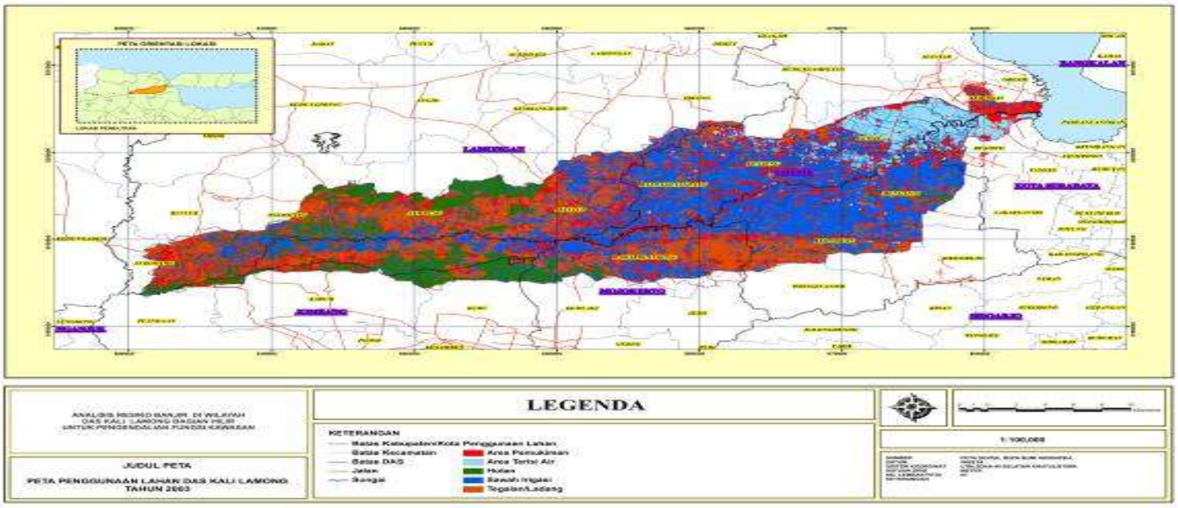


Fig. 4. Map of Land use in Kali Lamong Area 2003.

Data collection

Data act as model input to be developed and used to identified and described the study area. Data collection includes spatial and non-spatial data, map digitation in the form of analog map, format conversion and editing on digital map, key-in non-spasial data and preparation for the model data input. This parts include in the data processing of Digital Elevation Model (DEM) and rastering or data grid followed by spatial anaysis. Model developing of hydrology was used to obtained the parameters or properties of hydrology such as flow direction, elevation, Manning's roughness coefficient, curve number, and other parameters to develop hydrology models. From the data processing, we obtained groundcheck on the flood site (Table 1) and contour area of Kali Lamong, map of topography (Fig. 1), DEM (Fig. 2), and soil type (Fig. 3).

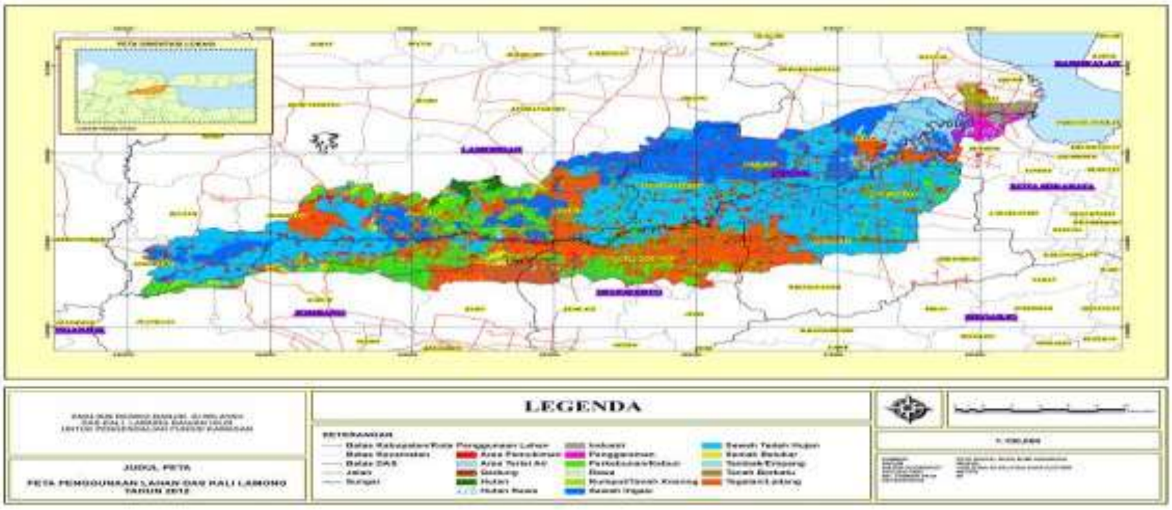


Fig. 5. Map of Land use in Kali Lamong Area 2012.

Topography model (TOPMODEL) was created refer to Beven and Kirby (1979) to predict the surface runoff of momentary rainfall on the watershed area with grid system approach (Fig. 1). TOPMODEL calculated the effect of watershed topography by the topography spread index. It used a concept of area-similar surfeited variable in the simple model. By comparing the models of spread parameters, TOPMODEL need less input of spread parameters.

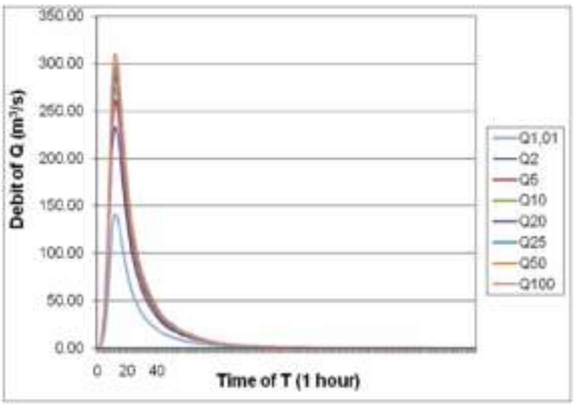


Fig. 6. Flood Debit Hydrograph of Kali Lamong watershed with HSS Nakayasu.

Chairat and Delleur (1993) modified the TOPMODEL to consider the effects of drainage system in the sub-surface as used on the agriculture production. By this modification, the model works well to predict the hydrograph of surface runfoff of agriculture watershed area in Cental Southern Indiana. They also integrated the TOP-MODEL with GRASS-GIS to the utilization of simple model.

The map of Digital Elevation Model (DEM) was used to estimate the elevation of the area around Kali Lamong (Fig. 2). DEM is a digital map contains data of height, raster (pixel) or vector base with Triangulated Irregular Network (TIN) (Sukatja, 2004). Data DEM is important to create other thematic map, especially in management of water resources.

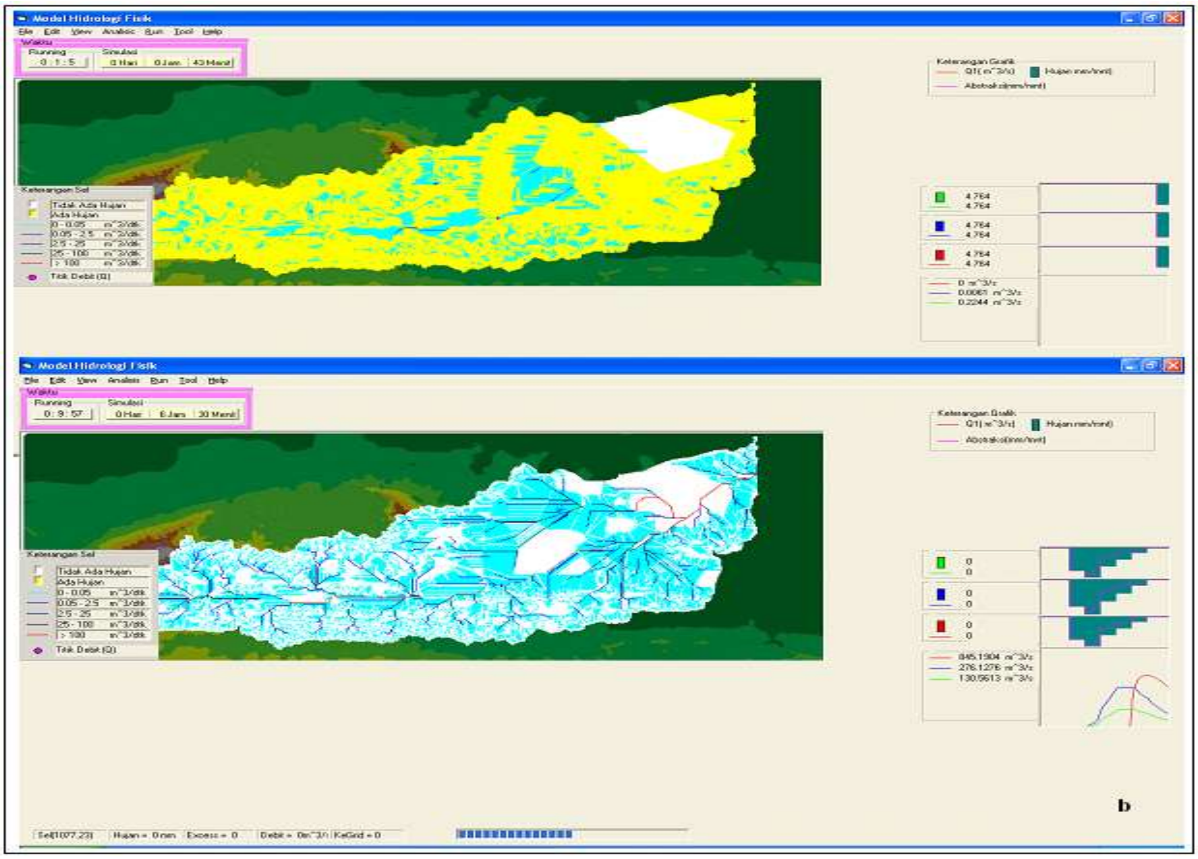


Fig. 7. Flood debit analysis in distance period of 5 years. a. simulation of flood debit with SIMODAS, b. simulation of flood debit with HSS Nakayasu.

In the process of digital mapping/digmap, DEM was made with interpolation of regular high dots and structure line (break lines, river lines, etc) which measured stereocally in the photogrammetric compilation. Some expert also mentioned the dots as the results of this stereo-plotting as DEM, but it it missinterpreted. Data grid from stereo-plotting was only raw data for DEM.

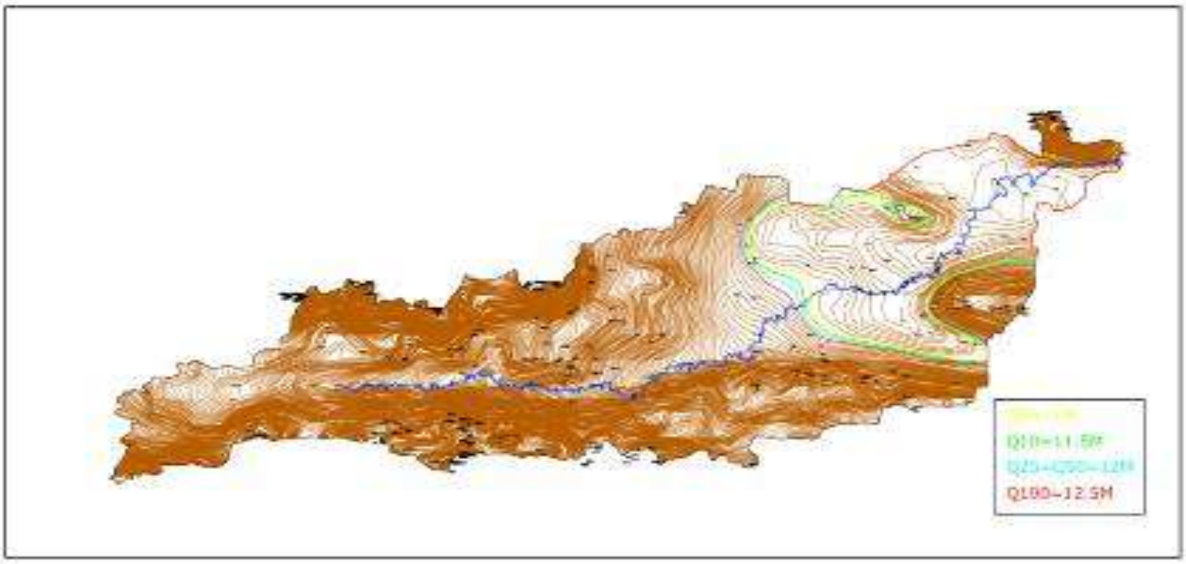


Fig. 8. Map of Flood Model in Kali Lamong Watershed area.

To obtain DEM in regular grid from random dots or grid measured dots in different resolution, we conducted interpoltion. The types of interpolation are (linier, spline, krigging, etc.) will affect the results grid. Further different interpolation would be needed to create derivative product such as contour. Interpolation which produce correct contour with area and prudent dots is Akima interpolation (Ackermann, 1994).

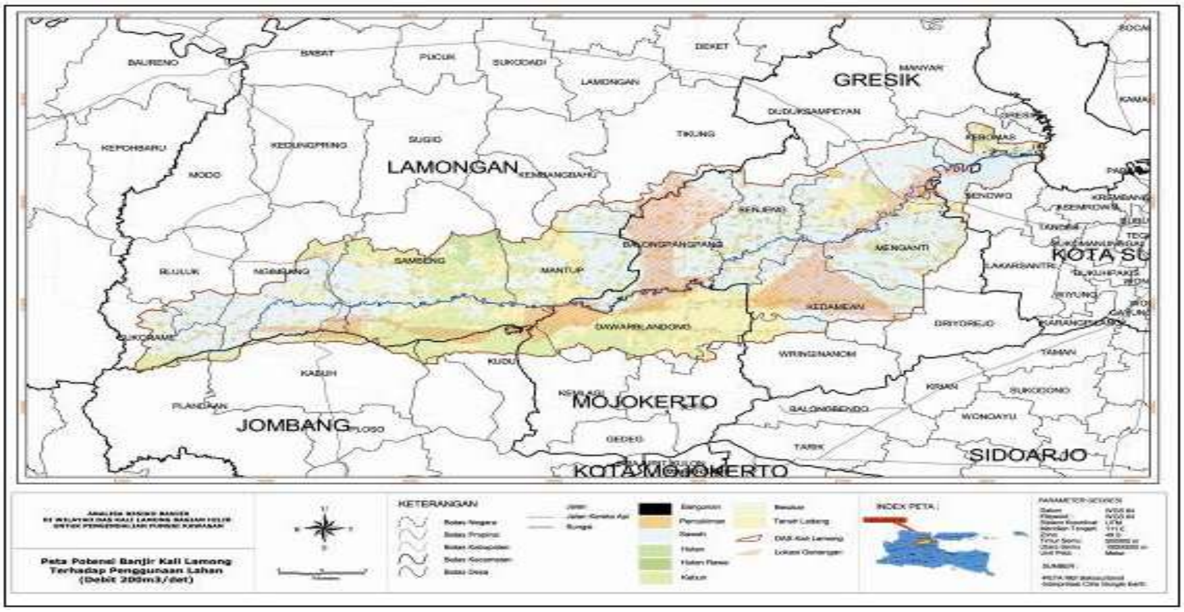


Fig. 9. Map of Flood Model in Kali Lamong Watershed area with input debit 200 m3/s.

Advanced software of DEM includes various features of interpolation, and even giving different weight on different method collected points (Ackermann 1992, IPF 1994). It recognized point from GPS more than photogrametry point. It also concerns the additional information such as breakline, riverline, singular point, borderline, etc.

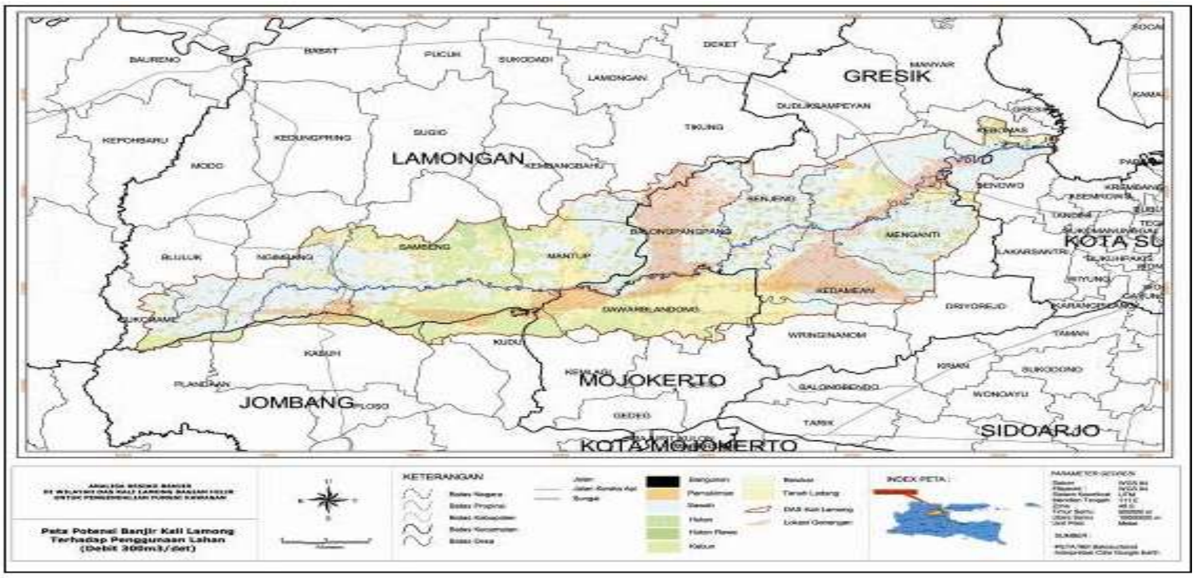


Fig. 10. Map of Flood Model in Kali Lamong Watershed area with input debit 300 m3/s.

Model development

The phase of model development includes: the determination on format data of model input, rain distribution or Thissen polygon, shape and grid size or rasterization, synthetic river networks, model of direct rain runoff, equation of flow from cell to cell, the numeric breakdown of flow equation, and visualization. Lastly in this phase is the determination of algorithm, flow chart and coding for the computer program.

Model testing

The phase of model testing corrected the possible errors, calibration of hydrology and hydraulic parameters, and model verification. Error corrections should be initiated by eliminates the errors, or minimizes the errors. Errors could have happen because the mistakes in data interpolation and data accuracy, e.g. elevation from DEM of agriculture area with certain land handling.

Calibration was aimed to obtain the value of hydrology and hydraulic parameters in the determination of infiltrated raifall, and other parameters such as Manning's roughness index, which will be used in the development of the model. After the value of parameters correspond the real condition of the study area, then we condcuted verification. Verification was conducted by comparing the results of model simulation with other modle as well as to the observational data for others flood phenomenon. Other model that used as comparison for verification is Model of ANSWERS. The ANSWERS model are widely used for watershed in world, and spesifically in Indonesia.

Model application

Model application is in the form of the testing of integrated model with the formulation of flood risk. The formula consisted of physical aspects and socio-economic aspects (level of danger and social vulnerability). It was arranged with database system which showed the relation patterns of flood potential.

Data analysis

Analysis of designed flood debit

Analysis of designed flood debit will produce accurate results if it is supported by the observational data debit, i.e. in the form of Automatic Water Level Record (AWLR) and Automatic Raingauge Record (ARR) data as inputs. If the data on flood debit was available for long period (>20 years), the flood debit could be directly calculated with the method of Log Pearson Type III. Main objective of the flood debit analysis is to obtain peak debit and flood hydrograph. It will be used to determine the planned building dimension.

Method that used in the calculation of flood debit is Nakayasu method. Following formula is the formula for hydrograph with Nakayasu unit. The formula is empirical, thus the application on an area should be preceded with the appropriate parameters selection, i.e. T_p and α, as well as the rain distribution pattern to obtain appropriate hydrograph pattern towards observed flood hydrograph.

$$Q_p = \frac{A.R_0}{3{,}6.(0{,}3.T_p + T_{0,3})}$$

Description

Q_p = peak debit of flood (m^3/s)

R_o = rain unit (mm)

T_p = initial time until flood peak (hours)

$T_{0.3}$ = time of flood peak shedding to 30%

A = the width of catchment area to outlet

Thus, the peak debit of flood calculated with the following formula.

$$Q_p = \frac{A.R_0}{3{,}6.(0{,}3.T_p + T_{0,3})} = \frac{71465{,}41 \cdot 1}{3{,}6 \cdot ((0{,}3 \cdot 9{,}43) + 12{,}919)} = 1269{,}907 \text{m3/s}$$

Analysis of log pearson type III

Rainfall design is the highest possible rainfall in an area with certain possibilities. This study used the method of Log Pearson Type III to analyze the rain design. The procedure of Log Pearson Type II described as follows.

1. Transform the data of maximum annual daily rainfall in the form of logarithm (rainfall data was sorted before).
2. Calculate empirical possibility (P_e) in % with Weibull formula (Soewarno, 1995):

$$P_e\,(\%) = \frac{m}{n+1} \text{ x } 100\,\%$$

3. Calculate the logarithm of average rain ($\overline{LogX}$) from n data number with following formula:

$$\overline{LogX} = \frac{\sum_{i=1}^{n} LogXi}{n}$$

4. Calculate the coefficient of elevation (in log) with formula:

$$Cs = \frac{n\sum_{i=1}^{n}\left(LogXi - \overline{LogX}\right)^3}{(n-1)(n-2)S^3}$$

Conformance test of frequency distribution

The conformance test of distribution was meant to assess the selected distribution could be used or not; for a set of available data. We used two statistical methods to test the distribution conformance, i.e. Chi Square (Soewarno, 1995) and Smirnov Kolmogorov. Chi Square determine whether the selected distribution of possibilities represent the statistical distribution of the sampled data. The decision of this test was determined by using the parameter X^2. Otherwise, Smirnov Kolmogorov test was used to compare the most maximum possibilities between the empirical distribution and theoretical distribution called Δ_{maks}. The steps for Smirnov Kolmogorov test are:

1. Data sorting
2. Calculate empirical possibilities (P_e) with Weibull Formula (Soewarno, 1995)

$$P_e = \frac{m}{n+1}$$

3. Calculate the theoretical possibilities (P_t) with following formula:

Pt = 1 - Pr

To determine the value of Possibilities rate (P_r), we interpolated from the table of distribution Log Pearson Type III (Cs Negative).

Analysis of flood debit with SIMODAS

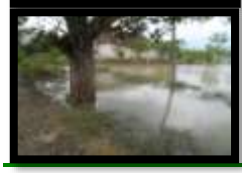
The flood risk simulation (SIMODAS) used the debit in stations of Kali Lamong. Debit measurement was conducted in outlet of three points, i.e. third part of upstream, two-third of middle stream, and outlet in downstream. Areas that used to indicate the change of flood risk area are sea water, freshwater, building, shrub, lake, ponds, swamp forest, garden, land sand, salting area, settlement, swamp, grassland, irrigation paddy field, rainfed paddy field, and farmlands. The land uses in the area of Kali Lamong was described in Fig. 4 and 5. The flood risk was simulated in the distance period of 5 years, i.e. 5 years (Q_5), 10 years (G_{10}), 25-50 years ($Q_{25\text{-}50}$), and 100 years (Q_{100}). The potential flood was simulated by SIMODAS for the input debit 300 m³/s.

Results and discussion

Synthetic hydrograph of designed flood debit

Following Fig. 6 is the recapitulation of synthetic hydrograph of designed flood debit with the method of HSS Nakayasu. From the unit hydrograph we calculated the flood hydrograph for various time periods by multiply with effective rainfall.

Table 1. Groundcheck of flood in Kali Lamong area.

Condition of Site	Site	Coordinate
	Village of Iker Iker Geger, Cerme – Gresik	7°14'24.65" S 112°33'48.14" E
	Around the bridge in Raya Morowudi Street, Cerme - Gresik	7°14'53.52" S 112°33'39.43" E
	Village of Boboh, District of Menganti - Gresik	7°15'50.74" S 112°33'47.40" E
	Village of Morowudi, District of Cerme - Gresik	7°15'90.44" S 112°33'30.36" E
	Village of Sermenlerek, District of Kedamean - Gresik	7°16'21.42" S 112°31'50.92" E
	Village of Klampok, District of Benjeng - Gresik	7°15'15.68" S 112°30'00.01" E
	Village of Klotok, District of Balongpanggang - Gresik	7°14'39.11" S 112°27'33.84" E

Peak debit of HSS Nakayasu in Kali Lamong Watershed

The results show recapitulation on the peak flood debit with HSS Nakayasu method (Table 2). It implied the amount of flood discharge to Watershed Area of Kali Lamong.

Rain analysis with Log Pearson Type III

The result of empirical possibilities percentage (P_e %) in this study is 9.09 with $\overline{LogX}$ 1.988. Thus we obtained the coefficient of elevation or Cs Negative for -0.89 (Supplementary 1).

Supplementary 1. Distribution of Log Pearson Type III.

No.	Tahun	Xi (mm)	P (%)	Log Xi	$\text{Log Xi-}\overline{\text{Log X}}$	$(\text{Log Xi-}\overline{\text{Log X}})^3$
1	2012	69.90	9.09	1.84	-0.14	-0.002941
2	2007	80.72	18.18	1.91	-0.08	-0.000527
3	2004	94.58	27.27	1.98	-0.01	-0.000002
4	2009	95.58	36.36	1.98	-0.01	0.000000
5	2008	96.02	45.45	1.98	-0.01	0.000000
6	2003	99.25	54.55	2.00	0.01	0.000001
7	2005	100.96	63.64	2.00	0.02	0.000004
8	2010	114.12	72.73	2.06	0.07	0.000337
9	2011	114.84	81.82	2.06	0.07	0.000378
10	2006	117.30	90.91	2.07	0.08	0.000542
Jumlah		983.27		19.88		-0.002208
Rerata		98.33		1.99		
Stand. Dev		14.29		0.07		
Koef. Kemencengan (Cs)				-0.89		

Frequency distribution analysis

Distribution test with Chi square

The value of critical X^2 for α=1% is 6.635 while α=5% is 3.841 (Supplementary 2).

Table 2. Peak of Flood Debit Recapitulation in Kali Lamong Watershed.

Q peak ($m^3.s^{-1}$)							
$Q_{1.01}$	Q_2	Q_5	Q_{10}	Q_{20}	Q_{25}	Q_{50}	Q_{100}
141.53	233.37	261.468	274.47	286.39	293.14	298.55	310.68

Source: Simulation Analysis.

Supplementary 2. Test of Chi-Square.

No	Class	Batas Kelas		Frequency Theoritical	Frequency Observation	X^2_{Cal} (mm)
		(%)	(mm)	(Ej)	(Oj)	
1	I	0 - 25	0 - 87.982	2.5	2	0.1
2	II	25 - 50	87.982 - 99.540	2.5	4	0.9
3	III	50 - 75	99.540 - 109.507	2.5	1	0.9
4	IV	75 ~	109.507 ~	2.5	3	0.1
				Total	10	**2**

Thus, the test of Chi-Square concluded as following Table 3.

Distribution test with Smirnov-Kolmogorof

The result of empirical possibilities (P_e) in this study is 0.0909 with theoretical possibilities 0.043. From the calculation of Smirnov Kolmogorof (Supplementary 3).

Table 3. Results of Chi-Square Test.

No.	α	X^2_{table}	X^2_{cal}	Description	
1	1%	6.635	2	$X^2_{cal} < X^2_{table}$	Distribution accepted
2	5%	3.841	2	$X^2_{cal} < X^2_{table}$	Distribution accepted

Supplementary 3. Test of Smirnov-Kolmogorof.

No	Xi (mm)	Log Xi	Pe	K	Pr	Pt	Δ IPt-PeI
[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
1	69.90	1.844	0.091	-2.041	0.957	0.043	0.048
2	80.72	1.907	0.182	-1.151	0.867	0.133	0.049
3	94.58	1.976	0.273	-0.171	0.604	0.396	0.124
4	95.58	1.980	0.364	-0.105	0.582	0.418	0.054
5	96.02	1.982	0.455	-0.077	0.573	0.427	0.027
6	99.25	1.997	0.545	0.128	0.506	0.494	0.051
7	100.96	2.004	0.636	0.234	0.463	0.537	0.099
8	114.12	2.057	0.727	0.991	0.154	0.846	0.119
9	114.84	2.060	0.818	1.030	0.140	0.860	0.041
10	117.30	2.069	0.909	1.162	0.097	0.903	0.006
Total		19.878				**Δ max =**	**0.124**
Average ($\overline{LogX}$)		1.988					
Std. Dev (S $\overline{LogX}$)		0.070					
Cs		-0.887					

We obtained Δ_{max} = 0.124. Based on the table of $\Delta_{critical}$ for Smirnov Kolmogorof with N = 10, the results showed in the following Table 4.

Analysis of flood debit with SIMODAS

The results of flood debit from SIMODAS for distance period 5 years, 25 years, 50 years, and 100 years which were obtain by comparing the peak debit of HSS Nakayasu and SIMODAS showed significant difference. Result from the estimation with HSS Nakayasu was much smaller than estimation of flood from SIMODAS (Fig. 7). We assumed it is due to the debit estimation with HSS Nakayasu with coefficient of surface flow (C) for 0.2.

Table 4. Results of Smirnov-Kolmogorof Test.

α	$\Delta_{critical}$	Δ_{max}	Description
0.2	0.32	0.124	accepted
0.1	0.37	0.124	accepted
0.05	0.41	0.124	accepted
0.01	0.49	0.124	accepted

Analysis of flood debit with ground check data

The result flood debit analysis with ground check in Kali Lamong (Table 5) showed that the widest flooded area in period of Q_5 is rainfed paddy field, followed by ponds. Similar result was also showed in Q_{10}. The change of flooded area was slight. The same happens to the next distance period, Q_{25-50} and Q_{100}. However, the increase was still occurred. The two areas of rainfed paddy field and ponds get more flooded area in every distance period because both are the main area for the community's occupation. From these data, we create flood model in a map form consisted of Q_5, Q_{10}, Q_{25-50}, and Q_{100} (Fig. 8). Q_5 was described in contour line of yellow with interval 11 m. Q_{10} in green contour line with interval 11.5 m. Q_{25-50} in blue with interval 12 m and Q_{100} in red with interval 12.5 m. From the simulation, we used input debit 200 m^3/s (Fig. 9) and 300 m^3/s (Fig. 10).

The result map of food model in Kali Lamong is not accurate enough because the used topography map in scale 1:25.000 with contour interval 12.5 m. It would be better for further research in the area using map with scale 1:1.000 and contour interval 1 m.

From the simulation, input debit 300 m^3/s obtained from distance period of 2-5 years. Thus, if the average rate of rainfall in Kali Lamong Watersehd area is more than 100 mm, then the flood will keep occur along Kali Lamong, especially in the downstream area. Dewandaru and Lasminto also conducted the similar study in Kali Lamong, but with HEC-RAS program to estimate the flood debit. The program used superposition that showed a decreased flood debit from Q_{25} 460.282 m^3/s into 223.9 m^3/s. However, it is still over the threshold for the watershed capacity to carrying the debit.

SPOT images interpretation showed that Kali Lamong Watershed area in Jombang Regency, Dictrict of Kabuh, Kudu, and Ngusikan act as buffer zone due to its good quality of vegetation cover. Mostly it consisted of forest, farmlands and bushes.

Table 5. Total of flooded area in every 5 years distance period.

Indicator Area	Area (ha)				%				Number of Sites			
	Q_5	Q_{10}	Q_{25-50}	Q_{100}	Q_5	Q_{10}	Q_{25-50}	Q_{100}	Q_5	Q_{10}	Q_{25-50}	Q_{100}
sea water	8.456	8.456	8.456	8.456	0.05	0.05	0.05	0.05	9	9	9	9
freshwater	120.914	130.288	133.063	134.289	0.77	0.78	0.70	0.75	44	46	46	47
building	33.851	37.426	39.260	40.724	0.21	0.23	0.23	0.23	105	110	117	118
shrub	38.836	39.782	41.321	42.270	0.25	0.24	0.24	0.24	12	12	13	13
lake	47.192	47.309	47.355	49.375	0.30	0.28	0.27	0.27	46	46	47	49
ponds	3,867.494	3,880.742	3,892.483	3,899.483	24.47	23.33	22.42	21.72	174	175	177	179
swamp forest	73.421	74.567	76.161	77.730	0.46	0.45	0.44	0.43	14	14	14	13
garden	618.694	684.628	751.788	780.670	3.91	4.12	4.33	4.35	223	244	258	269
land sand	3.428	3.762	3.922	3.922	0.02	0.02	0.02	0.02	1	1	1	1
salting area	786.924	786.924	786.924	786.924	4.98	4.73	4.53	4.38	32	32	32	32
settlement	1,219.929	1,290.458	1342.512	1,381.502	7.72	7.76	7.73	7.69	233	250	268	281
swamp	29.465	29.465	29.474	29.558	0.19	0.18	0.17	0.16	10	10	11	11
grassland	428.531	451.601	482.822	497.390	2.71	2.72	2.78	2.77	101	105	109	110
irrigation paddy field	1,843.477	1,965.147	2,085.798	2,177.771	11.66	11.81	12.02	12.13	24	26	24	26
rainfed paddy field	5,724.170	6,196.167	6,591.190	6,952.872	36.22	37.25	37.97	38.72	48	53	54	49
farmlands	960.502	1,006.208	1,046.736	1,093.765	6.08	6.05	6.03	6.09	57	61	65	68
Total	15,805.284	16,632.930	17,359,265	17,956.701	100	100	100	100	1133	1,194	1,245	1,275

Conclusion

The total flooded area in Q5 is 15,805.284 ha, Q10 16,632.930 ha, Q5-50 17,359.265 ha, and Q100 17,956.701 ha. The results of SIMODAS (flood simulation for input debit 300 m^3/s) showed flood expand from the Sambeng District to Mantup District, of Balongpanggang District flooded to the north to Benjeng District. Overflood also happens in Kebomas District and Menganti District around the river, as well as Benowo District; which passed by Kali Lamong. The land use areas which affected most by the flood risk are rainfed paddy field and ponds for all distance period. The maximum average rainfall on Kali Lamong is 100 mm/s. If the average rainfall passed the threshold, then the area surround Kali Lamong will be flooded.

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