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Analysis of Rain – Flood Discharge Using HEC-HMS Model in Sadar Sub-catchment, Mojokerto

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Abstract— *Increased rainfall in watershed is able to influence water level-discharges and cause flood events. Hydrology model carried out to describe the watershed response from rainfall and spatial data review through GIS used to identify flood hazard area as an early warning. Sadar sub-catchment located in Mojokerto Regency / City which has a high level of flood vulnerability, HEC-HMS model performance evaluation with statistics parameter result of Nash-Sutcliffe Efficiency (NSE) is 0.608 (satisfactory), Root Mean Squared Error (RMSE) - standard deviation ratio (RSR) is 0.603 (satisfactory) and Percent Bias (PBIAS) is 0.08 (very good). Six influence factors produce spatial map of flood hazard area in Sadar sub-catchment, these factors are flow accumulation, land slope, elevation, rainfall, soil type and land use.*

Keyword— *Flood hazard, HEC-HMS, Sadar sub-catchment.*

I. INTRODUCTION

Hydrometeorological disasters influenced by hydrological cycles in watershed, depend on physical characteristics of watershed such as watershed shape, topography, texture, soil density, ground water level and land use. Meteorology factor in the watershed includes intensity, duration, distribution, frequency, temperature, wind, humidity.

HEC-HMS (Hydrologic Engineering Center-Hydrology Modeling System) developed by the US Army Corps of Engineers-Institute for Water Resources, is a software that simulates runoff rainfall processes in watershed area (USACE 2010).

Sadar sub-catchment as part of Brantas River Basin, located in the Regency and City of Mojokerto East Java Province which has a high level of flood vulnerability.

The response of sub-catchment to rainfall and physical characteristics of Sadar Sub-catchment, surface runoff and water discharge affects to Sadar River can be simplified into hydrology model. Spatial data review conducted to identify flood hazard areas as an early warning and to minimizing disasters impact.

II. MATERIALS AND METHODS

Study Location

The research location on the Sadar Sub-catchment area of 386 km^2 with main River Sadar 23 km long in the Regency / City of Mojokerto, East Java Province.

US Soil Conservation Service method links the characteristics of watersheds such as soil, vegetation and land use to curve numbers. Four Hydrologic Soil Groups (HSG) with A, B, C, and D notations connected the minimum infiltration rate of soil. Antecedent Moisture Condition (AMC) in this study using AMC II.

Baseflow discharge and flood routing calculation in this study uses Gama I Synthetic Hydrograph equation (Harto, 2010) and Muskingum method. Gama I based on watershed area and drainage for baseflow discharge, Muskingum flood routing is a hydrograph forecasting at one point on stream or river section into another point (river trough or reservoir).

HEC-HMS simulates rain-flow and routing process, there are 3 components in hydrology model including basin models, meteorological models and control spesification. HEC-HMS model requires calibration and validation to verify model output compared to observed data. Evaluation using statistical parameter to provide model accuracy and reliability, there are Nash Sutcliffe Efficiency Index (NSE), Root Mean Squared Error (RMSE)-standard deviation ratio (RSR) and Percent Bias (PBIAS) equation:

1. (NSE)

$$NSE = 1 - \left[\frac{\sum_{i=1}^{n}(Y_i^{obs} - Yi_i^{model})^2}{\sum_{i=1}^{n}(Y_i^{obs} - Yi_i^{rerata})^2}\right]$$

2. Root Mean Squared Error (RMSE)-Standard Deviation Ratio (RSR),

$$RSR = \frac{RMSE}{STDEV_{obs}} = \left[\frac{\sqrt{\sum_{i=1}^{n}(Y_i^{obs} - Yi_i^{model})^2}}{\sqrt{\sum_{i=1}^{n}(Y_i^{obs} - Yi_i^{rerata})^2}}\right]$$

3. *Percent Bias* (PBIAS),

$$PBIAS = \left[\frac{\sum_{i=1}^{n}(Y_i^{obs} - Yi_i^{model}) * 100}{\sum_{i=1}^{n} Y_i^{obs}}\right]$$

Model evaluation divided into 4 performance criteria: very good, good, satisfactory, unsatisfactory shown in Table 1.

TABLE 1. Model Evaluation Performance Criteria

Criteria	NSE	RSR	PBIAS
Very good	0.80 < NSE ≤ 1.00	0.00 ≤ RSR ≤ 0.50	PBIAS < ± 5
Good	0.70 < NSE ≤ 0.80	0.50 < RSR ≤ 0.60	±5 ≤ PBIAS < ±10
Satisfying	0.50 < NSE ≤ 0.70	0.60 < RSR ≤ 0.70	±10 ≤ PBIAS < ±15
Not satisfactory	NSE ≤ 0.50	RSR > 0.70	PBIAS ≥ 15

Source: Moriasi (2015, 2007)

Land evaluation of soil, vegetation, climate and other components identify the factors causing flood events, these factors are flow accumulation, land slope, elevation, rainfall, soil type and land use (Kourgialas, 2011), interactions of

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influence factors linked through distinguishing lines that have major and minor impacts on both.

Flood hazard areas grouped into 5 (five) levels: very low, low, moderate, high, and very high.

III. Results and Discussion

Watershed Delineation determinate boundaries of the Sadar Sub-catchment using Digital Elevation Model (DEM) map (http://tides.big.go.id/ DEMNAS/), river network and catchment name/code for HEC-HMS basin model component shown in Fig. 1.

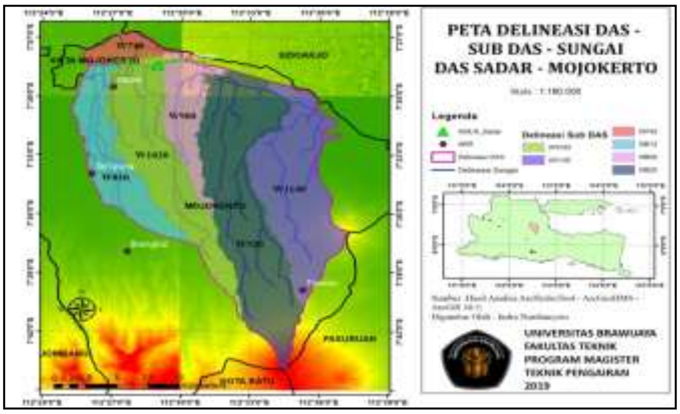

Fig. 1. Watershed Delineation Map of Sadar Sub-catchment

Watershed delineation of Sadar Sub-catchment divided into 6 (six) area, coded to W740 (12.43 km^2), W810 (47.59 km^2), W900 (32.81 km^2), W920 (119.22 km^2), W1030 (79.32 km^2) and W1140 (84.76 km^2).

Curve Number (CN) using SCS method AMC II shown in Table 2.

TABLE 2. Land Use Curve Numbers

Information	HSG			
	A	B	C	D
Water	92	92	92	92
Brush	48	67	77	83
Building	81	88	91	93
Forest	30	55	70	74
Wood Grass	43	65	76	82
Resident District	51	68	79	84
Pasture	49	69	79	84
Irrigated Rice fields	58	69	77	80
Non Irrigated Rice Fields	58	69	77	80
Fallow	77	86	91	94
Farmsteads	59	74	82	86

Source: Spatial Data Processing

TABLE 3. HSG Values For Soil Types

Information	HSG			
	A	B	C	D
Regosol & Litosol Complex		50		50
Association of Mediterranean Reddish Brown & Grumusol Gray		100		
Reddish Brown Latosol				100
Brown Andosol Complex, Yellowish & Litosol Brown Andosol	50			50
Regosol Gray			100	
Alluvial Gray and Alluvial Gray Brown Association				100
Brown & Regosol Gray Latosol Association		100		
Alluvial Gray	100			

Source: Spatial data processing

Hydrologic Soil Groups (HSG) Criteria for soil types shown in Table 3.

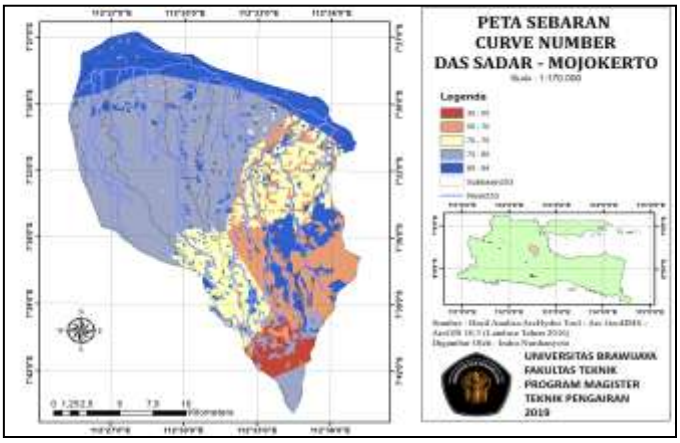

Fig. 2. Composite Curve Numbers Map

Time concentration is time for water to flow from furthest point to outlet in watershed shown in Table 4.

TABLE 4. Time concentrations Sadar Sub-catchment

DAS Sub Code	Area (km^2)	*Lag Time*	
		Hours	Minutes
W740	12.431	3 h 44 m	223.656
W810	47.587	1 h 42 m	102.054
W900	32.808	2 h 6 m	126.344
W920	119.218	2 h 29 m	148.903
W1030	79.318	2 h 41 m	160.526
W1140	84.764	1 h 46 m	106.023

Source: Spatial data processing

Initial abstraction are loss value before surface runoff starts, included water storage, soil infiltration rate, land use, evaporation affected by watershed soil parameters shown in Table 4.

TABLE 4. Initial Abstraction Sadar Sub-catchment

Code	Pot Retention. Max (S-mm)	Initial Abstraction (Ia - mm)
W740	42.749	8.550
W810	66.228	13.246
W900	59.509	11.902
W920	90.245	18.049
W1030	67.768	13.554
W1140	81.294	16.259

Source: Spatial Data Processing

TABLE 5. Loss & Transform Parameters

Information	Watershed Delineation					
	I	II	III	IV	V	VI
HEC-HMS Code	W740	W810	W900	W920	W1030	W1140
Area	12.431	47.587	32.808	119.220	79.319	84.764
Imperviousness	16.269	14.580	14.641	12.463	15.150	10.957
Initial loss/abstraction	8.550	13.246	11.902	18.049	13.554	16.259
SCS Curve Number	85.594	79.318	81.018	73.785	78.939	75.754
SCS UH Lag	223.656	102.054	126.344	148.903	160.526	106.023

Source: Data processing

Input data to HEC-HMS from land evaluation result through spatial processing, created hydrology parameters loss and transform shown in Table 5. Basin models is physical models that describe Sadar Sub-catchment into boundaries, river basins, reservoirs, reach and junction shown in Fig. 3.

Fig. 3. HEC-HMS Basin Model Input

Hydrology Analysis

Rainfall and river elevation data from Jasa Tirta I Public Corporation, period from 2012 to 2018 namely ARR Sadar, Tampung, Brangkal, Trawas and AWLR Sadar.

Hydrology analysis using thiessen polygon method for HEC-HMS meteorological component and isohiet method for flood hazard analysis using Inverse Distance Weighted (IDW) interpolation - ArcView. Thiessen polygon that influenced Sadar telemetry station for validation-calibration model are Sadar, Brangkal and Tampung rainfall stations (Trawas excluded) shown in Fig. 4.

Fig. 4. Map of Polygon Thiessen

Baseflow discharge calculation use Gama I Synthetic Hydrograph (Harto, 2010) as input to HEC-HMS baseflow parameter. Baseflow discharge value for W810 is 7.455 m^3/s, W740 is 1.936 m^3/s, W920 is 14.10 m^3/s, W900 is 5.520 m^3/s, W1030 is 11.069 m^3/s and W1140 is 7.876 m^3/s. Input to HEC-HMS model routing parameter, flood routing using the Muskingum method, coefficient values produce K of 5.52 hours and X of 0.21.

Control specification model for HEC-HMS input selected from flood hydrograph event criteria: peak discharge > 100.00 m^3/s, isolated hydrograph type, one peak / single peak and enough rain, contain information such as date, peak discharge and rain accumulation of flood event shown in Fig. 5.

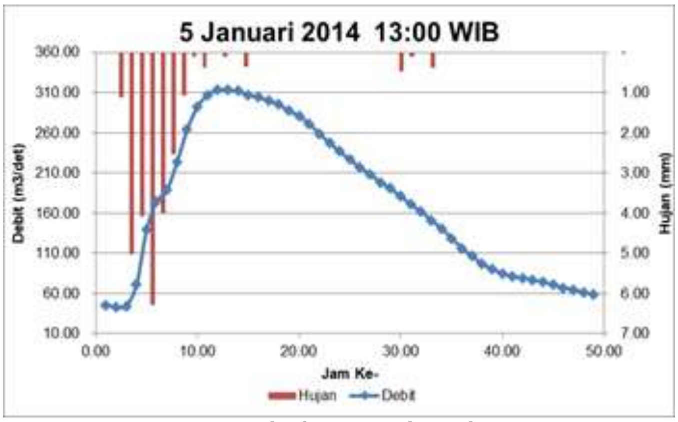

Fig. 5. Flood Events Hydrograph

Flood event identification used for calibration - validation of the HEC HMS model, in the study calibration period are telemetry data 2013, 2014, 2015 and validation period is telemetry data 2017. Insufficient telemetry data for 2012, 2016 and 2018 not used as identification of flood event shown in Table 6.

TABLE 6. Flood Events Identification

No	Date Event	Peak Discharge m^3/s	Thiessen Rainfall mm	Period
1	26 Mei 2013 16:00 - 28 Mei 2013 20:00	271.50	16.51	Calibration
2	28 Mei 2013 20:00 - 30 Mei 2013 16:00	141.10	8.65	
3	16 Jun 2013 21:00 - 17 Jun 2013 23:00	127.20	3.37	
4	14 Juli 2013 17.00 - 16 Juli 2013 05.00	245.50	10.14	
5	25 Nov 2013 15.00 - 26 Nov 2013 19.00	141.10	11.96	
6	09 Des 2013 16.00 - 10 Des 2013 17.00	177.30	8.06	
7	11 Des 2013 15.00 - 12 Des 2013 18.00	141.10	9.11	
8	14 Des 2013 11.00 - 15 Des 2013 15.00	169.00	19.38	
9	05 Jan 2014 13.00 - 07 Jan 2014 13.00	313.50	18.87	Calibration
10	31 Jan 2014 13.00 - 01 Feb 2014 18:00	313.50	11.33	
11	06 Feb 2014 15.00 - 07 Feb 2014 15:00	177.30	24.78	
12	10 Feb 2014 15.00 - 11 Feb 2014 13.00	186.80	24.12	
13	13 Mar 2014 13.00 - 14 Mar 2014 23.00	174.60	16.83	
14	22 Apr 2014 15:00 - 24 Apr 2014 10.00	130.40	6.50	
15	14 May 2014 23:00 - 16 May 2014 05.00	172.70	5.25	
16	20 Des 2014 15.00 21 Des 2014 23.00	239.00	-	
17	29 Jan 2015 13.00 - 30 Jan 2015 16.00	206.50	11.74	Calibration
18	19 Feb 2015 13.00 - 21 Feb 2015 21.00	241.20	18.25	
19	01 Mar 2015 15.00 - 02 Mar 2015 15.00	261.20	21.52	
20	05 Mar 2015 16.00 - 06 Mar 2015 19.00	170.90	35.48	
21	28 Mar 2015 18.00 - 29 Mar 2015 19.00	214.70	8.71	
22	18 Apr 2015 20.00 - 20 Apr 2015 10.00	163.60	43.65	
23	27 Apr 2015 14:00 - 28 Apr 2015 16.00	154.70	23.78	
24	01 Mei 2015 13.00 - 02 Mei 2015 15.00	153.00	29.72	
25	02 Mei 2015 11.00 - 03 Mei 2015 23.00	217.80	2.97	
26	19 Feb 2017 18:00 - 20 Feb 2017 23:00	116.00	155.39	Validation
27	20 Feb 2017 20.00 - 21 Feb 2017 21:00	141.40	102.29	
28	24 Feb 2017 19.00 - 25 Feb 2017 20:00	381.30	89.25	
29	25 Mar 2017 16.00 - 26 Mar 2017 15.00	186.40	74.42	
30	30 Mar 2017 14.00 - 31 Mar 2017 18.00	167.50	58.34	

Source: Data processing

Hydrology parameter for HEC-HMS simulation are loss, transform, baseflow and routing with input value shown in Table 7.

TABLE 7. HEC-HMS Parameters Input

Information	Watershed Delineation					
	I	II	III	IV	V	VI
Kode HEC-HMS	W740	W810	W900	W920	W1030	W1140
Area	12.431	47.587	32.808	119.220	79.319	84.764
Imperviousness	16.269	14.580	14.641	12.463	15.150	10.957
Initial loss/abstraction	8.550	13.246	11.902	18.049	13.554	16.259
SCS Curve Number	85.594	79.318	81.018	73.785	78.939	75.754
SCS UH Lag	223.656	102.054	126.344	148.903	160.526	106.023
Initial baseflow discharge	1.936	7.455	5.520	14.481	11.069	7.976
Recession Constant	0.800	0.800	0.800	0.800	0.800	0.800
Treshold type (ratio to peak)	0.300	0.300	0.300	0.300	0.300	0.300
Muskingum K	5.520	5.520	5.520	5.520	5.520	5.520
Muskingum X	0.210	0.210	0.210	0.210	0.210	0.210

Source: Data processing

Calibration-validation period for optimum result of HEC-HMS model using trial error manual, sub-catchment and river segment in model basin for model calculation influenced by Sadar water level telemetry which is located in the middle of Sadar River are sub-catchment code W740, W810, W1030, and reach R-40, R-60, R-70. Sensitive parameter are initial abstraction, curve number, initial base flow discharge, recession constant, ratio to peak, muskingum k – x and lag time.

Calibration period for flood event January 5th until January 7th, 2014 shown in fig. 10.

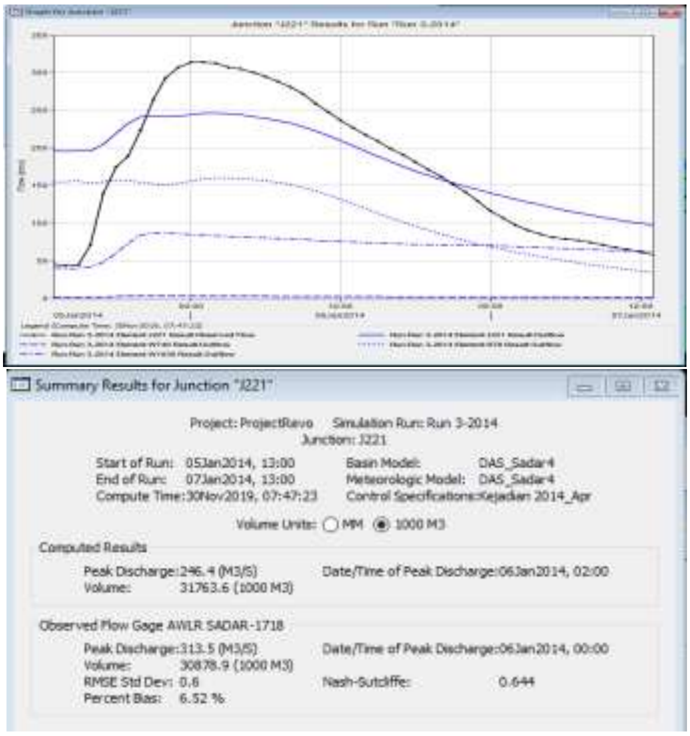

Fig. 10. Calibration period HEC-HMS model on January 5th, 2014

TABLE 8. HEC-HMS Model Calibration on January 5th, 2014

Parameter	Sub-catchment					
	W740		W810		W1030	
	initial	calibration	initial	calibration	initial	calibration
Initial loss/abstraction	8.550	7.810	13.246	20.985	13.554	1.002
SCS Curve Number	85.594	88.504	79.318	72.531	78.939	98.978
SCS UH Lag	223.656	123.180	102.054	108.720	160.526	201.370
Initial baseflow discharge	1.936	1.043	7.455	154.800	11.069	40.000
Recession Constant	0.800	0.457	0.800	0.277	0.800	0.799
Treshold type (ratio to peak)	0.300	0.994	0.300	0.324	0.300	0.999
		R - 40		R - 60		R - 70
Muskingum K	5.520	6.707	5.520	4.629	5.520	8.295
Muskingum X	0.210	0.500	0.210	0.500	0.210	0.500

Source: Data processing

Validation period for flood event March 25th 2017 until March 26th 2017 shown in Fig. 11.

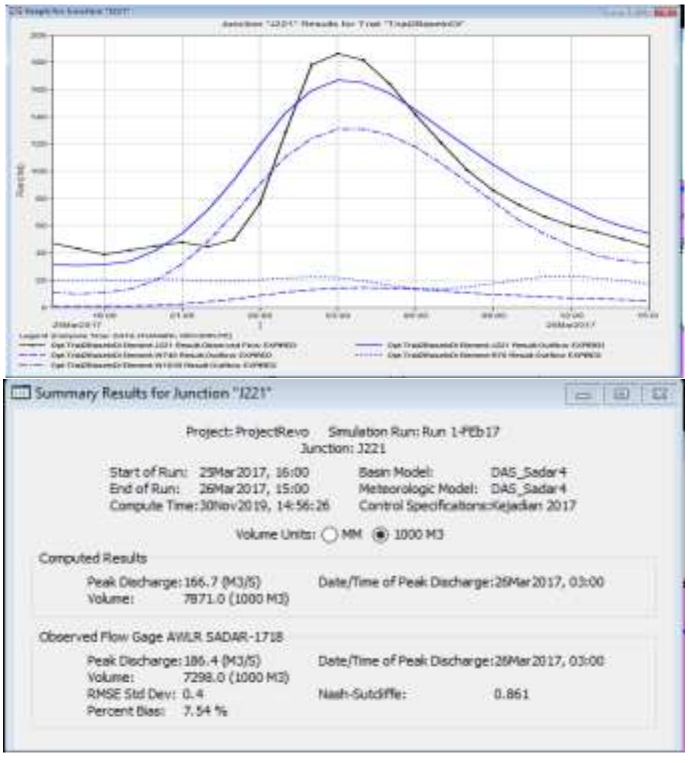

Fig. 11. HEC-HMS model validation on March 25th, 2017

HEC-HMS Model on March 25th, 2017 at 16:00 WIB until March 26th, 2017 at 15:00 WIB, peak discharge of HEC-HMS model 166.70 m^3/s (observed peak discharge 186.40 m^3/s), Nash-Sutcliffe validation is 0.861, RMSE Std Dev (RSR) is 0.4 and Percent Bias (PBIAS) is 7.54%. Comparison of initial parameters and model validation on March 25th, 2017 shown in Table 9.

The resulting HEC-HMS model is then evaluated by the reliability of the model with the statistical parameters Nash-Sutcliffe Efficiency (NSE), Root Mean Squared Error (RMSE) -standard deviation ratio (RSR), and Percent Bias (PBIAS). Evaluation on 30 flood events of the HEC-HMS Model was carried out to determine the level of model reliability so that a hydrological model was obtained that approached the field conditions.

TABLE 9. HEC-HMS Model Validation on March 25th, 2017

Parameter	Sub-catchment					
	W740		W810		W1030	
	initial	validation	initial	validation	initial	validation
Initial loss/abstraction	8.550	25.115	13.246	77.860	13.554	1.000
SCS Curve Number	85.594	98.570	79.318	50.002	78.939	99.000
SCS UH Lag	223.656	493.780	102.054	272.380	160.526	500.000
Initial baseflow discharge	1.936	1.081	7.455	27.645	11.069	10.000
Recession Constant	0.800	0.077	0.800	0.010	0.800	0.262
Treshold type (ratio to peak)	0.300	0.711	0.300	0.328	0.300	0.271
		R - 40		R - 60		R - 70
Muskingum K	5.520	4.625	5.520	4.983	5.520	4.068
Muskingum X	0.210	0.500	0.210	0.500	0.210	0.487

Source: Data processing

HEC-HMS Sadar sub-catchment model evaluation performance using mean value of Nash Sutcliffe Efficiency Index (NSE), Root Mean Squared Error (RMSE)-standard deviation ratio (RSR) and Percent Bias (PBIAS) equation shown in Table 10.

TABLE 10. Evaluation HEC-HMS Sadar Sub-catchment Model

Parameter Evaluation		
NSE	RSR	PBIAS
0,608	0,603	0,08%
satisfactory	*satisfactory*	*very good*

Source: Data processing

Land evaluation uses for flood hazard areas identification, influence factors of flood events and interactions between these factors, including flow accumulation, land slope, elevation, rainfall, soil type and land use (Kourgialas, 2011) shown in Fig. 12. Straight line and dotted line between factors indicates major or minor effect for each factor, to measure two different type one (1) point assigned to major effect and half a point (0.5) to minor effect, sum of factors rate shown in Table 11.

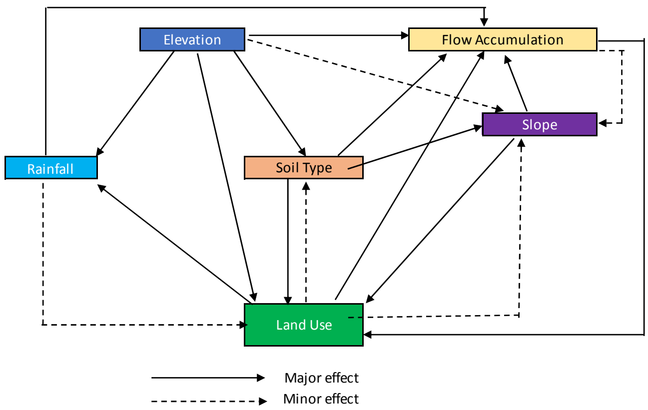

Fig. 12. Flood Hazard Influence Factor of Interaction Scheme

TABLE 11. Factors Rate of Flood Hazard

Group	Interaction Between Factors	Calculation	Results
Flow accumulation	1 major + 1 minor	(1 x 1) + (1 x 0,5)	1,5 point
Slope	2 major + 0 minor	(2 x 1) + (0 x 0,5)	2,0 point
Land Use	2 major + 2 minor	(2 x 1) + (2 x 0,5)	3,0 point
Rainfall	1 major + 1 minor	(1 x 1) + (1 x 0,5)	1,5 point
Soil Type	3 major + 0 minor	(3 x 1) + (0 x 0,5)	3,0 point
Elevation	4 major + 1 minor	(4 x 1) + (1 x 0,5)	4,5 point

Source: Kourgialas (2011)

Analysis of flood hazard areas are calculated by multiplying weights and scores of influence factors, each value of contribution factors determined by percentage shown in Table 12.

Flood hazard areas influence factors in percentage namely for elevation factor is 31.5%, land use is 23.6%, soil type is 19.3%, rainfall is 11, 8%, slope is 7.4%, and flow accumulation is 6.4%. From analysis shown Sadar Sub-catchment has 37% area located in <50 meters above sea level, 73% area is paddy fields, buildings and resident district which has high drainage coefficient. 51% area are regosol and litosol complex, rainfall cumulatif yearly > 1,900 mm, 83% area has 0-8% slope and flow accumulation especially outlet has high flood hazard criteria.

Sadar Sub-catchment flood hazard map result 5.9% area has very low, 7.2% area low, 27.2% area moderate, 56.4% area high and 3.2% area very high shown in Fig. 13.

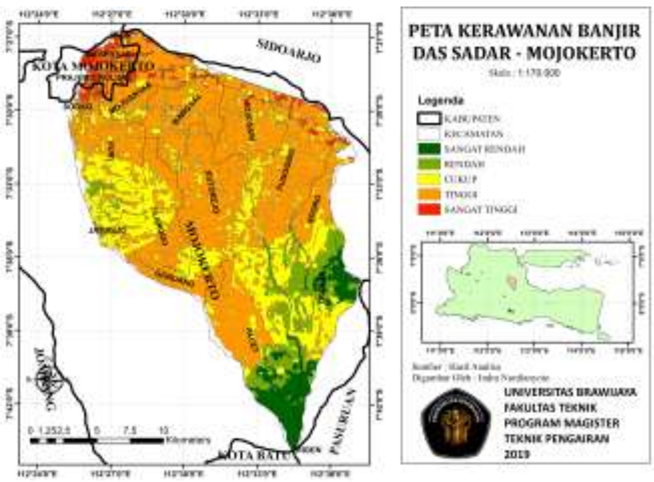

Fig. 13. Flood Hazard Map for Sadar Sub-catchment.

IV. Conclusion

1. Calibration-validation HEC-HMS model of Sadar sub-catchment for 30 flood events identification in 2013-2017, hydrology parameter model are loss (initial abstraction, curve number), base flow (initial base flow discharge, recession constant, ratio to peak), routing (muskingum k and x) and transform (lag time). HEC-HMS model performance evaluation for Nash-Sutcliffe Efficiency (NSE) is 0.608 (satisfactory), Root Mean Squared Error (RMSE) -standard deviation ratio (RSR) is 0.603 (satisfactory), and Percent Bias (PBIAS) is 0.08% (very good).

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TABLE 12. Classification and Weighting Factor

Factor	Classification	Flood Hazard level	Proposed weight	Score	Weighted Rating	Total Weigth	%
Rainfall	< 1400 mm	Very Low	1.0		1.5	82.5	11.8
	1400 - 1500 mm		2.0		3.0		
	1500 - 1600 mm		3.0		4.5		
	1600 - 1670 mm	Low	4.0		6.0		
	1670 - 1750 mm		5.0	1.5	7.5		
	1750 - 1830 mm	Moderate	6.0		9.0		
	1830 - 1900 mm		7.0		10.5		
	1900 - 1980 mm	High	8.0		12.0		
	1980 - 2060 mm		9.0		13.5		
	> 2060 mm	Very High	10.0		15.0		
Land Use	Forest		0.1		0.3	165.3	23.6
	Brush	Very Low	1.0		3.0		
	Farmsteads		2.0		6.0		
	Wood Grass		3.0		9.0		
	Pasture	Low	4.0	3.0	12.0		
	Non Irrigated Rice Fields		5.0		15.0		
	Irrigated Rice Fields	Moderate	6.0		18.0		
	Fallow		7.0		21.0		
	Resident District	High	8.0		24.0		
	Building		9.0		27.0		
	Water	Very High	10.0		30.0		
Soil Type	Alluvial Gray	Very Low	1.3		3.8	135.0	19.3
	Brown Andosol Complex, Yellowish & Litosol Brown Andosol	Low	2.5		7.5		
	Regosol Gray		3.8		11.3		
	Brown Latosol & Regosol Gray	Moderate	5.0	3.0	15.0		
	Association of Mediterranean Reddish Brown & Grumusol Gray		6.3		18.8		
	Regosol & Litosol Complex	High	7.5		22.5		
	Reddish Brown Latosol		8.8		26.3		
	Aluvial Gray & Aluvial Brown Gray	Very High	10.0		30.0		
Slope	> 40%	Very Low	1.0		2.0	52.0	7.4
	25 - 40 %	Low	2.0		4.0		
	15 - 25%	Moderate	5.0	2.0	10.0		
	8 - 15%	High	8.0		16.0		
	0 - 8%	Very High	10.0		20.0		
Elevation	2000 - 3150 m	Very Low	0.1		0.5	221.0	31.5
	1500 - 2000 m		1.0		4.5		
	500 - 1500 m		2.0		9.0		
	300 - 500 m	Low	3.0		13.5		
	200 - 300 m		4.0	4.5	18.0		
	150 - 200 m	Moderate	5.0		22.5		
	100 - 150 m		7.0		31.5		
	50 - 100 m	High	8.0		36.0		
	25 - 50 m		9.0		40.5		
	< 25 m	Very High	10.0		45.0		
Flow Accumulation (Piksel)	0-150.000	Very Low	2.0		3.0	45.0	6.4
	150.000 - 550.000	Low	4.0		6.0		
	550.000 - 1.200.000	Moderate	6.0	1.5	9.0		
	1.200.000 - 2.500.000	High	8.0		12.0		
	2.500.000 - 5.450.000	Very High	10.0		15.0		
	SUM					700.8	

Source: Data processing

2. Sadar sub-catchment influence factors to flood hazard areas in percentage are 31.5 % of elevation factor, 23.6% land use, soil type is 19.3%, rainfall is 11.8%, land slope is 7.4%, and flow accumulation is 6.4%. Flood hazard map result 5.9% area has very low, 7.2% area low, 27.2% area moderate, 56.4% area high and 3.2% area very high.

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