Asian Journal of Applied Science and Technology (AJAST)

(Peer Reviewed Quarterly International Journal) Volume 3, Issue 2, Pages 105-115, April -June 2019

The Effect of Land Use Change to the Flood Magnitude in the Sagulung Watershed-Batam-Indonesia

Mardalina Silitonga[1], Lily Montarcih Limantara[2] & Suhardjono[2]

[1]Master Program on the Department of Water Resources, Faculty of Engineering, University of Brawijaya, Malang, Indonesia.
[2]Department of Water Resources, Faculty of Engineering, University of Brawijaya, Malang, Indonesia.
Email: lynasilitonga@gmail.com, lilymont2001@gmail.com, suhardjonosisno@yahoo.co.id

Article Received: 19 September 2018 Article Accepted: 30 January 2019 Article Published: 10 June 2019

ABSTRACT

This research intends to analyze the land use change and the flood magnitude that occurs. In further, this study also investigates the effect of land cover change to the design flood, the location and the inundation that occurs in the Sagulung watershed. The methodology consists of analyzing the land use change and the effect to the design flood that occurs, the location and inundation that occurs on 1990, 2000, 2008, and 2017 due to the design flood with the return periods of 25 and 50 years (Q_{25} and Q_{50}) in the Sagulung watershed. Result shows that the land use change in the Sagulung watershed on 1990, 2000, 2008, and 2017 due to the Q_{25} and Q_{50} give the significant impact to the inundation area that occurs.

Keywords: *Land use change, design flood, inundation location, inundation.*

1. INTRODUCTION

Hydrological modeling is usually used to predict the hydrological response of a basin related to the rainfall [1, 2, 3]. Rainfall is one of the God's graces that give many benefits. However, if the distribution and quantity are uncontrolled, it also becomes as disaster. In terms of the very large number of parameters of flood models thereby required, the models are over parameterized regarding to the available data for calibration [4, 5]. Therefore, to place the great reliance on a priori estimation of the required scale or effective and efficient parameters required. However, regarding to these limitations, it would also be hoped that the prediction and estimation of flood inundation would be uncertain [6].

The city of Batam is as an industrial, business, and service city. It is surrounded by the other city that has the very potential natural resources so it opens the opportunities for the inside as well as outside investors to invest their capital. However, it increases the development in residence as well as industry and then decreases the water infiltration, and by the end it causes the flooding. The flooding will inhabit the society activity and cause material loss. The Sagulung river is as one of the rivers in the Batam city where is located in the industrial region with the crowded population. The increasing of population number, residence, and business area cause the decreasing of water infiltration in the Sagulung watershed, so if there is happened the high rainfall, it can cause flooding in it.

Based on the problem as above, it is needed to carry out some efforts so the flooding in the Sagulung watershed can be solved immediately. The increasing of watertight land gives the impact on the concentration time is faster, the runoff volume is increasing, the peak discharge is higher, or the combination of them.

2. MATERIALS AND METHODS

The research location is in the Sagulung watershed, Batam city-Riau islands-Indonesia. The area of Sagulung watershed is 24.24 km^2. The Sagulung watershed has the island typical watershed that is it has the short stream and is dominated by low land. Map of location is presented as in the Figure 1.

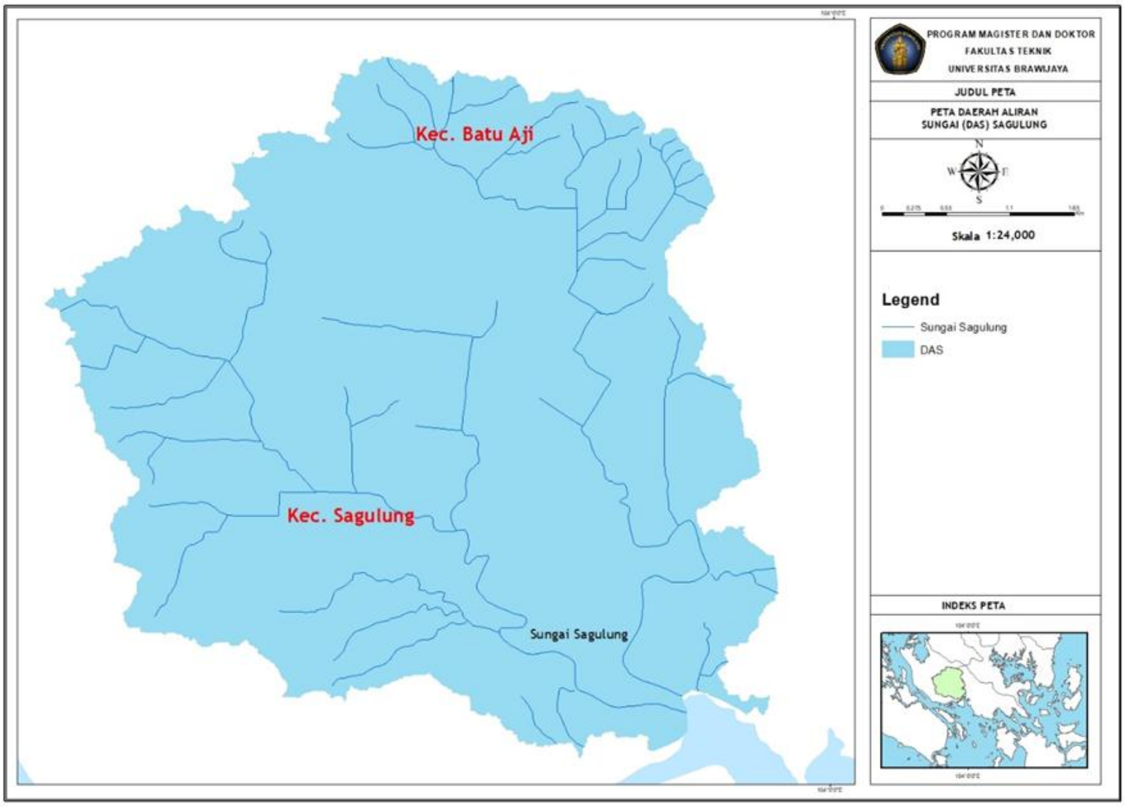


Fig.1. Map of study location

2.1. Soil Conservation Service (SCS)

The method of SCS is developed from the observation of rainfall during many years and it is involving many agricultural areas in the USA. This method makes an effort to integrate the watershed characteristics that are soil, vegetation, and land use by using the run-off curve number that indicates running water potency for the certain rainfall.

The method of CN is based on the relation between the infiltration on every type of soil and the amount of rainfall that is dropped on every rainfall. The total of rainfall that is dropped on every rainfall (P) above ground with the maximal potency of soil to hold water (S), will be divided into three components that are running water (Q), infiltration (F), and initial abstraction (Ia) with the formula as follow:

$$Q = \frac{(P-I_a)^2}{(P-I_a+S)} \quad \text{.......................................}(1)$$

where:

Q = volume of surface run-off (mm)

Ia= initial abstraction

P= daily rainfall (mm)

S = volume of surface saving total (mm)

To determine the depth excess rainfall or the surface run-off, can be formulated with the formula above which the correlation value of Ia and S ia as follow [7]:

$I_a = 0,2\ S$ (2)

To facilitate the analysis of antecedent moisture condition, land use, and soil conservation, the US SCS determines the S as follow:

$$S = 25,4\left(\frac{1000}{CN} - 10\right) \quad (3)$$

Where CN is curve number of running water with the range from 0 until 100.

By plotting the value of P and Q on the SCS curve, so the value of CN can be determined. The method of SCS classifies the soil type into 4 types that is known as hydrology soil group. The initial abstraction (Ia) usually uses the approach of 0.2 S, so the formula becomes as follow:

$$Q = \frac{(P-0,2S)^2}{(P+0,8S)} \quad (4)$$

2.2. Hydrological Model of HMS

The US Army Corp of Engineers has developed the Hydrological Engineering Center-Hydrologic Modeling System (HEC-HMS). HEC-HMS is as a hydrological model that can simulate the flood magnitude spatially in the watershed scale. The HEC-HMS adopted the work principle of SCS-CN model for analyzing the direct run-off [8]. To illustrate the flow through the channel or river, it is illustrated through the reach, The formulation of SCS-CN is as follow [7,8]:

$$\frac{F_a}{S} = \frac{P_a}{P-I_a} \quad (5)$$

$$P = P_e + I_a + F_a \quad (6)$$

$$P_e = \frac{(P-I_a)^2}{P-I_a+S}$$

Where $I_a = 0.2S$ (7)

$$P_e = \frac{(P-0.2S)^2}{P+0.8S} \quad (8)$$

$$S = 25.4\left(\frac{1000}{CN} - 10\right) \quad (9)$$

where:

P = total of rainfall, Ia = initial abstraction, S = retention capacity that is influenced by Curve Number (CN) and the CN is range from 0 to 100.

3. RESULTS AND DISCUSSION

The yearly rainfall data in the station of BMKG Hang, Nadin (Batam city) is presented as in the Table 1 and the result of consistency test is presented as in the Table 2.

Table 1. Yearly rainfall data in the rainfall station of BMKG Hang Nadim-Batam city

Year	R_{yearly} (mm)	Year	R_{yearly} (mm)
2003	2,552.80	2011	2,921.80
2004	2,066.90	2012	345.60
2005	2,280.60	2013	549.60
2006	2,965.50	2014	1,875.50
2007	2,960.60	2015	1,875.50
2008	2,471.10	2016	1,883.50
2009	1,976.50	2017	2,587.10
2010	2,058.00	2018	1,204.80

Source: own study (2019)

Table 2. Test of RAPS on the rainfall station of BMKG Hang Nadim-Batam city

No.	Year	Yi	$Yi – Y_{mean}$	$(Yi – Y_{mean})^2$	Sk*	Sk** = Sk*/Dy
1	2003	2,552.80	516.84	267,121.00	516.84	0.68
2	2004	2,066.90	30.94	957.13	547.77	0.72
3	2005	2,280.60	244.64	59,847.51	792.41	1.05
4	2006	2,965.50	929.54	864,039.96	1,721.95	2.28
5	2007	2,960.60	924.64	854,954.51	2,646.59	3.50
6	2008	2,471.10	435.14	189,344.64	3,081.73	4.07
7	2009	1,976.50	-59.46	3,535.79	3,022.26	3.99
8	2010	2,058.00	22.04	485.65	3,044.30	4.02
9	2011	2,921.80	885.84	784,708.08	3,930.14	5.19
10	2012	345.60	-1690.36	2,857,325.38	2,239.78	2.96
11	2013	549.60	-1486.36	2,209,273.48	753.41	1.00
12	2014	1,875.50	-160.46	25,748.21	592.95	0.78
13	2015	1,875.50	-160.46	25,748.21	432.49	0.57
14	2016	1,883.50	-152.46	23,244.81	280.03	0.37

Asian Journal of Applied Science and Technology (AJAST)
(Peer Reviewed Quarterly International Journal) Volume 3, Issue 2, Pages 105-115, April -June 2019

No.	Year	Yi	Yi – Y_{mean}	$(Yi – Y_{mean})^2$	Sk*	Sk** = Sk*/Dy
15	2017	2,587.10	551.14	303,752.54	831.16	1.10
16	2018	1,204.80	-831.16	690,831.10	0.00	0.00
Total		32,575.40		9,160,918.02		
Mean (Ymean)		2,035.96				
Dy		756.68				

Source: own study (2019)

Based on the analysis as above, then it is found the value of Q and R. The value of Q is as the statistical value that is as the maximum of │S**k│.However, the value of R is Δ from the maximal value of S**k with the minimum value is S**k.

$$Q = Maks\ |S**k| = 5.19$$

$$\frac{Q}{\sqrt{n}} = 1.298$$

$$R = Maks\ |S**k| - Min\ |S**k| = 5.19$$

$$\frac{R}{\sqrt{n}} = 1.298$$

Then the value of $\frac{Q}{\sqrt{n}}$ and $\frac{R}{\sqrt{n}}$ is compared with the conditional value as presented in the Table 3.

Table 3. Conditional value of RAPS test

n	$Q/\sqrt{n}$			$R/\sqrt{n}$		
	90%	95%	99%	90%	95%	99%
10	1.05	1.14	1.29	1.21	1.28	1.38
20	1.10	1.22	1.42	1.34	1.43	1.60
30	1.12	1.24	1.46	1.40	1.50	1.70
40	1.13	1.26	1.50	1.42	1.53	1.74
50	1.14	1.27	1.52	1.44	1.55	1.78
100	1.17	1.29	1.55	1.50	1.62	1.86
>100	1.22	1.36	1.63	1.62	1.75	2.00

Source: own study (2019)

By the value of $Q/\sqrt{n}_{calculated}$= 1.298 and the value of $R/\sqrt{n}$ calculated = 1.298, so the level of significant of data that is evaluated is assumed consistent with the level of significant of 90%.

3.1. Model of HEC-HMS

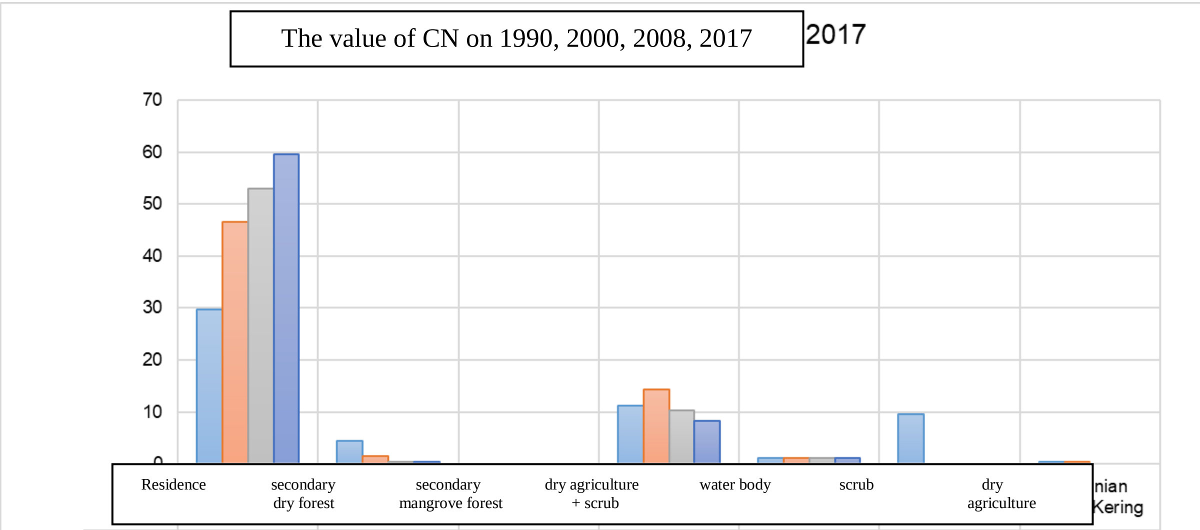
The model of HEC-HMS is used for analyzing the design flood in the control point and eraly warning system which will be developed. Data that is needed is the rainfall hyetograph, so it is needed the automatic rainfall recorder. The topography map is also needed for determining the inundation area in every level, location of weir structure, and dodger channel. Map or the GIS data is needed for determining the parameter of watershed such as area, slope, and the other parameters. The HEC-HMS is software that is developed by US Army corps of Engineering. This software is used for analyzing hydrology by simulating the process of rainfall and run-off of a river region.

In this research, the Sagulung watershed is divided into 4 sub-watersheds. The data of 4 sub-watersheds is presented as in the Table 4.

Table 4. Property of Sagulung sub-watershed

Location	Area (km^2)	The longest length of river (km)
Sub-watershed 1	3.71	3.578
Sub-watershed 2	4.86	5.361
Sub-watershed 3	5.59	3.13
Sub-watershed 4	10.26	6.656

Source: own study (2019)



CN 1990	29.738	4.407	0	11.198	1.044	9.458	0.378
CN 2000	46.506	1.46	0	14.345	1.044	0	0.378
CN 2008	52.929	0.324	0	10.209	1.0438	0	0
CN 2017	59.58	0.324	0	8.231	1.044	0	0

Fig. 2. The total value of CN in the Sagulung watershed on 1990, 2000, 2008, and 2017

Source: pwn study (2019)

Based on the analysis by using SIG [9], it is obtained the land cover of Sagulung watershed on 1990 which is dominated by residence (35%) and the value of CN is 56.224. On 2000, there is land cover area change such as scrub which is 4.81 km^2 becomes as residential area, so the residential area is increasing into 13.35 km^2 or 55% of Sagulung watershed area on 2000 and the value of CN is 63.735,

The analysis result of land cover on 2008 shows that the residential area reaches 62% of Sagulung watershed area, the dry agricultural area is decreasing 6%, and the value of CN on 2008 is 64.506. However, the analysis result of land cover on 2017 shows that the residential area in Sagulung watershed reaches 70% of thw watershed area that is 17.11 km^2, the dry agricultural area is decreasing 2%, and the value of CN on 2017 is 69.179. The changes can be seen in the Figure 2.

3.2. Analysis of design flood change by using the HEC-HMS

Modeling by using the HEC-HMS can produce the peak flow [10] from each model that is carried out in the outlet of Sagulung watershed. For the modeling based on the land cover of Sagulung watershed on 1999, the value of CN is 56.224 and the result of peak flow (design flood). Q_{25} and Q_{50} are 113.4 m^3/s and 179.5 m^3/s.

Based on the result of modeling by using HEC-HMS, it is obtained the hydrograph for each scenario. The land cover change from 1990 to 2017 causes the big enough change of the CN value that is from 56.224 into 69.179. Therefore, the design flood is also changed from 113.4 m^3/s and 179.5 m^3/s into 199.1 m^3/s and 286.9 m^3/s. The recapitulation of design flood is presented as in the Table 5.

Table 5. Recapitulation of design flood (Q_{25} and Q_{50})

No	Design flood	Year (m^3/s)			
		1990	2000	2008	2017
1	Q_{25}	113.4	160.6	165.9	199.1
2	Q_{50}	179.5	240.9	247.3	286.9

Source: own study (2019)

3.3. Running Result of HEC-RAS

The running process of HEC-RAS 4.10 indicates that there is run-off happened in some Sagulung river sections due to the design flood of Q_{25} and Q_{50} on 1990, 2000, 2008, and 2017. The run-off is fitted with the field condition where every year is happened the river run-off due to the rainfall that is happened in the location and it can be seen on the documentation illustration of flood condition in Sagulung on 2016.

To know the effect of land use change that are happened on 1990, 2000, 2008, and 2017 due to the simulation result of HEC-RAS 4.1.0 on the river section STA +150 (River Station 79) with the input of Q_{25} and Q_{50} and on the river section STA 0+150 (River Station 79) due to the simulation result of HEC-RAS, there is the increasing of water level elevation on each year due to the Q_{25} and Q_{50}. However, all of simulation results can be seen on the Table 6 and 7.

Table 6. Simulation result of HEC-RAS on the STA +150 each year due to the Q_{25}

STA	Profile	Q Total	Min Ch El	W.S. Elev	E.G. Elev	E.G. Slope	Vel Chnl	Froude
		(m3/s)	(m)	(m)	(m)	(m/m)	(m/s)	
0+150	Q25 Th 1990	113.4	3.11	5.7011	5.95	0.00147	2.19	0.47
0+150	Q25 Th 2000	160.6	3.11	6.1902	6.52	0.00160	2.54	0.5
0+150	Q25 Th 2008	165.9	3.11	6.2377	6.57	0.00160	2.57	0.5
0+150	Q25 Th 2012	166.1	3.11	6.2395	6.58	0.00160	2.57	0.5
0+150	Q25 Th 2017	199.1	3.11	6.5435	6.89	0.00150	2.65	0.49

Source: own study (2019)

Table 7. Simulation result of HEC-RAS on the STA +150 each year due to the Q_{50}

STA	Profile	Q Total	Min Ch El	W.S. Elev	E.G. Elev	E.G. Slope	Vel Chnl	Froude
		(m3/s)	(m)	(m)	(m)	(m/m)	(m/s)	
0+150	Q50 Th 1990	179.5	3.11	6.3725	6.71	0.00156	2.61	0.49
0+150	Q50 Th 2000	240.9	3.11	6.8639	7.16	0.00126	2.57	0.45
0+150	Q50 Th 2008	247.3	3.11	6.9163	7.2	0.00121	2.56	0.45
0+150	Q50 Th 2017	286.9	3.11	7.2274	7.47	0.00099	2.45	0.41

Source: own study (2019)

3.4. Analysis of flooding/ inundation distribution

The analysis if inundation distribution is obtained based on the simulation result from the HEC-RAS program due to the Q_{25} and Q_{50} on 1990, 2000, 2008, and 2012. Then, the simulation result of HEC-RAS is overlaid to the

Google earth program for knowing the flooding/ inundation area in Sagulung watershed. The flooding/ inundation area due to the Q_{25} and Q_{50} are presented as in the Table 8.

Table 8. The flooding/ inundation area due to the Q_{25} and Q_{50}

Year	Inundation area (km^2)	
	Q_{25}	Q_{50}
1990	0.35	0.50
2000	0.37	0.50
2008	0.44	0.53
2017	0.50	0.60

Source: own study (2019)

Figure 3 presents the inundation area in the Sagulung watershed due to the Q_{25} and Q_{50} on 2017.

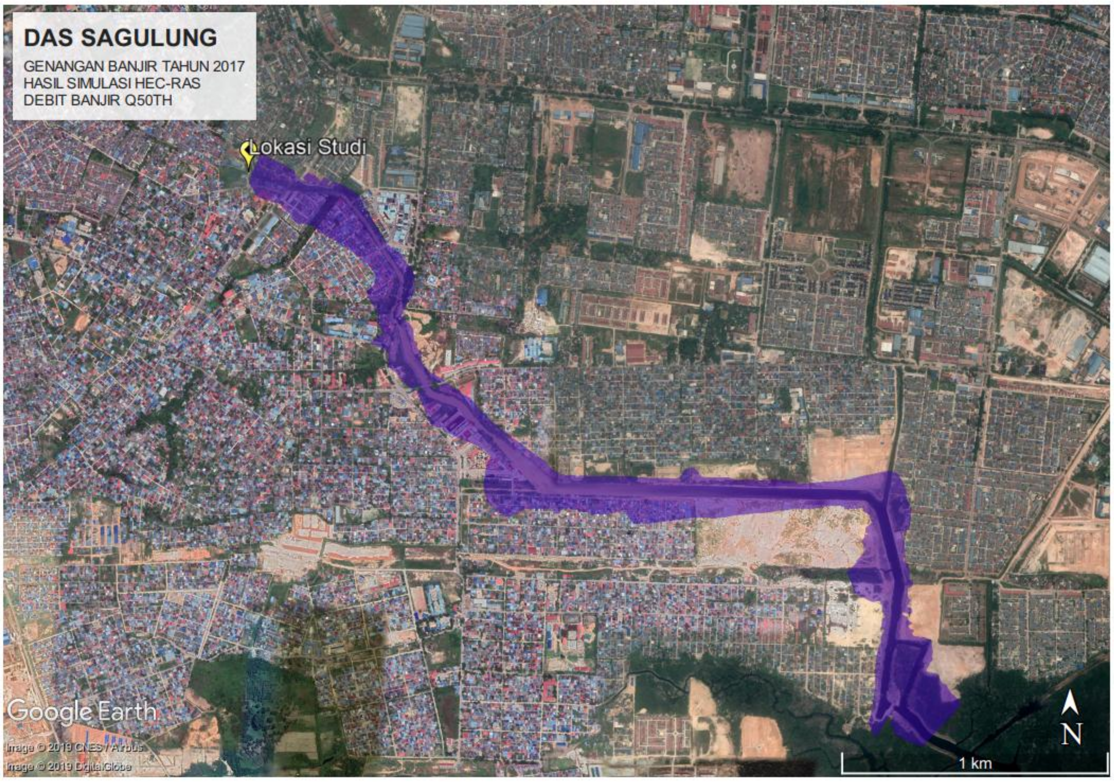


Fig. 3. Flooding/ inundation distribution on 2017 due to the Q_{25} and Q_{50}

Source: own study (2019)

3.5. The analysis result of land use change effect to the flood magnitude

Based on the analysis that has been carried out, the land use change on 1990, 2000, 2008, and 2017 in the Sagulung watershed, can be identified as follow:

a. The land cover in the Sagulung watershed on 1990 has been dominated by residence area that is 35% and the value of CN is 56.221

b. On 2000, the scrub that has the area of 4.81 km^2 on 1990 is switch functioned into residential area, so on 2000 the residential area becomes as 13.35 km^2 or 55% of watershed area and the value of CN is 63.735.

c. On 2008, the residential area in the Sagulung watershed reaches 62% of watershed area. The dry agricultural area is decreasing in amount of 6% and the value of CN is 64.506.
d. On 2017, the residential area reaches 70% of Sagulung watershed area, so there is leaving about 30$ for agriculture, forest, and water body. The value of CN is 69.179.

The modeling by using HEC-RAS is carried out on 1999, 2000, 2008, and 2017. The modeling is carried out by attending the area change every year. The design flood that is analyzed by using HEC-RAS is for the return periods of 25 and 50 years. However, the modeling result by using HEC-HMS can show the peak flow of each model that is carried out on the outlet of Sagulung watershed as follow:

a. For the modeling based on the land cover on 1990 with the CN = 56.224, it is produced the peak flow for the return periods of 25 years and 50 years each in amount of 113,4 m^3/s and 179.5 m^3/s
b. The land cover on 2000 has the CN of 63.735%. Based on the modeling result, the peak flow due to the return period of 25 years is 160.6 m^3/s, however for the return period of 50 years is in amount of 240.9 m^3/s.
c. Then, for the land cover on 2008, it has the CN of 64.506%. Based on the modeling result, the peak flow for the return period of 25 years is 165.9 m^3/s and for the return period of 50 years is 247.3 m^3/s.
d. On 2017, the land caver change causes the value change of CN. The value of CN on 2017 is 69.179%. Due to the value change of CN, it is produced the peak flow for the return period of 25 and 50 years each in amount of 199.1 m^3/s and 286,9 m^3/s.
e. Based on the modeling result by using HEC-HMS, it is obtained the each hydrograph for every scenario. The lands cover change on 1990 until 2017 causes the big enough value change of CN that is from 56.221& into 69.179%. Therefore, the design flood (peak flow) due to the return periods of 25 and 50 years has changed each from 113.4 m^3/s into 179.5 m^3/s and 199.1 m^3/s into 286.9 m^3/s.

To know the flooding/ inundation distribution that is happened, it is carried out the hydraulics analysis by using the program of HEC-RAS due to the design flood Q_{25} and Q_{50} that is as the result of HEC-HMS on 1990, 2000, 2008, and 2017. The result is as presented in the Table 8. Based on the analysis above, there is obtained the relation between CN, design flood, and elevation of river water level. The bigger CN causes the highest design flood and in further the river water level elevation is higher. The land use change in the Sagulung watershed on 1990, 2000, 2008, and 2017 due to the design flood of Q_{25} and Q_{50} give the impact to the flooding/ inundation mainly for the switch function in the watershed upstream and the river section change in surrounding of residential area in the watershed downstream along the river riparian area, and the green opened space is decreasing that causes the high run-off. Based on the Figure 2 above, the land use change with the increasing of residential area from 1990 to 2017 that is from 8,54 km^2 on 1990 becomes as 17.11 km^2 on 2017 causes some locations along the Sagulung river riparian area is narrowed down due to the society residences. The river riparian area often uses by the society as the building footprint the infiltration area is decreasing that causes the big flooding.

4. CONCLUSION

Based on the analysis above, it can be concluded as follow:

1. There is happened the land use change in the Sagulung watershed on the observation year of 1990, 2000, 2008, and 2017. On 2017, the residential is increasing and reaches 70% of Saguling watershed area and only leaving 30% for the agriculture, forest, and water body with the value of CN is 69.179%.

2. Based on the modeling result by using HEC-HMS, it is obtained each hydrograph for every scenario. The land cover change from 1990 until 2017 causes the big enough value change of CN that is from 56.224% becomes as 69.179%. Therefore, the design flood of Q_{25} and Q_{50} are also change, each from 113.4 m^3/s into 179.5 m^3/s and 199.1 m^3/s into 286.9 m^3/s.

3. The land use change in the Sagulung watershed on 1990, 2000, 2008, and 2017 due to the design flood of Q_{25} and Q_{50} give the significant impact to the flooding/ inundation area.

4. Based on the analysis that has been carried out, there is obtained the relation between CN, design flood, and elevation of river water level. The bigger CN causes the highest design flood and in further the river water level elevation is higher.

REFERENCES

1. Mokhtari, E.H., Remini B., and Hamboudi S.A., 2016, Modelling of the rain-flow by hydrological modelling software system HEC-HMS – watershed's case of wadi Cheliff-Ghrib, Algeria, Journal of Water and Land Development, No. 30 p. 87–100. DOI 10.1515/jwld-2016-0025.
2. Limantara L.M., Harisuseno D.H., Dewi V.A.K., 2018, Modelling of rainfall intensity in a watershed: A case study in Amprong watershed, Kedungkandang, Malang, East Java of Indonesia, Journal of Water and Land Development, No. 38 p. 75–84. DOI: 10.2478/jwld-2018-0044
3. Limantara, L.M., 2009, Evaluation of roughness constant of river in synthetic unit hydrograph, World Applied Sciences Journal, Vol. 7(9) p. 1209–1211.
4. Romanowicz, R. and Beven, K., 1998, Dynamic real-time prediction of flood inundation probabilities, Hydrological Sciences Journal, Vol. 43(2), page 181-196, April 1998.
5. Juwono, P.T., Limantara, L.M., and Amrie, S., 2019, The effect of land use change to the depth and area of inundation in the Bang sub-watershed, Malang-Indonesia, International Journal of Geomate, Vol. 16 Issue 53, pp. 238-244
6. Beven, K. J. and Binley, A., 1992, The future of distributed models: model calibration and uncertainty prediction. Hydrol. Processes, 6, page 279-298.
7. Chow, V. T., Maidment, D. R., and Mays, L. W. 1988. Applied Hydrology. New York, U.S.A: Mc.Graw-Hill
8. Arnold, J.G. and Neitsch, F., 2005, SWAT2000: current capabilities and research opportunities in applied watershed modeling, Hydrol. Process, 19(3): 563-572
9. Aronoff, S., 1989, Geographic Information System; a management perspective, Ottawa: WDL, Publications
10. Hydrologic Engineering Center, 2010, HEC-RAS river analysis system, hydraulic reference manual, Version 4.1, January 2010, U. S. Army Cormps of Engineers: Davis, CA.