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Flood-Reduction Scenario Based on Land Use in Kedurus River Basin Using SWAT Hydrology Model

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Abstract: *The rapid growth population phenomenon has caused excessive land demand for residential and economic activity. Moreover, rapid urbanization also increases the contribution of land constraints. Land conversion from conservation to cultivation uses affects the surface runoff volume that leads to flooding. According to these problems, it is necessary to take steps to control floods in Kedurus Watershed. One of the proper urban development concepts is Water Sensitive City (WSC). The protection against floods in WSC can be accomplished using the land use arrangement to reduce the surface runoff. The aim of this research is to determine the proper land use scenario to reduce floods in Kedurus Watershed. In order to reach this aim, the writer uses sensitivity analysis to identify the proper land use scenario to be applied in the watershed and SWAT to select the best scenario. The efforts to reduce flood through the land use scenario (scenario 2) could reduce the flood volume by 44,320.32 m3 or 8.11% of the total volume of flood in the area. The average reduction of flood volume in each sub-basins is 12,92% and the highest number of reduction is 65,67% (sub-basin 22).*

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1. INTRODUCTION

Indonesia, as one of the developing countries, still faces big problems in the development of its cities. The urbanization that occurs in big cities has increased the need for housing, which is one of the basic human needs (Machyus, 2006). It has also increased land constraints and land conversions from unbuilt areas into built areas (Masitoh, Ma'rif, & Rudiarto, 2002). The impact of land conversion from the unbuilt area to be residential, especially in the catchment area, has increased the volume of surface runoff. The land conversion in the entire sub-basin has contributed to a 9.84% increase in water volume and a 4.13% increase in peak discharge volume. On the contrary, by doing conservation in the sub-basin, the water volume will be decreased by 10.7%, and the peak discharge rate will also decrease by 5.67% (Aryanto, 2010).

Recent studies discuss disaster mitigation scenarios dan intervention reducing the disaster's impact (Garschagen, 2017; Mertens et al., 2018; Peters et al., 2019; Rahmawati et al., 2016; Schryen & Wex, 2014; Waghwala & Agnihotri, 2019). Floods are a common disaster in high-density cities caused by a combination of human activities and climate change. Therefore, flooding is one of the problems in cities with a high level of urbanization in Indonesia such as Surabaya.

Surabaya, as the core urban area of Gerbangkertosusila, has a high urbanization rate. Based on the Central Bureau of Statistics, in 2014, Surabaya had a total population of 67,416, and it increased by 3.64% from the previous year. The high rate of urbanization and economic growth in Surabaya has increased land demands. The additional land for residential from 2001 to 2015 was recorded at 4,556.16 ha (37.2%) (Zulkarnain, 2016).

Kedurus River has upstream in Gresik Regency and downstream in Surabaya City. The area around the Kedurus River often experiences flood when the rainy season comes. In 2016, in Driyorejo, the flood had reached 70 cm in height and be the worst flood in Gresik Regency (Perdana, 2016). Meanwhile, in Surabaya, the worst floods have occurred in Wiyung District. The flood has reached 1 m in height (Sugiharto, 2016). The flood caused by Kedurus River has inundated a more than 100 ha area (Development Planning Agency of Surabaya City, 2014). According to RTRW Surabaya 2014-2034, medium density residential area will be developed in Wiyung District. In addition, the urban settlement will also be developed in Driyorejo District. With the current flood problems, while the city's growth continues, it is necessary to reduce flooding in Kedurus river basin.

One of the urban planning concepts that support flood controlling is Water Sensitive City. Water Sensitive City is a concept that prioritizes the sustainability of water resources in a city. The best urban water management and planning are considered capable of protecting and sustaining the benefits and services of water cycles heavily influenced by the community, including flood protection. In WSC, flood protection can be achieved with land use management that reduces surface runoff (Wong & Brown, 2009). Therefore, this study aims to determine the most appropriate land use scenario in reducing floods in Kedurus river basin.

2. DATA AND METHODS

In terms of methodology, we used SWAT model simulation to find out the boundary of the research area, including the hydrology model of Kedurus river basin. The data required in this stage were slope, soil types, rainfall data, relative humidity, temperature, wind speed, solar radiation, and land use types (Gibbs, 1987; Meteorology Climatology and Geophysical Agency, 2017; Rahayu et al., 2009; Triatmojo, 2014). Then we used sensitivity analysis to build potential scenarios applicable in Kedurus river basin and SWAT model simulation of the scenario that has been built. The data required in this research are the daily peak discharge rate of each sub-basins (Wong & Brown, 2009), and the volume of the flood of each sub-basins in Kedurus River Basin that has been obtained from the previous stage.

2.1. Identify the hydrology model of Kedurus river basin using SWAT hydrology model

To identify the hydrology model of Kedurus river basin, we used SWAT model simulation. The first stage was delineating the boundary of Kedurus river basin, then we defined the HRUs using the slope, soil, and land use data, then we generated the weather data, and the last we simulated the model for the year of 2016. More detailed explanations and research steps are published in previous journals.

2.2. Building potential land use scenario to be applied in Kedurus river basin

Scenarios are what may and/or can happen in the future presented in the form of descriptions of stories. Scenarios can be used to identify future alternatives and identify the steps that may cause them to arise (Ogilvy, 2015). We used sensitivity analysis to build the scenarios. Sensitivity analysis is an analysis that can be used to identify sensitive variables or variables that have a high influence on a model (Pannell, 1997).

There were several steps taken to build the potential land use scenarios applicable in the Kedurus river basin. The first stage was determining the parameters to identify the impacts of variable changes. In this research, the parameters used were the daily discharge peak rate in the flooded sub-basin. Then conducted the sensitivity analysis by doing simulation to the hydrology model of Kedurus river basin by changing the variable of land use by + 10% from its existing value to know the priorities of variable change that can be used to build the land use scenario. After the priority of land use change has been identified, then compared it with the existing regulation to find out the possible variable changes to be applied in Kedurus River Basin. The selected variable changes were then built into a scenario.

2.3. Identify the best land use scenario to reduce flooding in Kedurus river basin

The scenarios arranged in the previous stage were then simulated using the SWAT model to find out how many discharges were successfully reduced by the implementation of the scenario. The result of the simulation was then compared by the result of the first target simulation (the discharge rate of SWAT simulation before the implementation of the scenario) to know the difference of discharge rate simulated by the model and the channel capacity to find out how much flood volume occurred after the implementation of the scenario. If the scenario simulation results can overcome the flood, it can draw conclusions about the effective scenario to reduce floods. If the scenario simulation results cannot overcome the flood in the entire flooded sub-basins yet, a new scenario was formulated with a modification of one or more variable changes from the previous scenario.

3. RESULTS AND DISCUSSION

Kedurus river basin located in 112º33'40" LE - 112º43'30" LE, and 7º16'35' SL - 7º20'25" SL (Figure 1a). Based on SWAT simulation using DEM IFSAR 2013 map data input with cell size 3m x 3m, Kedurus river basin has an area of 7.270,10 ha and is divided into 27 sub-basins (Purwitaningsih & Pamungkas, 2017). Land use in Kedurus river basin consists of residential (high density), industry, trade and services, public facilities, paddy fields, row crop agricultural, plantations, green open space and water bodies (blue open space) (Figure 1b).

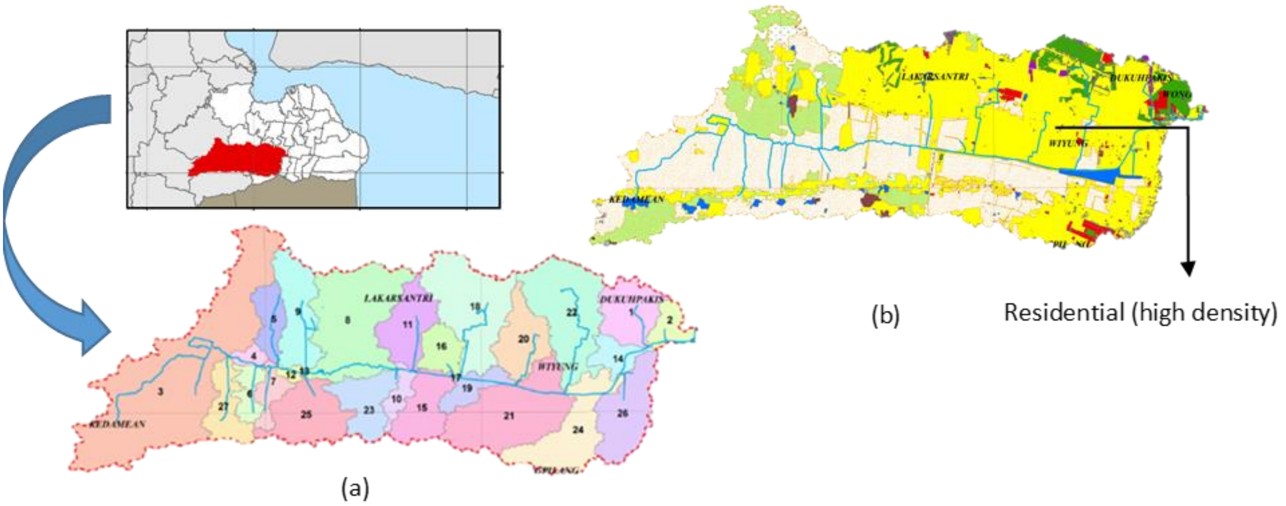

Figure 1. (a) Research area and (b) land use of Kedurus river basin (Purwitaningsih & Pamungkas, 2017)

The SWAT hydrology model simulation was performed after combining the watershed hydrological network, HRU data, and climate data together (Neitsch et al., 2005). The results of the SWAT model simulation were daily flow data and hydrological data of the Kedurus river basin during the simulation period within 1 year starting from January 1st 2016 until December 31st 2016. Based on the simulation results, the highest daily discharge rate in Kedurus river basin occurred in March 2016 and reached 15.59 m3/s, which in sub-basin 2. The daily average discharge was 0.41 m3/s (Purwitaningsih & Pamungkas, 2017) (Table 1).

The total flood volume in the Kedurus river was 546,797.53 m3, which occurred in 12 sub-basins, they were sub-basin 1, 2, 3, 5, 6, 8, 12, 13, 15, 22, 24, and 27. The following data bellow is the channel capacity and flood volume of each sub-basins of Kedurus river basin (Purwitaningsih & Pamungkas, 2017) (Table 2).

Table 1. Peak discharge rate in each sub-basins of Kedurus river basin (Purwitaningsih & Pamungkas, 2017)

Sub-basin	Peak discharge rate (m^3/s)	Sub-basin	Peak discharge rate (m^3/s)
1	0.66	15	7.84
2	15.59	16	0.33
3	2.54	17	8.15
4	3.01	18	1.43
5	0.27	19	9.37
6	0.21	20	0.72
7	3.43	21	14.72
8	6.21	22	1.31
9	0.56	23	0.51
10	6.91	24	13.58
11	0.58	25	0.69
12	3.74	26	0.83
13	4.43	27	0.40
14	14.72		

Table 2. Identification of Kedurus flooded sub-basin (Purwitaningsih & Pamungkas, 2017)

Sub-basin	Peak discharge rate (m^3/s)	Channel capacity (m^3/s)	Flood discharge (m^3/s)	Daily flood volume (m^3)
1	0.66	0.20	0.45	6,515.71
2	15.59	12.44	3.15	45,406.28
3	2.54	0.34	2.20	31,707.19
4	3.01	16.51	0.00	0.00
5	0.27	0.07	0.19	2,804.69
6	0.21	0.12	0.09	1,346.46
7	3.43	11.63	0.00	0.00
8	6.21	0.25	5.96	85,779.18
9	0.56	18.96	0.00	0.00
10	6.91	24.37	0.00	0.00
11	0.58	3.92	0.00	0.00
12	3.74	1.34	2.40	34,630.30
13	4.43	0.52	3.92	56,393.81
14	14.72	40.68	0.00	0.00
15	7.84	1.40	6.43	92,621.18
16	0.33	18.78	0.00	0.00
17	8.15	16.86	0.00	0.00
18	1.43	23.10	0.00	0.00
19	9.73	15.11	0.00	0.00
20	0.72	1.44	0.00	0.00
21	14.72	16.35	0.00	0.00
22	1.31	1.16	0.14	2,061.24
23	0.51	4.88	0.00	0.00
24	13.58	0.85	12.73	183,246.57
25	0.69	23.10	0.00	0.00
26	0.83	31.14	0.00	0.00
27	0.40	0.10	0.30	4,284.92
	TOTAL			546,797.53
Red cell means flooded sub basin				

3.1. Building potential land use scenario to be applied in Kedurus river basin

In building a potential land use scenario to be applied in the Kedurus river basin, the first step was identifying the variable changes that significantly affect the hydrology model of the Kedurus river basin. From the sensitivity analysis conducted before, 11 variable changes became a priority in the preparation of land use scenarios to reduce flooding in the Kedurus river basin (Table 3).

Not all priorities were used in developing land use scenarios. Choosing the appropriate variable changes was based on regulations in the study area (in this case were RTRW Kota Surabaya, RTRW Kabupaten Gresik, Regulation of Mayor of Surabaya, and Minister of Public Works Regulation No. 41), and based on the number of land use changes. After the justification, the selected variables were then organized into a scenario. This scenario then became in Scenario 1.

1. Changes in Types of Land Uses
   It is a change of one land use type to other land uses
   - Land type change 10% from the paddy field to green open space
   - Land type change 10% from row crop agricultural to green open space
   - Land type change 10% from row crop agricultural to blue open space
   - Land type change 10% from the paddy field to blue open space
   - Additional green open space 10% taken from the plantation or 14.6% change of plantation to green open space
2. Changes the portion of built-up area/green space area in a parcel land
   Changes in Floor Area Ratio or Green Area Ratio in built up areas.
   - Additional Green Area Ratio 10% in residential areas. The addition of GAR is done by increasing the green open space in residential areas.
   - Additional blue open space 10% in residential areas

Table 3. The priority of variable changes

Priority	Variable Changes	*Average of Discharge Rate Reduction (%)*
1	Additional Green Area Ratio 10% in the residential area	1.40
2	Land type change 10% from the paddy field to green open space	0.95
3	Land type change 10% from residential to blue open space	0.92
4	Additional paddy fields 10% from row crop agricultural	0.85
5	Additional paddy fields 10% from residential	0.65
6	Land type change 10% from row crop agricultural to green open space	0.61
7	Land type change 10% from row crop agricultural to blue open space	0.36
8	Land type change 10% from paddy fields to green open space	0.22
9	Additional green open space 10% from row crop agricultural	0.22
10	Additional green open space 10% from plantations	0.19
11	Land use type change 10% from plantations to green open space	0.13

3.2. Determine the best land use scenario to reduce flooding

The scenarios that had been established based on the sensitivity analysis were then tested to determine the appropriate land use scenarios in reducing flood seen from the decrease of flood volumes in the flooded sub-basin after scenario implementation. Scenario testing was done using SWAT model simulation.

Table 4. The simulation result of Scenario 1

Sub-basin	*Q_0 (m^3/s)*	*Q_1 (m^3/s)*	*Q_s (m^3/s)*	*Q_b (m^3/s)*	*V_0 (m^3/day)*	*V_1 (m^3/day)*	*ΔV (%)*
1	0.66	0.63	0.20	0.42	6,515.71	6,093.79	6.48
2	15.59	14.91	12.44	2.47	45,406.28	35,614.28	21.57
3	2.54	2.46	0.34	2.13	31,707.19	30,641.59	3.36
5	0.27	0.26	0.07	0.19	2,804.69	2,701.01	3.70
6	0.21	0.20	0.12	0.09	1,346.46	1,275.90	5.24
8	6.21	5.99	0.25	5.74	85,779.18	82,625.58	3.68
12	3.74	3.64	1.34	2.30	34,630.30	33,147.10	4.28
13	4.43	4.24	0.52	3.72	56,393.81	53,542.61	5.06
15	7.84	7.44	1.40	6.03	92,621.18	86,861.18	6.22
22	1.31	1.24	1.16	0.08	2,061.24	1,082.04	47.51
24	13.58	13.00	0.85	12.15	183,246.57	174,894.57	4.56
27	0.40	0.39	0.10	0.29	4,284.92	4,119.32	3.86
				TOTAL	546,797.53	512,598.97	-

The simulation results show that the implementation of Scenario 1 was still not able to overcome the flood. Implementation of Scenario 1 was only able to decrease the flood volume by 34,198.56 m3 (6.25%). The average decrease in flood volume of each flooded sub-basin is 9.63%, with the highest percentage of flood volume decrease was in sub-basin 22, (47.51%) (Table 4). Therefore, it is necessary to modify the scenario so that flooding problems in sub-catchments 1, 2, 3, 5, 6, 8, 12, 13, 15, 22, 24, and 27 can be solved.

The modifications of the scenario were done by increasing the percentage of variable changes in the flooded sub-basin according to the existing land uses.

1. Additional Green Area Ratio 20% in residential area in sub-basin 1, 8, 22, and 24.
2. Land type changes 20% from the paddy field to green open space in sub-basin 3, 6, 8, 12, 13, 15, and 27.
3. Land type changes 20% from the paddy field to blue open space in sub-basin 3, 6, 8, 12, 13, 15, and 27.
4. Land type changes 20% from row crop agricultural to green open space in sub-basin 3, 5, and 17.
5. Land type changes 20% from row crop agricultural to green open space in sub-basin 3, 5, and 17.

These scenario modifications then became Scenario 2.

Table 5. The simulation result of Scenario 2

Sub-basin	*Q_0 (m^3/s)*	*Q_1 (m^3/s)*	*Q_s (m^3/s)*	*Q_b (m^3/s)*	*V_0 (m^3/day)*	*V_1 (m^3/day)*	*ΔV (%)*
1	0.66	0.61	0.20	0.41	6,515.71	5,884.99	9.68
2	15.59	14.76	12.44	2.32	45,406.28	33,454.28	26.32
3	2.54	2.43	0.34	2.09	31,707.19	30,166.39	4.86
5	0.27	0.26	0.07	0.19	2,804.69	2,701.01	3.70
6	0.21	0.20	0.12	0.09	1,346.46	1,226.94	8.88
8	6.21	5.91	0.25	5.66	85,779.18	81,487.98	5.00
12	3.74	3.60	1.34	2.26	34,630.30	32,614.30	5.82
13	4.43	4.15	0.52	3.63	56,393.81	52,318.61	7.23
15	7.84	7.30	1.40	5.90	92,621.18	84,917.18	8.32
22	1.31	1.21	1.16	0.05	2,061.24	707.64	65.67
24	13.58	12.86	0.85	12.01	183,246.57	172,878.57	5.66
27	0.40	0.39	0.10	0.29	4,284.92	4,119.32	3.86
				TOTAL	546,797.53	502,477.21	

The result of the simulation of Scenario 2 shows that Scenario 2 also couldn't overcome the flood problem in Kedurus river basin. Scenario 2 was only able to reduce the flood volume by 44,320.32 m3 (8.11%). The average decrease in flood volume of each flooded sub-basin was 12.92%. with the highest percentage of flood volume decrease in sub-basin 22 (65.67%) (Table 5).

Table 6. The comparison between the implementation of Scenario 1 and Scenario 2

Sub-basin	*$ΔV_1$ (%)*	*$ΔV_2$ (%)*	*$ΔV_{1-2}$ (%)*
1	6.48	9.68	3.20
2	21.57	26.32	4.76
3	3.36	4.86	1.50
5	3.70	3.70	0.00
6	5.24	8.88	3.64
8	3.68	5.00	1.33
12	4.28	5.82	1.54
13	5.06	7.23	2.17
15	6.22	8.32	2.10
22	47.51	65.67	18.16
24	4.56	5.66	1.10
27	3.86	3.86	0.00
Average	9.63	12.92	3.29

The implementation of scenario 1 to scenario 2 still cannot solve the flood problem in the Kedurus river basin. Each scenario only contributes to the average decrease in flood volume in each sub-basin by 9.63% and 12.92% (Table 6). Of the 12 flooded sub-basins. sub-basin 22 experienced a significant increase in the percentage of the decrease of flood volume (18.16%). The implementation of scenarios that emphasize the addition of Green Area Ratio in residential areas had a significant effect on flood reduction in sub-basin 22. This is caused by the land use in sub-basin 22 is dominated by high-density residential. as well as the large presence of existing green open space. Thus the addition of GAR and blue open space in residential areas had a significant impact. In addition. the channel capacity in sub-basin 22 does not have a high disparity with the simulated discharge rate. so the existing flood volume was also relatively low.

In the sub-basin 1. after the implementation of Scenario 2 that emphasized the addition of GAR in the residential area was only able to increase the decrease of flood volume by 3.20%. The channel capacity at the measurement point at sub-basin 1 is relatively small and only had a channel capacity of 0.20 m3/s. while the simulated discharge rate is 0.66 m3/s. There's no scenario modification implemented in sub-basin 2. but there was an increase in the decrease of flood volume by 4.76%. Sub-basin 2 is located at the downstream of the river. therefore it can be seen that the flood occurred or the hydrological conditions presented in the sub-basin 2 were influenced by the upstream sub-basins.

In sub-basin 3. which is dominated by paddy field and row crop agricultural land use type. the implementation of Scenario 2 was only able to increase the decrease of flood volume by 1.50%. The reason behind this was the small channel capacity. which is only 0.34 m3/s. meanwhile. the simulated discharge in sub-basin 3 was 2.54 m3/s. The implementation of Scenario 1 and Scenario 2 in sub-basin 5 did not have any effect on the flood volume. Therefore. more technical flood reduction efforts are required in sub-basin 5.

In sub-basin 8. the implementation of Scenario 2 was only able to increase the decrease of flood volume by 1.33%. The reason was the small channel capacity. which is only 0.25 m3/s. meanwhile. the simulated discharge in sub-basin 8 is 6.21 m3/s. In sub-basin 12. the implementation of Scenario 2 was only able to increase the decrease of flood volume only by 1.54%. This is partly due to the small area of sub-basin so the implementation of land use scenarios also didn't have an insignificant impact.

Similar to sub-basin 12. the implementation of Scenario 2 in sub-basin 13 was only able to increase the decrease of flood volume percentage by 2.17%. The area of the sub-basin was small. and the channel capacity in sub-basin 13 was also small. The channel capacity was only 0.52 m3/s. meanwhile. the simulated discharge rate was 4.43 m3/s. In sub-catchment 15. the implementation of Scenario 2 was only able to increase the decrease of flood volume percentage by 2.10%. This was due to the too small channel capacity in sub-basin 15. which had a discharge rate of 7.84 m3/s had a channel capacity of 1.40 m3/s.

Implementation of Scenario 2 in sub-basin 24 was only able to increase the decrease in flood volume percentage by 1.10%. The channel capacity in sub-basin 24 was too small to accommodate the discharge rate of 13.58 m3/s (it's only 0.85 m3/s). Meanwhile. the implementation of Scenario 1 and Scenario 2 in sub-basin 27 did not have any effect on the flood volume.

From the discussion. it can be seen that the flood reduction efforts through land use arrangements can effectively reduce flood volumes in river basin/sub-basin that have dominant land use in the form of high-density residential. and have sufficient channel capacity. Meanwhile. the implementation of the land use scenario has not been able to reduce flooding across the Kedurus river basin. Therefore. there should be more technical and management flood reduction efforts.

4. CONCLUSION

The addition of Green Area Ratio in the built-up area has the highest impact compared to other land use changes in reducing flooding. Therefore. the addition of GAR is the key to land use arrangements. Land use scenarios can be effective if applied in a river basin/sub-basin that has dominant land use in the form of high-density residential. and also has sufficient channel capacity. In addition. we still need the other flood reducing efforts. which are technically relevant. In the future. it is hoped that there will be a collaboration between the implementation of land use scenarios to reduce flooding and other efforts so that the flood problem in Kedurus river basin can be solved thoroughly.

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