Evaluation of spatial plan in controlling stream flow rate in Wakung Watershed, Pemalang, Central Java, Indonesia

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Abstract. Evaluation study for such a regional spatial plan (RTRW) in Indonesia has not been evaluated for its effectiveness in controlling the surface run off that contributed to streamflow. This necessity can be accomplishsed by applying a modeling approach, such as Soil Water Assessment Tool (SWAT). The objectives of this research are 1) to simulate the streamflow of Wakung watershed based on actual landuse, 2) to predict streamflow of Wakung watershed based on RTRW, and 3) to evaluate the effectiveness of the RTRW of Pemalang District in controling streamflow rate at Wakung Watershed. ArcSWAT model was used to determine the erosion rate prediction. The model was then calibrated by using SWATCUP. Model performance were tested by using R^2 and E_{NS}. The calibration and validation results showed that R^2 and E_{NS} (monthly) > 0.5. The result of SWAT simulation in Wakung sub-watershed reaching 161 - 4950 m^3/s/years for W-A scenario (actual landuse and weather data of 2013), for scenario W-R (RTRW and weather data of 2013), 330 – 4919 m^3/s/year. The comparison between actual and spatial plan land use data for stream flow is showing that the W-A scenario is lower than the W-R scenario in 19 sub watersheds. This is because there are many plans for adding land use for urban and intensive horticulture land in areas with steep slopes (> 25%). This condition is caused by the demands of fulfilling the needs of settlement and food for people in the Wakung watershed.

1. Introduction

The Watershed Management Plan can't be implemented optimally, as watershed planning compiled by the Watershed Management Bureau (BPDAS) must be supplemented by the District/City Spatial Plan (RTRW). The challenge is that the watershed area is not always coincident with the administrative area so as to allow synergies between agencies cannot run harmoniously and produce no real technical action [19]. For example, making a grand design of a watershed can have a different direction of environmental function with a land allocation, which is arranged in the Regional Spatial Plan (RTRW). Therefore, the evaluation of the suitability of the regional functions in the RTRW and the watershed functions is necessary to be studied.

Mismatching land use allocation with watershed functions may result in a decrease in watershed support capacity [17]. The decreases are characterized by flood, landslide, erosion, sedimentation and drought. Adjustment of the spatial plan covering the watershed should consider the environmental carrying capacity [17] [22]. Conditions like this occur in the Wakung watershed.

Wakung watershed is a part of the Comal watershed system that falls into the priority watershed (critical) category since the start of the current decision [11] [12] [13] [14]. Although many techniques of conservation have been conducted in the Comal watershed but still cannot reduce the criticality of the watershed. This matter is critical of Wakung watershed not only because of the human factor and also physical factor of the watershed, which naturally is vulnerable to experience criticality.

In implementing spatial planning in watershed priority needs monitoring and evaluation [13]. Monitoring and evaluation conducted for streamflow data. One of the streamflow monitoring techniques usually uses the model because of limited resources and available funds. One of the model for predicting streamflow is the Soil and Water Assessment Tool (SWAT). SWAT is a model developed by the United States Department of Agriculture [3] [7], it is an effective tool to model streamflow in a variety of watersheds [5] [8] [10] [16] [22] [23].

The objective of the study is to simulated and predicted of Wakung watershed based on actual and spatial plan land use. Result of this simulation is intended to see streamflow changes. These changes can provide an overview to evaluate the effectiveness of spatial plan of Pemalang District in controlling streamflow rate at Wakung watershed.

2. Methods and Material

2.1 SWAT model description

ArcSWAT (Arc GIS Soil and Water Assessment Tool) is a software based on ArcGIS geographic information system (GIS) as an additional extension of ArcGIS software based on GUI (Graphical User Interface) by using SWAT model (Soil and Water Assessment Tool) [2] [15]. This program is issued by the Texas Water Resource Institute, College Station, Texas, USA. SWAT is designed to predict the effect of land management for streamflow, erosion, sedimentation, and pollution in a complex relationship to a watershed including land type, land use, planting calendar or land management. For modeling purposes, the ArcSWAT program makes users easy to divide the watershed into several sub-basins and the HRUs (Hydrological Response Units) [2]. HRUs describe spatial heterogeneity in terms of land cover, soil type and slope within a watershed.

SWAT offers two methods for estimating surface runoff: The Soil Conservation Service (SCS) Curve Number (CN) procedure and the Green and Ampt infiltration method [15]. Using daily or sub-daily rainfall amounts, SWAT simulates surface runoff, volumes and peak runoff, rates for each HRU [15]. In this study, the SCS curve number method was used to estimate surface runoff volumes because of the unavailability of sub-daily data for the Green and Ampt method.

2.2 Preparation and model input

SWAT is a comprehensive model that requires diverse information in the process of running. Input required in SWAT model is land use (actual and based on spatial plan), digital elevation model (DEM), soil characteristics, climate (precipitation, temperature, solar radiation, wind speed and relative humidity), and cropping calendar. The availability of data input will influence the results of research, more complete of sustainable data input such as climatology data will provide simulation results that are almost close to reality in the field.

The DEM data input is derived from topographic map (scale 1: 25.000), while the existing land use input is derived from the interpretation and field check of the image from google earth and land use based on spatial plan using spatial plan (RTRW) map Pemalang District. Soil input in the Wakung watershed is derived from landform (figure 1), due to the unavailability of detailed soil data in the Wakung watershed. All three inputs above are the main inputs as the formation of unit analysis or known as hydrologic response units (HRUs). The availability of climate data in the Wakung watershed is only rainfall data, so other climate data use climate data from the global weather already provided by SWAT.

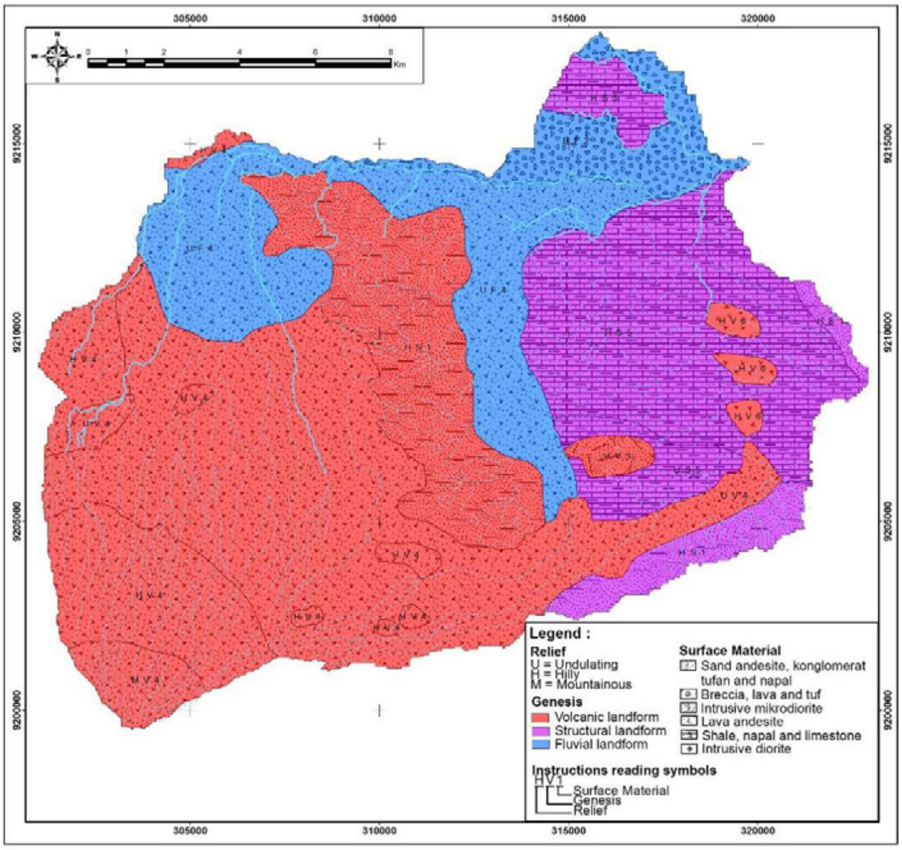


Figure 1. Landform of Wakung Watershed.

2.3 Scenario running model

SWAT scenario running model to predict the rate of streamflow in Wakung watershed consists of two scenarios; (1) running SWAT model based on actual land use (W-A) (2) running SWAT model based on land use based on spatial plan (RTRW) (W-R). Limitations of climate data in the Wakung watershed make the model unable to make predictions with a homemade weather generator (WGN), so running model only uses actual climate (2013 climate date).

2.4 Model calibration and validation

The calibration process was using SWAT-CUP software (Soil and Water Assessment Tool-Calibration and Uncertainty Programs). Model calibration performed by comparing daily streamflow of Sub watershed out from Nambo dam outlet, with SWAT simulation result from June 2009 to May 2010. While validation use daily streamflow data June 2012 - May 2013.

Statistical analysis used in calibration and validation using coefficient of determination (R^2) and Nash-Sutcliffe coefficient of Efficiency (NSE). R^2 and NSE values ranged from 0 to 1. The values of R^2 and NSE close to 1 indicate a close relationship between the simulated data and the observed data. The equations R^2 and NSE are determined by equation 1 and 2.

$$R^2 = \frac{[\sum_i^n (Q_{Obs,i} - \overline{Q}_{Obs,i})\,(Q_{Cal,i} - \overline{Q}_{Cal,i})^2]}{\sum((Q_{Obs,i} - \overline{Q}_{Obs,i}))^2 \sum((Q_{Cal,i} - \overline{Q}_{Cal,i}))^2} \quad (1)$$

$$NSE = 1 - \left(\frac{\sum_{i=1}^{n}\left(Q_{Obs,i} - Q_{Cal,i}\right)^2}{\sum_{i=1}^{n}\left(Q_{Obs,i} - \overline{Q}_{Cal,i}\right)^2}\right) \quad (2)$$

Description:
$Q_{Obs,i}$ / O_i = streamflow observation (m^3/s)
$Q_{Cal,i}$ / P_i = streamflow simulation (m^3/s)
$\overline{Q}_{Obs,i}$ = average of streamflow observation (m^3/s)
$\overline{Q}_{Cal,i}$ = average of streamflow simulation (m^3/s)

Classified the results of the NSE-based simulation into 5 groups [6] as in Table 1.

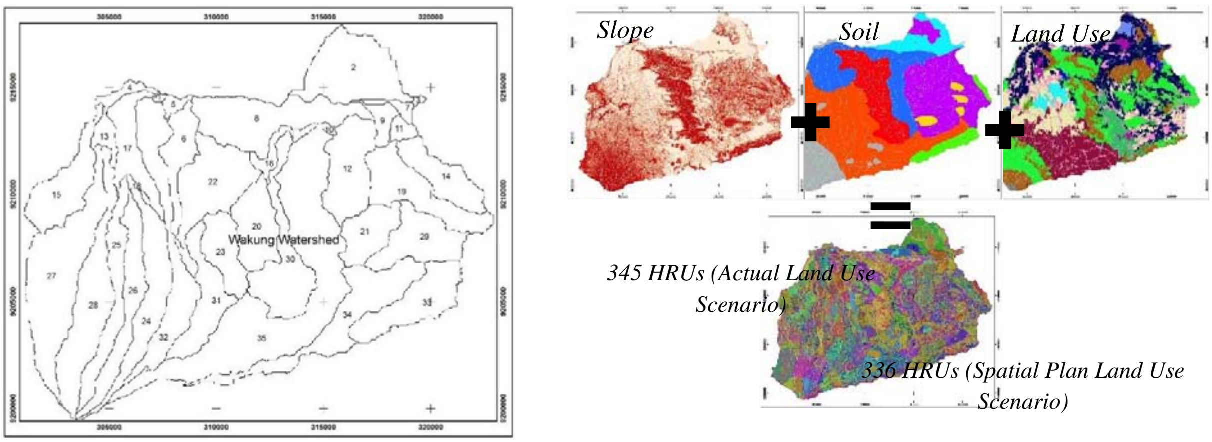
Table 1. Statistical criterion of NSE.

No	Statistical criterion	NSE
1	Very good	0.75 ≤ NSE ≥ 1.00
2	Good	0.65 ≤ NSE ≥ 0.75
3	Satisfactory	0.50 ≤ NSE ≥ 0.65
4	Acceptable	0.40 ≤ NSE ≥ 0.50
5	Un-satisfactory	NSE ≥ 0.40

3. Result and Discussion

3.1. Unit analysis of SWAT model

The SWAT model divides the watershed into sub-watersheds and HRUs as the unit of analysis. Based on the SWAT analysis Wakung Watershed divided into s35 sub-watersheds shown in figure 2 (a), 345 HRUs based on actual land use and 336 HRUs based on spatial plan (RTRW) land use. HRUs are the result of SWAT model by overlaying land use, soil and slope maps in figure 2 (b). The HRUs for the Wakung Watershed have been generalized with the value thresholds of land use, soil and slopes are 25 Ha (Scale 1: 100,000).



(a) (b)

Figure 2. (a) Sub-watershed of Wakung Watershed and (b) HRUs of Wakung Watershed.

3.2. Calibration and validation of SWAT Model

3.2.1. Parameter Sensitivity Test. During SWAT Model simulation, some parameters are enhanced through calibration process automatically with SUFI-2 (SWAT CUP). The results of the SUFI-2 algorithm are used to determine the fit value of each parameter and how sensitive each parameter. The parameter sensitivity is used as the key parameter of whether the parameter is sufficiently influential to the streamflow, if the parameter is altered the fit-value and parameter sensitivity in the Wakung Watershed uses simulated streamflow comparison with the daily short-observation streamflow from the Nambo dam June 2009 - May 2010, due to limited availability of streamflow data in the Wakung watershed. Based on the results of the running algorithm SUFI-2 (SWAT CUP) with 100 iterations can be obtained the value of fitted-value parameter as in table 2.

Table 2. Fitted, Minimum, Maximum and Sensitivity Value of Streamflow in Wakung Watershed.

Parameter_Name	*Fitted Value*	*Min value*	*Max value*	*t – Stat*	*P - value*
CN2.mgt	0.12	0	2	-1.04	0.30
ALPHA_BF.gw	0.59	0	1	-0.23	0.82
GW_DELAY.gw	29.54	20	120	0.84	0.40
GWQMN.gw	0.93	0	2	-0.51	0.61
GW_REVAP.gw	0.03	0.02	0.2	0.43	0.67
RCHRG_DP.gw	0.20	0	1	0.62	0.54
ESCO.bsn	0.90	0	1	-0.09	0.92
EPCO.bsn	0.33	0	1	-1.49	0.92
SURLAG.bsn	0.31	0	10	-1.16	0.25
SOL_AWC.sol	0.26	0	2	-0.50	0.14
SOL_K.sol	1.77	0	2	0.59	0.56

In addition to fitted value analysis of eleven parameters with SUFI-2 SWATCUP with minimum range and maximum value as in Table 2, also obtained the sensitivity value of eleven parameters. The most sensitive parameters are EPCO, SURLAG, CN2 and GW_DELAY. Greater the t-stat value indicates if the parameter is more sensitive, this can be proved by the value of p-value which is closer to zero, which means the level of significant t-stat significance. This value indicates that change of the value of four parameters gives quite a lot of change of simulation result of streamflow in Wakung watershed.

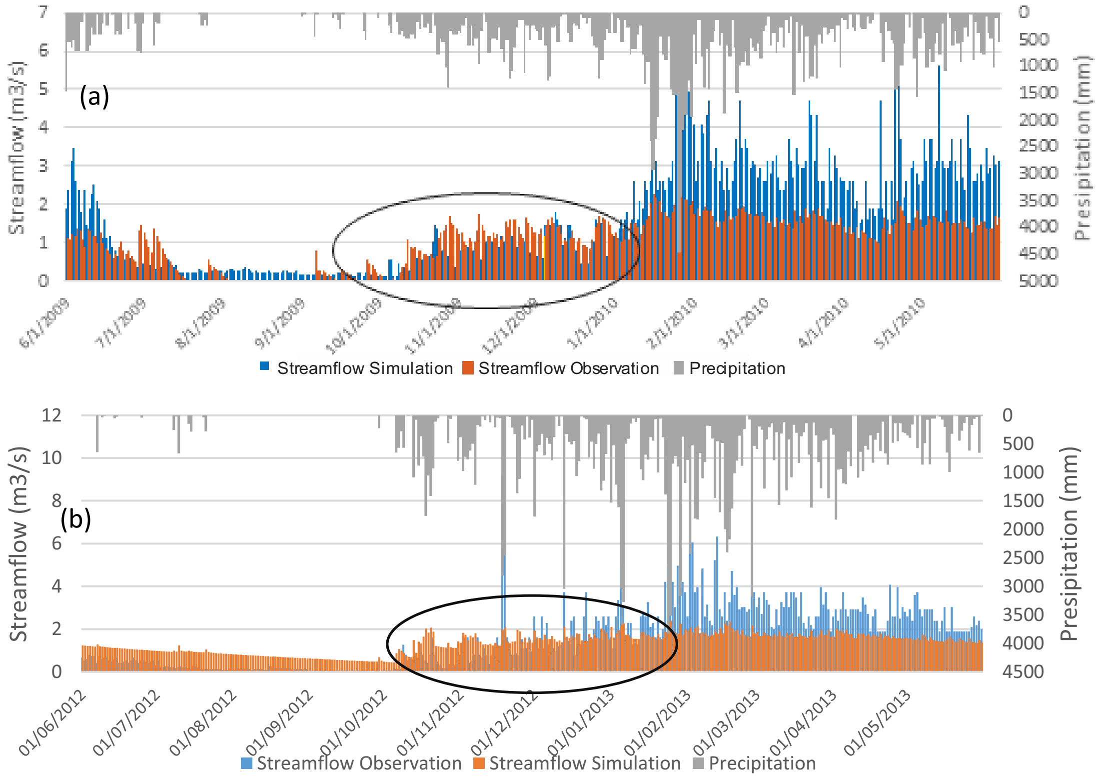
3.2.2. Performance calibration and validation. Calibration using simulation and observation streamflow daily and monthly dates from June 2009 to May 2010.

Table 3. Performance of Calibration and Validation.

Performance Calibration of Streamflow June 2009 – May 2010	R^2	wr^2	E_{NS}
Daily	0.61	0.36	0.35
Monthly	0.77	0.42	0.50
Performance Validation of Streamflow June 2012 – May 2013			
Daily	0.61	0.24	0.37
Monthly	0.89	0.33	0.51

Validation using simulation and observation streamflow daily and monthly dates from June 2012 to May 2013. Selection of this time range is chosen because of limitations continuous daily observation streamflow dates without a vacuum of instantaneous streamflow observation from the weir guard. Table 3 shows the performance of calibration and validation streamflow in Wakung Watershed and the value of R^2 calibration and daily validation entered in satisfactory category with wr^2 0.36 for calibration and 0.24 for validation. This weighted value of R^2 indicates that the range of observation and simulation values whose value is almost close is 36% for calibration and 24% for validation. The monthly R^2 value shows good correlation with R^2 weighting 0.42 for calibration and 0.33 for validation.

Monthly statistical tests show better results than daily. This is because monthly statistical test has lower value of streamflow less than daily statistical test for simulation of streamflow at peak of rainy season. However, when looked from the value of wr^2 for calibration and validation (daily and monthly) have low value, because many values are not equal of streamflow observation and simulation, especially at peak of rainy season (figure 3).



Calibration and Validation whose value is almost the same for precipitation and streamflow simulation and observation.

Figure 3. Comparison streamflow simulation, observation and precipitation (a) Calibration and (b) Validation.

Daily E_{NS} values are unsatisfactory categories for both of calibration and validation. Daily statistical tests generally in low values, although this is not universally applicable [6]. The low of daily E_{NS} is due to the extreme value of peak during rainy season, this condition made E_{NS} statistic test shows unsatisfactory. The monthly statistical tests of E_{NS} show satisfactory results for calibration and validation. This is because of the absence of extreme values in monthly dates.

3.3. Streamflow in Wakung Watershed

Running SWAT model in this research using two scenarios; 1) running SWAT model using actual land use (W-A), and 2) running model SWAT using spatial plan land use (W-R). Based on W-A Scenario, streamflow rate in Wakung watersheds has ranged from 161 - 4950 m^3/s /year (figure 4). The highest streamflow value was in sub-watershed 21st (4950 m^3/s /year) with 8.8% of the slopes> 40% and the use of pine forests, and 8% of sub-watershed on slopes of 25% - 40%. The smallest streamflow rate in 3rd sub-watershed (161 m^3/s /year) with slopes 0 - 8 and land use in the form of paddy fields.

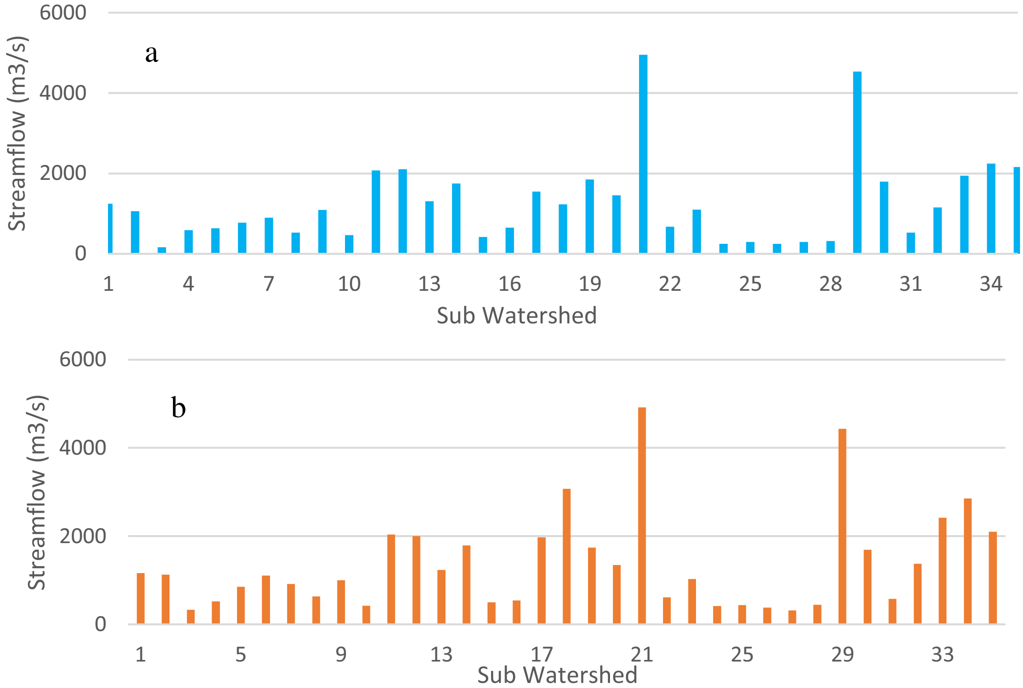


Figure 4. Streamflow Graphs (a) W-A Scenario (b) W-R Scenario.

The result of running model SWAT scenario W-R has streamflow range 330 – 4919 m^3/s/year (figure 4). The highest and lowest streamflow is still same in 21st sub-watershed (4919 m^3/s/year) and 3rd sub-watershed (330 m^3/s/year).

3.4. Evaluation Spatial Plan Land Use (RTRW) to controling streamflow

To evaluate spatial plan land use to control streamflow use comparison between streamflow from actual land use and spatial plan land use. The comparison of two streamflow is showed in figure 5. Spatial plan land use can control and reduce streamflow in 16 sub-watershed and can't control and increase streamflow in 19 sub-watershed. Streamflow reductions ranged of 16 sub watershed are 116 to 31 m^3 /s/ year. Streamflow reductions occurring in sub-watersheds that planned for forest areas or for horticultural areas with perennials plant. Land areas was planned for forests such as sub-watershed 20, 22, 30 and 35, and while for horticultural area with perennials plant are located in sub watershed 22, 12, 19, 21, 22, 23, 29 and 35. The highest reduction streamflow was in sub-watershed 20 (116 m^3/s/year) with forest area planning of 1039.5 Ha.

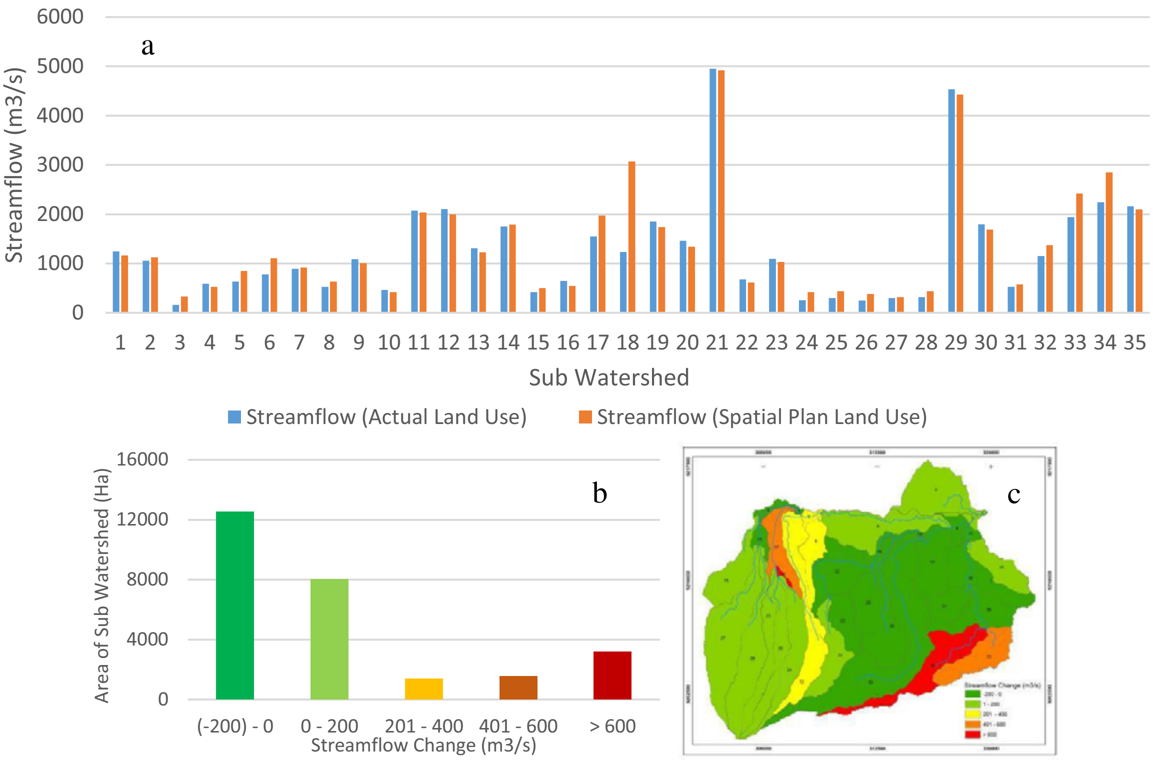


Figure 5. (a) Comparison Streamflow Change, (b) Sub Watershed Area of Streamflow Change (c) Distribution of Streamflow Change in Wakung Watershed.

The increasing streamflow ranged from 21 - 1841 m^3/s/year. This is due to increase in residential area planning and intensive agriculture such as seasonal horticultural agriculture or paddy and corn agriculture. The highest increase of streamflow occurred in sub-watershed 18 (1841 m^3/s/year) with almost all of the sub watershed allocated for settlements (URHD). While the lowest increasing streamflow occurred in sub DAS 27 (21 m^3/s/year). This is because the land allocates in the sub-watershed is not too much change with the actual land use.

This condition is caused by the amount of land allocated for the fulfillment of housing and food needs. So much of the land with a steep slope is used for agricultural and settlement areas. as a result of this condition made increasing of streamflow in 19 sub watersheds. For more details of land use planning in Wakung watershed can be seen in table 4. Based on table 4, the increase of streamflow is due largely to the addition of settlements almost across the watershed, especially in sub-district town centers, such as Belik, Pulosari, Randudongkal, and Moga. The most extensive addition of settlements occurred in Randudongkal and Belik.

Table 4. Comparison Actual and Spatial Plan Land Use in Wakung Watershed.

Clasification of Land Use	Actual Land Use	Area (Ha)	Spatial Plan Land Use	Area (Ha)
Open space	*Barren*	29.4		
Horticulture	*Cabbage*	3750.5	*Cabbage*	3561.6
	Coconut	37.8	*Coconut*	131.2
	Corn	170.2	*Corn*	287.4
	Vineyard	470.5	*Vineyard*	692.0
	Peppers	23.9		
	Poplar	3356.8	*Poplar*	4388.9
	Pineapple	1081.6	*Pineapple*	770.4
Forest	*Oaks*	239.9	*Forest-Evergreen*	3454.1
	Pine	5286.3	*Pine*	5108.3
Paddy	*Rice*	5413.3	*Rice*	4162.6
Brush	*Range-Brush*	3035.3		
Urban	*URLD (Urban Low Density)*	2054.7	*URLD (Urban Low Density)*	1543.7
	URMD (Urban Middle Density)	112.0		
	URHD (Urban High Density)	349.0	*URHD (Urban High Density)*	1345.5
Water	*Water*	34.7		
	Total	25445.7		25445.7

This streamflow change when viewed based on the width of the sub-basin area, implemented of land use planning will be able to reduce the streamflow in the 16 sub watersheds (0 - 200 m^3/s/year) of 12275.17 Ha (47% of Wakung watershed). while for increasing streamflow from 1 - 200 m^3/s/year occurred in 12 sub watersheds with 7771.96 Ha (30% of Wakung watershed) and for streamflow increase > 200 m^3/s/year occurred in 7 sub watersheds with 5398.62 Ha (23% of Wakung watershed).

4. Conclussion

SWAT was applied to simulate actual land use and spatial plan land use to determine streamflow changes in Wakung watershed. The comparison between actual and spatial plan land use data for streamflow showing that the W-A scenario is lower than the W-R scenario in 19 sub watersheds. This is because there are many plans for adding land use for urban and intensive horticulture land in areas with steep slopes (> 25%). This condition is caused by the demands of fulfilling the needs of settlement and food for people in the Wakung watershed.

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