Simulating Streamflow Through The SWAT Model in The Keduang Sub-Watershed, Wonogiri Regency, Indonesia

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ABSTRACT

Water resource modelling has been used to analyze the sustainability of the watershed affected by human activity and natural disasters. The objective of this research was to evaluate the SWAT model and its applicability in the Keduang Sub-Watershed for streamflow prediction, which is part of Bengawan Solo Watershed. A SWAT integrated with Geographic Information Systems (ArcGIS, version 10.4.1) was used to simulate Keduang Sub-Watershed streamflow for the period from 2008 to 2017. Model calibration and validation were performed for monthly and daily periods using Sequential Uncertainty Fitting 2 (SUFI-2) within SWAT-CUP using daily observed streamflow data at the catchment outlet. The results during calibration and validation periods showed that the value of the Nash-Sutcliffe Efficiency (NSE), the coefficient of determination (R2), Percent Bias (PBIAS) and Root Mean Square (RSR) had different values for daily and monthly simulation. The calibration and validation outputs for daily and monthly simulation showed a good model performance for discharges. In the daily simulation, the value of NSE, R2, PBIAS and RSR were 0.57; 0.58; -3.4 and 0.67 for calibration periods, whereas in the validation period the values of NSE, R2, PBIAS and RSR were 0.50; 0.51; -10.7 and 0.65, respectively. The monthly simulation had better results than the daily simulation where the value of NSE, R2, PBIAS, RSR were 0.79; 0.81; -6.2 and 0.54 for calibration periods, as well as 0.73; 0.69;-1.9 and 0.71 for validation periods, respectively. Those results indicated that the SWAT model was acceptable for Keduang watershed simulation based on the model performance which was higher than the minimum standard acceptance.

Keywords: Discharges; Keduang Sub-Watershed; SUFI-2; SWAT-CUP; SWAT model

INTRODUCTION

The Gajah Mungkur Reservoir is practically utilized as economic activities such as fisheries, tourism, drinking water, hydroelectric power and water supply for irrigation in the Wonogiri Regency and other regencies. The current problem in this reservoir is sedimentation into Gajah Mungkur reservoir which delivers from several watersheds that surrounded this reservoir such as Keduang Sub-Watershed, Alang Watershed, Tirtomoyo Watershed, Wuryantoro Watershed, Upper solo Watershed, Temon Watershed, and Ngunggahan Watershed. According to JICA's study in (2007), the Keduang sub-Watershed is the most significant contributor to the sediment rate that enters into the Gajah Mungkur reservoir, which is caused by several factors such as inappropriate water management, climate change, land-use change, increasing population. Keduang Sub-Watershed is the largest Sub-Watershed that stand out for land-use change among other sub-

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watershed that surround Gajah Mungkur reservoir in the periods 1993 until 2008 (Sutrisno, 2011) where several green land change to residential area. Agus and Susanti (2015) had researched population pressure on the agricultural sector in Kedung Sub-Watershed, and the results showed that Keduang Sub-Watershed is categorized as "bad" condition. It indicated that the role of people in their activities has a significant effect on the sustainability of Keduang Sub-Watershed. In other hands, sedimentation is carried by stream flow that enters onto Gajah Mungkur reservoir so that understanding of hydrological characteristic to develop an adequate water resources plan is needed for estimating water budget which is usually done by analyzing data, e.g., by modeling of hydrological processes. However, in a poorly gauged watershed, there are some problems regarding the data such as missing data, old instruments, mistake on putting devices those affecting on quality of the data., so that the effectiveness of water resources planning is likely to be constrained for sustainability of the watershed.

One of the hydrological models often used by researchers for analysing watershed is the Soil and Water Assessment Tools (SWAT) model which is basin-scale model for predicting hydrological processes, sediment, nitrogen cycle, phosphorus cycle, plant growth, instream processes, land use summary, nutrient losses as a result of management practices inside the watershed (Neitsch *et al*., 2001). SWAT model was developed for predicting quantity and quality of the water, and their daily precesses in the continuing time (Arnold *et al*., 1993). Inside the SWAT model, there are relatively full of management practices for agricultural activities such as tillage, planting, irrigation with source by stream or reservoir, fertilizer application, pesticide application, harvesting and grazing for applying inside the watershed (Neitsch *et al*. 2011). Based on its advantages, SWAT model is chosen in this study for analyzing streamflow in Keduang Sub- Watershed. In Indonesia, several researchers had applied SWAT model to watersheds scale projects such as in Cisadane Watershed by Junaedi and Tarigan (2012) that used the SWAT model for identifying Watershed management for modeling mountainous catchment that focusing on Cisadane Catchment Area in West Java Province and Sulaeman (2016) that used SWAT model to simulate soil and water conservation technique with vegetative and civil engineering method in Ciujung Watershed.

The application of hydrological model such as SWAT model needs to be calibrated since complicated in its environmental processes and a large number of input data for successfully applying hydrological models. For calibrating output of SWAT model (Arnold *et al*., 1998), Abbaspour *et al*. (2007) have linked output by swat model into SWAT-CUP (SWAT Calibration Uncertainty Processes). There are four procedure for calibrating the output from SWAT model namely Generalized Likelihood Uncertainty Equation (GLUE) that developed by (Beven and Biinley, 1992); ParaSol that developed by (Van Griensven and Meixner, 2006) and Sequential Uncertainty Fitting Ver. 2 (SUFI-2) that developed by (Abbaspour *et al*., 2007). The purpose of the research was evaluating the Soil and Water Assesment Tool (SWAT) Model and its applicability to Keduang Sub-Watershed for streamflow prediction, which is part of Bengawan Solo Watershed.

MATERIALS AND METHODS

Site of Study

Keduang Sub-Watershed is part of Bengawan Solo Watershed. Geographically, The Keduang Sub-Watershed is located between 7°42'30.6" S- 7°55'29.3" S and 110°56'53.39" E- 111°13'23.8" E. The Walikan Sub-Watershed borders it in the north, the Wiroko Sub-Watershed in the south, and the Madiun River Sub-Watershed in the east (Figure 1). Administratively, the Keduang Sub-Watershed is located in Karanganyar Regency and Wonogiri Regency and empties into the Bengawan Solo River in Wonogiri District, Central Java Province. The area of the Keduang Sub-Watershed is 39,736.28 ha, whereas the location of Keduang sub-Watershed, Land use map, soil map, and slope map are shown in Figure 2.

According to BIG (2000), There are eight classes of land use in Keduang Sub-Watershed, whereas paddy cultivation is the biggest land use in this watershed. The following is distribution of land use; paddy cultivation (RICE) (35%), urban area (URHD and URML) (26%), agricultural land close grown (AGRC) (17%), forest deciduous (FRSD) (16%), forest evergreen (FRSE) (6%), waterbody (WATR) (0.42%) and grasslands (PAST) (pastures and range-grasses) (0.15%) respectively . Rice fields are spread out in this area, especially in the upper and middle Watersheds, which are applied bench terrace to cultivate rice production in the upstream area to reduce erosion and landslide in this area. Meanwhile, land use in the form of forests, gardens, and shrubs is found in the northern upstream part of the basin. Agroforestry has been applied using a combination of perennials and agricultural plants (peanuts, corn, and cassava). The residential area spread over a flat area up to the hilly area with spread patterns. By association, the residential area is close to agriculture fields and gardens. There is four soil type in this watershed; Alfisol

(Lv5-3b-4538), Entisol (Tm23-2c-4573), Inceptisol (To-2b-4576), and Vertisol (I-Lc-3b-4510) respectively. In this study, slope classes has divided into five classes namely 0–8%, 8–15%, 15–25%, 25–45% and >45%. Respectively, which dominated by 8–15% slope classes found in the middle and downstream area.

The climate characteristic of this area is commonly tropical monsoon which rainy happens throughout the year. Commonly, the season in this area divided into two seasons namely dry season (April until October) and rainy season (October until April) but sometimes the rainfall occurred until June or July, which both of them occurs every six months. Total rainfall in this area is about 2822 mm per year with the spread of the precipitation around the mountainous area. Thus, the climate type in the Keduang Sub-Watershed is slightly wet. The average annual temperature in the Keduang Sub-Watershed is 26 °C with maximum temperature is 34.33 °C, and minimum temperature is 14 °C.

SWAT Description

The SWAT model is made for counting water, sediment and chemical residue from the watershed with adding calculating each sub-watershed based on spatially semi dispersed hydrological and water quality throughout the river network inside the basin (Arnold *et al*., 1998; Chen *et al*., 2014; Raksmey Ang and Chanta Oeurng, 2018). The use of SWAT model has widely used for calculating several parameters of hydrology such as precipitation, surface run-off, evapotranspiration, groundwater flow infiltration and also water quality parameters such as sediment delivery, nutrient losses and pesticide losses inside watershed. SWAT model is built upon a continuous period model that surgery on daily period for hydrological and water quality processes. The theories and fundamental of hydrological and water quality processes were explained by Neitsch *et al*. (2001). The following formula is water balance equation used in SWAT model (Neitsch *et al*., 2011)

$$SW_t = SW_0 + \sum_{i-1}^{t}(R_{day} - Q_{surf} - E_a - w_{seep} - Q_{gw}) \quad (1)$$

Where SW_o is the initial soil water content in day i(mm), t is the time (days), Rday is the measure of precipitation in dayi (mm), Qsurf is the measure of surface run off in dayi (mm), Ea is the amount of ET in day i (mm), Wseep is the measure of water entering the vadose zone from the soil profile on dayi (mm), and Qgw is the measure of groundwater discharge in dayi (mm).

SWAT model is integrated with Geographic Information System for managing raster, vector, and alphanumeric data. All of the data will be integrated for building the model to calculate hydrological and water quality processes. Integration among them has more advantages for the user for editing, manipulating, and setting the parameter related to the characteristics of the study area (Hallouz *et al*., 2018).

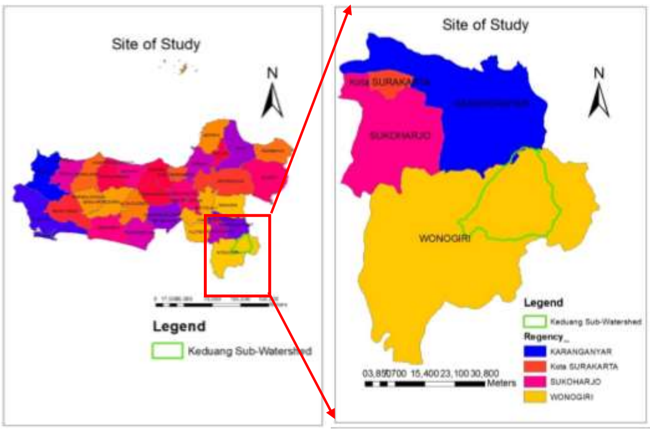
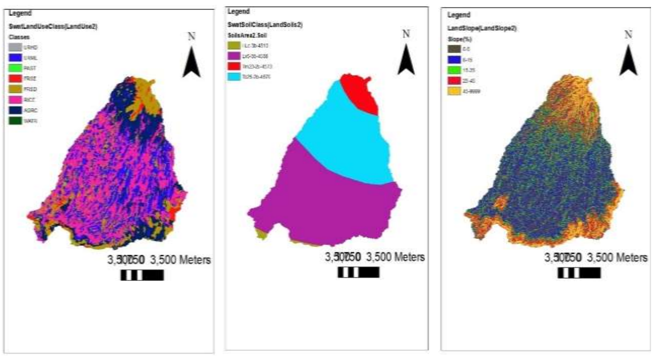


Figure 1. Keduang Sub-watershed map



(a) (b) (c)

Figure 2. a) Land use class distribution b) soil type class distribution c) slope class distribution

Data Acquisition

The minimum required data of the SWAT model are digital elevation model (DEM), stream network map,

Figure 3. Monitoring point map

land-use map, soil map, weather data, and management data are outlined in Table 1. Daily discharge data for comparing simulation and observation has obtained from Research Center and Development Technology of Watershed Management Surakarta. The available discharges data that got from the institution are from 2008 until 2017. The monitoring of discharges is in the outlet of the Watershed which located in bolak, Pengkol, Sembukan, Sidoharjo, Wonogiri Regency (see Figure 3).

Model Setup

For building the SWAT model, Firstly, DEM and river network map used for delineating the basin to divide basin several into sub-basin. The final sub-basin that generated by delineating the basin is 48sub-basins. Afterward, land use, soil, and slope definition for each sub-basin were overlaid using land use map, soil map and slope criteria then creating Hydrologic Response Units (HRUs) was based on dominant land use, soil, and slope criteria. Every HRUs has a specific composite of land use, soil type, and slope criteria in a sub-basin. The weather data such as precipitation, maximum temperature, minimum temperature, relative humidity, solar radiation, and wind speed were used for supporting the calculation of water balance, especially for computing evapotranspiration. Finally, it was run and simulated ten years with two years warm-up from 2008 to 2009.

Model Calibration, Validation and Evaluation

Model calibration is a modification value of the parameters related to the model and comparison between predicted data and observed data. The purpose of calibration is to reveal the results of the model like real condition. Identifying the most parameters related to the model is required for calibration processes in SWAT-CUP. SWAT-CUP was used for calibration the model output using SUFI-2 method. The use of SWAT-CUP was for calibrating parameters to meet the appropriate values of the parameters. The advantages of using SWAT-CUP knew which parameters were essential towards the model for getting good results.

Model validation was using same parameters those used in calibration processes but different in periods for both calibration and validation where model validation was also using SWAT-CUP with SUFI-2 method. Same as calibration process, model validation was comparing between simulated data from SWAT and observed data. The purpose of model validation is increasing the credibility of the model and convincing the results of the model.

For evaluating the model, four measurements were used for assessing the quality of calibration and validation (a) the coefficient of determination (R^2), (b) the coefficient of Nash–Sutcliffe Efficiency (NSE), (c) percent BIAS (PBIAS), and (d) root mean square (RSR)

Table 1. The available input data for setting the SWAT model

Data	Information	Period	Description	Source
Digital elevation model (DEM)	Raster, 30 m-resolution	2011	Terrain elevation	USGS
River network map	Vector, 1: 25.000	2001	River network	Indonesian Geospatial Agency
Land-use map	Vector, 1: 25.000	2001	Land-use classification	Indonesia Geospatial Agency.
Soil map	Vector, 1: 25.000	2001	Soil classification and physical properties	Research and Development Technology of Watershed Management under the Ministry of Environment and Forestry
Meteorological data	Daily	2008-2017	Observed daily rainfall, maximum and minimum temperature, wind speed, sunshine hours, humidity	Water resources institution under the Ministry of Public Works
Discharge	Daily	2008-2017	Observed daily streamflow	Research and Development Technology of Watershed Management under the Ministry of Environment and Forestry.
Management data	Watershed data	-	Watershed management	Research and Development Technology of Watershed Management under the Ministry of Environment and Forestry.

respectively. Abbaspour (2007) correlation between calibration and uncertainty analysis are connected to each other due to calibration without uncertainty analysis is pointless and perverting. SWAT simulations have done for the period 2008–2017, where the simulation (Monthly and Daily simulation) period 2008–2009 serves as a warm-up period for the model and is not considered in the sensitivity analysis and calibration process. For the daily simulation, the period 2011-2012 was selected for calibration, and the period 2013-2014 was selected for validation. For the Monthly Simulation, The period 2010-2013 was chosen for calibration (4 years) and the period 2014-2017 (4 years) was selected for validation, The difference of period within calibration and validation in simulation period is due to availability of the data and missing the data. Some of the data has been missing due to several reasons, such as broken instruments, not recorded data. The formula for evaluating the model are given in the following equations: (Equations (2) – (5), respectively);

$$R^2 = \left[\frac{\sum_{i=1}^{n}(Q_{obs}-\bar{Q}_{obs})(Q_{sim}-\bar{Q}_{sim})}{\sqrt{\sum_{i-1}^{n}(Q_{obs}-\bar{Q}_{obs})^2\ \sum_{i-1}^{n}(Q_{sim}-\bar{Q}_{sim})^2}}\right]^2 \tag{2}$$

$$NSE = 1 - \frac{\sum_{i=1}^{n}(Q_{obs}-Q_{sim})^2}{\sum_{i=1}^{n}(Q_{obs}-\bar{Q}_{obs})^2} \tag{3}$$

$$PBIAS = \frac{\sum_{i=1}^{n}\left(Q_i^{obs}-Q_i^{sim}\right)*100}{\sum_{i=1}^{n}Q_i^{obs}} \tag{4}$$

$$RSR = \frac{RMSE}{STDV_{obs}} = \frac{\sqrt{\sum_{i=1}^{n}(Q_i^{obs}-Q_i^{sim})^2}}{\sqrt{\sum_{i=1}^{n}(Q_i^{obs}-Q_{mean}^{obs})^2}} \tag{5}$$

Where: Q_{obs} is observed discharge, $_{obs}$ is mean of observed discharge, Q_{sim} is simulated discharge, $_{sim}$ is mean of simulated discharge.

Based on previous studies in this watershed (Nugroho, 2015.; Priyanto, 2018) and after identifying the watershed., as many as 14 parameters had chosen for calibration and sensitivity analysis processes. The selection of the parameter is considered on historical data, survey location, and previous research. All selected parameters for calibration and sensitivity analysis processes are summarized in Table 2.

RESULTS

Sensitivity Analysis of The Parameters

Sensitivity analysis of the parameters is required for analyzing which parameter that affected output from the model according to the input model. There are seven parameters that most sensitive towards the model output, which are presented in table 3. The selection of the most sensitive parameters was considered by their p-values, which the smallest of p-values is most sensitive. The most parameters that most sensitive

Table 2. Summarize of parameters that used in SWAT-CUP

No	Parameter name	Description of parameters	Range		Method
			Min	Max	
1	CN2.mgt	Moisture condition II curve number	-0.05	0.05	r
2	Alpha.BF.gw	Baseflow alpha factor	-0.3	0.2	v
3	GW_Delay.gw	Groundwater delay	21	63	v
4	SOL_K.sol	The saturated hydraulic conductivity	0.2	0.7	r
5	SOL_BD.sol	Moist bulk density	-0.02	0.06	r
6	SOL_AWC.sol	Available water capacity	-0.05	0.05	r
7	HRU_SLP.hru	Average slope steepness	1.75	3.25	r
8	SOL_EC.sol	Electrical conductivity	1.75	2.50	r
9	SLSUBBSN.hru	Average slope length	-0.75	0.50	r
10	GW_SPYLD	Specific yield of the shallow aquifer	-5.00	-0.05	r
11	SUB_ELEV.sub	Elevation of subbasin	-3.75	-1.00	r
12	RAIN_YRS.wgn	The number of ears of maximum monthly 0.5 h rainfall data used to define value	1.75	4.75	r
13	SURLAG.bsn	Surface runoff lag coefficient	-5	5.00	r
14	LAT_TTIME.hru	Lateral flow travel time	-2.5	3.75	r

* r: relative, * v: replace

in this model are the Slope of sub-basin, groundwater delay, the slope of HRU, Alpha baseflow, SCS Curve number, The saturated hydraulic conductivity, and Moist bulk density. According to the results of sensitivity analysis, it indicated that topography has a significant role in hydrological processes, especially in groundwater recharge processes. The characteristics of the topography in this area are terraced area which spread throughout almost all watershed. The advantages of applying terrace conservation for agricultural activities is retaining water in its embankment and reduce direct run-off that can increase erosion and sedimentation. The other parameters are not too affected by the simulation since their value of p-value is stay away from zero, which is not sensitive.

Model Calibration

The calibration process was done from 2011 to 2012 for daily simulation and 2010-2013 for monthly simulation. The calibration would be performed after sensitivity analysis to know the most sensitive parameters related to streamflow simulation. Model calibration through the SUFI-2 method was comparing between observed discharges in the outlet of the basin and simulated discharges by SWAT.

Daily time series simulation.

The results of daily simulation have a different value in the daily and monthly simulation. For calibration in daily time series simulation, the value of NSE, R^2, PBIAS, RSR are 0.57; 0.58; -3.4 and 0.67 respectively. Those values describe that the SWAT model could be simulated well in this area. According to Moriasi *et al*. (2007), those results categorize as satisfactory due to the results is more than 0.5 for NSE, R^2, RSR values. The comparison between simulated and observed value of daily simulation is presented in Figure 4, and the scatter plot of the daily simulation is presented in Figure 6.

Monthly time series simulation

The output of calibration in monthly simulation has better value than daily simulation. the value of NSE, R^2, PBIAS, RSR in monthly simulation are 0.79; 0.81; -6.2; 0.54 respectively. According to Moriasi et al. (2007), those results categorize as very good. It indicated that the model could describe hydrological processes very good for monthly simulation. The hydrograph of monthly simulation is presented in Figure 5, and the scatter plot of the monthly simulation is presented in Figure 7.

Model Validation.

The aim of conducting model validation is to check accuracy of the output representation towards the real system. Model validation was conducted for a different period of the calibration using comparison observed data and simulated data. The model validation process both daily and monthly simulation was conducted from 2013 to 2014 for daily simulation and 2014-2017 for monthly simulation

Daily time series simulation.

In validation periods for daily simulation, the value of the NSE, R^2, PBIAS, RSR are less than calibration periods. The value of NSE, R^2, PBIAS, RSR are 0.50; 0.51; -10.7 and 0.65 respectively. According to Moriasi et al. (2007), Those results can be categorized as satisfied simulation. The hydrograph of daily simulation is presented in Figure 4, and the scatter plot of the daily simulation is presented in Figure 6.

Monthly time series simulation.

In validation periods for monthly simulation, the value of the NSE, R^2, PBIAS, RSR are less than calibration periods. The value of NS, R^2, PBIAS, RSR are 0.73; 0.78;-1.9 and 0.71 respectively. According to Moriasi *et al*. (2007), Those results can be categorized as good simulation. The hydrograph of monthly simulation

Table 3. Parameters for simulating streamflow in Keduang Sub-Watershed

No	Parameter name	Description	Rank	p-value	fitted value
1	SOL_K.sol	The saturated hydraulic conductivity	7	0.000966	0.245
2	SOL_BD.sol	Moist bulk density	6	2.06E-09	-0.014
3	CN2.mgt	Moisture condition II curve number	5	2.71E-16	-0.102
4	ALPHA_BF.gw	Baseflow alpha factor	4	1.27E-22	0.012
5	HRU_SLP.hru	Average slope steepness	3	2.62E-24	2.26
6	GW_DELAY.gw	Groundwater delay	2	8.52E-65	57.939
7	SLSUBBSN.hru	Average slope length	1	4.99E-90	0.258

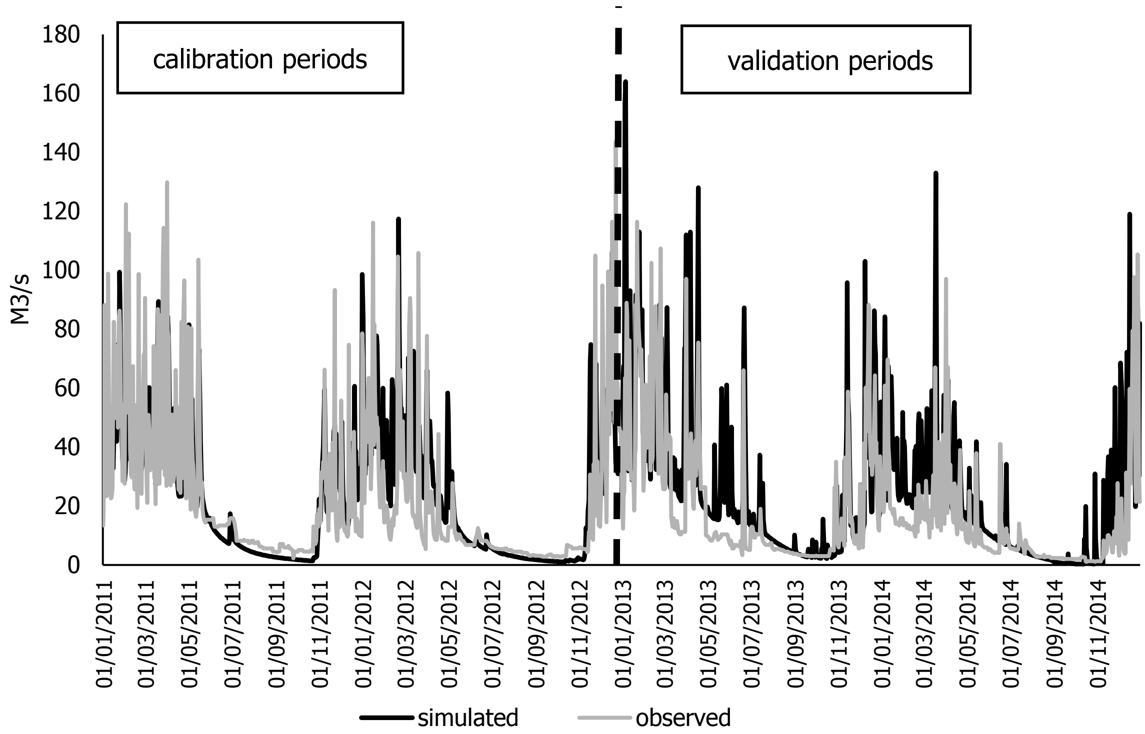


Figure 4. The hydrograph of daily simulated and observed flow for calibration and validation period

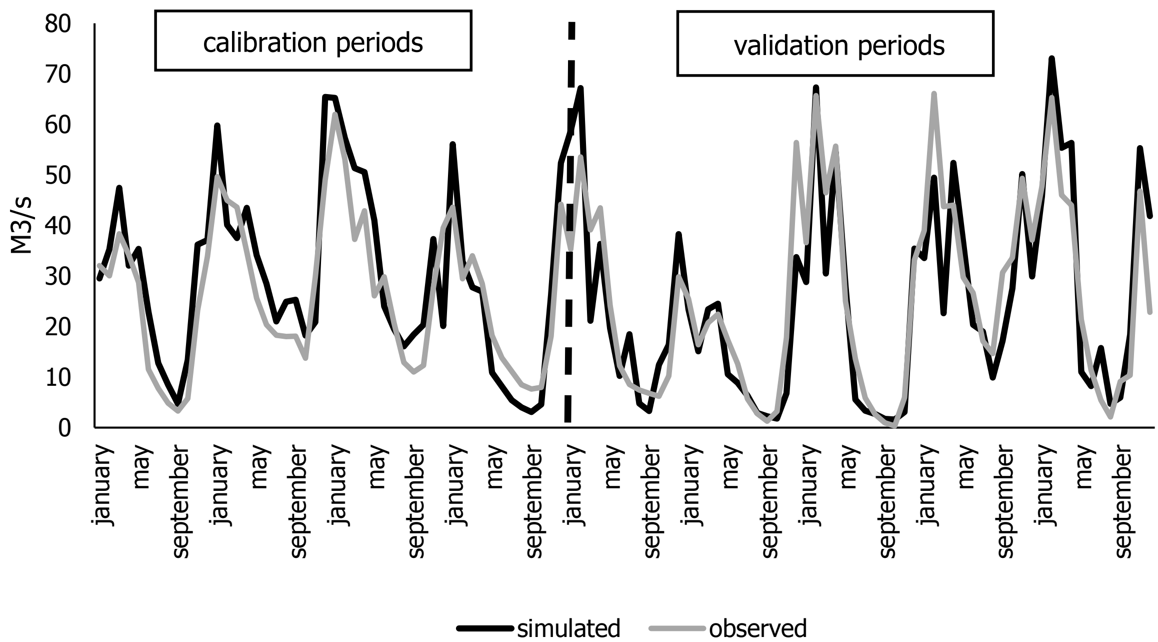


Figure 5. The hydrograph of monthly simulated and observed flow for calibration and validation period

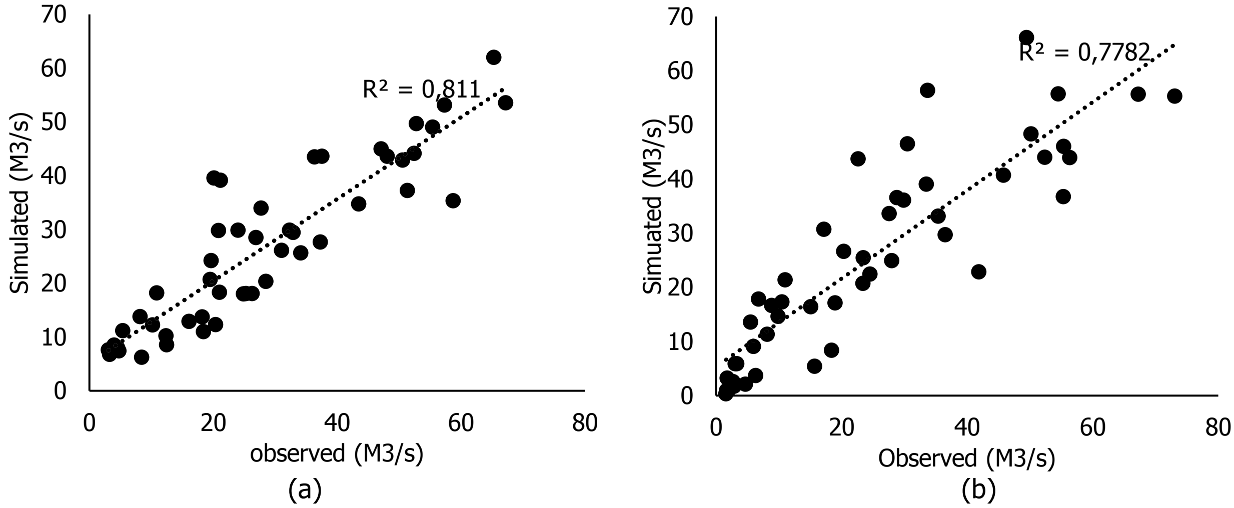


Figure 6. Scatter plot for daily simulation (a) calibration periods (b) validation periods

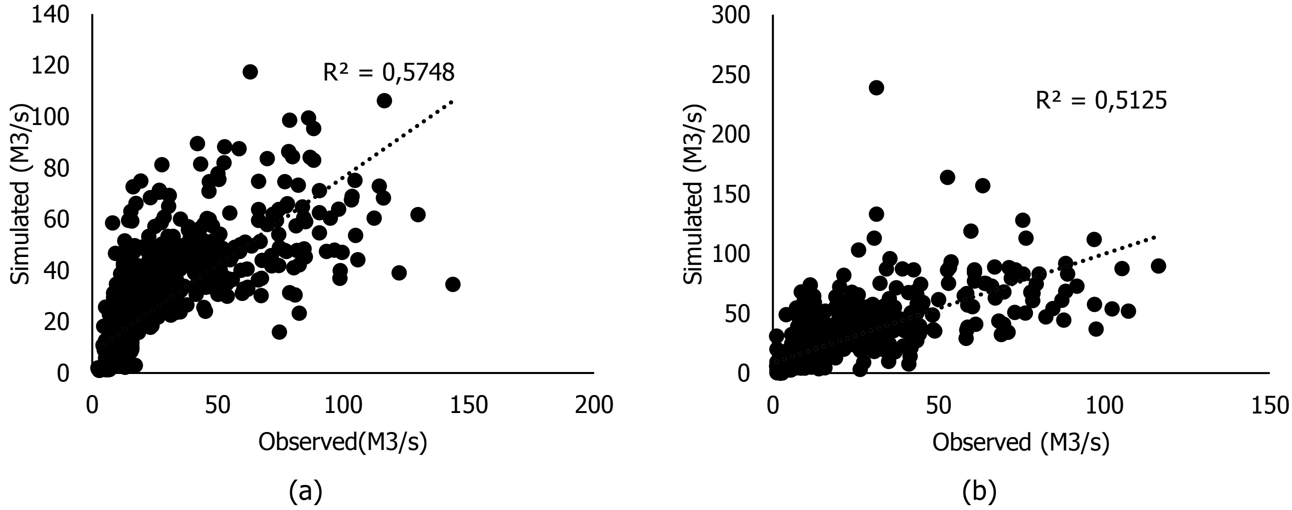


Figure 7. Scatter plot for monthly simulation (a) calibration periods (b) validation periods

is presented in Figure 5, and the scatter plot of the monthly simulation is presented in Figure 7.

Scatter plot was graphically served to represent the correlation between observed values and simulated value. According to the results between observed and simulated, the correlations are positive correlations for all calibration and validation in both daily and monthly simulation. Positive correlation shows that simulated and observed has the same thing due to one variable will be followed by changes in the other variables regularly in the same direction. The highest correlation is in the calibration period in monthly simulation.

DISCUSSIONS

Comparison results between the current results and previous results (Nugroho,2015) have different results for both daily and monthly simulation. The current result was better than the previous one, especially in daily simulation. The difference in the results may be caused by differences in the parameters used in the simulation. Parameter selection must consider the characteristics of the watershed. The characteristics of the Keduang Sub-Watershed is the mountainous area that has different slope spreading the basin so that slope has a significant role in the result of the discharge. Agricultural practices inside the watershed such as rice production that cultivated in terrace paddy field also affected in water-saving inside the watershed. Bench terrace has used for agricultural activity in the Keduang Sub-Watershed. The advantages of applying bench terraces are reduction direct surface run-off that can reduce erosion and sedimentation. In another research, Khelifa *et al*. (2017) Bench terrace can decrease surface run-off and sediment yield 19% and 22% respectively. So that terrace paddy fields inside the Keduang Sub-Watershed have a significant role regarding water availability inside Keduang-Sub-Watershed.

Human activity, Climate change, the increasing population may affect the hydrological processes. Human activity such as agricultural, industry, an extension of the residential area would have affected hydrological processes. Climate change has been occurring around the world especially in Indonesia that would have change on water cycle that affected on rainfall pattern so that the availability of water has limited or excesses depend on El-Nino or la-Nina events. The increasing population would have affected food demand, residential area, and other stuff and also water demand in line with increasing population.

Several reasons cause the difference between daily and monthly simulation in both calibration and validation processes. The SWAT simulation was more successful in monthly or annual simulation rather than daily simulation due to the SWAT model was developed for use in basins scale with the continuous flow. The quality of the recorded data in the outlet of the basin has a significant role in the simulation, especially in the calibration and validation processes. Missing data, quality, error in data retrieval, several instruments, quality of the instruments are some factors that are affecting the quality of the data. Besides streamflow data, weather data also needed for SWAT model simulation since the weather data was used for input data. The use of weather data is crucial in this modeling since weather data were used for input data, but the weather station in this study area is located in the outside of the watershed so that the quality of the data also is not similar to actual data in the inside of watershed. For the future application of the SWAT Model or other hydrologic simulation, it is better to establish some streamflow gauge with a stable hydraulic control section that applied in several points inside the watershed and also to establish weather station inside of the Keduang Sub-Watershed in several locations so that the quality of streamflow and weather data will be increasing for future research.

CONCLUSIONS

The results of the study showed that the SWAT model gave a good performance for simulated the real system of the Keduang Sub-Watershed. Furthermore. The SWAT model could nicely simulate for the local condition with the lacks of the data. Moreover, the applicability of the SWAT model to simulate an area that has limited data for simulating their real systems. Monthly simulation has better results than daily simulation in this area with the categorize of monthly simulation as very good for calibration and good for validation periods in other hand classification of daily simulation categorize as satisfactory for both calibration and validation periods. Furthermore, the results from simulation can be used for a policymaker to manage the sustainability of the Watershed/

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CONFLICT OF INTEREST

The author declares that there is no conflict of interest regarding the publication of this article.

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