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Analysis of River Discharge Using the Modified Soil and Water Assessment Tools (SWAT) Program

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ABSTRACT

Soil and Water Assessment Tools (SWAT) which is developed in America was used to analyze the effect of land management on discharge, sedimentation, and water quality in a river basin area. The hydrological conditions in the Americas are different from Indonesia, so a modified SWAT is done. This research aimed to implement a modified SWAT program to predict the results of a better discharge analysis based on hydrological analysis in the sub-Watershed area. About 13.90% of the area was paddy fields. The evaluation of the module had been done by looking at the coefficient of determination (R^2) and Nash-Sutcliffe Efficiency (NSE) based on the comparison of simulated discharge results with an observation discharge. Research began with delineation DEM, HRU formation, simulation, calibration, and validation. The R^2 value for daily data on modified SWAT was 0,725. It was better than the original SWAT and SWAT with Pothole, which were 0,706 and 0,708 respectively. Likewise, the NSE value for daily data on modified SWAT was 0,721, on original SWAT and on SWAT with Pothole was 0,668 and 0,685 respectively. The analysis result showed that the modified SWAT provide good discharge prediction results, indicated by relatively high R^2 and NSE values.

1. INTRODUCTION

Hydrological analysis can be done by assuming a transformation process that will occur following specific rules to describe the biophysical condition of the watershed, such as soil maps and land use in the transformation process, which will be compiled in a hydrological model (Harto, 2000). One of the examples is the Soil and Water Assessment Tools (SWAT). SWAT is one of the hydrological models which can be use to analyze such things as discharge, water quality, and sedimentation in a watershed (Arnold & Fohrer 2005).

SWAT is a model developed in America used to analyze sedimentation, the effect of land management, and water quality (Betrie *et al.,* 2011). SWAT has been widely used in Asian countries to assess the impact of land-use, including paddy fields, discharge, and sedimentation analysis. The calculation of the water in SWAT for paddy plants is still the same as other crops that should be different, which use the SCS (Soil Conservation Service) method by getting the best curve number (CN) value. This condition still does not describe the actual conditions in Indonesia, where the use of water systems for lowland paddy in Indonesia is very different from paddy in America (Sapei *et al*., 2015).

Kang *et al*. (2006) developed an algorithm related to the calculation of the percolation of puddles in paddy fields in Japan to calculate the maximum number of daily loads. Then Xie & Cui (2011) developed an algorithm for paddy fields related to the maximum depth of inundation and irrigation. Watanabe *et al*. (2013) discussed using two approaches to insert the influence of lowland paddy in SWAT, which use the curve number (CN) to use maximum inundation and look at the response of runoff to rain. The model of the development of the SCS method has also been stimulated by Jung *et al*. (2012). The development of the paddy field module from the Pothole module in SWAT has been modeled according to the hydrological conditions in Japan (Sakaguchi *et al*., 2014).

The Maros River is located in the Maros Regency area. The area of the Maros watershed is 597087.08 ha. The area of paddy fields is in the Maros watershed of 8300.253 ha or 13.90% of the watershed (Wahyuni, 2012). Maros River discharge analysis can be modeled using the modified SWAT (mSWAT) program. Modified of the SWAT module has been carried out in research of Stiyanto, (2015) to be used as a reference and produce more accurate analytical data because it uses a water balance approach with inundation to paddy fields. The purpose of this research was to implement a mSWAT program to predict the results of discharge based on hydrological analysis in the sub-Watershed area of Maros River in South Sulawesi.

2. MATERIALS AND METHODS

2.1. Method of Collecting Data

The research was carried out in several stages: collecting secondary data, conducting library research such as books and journals, processing simulation data, and compiling reports. The stages of activity in this research begin with collecting related data that will be used for the simulation process. Furthermore, it is carried out with a literature study to obtain supporting theories that can assist the research preparation process.

The tools used, such as MapWindow 4.8.8, MWSWAT 2012, MWSWAT, has been modified. The materials used include: (1) climate data include daily rainfall were obtained from the BMKG office for the period 2015 to 2019 at five closest rain stations from the Maros River; (2) daily discharge data at the outlets (for the period 2015 to 2019) were obtained from the River Basin Organization (BBWS) of Pompengan – Jeneberang; (3) land use maps in 2020 were obtained from the Center for the Ministry of Environment and Forestry (KLHK); (4) Indonesian Map (RBI) was obtained from the Geospatial Information Agency (BIG) in the form of a Digital Elevation Model (DEM) and slope class; (6) soil map with a scale of 1: 250,000 was obtained from Food and Agriculture Organization (FAO).

2.2. Data Processing

The required input data such as soil types, climate data include rainfall data, land use, and hydrolog data have been prepared in the data collection process. They are inputted into the input data file. The stages of the analysis activities carried out are as follows:

2.2.1. Watershed Delineation Process

The delineation process uses DEMNAS data with a resolution of 30 m processed using MapWindows software. The observation area will be delineated based on the natural topographic boundaries in the Maros River watershed. The method used in the delineation process was the threshold area method 100 ha, where the size of the threshold value used will determine the number of sub-basins formed.

2.2.2. Establishment of HRU (Hydrological Response Unit)

The hydrological analysis was formed based on creating the Hydrological Response Unit (HRU) in the SWAT model (Olivera *et al.,* 2006). HRU can describe the influence of a watershed area on the hydrological factors that occur in the area, the division of the area based on soil characteristics, land use, and land slope.

2.2.3. Daily and Monthly Discharge Simulation

After establishing the HRU, the climate data for a weather generator (WGN) input were formatted. The 2012 SWAT will use the climate data from WGN output to run the SWAT model in the Maros River.

2.2.4. Model Calibration and Validation

The simulation discharge obtained from the 2012 MWSWAT Running program process is calibrated and validated using mSWAT software. This calibration and validation were performed using the SUFI2 (sequential uncertainty fitting version 2) method. This method works by entering hydrological parameters by trial and error. Before calibration, the NSE and R^2 values of the daily discharge from the SWAT simulation results are known. According to Latifah (2013), the value of NSE (Nash Sutcliffe Efficiency) is defined as an objective function for optimization purposes. The value of the NSE coefficient shows the level of accuracy of the model (Allen *et al.*, 2019). The NSE value is determined using equation (1).

$$NSE = 1 - \frac{\Sigma(y-\hat{y})^2}{\Sigma(y-\acute{y})^2} \quad (1)$$

The simulation is considered good if the NSE value > 0.75, satisfying if 0.36 ≤ NSE ≤ 0.75, and not good if NSE < 0.36 (Neitsch *et al.*, 2004). To see the accuracy of the model output pattern with the results of field observation, a deterministic coefficient R^2 is used. The value of R^2 is determined using equation (2).

$$R^2 = \frac{[\sum_{i}^{n}=1(Qm,i-\bar{Q}m)(Qs,i-\bar{Q}s)]^2}{\sum_{i}^{n}=1(Qm,i-\bar{Q}m)^2 \sum_{i}^{n}=1(Qs,i-\bar{Q}s)^2} \quad (2)$$

If R^2 is close to 1, then there is a pattern of a close relationship between the prediction results of the model and the results of field observations. The SWAT model uses more than 500 hydrological parameters for calibration (Arnold *et al.*, 2012). Not all parameters are used at the calibration stage. Parameter selection is made by conducting a literature study on the often-used parameters in the SWAT model. The value of these parameters is calibrated by trial and error to get the best value seen from the results.

Validation is done by entering the best parameter values from the calibration results. SWAT model was calibrated and validated using SWAT Model, the obtained R^2 and NSE values were re-analyzed with the Pothole application value for paddy fields in the Maros sub-River. The resulting output value was more accurate than the previous one.

2.2.5. Original SWAT (Original) and mSWAT Program for paddy fields

It was carried out in three conditions of the paddy field hydrology approach: (1) without the Pothole module (original) with the SCS method and the default CN value, (2) with the Pothole module (pothole), (3) and with the modified lowland paddy module. At First, simulations for each condition were carried out on three land-use conditions. Then, the treatment was carried out to see and compare the value of the model evaluation and discharge for each condition. After simulation, the SWAT model is calibrated and validated according to the inputted data.

2.2.6. Evaluation

This SWAT is evaluated by calibration and validation performance. Performance evaluation in this study uses the statistical method of deterministic coefficients (R^2) and NSE based on comparing the simulation discharge results with the observed discharge from the original, pothole, and mSWAT. The three treatments were carried out equally, and the better one would be chosen based on the three treatments' most significant R^2 and NSE values. The conditional value of R^2 is 0 – 1, and the conditional value of the NSE is 0.75 ≤ NSE ≤ 0.36. The original was carried out without changing anything from the ArcSWAT system, and the pothole was slightly modified by activating the paddy module in the ArcSWAT system. In contrast, the mSWAT was modified to the paddy module which was adjusted to the situation in Indonesia.

Tabel 1. Land use of Maros River (KLHK, 2020)

Land Use Type	Area	
	(ha)	(%)
Secondary Dryland Forest	11,060.552	18.52
Plantation Forest	1,765.332	2.96
Shrubs	1,899.297	3.18
Settlement	579.430	0.97
Open Ground	78.565	0.13
Meadow	120.111	0.20
Waterbody	417.380	0.70
Secondary Mangrove Forest	3.791	0.01
Dryland farming	4,364.598	7.31
Mixed Dryland Farming	28,999.766	48.57
Paddy field	8,300.253	13.90
Pond	2,054.556	3.44
Airport/Port	65.076	0.11
Total	**59,708.707**	**100.00**

3. RESULTS AND DISCUSSION

3.1. Location Interview

Generally, the climate in Maros Regency can be categorized as a humid tropical climate. Types of land use and changes in land use in a watershed significantly affect the area's hydrology. Types of land use on the Maros River are grouped into several types of use such as secondary forest land, plantation forest, shrubs, settlements, open land, on grass, water bodies, secondary mangrove forest, dryland agriculture, secondary dryland agriculture, paddy fields, ponds. The most prominent land-use of the total area of the Maros River is mixed dryland agriculture with a percentage of 48.57%, and the slightest land use of the total area of the Maros River is a secondary mangrove forest with a percentage of area coverage of 0.01% (Table 1). The land use of the Maros River is presented in Figure 1a.

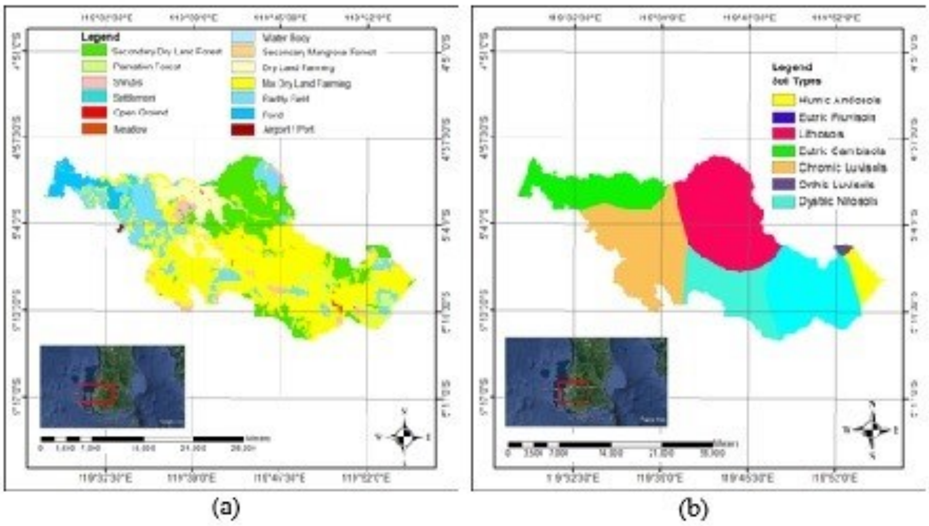


Figure 1. (a) Land use map, and (b) Soil type map

There are several elements that influence the type of soil in an area, including the color of the soil, soil texture, soil structure, and consistency land (Setiawan *et al.*, 2018). Soil types in the Maros River are grouped into seven soil types: humic andosols, orthic luvisols, lithosols, eutric cambisols, chromic luvisols, eutric luvisols, and dystric nitosols. The type of soil in the Maros River, as shown in Figure 1b, is dominated by lithosols with a percentage of 25.85% (15,434.049 Ha), and the minor soil type is orthic luvisols with a percentage of 0.41% (245.759 Ha). The type and area of land on the Maros River can be presented in Table 2.

Table 2. Soil types distribution of Maros River (FAO, 2020)

Type of Soils	Area	
	(ha)	(%)
Lithosols	15,434.049	25.85
Eutric Cambisols	7,991.071	13.38
Humic Andosols	1,892.962	3.17
Dystric Nitosols	7,883.180	13.20
Chromic Luvisols	14,550.293	24.37
Orthic Luvisols	245.759	0.41
Eutric Fluvisols	11,711.393	19.61
Total	**59,708.707**	**100.00**

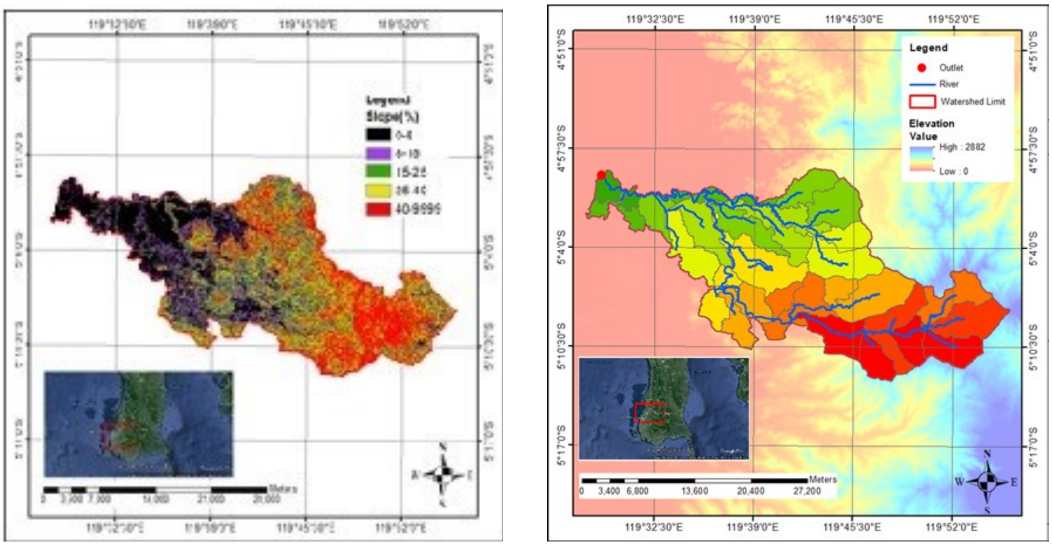
Table 3. Slope of Maros River

Slope (%)	Area	
	(ha)	(%)
0 – 8	15,677.425	26.26
8 – 15	10,437.894	17.48
15 – 25	10,969.421	18.36
25 – 40	13,610.655	22.80
> 40	9,013.262	15.10
Total	**59,708.707**	**100.00**

Land slope map with five different classes are shown in Figure 2a. The land slope of 0 – 8% is about 26.26%, and land slope of 25 – 40% is 22.80%. The Maros River area is close to two Bantimurung Bulusaraung Mountain and Tompobulu National Parks, so the slope height varies. The distribution of slope were presented in Table 3.

3.2. Watershed Delineation Process

This delineation stage uses 8 x 8 m DEMNAS data, coordinates of discharge measurement outlet points, watershed boundary maps, and river flow network maps. The delineation process is carried out to divide the catchment area into several sub-basins or catchment areas (Neitsch *et al.,* 2004). After delineation, the Maros River is divided into 39 catchments. The pattern of water flow is very dependent on the elevation value. The chosen outlet is the discharge measurement post of Maros Kassi. The delineation map is presented in Figure 2b.



(a) (b)

Figure 2. (a) Slope and (b) Delineation map of Maros River

3.3. Establishment of Hydrological Response Unit (HRU)

HRU is a land unit with elements of sub-watershed characteristics that affect the occurrence of erosion and the smallest unit of analysis used in the calculation of the SWAT model. The land unit formed by the SWAT model overlays the results of DEM data, soil type data, and land use data. The HRU formed by the model using the threshold by percentage method is 165 HRU.

The results of the HRU formation provide information on land use, soil, land slope, area, and percentage of the watershed (Ekaputra *et al.,* 2017). In addition to performing hydrological analysis based on soil types and specific land uses, this process is useful in entering slope data. Types of land use and changes in land use in a watershed significantly affect the area's hydrology.

3.4. Daily Discharge Simulation

Input climate data in daily rainfall data, maximum and minimum temperatures, humidity, solar radiation, and wind speed for five years (2015-2019). In this SWAT simulation, a heating period of 2 years is carried out. The heating period or the number of years skip (NYSKIP) is required for better estimation results (Spruill *et al.,* 2000). Without a warm-up period, the model tends to overestimate the yield at the start of the model simulation (Leo *et al.,* 2013). First, the climate data are entered into ArcSWAT 2012 in wgn (weather generator) format. Then, the data will be run to obtain the daily simulation discharge data. The comparison of SWAT simulation discharge and observation discharge is presented in Figure 3.

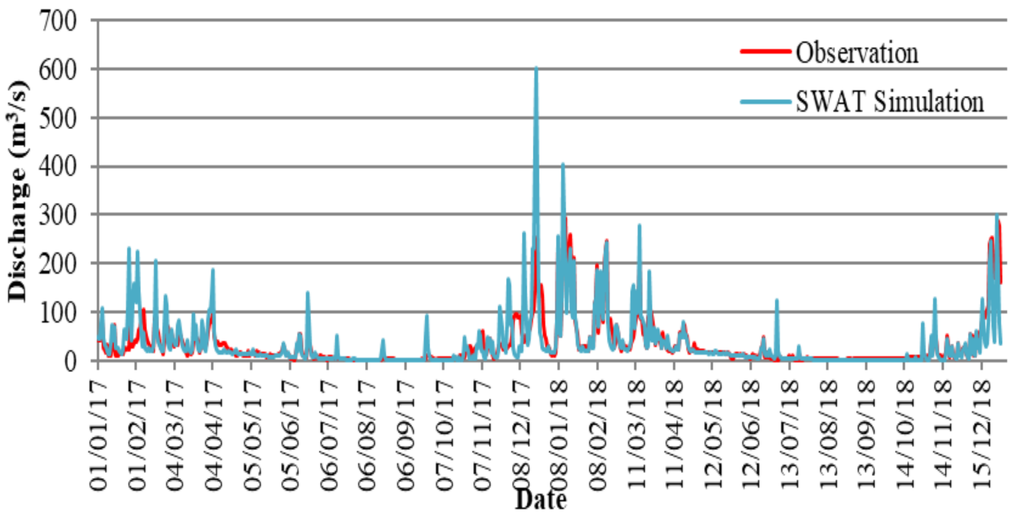


Figure 3. The daily discharge simulation and observation discharge original before calibration process

The simulation of daily discharge results that have been compared with observational discharge data from the Pompengan – Jeneberang River Basin Basin (BBWS) before calibration was obtained with an R^2 value of 0.586 and an efficiency of NSE 0.375. The NSE value is in the satisfying category when viewed from the literature. The simulation is considered good if the NSE value > 0.75, satisfying if 0.36 < NSE < 0.75, and not good if NSE < 0.36 (Neitsch *et al.,* 2004). A satisfying value is still required for calibration and validation. The simulated discharge data in the SWAT model has a value close to the field's observation data.

3.5. Calibration and Validation Model

Calibration is the process of selecting a combination of parameters to improve the coherence between the observed/measured hydrological response (observations) and the simulation results (Abbaspour 2008). Model calibration is carried out to obtain adaptive conditions in the field. According to Indarto (2012), validation is evaluating the model to get an idea of the level of uncertainty possessed by a model to predict the hydrological process. The calibration and validation of the SWAT model carried out in this study used SWAT-CUP with the SUFI2 (Sequential Uncertainty Fitting) method.

Calibration and validation were performed by comparing the daily discharge simulation results with the observed discharge in the 2017 – 2018 range. The calculation was carried out by trial and error. This method only takes 18 parameters that are considered sensitive and are considered to be able to affect the results, as in Appendix 2 significantly. The value of this calibration parameter is obtained from a literature study on research that has been done previously, namely Ryandika (2015). The aim of calibration is that the output of the model used is close to the output of the Maros River. The calibrated output is the discharge result by comparing the predicted results (flow_out) with the observations at the Maros Kassi observation station using statistical criteria. The calibration uses 2017 and 2018 water discharge data for the daily period from January 1 to December 31 from the Maros Kassi outlet.

Observational discharge data entered as input into the model is data for 2017 – 2018. After calibration, the daily simulation R^2 and NSE values become 0.706 and 0.668. These results indicate that the model is included in the satisfactory category and has increased from before the calibration process. This can happen because R^2 is a validity index that measures the goodness of a value or goodness of fit from the regression equation, so the percentage of variation in total data in the dependent variable described by the independent variable is required to have the same characteristics or distribution fluctuations (Rau, 2012). In the case of the Maros River discharge analysis, the fluctuations in the discharge distribution are close, so a good NSE value is produced. The comparison graph of daily discharge simulation and daily discharge observation after parameter calibration is performed presented in Figure 4.

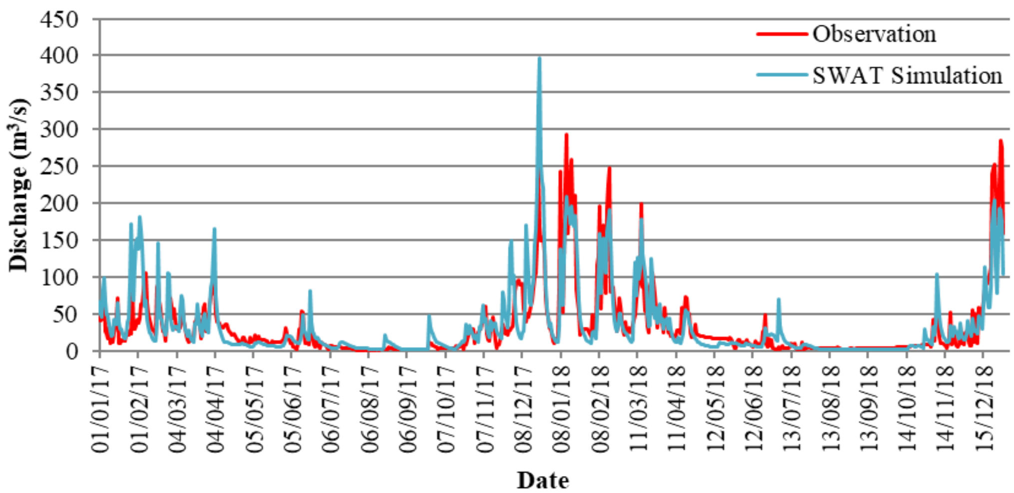


Figure 4. The daily discharge simulation and observation discharge original after calibration process

The next stage is to carry out the model validation process. The validation step proves that a process/method can provide consistent results following the established specifications. The validation was used in 2019, where the year is the year after the previous calibration process, namely 2017 – 2018. The parameter values used during calibration are reused in the validation process. Validation is still carried out on the

SUFI2 program at SWAT-CUP, only replacing the 2019 discharge observation value that has been included in the program. The comparison of daily discharge simulation and daily discharge observation without a validated pothole is presented in Figure 5.

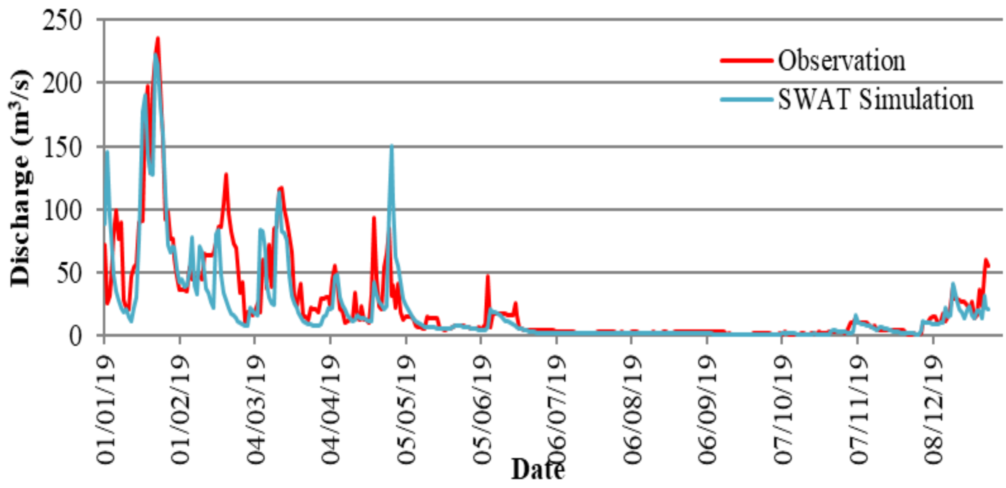


Figure 5. The daily discharge simulation and observation discharge original after validation process

The validation process produces an R^2 value of 0.706 and NSE of 0.685 for the daily simulation validation results. Therefore, the model is categorized as satisfactory and can be used. The simulation results originals will be compared with the second simulation with a mSWAT program, and a more accurate discharge output will be produced later.

3.6. Application of Pothole Module

This stage re-simulates the SWAT model, but changes have been made by applying the Pothole module for paddy fields. The function of the application of potholes for paddy fields is to calculate the water system of paddy fields because paddy fields cannot be equated with other plants. The simulation process produces a comparison of the daily discharge simulation and daily discharge observed, which is presented in Figure 6.

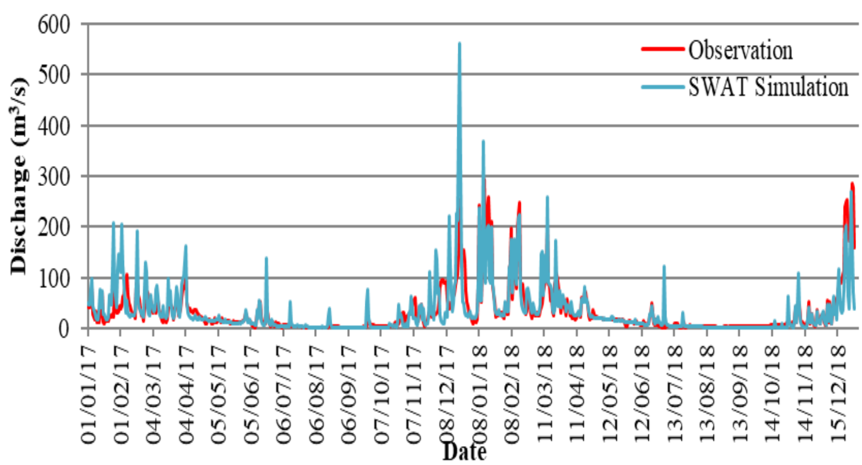


Figure 6. The daily discharge simulation and observation discharge with Pothole before calibration process

This Pothole is simulated in the form of a cone so that in this application, it is possible to inundate the formed HRU. Therefore, changing the POT_FR, POT_TILE, and POT_VOLX parameter values is necessary. The POT_FR value is obtained from the percentage of HRU formed on paddy fields, which is 100%. POT_TILE and POT_VOLX are the default values in the 2012 SWAT database, namely 5 and 100. This data will be used in the SWAT EDITOR to get the new daily discharge data results, as shown in Figure 7.

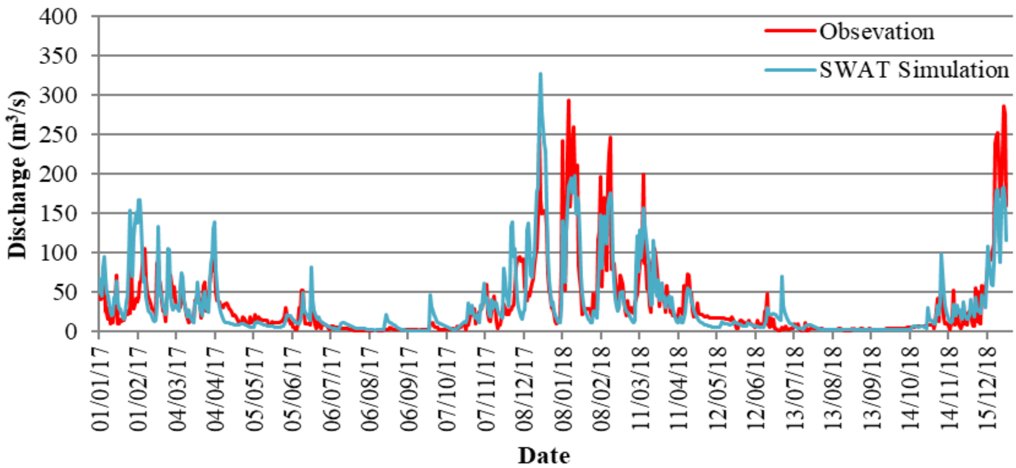


Figure 7. The daily discharge simulation and observation discharge with pothole after calibration process

The results of the Pothole module SWAT simulation for paddy fields that have been carried out produce R^2 and NS values, namely 0.589 and 0.459. They were then calibrated and validated in the same way using SWAT-CUP and the same input parameters as the pothole module simulation. Therefore, the first stage is calibration with several sensitive parameters, the same as simulations originals. The calibration results produce R^2 and NSE values, namely 0.708 and 0.685. The comparison of simulated discharge and daily observation discharge from calibration results is presented in Figure 8.

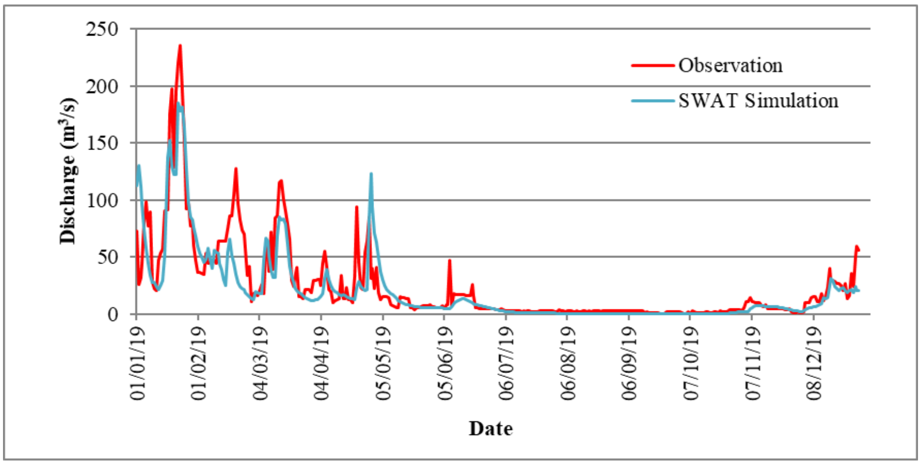


Figure 8. The daily discharge simulation and observation discharge with pothole after validation process

The validation stage is carried out in the SWATCUP program by replacing the calibration observation discharge with the validation observation discharge (Nash & Sutcliffe, 1970). From the validation process, the results of R^2 and NSE for daily simulations are 0.736 and 0.726. The results obtained indicate that the model is good and can be used. The comparison of daily discharge simulation and daily discharge observation after validation is presented in Figure 8. This curve is different from SWAT original, and mSWAT was compared to SWAT original, the fit of the flow rate fit between the results of running data is closer to the flow of observation data. However, the mSWAT resulted in a better fit between the flow of running data and the flow of observation data compared to SWAT with the pothole module. The calibration and validation results of the pothole simulation model are included in the excellent category by increasing R^2 and NSE values from the process before calibration.

3.7. mSWAT

The SWAT modification that has been carried out is a change to the paddy field or pothole module to suit the hydrological model that exists in Indonesia. The SWAT model simulation is carried out again at this stage, but changes have been made, namely by applying a modified Pothole module for paddy fields. The modified paddy field module can be used by copying the modified executable to MWSAT2012 with the name SWATUser and changing the database according to hydrology in Indonesia. Then run SWAT. The paddy field cover from other land cover is separated after the HRU formation process.

After being selected and separated, only the paddy field cover is shown. In the POT_FR, POT_TILE, and POT_VOLX columns, the values are changed according to the results of the modifications that have been made, namely changing the POT_FR value to 1, POT_TILE to 5, and POT_VOLX to 100. The SWAT process is continued by re-reading the HRU section that has been changed and in the running SWAT section is custom, i.e., userSWAT.exe. The SWAT EDITOR will use this data to get a new daily discharge data result. Finally, the simulation process produces a comparison of the simulated discharge and daily observed discharge.

The results of the mSWAT simulation for paddy fields that have been carried out have changed the simulation value original. Although the change value is not too large, it affects the daily R^2 and NSE values, of 0.433 and 0.593 respectively. The mSWAT simulation carried out is then calibrated and validated in the same way using SWAT-CUP and the same input parameters as the simulation original. The first stage is calibration with several sensitive parameters that have been determined from several kinds of literature. The calibration results produce R^2 and NSE values of namely 0.725 and 0.721 respectively. The comparison of daily discharge simulation and daily discharge observed is presented in Figure 9.

The results of the calibration of the mSWAT simulation model are included in the excellent category. The parameters used for the modification are presented in Appendix 2. There was a change in the values of R^2 and NSE in both simulations. The relationship between observation and simulation discharge original and with mSWAT after calibration is presented in Figure 10.

The calibration process entered the good category can proceed to the validation stage. The validation stage is carried out in the SWATCUP program by replacing the calibration observation discharge with the validation observation discharge. From the validation process, the results of R^2 and NSE for daily simulations are 0.756 and 0.754. The comparison of daily discharge simulation and daily discharge observation after validation is presented in Figure 11. The values of R^2 and NSE at the validation stage changed, but the changes were not too significant.

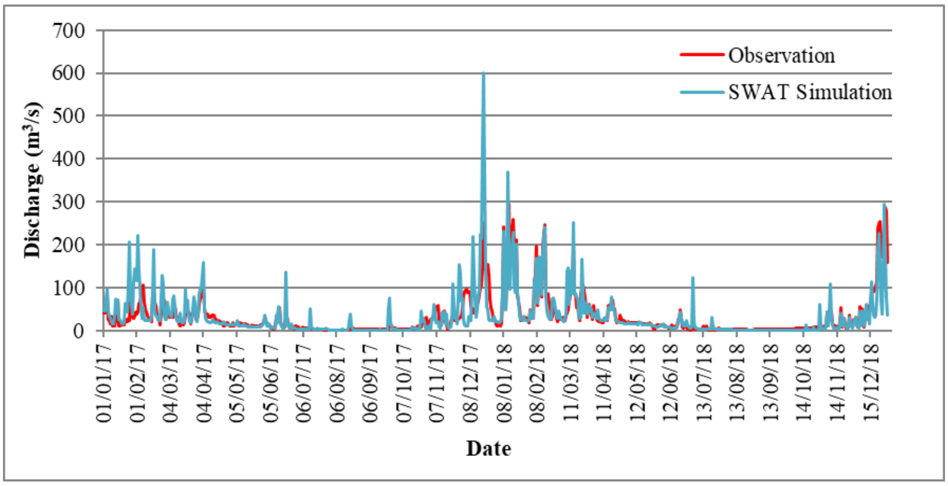


Figure 9. The daily discharge simulation and observation discharge mSWAT before calibration process

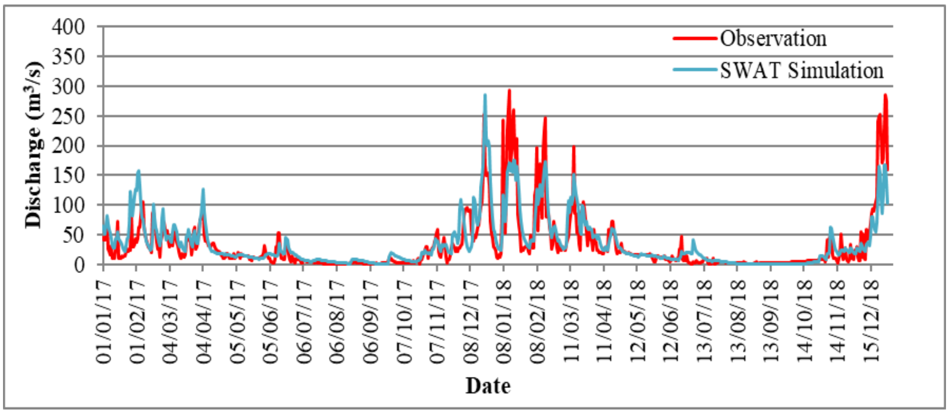


Figure 10. The daily discharge simulation and observation discharge MSWAT after calibration process

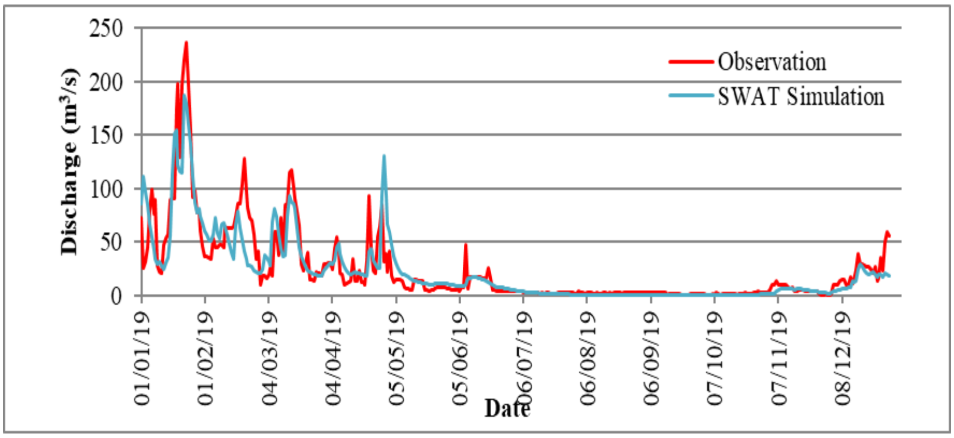


Figure 11. The daily discharge simulation and observation discharge MSWAT after validation process

3.8. Evaluation

After the simulation of the SWAT model, it can be seen the difference in the values of R^2 and NS between the method original and the mSWAT. Run data was also carried out using the original pothole module as an additional comparison. The minimum and maximum discharge values for SWAT original, SWAT with pothole module, and mSWAT are presented in Table 4. The discharge relationship is compared between the results of running data and observed discharge. Of the three types of running data, the mSWAT maximum and minimum discharge values are closer to the observed discharge data than the results of running SWAT pothole and SWAT data originals. Meanwhile, the relationship between pothole SWAT discharge and observation discharge is closer than SWAT original or original.

Table 4. Maximum and minimum discharge values

Proses	Qmax (m^3/s)	Qmin(m^3/s)
Observation	293.090	0.100
Original	397.300	1.194
Pothole	327.400	1.303
mSWAT	285.800	0.354

The values of R^2 and NS can be seen in Table 5. It can be seen that the mSWAT program has a better value than the SWAT model original. This is due to changes in the parameter values POT_FR. POT_TILE. and POT_VOLX have a large impact on the use of paddy fields in the Maros River area.

Table 5. The values of R^2 and NS

Process	Original		pothole		mSWAT	
	R^2	NSE	R^2	NSE	R^2	NSE
Before Calibration	0.586	0.375	0.589	0.459	0.593	0.433
After Calibration	0.706	0.668	0.708	0.685	0.725	0.721
After Validation	0.706	0.685	0.736	0.726	0.756	0.754

Iterations performed on the three processes (original, pothole, and mSWAT) are different. In the SWAT process without a pothole, eight iterations are performed. The SWAT process with the pothole module and mSWAT is carried out in fewer iterations than the original. Which is only one iteration.

Based on Table 5, the modified NSE and R^2 SWAT values produced better values than SWAT original or original and SWAT using the pothole module. This happens because the modification of SWAT has changed the shape of the paddy module (Pothole), which was initially a cone shape to a square shape. Moreover, the hydrological conditions have been adjusted to the hydrological conditions in Indonesia.

4. CONCLUSIONS AND SUGGESTIONS

The mSWAT program had R^2 and NSE value of 0.725 and 0.721 respectively. By using SWAT program original was obtained R^2 values of 0.706 and NSE value of 0.668. While the SWAT with Pothole that has been validated produces an R^2 value of 0.708 and NSE 0.685. The comparison of discharge between the simulation results and the observed result showed that the discharge of mSWAT was closer to the observed results than the discharge of SWAT original and SWAT with Pothole. It meaned that mSWAT produces a better discharge analysis value than the SWAT with pothole module and without pothole module.

The SWAT hydrological model can be used as an alternative tool in watershed management planning. The discharge analyis using mSWAT program for paddy fields had been satisfactory. The modifications made have indeed been successful, but for the parameter values the changes are still an adjustment from some literature. Adjusted parameters in mSWAT that need to be studied further.

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