Development of Paddy Field Module for Analysis Water Yield by using SWAT Program

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ABSTRACT— *SWAT has been widely used and applied to various countries in the world. However, for usage SWAT in Asia, especially in Indonesia, where water management for rice crop is different from America, the existing module was in SWAT need to be adapted to the condition watering paddy field. This research aims to develop modules rice crop that accordance with the management of paddy fields in Indonesia. It was developed by making modifications to module pothole from source code in SWAT program. Module testing was carried out on sub – upper watershed Cisadane. For evaluating the results of developed a module was seen from the value of determination (R^2) and the Nash-Sutcliffe of efficiency (NSE) based on the comparison between discharge results simulation with observation. It was also analyzed the effect of modifications toward water balance on paddy fields. Based on the results of initial simulation shows the value that was satisfactory with a reduction in discharge simulation, influence algorithm module to paddy totaling 1.37%, after going through the process of calibration and validation of the results of the model grades more satisfactory, with grades R^2 0.72 and NSE 0.71 for daily period and R^2 0.70, NSE 0.63 for monthly periods.*

Keywords— SWAT, model development, watershed, paddy field, water yield, water balance

1. INTRODUCTION

SWAT (Soil and Water Assessment Tools) is a model which is developed in the United States, it is used to analyze the influence of land management toward discharge, sedimentation, and water quality in a watershed, SWAT also has been widely used in Asia to analyze the impact of land usage including Paddy fields toward discharge and sedimentation. SWAT also has been widely used in Asia to analyze the impact of land usage including paddy fields toward discharge and sedimentation. However, the calculation of water balance in SWAT for rice crop in United State is still equated with other crops, namely using SCS (Soil Conservation Service). SCS method itself can not represent the governance of water in Paddy fields. Therefore, this condition has not depicted yet specially for the real conditions of the Paddy fields. Besides that the parameter grade of the hydrological conditions in the United States and Indonesia must be different.

Kang et al. (2006) have developed total maximum daily load (TMDL) programs for a small watershed containing rice paddy fields. Xie and Cui (2011) have developed an algorithm for paddy field related impoundment depth. Watanabe et al. (2013) have discussed the usage of two approaches to incorporate the effect of paddy field in SWAT, by using curve number (CN) to see the response runoff toward rainfall and the use of impoundment. Application of SCS development also has been tested by Jung et al. (2012). Sakaguchi et al. (2014) developed a module paddy field from pothole modules available in SWAT that are intended for paddy Field in Japan.

Cisadane watershed is one of the watersheds which passes through several administrative regions, namely Bogor, Bogor regency, the City Administration of Depok, Tangerang and South Tangerang City. The conditions Cisadane watershed today are very concerned because of the high discharge fluctuations between the rainy season to the dry season, as well as a high level of sedimentation. It is caused by population growth accompanied by economic and industrial growth in the region. The proportion of paddy fields in the watershed Cisadane wide enough, for example, Paddy field area in the sub-upper watershed Cisadane (outlet Batu Beulah) reached 18086 ha (21.21% of total sub-upper watershed Cisadane). Alternative analysis of management planning watershed Cisadane using SWAT has done by Junaidi (2009) and the influence of land management also have been analyzed by Nilda (2014).

This research aims to develop paddy field module to predict the water yield using the program Soil and Water Assessment Tool (SWAT) in accordance with the conditions of the paddy fields in Indonesia by taking the case sub-upper Cisadane watershed.

2. METHODOLOGY

The research is done in the sub-upper watershed Cisadane with outlets in Batu Beulah at Bogor, Indonesia as shown in Figure 1.
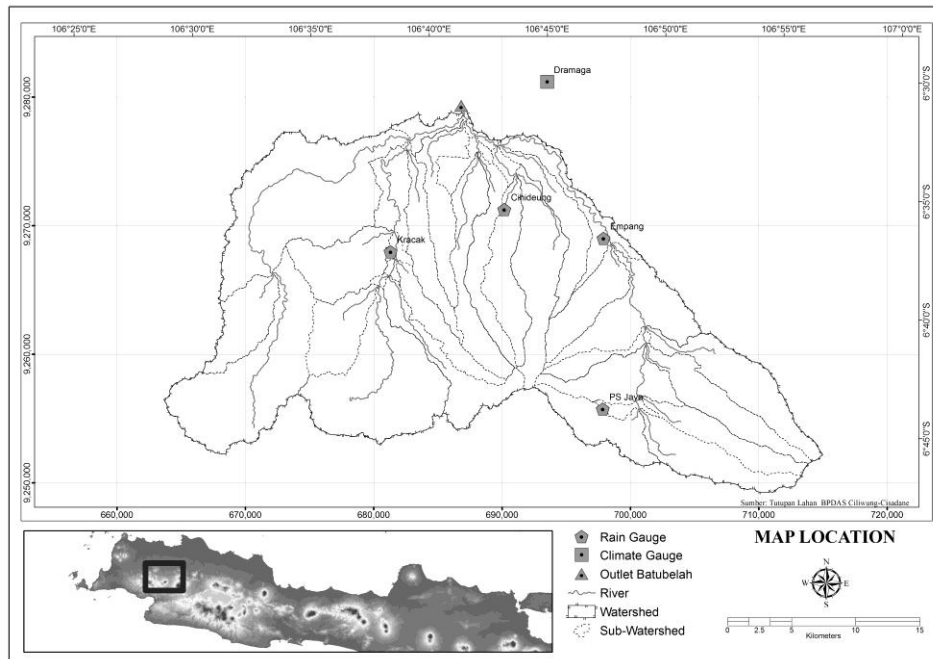

Figure 1: Sub-upper watershed Cisadane

2.1 Research framework

Research framework development is originated from simplifying the conditions of actual paddy field water system (Figure 2a). Module paddy is developed from module pothole (Figure 2b) are modified for the Paddy field with the layout of the plot-to-plot which is the general layout of the fields in Indonesia (Figure 2c).
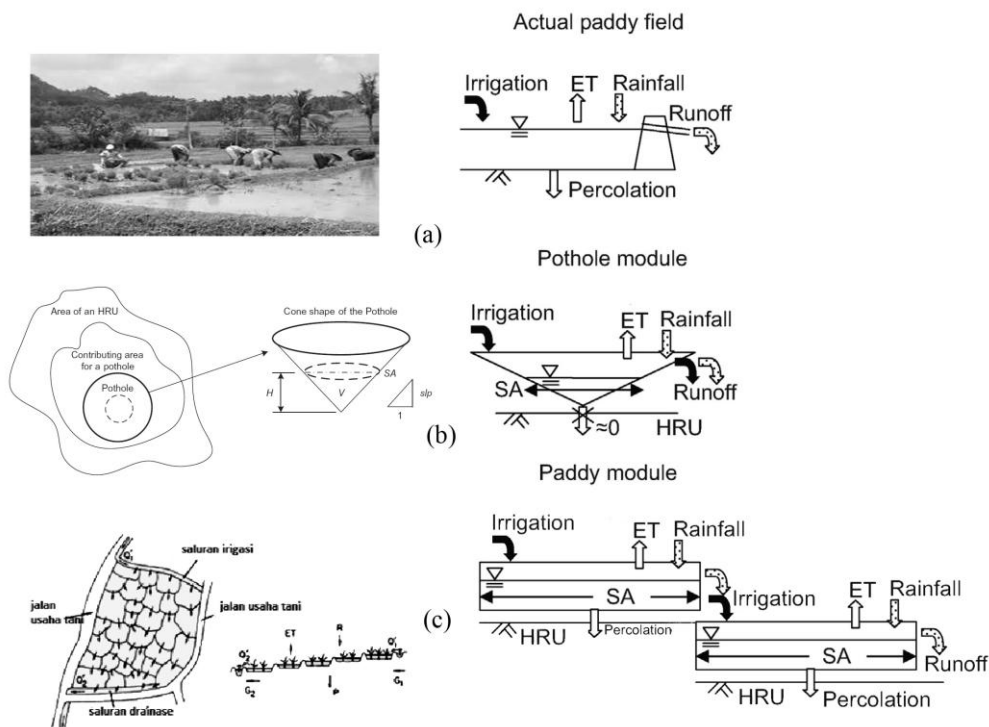

Figure 2: Schematic diagram of paddy water balance (a) the real Paddy field (b) pothole (c) module of paddy field (Sakaguchi et al, 2014, Xie and Cui 2011)

2.2 Shape of the impoundment

Module Paddy field in SWAT is pothole module where the impoundment shaped as a cone with algorithm (Eq. (1)) (Neitsch et al, 2011) and modified in order to be close to paddy field (Eq. (2)) (Xie and Cui, 2011).

$$SA = \frac{\pi}{10^4}\left(\frac{3*V}{\pi*slp}\right)^{2/3} \tag{1}$$

$$SA = area_{hru} \tag{2}$$

Where

SA	: surface area of the water body (ha)
V	: volume of water in the impoundment (m³ H₂O)
slp	: slope the HRU (m/m)
area_hru	: area of the HRU (ha)

2.3 Percolation Algorithm

The algorithm module pothole in SWAT (Eq. (3) - (5)) which has been described in SWAT theory (Neitsch et al, 2011) the process of seepage on the pothole is used to calculate the amount of percolation of water bodies to the soil profile, the process stopped when level ground water reaches field capacity (Eq. (5)). On the other hand, the discussion of ground water (Eq. (6) and (7) the process drainable will stop or equal to zero when the soil moisture content is below field capacity (Eq. (5)) As a result, the condition of the model will remain at field capacity although some of the water is still undergoing a process of ET. Mutual link grade field capacity between algorithms process the seepage and the process of percolation will cause a problem (deadlock).The process of seepage can not continue the calculation because percolation process does not diminish grade of soil moisture content, and so does percolation process could not continue as the seepage does not increase the grade of soil moisture. To overcome this Sakaguchi et al (2014) modified by entering new parameters such as the rate of potential percolation (Eq. (8) and (9)).

$$V_{seep} = 240K_S SA \qquad \text{if } SW < 0.5\ FC \tag{3}$$

$$V_{seep} = 240\left(\frac{1-SW}{FC}\right)K_S SA \qquad \text{if } 0.5FC \le SW < FC \tag{4}$$

$$V_{seep} = 0 \qquad \text{if } SW \ge FC \tag{5}$$

$$SW_{ly,excess} = SW_{ly} - FC_{ly} \qquad \text{if } SW_{ly} > FC_{ly} \tag{6}$$

$$SW_{ly,excess} = 0 \qquad \text{if } SW_{ly} \le FC_{ly} \tag{7}$$

$$V_{seep} = 10P_p SA \qquad \text{if } V_{stored} > 10P_p SA \tag{8}$$

$$V_{seep} = V_{stored} \qquad \text{if } V_{stored} \le 10P_p SA \tag{9}$$

Where

V_{seep}	: volume of water lost from the water body by seepage (m³ H₂O)
K_S	: effective saturated hydraulic of the 1st soil layer in the profil (mm/hr)
SA	: surface area of water body (ha)
SW	: soil water content of the profil on a given day (mm H₂O)
FC	: field capacity soil water content (mm H₂O)
$SW_{ly,excess}$	: drainable volume of water stored in the saturated layer (mm H₂O)
SW_{ly}	: water content of layer on a given day (mm H₂O)
FC_{ly}	: water content of the soil layer at field capacity (mm H₂O)
P_P	: daily rate of potential percolation of a paddy field during ponded condition (mm H2O)
V_{stored}	: daily volume of water stored in water body at the beginning of day (m³ H₂O)

2.4 Evaporation Algorithm

Calculation of evaporation in a pothole modules is limited by the potential evapotranspiration (PET) (Eq. (10)) so that the existing of the equation make the less water which involve in this process. For fixing this condition is by utilizing the modified algorithm evaporation algorithms that exist in the HRU (Eq. (11)). In addition, these conditions also continue to

use the lower limit, namely when there is no water in the impounding, the evaporation process is considered zero (Eq. (12)). To avoid overflow in the next stage then used the coefficient of evaporation (η) where the pothole has been set at 0.6.

$$V_{evap} = 5\left(1 - \frac{LAI}{LAI_{evap}}\right)E_0 SA \qquad if\ LAI < LAI_{evap} \qquad (10)$$

$$V_{evap} = \eta * 10\left(1 - \frac{LAI}{LAI_{evap}}\right)E_0 SA \qquad if\ LAI < LAI_{evap} \qquad (11)$$

$$V_{evap} = 0 \qquad if\ LAI \geq LAI_{evap} \qquad (12)$$

Where;

V_{evap} : volume of water removed from the water body by evaporation during the day (m^3 H$_2$O)
η   : evaporation coefficient
LAI   : leaf area index of the plants growing in the impoundment
LAI_{evap} : leaf area index at which evaporation from the watersurface does not occur
E_0 : PET for a given day (mm)

2.5 Paddy field HRU Management

To separate the process between the sub-upper watersheds which has a paddy field with a sub-upper watershed that does not have the role of paddy field pothole fraction (POT_FR) is necessary. For sub-upper watershed that has paddy field rated one and that is not zero, it is because a pothole played for the HRU. The maximum grade of the puddle of paddy field (POT_VOLX) is 100 mm for all HRU paddy fields and to flow default the pothole (POT_TILE) average 5 mm / day (Supangat and Sukresno 2008). Then to the new parameters of the percolation rate of potential (pp_perc) has a grade of 0 – 5 mm / day (Sapei 2000; Akmal et al 2014).

2.6 Model Evaluation

Evaluation of the results of the model used: the coefficient of determination (R^2), and Nash Efficiency - Sutcliffe Index (NSE) (Nash and Sutcliffe 1970).

3. RESULT AND DISCUSSION

3.1 Characteristic of sub – upper watershed Cisadane

The Land use sub-upper watershed Cisadane Upstream in 2012 can be grouped into 10 land use as shown in Figure 3. The field is the dominant land use in the sub-upper watershed Cisadane. The type of soil in sub-upper watershed Cisadane consists of 11 types of soil and it is dominated by complex red latosol yellowish brown latosols p. In general, the type of soil in the sub-upper watershed Cisadane textured loam, sandy clay loam, clay loam, and clay dust. The distribution of soil types can be seen in Figure 4.
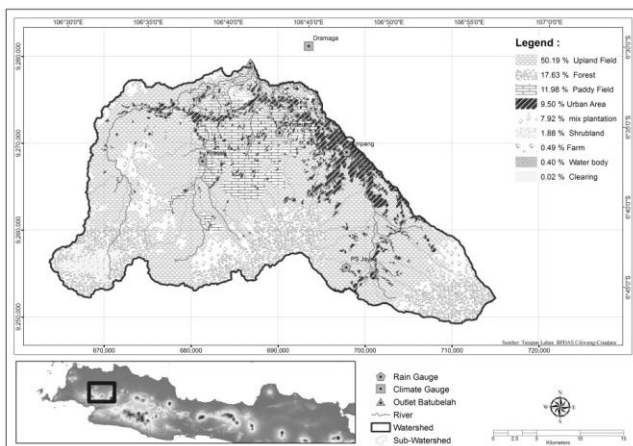

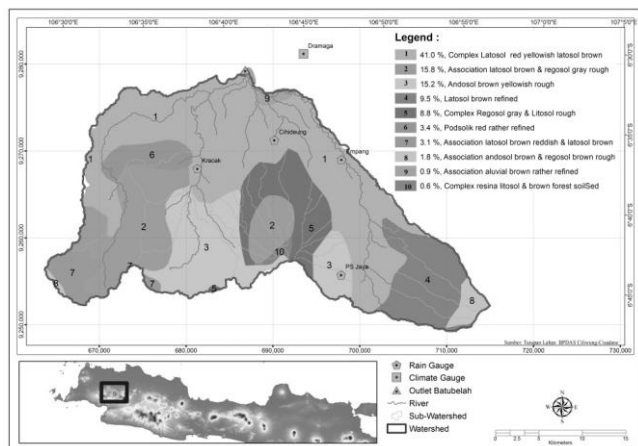**Figure 3:** Land use sup-upper watershed Cisadane   **Figure 4:** Soil type sup-upper watershed Cisadane

Climatic conditions in the sub-upper watershed Cisadane, in general, can be seen in Table 1. Monthly rainfall ranged from 182.88 mm in July to 451.37 mm in November. While the air temperature ranged between 27.69 – 29.65 0C.

Table 1Iklim sub-upper watershed Cisadane

Month	Raifall (mm)	Temperature (°C)	Humidity (%)	Radiation (MJ/m²)	Wind Speed (m/s)
January	385.11	27.69	86.94	11.14	1.15
February	392.68	27.88	87.88	11.31	1.15
March	330.57	28.67	84.82	12.83	1.20
April	340.39	29.17	85.13	14.03	1.10
May	340.06	29.17	84.68	13.82	1.08
June	208.42	28.89	83.29	13.55	1.05
July	182.88	28.65	80.95	14.88	1.09
August	199.74	29.03	79.00	16.33	1.18
September	255.53	29.55	78.25	16.18	1.24
October	326.13	29.65	80.31	15.30	1.18
November	451.37	29.14	84.07	13.40	1.09
December	346.93	28.49	85.72	11.66	1.08

Data source : BMKG Dramaga

3.2 Simulation SWAT

SWAT simulations did without options pothole (original) for the year 2010 - 2014 resulted in the average daily discharge of 89.41 m^3/s, the grade R^2 of 0.4864 and Nash-Sutcliffe efficiency (NSE) of -1.1339. For the simulation results with pothole options for land use paddy field river discharge an average of 89.68 m^3/s, with R^2 of 0.4802 and NSE of -0.8213, while modified to paddy field module river discharge the average 89.08 m^3/s, R^2 of 0.4830 and NSE of -0.8610. Fluctuations in daily discharge simulation results are presented in Figure 5. The use of paddy module can reduce the rate of water on batu belah outlet so that the closer the grade of observation. This is because in the simulation models get additional algorithms to calculate hydrological process that occurs in sub-upper watershed Cisadane. Based on the discharge rate of the resulting runoff count will be recalculated at a smaller scale again in the hydrologic response unit (HRU).

For a monthly discharge, simulation original for land use paddy field has average discharge results 90.70 m^3/s and the grade R^2 of 0.4109 and NSE of -0.2919. Simulations with the option pothole of having a discharge average 90.04 m^3/s with a grade R^2 and NSE of 0.4121 and -0.2104. While the paddy field module results obtained discharge average 89.44 m^3 / s with a grade R^2 and NSE of 0.4072 and -0.2365 Fluctuation of monthly discharge simulation before calibration results are presented in Figure 6.
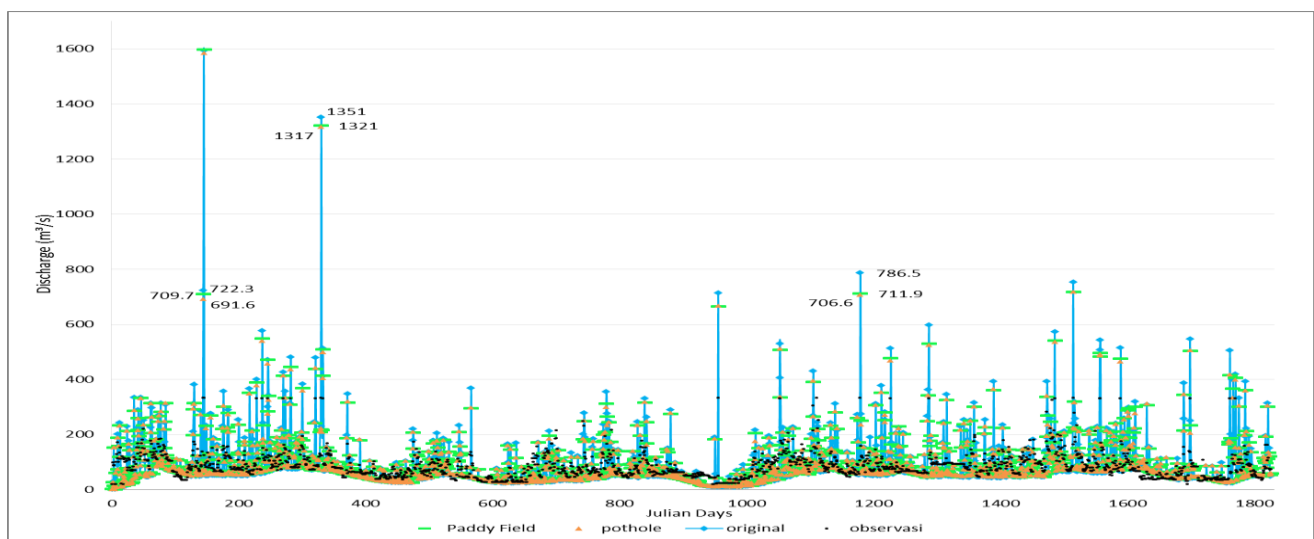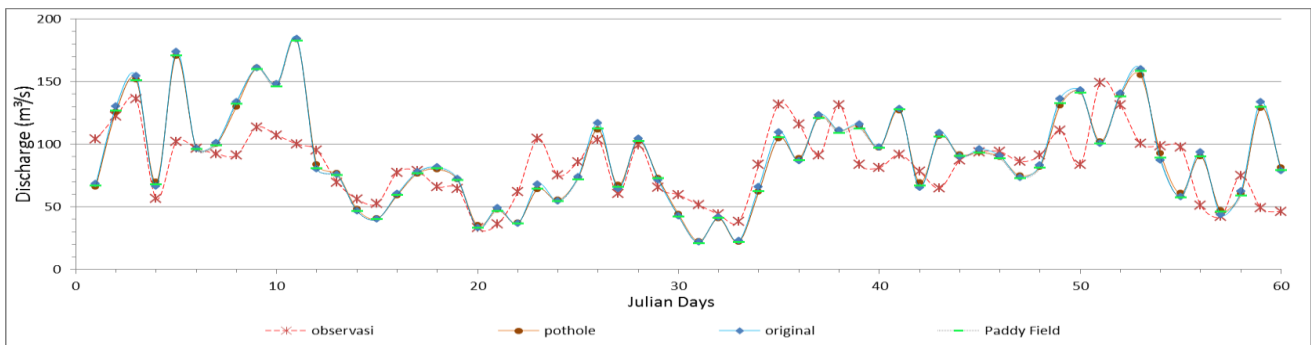

**Figure 5:** Daily discharge simulation result before calibration

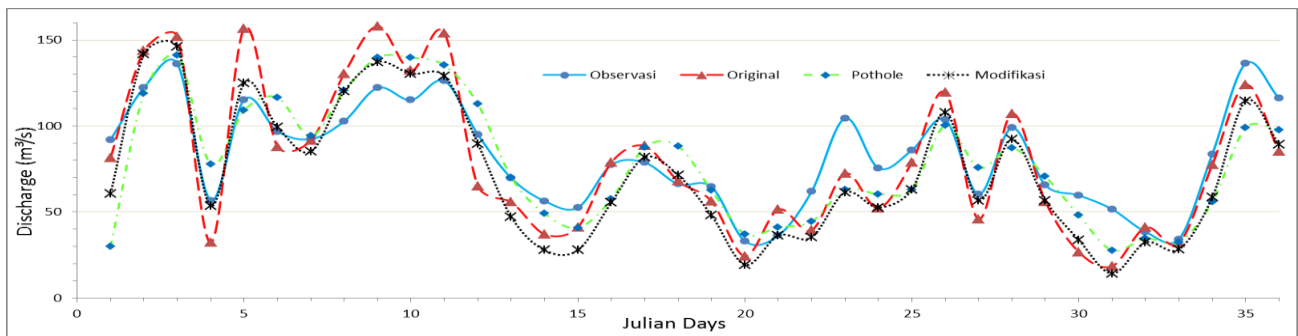**Figure 6:** Monthly discharge simulation result before calibration

The beginning of the simulation results the daily discharge and monthly discharge has not given satisfactory results when viewed from the grade of the evaluation models. It is, therefore, necessary calibration and validation process to increase the level of satisfaction with the results of the model, the influence of parameters sensitive of the model for the sub-upper watershed Cisadane.

3.3 Calibration

Calibration is done by using SWAT-CUP program. Calibration daily discharge of original the produced discharge average 75.20 m³/s, with grade R^2 of 0.50 and NSE of 0.41 by using pothole discharge average yield 76.16 m³/s, with the grade R^2 of 0.57, NSE of 0.33. whereas a paddy field module has calibration grade with average discharge 70.02 m³/s, with R^2 of 0.57, and NSE of 0.39 with the results of the calibration phase paddy field module results are still consistent with a satisfactory grade. Fluctuation is presented in Figure 7.
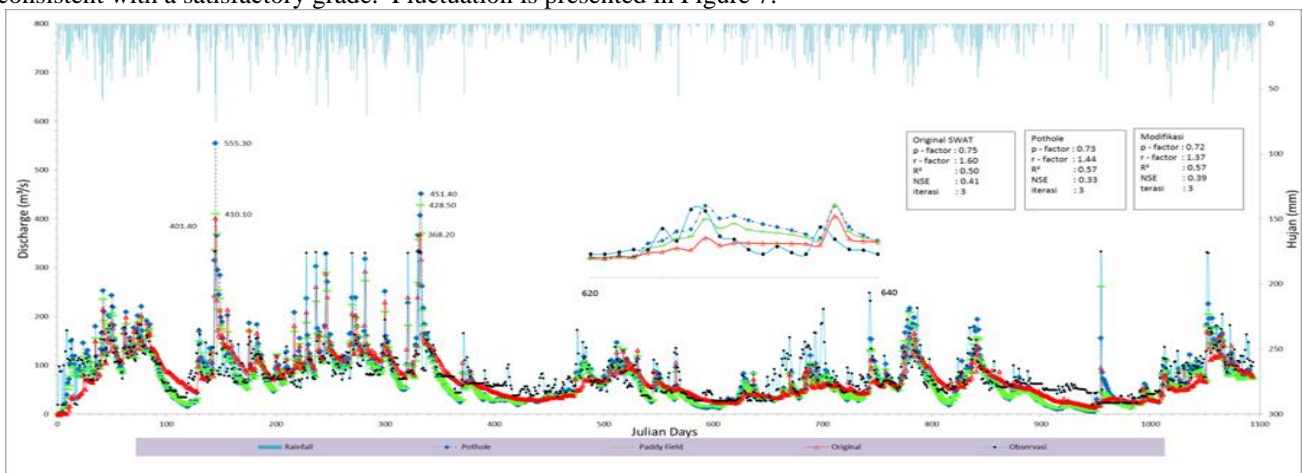
Calibration is also used for the period of discharge monthly, with original produce discharge average 79.51 m³/s, with R^2 of 0.81 and NSE of 0.53 and then option pothole produce discharge average discharge 78.60 m³/s, the grade R^2 of 0.68 and NSE of 0.55 while the module paddy field discharge average discharge 73.05 m³/s, grade R^2 of 0.84, NSE of 0.58 the iteration when calibration 4 times for all events. Fluctuation is presented in Figure 8.

Figure 8: Monthly discharge simulation result after calibration

3.4 Validation

To test the results grade parameter of calibration, validation was done using data from 2013-2014. Validation daily discharge for original produced discharge average 96.76 m^3/s, R^2 of 0.72, NSE of 0.70. Validation daily discharge with an option pothole produces 89.08 m^3/s, R^2 of 0.74, NSE of 0.71. While the paddy field module of the daily discharge validation getting a very good grade with average discharge average 94.45 m^3/s with a value R^2 of 0.72 and NSE of 0.71. With monthly discharge period for original result discharge average 97.73, R^2 of 0.72, NSE of 0.63. Validation monthly discharges with options pothole discharge yield average 89.04 m^3/s, R^2 of 0.68, NSE of 0.51, while the paddy field grade average discharge 94.55 m^3/s, R^2 of 0.70, NSE of 0.63. Figure 9 shows the daily discharge fluctuations after validation and Figure 10 monthly fluctuations.
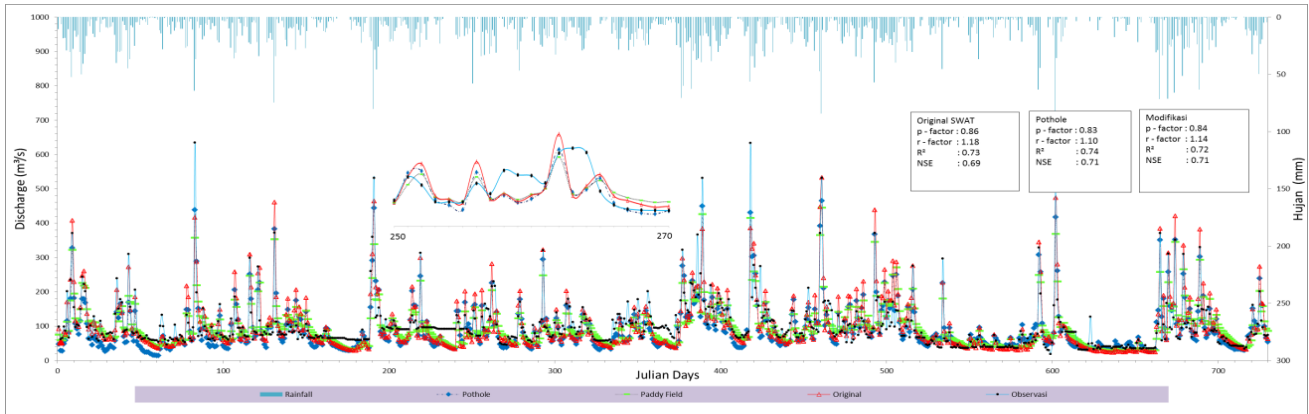

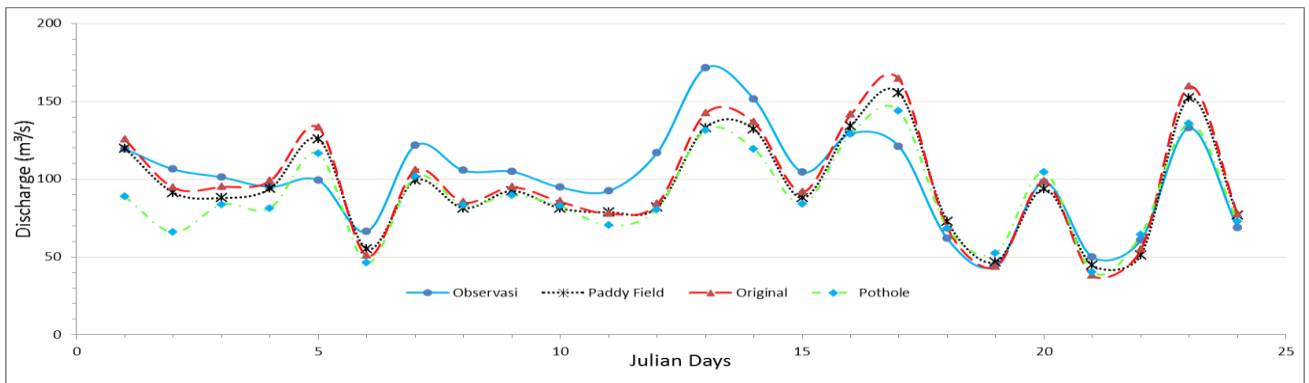**Figure 9:** Daily discharge simulation result after validation

Figure 10: Monthly discharge simulation result after validation

4. CONCUSION

The conclusion of this research proves that the modification paddy field in SWAT program reached more satisfactory grade than the original SWAT model or with an option pothole. It is based on the evaluation of the grade R^2 of 0.72 and NSE 0.7 for a daily period, R^2 of 0.7 and the NSE of 0.63 monthly periods. In addition modifications can reduce the total discharge in general for each simulation the algorithm is modified to indicate the governance of water or hydrological processes occurring in paddy fields has been managed in accordance with the purpose.

5. ACKNOWLEDGMENTS

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