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SWAT Model Performance on QSWAT Program to Predict Water Discharge in the Upper Citanduy Sub-watershed

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Abstract: The Citanduy Watershed is one of the largest watersheds on Java Island and is in a critical condition. The Upper Citanduy Sub-watershed is the main sub-watershed in the Citanduy Watershed, which requires attention because it greatly affects the quantity and quality of its water. The Soil and Water Assessment Tool (SWAT) model, a hydrological model developed in the United States, can be used to predict the quantity of water. However, the water balance in the SWAT model uses the water balance for plants planted on dry land (*upland*) and is less suitable for watersheds with rice fields (*lowland*). For watersheds with rice fields, pot holes, and modified SWAT features have been tried and developed. This study aimed to analyze the performance of the SWAT model with original, pot hole, and modified features in the QSWAT program to predict water discharge in the Upper Citanduy Sub-watershed. The results of the study indicate that the modified SWAT had the best performance compared to the original SWAT and pot-hole SWAT, as indicated by the NSE and R^2 values. The NSE values of the original SWAT, pot hole SWAT, and modified SWAT were 0.70, 0.73, and 0.75, respectively. The R^2 values of the modified SWAT, Original SWAT, and pot hole SWAT were 0.94, 0.93, and 0.94, respectively.

Keywords: Discharge; Sub-watershed; SWAT Modification; Upper Citanduy

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1. Introduction

A watershed or river basin is a natural ecosystem confined by a ridge or an area separated by topographic conditions that stores and drains rainwater [1]. Watersheds can be divided into two areas: the water-shedding area (upstream) and the water-receiving area (downstream). Citanduy Watershed is one of the largest watersheds in Java Island which is in critical conditions [2]. Citanduy Watershed has an area of 352,080 ha, consisting of five sub-watersheds, namely: Upper Citanduy Sub-watershed, Cimuntur Sub-watershed, Cijalong Sub-watershed, Ciseel Sub-watershed, and Cikawung Sub-watershed. Based on the administrative area, the Citanduy Watershed passes through two provinces in 60 sub-districts, seven regencies, and two cities. Citanduy Watershed is the main priority watershed in Java Island because it is a source of agriculture and fisheries for the community around the watershed area [3].

The Upper Citanduy Sub-watershed is located at the head of the Citanduy Watershed, which passes through 6 districts and 2 cities, namely Majalengka Regency, Garut Regency, Sumedang Regency, Kuningan Regency, Tasikmalaya Regency, Tasikmalaya City, Ciamis Regency, and Banjar City. Land use in the Upper Citanduy Sub-watershed is dominated by rice fields (29%) and mixed gardens (36%) [4]. As a buffer zone for the Citanduy

Watershed, optimal management, and good hydrological analysis are needed to maintain its quality and quantity [5]. One of the widely applied methods for assessing watershed conditions is the hydrological model [6].

The Soil and Water Assessment Tool (SWAT) model can be used to study the hydrological processes of a watershed. The SWAT is a hydrological model that is widely used to determine the impact of changes in a watershed and is a physical model used to evaluate and predict watershed conditions [7], [13], [14]. This is possible because SWAT can directly describe the characteristics of a watershed into model parameters, making it excellent for predicting the impact of existing changes. The SWAT model, which was developed in the United States, is based on the water balance for plants planted on dry land (*upland*) and is less suitable for watersheds with rice fields (*lowland*). For watersheds with rice fields, pot hole features and SWAT modifications have been attempted and developed [9,11-12,14,16]. Currently, one of the applications that can run SWAT modeling is the QGIS application using the QSWAT plugin program.

This study aimed to analyze the performance of the SWAT model with original SWAT, pot hole SWAT, and modified SWAT features on the QSWAT program to predict water discharge in the Citanduy Hulu Sub-DAS.

2. Method

This study was conducted from February to July 2024. The research location was the Upper Citanduy Sub-watershed in West Java Province. The research location is shown in **Figure 1**.

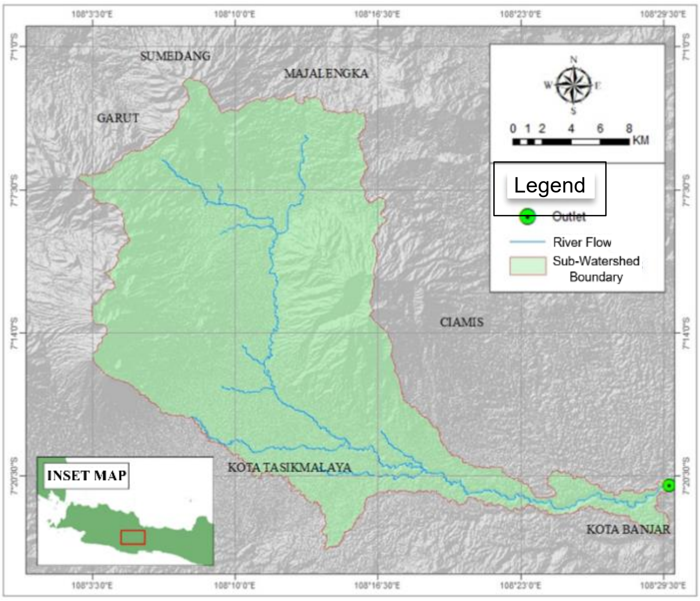

Figure 1. Research Location Map

2.1. Tools and Data

The tool used in this study was a laptop computer. The laptop was equipped with Microsoft Access, Microsoft Excel, Google Earth Pro, QGIS 3.34.6, QSWAT 3.12, SWAT Editor, SWAT Modification [11] and SWATCUP 2012 software. The data used were as follows: (1) rainfall and climate data obtained from the Citanduy River Basin Office (BBWS) for a five-year period (2019-2023); (2) daily discharge data obtained from the Citanduy River Basin Office (BBWS) for a five-year period (2019-2023); (3) land cover maps obtained from online data from the Geospatial Information Agency (BIG); (4) Digital Elevation Model (DEM) data obtained from online data from the Geospatial Information Agency (BIG); and (5) land data obtained from online data from the Food and Agriculture Organization (FAO).

2.2. Research Procedures

2.2.1. Sub-watershed Delineation

The sub-watershed delineation in this study was carried out using DEM data and river networks with natural topographic boundaries and predetermined outlet *points.* The delineation process uses the threshold size determination method, which affects the number of sub-basins and river networks formed in the watershed. A default threshold was applied in this study.

2.2.2. Formation of Hydrological Response Unit (HRU)

The formation of the HRU in SWAT aims to divide the hydrological area based on soil type, land slope, and land cover, which is reclassified according to the SWAT database. Soil type data were obtained from the FAO usersoil database. The land slope was based on DEM data and classified into five categories: flat (0%–8%), gentle (8%–15%), slightly steep (15%–25%), steep (25%–40%), and very steep (>40%). Land cover was classified using the SWAT code. The initial HRU was then redefined using the threshold by the percentage method of 20%, resulting in the final HRU in the Sub-watershed.

2.2.3. Daily discharge simulation

Rainfall and climate data (temperature, humidity, and wind speed) were processed using a weather generator and converted to. txt format before being entered into the SWAT Editor after the Sub-watershed and HRU delineation. The SWAT was then modeled in three scenarios: original SWAT, pot hole SWAT, and modified SWAT. In the original SWAT, the parameters followed the default values. In the pot hole SWAT, the POT_FR parameter in the rice field was changed to 1 (100%), POT_TILE to 5 mm/day, and POT_VOLX to 100 mm. In the modified SWAT, POT_VOLX was set to 150 mm, and the planting period (icpst) was set to three times the planting period for rice fields.

2.2.4. Model calibration and validation

The water discharge simulation results were calibrated and validated using SWATCUP 2012 with the Sequential Uncertainty Fitting Version 2 (SUFI2) method. Calibration was performed by trial and error by entering the hydrological parameters. Before calibration, the NSE and R^2 values of the daily discharge of each SWAT model must be known as indicators of model performance [8]. NSE was used as an objective function with a range of $-\infty$ to 1, whereas R^2 shows the suitability of the simulation result pattern with observations in the range of 0 to 1. The classification of the NSE and R^2 values is presented in **Table 1** [9].

Table 1. Classification of NSE and R^2 values [9]

NSE	R^2	Classification
0.75 < NSE ≤ 1	0.75 < R^2 ≤ 1	Very good
0.60 < NSE ≤ 0.75	0.60 < R^2 ≤ 0.75	Good
0.36 < NSE ≤ 0.60	0.50 < R^2 ≤ 0.60	Satisfactory
0 < NSE ≤ 0.36	0.25 < R^2 ≤ 0.50	Bad
NSE ≤ 0	R^2 ≤ 0.25	Inappropriate

The SWAT model has 548 hydrological parameters; however, not all of them were used for calibration. Parameter selection was based on previous studies, and the parameter values were calibrated by trial and error to obtain optimal results. After calibration, validation was performed to test the consistency of the model for different periods using the same parameters. The validation process included the best parameter values from calibration. Subsequently, each SWAT model was re-evaluated using the NSE and R^2 values.

2.2.3. Evaluation

The SWAT evaluation was conducted based on the results of calibration and validation using the NSE and R^2 methods. Comparisons were made between the simulated discharge from the original SWAT feature, pot hole SWAT, and modified SWAT with the observed discharge from the BBWS Citanduy in the Upper Citanduy Sub-watershed.

3. Results and Discussion

3.1. Overview of Research Location

The Upper Citanduy Sub-watershed has an area of 74,136 ha, covering 21% of the total Citanduy Watershed, which stretches across West and Central Java. Its land cover is diverse, consisting of 27, 410 ha (36.97 %) of mixed dryland agriculture, 18, 934 ha (25.54 %) of rice fields, 8, 982 ha (12.12 %) of plantation forests, 7, 070 ha (9.54 %) of settlements, and 5, 204 ha (7.02 %) of secondary dryland forests. In addition, there are smaller areas of water bodies, airports, bushes, mines, and open land in the region. The Upper Citanduy Sub-watershed also stretches from highlands to lowlands, with variations in land slopes ranging from very steep to flat slopes. The slope class was dominated by flat slopes (0–8%) covering an area of 17,504 ha (23.61%) and gentle slopes (8–15%) covering an area of 16,101 ha (21.72%). The upstream region, consisting of mountains, causes large topographic variations. Based on data from the FAO processed in QGIS, there are five types of soil in the Upper Citanduy Sub-watershed: Lithosols, Eutric Eluvisols, Vertic Fluvisols, Humic Andosols, and Vitric Andosols. The Ochric Andosol soil type was dominant, covering 39,635 ha (53.46%), followed by the Humic Andosol soil type*, covering* 12,078 ha (16.29%).

3.2. Delineation of the Upper Citanduy Sub-DAS

The process of delineating sub-watersheds using the SWAT model was carried out by utilizing DEM data and river networks, which divided the sub-watersheds into several subbasins. The threshold size was used to determine the number and formation of river networks, including both main rivers and tributaries. The smaller the threshold value, the more sub-basins are formed [10]. In this study, the default threshold was used with a cell count of 290,072 and an area of 1,969 ha. The results of the Upper Citanduy Sub-watershed delineation process produced 27 Sub-Basins, where the Sub-basin with the largest area was sub-basin 9 with an area of 10,162.37 ha (13.71%), followed by sub-basin 26 with an area of 5,827.33 ha (7.86%).

3.3. Formation of Hydrological Response Unit (HRU)

HRU analysis was carried out by an overlay process using a land cover map, soil type, and land slope that had been reclassified based on the Upper Citanduy Sub-watershed. Initially, 942 HRU were formed in 27 sub-basins with a threshold of 0%. To reduce the number of HRU, a threshold of 20% was used for land cover, soil type, and land slope. A total of 130 HRU were formed in 27 Sub-basins in the Upper Citanduy Sub-watershed.

3.4. Implementation of Original SWAT

The original SWAT for the discharge simulation was performed without changing any parameters (using the default values of the SWAT program). The simulation was carried out for 2019 to 2023, with the application of the NYSKIP value (1.5 years of warming) to avoid overestimated discharge-simulation results. The application of the original SWAT included 1.5 years of warming, 1 year of calibration, and 1 year of validation. The results of the discharge simulation before the calibration process compared with the Citanduy BBWS observation discharge (July 2020–June 2021) are shown in **Figure 2** and **3**.

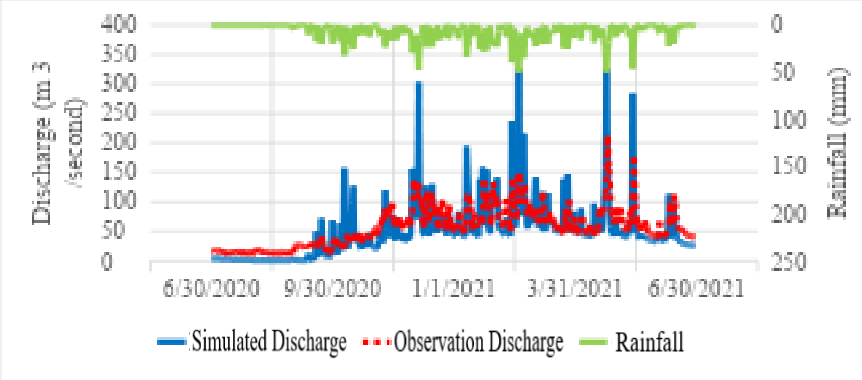

Figure 2. Comparison of simulated discharge (original SWAT before calibration) with observed discharge

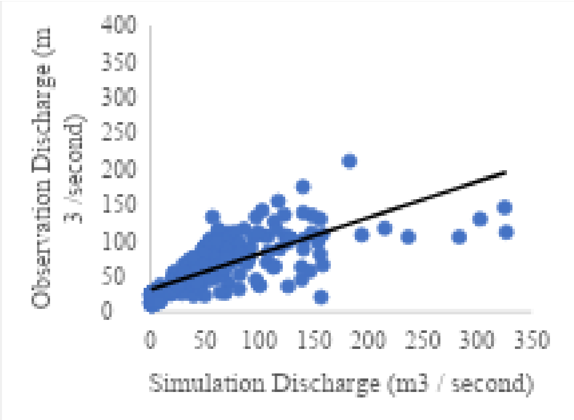

Figure 3. Comparison graph of simulated discharge (original SWAT before calibration) with observed discharge.

Before the calibration process, the original SWAT produced an NSE value of 0.21 (poor) and an R^2 of 0.77 (very good). The next calibration process was performed to improve the NSE and R^2 values. The calibration process was performed to align the discharge simulation with the observed discharge using the SUFI2 method in SWAT-CUP. The calibration involved 18 parameters that affected the discharge simulation results. The results of the discharge simulation after the calibration process compared to the Citanduy BBWS observation discharge (July 2020–June 2021) are shown in **Figure 4** and **5**.

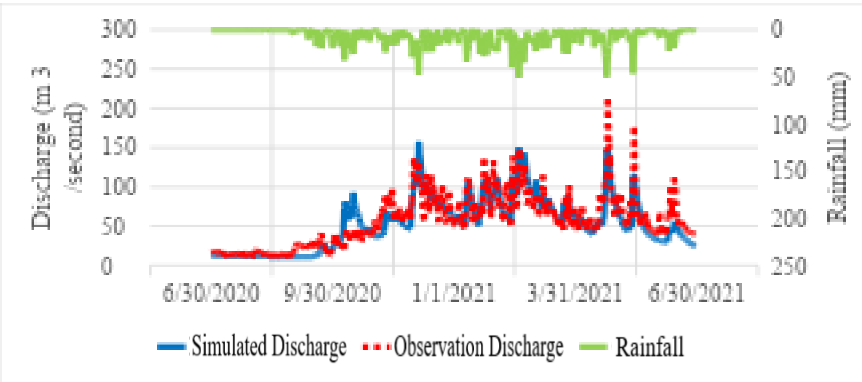

Figure 4. Comparison of the simulated discharge (original SWAT after calibration) with the observed discharge.

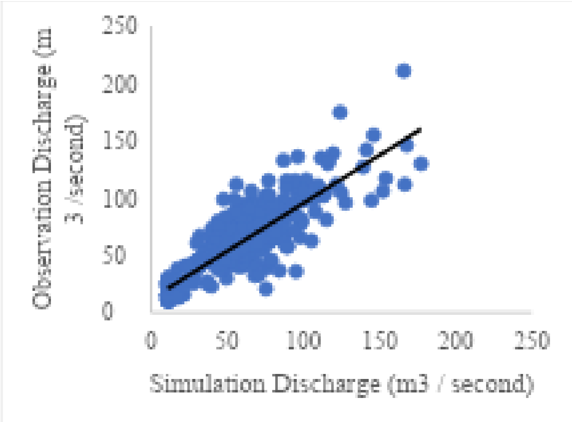

Figure 5. Comparison graph of simulated discharge (original SWAT after calibration) with observed discharge.

After the calibration process, the original SWAT produced an NSE value of 0.69 (good) and an R^2 of 0.93 (very good). The validation process was carried out to test the consistency of the model using the same parameters as in the calibration with the SUFI2 method in SWAT-CUP. The results of the discharge simulation after the validation process compared to the Citanduy BBWS observation discharge (April 2022–March 2023) are shown in **Figure 6** and **7**.

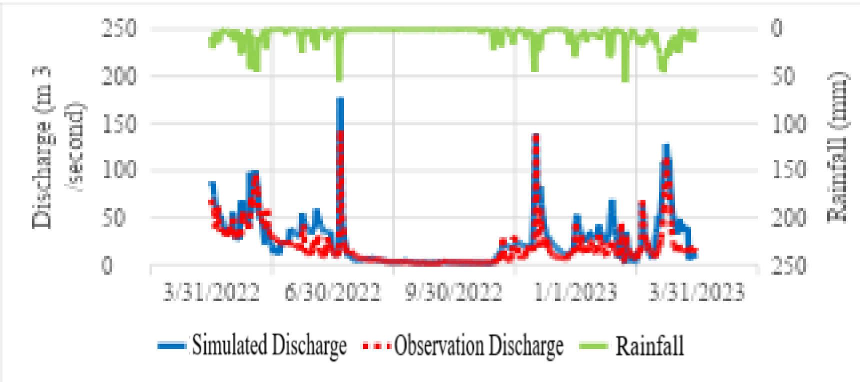

Figure 6. Comparison of the simulated discharge (original SWAT after validation) with observed discharge.

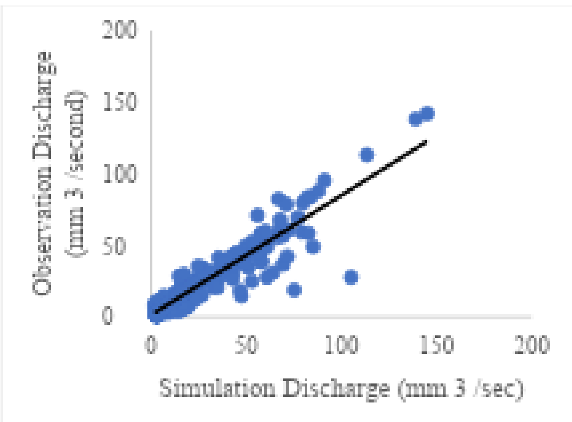

Figure 7. Comparison graph of simulated discharge (original SWAT after validation) with the observed discharge.

After the validation process, the original SWAT produced an NSE value of 0.70 (good) and an R^2 of 0.93 (very good). This indicates a positive relationship between the simulated and observed discharges.

The validation results were better than those of the calibration process, with NSE and R^2 values closer to 1.

3.5. Application of Pot hole SWAT

In the pot hole SWAT, parameter changes were made to the rice field, namely, the pot hole fraction (POT_FR) became 1 (100%), the default flow rate (POT_TILE) became 5 mm/day, and the height of the rice field inundation (POT_VOLX) became 100 mm. These changes were aimed at calculating the water system in the rice field, which was simulated as a cone-shaped perforated pot, so that inundation occurred in the existing HRU. The results of the discharge simulation before the calibration process compared to the Citanduy BBWS observation discharge (July 2020–June 2021) are shown in **Figure 8** and **9**.

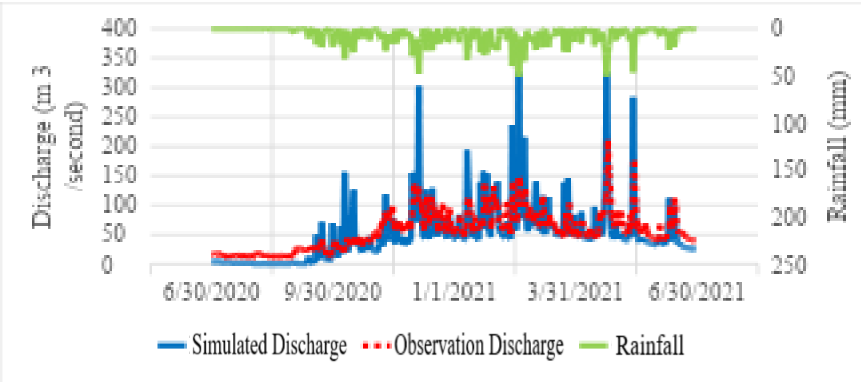

Figure 8. Comparison of simulated discharge (pot hole SWAT before calibration) with the observed discharge.

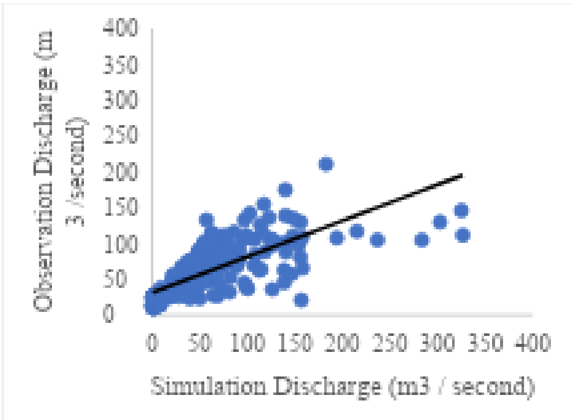

Figure 9. Comparison graph of simulated discharge (pothole SWAT before calibration) with observed discharge.

Before the calibration process, the pot hole SWAT produced an NSE value of 0.37 (satisfactory) and R^2 of 0.77 (very good). The next calibration process was performed to increase the NSE and R^2 values. The calibration process involved 18 parameters that affected the discharge simulation results (the same as in the original SWAT). The results of the discharge simulation after the calibration process compared with the Citanduy BBWS observation discharge (July 2020–June 2021) are shown in **Figure 10** and **11**.

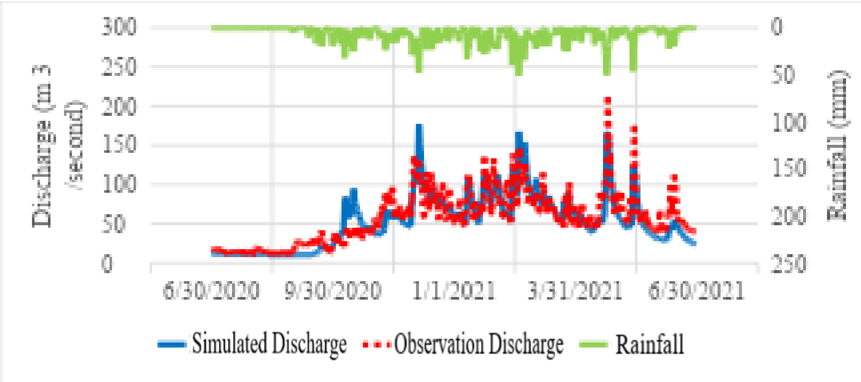

Figure 10. Comparison of simulated discharge (pot hole SWAT after calibration) with observed discharge

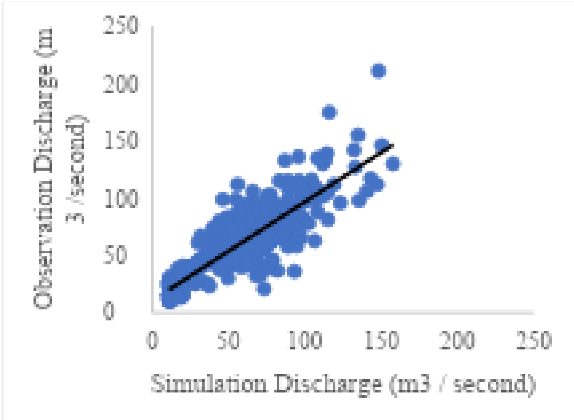

Figure 11. Comparison of simulated discharge (pot hole SWAT after calibration) with observed discharge

After the calibration process, the original SWAT produced an NSE value of 0.72 (very good) and an R^2 of 0.93 (very good). The validation process was performed to test the consistency of the model using the same parameters as those used in the calibration process. The results of the discharge simulation after the validation process compared to the Citanduy BBWS observation discharge (April 2022–March 2023) are shown in **Figure 12** and **13**.

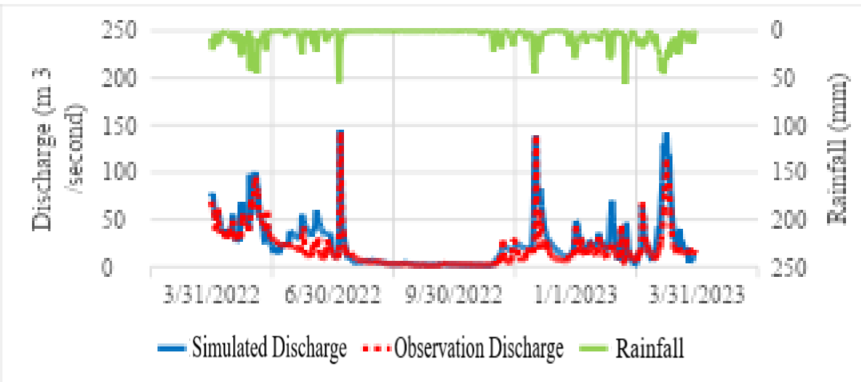

Figure 12. Comparison of simulated discharge (pot hole SWAT after validation) with the observed discharge.

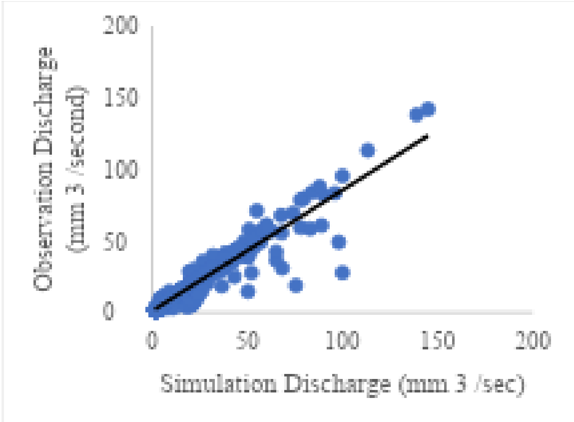

Figure 13. Comparison graph of simulated discharge (pot hole SWAT after validation) with the observed discharge.

After the validation process, the pot hole SWAT produced an NSE value of 0.73 (very good) and R^2 of 0.94 (very good). A positive relationship was observed between the simulated and observed discharge. The validation results were better than those of the calibration process, with NSE and R^2 values closer to 1.

3.6. Implementation of Modified SWAT

The application of the modified SWAT in this study refers to the Fausan Modified SWAT model (2022) [11], with changes to the maximum inundation height parameter (POT_VOLX) set at 150 mm for rice fields and adjustments to the planting period from *the default* one time to three planting periods. These changes were made to the SWAT model database for the HRU rice fields, which were adjusted to the conditions of the Upper Citanduy sub-watershed. The results of the discharge simulation before the calibration process compared to the Citanduy BBWS observation discharge (July 2020–June 2021) are shown in **Figure 14** and **15**.

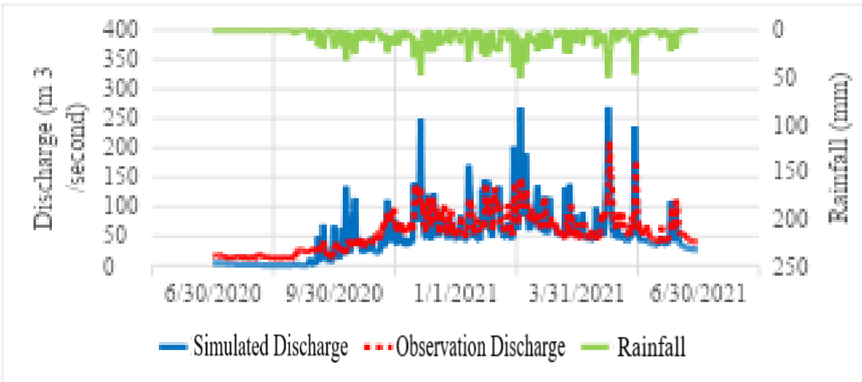

Figure 14. Comparison of simulated discharge (modified SWAT before calibration) with the observed discharge.

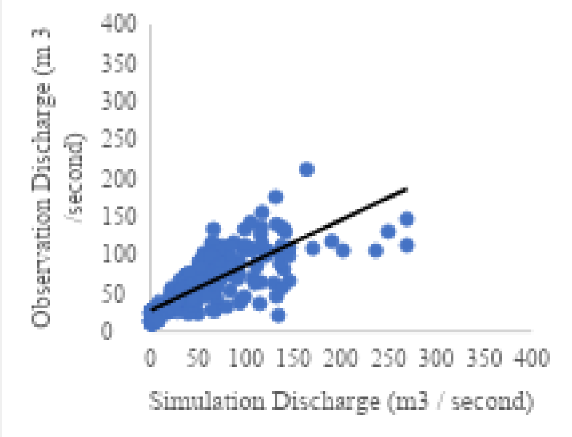

Figure 15. Comparison graph of simulated discharge (modified SWAT before calibration) with observed discharge.

Before the calibration process, pot hole SWAT produced an NSE value of 0.51 (satisfactory) and an R^2 of 0.82 (very good). The next calibration process was performed to increase the NSE and R^2 values. The calibration process involved 18 parameters that affected the discharge simulation results (the same as the original SWAT and pot hole SWAT). The results of the discharge simulation after the calibration process compared with the Citanduy BBWS observation discharge (July 2020–June 2021) are shown in **Figure 16** and **17**.

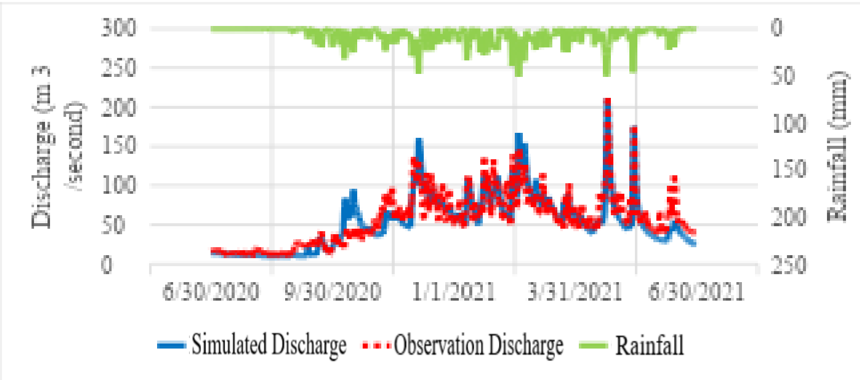

Figure 16. Comparison of simulated discharge (modified SWAT after calibration) with the observed discharge.

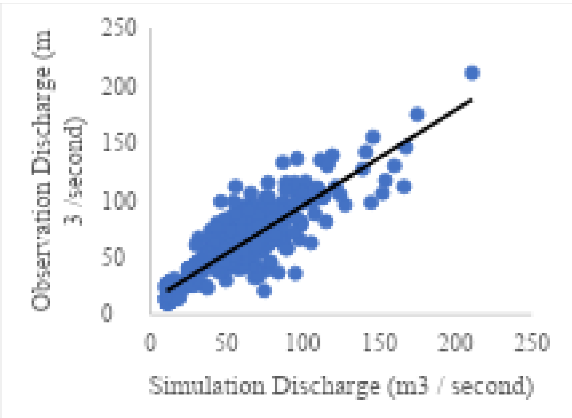

Figure 17. Comparison graph of simulated discharge (modified SWAT after calibration) with observed discharge

After the calibration process, the original SWAT produced an NSE value of 0.74 (very good) and an R^2 of 0.93 (very good). The validation process was performed to test the consistency of the model using the same parameters as those used in the calibration process. The results of the discharge simulation after the validation process compared to the Citanduy BBWS observation discharge (April 2022–March 2023) are shown in **Figure 18** and **19**.

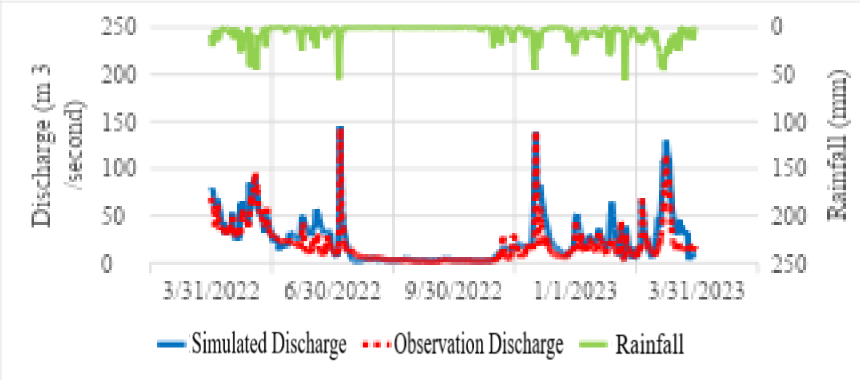

Figure 18. Comparison of simulated discharge (modified SWAT after validation) with observed discharge

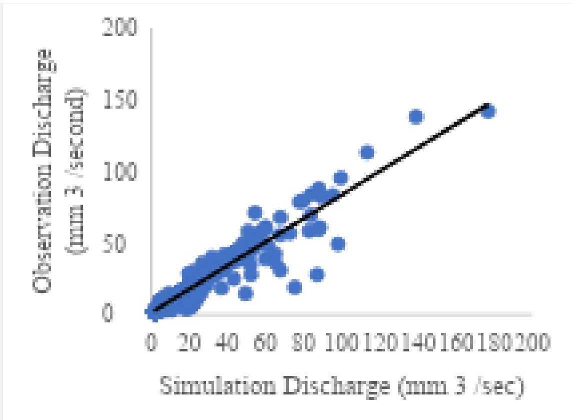

Figure 19. Comparison graph of simulated discharge (modified SWAT after validation) with observed discharge

After the validation process, pot hole SWAT produced an NSE value of 0.75 (very good) and an R^2 of 0.94 (very good). A positive relationship was observed between the simulated and observed discharge. The validation results were better than those of the calibration process, with NSE and R^2 values closer to 1.

4. Conclusion

SWAT modeling in the Citanduy Hulu Sub-DAS was carried out by comparing three features (original SWAT, pot hole SWAT, and modified SWAT). Different NSE and R^2 values were obtained based on the validation results of the three models. In the original SWAT, the NSE value were 0.70 (very good) and the R^2 value was 0.93 (very good), respectively. In the pot hole SWAT, the NSE value were 0.73 (very good) and the R^2 value was 0.94 (very good), respectively. Meanwhile, in the modified SWAT, the NSE value was 0.75 (very good), and the R^2 value was 0.94 (very good). The modified SWAT had the best modeling performance compared to the original SWAT and pot hole SWAT, and was recommended for use.

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