Analysis of Upstream Citarum Watershed Flow Using Semi-Distributed Hydrology Model with SWAT

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ABSTRACT.

The large conversion of forests' areas that have a significant spatial impact on the area causes an increase in annual sediment rates that exceed 100 tons/km^2. This sediment build-up can potentially reduce the rivers capacity to handle large intensity rainwater. This research aims to find out how reliable the Semi-Distributed model with the Soil and Water Assessment Tool (SWAT). The SWAT model is when applied to the Upper Citarum watershed (UCW). The results of simulations carried out for one year showed a maximum flow discharge of 441 m^3/sec and a minimum flow discharge of 2.15 m^3/sec. However, based on existing water estimation post data, the maximum observed discharge value is 460 m^3/sec and the minimum observed discharge is 4.06 m^3/sec. After calibrating the discharge from the simulation results of the SWAT method with the observed discharge, we obtained quite good results with NSE value > 0.56, which value indicates that the SWAT model has good results. Meanwhile, the R value ≥ 0.79. In other words, the SWAT method of flow discharge modeling can be applied and can be one of the method choice for generating discharge in the UCW.

Keywords: discharge; SWAT; Watershed; NSE; upper Citarum watershed.

INTRODUCTION

Land use plays a very important role in balancing ecosystem and water availability including watersheds (Manggala, et al, 2017). Each land use has different surface run off characteristics in controlling falling rainwater. A forest area is able to hold and store some rainwater not to overflow directly into the outlet so that water does not flow. It is easy to overflow which will cause flooding in the rainy season or water does not disappear easily during the dry season.

Several factors can affect the amount of discharge in a river, including the characteristics of rainfall, climate, and land cover in a watershed (Jacques, et. al, 2010, Asdak, 2014, Harto, S., 2000). The fluctuations in discharge in rivers can be monitored if the watershed has a water estimation post (PDA). However, if a watershed does not have a water estimating post, then the amount of river discharge can be found using the hydrological model approach (Harto,S, 2000). One hydrological model that can estimate the amount of discharge in a river is a semi-distributed model with a soil and water assessment tool (SWAT) (Kim et. al, 2020). SWAT models can be done with the help of ArcSWAT. ArcSWAT is one of the tools in the ArcGIS software. The output that can be obtained later is in the form of Direct Run-off.

The use of the SWAT model is identify assess, evaluate the level of problems in a watershed, and also as a tool for selecting management actions to control these problems. Even though there will be quite large errors in the results of observations in small drainage areas, the SWAT model is quite reliable at quite large scales (Vigiak,et.al, 2015). The problem in this research is; there are landform changes occurring in the Citarum watershed with an increase in agricultural and plantation areas, but there is an increase in sediment processes in the watershed.

The output from the hydrological model includes water availability, sedimentation and pollutants (Janjic and Tadic, 2023). There are several models for hydrological simulation based on

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hydrologicalprocesses, including: a) Lump/Tank, a single calculation for the entire watershed and is usually usedto average discharge or total volume. For example: Rational Method - single outlet; b) Distributed, calculation of hydrological processes for each data grid and to determine water flow. For example: GSSHA, Mike HSE; c) Semi-distributed, simplifying distribution by creating a unit as a Hydrologic Response Unit (HRU) which has unique parameters (consisting of several grids with the same parameters). For example: SWAT, APEX (Sitterson, et. al, 2017). Run off is calculated for each sub-catchment at the pour point represented by the black dot in figure 1b. The distributed model calculates run off for each grid cell, while equalizing it figure 1c below.

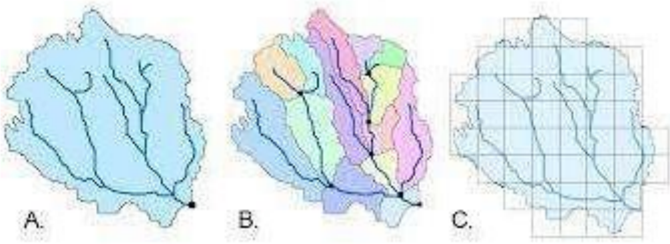

Figure 1. Visualization of the spatial structure in runoff models. A: Lumped model, B: Semi-Distributed model by sub-catchment, C: Distributed model by grid cell.

MATERIAL AND METHOD

Soil and Water Assessment Tool

Rainfall and climatology data from Citarum Watershed (Lufi, et. al, 2020) SWAT is a hydrological model developed by Dr. Jeff Arnold in the early 1990s for the USDA's Agricultural Research Service (ARS). SWAT was developed to predict the effect of agricultural land management on water availability, sedimentation, and chemicals in a complex watershed by considering variations in soil type, land use, and management of watershed conditions over a long period of time (Kim, et.al, 2020, Kibii, et. al, 2021).

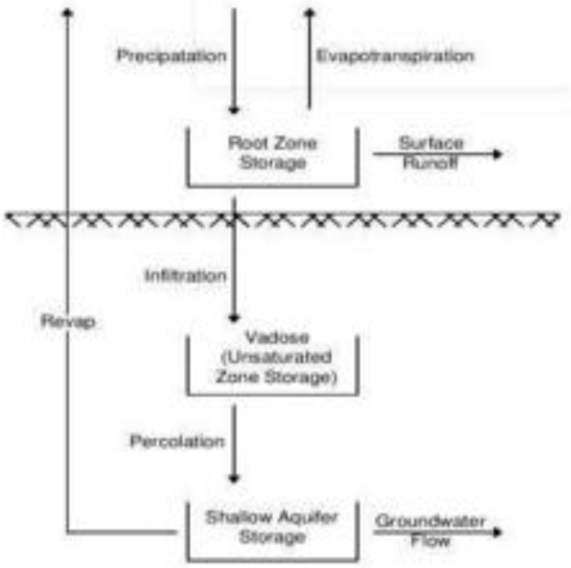

Figure 2. Model SWAT Scheme

Research Flow Chart

The research framework is a stage that explains the steps of analyzing aresearch as bellows (Khadka, et. al, 2023, Yu,et al, 2023, Mohajerani, et. al, 2023). Its can be seen in Figure 3 figure 4 below.

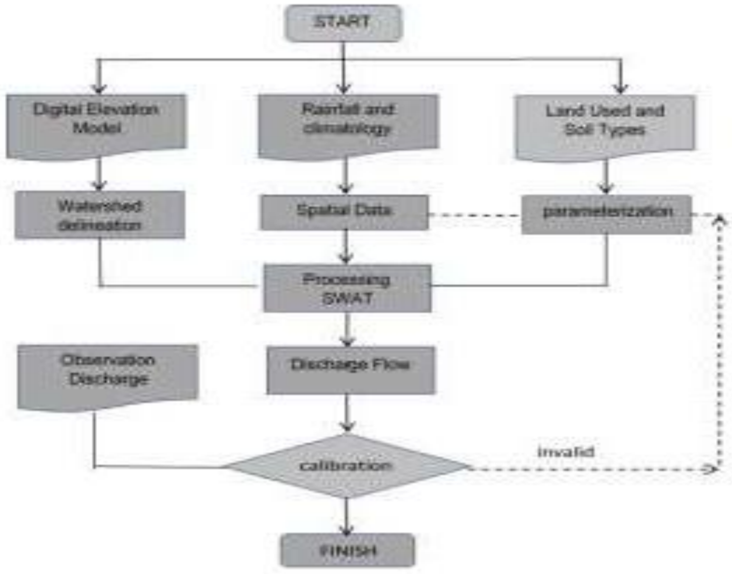

Figure 3. Research Flow Chart

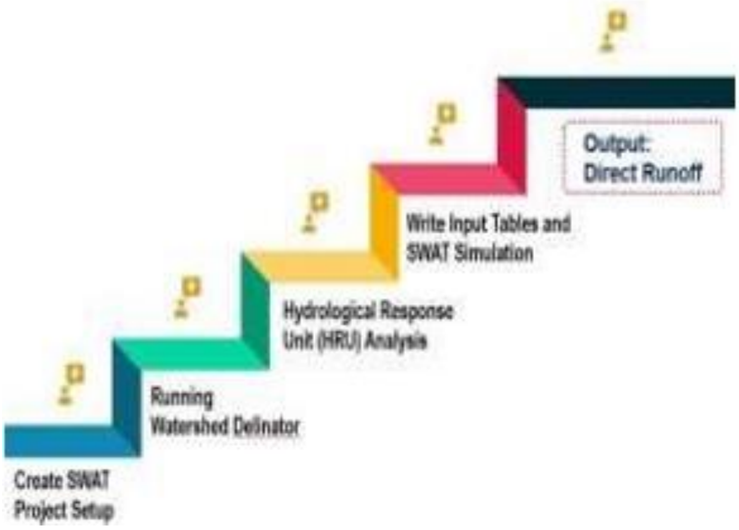

Figure 4. SWAT Modeling Stages

Research Location

The study location is in the UCW area. The location of the UCW is administratively located in West Java Province and crosses several cities and regencies, including the City of Bandung, Cimahi City, Bandung Regency, West Bandung Regency, and Sumedang Regency figure 5 below.

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Figure 5. Research Location

Data Sources

The data used in this study is secondary data obtained from related agencies which related to the research title. These secondary data include: a)Daily rainfall data and observation discharge, BBWS Citarum, Ministry of Indonesia Public Work; b) Climatological data, Meteorological, Climatological, and Geophysical Agency: BMKG; c) Land cover year, KLHK; d) Topography, BIG;

e) Soil Type, National Survey and Mapping Coordinating Agency

$$NSE = 1 - \frac{\sum_{t=1}^{T}(Q_o^t - Q_{SWAT}^t)^2}{\sum_{T=1}^{T}(Q_o^t - Q_o)^2} \quad (1)$$

$$R^2 = \left(\frac{\sum_{i=1}^{n}(Qmi - Qm)(Qsi - Qs)}{\sqrt{(Qmi - Qm)(Qsi - Qs)}}\right)^2 \quad (2)$$

$$P_{BIAS} = \left(\frac{\sum_{t=1}^{n}(Qi^{sim} - Qi^{obs})x100}{\sum_{i=1}^{n} Qi^{obs}}\right) \quad (3)$$

Where:

Q_{SWAT}^t	= discharge simulation results (m^3/sec)
Q_o^t	= discharge observation results (m^3/sec)
Q_o	= average discharge from observations (m^3/sec)
R^2	= coefficient of determination
Qi^{obs}	= actual discharge observation (m^3/sec)
Qi^{sim}	= discharge simulation results (m^3/sec)
P_{BIAS}	= Percentage of bias
Q_m	= average actual discharge of observations (m^3/sec)

RESULTS AND DISCUSSION

Watershed Delineation

The first step to modeling the flow rate with the SWAT method is to delineate the watershed. The Watershed delineation in this study is based on data from the DEM around the watershed area to be studied. The method used in this delineation process is the threshold method, where the size of the threshold value used will determine the number of river networks that will form in the watershed. It can be seen in Figure 6 as bellows:

Hydrological Response Unit (HRU) Analysis

The second stage after completing the Watershed deliniator is HRU Analysis. The HRU analysis includes land use data and soil data, which will later be adjusted to the SWAT database. After the land use and soil data have been adjusted to the SWAT data base, the next step is to classify land use, soil and slope definition. The following is the result of the classification of the 3 data (Figure 7-9).

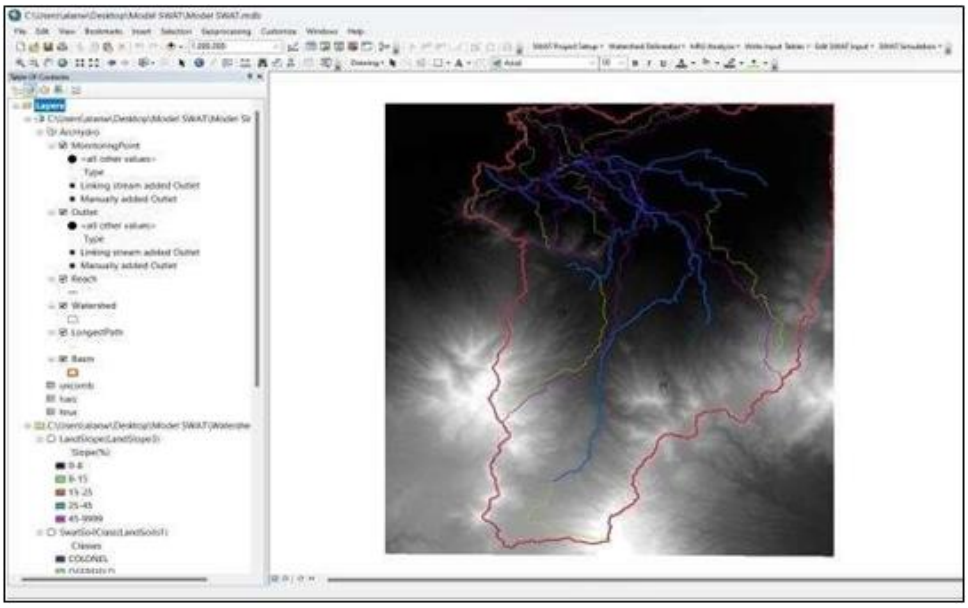

Figure 6. Watershed Delineation Results

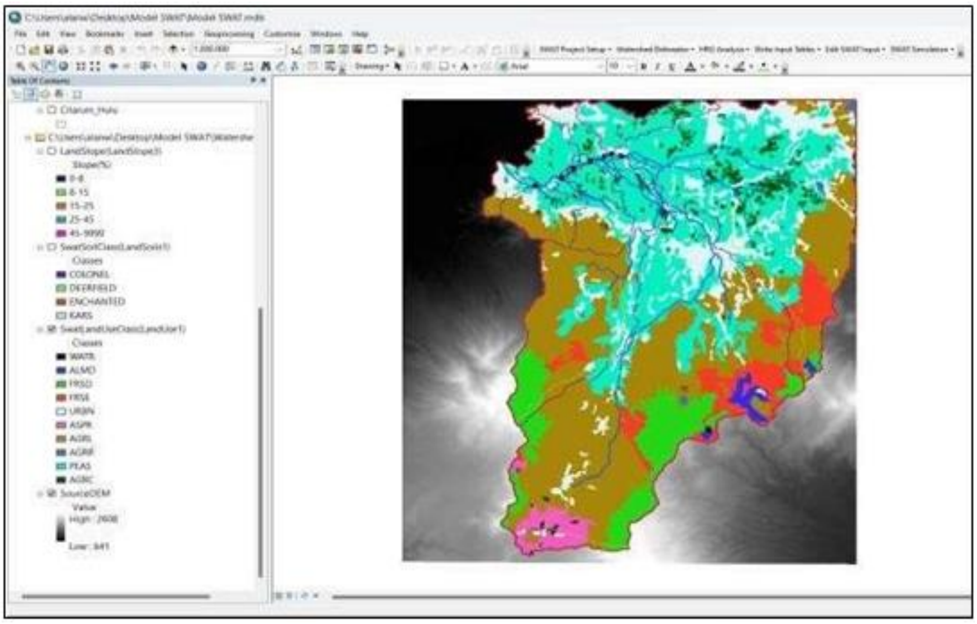

Figure 7. Land Use Classification Results

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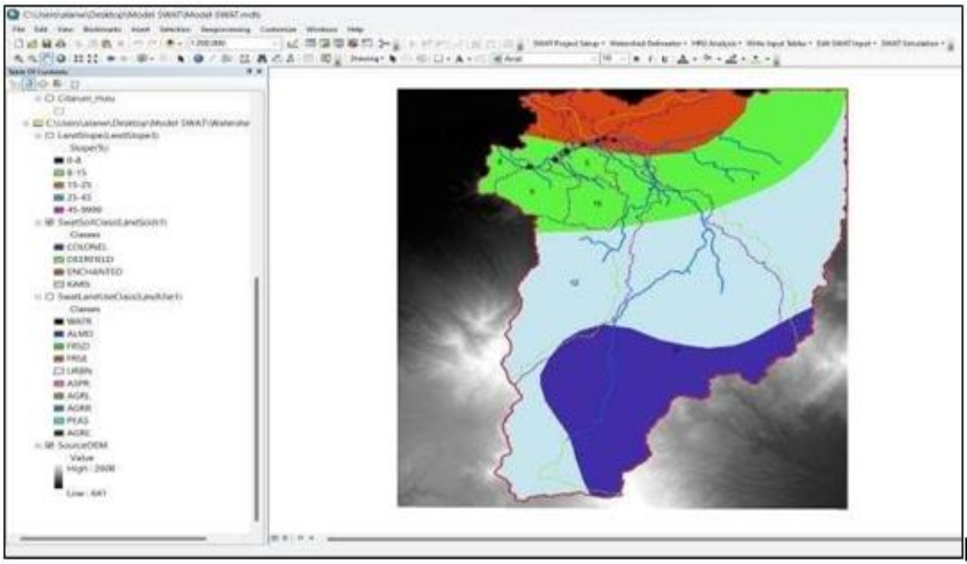

Figure 8. Soil Classification Results

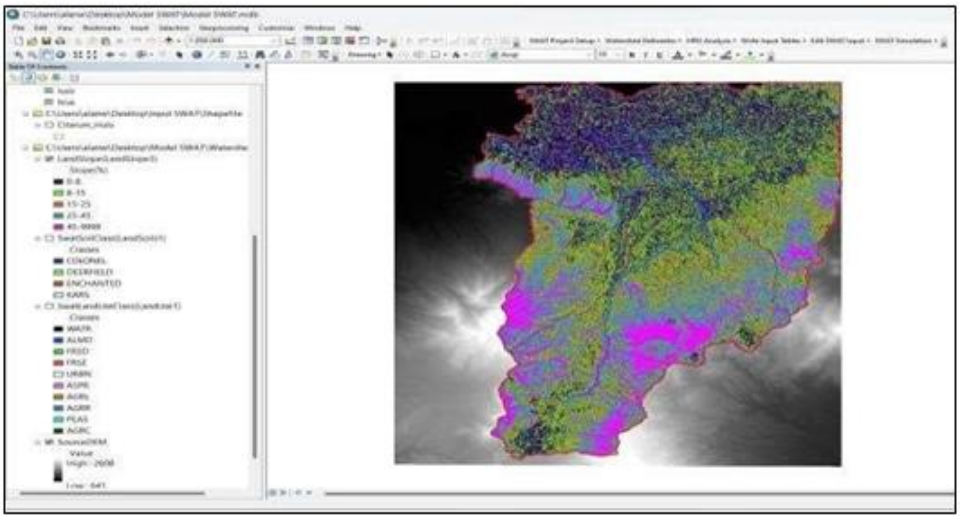

Figure 9. Slope Definition

Input Data Weather Station

The third stage after the HRU Analysis is to input Weather Station data. In the previous stage (HRU Analysis) was to enter data on land cover and soil type, while at this stage it was to enter data related to hydroclimatology such as rainfall, air temperature, air humidity, sunshine duration and wind speed.

The data used is daily data for one year in 2016. The data is compiled based on the SWAT database format and stored in a txt file. Following are the input fields for each of the above parameters (see figure 10). After all the hydroclimatology data has been input, then in the write input figure, choose select all and click create figure 11 below.

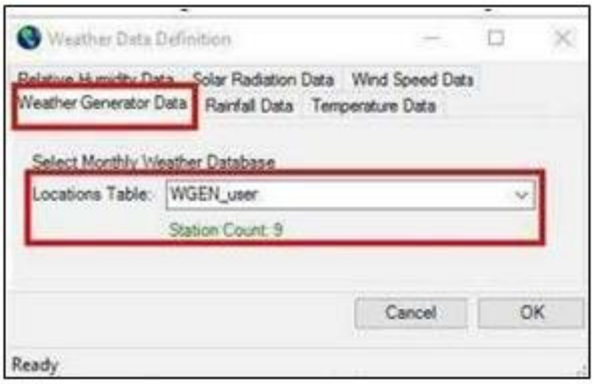

Figure 10. Input Weather Generator Data

Figure 11. Input Weather Generator Data

After all the data has been input and adjusted to the SWAT data base itself, the SWAT model is ready to run.

Running SWAT

After the 3 (three) stages have carried out, then enter the final stage, namely running SWAT. To run a SWAT model, select SWAT simulation and click Setup SWAT Run. But before that, make sure the running time period is set correctly and according to your needs. It can be seen in figure 12. In

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the SWAT Output section, click import files to database and don't forget to tick output RCH, sub and HRU, so that you can get the discharge output figure 13 below.

Figure 12. Setup dan Run Simulation Display

Figure 13. Read SWAT Output

Discharge results from SWAT simulation

The output of running SWAT can be seen in the Scenarios folder. The output will be presented in the microsoft access data base. The following is the result of the upstream Citarum watershed discharge for 1 (one) year in 2016 based on the results of the SWAT simulation. The calibrated model results produce test values reliability R = 0.79, NSE = 0.56, as the calibrated flow hydrograph can be seen in Figure 14-15. Khuzaimy, et. al., 2017[14] reported that the simulation model results produce test values reliability R = 0.58, NSE = 0.57 as the calibrated flow hydrograph. Their observation value of flow rate is higher than the SWAT value. However Diah et. al, 2020 [15] research conducted that the results produce test values reliability R = 0.84, NSE = 0.78 and their observation value flow rate is lower than the SWAT value. This result shows that the simulation results after being carried out the calibration value is close to the observation data. All the reliability test value after calibration has been carried out improvement from before. The results obtained include categories satisfying.

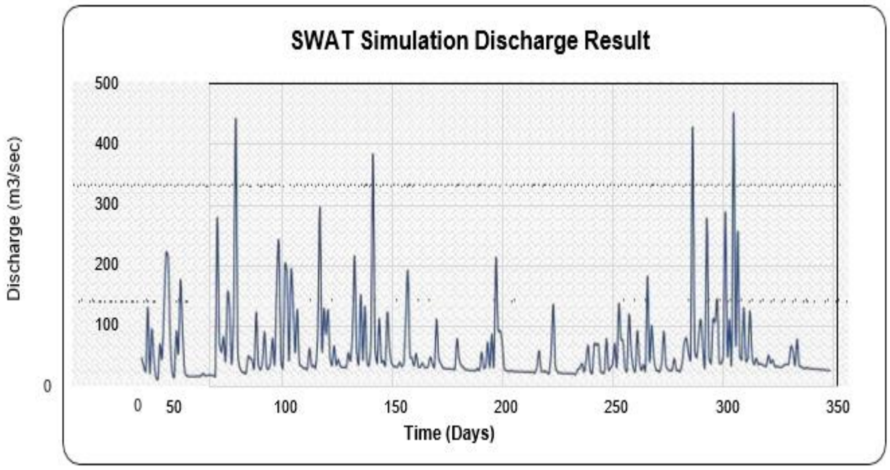

Figure 14. SWAT Simulation Discharge Result

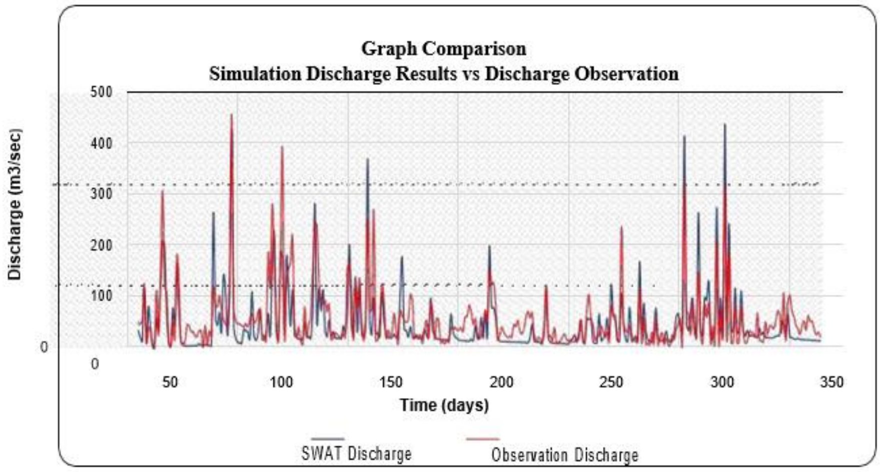

Figure 15. Discharge Comparison Graph

Table 1. Correlation Coefficient Criteria

R Value	Interpretation
0 – 0.19	Very low
0.20 – 0.39	Low
0.40 – 0.59	Medium
0.6 – 0.79	Strong
0.8 - 1	Very Strong

Source: Sugiyono, 2013

Table 2. NSE Value Criteria

NSE Value	Interpretation
NSE > 0.75	Good
0.36 < NSE < 0.75	Satisfy
NSE < 0.36	Not Satisfy

Source: Motovilov, et. al, 1999

After calibration, the Correl value is 0.79, and the NSE is 0.56. Based on the Table of criteria for the value of the correlation coefficient, the results of this model are categorized as "strong" and based on the criteria for the NSE value (Akoko, et. al, 2019), this modeling is included in the interpretation that meets the requirements. The results of this research can be compared with research conducted by Khuzaimy, et. al., 2017.

CONCLUSION

Based on the results of the discussion, it can be concluded as follows: 1) the results of a simulated flow rate for one year in the Upstream Citarum Sub-watershed using the SWAT method obtain a maximum flow rate of 441 m^3/sec. and a minimum flow rate of 2.15m3/sec. However, based on the existing water estimating post data, the maximum observation discharge value is 460 m^3/sec. and the minimum observation discharge is 4.06 m^3/sec. There is a difference between the simulated debit value and the observed debit, but the difference is not that far away, 2) after calibration between the discharge from the SWAT simulation results and the observation discharge, the results are quite good with an NSE value of 0.56 and a correlation value (Correl) of 0.79. In other words, the SWAT method of flow discharge modeling can be applied to the Upstream Citarum Sub-watershed.

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