SWAT Application for Gajahwong River Streamflow Simulation

P N Wardhana¹ and S Izzah¹
¹Civil Engineering, Universitas Islam Indonesia, Yogyakarta, Indonesia
Email: pradipta.nw@uii.ac.id

Abstract. Gajahwong River flows along Daerah Istimewa Yogyakarta (DIY) that is located in southern Java Island. Gajahwong River has an important role for water supply purpose especially for agriculture activities. On the other hand, DIY is seeing 1.18% population growth each year. The population surge influences land cover change that can seize continuous discharge of Gajahwong River. Therefore, continuous discharge simulation needs to be conducted for assessing Gajahwong River water availability. Soil and Water Assessment Tool (SWAT) was employed for modelling Gajahwong River streamflow discharge. The simulation result discharge was compared with observed data acquired at AWLR Wonokromo by using NSE and $R^2$ statistical parameter. Finally, the statistical parameter was applied to justify quality of simulation. Findings showed that daily time step yielded NSE value of 0.61, $R^2$ value of 0.79, and PBIAS value of -2.41%. Overall, the simulation showed good result based the statistical parameters.

1. Introduction
Gajahwong River flows along Daerah Istimewa Yogyakarta where the river location is in the middle southern part of Java Island (see figure 1). River upstream region is in the area around Merapi Mount whereas the river discharge will flow into Opak River in the Wonokromo junction. The river crosses Sleman, Kota Yogyakarta, and Bantul where all the regions experience high population growth every year. Surge of population number generates land use change that can reduce soil capability in infiltrating water. In the recent years, Gajahwong River has played an important role in supplying irrigation water. Therefore, simulation of river streamflow is committed to evaluate land use change toward water availability. Finally, simulation output can be used to plan planting systems based on water availability in Gajahwong River.

Soil Water Assessment Tool (SWAT) has been used widely by researchers in various regions and various research objectives where SWAT model reliability can be measured both quantitatively and qualitatively. Specifically, there were numerous researchers who had employed the SWAT model in Indonesia. Sustainable water balance in Jambi Sumatera was simulated by applying the SWAT model, in which the simulation analyzed minimum forest land that was required to support sustainable water balance [1]. The results showed Nash-Sutcliffe efficiency (NSE) value range 0.80-0.88 (calibration) and 0.80-0.85 (validation), whilst PBIAS value -2.9%-1.2% (calibration) and 7%-11.9% (validation). Deforestation effect toward runoff generation was simulated in Batanghari River Basin by utilizing Curve Number (CN) number and Green Ampt methods as provided by SWAT model [2]. The findings showed changes in water balance as evaporation shrunk and total discharge grew up. In addition, effect of land use and climate variability on hydrological processes was analyzed in Upper Brantas River Basin Indonesia by applying SWAT model [3]. The results showed good coefficient of
determination ($R^2$) (calibration:0.905; validation:0.916), NSE (calibration:0.997; validation:0.995), and percentage of bias (PBIAS) values (calibration:5.7%; validation:-6.967%). SWAT was applied in simulating several scenarios to determined best alternative in managing Cilemer Watershed in Banten Indonesia [4]. The selected alternative was strip cropping, agroforestry, and reservoir combination that could shrink $Q_{\text{min}}/Q_{\text{min}}$ ratio, surface flow, and runoff coefficient. On the other hand, simulation showed that the alternative would improve base flow and water yield. Best Practice Management scenario was simulated by using the SWAT model to mitigate problems particularly for surface runoff and sedimentation yield in Jatigede Reservoir Catchment Indonesia [5]. SWAT simulations gave a reasonable NSE value of 0.71. Flood hazard was investigated as results of climate variability specifically the rise of rainfall intensity in Bantimurung Bulusaraung National Park in Sulawesi [6]. The research found some villages in buffer area where exhibit very high-level floods. Streamflow of Keduang Sub-Watershed was predicted for daily and monthly time series and the simulations gave good model performance as showed by $R^2$, NSE, and PBIAS statistical parameters [7].

2. Theoretical review

2.1. Soil Water Assessment Tool (SWAT)
Soil Water Assessment Tool (SWAT) has been developed by Dr. Jeff Arnold from USDA Agricultural Research Service (ARS) since 1990 [8]. SWAT is a catchment modelling tool that has ability to predict effect of catchment management toward water, sediment, pesticide, and chemicals as a result
of agriculture activity. Moreover, SWAT also has ability to respond various catchment parameter in hydrology modelling such as soil type, land use, and long-term catchment management. SWAT is developed by involving several modules such as CREAM (Chemicals, Runoff, and Erosion from Agricultural Management Systems), GLEAMS (Groundwater Loading Effects on Agricultural Management Systems) and EPIC (Erosion-Productivity Impact Calculator).

Hydrology modelling by using SWAT will be divided into soil phase and water phase (see figure 2). In soil phase, the hydrology cycle has ability to control the amount of water, sediment, and pesticide flowing into river for each sub catchment. Whereas water phase can be defined as movement of water, sediment, and pesticide through river network into the catchment outlet.

Equation below is employed for modelling water depth in each layer of soil phase.

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

Where \( SW_t \) is final soil moisture content (mm H_2O), \( SW_0 \) is initial soil moisture content (mm H_2O), \( t \) is time (days), \( R_{day} \) is depth of rainfall intensity (mm H_2O), \( Q_{surf} \) is depth of surface runoff (mm H_2O), \( E_a \) is evapotranspiration depth (mm H_2O), \( w_{seep} \) is depth of water flowing into vadose zone from soil profile (mm H_2O), and \( Q_{gw} \) is return flow depth (mm H_2O).

Inputs and processes applied for simulation part in soil phase are climatology (rainfall intensity, and snow), hydrology (infiltration and evaporation), land cover (growth potency, nutrient absorption), erosion, nutrient, pesticide, and management. In water phase or flow routing process, SWAT model transforms water flow to maintain along river reach. This phase consists of two processes, they are routing process in the main river (water, sediment, nutrient, and organic chemical) and storage routing (inflow, outflow, rainfall intensity in surface, evaporation, storage seepage).
2.2. Statistical Parameter

Statistical parameters are used widely in evaluating hydrology simulation result toward observed data. Three statistical parameters are suggested to evaluate hydrology simulation results such as coefficient of determination ($R^2$), Nash Sutcliffe efficiency (NSE) value, and PBIAS value. Below are equations employed to calculate these statistical parameters [9].

\[
R^2 = \left( \frac{\sum_i (Q_{m,i} - Q_{m,avr})(Q_{s,i} - Q_{s,avr})}{\left[\sum_i (Q_{m,i} - Q_{m,avr})^2 \sum_i (Q_{s,i} - Q_{s,avr})^2\right]^{0.5}} \right)^2
\]

\[
NSE = 1 - \frac{\sum_i (Q_m - Q_s)^2}{\sum_i (Q_{m,i} - Q_{m,avr})^2}
\]

\[
PBIAS = \left[ \frac{\sum_{i=1}^{n} (Y_{i,obs} - Y_{i,sim})}{\sum_{i=1}^{n} Y_{i,obs}} \times 100 \right]
\]

Where $R^2$ is coefficient of determination, NSE is Nash-Sutcliffe efficiency value, $Q_m$ is observed river discharge (m³/second), $Q_{m,avr}$ is average observed river discharge (m³/second), $Q_s$ is modelling river discharge (m³/second), $Q_{s,avr}$ is average modelling river discharge (m³/second). Coefficient of determination $R^2$ gives information regarding relation between simulation and observed data. Below is further explanation regarding these statistical parameters.

1. Coefficient of determination ($R^2$) measures linear relation between simulation discharge and observed discharge. $R^2$ value ranges from 1 to 1. The optimum value of $R^2$ is 1 that describes less error variance.
2. Nash-Sutcliffe efficiency (NSE) value compares model discharge variance toward observed discharge variance. NSE shows the plot performance of observed discharge versus simulation discharge that fits 1:1 line. NSE value ranges from -∞ to 1.0, with 1.0 as the optimal value. NSE value from 0.0 to 1.0 is classified as accepted value, while value ≤ 0.0 is considered as unacceptable value.
3. PBIAS value gives information regarding average tendency of simulation discharge to be larger or smaller than observed discharge. The smallest value 0.0 of PBIAS shows simulation discharge has a similar tendency toward observed discharge.

3. Data

These are several data that was applied to arrange the streamflow simulation. These data can be classified as two types of data such as point data and raster data. Below are lists of point data.

1. Climatology data that was acquired from Playen Climatology Station in 2012-2015 [10].
2. Rainfall data was obtained from Bedugan rainfall station, Santan rainfall station, Prumpung rainfall station, and Kemput rainfall station in 2012-2015 (see table 1) [10].
3. Gadjahwong River Discharge that was collected from Wonokromo AWLR Station in 2012-2015 [10].
Table 1. List of rainfall station

| Rainfall Station | Latitude | Longitude | Elevation (m) |
|------------------|----------|-----------|---------------|
| Bedugan          | -7.86    | 110,40    | 18            |
| Santan           | -7.78    | 110,42    | 118           |
| Prumpung         | -7.70    | 110,39    | 575           |
| Kemput           | -7.64    | 110,40    | 575           |

While these are some of raster data employed for simulation.
1. Digital Elevation Model Nasional (DEMNAS) that is issued by Badan Informasi Geospasial (BIG) of Indonesia [11].
2. Landsat 8 OLI image published by United Stated Geological Surve (USGS) that was processed to create land use map [12].
3. Soil type map that is issued by Food and Agriculture Organization (FAO). Plotting of Gadjahwong Basin on FAO soil map showed that Gadjahwong soil type was Tm23-2c-4573. Harmonized World Soil Database of FAO explains that Tm soil type refers to Mollic Andosol [13]. Percentage of each of land use classification is given in table 2 below.

Table 2. Land cover percentage

| Number | Land use classification | Percentage (%) |
|--------|-------------------------|----------------|
| 1      | Forest                  | 6.32           |
| 2      | Dryland farming         | 15.98          |
| 3      | Wetland farming         | 1.52           |
| 4      | Paddy field             | 26.88          |
| 5      | Built area              | 17.56          |
| 6      | Open space              | 0.73           |
| 7      | Grass                   | 2.71           |
| 8      | Bushes                  | 25.92          |
| 9      | Water                   | 2.37           |
|       | Total                   | 100            |

4. Result and Discussion

4.1. Parameter optimization
Parameter optimization was committed to adjust the parameter value of hydrology model so that simulation discharge value can coincide with observed value behaviour. Optimization process was conducted by using 2013 discharge data. In the statistical field, model optimization aims to surge correlation between simulation discharge and observed discharge because of the hydrology model limitation in simulation of all hydrology aspects. Hydrology parameter was optimized by using SUFI-2 (Sequential Uncertainty Fitting) as part of SWAT-CUP (SWAT Calibration and Uncertainty Program). The simulation revealed that there were 6 parameters that can influence simulation discharge significantly to coincide observed discharge. The parameters are CN2.mgt, ALPHA_BF.gw, GW_DELAY.gw, CH_N2.rte, and ALPHA_BNK.rte. Explanation regarding definition of each parameter, value range, and optimum value can be seen in table 3.
**Tabel 3. List of optimized parameters**

| Parameter       | Definition                                      | Value range             | Optimum value for simulation |
|-----------------|-------------------------------------------------|-------------------------|------------------------------|
| r_CN2.mgt       | Initial SCS runoff curve number for MC II       | -0.091265 – 0.066447    | -0.039483                    |
| v_ALPHA_BF.gw   | Baseflow alpha factor (days)                    | 0.027858 – 0.125464     | 0.086910                     |
| v_GW_DELAY.gw   | Groundwater delay (days)                        | 342.524353 – 404.265137 | 364.030731                   |
| v_CH_N2.rte     | Manning's "n" value for the main channel        | 0.139026 – 0.210842     | 0.172660                     |
| v_CH_K2.rte     | Effective hydraulic conductivity in main channel | 48.857857 – 67.555634   | 66.402603                    |
| v_ALPHA_BNK.rte | Baseflow alpha factor for bank storage          | 0.019591 – 0.117995     | 0.093558                     |

P-Value and t-Stat value that are obtained by SWAT-CUP can be utilized to determine sequence of influencing parameter [14]. The most relative significant parameter can be determined by absolute smallest t-Stat value and largest P-Value. From both aforementioned statistical parameters, the most influences parameter is CN2 parameter. The sequence of influential parameter can be seen in table 4.

**Table 4. Sequence of most influencing parameter**

| Parameter Name   | t-Stat | P-Value |
|------------------|--------|---------|
| 1: R__CN2.mgt    | -1.63  | 0.13    |
| 2: V__ALPHA_BF.gw| -0.28  | 0.79    |
| 3: V__GW_DELAY.gw| 0.85   | 0.41    |
| 4: V__CH_N2.rte  | -0.99  | 0.34    |
| 5: V__CH_K2.rte  | -0.38  | 0.71    |
| 6: V__ALPHA_BNK.rte| -1.29 | 0.22    |
| 7: V__SFTMP.bsn  | -0.92  | 0.37    |

4.2. Simulation result

Limited pair of rainfall and AWLR data caused short simulation time series that the pair data just consisted of 4 years consecutive data. Actually, there was two years discharge simulation. Comparison of simulated discharge and observed discharge is shown in figure 3.

Continuous flow simulation of Gajahwong River was initiated by a simulation warming up process employing 2012 data. Simulation of year 2012 yielded poor statistical parameter values which were \( R^2 \) value = 0.93, NSE value = -0.41, and PBIAS value = 70.20% (see figure 4). Low statistical parameters value for 2012 simulation was caused by model adaptation process in the initial time of simulation. After the warming up process, the simulation was continued into calibration phase to optimize some parameters that influenced simulated discharge in order to approach the observed discharge value. Calibration that used data from 2013 process gave better statistical parameter value compared to the warming up process that the \( R^2 \) value rose to 0.99, NSE value improved to 0.48, and PBIAS value increased to -3.45% (see figure 5).

Continuous flow simulation of 2014 saw significant surging NSE value of 0.60. The statistical value of PBIAS went down to 9.88%. The PBIAS got more positive value, but actually the optimum value is 0.00. Positive and negative signs showed tendency of simulated discharge magnitude toward observed discharge. While the simulation resulted in stable \( R^2 \) value (see figure 6). In the year 2015, simulated discharge resulted in constant values of NSE and \( R^2 \) (see figure 7). PBIAS value improved into 3.58%. Moreover, overall statistical parameters of continuous flow from 2013-2015 were \( R^2 = 0.95, \) NSE = 0.61, and PBIAS = -2.41%.
Figure 3. Comparison between simulated discharge result and observed discharge from year 2012 until year 2015

Figure 4. Comparison between simulated discharge result and observed discharge year 2012
Figure 5. Comparison between simulated discharge result and observed discharge year 2013

Figure 6. Comparison between simulated discharge result and observed discharge year 2014
Figure 7. Comparison between simulated discharge result and observed discharge year 2015

5. Conclusion and Recommendation
From the statistical results, it can be concluded that the SWAT model has good ability in simulating the streamflow of Gajahwong River. Overall, the NSE value was more than 0.5, R² value was above 0.90, and PBIAS value was less than |5%|. Nevertheless, longer observed discharge data time series is required to test the reliability of the hydrology model. Furthermore, some improvements can be injected in the simulation such as applying spatial rainfall data acquired by satellite or weather radar.

References
[1] Tarigan S, Wiegand K, Sunarti S, and Slamet B 2018 Hydrol. Earth Syst. Sci. 22 581–594
[2] Yamamoto EMS, Sayama T, Yamamoto K, and App A 2020 Hydrological Research Letters 14(2) 81–8
[3] Setyorini A, Khare D, and Pingale SM 2017 Applied Geomatics 9 191–204
[4] Rachman LM, Nursari E, and Baskoro D P T 2021 IOP Conf. Ser.: Earth Environ. Sci. 622 012023
[5] Iwan Ridwansyah I, Fakhruadin M, Wibowo H and Yulianti M 2018 IOP Conf. Ser.: Earth Environ. Sci. 118 012030
[6] Barkey R, Nursaputra M, Mappiase MF, Achmad M, Solle M and Dassir M 2019 IOP Conf. Ser.: Earth Environ. Sci. 235 012022
[7] Ansari A, Kato T, Fitriah A 2019 Agritech 39 60-9
[8] Neitsch SL, Arnold JG, Kiniry JR and Williams JR 2011. Soil and Water Assessment Tool Theoretical Documentation Version 2009 (Texas: Texas A&M University System)
[9] Moriasi DN, Arnold JG, Van Liew MW, Bingner RL, Harmel RD, and Veith TL 2007 Transactions of the ASABE. 50(3) 885-900
[10] BBWS Serayu Opak 2020 Direktorat Jenderal Sumber Daya Air Kementerian Pekerjaan Umum dan Perumahan Jakarta Indonesia
[11] BIG (Indonesia Geospatial Information Agency). Seamless Digital Elevation Model (DEM) dan Batimetri Nasional. [Online]. Available: http://tides.big.go.id/DEMNAS/. [Accessed: 01-Jan-2021]
[12] Landsat-8image courtesy of the U.S. Geological Survey
[13] Nachtergaele FO, van Velthuizen HT. and Verelst L 2009 *Harmonized World Soil Database* FAO, Rome, Italy, and IIASA, Laxenburg, Austria

[14] Abbaspour KC 2012 *SWAT-CUP-2012.SWAT Calibration and Uncertainty program—A User Manual* (Dübendorf: Swiss Federal Institute of Aquatic Science and Technology)