Streamflow Simulation of Progo River by Using SWAT Model

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Abstract. Watershed is an area formed by the ridges of the mountains that limit a region. The natural boundary of the watershed was the result of geomorphology and hydrology. Watershed as water catchment area is very potential to provide water in a territory. Hence, the watershed management needs to be applied as well as possible. The Progo River watershed is located along the Central Java and Special Region of Yogyakarta. Progo River watershed have several creeks that ends at Trisik beach located on the south side of Java land headed to Indian Ocean. Simulation analysed the water discharge in Progo River with Sapon Weir outlet using Soil Water Assessment Tools (SWAT) with time step period for 3 years, between 2013 until 2015. Data of watershed condition used as input data were soil characteristic data, land use data, land slope data, climate data, and water discharge measurement data. SWAT simulation process was carried out through four stages, they were watershed delineation, formation of a hydrological response unit, data processing, and model simulation with simulation testing result based on $R^2$ statistic parameter, NS model efficiency, and PBIAS parameter. From the result of the simulation, it was known that the comparison of the result between water discharge simulation and field observation shows various quantitative result. Each of evaluation parameter gave different performance classification. $R^2$ statistic parameter evaluation gave good-very good classification, while NS model efficiency and PBIAS parameter gave not satisfactory performance classification.

1. Introduction

River basin is land area where precipitation is collected, reserved, and drained off in certain outlet naturally. Progo River Basin stretches along Central Java Province and Daerah Istimewa Yogyakarta Province. Progo River has ± 140 km length, and ± 2380 km$^2$ river basin area size. The main upstream area of Progo River is laid at Sindoro Mount and the downstream area is positioned at Trisik Beach located at southern of Java Island. Figure 1 shows map of Progo River basin. Progo River has several tributaries such as Krasak River, Bedog River, Tangsi River, Tingal River, dan Elo River. Progo River has main role for Central Java and Daerah Istimewa Yogyakarta to supply irrigation water, drinking water, etc.

River discharge condition changes throughout year, hence it is important to monitor discharge continuously in either wet season and dry season. River basin management will influence river discharge fluctuation, moreover the fluctuation can be utilized to assess the river basin condition.

Soil and Water Assessment Tools (SWAT) is a hydrology model employed widely around the world to simulate river streamflow with respect to land cover change [1]. Particularly, SWAT is developed by Dr. Jeff Arnold from United State Department of Agricultural - Agricultural Research Service (ARS) to
predict influences of land management toward water, sediment, pesticide content, chemical content as result of agriculture activity. Figure 2 shows schema of SWAT model.

![Figure 2: Schema of SWAT model](image)

**Figure 2.** Schema of SWAT model

SWAT model is well known to simulate river streamflow. Many researches had been done that gave various results. Streamflow simulation of Xedone River basin, Lao PDR by using SWAT yielded high value of R² and NS value higher than 0.7 [3]. SWAT model utilization in Xinjiang River Basin resulted value of 0.63 coefficient of determination (R²), 0.62 Nash–Sutcliffe efficiency (NSE), and 3.8% PBIAS value [4]. Along technology advancement, SWAT model was also applied by using satellite precipitation data in Middle Nueces River Watershed in South Texas and Middle Rio Grande Watershed in South Texas and northern Mexico [5].

2. **Theoretical Review**

2.1. **Soil Water Assessment Tools**

In simulating streamflow, SWAT applies water balance as basic concept of modelling. SWAT divides hydrology modelling into two phases. The first phase is area phase on hydrology cycle, and the second phase is routing phase of hydrologic cycle.

2.1.1. **Area Phase**
The area phase determines amount of water, sediment, nutrient content, pesticide content in filling main channel for every sub basin (see Figure 2). Equation (1) below is water balance equation employed by SWAT model.

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

Where \(SW_t\) is final soil water content (mm), \(SW_0\) is initial soil water content on day \(i\) (mm), \(R_{day}\) is amount of precipitation in day \(i\) (mm), \(Q_{surf}\) is amount of surface runoff on day \(i\) (mm), \(E_a\) is amount of evaporation on day \(i\) (mm), \(W_{seep}\) is amount of water entering vadose zone from the soil profile on day \(i\) (mm), and \(Q_{gw}\) is amount of return flow on day \(i\) (mm).

2.1.2. Routing Phase
To simulate flood propagation, SWAT employs Muskingum routing method by modelling channel volume as combination of prism and wedge storage. Equation (2) shows Muskingum routing method equation.

\[
V_{storage} = K \cdot q_{out} + K \cdot X \cdot (q_{in} - q_{out})
\]

Where \(V_{storage}\) is storage volume (m³), \(K\) is storage coefficient (assumption of time travel needed by water flows into river) (s), \(q_{out}\) is outflow (m³/s), \(q_{in}\) is inflow (m³/s), and \(X\) is weighting factor (the value varies between 0 and 0.5).

2.2. Statistic Parameters
There are coefficient of determination (R²), efficiency model Nash-Sutcliffe (NS), and PBIAS applied to verify simulation result toward river discharge data.

1. The coefficient of determination (R²) was applied to identify degree of collinearity between simulation result and observed data. R² as seen in equation (3) also shows the proportion of variance measured data defines by the model. Furthermore, calibration data process also employed correlation coefficient. The calibrated parameters were iterated simultaneously to
obtain maximum coefficient correlation. \( R^2 \) ranges from 0 to 1, higher value informing less error variance, and value more than 0.5 indicates acceptable performance.

\[
R^2 = \frac{\sum_i (Q_{m,i} - Q_{m,avr})(Q_{s,i} - Q_{s,avr})}{\left(\sum_i (Q_{m,i} - Q_{m,avr})^2 \sum_i (Q_{s,i} - Q_{s,avr})^2\right)^{0.5}}
\] (3)

2. Whilst, the Nash-Sutcliffe parameter utilization was intended to assess hydrology model in simulating river streamflow by normalizing residual variance of simulated result toward measured data variance (see equation (4)). The optimal value of NS parameter is 1.0, value between 0 and 1 is assumed as acceptable, and value less than 0.0 shows unacceptable performance.

\[
NS = 1 - \frac{\sum_i (Q_{m,i} - Q_{s,i})^2}{\sum_i (Q_{m,i} - Q_{m,avr})^2}
\] (4)

3. PBIAS value is utilized to determined tendency of simulated result toward observed result. Equation (5) is utilized to calculate PBIAS value. Positive value shows overestimated bias and negative value indicates underestimated bias. Perfect simulation value is shown by 0.0.

\[
PBIAS = 100 \left( \frac{\sum_{i=1}^{n} (Y_{i}^{\text{obs}} - Y_{i}^{\text{sim}})}{\sum_{i=1}^{n} Y_{i}^{\text{obs}}} \right)
\] (5)

Where \( R^2 \) is correlation coefficient, \( NS \) is Nash-Sutcliffe model efficiency, \( Q_m \) is observed river discharge (m³/second), \( Q_{m,avr} \) is mean observed river discharge (m³/second), \( Q_s \) is modelled river discharge (m³/second), and \( Q_{s,avr} \) is mean modelled river discharge (m³/second).

Moriasi et al. [6] suggest above parameter statistic to evaluate hydrology simulation performance. Moriasi et al. (2015) suggested Table 1 below regarding performance criteria of \( R^2 \), \( NS \), and PBIAS to classify hydrology simulation result.

| Performance criteria classification suggested by Moriasi et al (2015) |
|-----------------|-----------------|-----------------|-----------------|
| Statistic parameter | Very Good | Good | Satisfactory | Not satisfactory |
| R²               | \( R^2 > 0.85 \) | \( 0.75 < R^2 \leq 0.85 \) | \( 0.60 < R^2 \leq 0.75 \) | \( R^2 \leq 0.60 \) |
| NS               | \( NS > 0.80 \) | \( 0.70 < NS \leq 0.80 \) | \( 0.50 < NS \leq 0.70 \) | \( NS \leq 0.50 \) |
| PBIAS (%)        | PBIAS < ±5 | ±5 < PBIAS < ±10 | ±10 < PBIAS < ±15 | PBIAS ≥ ±15 |

2.3. Point data

Below are descriptions of several point data employed for streamflow simulation.

1. Climatology data that was obtained from Tegal station from year 2013 until 2015.
2. Rainfall data from that was acquisitioned in 14 stations from year 2013 until 2015. They are Badran station, Brosot station, Caturanom station, Gembongan station, Godean station, Kalibawang station, Kalijoho station, Kenteng station, Mendut station, Pajang an station, Sanden station, Sapon station, Seyengan station and Tegal station.
3. Discharge data from Sapon AWLR station from year 2013 until 2015.

2.4. Spatial data

Spatial characteristic data applied for streamflow simulation were explained below.

1. ALOS PALSAR Digital Elevation Model that is issued by Alaska Satellite Facilities was utilized as topographic map for basin delineation process [7].
2. Land cover map was extracted Landsat image published by United State Geological Survey. Figure 4 shows land cover that were employed for the simulation [8].
3. Food Agriculture Organization of United Nations (FAO) soil map was employed for spatial simulation data [9].

3. Result and Discussion
3.1. Model calibration process
As we know that in hydrology modelling, there are many limitations in determining parameters influencing hydrology process. Calibration process is needed to gain parameters value that is hard to be determined. In this simulation, calibration process was conducted by using SUFI2 (Sequential Uncertainty Fitting) by comparing between simulated discharge and observed discharge. In this research, calibration process is conducted based on observed data in year 2013. Then, the obtained data would be applied for hydrology simulation on year 2014 and 2015. Table 2 shows value of calibrated parameters.

Figure 4. Land cover map of Progo River basin
Table 2. Value of calibrated parameters

| No | Parameter             | Definition                                                                 | Min     | Max    | Min     | Max        | Best Parameter |
|----|-----------------------|---------------------------------------------------------------------------|---------|--------|---------|------------|----------------|
| 1  | ALPHA_BF.gw           | Baseflow alpha factor                                                     | 0       | 1      | 0.813841| 1.369635   | 0.90777       |
| 2  | GW_DELAY.gw           | Delay time for aquifer recharge (days)                                   | 30      | 450    | -29.44234| 82.659355  | 75.148537     |
| 3  | GWQMNN.gw             | Threshold water level in shallow aquifer for base flow (mm)               | 0       | 2      | 0.598469| 1.071395   | 0.881752      |
| 4  | GW_REVAP.gw           | Revap coefficient                                                         | 0.02    | 0.2    | 0.107704| 0.143004   | 0.135909      |
| 5  | REVAPMN.gw            | Threshold water level in shallow aquifer (mm)                             | 0       | 300    | 0.006705| 0.066009   | 0.019574      |
| 6  | CH_K(2).rte           | Hydraulic conductivity of main channel (mm/hr)                            | 0.01    | 0.3    | 0.037974| 0.11415    | 0.068521      |
| 7  | CH_N(2).rte           | Manning value for main channel                                            | 0.01    | 500    | 144.92996| 307.51709  | 176.959625    |

3.2. Streamflow Simulation Verification

Comparison between simulation discharge and observed discharge seen in Figure 5, Figure 6, and Figure 7 below. The research revealed that correlation coefficient ($R^2$) and Nash-Sutcliffe (NS) saw increment value between year 2013 and 2015. The $R^2$ value grew from 0.81 in 2013 to 0.83 in year 2014 and 0.95 in 2015. $R^2$ value result could be classified as good for year 2013 and year 2014, whereas simulation for year 2015 could be classified as very good.

![Figure 5. Streamflow simulation result of year 2013](image-url)
Furthermore, NS statistic value was fluctuated along simulation time step. In year 2013 NS value was 0.34 then it plummeted to 0.25 in year 2014, finally the NS value rose in 2015 to 0.32. The NS parameter classification gave not satisfactory value based on Table 2.

Calculation of PBIAS parameter resulted slip tendency value. Based on performance criteria shown in Table 2, PBIAS value gave not satisfactory classification. Calculation of PBIAS parameter for year from 2013 until 2015 showed 22.81%, 27.57%, and 53.43% respectively.

![Figure 6. Streamflow simulation result of year 2014](image6.png)

![Figure 7. Streamflow simulation result of year 2015](image7.png)
4. Conclusion and Recommendation

Based on conducted streamflow simulation, NS and PBIAS value yielded not satisfactory value even though several scenarios had been run. Thus, several plan can be introduced to improve simulation performance. Application of spatial rainfall and temperature data obtained from satellite mission are expected can improve both statistical values.

5. References

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