Calibration and Validation of the SWAT Hydrological Model for the Air Dingin Watershed

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Abstract. Computer technology has revolutionized the study of hydrological systems and management of water resources. Several computer-based hydrological models have been developed for applications in hydrological modeling and water resource studies. Geographic Information Systems (GIS) Interface models help create input data files, analyze and display results in a more efficient way. One interface GIS model available for water resources analysis is the Arc - Soil and Water Assessment Tool (ArcSWAT), a distributed parameter model developed by the United States Department of Agriculture. ArcSWAT has been applied, validated and calibrated for analyzing surface runoff in Air Dingin Watershed in Padang City - West Sumatra Indonesia. Validation was conducted to test the accuracy of the model in representing the real situation of the Air Dingin Watershed. Furthermore, calibration was performed to enhance the accuracy of the model. The results of ArcSWAT validation indicated that the Nash–Sutcliffe Efficiency (NSE) value was 0.12 and Coefficient of Determination ($R^2$) was 0.4. After the calibration was carried out by changing the value of some parameters in the model, the NSE value becomes 0.68 and $R^2$ becomes 0.66. This accepted model furthermore could be used to simulate water balance in the Air Dingin watershed.

Keywords: ArcSWAT; Calibration; Model; Validation; Watershed

1. Introduction

Hydrological model is a simple description of an actual hydrological system. Hydrological models are usually created to study the function and response of a watershed from various watershed inputs. Through the hydrological model, hydrological events can be studied which in turn can be used to predict hydrological events that will occur [1] [2]. The basic concept used in every hydrological system is the hydrological cycle [3]. The basic equation that forms the basis of all hydrological analysis is the water balanced equation.

Soil and Water Assessment Tool (SWAT) is a model that has been widely used to estimate the hydrological conditions based on physical processes. The Soil and Water Assessment Tool (SWAT) is a continuous-time, semi-distributed and processed-based model developed and supported by the USDA Agricultural Research Service. The model was originally developed to evaluate the impact of land management practices on water resources, sediment and agricultural chemical yields in large complex catchments with varying soils, land use and management conditions [4] [5].

The model requires several input data to simulate catchment hydrologic processes, and these include a digital elevation model (DEM), land use–land cover data, soil types, and different daily weather data, including details of precipitation, maximum and minimum air temperatures, solar radiation, wind speed, and relative humidity. SWAT has received international acceptance as a robust interdisciplinary...
catchment-scale modelling tool, and now this application has also been combined with Geographical Information Systems (GIS), known as ArcSWAT. However, model application is still challenging due to specific condition in a watershed. Calibration and validation are necessary before implementing the model in a watershed.

This study aims to validate and calibrate the ArcSWAT model in Air Dingin Watershed, with the meaning of this model could be used to analyze water balance and furthermore being a reference for a planning or decision making in Air Dingin Watershed.

2. Methods

This research was conducted in July to October 2019 at the Air Dingin Watershed, Padang City, West Sumatra Province – Indonesia (Figure 1). Data processing was completed at the Laboratory of Agricultural Management and Geographic Information System, Department of Agricultural Engineering, Faculty of Agricultural Technology, Andalas University, Padang City. Data used in this research were data for year 2017 and 2018. Data input and processing were used some software ie. ArcGIS 10.5, ArcSWAT 2012, SWAT CUP, HWSD Database, and Microsoft Office.

2.1 SWAT data processing

The steps in using SWAT for a watershed are: 1) Data Input, 2) Data Processing, and 3) Data Output. Data input includes daily rainfall and climate data for year 2017 and 2018, soil type map, Digital Elevation Model (DEM), land use map, climatology data, and daily debit for year 2017 and 2018. To determine the watershed boundaries, the model would make a delineation based on the DEM and furthermore the model would create a Hydrologic Responses Unit (HRU). HRU was established by overlaying the land use, soil type, and slope maps. After the HRU analysis report is obtained, the next step is combining HRU with climate data. To fulfill our simulation, the period of simulation should be input.

2.2 Validation and calibration
Validation was performed to observe the accuracy of SWAT model in representing the real situation in Air Dingin Watershed. Three methods of validation were used in this study, there were: 1) Graphical Comparison, 2) Nash Sutcliffe (NS) Coefficient, and 3) the Coefficient of Determination ($R^2$). The debit recorded from observations ($Q_{\text{observation}}$) and the debit from model simulation ($Q_{\text{simulation}}$) were used for analyzing model validation.

Graphical comparison is visually comparing graphs between observed and simulated debit. In this method, flow patterns and discrepancies between observation and simulation discharges will be seen.

The Nash–Sutcliffe coefficient had widely used and potentially reliable statistic for assessing the goodness of fit of hydrologic models [4].

$$NS = 1 - \frac{\sum_{t=1}^{T}(Q_{\text{sim}}^t - Q_{\text{obs}}^t)^2}{\sum_{t=1}^{T}(Q_{\text{obs}}^t - Q_{\text{obs}}^\bar)^2}$$  \hspace{1cm} (1)$$

where NS is Nash Sutcliffe Coefficient, $Q_{\text{sim}}^t$ is simulation debit, $Q_{\text{obs}}^t$ is observed debit at time $t$, and $Q_{\text{obs}}^\bar$ is mean of observed debit. Classification for Nash Sutcliffe Coefficient was presented in Table 1.

| NS Value | Classification |
|----------|----------------|
| NS > 0.75 | Good          |
| 0.36 < NS < 0.75 | Satisfactory  |
| NS < 0.36 | Less Satisfactory |

Coefficient of Determination ($R^2$) explained the correlation or the relationship between $Q_{\text{observation}}$ and $Q_{\text{simulation}}$ [4].

$$R^2 = \left( \frac{\sum_{i=1}^{n}(Q_{o,i} - Q_{o})^2}{\sum_{i=1}^{n}(Q_{s,i} - Q_{s})^2} \right)^2$$  \hspace{1cm} (2)$$

where $Q_o$ is average observation debit (mm), $Q_{o,i}$ is observation debit (mm), $Q_s$ is average simulation debit (mm), and $Q_{s,i}$ is simulation debit (mm).

3. Results and Discussion

3.1. Description of study area

Air Dingin Watershed has an area about 11,380 ha, with altitude from 0 to 1,808 meters above sea level. The topography of the Air Dingin Watershed has a steep slope in the upper stream and flat in the downstream. The length of the main river is about 27.8 km, and there are several tributaries in the upper stream, namely Air Tiris, Kacepong, Abu, Batang Sako and Latung.

Land use type in the study area (Table 2a) was dominated by green forest (7,139 ha), and another land use type were shrub (1,803 ha), Settlement (963 ha), dry land (574 ha), and Agriculture land (901 ha). Based on Harmonized World Soil Database / HWSD [6], soil types in the Air Dingin Watershed can be classified into five types (Table 2b), namely Alluvial (583 ha), Andosol (47 ha), Latosol (10,599 ha), Organosol (59 ha), and Regosol (92 ha). Most of the study areas were classed into steep and very steep slope (74%). Downstream watershed was flat and moderately sloping (10%).

| No | Land use  | Area (ha) | (%) |
|----|-----------|-----------|-----|
| 1  | Forest    | 7.139     | 62.74 |
| 2  | Shrub     | 1.803     | 15.85 |
| 3  | Settlement | 963       | 8.45 |
| 4  | Dry land  | 574       | 5.04 |
| 5  | Agriculture | 901      | 7.92 |
|    | Total     | 11,380    | 100.00 |

| No | Soil Types | Area (ha) | (%) |
|----|------------|-----------|-----|
| 1  | Aluvial    | 583       | 5.12 |
| 2  | Andosol    | 47        | 0.41 |
| 3  | Latosol    | 10,599    | 93.14 |
| 4  | Organosol  | 59        | 0.52 |
| 5  | Regosol    | 92        | 0.80 |
|    | Total      | 11,380    | 100  |

(a)  

(b)
3.2 Validation and calibration

Simulation carried out using ArcSWAT in Air Dingin Watershed show that peak debit occur in November and December, while the lowest debit occurred in June and July. In the validation, the debit from the simulation was compared to observation debit and show that the graph of these two debits have similar pattern, but the line of the observed debit was above the line of the simulation debit (Figure 2a). It means that model gave an under prediction. This condition was called the model consistently under predict the discharge. The validation method using NS coefficient gives a result of 0.12, while the value of R2 is 0.414 (Figure 2b). Based on these three validation methods, it could be concluded that the SWAT model gave an unsatisfactory representation for Air Dingin Watershed. A calibration was necessary if we want to furthermore apply the SWAT model in this watershed.

Calibration of the model was carried out by following the instructions Manual Calibration Helper in SWAT Simulation [7] [8]. Manual calibration involving the following steps: (1) perform the simulation, (2) compare measured and simulated values (3) assess if reasonable results have been obtained, (4) if not, adjust input parameters based on expert judgment and other guidance within reasonable parameter value ranges; and (5) repeat the process until it is determined that the best results have been obtained. Regarding that the model consistently under predict the debit, it was presumed that the model had a) low surface flow, b) low base flow, and c) too high evaporation.

To get a valid model, adjustments should be made for these three problems. Modification that need to be done for low surface flow were increase CN for different land uses, increase soil available water, and soil evaporation compensation factor. Adjustments for low base flow were decreased deep percolation, decreased groundwater revap coefficient, and increased threshold depth of water in shallow aquifer. Another adjustment should be done was decrease the evaporation value. Table 3 presented the adjustment SWAT parameters for Air Dingin Watershed.

### Table 3. Adjustment parameters for SWAT validation in Air Dingin Watershed

| No | Parameters                     | Symbols   | Min | Max | Default | Validation |
|----|--------------------------------|-----------|-----|-----|---------|------------|
| 1  | Groundwater delay (days)       | V_Gw_Delay| 0   | 5000| 31      | 16.4       |
| 2  | SCS runoff curve number        | R_Cn2     | 35  | 98  | -999    | 40         |
|   | Parameter Description                              | Symbol  | Value 1 | Value 2 | Value 3 | Value 4 |
|---|---------------------------------------------------|---------|---------|---------|---------|---------|
| 3 | Baseflow alpha factor (days)                      | V_Alpha_Bf | 0       | 1       | 0.048   | 0.15    |
| 4 | Soil evaporation compensation factor              | R_Esco | 0       | 1       | 0.95    | 0.40    |
| 5 | Deep aquifer percolation fraction                 | R_Rchrg_Dp | 0       | 1       | 0.05    | 0.25    |
| 6 | Manning’s “n” value for overland flow             | R_Ov_N | -0.52   | 0.61    | 0.1     | 0.50    |
| 7 | Available water capacity (mm/hour)                | R_Sol_Awc | 0       | 2000    | 0.1     | 0.85    |
| 8 | Threshold water depth in the shallow aquifer for revap | R_Revapmn | 0       | 1000    | 750     | 173.4   |
| 9 | Threshold depth of water in the shallow aquifer   | R_Gwqmn | 0       | 5000    | 1000    | 1250    |
| 10| Effective hydraulic conductivity in channel (mm/hour) | R_Ch_K2 | -0.01   | 500     | 0       | 50.35   |
| 11| Manning’s “n” value for main channel              | R_Ch_N2 | -0.01   | 0.3     | 0.014   | 0.013   |
| 12| Average slope length (m)                          | R_Slsubbsn | 10      | 150     | 50      | 65.50   |
| 13| Surface runoff lag time (days)                    | R_Surlag | 0       | 24      | 20      | 1.50    |

Subsurface flow parameters are $V_{Gw\_Delay}$, $V_{Alpha\_Bf}$, $R_{Rchrg\_Dp}$, $R_{Revapmn}$ and $R_{Gwqmn}$. The $V_{Gw\_Delay}$ parameter is the length of time the water flows and absorbed into the ground through the soil profile until the layers are saturated (aquifers) and then returns to discharge and flow into the river. The value of $V_{Gw\_Delay}$ on calibration is 16.4 days, meaning that water that flows into the ground and flows back to the river becomes a discharge for 16.4 days. The $V_{Alpha\_Bf}$ parameter or alpha base flow factor is an underground flow index response to changes in flow. $V_{Alpha\_Bf}$ calibration results of 0.15 days is equivalent to 3 hours 36 minutes. $R_{Rchrg\_Dp}$ is a groundwater percolation fraction with a calibration value of 0.25. $R_{Revapmn}$ is the depth of the water threshold in shallow aquifers so that percolation reaches deep aquifers with a calibration value of 173.4 mm. $R_{Gwqmn}$ is the minimum depth limit of shallow aquifers to enable underground flow and reverse flow. The calibrated $R_{Gwqmn}$ value is 1250 mm.

The parameter for ground data input used is $R_{Sol\_Awc}$. $R_{Sol\_Awc}$ is the capacity of the soil to hold water. The value of $R_{Sol\_Awc}$ calibration results is 0.85 mm / hour. The parameter used for the basin input is $R_{Surlag}$. $R_{Surlag}$ is the surface runoff time. The calibrated $R_{Surlag}$ value is 1.5 days, meaning that the time taken for rain to peak the surface flow is 1.5 days. Parameters for ground level input data are $R_{Esco}$, $R_{Ov\_N}$, and $R_{Slsubbsn}$. $R_{Esco}$ is an evaporation factor for ground water, which is the calibration value of 0.40. $R_{Ov\_N}$ is the coefficient value of manning hardness, which is obtained the calibration coefficient value of 0.50, and $R_{Slsubbsn}$ is the average slope length of the watershed and a calibration value of 65.50 m is obtained.

The parameters for the main channel data input are $R_{Ch\_K2}$ and $R_{Ch\_N2}$. $R_{Ch\_K2}$ is the hydraulic conductivity on the main channel, the value of $R_{Ch\_K2}$ results of calibration is 50.35 mm / hour. $R_{Ch\_N2}$ is a riverbed manning value that influences calibration. $R_{Ch\_N2}$ value after calibration is 13.45. The parameters for input processing data and land cover used are $R_{Cn2}$. $R_{Cn2}$ is runoff coefficient value. The $R_{Cn2}$ parameter has a direct impact on the simulation discharge value. Runoff coefficient shows the percentage of rainwater that becomes runoff. Greater runoff coefficient value will give more runoff. The best runoff value of the model is 40.

Subsequently conducted some calibration in the SWAT parameters, the model gave a better result for model simulation. Graphical comparison show that the graph line of the observation and simulation debit were coincide each other (Figure 3a). The new NS value was 0.68 and $R^2$ was 0.6634. Hence, the SWAT model prior to validation and calibration gave a satisfactory and acceptable result for Air Dingin Watershed. Furthermore, the model could be used for analyzing water balance in this watershed.
4. Conclusions
In the initial stage of the simulation, ArcSWAT model gave an unsatisfactory result for Air Dingin Watershed, where the graph comparison shows that the model has made an under prediction, NS value was 0.12 and the Coefficient of Determination ($R^2$) was 0.4. To improve the performance of the model, a calibration is performed by changing several parameters, namely increasing CN for different land uses, increasing soil available water, and soil evaporation compensation factor, decreased deep percolation, decreased groundwater revap coefficient, increased threshold depth of water in shallow aquifer and decrease the evaporation value. Afterward calibration, a better model could be obtained. Graphical comparison show that the graph line of the observation and simulation debit were coincide each other. The new NS value was 0.68 and $R^2$ was 0.6634. Therefore, the SWAT model afterward gave a satisfactory and acceptable result for Air Dingin Watershed. Consequently, the ArcSWAT model could be used for analyzing water balance in this watershed, and information obtained from simulation models could be considered as reference in planning and decision making.

References
[1] Brooks R.P, S.E. Yetter, R.F. Carline, J.S. Shortle, J.A. Bishop, H. Ingram, D. Weller, K. Boomer, R. Stedman, A. Armstrong, K. Mielcarek, G. Constantz, S. Goslee, T. Veith, D. Piechnik. 2011. Analysis of BMP Implementation Performance and Maintenance in Spring Creek, an Agriculturally-Influenced Watershed in Pennsylvania. Final report to USDA-NIFA-CEAP, Washington, DC USA . 66p
[2] Arlius, F., C. Asdak, T.S. Hasan. 2009. Spatial Hydrology Modeling for Water Resources in Cisankuy Sub-Watershed, West Java-Indonesia. 10TH SOUTH EAST ASIAN SURVEY CONGRESS 2009: 4 – 7 August 2009, Bali, Indonesia. Page 16. Proceedings Editor: Mulyana, A. K., Gatot H. P, Anton B. W., Adi J. M., Sri L.M, Dian A, Murdaningsih. (BAKOSURTANAL), Bogor,
[3] Harto, S., 1993. Hydrological Analysis (in Indonesian). Gramedia Pustaka Utama. Jakarta.
[4] Neitsch, S.L., Arnold, J.G., Kiniry, J.R., and Williams, J.R.. 2011. Soil and Water Assessment Tool theoretical documentation: Version 2009. USDA–ARS, Grassland, Soil and Water Research Laboratory, Temple, TX; and Blackland Research and Extension Center, Texas AgriLife Research, Temple, TX. Texas Water Resources Institute Technical Rep. 406, Texas A&M University System, College Station, TX.
[5] Daniel, E.B., Camp, J.V., Le Boeuf, E.J., Penrod, J.R., Dobbins, J.P., and Abkowitz, M.D., 2011. Watershed modeling and its applications: A state-of-the-art review. Open Hydrol. J. 5: 26–50.
[6] FAO-Unesco. 1974. FAO-Unesco Soil Map of the World: Vol. I, Legend. Unesco, Paris.
[7] Arnold, J.G., Moriasi, D.N. Gassman, P.W. Abbaspour, K.C. White, M.J. Srinivasan, R. Santhi, C. Harmel, R.D. van Griensven, A. Van Liew, M.W. 2012. SWAT: Model Use, Calibration, and Validation. Trans. ASABE 2012, 55, 1491–1508.
[8] Abbaspour, K.C. 2011. SWAT-CUP2: SWAT Calibration and Uncertainty Programs Manual Version 2. Department of Systems Analysis, Integrated Assessment and Modelling (SIAM). Swiss Federal Institute of Aquatic Science and Technology: Duebendorf, Switzerland, 106p.