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Research Article

Soil and Water Assessment Tool (SWAT) model for hydrological response analysis in the Gajahwong subwatershed, Yogyakarta, Indonesia

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Abstract

Hydrological response is a specific reaction of a watershed to rainfall, and one form is surface runoff, which can be influenced by climatic and physiographic factors. These factors are represented by various parameters that have their own impact on surface runoff, otherwise known as parameter sensitivity. The purpose of this study was to identify the hydrological response in the form of flow discharge based on the application of the Soil and Water Assessment Tool (SWAT) model and to identify the sensitivity of parameters that affect the hydrological response in the Gajahwong subwatershed. The data used in this study came from secondary data obtained from relevant agencies and primary data collected through sampling and laboratory testing. Flow discharge modeling was carried out using SWAT+ software, and the modeling results were automatically calibrated and validated using statistical tests. Meanwhile, sensitivity analysis was conducted by calculating the relative sensitivity values. The results showed that the flow discharge modeling of the Gajahwong subwatershed exhibited a pattern that is similar to the observed discharge. Based on this finding and the validation results with statistical tests, it can be said that the SWAT model can model and predict the flow discharge in the watershed quite well. The input parameter that is very sensitive and has a significant influence on the hydrological response in the subwatershed is the curve number (cn2), with a relative sensitivity value of 1.12.

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Introduction

A watershed is a spatial unit characterized by the integration of diverse physical, ecological, and socio-environmental components (Flotemertch et al., 2015). The components within a watershed are highly dynamic, which can lead to imbalances and complex problems, such as floods and erosion. Watershed management is one of the efforts that can be made to address these problems, and one way to do this is by monitoring the hydrological response in a watershed.

Hydrological response is a specific reaction of a watershed to rainfall, which can be influenced by morphometric and man-made factors, such as land use. The hydrological response in the form of flow includes surface runoff, lateral flow (interflow), baseflow, and water yield (Kusumawardani, 2018). Surface runoff is influenced by various factors related to the climate and physiography of a watershed (Munajad and Suprayogi, 2015). Climate factors include precipitation type, rainfall duration, rainfall distribution, temperature, and other conditions, whereas physiographic factors relate to topographic conditions, soil types, river networks, land use, and other physical factors. The characteristics of these factors can be represented through various parameters, which have different degrees of influence on surface runoff.

The variation in the influence of these parameters on the hydrological response is known as parameter sensitivity (Prayudi et al., 2017). Changes in the condition or value of these parameters will affect the hydrological response, and the parameter that has the greatest impact is considered the most sensitive. Sensitivity analysis of parameters is very useful for determining the appropriate watershed management plans. By understanding the parameter sensitivity, it is possible to prioritize the parameters in watershed management planning, which can help make the calibration process more efficient.

The Gajahwong subwatershed is located in Yogyakarta, Indonesia, and is part of the Opak watershed, which is categorized as a critical watershed. Yogyakarta has a large settlement and activity area, up to 77% (Da Costa et al., 2021). Settlements have a high curve number value, indicating a greater potential for runoff (Krisnayanti et al., 2021). The subwatershed has experienced an increase in the curve number due to land use changes from undeveloped land to developed land, which leads to a potential increase in flow discharge. Therefore, hydrological modeling is necessary to analyze the hydrological response in the form of flow discharge in the Gajahwong subwatershed and to identify the sensitivity of parameters that influence the response. In this study, the Soil and Water Assessment Tool Plus (SWAT+) was selected as the hydrological model. According to Junaidi and Tarigan (2012), the SWAT model can be effectively used to represent the hydrological conditions of various watersheds, even the large and complex watersheds.

Materials and Methods

Description of the study area

This study was conducted in the Gajahwong subwatershed and used the observation outlet at the automatic water level recorder (AWLR) station located in the lower part of the Gajahwong River in Wonokromo Village, Pleret District, Bantul Regency, Special Region of Yogyakarta, Indonesia. It is located in 7°35’0” S to 7°52’30” S, and 110°22’30” E to 110°27’30” E, and the map of the study area is shown in Figure 1. This subwatershed originates in the Pakem District in Sleman and flows into the Opak River in Bantul Regency. The selection of the study area was based on the availability of the AWLR, which provided sufficient flow data for use in this study.

Based on its physiography and climate, the Gajahwong subwatershed has complex and varied conditions. It is elongated, with a main river length of 22.9 km and a total watershed area of 63.4 km². In addition, this subwatershed stretches along the southern slopes of Mount Merapi to the foothills. According to the Yogyakarta geological map at a scale of 1:100,000, the subwatershed lies on Qmi lithology, consisting of young Merapi volcanic deposits. These deposits include tuff, ash, breccia, agglomerate, and inseparable lava flows. Dominated by gentle and flat slopes, the subwatershed also passes through rapidly developing urban areas, resulting in varied land use, predominantly residential. Based on the Schmidt-Ferguson classification, the climate in the Gajahwong subwatershed falls under type C, which is categorized as fairly wet. This means the average number of wet months is greater than the average number of dry months. According to Sasminto et al. (2014), areas with a fairly wet climate have homogeneous vegetation, and the Gajahwong River is a perennial river that flows year-round and never dries up.

Materials and data

In this study, three main data sets, primary and secondary data, were used as inputs in the modeling (Table 1). The primary data collected in the field included soil data (e.g., texture, permeability, bulk density, organic matter, and coarse material), which were then tested in the laboratory. Secondary data included rainfall and climate data (e.g., temperature, humidity, wind speed, and solar radiation duration), which were obtained from various relevant agencies, including the Meteorology, Climatology, and Geophysics Agency (BMKG) and the Public Works, Housing, and Energy and Mineral Resources Office (DPUP ESDM) of the Special Region of Yogyakarta. Land use data were obtained from the Indonesian Topographic Map (RBI), which has been updated with 3-m resolution Planetscope imagery. In addition, incomplete primary soil data parameters were obtained from secondary data, such as the Digital Soil Open Land Map (DSOLMap), which included available water capacity and root depth. According to López-Ballesteros et al. (2023), DSOLMap provides more detailed soil characteristics with a higher resolution of 250 m compared to previous global datasets and includes six soil laters/horizon data.

Modeling method

The SWAT is a hydrological model that is used to calculate infiltration and surface runoff using the Soil Conservation Service Curve Number (SCS-CN) concept. The input data required include morphology, land use, soil, and climate data for a particular area. There are three main stages in operating the SWAT model, which includes watershed boundary delineation, creating hydrologic response units (HRUs), and editing and inputting tables for weather variables (Tehsome et al., 2021).

The results from SWAT modeling can include simulations of flow, sediment, erosion, water balance, and other outputs. The calibration and validation process was carried out automatically using the SWAT+ Toolbox and manually using the relative sensitivity equation. An analysis of the modeling results was carried out using statistical tests, including Nash–Sutcliffe efficiency (NSE), coefficient of determination (R^2), and percent bias (PBIAS). These tests were conducted during the calibration and validation processes and compared with the observed discharge data.

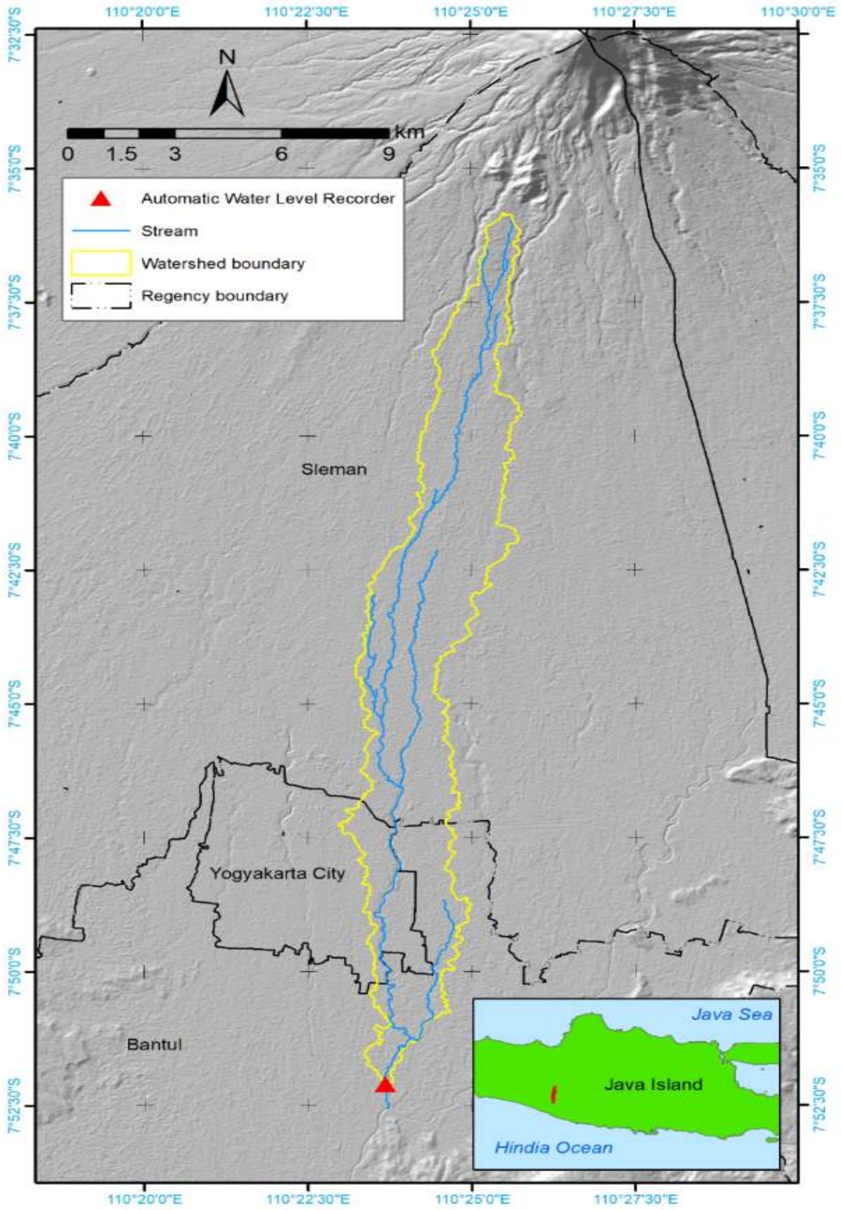


Figure 1. Study area (Gajahwong subwatershed).

Table 1. Research data.

Data	Type	Source
Rainfall in 2018-2023	Secondary	DPUP ESDM Yogyakarta
Climate data for 2018-2023	Secondary	BMKG - Yogyakarta Climatology Station
Flow discharge for 2018-2022	Secondary	DPUP ESDM Yogyakarta
Landuse	Secondary	RBI Map and Planetscope Imagery
Characteristics of soil	Primary and secondary	Measurement field, laboratory tests, and DSOLMap

The calibration process involved adjusting the input parameter values to obtain modeling results that closely match the observed data (i.e., closely resembling real-field conditions). Subsequently, validation was performed by applying the calibrated input parameter values to a different time period to assess the robustness of the modeling results. The NSE test is used to measure how well the hydrological model can predict river flow by comparing modeling results to observed data. The coefficient of determination, or R^2, is used to measure how well the variability of the observed data can be explained by the model. Meanwhile, PBIAS is used to measure the relative average error between the modeling results and the observed data, which provides information about the model's tendency: whether it tends to overestimate or underestimate (Table 2). The equations for NSE, R², and PBIAS are shown as follows (Moriasi et al., 2007):

$$NSE = 1 - \frac{\sum_{i=1}^{n}\left(Q_i{}^{obs} - Q_i{}^{sim}\right)^2}{\sum_{i=1}^{n}\left(Q_i{}^{obs} - Q^{mean}\right)^2} \quad (1)$$

$Q_i{}^{obs}$ = observation discharge at time i
$Q_i{}^{sim}$ = simulated discharge at time i
Q^{mean} = average observation discharge

$$R^2 = \frac{\sum_{i=1}^{n}(O_i - \bar{O})\,(S_i - \bar{S})}{\sum_{i=1}^{n}(O_i - \bar{O})^2 \sum_{i=1}^{n}(S_i - \bar{S})^2} \quad (2)$$

O_i = observation discharge at time i
$\bar{O}$ = average observation discharge
S_i = simulated discharge at time i
$\bar{S}$ = average simulated discharge

$$PBIAS = \left[\frac{\sum_{i=1}^{n}\left(Q_i{}^{obs} - Q_i{}^{sim}\right) \times (100)}{\sum_{i=1}^{n}\left(Q_i{}^{obs}\right)}\right] \quad (3)$$

$Q_i{}^{obs}$ = observation discharge at time i
$Q_i{}^{sim}$ = simulated discharge at time i

Table 2. Performance level.

Performance	NSE	R²	PBIAS
Very good	0.75-1.00	0.7-1.0	≤10
Good	0.65-0.75	0.6-0.7	10-15
Satisfactory	0.50-0.65	0.5-0.6	15-25
Unsatisfactory	≤0.50	≤0.5	>25

Source: Moriasi et al. (2007).

Sensitivity analysis

In this study, sensitivity analysis was performed by calculating the relative sensitivity value (Table 3), which represents the ratio between the percentage change in the output and the percentage change in the input parameter. The mathematical equation is presented in the following equation (Brouziyne et al., 2017):

$$Sr = \frac{(O_{P+\Delta P} - O_{P-\Delta P})/O_P}{(2\Delta P/P\,)} \quad (4)$$

$O_{P+\Delta P}$ = output value after calibration with changes positive
$O_{P-\Delta P}$ = output value after calibration with changes negative
O_P = output value before calibration
ΔP = large change, the value used is 25%
P = initial value of an input parameter

Table 3. Parameter sensitivity levels.

Sensitivity	Value
Very high	1.00 < |Sr|
High	0.20 < |Sr| < 1.00
Medium	0.05 < |Sr| < 0.20
Small to negligible	0.00 < |Sr| < 0.05

Source: Brouziyne et al. (2017).

Results and Discussion

SWAT+ modeling

SWAT model is designed to simulate hydrological processes, erosion, water quality, and land use dynamics within a watershed (Sood et al., 2010; Neitsch et al., 2011). Therefore, watershed boundary delineation as an analysis unit is a very important stage in SWAT model. The delineation results of the Gajahwong subwatershed boundaries are shown in Figure 1. The total area of the subwatershed is 63.4 km², with a main river length of 22.9 km. The delineation process resulted in five subbasins and 18 channels (i.e., river segments). Each subbasin influences the others, with the flow in the northernmost subbasin moving southward, following the slope direction. This causes the southern subbasins, particularly the outlet area, to accumulate flow from the upstream subbasins.

The river channel at the outlet of the Gajahwong subwatershed has a width of 4.8 m and a depth of 0.87 m. According to the SWAT modeling results, the channel at outlet 13 has a Manning’s roughness coefficient of 0.05, which reflects the river’s condition based on bed material, channel uniformity, vegetation, and the influence of nearby structures. Based on the survey results, it was found that the riverbed material consists primarily of soil due to significant sedimentation processes. The cross-sectional profile of the channel occasionally varies due to the narrowing caused by vegetation around the river. Although there are some structures near the river, they do not significantly affect the channel’s cross-sectional variation. Field observations indicate a Manning’s roughness coefficient of 0.06, which is close to the results obtained from the SWAT model.

According to Montjai et al. (2015), the high Manning’s roughness coefficient is due to obstructions, such as gravel, stones, vegetation, and structures like bridges, which can reduce river flow velocity. This condition can decrease channel capacity, potentially increasing the risk of ponding or flooding. A low Manning coefficient indicates a smoother surface, allowing water to flow more quickly. This condition can increase channel flow capacity, thereby reducing the risk of flooding.

The second step in SWAT model is defining HRUs. Creating HRUs requires land use, soil, and classified slope data. Land use in the Gajahwong subwatershed can be categorized into generic agricultural land, mixed grassland, orchard, rice field, settlement, and activity area, and water body (Figure 2). It is dominated by settlements and activity areas (64.3%), followed by rice fields (17.9%) (Table 4). It shows that Gajahwong can be categorized as a city with massive activity. Soil data analysis was conducted using a pedogeomorphology approach, which involves deriving data from geomorphological maps that contain information on various landforms.

Table 4. Land use in Gajahwong subwatershed.

Land use	SWAT Code	Area (km^2)	Persentase (%)
Agriculture field	AGRL	1.398	2.21
Mixed grassland	MIGS	0.582	0.82
Orchard	ORCD	9.330	14.72
Ricefield	RICE120	11.333	17.88
Settlement and activity area	URBN	40.734	64.25
Water body	WETW	0.018	0.03

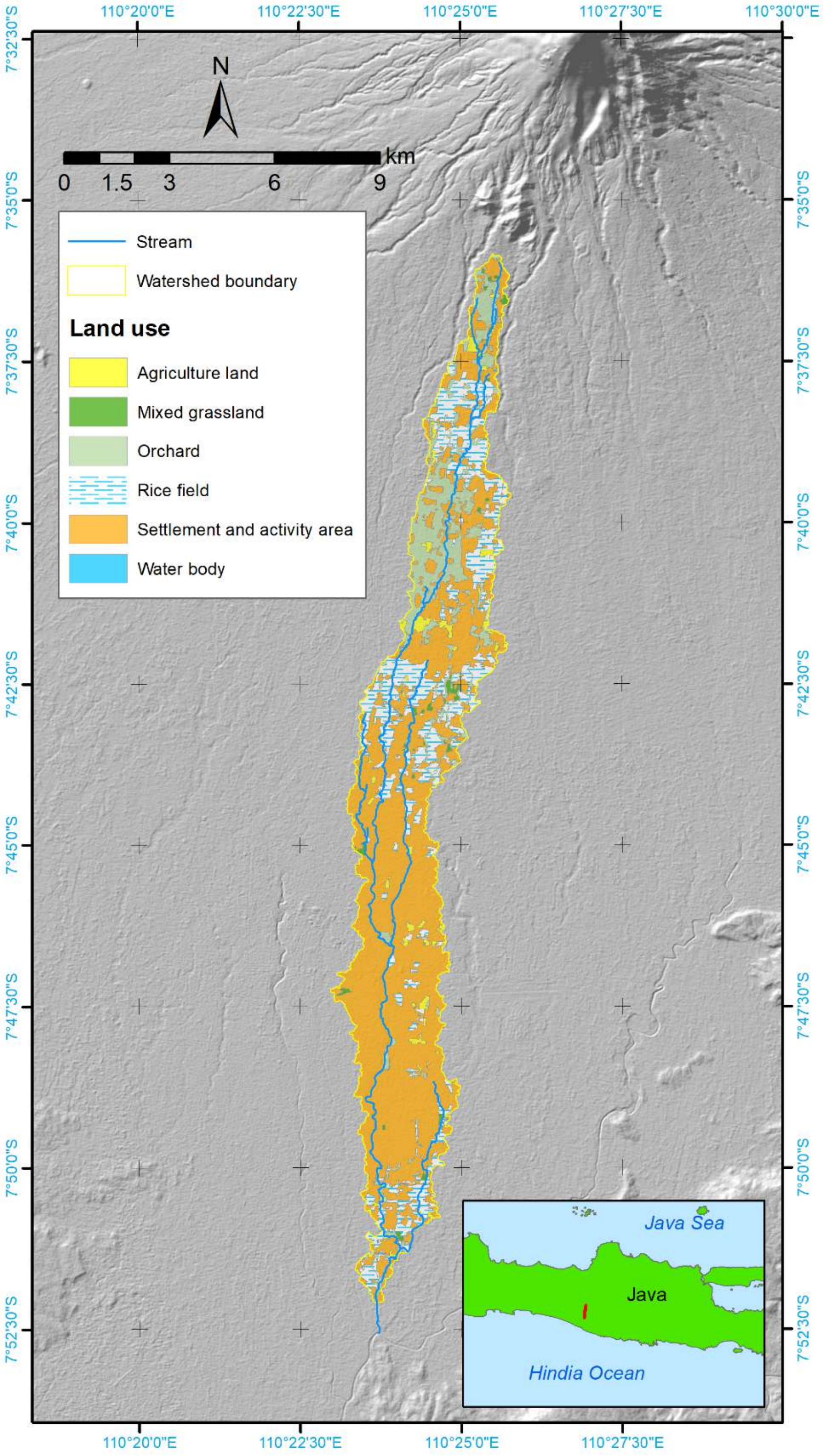


Figure 2. Land use in the Gajahwong subwatershed.

Geomorphological classification and mapping reveal that landforms are strongly influenced by lithological diversity, which subsequently evolves into soil through pedological processes (Lopes et al., 2022). A total of five soil samples were tested for various parameters (Figure 3), with one sample taken from each landform (e.g., top of hill to foothill area with the change of elevation and slope) (Sarkar, 2019). The results of the laboratory test are shown in Table 5 and Table 6. The determination of soil texture was conducted using a soil texture triangle based on the percentage of sand, clay, and silt content. Generally, soils in the Gajahwong subwatershed have relatively high sand content, ranging from 48% to 75%. This results in four out of five soil samples being classified as sandy in texture. Three samples also exhibit relatively high clay content, ranging from 20% to 26%. The highest silt content is found in sample SOL4, at 31%. Soil texture, closely related to soil porosity, significantly influences infiltration rates. According to Budianto et al. (2014), larger soil pores lead to higher infiltration capacity.

Table 5. Soil texture and its content based on laboratory tests.

Sample	Landform	Texture	Content (%)			
			Sand	Clay	Silt	Coarse material
SOL1	Footslope	Sandy loam	75	7	18	10
SOL2	Undulating plain	Sandy clay loam	70	23	8	28
SOL3	Alluvial Fan	Sandy clay loam	70	20	10	10
SOL4	Alluvial Plain	Loam	48	21	31	13
SOL5	Floodplain	Sandy clay loam	67	26	7	0.2

Table 6. Soil characteristics based on laboratory tests.

Sample	Landform	Texture	HSG	Bulk density (g/cm^3)	Organic (%)	Conductivity (cm/hour)
SOL1	Footslope	Sandy loam	B	1.80	2.02	31.08
SOL2	Undulating plain	Sandy clay loam	C	2.50	1.90	14.95
SOL3	Alluvial Fan	Sandy clay loam	C	2.32	1.82	9.51
SOL4	Alluvial Plain	Loam	B	1.82	0.82	3.06
SOL5	Floodplain	Sandy clay loam	C	2.36	0.58	18.85

Three samples with a sandy clay loam texture fall into Hydrologic Soil Group (HSG) C, indicating slow infiltration. Meanwhile, two other samples are categorized as HSG B, representing moderate infiltration. Determining the HSG is crucial in hydrological analysis as it relates to runoff potential and infiltration rates. Coarser soil textures allow water to infiltrate more quickly, while finer textures result in slower infiltration (Asrul et al., 2021). Consequently, slower infiltration rates can increase surface runoff and vice versa. Differences in land characteristics and land use compared to other areas are expected to result in varying infiltration rates (de Almeida et al., 2018).

Other soil parameters include moisture content and bulk density. Moisture content refers to the amount of water held within the soil. Sample SOL4, with a loam texture, has the highest moisture content at 3.09%, while the lowest moisture content is found in SOL5, which has a sandy texture. Bulk density, expressed in g/cm³, is the ratio of dry soil weight to its total volume (Harahap et al., 2021). In the Gajahwong subwatershed, bulk density ranges from 1.8 to 2.5 g/cm³. Sandy soils tend to have higher bulk density than clay soils.

Laboratory tests also examined soil organic matter and permeability. Organic matter originates from decomposed remains of living organisms and ranges between 0.58% and 2.02% in the Gajahwong subwatershed. Variations in organic matter content are influenced by vegetation type, climate, soil management, and texture. Soil permeability in the area varies from slow to fast. High permeability is observed in sandy soils due to their larger particles and more extensive pore space. Conversely, clay soils exhibit lower permeability due to their limited pore space.

A total of 545 HRUs were formed in the Gajahwong subwatershed. HRUs in the southern region tend to cover larger areas than those in the northern part, with each HRU showing homogeneous hydrological characteristics. The determination of curve number values was made during the HRU creation process (Harifa et al., 2017). These values are an important parameter in the SWAT model, which implements the SCS-CN method in its simulations. These values vary based on land use and hydrological soil groups (HSGs). There are four HSGs (Groups A, B, C, and D) based on soil's runoff potential. Group A has the highest infiltration capacity, while group D has the lowest (Ghanbarian et al., 2021). The average curve number value is obtained from the average area with each HSG based on land use. The highest average curve number value can be found in settlements and activity areas with a value of 98, whereas the lowest value is in mixed grassland with a value of 76 (Table 7). A high value indicates a reduction in the land's ability to store groundwater, which can lead to an increase in surface runoff (Sari et al., 2016). Therefore, it can be said that a high curve number value will result in greater surface runoff. That means settlements will have the highest surface runoff.

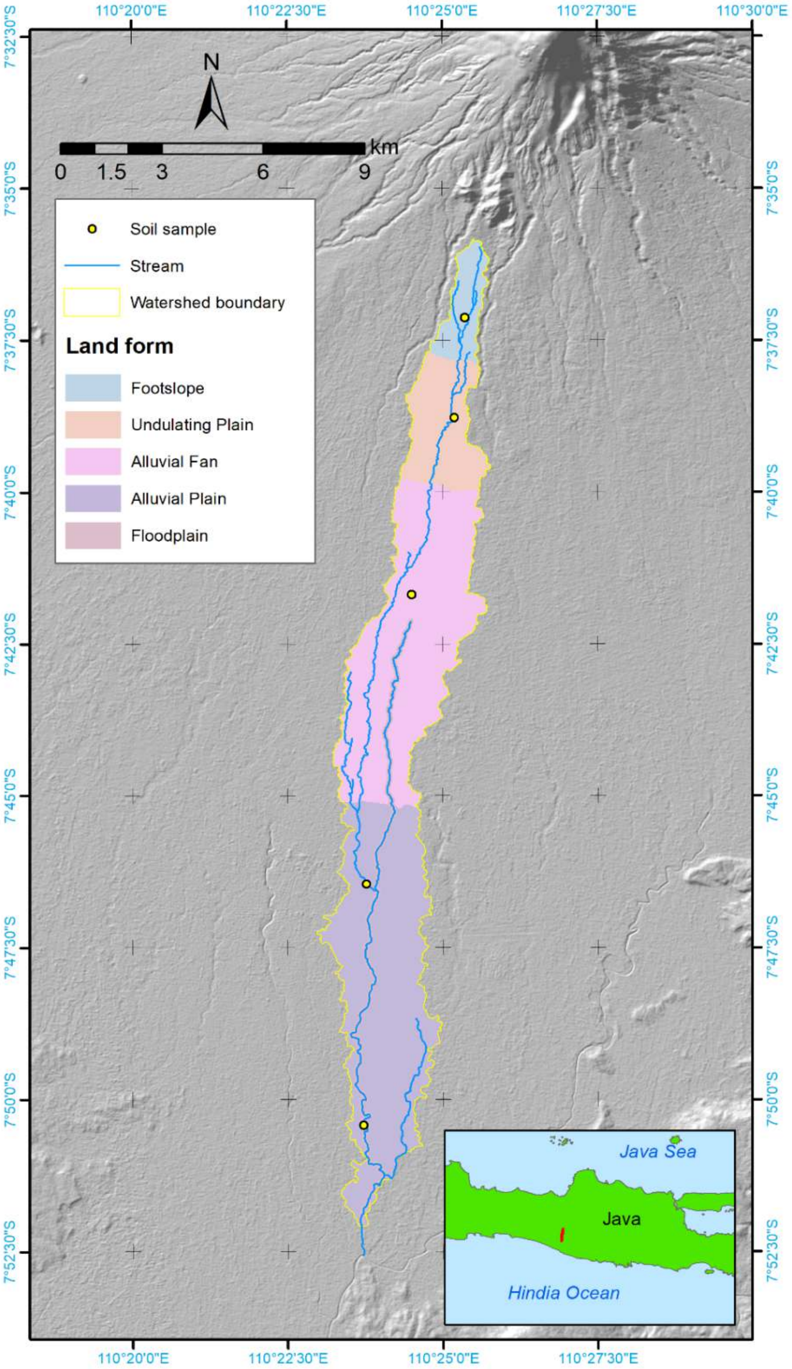


Figure 3. Landform in the Gajahwong subwatershed.

Table 7. Curve number of Gajahwong subwatershed.

Land Use	CN Values on various HSGs				CN Average
	A	B	C	D	
Agriculture field	67	78	85	89	77
Mixed grassland	67	78	85	89	76
Orchard	32	58	72	79	83
Ricefield	67	78	85	89	79
Settlements and activity area	98	98	98	98	98

Calibration and validation

The model was run from January 2019 to December 2022 for daily and monthly flow. The result was calibrated and validated automatically using SWAT+ Toolbox. The changes in parameter value at the calibration stage are shown in Table 8. There are 9 parameters from 3 group (e.g., HRU, aquifer, and soil) that calibrated with various change type (e.g., percentage, replace, and relative). Figures 4a and 4b show a significant difference in the calibration results. Given an adjustment in the discharge, previously overestimated, to become closer to the observed discharge values, daily flow calibration results yielded NSE, R², and PBIAS values of 0.67, 0.73, and 0.18% (Figure 4b), respectively, which fall within the good and very good classification. Peak discharge is highly influenced by rainfall, as seen with the peak flow on March 5, 2020, which coincided with higher rainfall compared to other days. It is worth noting that daily flow calibration was only conducted during the rainy season; hence, the consistency of the model's performance during the dry season may not be fully explained by the calibration results.

Table 8. Changes in parameter values at the calibration stage.

Group	Parameter	Information	Change Type	Min	Max	Best Value	Unit
hru	cn2	curve number	percent	-20	20	-59.9	
hru	cn3_swf	soil water factor for cn3	percent	-20	20	-14.3	
hru	esco		replace	0.02	0.2	0.02	
hru	perco		replace	0.3	1	0.99	fraction
aqu	flo_min	water table depth for return flow to occur	replace	0	1	0.99	m
aqu	alpha	baseflow recession constant	replace	0.01	0.30	0.76	days
sol	bd	bulk density	percent	-20	20	-3.20	mg/m^3
sol	k	hydraulic conductivity	replace	0	1	0.99	mm/hour
sol	awc	available water capacity of the soil	relative	-500	500	428.9	mm H_2O/mm

The validation process produced statistical test results with NSE, R², and PBIAS values of 0.57, 0.63, and 3.05%, respectively. The application of calibrated parameter values during the validation period, as shown in Figures 5 and 6, indicates that the modeled flow closely follows the general pattern of the observed flow, although some time points show overestimation and underestimation.

Calibration and validation were also performed on monthly flow discharge, which was calculated from the average daily flow within a month (Figure 7). The statistical test results indicate that the model's performance for monthly discharge is better than that for daily discharge. The calibration period results show NSE, R², and PBIAS values of 0.90, 0.91, and 4.74%, respectively, all of which fall under the very good category. Validation results also fall under the very good category, with NSE and R² values of 0.86 and 0.89, respectively. Meanwhile, PBIAS showed good results with a value of 13.02%. This value is close and even better to the statistical test by Ferijal (2019), which reported values of 0.71 for NSE, 0.77 for R², and 6.3% for PBIAS.

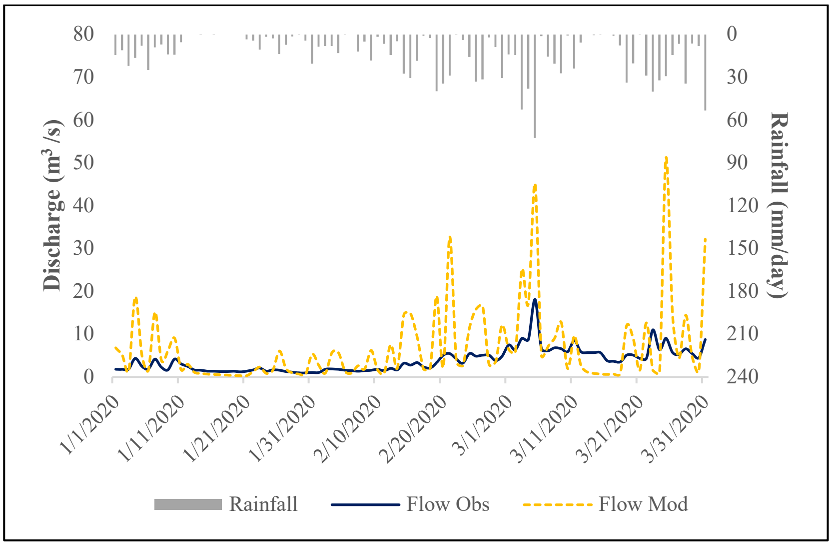
The SWAT model's daily flow results can be used to analyze the continuous availability of river water. According to Runtunuwu et al. (2011), evaluating water levels (which can generate flow values) is crucial for supplying water for crops. In addition, daily flow modeling can be used to assess peak discharges that have the potential to cause floods on a daily scale. This allows for appropriate preventive measures to be taken to reduce the risk of damage from flood events.

The SWAT model's monthly discharge results can be analyzed for long-term hydrological conditions. Monthly discharge analysis over a long period is typically used to identify seasonal patterns in a region. In addition, monthly discharge data can be used to assess water availability for various needs, such as agriculture, livestock, or even domestic use.

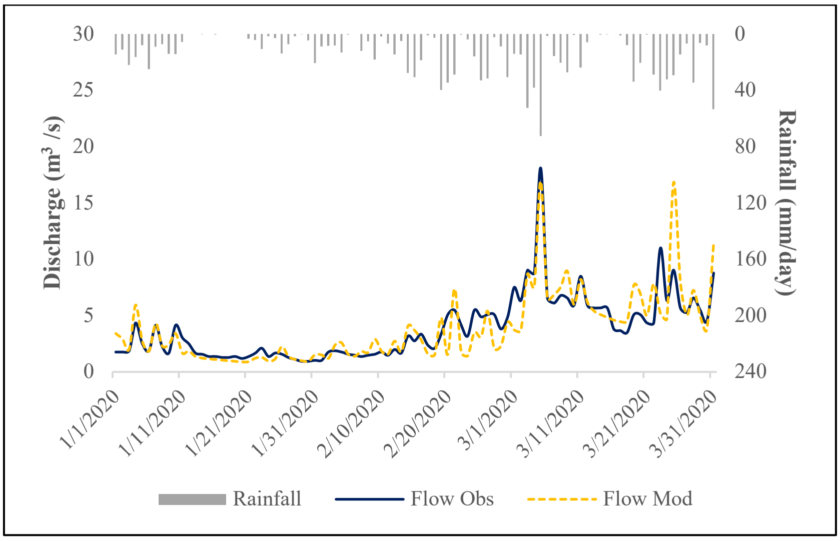
Based on the modeling results, it can be concluded that the data used in this study were effective in producing good modeling results. Although a combination of secondary and primary data was sufficient to achieve good modeling performance, the observed discharge data were the most important in this study. Without these data, there would be no comparison with real-world conditions to indicate the quality of the modeling results.

Parameter sensitivity

Sensitivity analysis was conducted on several parameters from the HRU (hydrological response unit), AQU (aquifer), and SOL (soil) groups. The analysis was performed manually by calculating the relative sensitivity values, which indicate the extent of output changes caused by changes in input parameters. Based on the calculations in Table 7, it was found that the cn2 parameter, which had a value of 1.12, had the highest sensitivity level (Table 9). This indicates that a 1% change in cn2 will result in a 1.12% change in the modeled discharge (Brouziyne et al., 2017).



(a)



(b)

Figure 4. Daily flow discharge in the Gajahwong subwatershed.
(a) before and (b) after calibration.

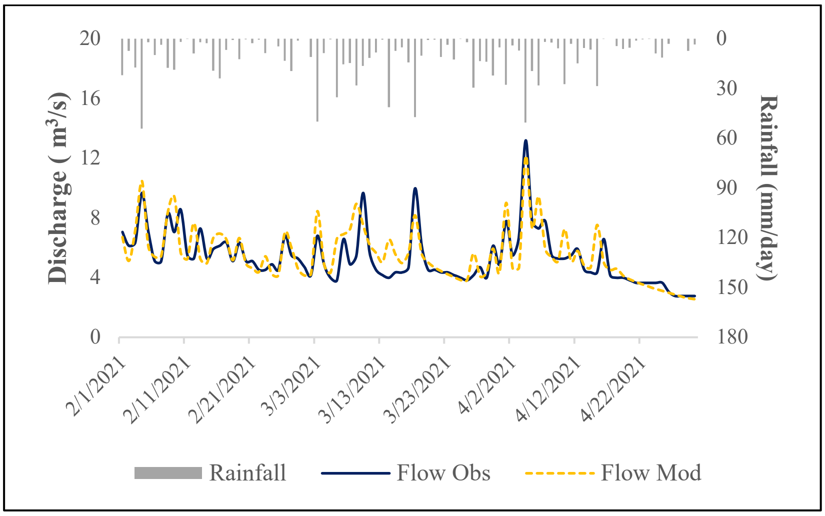


Figure 5. Validation of daily flow discharge in the Gajahwong subwatershed.

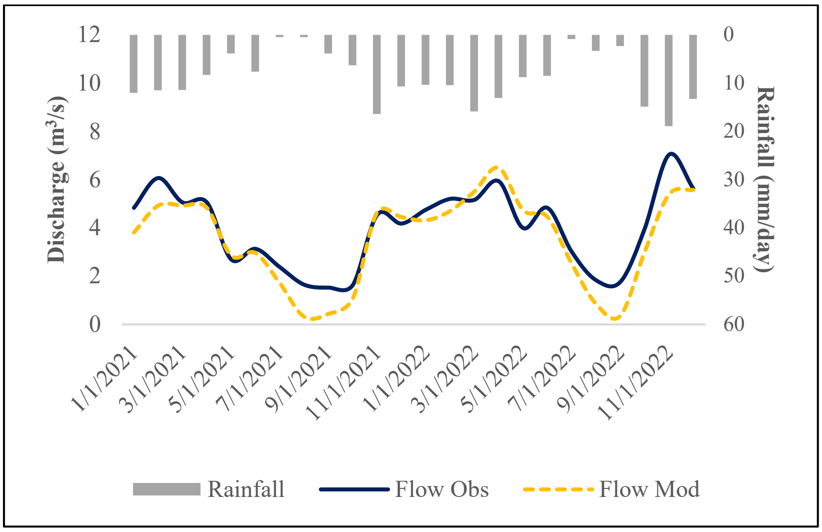
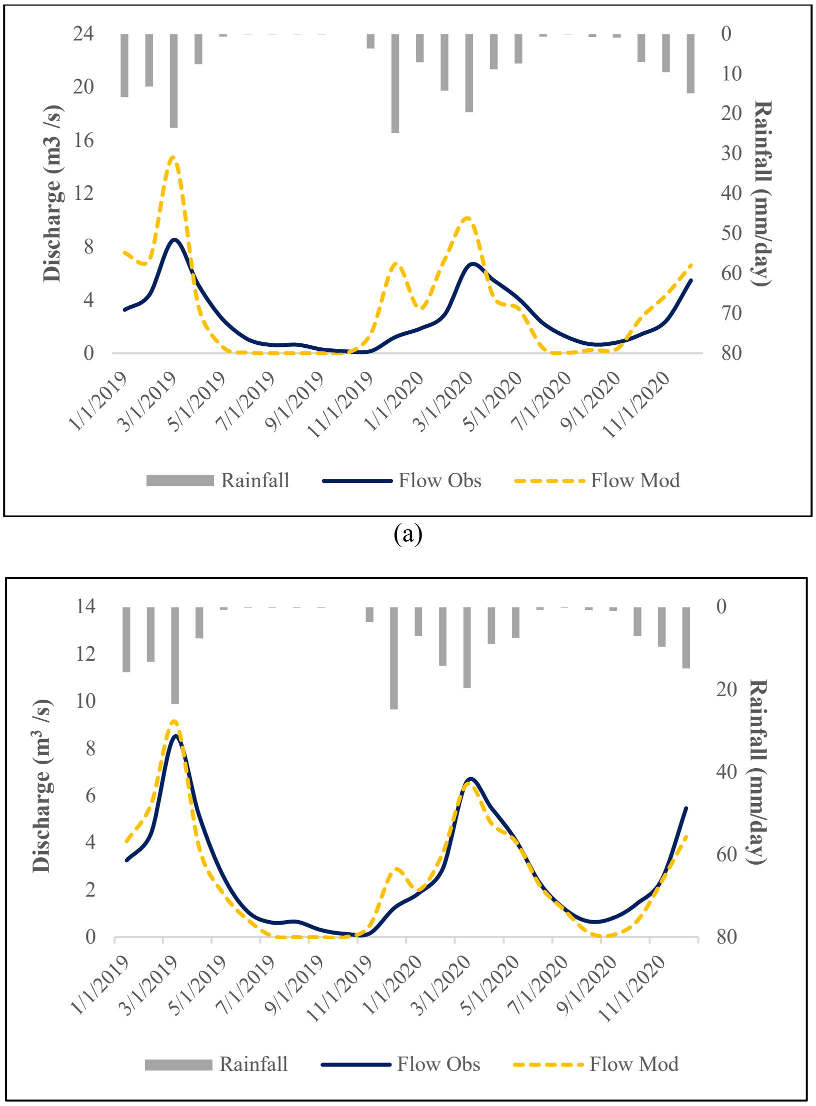


Figure 6. Validation of monthly flow discharge in the Gajahwong subwatershed.



(a)

(b)

Figure 7. Monthly flow discharge in the Gajahwong subwatershed.
(a) before and (b) after calibration.

The classification results show that this sensitivity value is considered very high since it is above 1. A positive value indicates a direct relationship, where an increase in the input parameter leads to an increase in the output value.

Parameters ranked 2 to 7 have small to very small sensitivity levels. The cn3_swf parameter has a relative sensitivity value of −0.002, indicating that a 1% change in this parameter will result in a 0.002% decrease in discharge. A negative value indicates an inverse relationship, where an increase in the input parameter leads to a decrease in the output value. The bd, perco, esco, flo_min, and k parameters all contribute positively to the modeled discharge, although the effects are not significant.

In the HRU group, cn2 is the most crucial parameter, as it has a significant impact on the hydrological modeling in the Gajahwong subwatershed. This curve number is an index that estimates the amount of surface runoff caused by rainfall, which is influenced by land use, hydrological conditions, and soil moisture (Munajad and Suprayogi, 2015). The larger the cn value, the more water is discharged because it is not absorbed into the soil. Reducing the cn value can lower the overestimated discharge. In addition to cn2, the HRU group also includes cn3_swf, perco, and esco. The cn3_swf (curve number 3 seasonal adjustment factor) parameter is used to adjust seasonal variations applied to cn3 (wet conditions). NRCS classified 3 levels of antecedent moisture conditions (AMC) that influence the curve number on land: dry (cn1), normal (cn2), and saturated and wet conditions (cn3) (Tikno et al., 2012; Assaye et al., 2021).

Table 9. Parameter sensitivity in the Gajahwong subwatershed.

Group	Parameter	Relative Sensitivity	Sensitivity
hru	cn2	1.124882246	very high
hru	cn3_swf	0.002220970	small
sol	bd	0.000818482	small
hru	perco	0.000318037	small
hru	esco	0.000113312	small
aqu	flo_min	0.000105649	small
sol	k	5.55258 E-05	very small
sol	awc	0	negligible
aqu	alpha	0	negligible

Soil becomes more saturated during periods of high rainfall, so cn3_swf can be used to increase the cn3 value. Meanwhile, the perco (percolation coefficient) parameter is used to regulate the rate of water percolation through the root zone into deeper soil layers, with faster percolation capable of reducing the amount of surface runoff. The esco (soil evaporation compensation factor) parameter controls the amount of water available for evaporation from the soil layer. A low esco value indicates that evaporation occurs in deeper soil layers, causing the top layer to become saturated, leading to higher infiltration and reduced surface runoff. This parameter has a small sensitivity because this model scenario did not make soil evaporation processes significantly affect water availability (Samadi, 2017).

In the SOL group, the bd (bulk density) parameter represents the ratio of dry soil weight to total soil volume, which is expressed in grams per cubic meter or g/cm³ (Harahap et al., 2021). Bulk density is influenced by factors such as texture, structure, and organic matter content, making it highly susceptible to changes caused by land management (Logsdon et al., 2004). In relation to texture, clay soils have smaller pores due to their high compaction levels, which directly affect their bulk density (Lee et al., 2009). High bulk density values result in low soil porosity and infiltration, which increases surface runoff volume. Meanwhile, the k (hydraulic conductivity) or permeability parameter measures the soil's ability to conduct water through it. The higher the k value, the higher the infiltration rate, which reduces the amount of surface water flow. The aquifer group parameter analyzed is flo_min, which determines the minimum baseflow that must be maintained, particularly during dry periods (or drought). This parameter does not directly affect surface runoff but ensures that the flow does not fall below a certain minimum threshold after runoff occurs.

Baseflow stability is maintained by the flo_min parameter; therefore, it does not have a significant impact on the modeled discharge, particularly on peak discharge. Alim et al. (2018) found that sensitive parameters include cn2, ch_k2, ch_n2, esco, gw_revap, and gw_delay, indicating two parameters that match the findings in this study, namely, cn2 and esco. The curve number parameter is highly sensitive across all regions due to its crucial role in estimating runoff from rainfall. Runoff is a key component of the hydrological cycle, which can influence water availability, soil erosion, and flood risks. Since the curve number directly affects runoff estimates, small changes in this parameter can significantly impact the modeling results (Soomro et al., 2019).

Conclusion

Based on the results from this study, it can be concluded that the hydrological response in the form of flow discharge based on SWAT modeling produced good results, as it closely resembled the observed discharge in both daily and monthly simulations. Daily discharge modeling is useful for flood discharge analysis, whereas monthly discharge can be used to analyze water availability in a region.

Based on the validation results using objective functions such as NSE, R², and PBIAS, it can be concluded that the model can effectively and accurately model and predict flow discharge in the Gajahwong subwatershed. The results indicate that the data used in this study were effective in achieving good modeling performance. Observed discharge data were the most important part of this study because, without them, the modeling results would merely be a model without any indication of its quality. The input parameters that are sensitive and can influence the hydrological response in the Gajahwong subwatershed, in order of importance, are cn2, cn3_swf, bd, perco, esco, flo_min, and k. The most sensitive parameter is cn2, or the curve number, with a sensitivity value of 0.96 and a relative sensitivity of 1.12. This value falls under the very sensitive category with a positive correlation. Therefore, the curve number or cn2 parameter becomes crucial in hydrological modeling in the Gajahwong subwatershed, and it is also sensitive in several other research areas.

Based on the results that have been achieved, some suggestions and considerations can be made for further research. First, a limitation of this study is the availability of observed data, which only included the flow discharge data. Hydrological response analysis would be more comprehensive if it were conducted using other outputs as well, not just flow discharge. Second, based on the results of the analysis, the most sensitive parameter is the curve number. It is recommended that future research and watershed management in the Gajahwong subwatershed prioritize this parameter over the others. The subwatershed, which is dominated by residential and activity land use, tends to have a high curve number value, which increases the potential for flooding. Therefore, appropriate management is necessary, particularly concerning this parameter.

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