Available online on: http://ejournal.undip.ac.id/index.php/teknik

TEKNIK, 46 (2), 2025, 114-122

Evaluation of Soil Water Assessment Tool (SWAT) Model Accuracy in Estimating Erosion and Sedimentation Rates in the Sutami Reservoir Watershed

Hendri Wijaya[*], Dyah Ari Wulandari, Suripin

Department of Civil Engineering, Faculty of Engineering, Diponegoro University,
Jl. Prof. Soedarto, SH, Tembalang, Semarang, Indonesia 50275

Abstract

The storage capacity of the reservoir is affected by poor management of the Watershed (DTA), which in turn influences erosion and sedimentation levels. In 1972, the erosion rate at Sutami Reservoir was 0,18 mm/year, rising to 1.44 mm/year by 2022. This data reflects a significant increase in the erosion rate within the Sutami Reservoir watershed, highlighting the need for effective watershed management modeling. The Soil and Water Assessment Tool (SWAT) is commonly used for watershed management assessment. This study aims to predict erosion and sedimentation rates using SWAT and evaluate the accuracy of its simulations through calibration and validation. The simulation results from SWAT show that the total erosion rate is 5,280.45 tons/ha/year, with a total sedimentation of 11,662,851.94 tons/year. Additionally, These results were compared with an analysis using the USLE method, which indicated an erosion rate of 5,178.98 tons/ha/year and sedimentation of 11,060,798.14 tons/year. The comparison of both methods showed similar outcomes, suggesting that the SWAT model provides reasonably accurate predictions. The calibration process, using observed discharge data from 2022 and SWAT-simulated discharge, yielded an NSE value of 0.778, classified as 'very good.' On the other hand, validation using discharge data from 2023 and SWAT-simulated discharge yielded an NSE value of 0.660, classified as "good." Based on these results, the SWAT simulation offers a reliable representation of calibration and validation, making it an appropriate model for this study.

Keywords*:* *erosion rate; sedimentation rate; SWAT model; watersheds; reservoir*

1. Introduction

A river and its tributaries that work together as an interconnected system are known as a watershed (DTA). Watersheds play a crucial role in collecting, storing, and directing rainwater to natural reservoirs such as lakes or directly to the sea (Perusahaan Umum Jasa Tirta I, 2023). However, erosion and sedimentation within watersheds remain significant challenges in reservoir management across Indonesia. Many major reservoirs, including the Sutami Reservoir, have been affected by these issues (Marhendi, 2018). Various physical characteristics define a watershed, including topography, geology, soil composition, vegetation, land use, hydrology, human activities, and morphometry, all of which are vital for effective management and planning (Asdak, 2023). When the Sutami Reservoir was first established in 1972, it had a total storage capacity of 343 $\times 10^6$ m³, with a initial sedimentation rate of 90 $\times 10^6$ m³ and an initial sedimentation rate of 900,000 m³ per year. Upon its completion in 1977, the Sutami Hydroelectric Power Plant (PLTA Sutami) had a capacity of 2 × 35 MW, which later increased to 3 × 35 MW following the construction of the Lahor Dam. In addition to electricity generation, the Sutami Dam serves multiple functions, including flood control, irrigation water supply for 34,000 hectares, raw water provision, and tourism development. Recent bathymetric data from 2022 indicate that the storage volume of the Sutami Reservoir at a normal water level of 272.50 meters has declined to 174.88 $\times 10^6$ m³. This represents a reduction of 168.12 $\times 10^6$ m³ from its original capacity, equating to a 49.01% decrease. The primary factor behind this reduction is land degradation, which has led to an accelerated erosion rate (Daruati & Arief, 2017). The erosion process contributes to sedimentation in the reservoir, with eroded materials making up 6.73% of the total sediment transported into the reservoir. A study by (Suroso et al., 2012) analyzed the capacity and lifespan of the Sutami Reservoir. Their

[*)] Hendri Wijaya
E-mail: hendriwijaya1719@gmail.com

doi: 10.14710/teknik.v46i2.67929

research found that by 2007, the sedimentation rate had risen to 1,085,500 m³ per year, exceeding the original 1972 projection of 900,000 m³ per year. This increase in sedimentation has significantly impacted the reservoir's effective storage capacity, which decreased from 253 × 10^6 m³ in 1972 to 146.57 × 10^6 m³ in 2004. As a result, the reservoir's projected lifespan, initially estimated at 100 years, had been reduced to just 16.21 years as of 2004 (Suroso et al., 2012).

To mitigate erosion and sedimentation, reforestation efforts have been carried out in the Upper Brantas Watershed by Perum Jasa Tirta I (PJT I), with details provided in Table 1.

Table 1. Afforestation Initiatives in the Upper Brantas Watershed (Perusahaan Umum Jasa Tirta I, 2023)

Years	Work Location	Volume (shaft)
2009	Malang Regency (Collaboration with the Forestry Department)	88.000
	PJT I (Malang Regency and Batu City)	1.650
2010	Malang Regency (Collaboration with the Forestry Department)	454.181
	Batu City (Collaboration with the Forestry Department)	110.800
	PJT I (Malang Regency and Batu City)	50.900
2011	Malang Regency (Collaboration with the Forestry Department)	876.584
	Batu City (Collaboration with the Forestry Department)	42.600
	PJT I (Malang Regency and Batu City)	75.050
2012	PJT I (Malang Regency and Batu City)	1.373.400
2013	Malang Regency (Collaboration with the Forestry Department)	640.500
	Batu City (In collaboration with the Forestry Department)	26.250
	Turen and Dau Subdistricts (In collaboration with Community Organizations)	35.532
2014	Malang Regency	531.000
	Blitar Regency	20.000
	Batu City	8.100
2015	Malang Regency	343.000
	Blitar Regency	32.000
2016	Malang Regency	305.000
	Blitar Regency	45.000
2017	Malang Regency	295.000
	Blitar Regency	32.000
	Batu City	1.000

According to data from Perum Jasa Tirta I (PJT I), the projected average erosion rate for the Sutami Reservoir in 1972 was 0.18 mm/year. However, calculations from 2022 indicate that the average erosion rate had increased to 1.44 mm/year. This significant increase in erosion within the Sutami Reservoir watershed suggests that current management and mitigation strategies,T as detailed in Table 1, have not been sufficiently effective or efficient. As a result, precise erosion and sedimentation modeling is essential. This study utilizes the SWAT model to assess watershed management due to its advantages in long-term analysis. Developed in the early 1990s by the United States Department of Agriculture (USDA), SWAT is widely regarded as an effective and efficient tool for evaluating the impacts of watershed management practices. One of its key benefits is its rapid processing capability and ease of use, making it a highly efficient modeling tool (Soma, 2024). Additionally, SWAT is well-suited for assessing long-term watershed management approaches. The SWAT model incorporates various field data inputs, including rainfall, climate conditions, soil characteristics, and land management practices (Fitriyana, 2019). In this research, SWAT is applied to simulate hydrological processes, erosion, and sedimentation across different land units. The sedimentation rate results from the SWAT model will be calibrated and validated (Vinay et al., 2024) by comparing simulated discharge data with observed discharge measurements. The total area of the sub-watershed examined in this study covers 2,009.45 km², as depicted in Figure 1.

doi: 10.14710/teknik.v46i2.67929

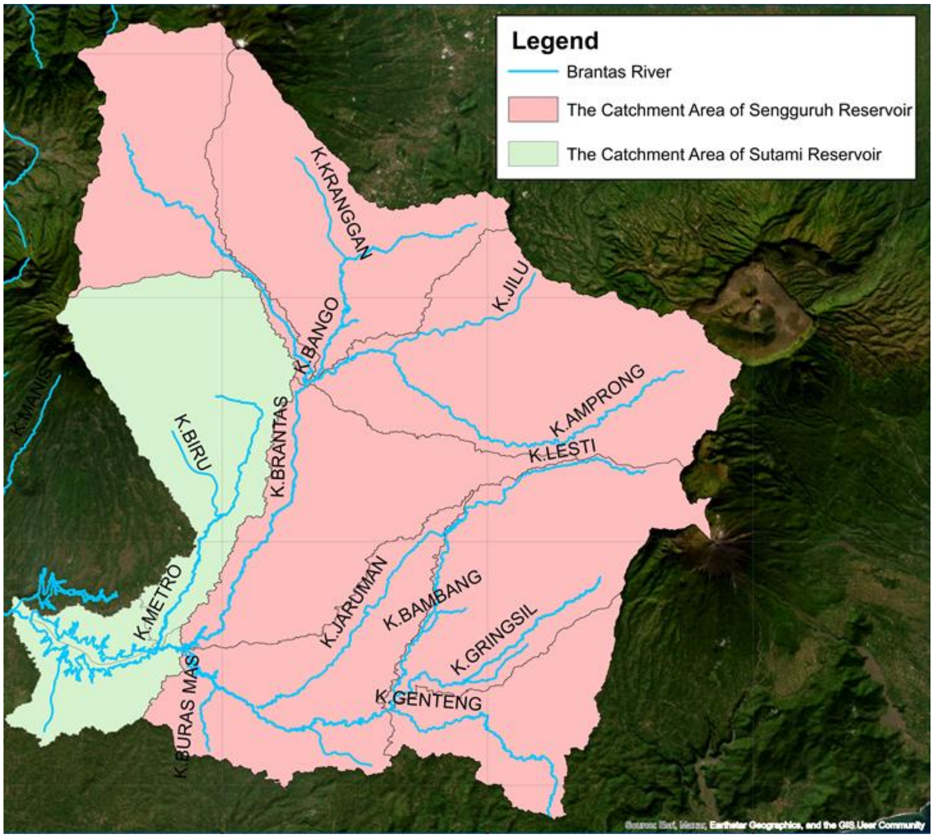


Figure 1. The study areas are the watershed regions of Sutami Reservoir and Sengguruh Reservoir.

The Sengguruh Reservoir watershed (DTA Waduk Sengguruh) administratively encompasses three districts in Batu City: Bumiaji, Junrejo, and Batu, along with a small portion of Malang Regency, including Pujon and Karangploso Districts. In contrast, the Sutami Reservoir watershed (DTA Waduk Sutami) falls within the administrative boundaries of Malang Regency and Malang City in East Java Province.

This research aims to quantify erosion and sedimentation in the Sutami Reservoir watershed and evaluate the accuracy of the SWAT model in reflecting the watershed's actual conditions. The model's accuracy will be assessed through calibration and validation by comparing SWAT-simulated discharge results with observed discharge measurements.

2. Materials and Methods

2.1 Materials

This study utilized data sourced from relevant agencies, including a Digital Elevation Model (DEM) map, land use map, soil classification map, rainfall records, and climatological parameters such as wind speed, temperature, humidity, and solar radiation. Additionally, observed discharge data were collected. All data used in this research are secondary and are summarized in Table 2.

Tabel 2. Research Data

No.	Data	Period (Year)	Source
1	DEM Map	2023	PJT I
2	Land Use Map	2023	PJT I
3	Soil Type Map	2023	PJT I
4	Rainfall Data	2019-2023	PJT I dan BBWS Brantas
5	Climatology (wind speed, temperature, humidity, solar radiation)	2019-2023	BMKG
6	Observed Discharge Data	2022 dan 2023	PJT I

The data utilized in this study is from 2023; therefore, erosion and sedimentation analysis may differ in future years based on various influencing factors. These factors include human activities (such as deforestation, land conversion, agricultural practices, irrigation systems, urbanization, infrastructure development, and natural resource exploitation), land use changes (including variations in vegetation and crop types), and conservation policies (such as watershed

doi: 10.14710/teknik.v46i2.67929

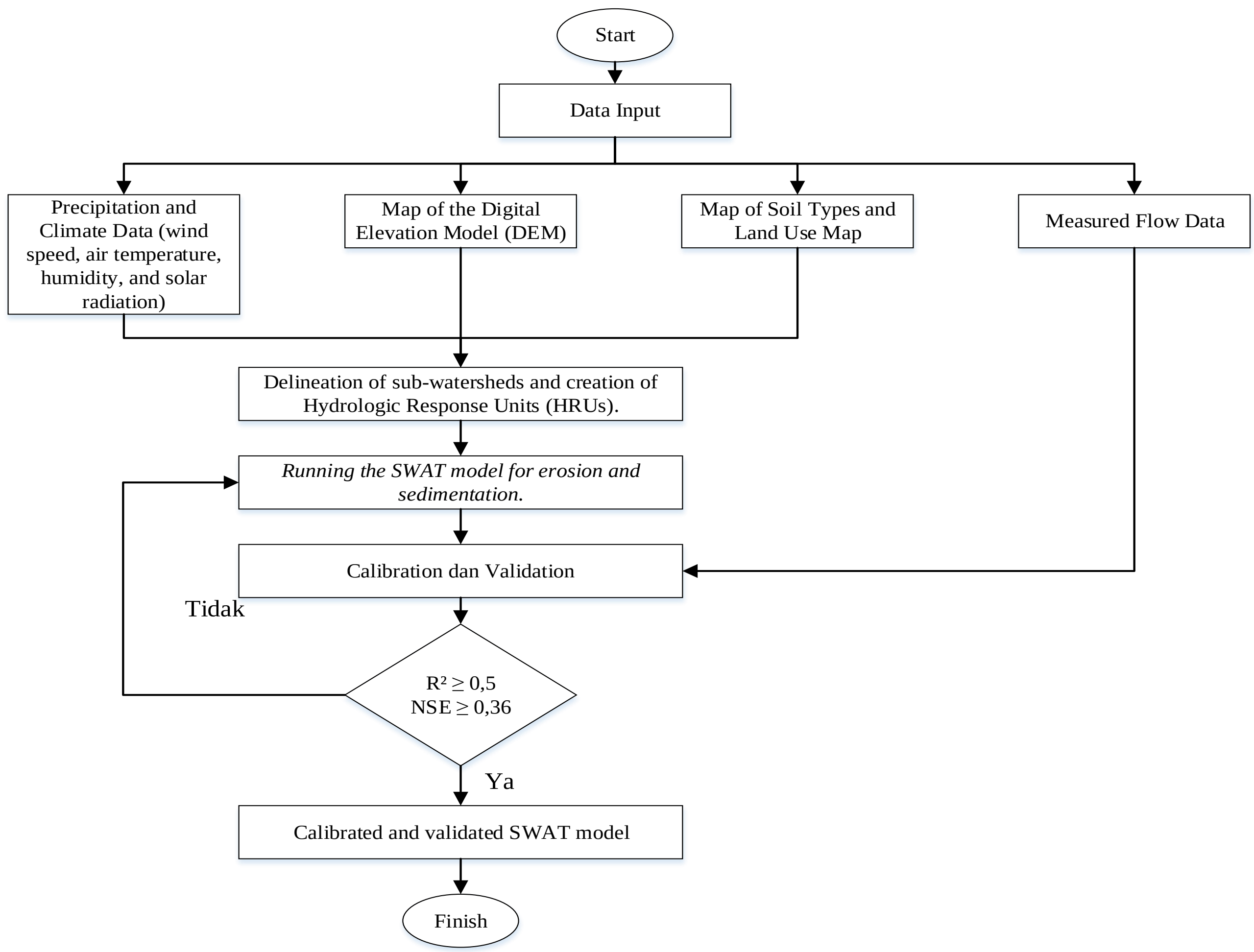
management strategies). The research data used as input for the SWAT model must adhere to the specified format. Before being used, the collected data must first be processed to ensure its suitability. The input data consists of the following:

(a) Spatial Data Processing
The spatial data processing steps include:
- Processing DEM maps, land use maps, and soil type maps.
- Modifying map attributes to match the required data.
- Adjusting map coordinates to align with the study area.

(b) Climatological Data Processing
Climatological data is formatted as follows:
- Converting the data into *.txt format.
- Saving rainfall data in *.pcp format.
- Storing temperature data in *.tmp format.
- Formatting wind speed data as *.wgn files.

2.2 Method

This study applies the Soil and Water Assessment Tool (SWAT) modeling method through a structured, step-by-step process (Christanto et al., 2018). The research flowchart for the SWAT model is illustrated in Figure 2.



Gambar 2. SWAT Modeling Process Flowchart.

Based on the flowchart, the data required for SWAT input must be processed in a specific order. The procedure consists of five (5) main stages:
(a) Delineation of watershed boundaries;
(b) Formation of Hydrologic Response Units (HRUs);
(c) Execution of the SWAT model;
(d) Data visualization;
(e) Calibration and validation.

Furthermore, the research data management and analysis process is divided into four stages:
(a) Data collection;
(b) Processing of input data;
(c) Application of the SWAT model; and
(d) Data analysis and presentation.

doi: 10.14710/teknik.v46i2.67929

2.2.1 Integration of QGIS - SWAT

QGIS-SWAT has been developed as an extension for the QGIS platform. The QGIS-SWAT data model manages geographic, numerical, and text-based input and output data from SWAT. It uses a geodatabase structure, which is a relational database designed to store both geographic and non-geographic data, such as numbers and text. As a result, the geodatabase is proposed as the primary storage for all spatial and temporal data generated by SWAT simulations, replacing the traditional method of using multiple text files. The QGIS-SWAT interface also integrates ArcObjects (Sujarwo et al., 2020), which follow the Component Object Model (COM) protocol. This integration allows QGIS-SWAT to utilize features that are already available in other Windows-based applications. Specifically, Microsoft Excel and MATLAB are used for visualizing results and performing statistical analysis. Another important feature of QGIS-SWAT is its ability to georeference Hydrologic Response Units (HRUs), which allows for more accurate model parameter calculation compared to averaging values across subbasins.

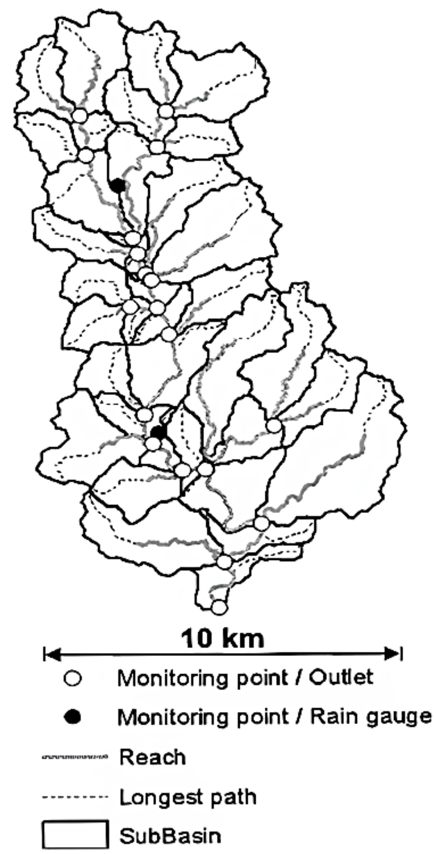
The QGIS-SWAT data model is made up of two primary components: a dynamic geodatabase that stores study area-specific information, and a static geodatabase that holds general project data, such as lookup tables and default parameter databases. The QGIS-SWAT interface includes several modules for:

- Watershed delineation
- HRU definition
- Synthetic weather generation
- Exporting data to prepare SWAT input files
- Importing SWAT results into the dynamic geodatabase
- Uncertainty analysis
- Data visualization and statistical analysis
- Model integration

The first three modules handle spatial analysis with data on topography, land use, soil types, and weather. The remaining modules connect the SWAT data model with the SWAT system, supporting hydrological analysis and model integration. The watershed delineation module identifies river networks and drainage divides using DEM data and the eight-direction pour point algorithm. This process is based on DEM-based watershed and stream delineation methods but is tailored to fit the structure of SWAT's data. A stream is identified when the drainage area exceeds a user-defined threshold. Subbasin outlets are automatically located at each stream reach, just upstream of confluences, and at user-specified points. Subbasins are defined as the contributing drainage area for each outlet. As required by SWAT, the relationships between reaches, outlets, and subbasins are organized so that each subbasin contains only one reach, and no reach is shared between multiple subbasins. Additionally, interactive elements can be defined on the map, such as:

- Inflow points to exclude upstream drainage areas and isolate specific watershed sections for modeling
- Reservoirs, which also serve as subbasin outlets
- Point source discharge locations

SWAT also uses the longest flow path within a subbasin as a substitute for residence time. Figure 3 provides an example of the hydrological elements in the Seco Creek watershed, Texas.



Gambar 3. Feature classifications produced by the watershed delineation process.

A Hydrologic Response Unit (HRU) is defined as the combination of land units and land use within each subwatershed (Riki et al., 2017). While users can provide their own soil and land use data, data processing is made easier by using soil information from the State Soil Geographic (STATSGO) database, along with lookup tables to convert various land use classifications into the SWAT system's classification. The STATSGO database defines mapping units, each consisting of one or more polygons with the same soil type.

doi: 10.14710/teknik.v46i2.67929

2.2.2 *Soil and Water Assessment Tools* (SWAT)

In 1998, the United States Department of Agriculture developed a model for watershed management called the Soil and Water Assessment Tools (SWAT) model (Arnold & Fohrer, 2005). SWAT uses hydrological cycle equations in the simulation process (Ines et al., 2024), based on Equation 1 for the water balance.

$$SW_t = SW_o + \sum_{i=1}^{t}(R_{day} - Q_{surf} - E_a - W_{sep} - Q_{gw}) \quad 1$$

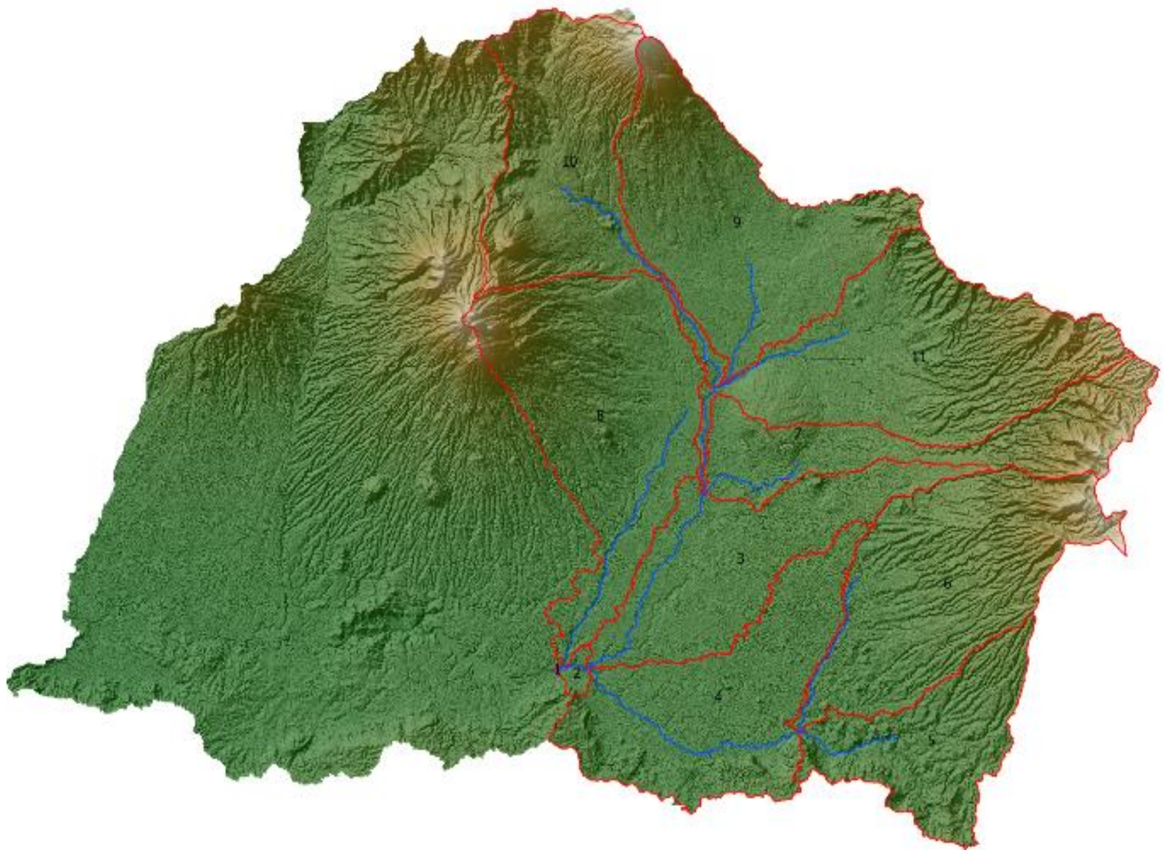
Where, SW_t s the soil water content (mm), SW_0 is the soil water content on day 1 (mm), T is time (days), R_{day} is the daily rainfall amount on day i (mm), is the daily surface runoff on day I (mm), $E\alpha$ is the daily evapotranspiration on day i (mm), W_{sep} is the amount of water entering the vadose zone (mm), dan Q_{gw} is the groundwater flow on day i (mm).

SWAT merupakan sebuah perangkat yang SWAT is a tool that may encounter errors. Some common errors in SWAT modeling include input errors (data errors and data format errors), model errors (model simplifications and improper parameter settings), and model errors (discrepancies between observations and predictions). Therefore, SWAT results should be compared with other methods to strengthen their accuracy.

3. Results and Discussion

3.1 Delineation Process

The purpose of the delineation stage is to establish the boundaries of the study watershed. The outcomes of the delineation process, using the DEM and river maps (Irsyad & Ekaputra, 2015), for the Sutami Reservoir and Sengguruh Reservoir subwatersheds are presented in Figure 4.



Gambar 4. Watershed delineation outcomes for Sutami and Sengguruh Reservoirs.

The outcome of the watershed delineation process will define the sub-watersheds. In the case of the Sengguruh Reservoir watershed, 7 sub-watersheds were identified, while the Sutami Reservoir watershed has 3 sub-watersheds. These delineation results will be used to create Hydrologic Response Units (HRUs) in the SWAT application.

3.2 HRU Formation

HRUs are created by overlaying DEM, soil type, and land use maps using the SWAT model (Irsyad & Ekaputra, 2015). The DEM map, soil type map, land use map, and the results from running the HRU process are presented in Figure 5.

doi: 10.14710/teknik.v46i2.67929

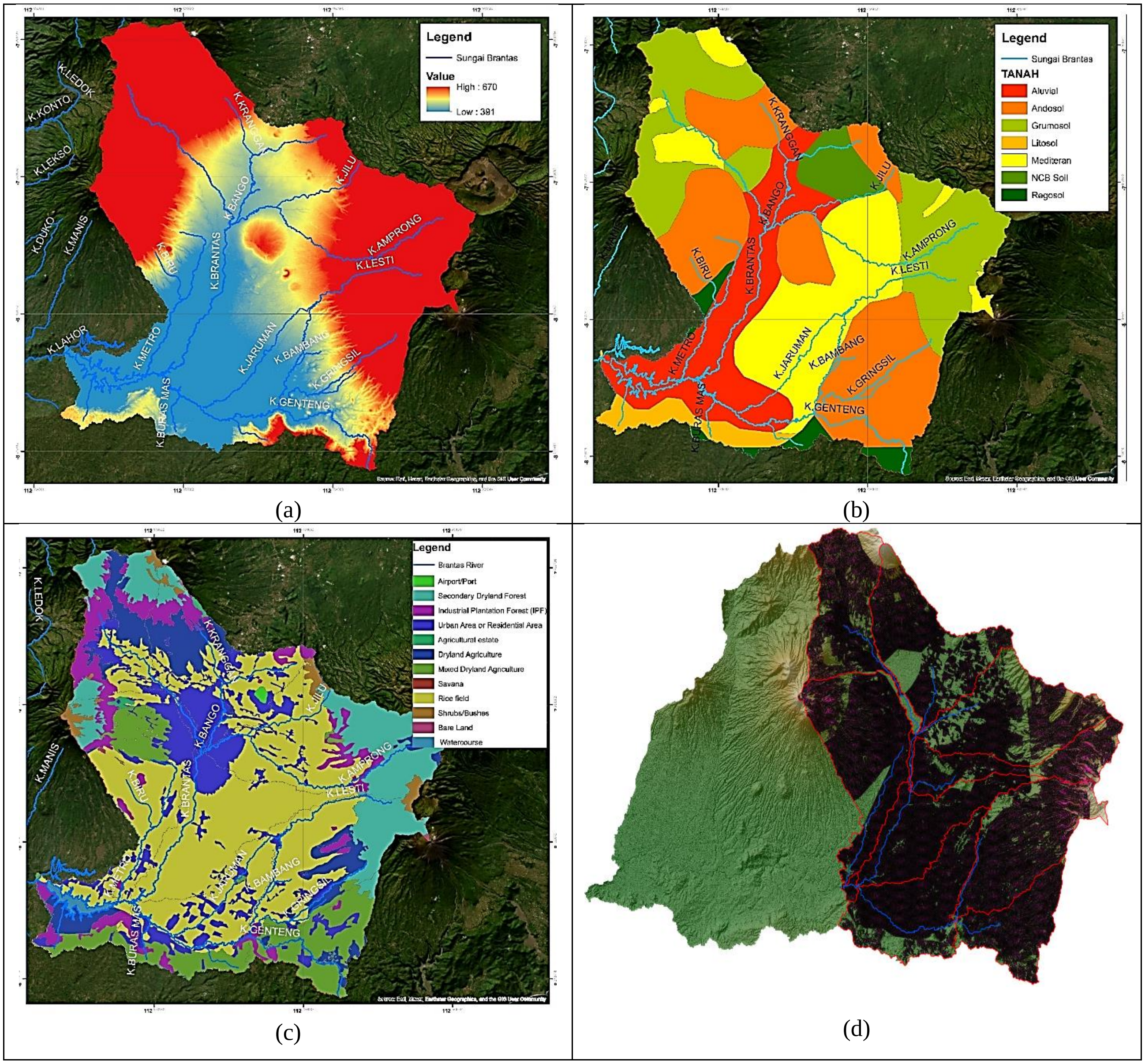


Figure 5. HRU Formation. (a) DEM map of the Sutami and Sengguruh Reservoir watersheds, (b) Soil type map of the Sutami and Sengguruh Reservoir watersheds, (c) Land use map of the Sutami and Sengguruh Reservoir watersheds, and (d) HRU formation in the Sutami and Sengguruh Reservoir watersheds.

Figure 5 (a) shows the DEM map, Figure 5 (b) depicts the Soil Type map, and Figure 5 (c) presents the land use map for the Sutami and Sengguruh Reservoir watersheds. These maps were utilized to run the SWAT model, leading to the HRU formation displayed in Figure 5 (d). After obtaining the HRU results, the next step is to input the data, as outlined in Subsection 3.3.

3.3 SWAT Simulation

The SWAT simulation is carried out by inputting data such as wind speed, temperature, solar radiation, rainfall, and humidity, as detailed in Subsection 2.1. The data used spans from 2019 to 2023. The results of this data input simulation are shown in Figure 6.

doi: 10.14710/teknik.v46i2.67929

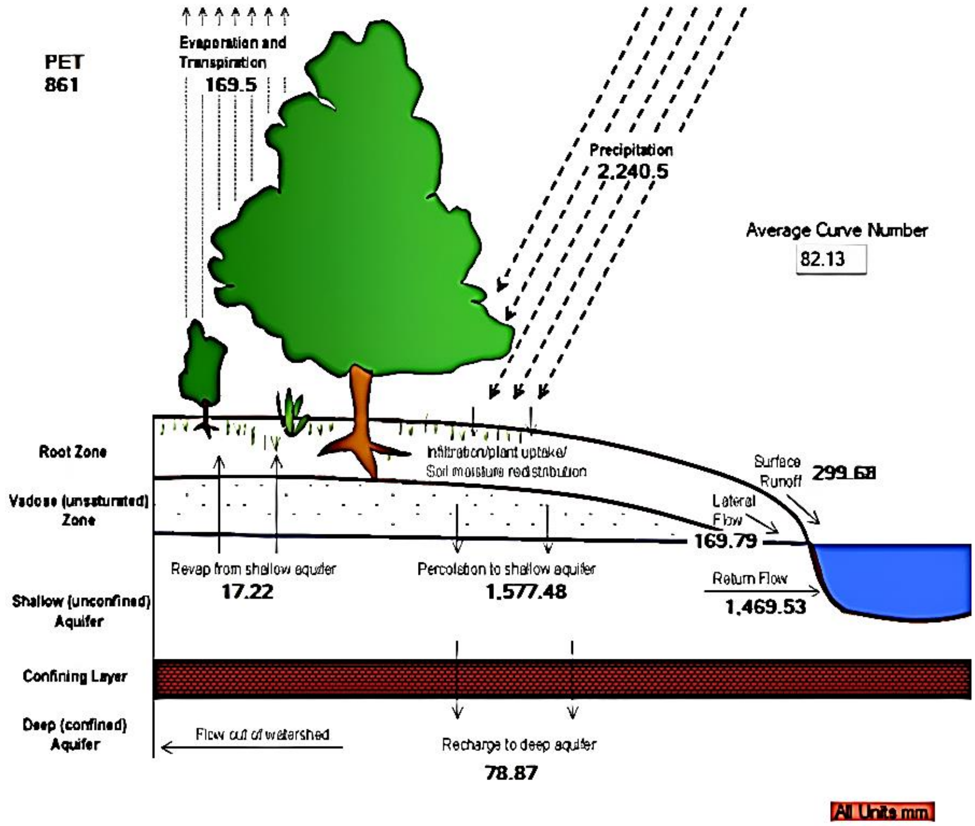
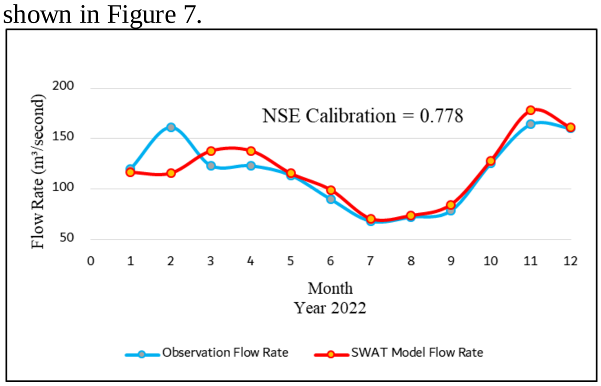


Figure 6. Results of the hydrological process simulation using the SWAT model.

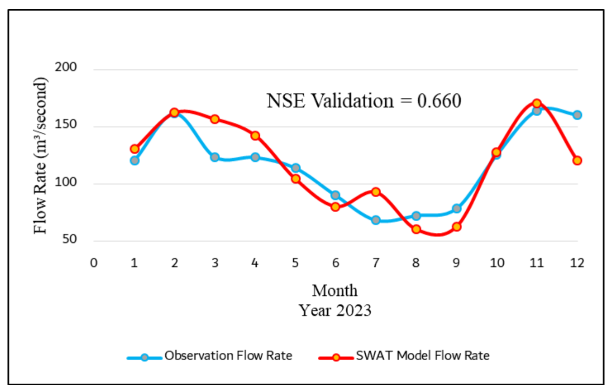
The simulation results indicate an average curve number of 82.13 mm, classifying it as high. However, the initial SWAT simulation results cannot be directly interpreted, as validation is necessary to enhance data accuracy (Saputri et al., 2022).

3.4 Streamflow Calibration and Validation

This study employs observed streamflow data from 2022 for calibration and data from 2023 for validation, as the 2024 data is not yet available. The results of the calibration and validation process are shown in Figure 7.



(a)

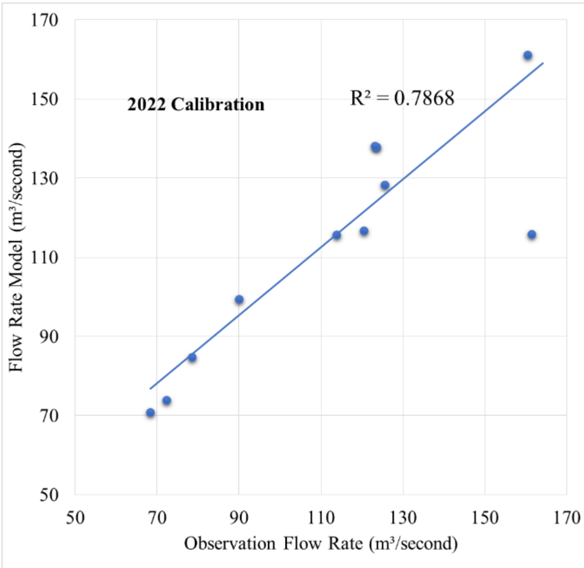


(b)

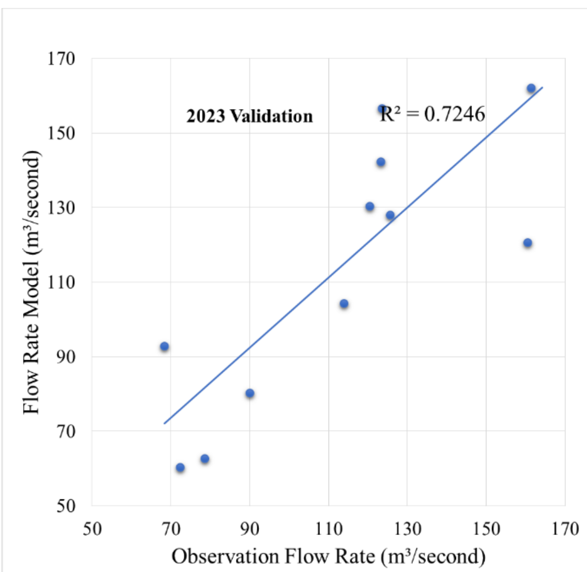
Figure 7. Streamflow Calibration and Validation. (a) Graph of monthly streamflow calibration simulation, (b) Graph of monthly streamflow validation simulation

The NSE value of 0.778 is categorized as "very good," whereas the validation NSE value of 0.660 is considered "good." The R^2 test graphs for both calibration and validation are shown in Figure 8.

doi: 10.14710/teknik.v46i2.67929



(a)



(b)

Figure 8. R^2 test plots for calibration and validation. (a) Calibration plot showing simulation and observation values, (b) Validation plot showing simulation and observation values

The R^2 test results indicate a strong correlation in the data during the 2022 calibration, with an R^2 value of 0.786, and during the 2023 validation, with an R^2 value of 0.724.

3.5 Erosion and Sedimentation Analysis

Figure 9 shows the graph depicting the Erosion Rate and Monthly Rainfall for the year 2023.

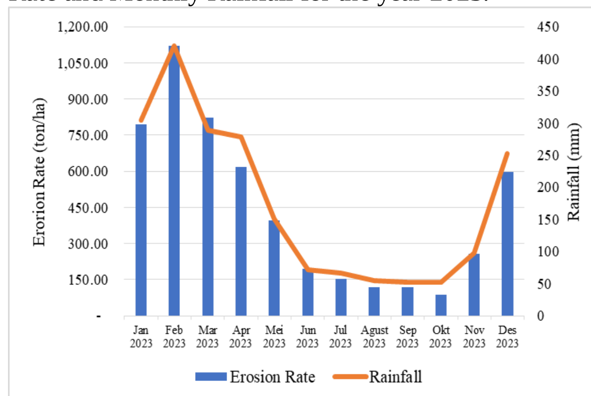


Figure 9. The graph shows the erosion rate and monthly rainfall for 2023.

Figure 9 illustrates that the erosion rate in 2023 rose in February and December, which can be attributed to the high rainfall during those months.

This study's erosion classification for the Sengguruh and Sutami subwatersheds identified two erosion levels: very light erosion and light erosion, as shown in Table 3.

Table 3. Classification of Erosion Levels

Erosion Level	Area (Ha)	%	Description
0 - 15	1,518	79.39	Very Light
15 - 60	394	20.61	Light
Total Area	**1,912**	**100**	

In the Sengguruh and Sutami subwatersheds, very light erosion is the dominant category, comprising 79.39%, while light erosion accounts for 20.61%. The use of the SWAT model is crucial for simulating long-term erosion and sedimentation rates. According to the SWAT simulation, the erosion rate is 5,280.45 tons/ha/year. The erosion risk map derived from these SWAT simulation results is displayed in Figure 10.

doi: 10.14710/teknik.v46i2.67929

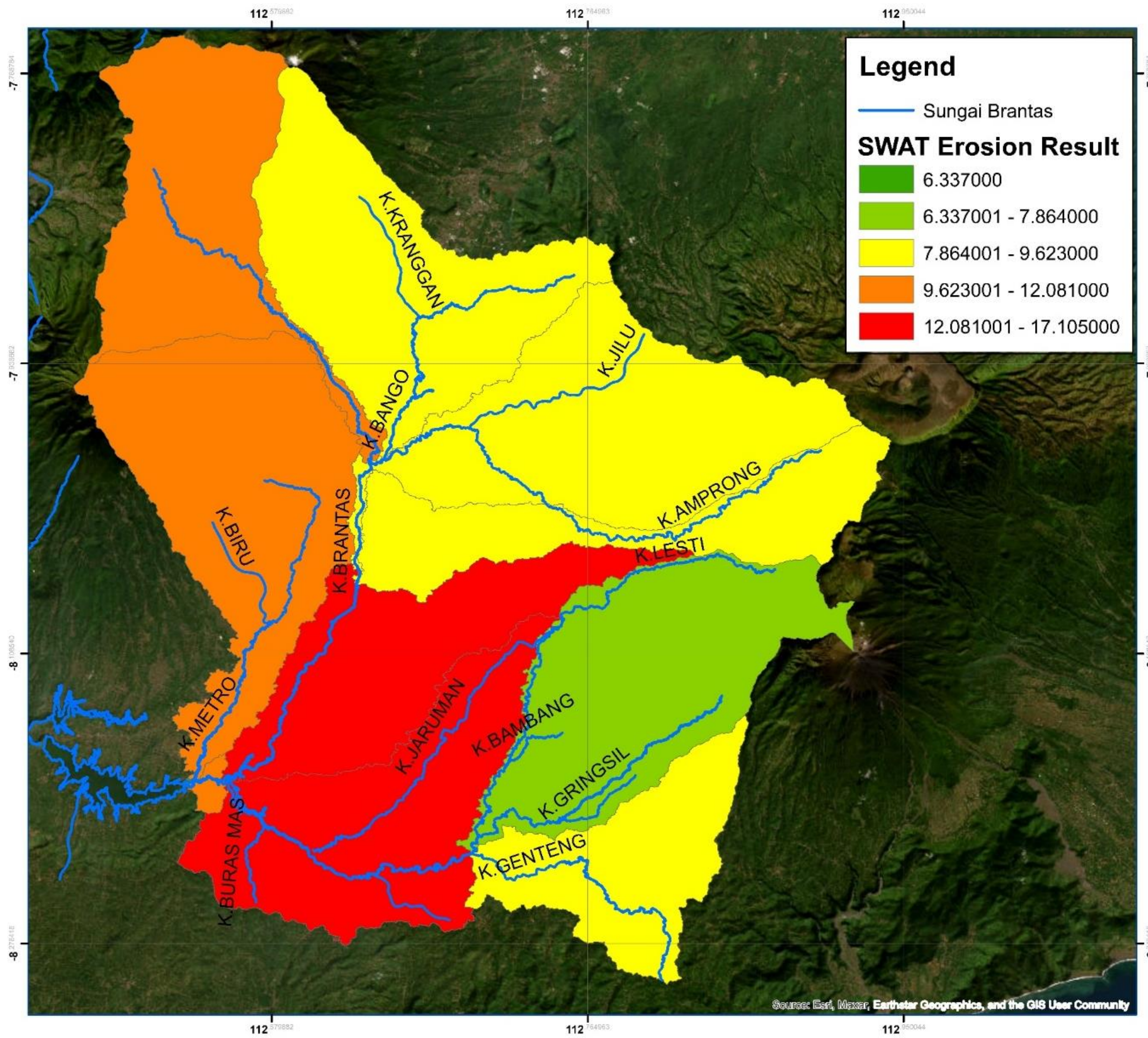


Figure 10. SWAT simulation-based erosion risk map

The erosion risk levels are categorized for each sub-watershed, with different levels of erosion risk. The erosion rate results are shown in Figure 11.

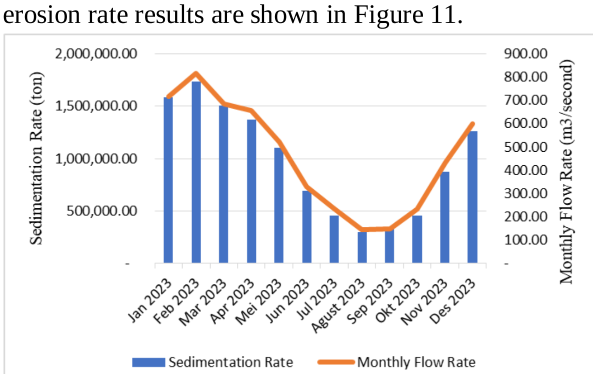


Figure 11. The graph shows sedimentation and monthly discharge for the year 2023.

The peak erosion rate in February 2023 coincided with the highest sedimentation, which can be attributed to the significant rainfall in that month. According to the SWAT simulation, the total sedimentation was 11,662,851.94 tons per year. The graph showing sedimentation rate and monthly discharge for 2023 is provided.

To evaluate the accuracy of the SWAT model, its results will be compared with calculations made using the USLE (Universal Soil Loss Equation) method. The analysis results from the USLE method are presented in Table 4.

Table 4. Erosion and Sedimentation Calculation Results Using the USLE Method

No.	Watershed Name	Watershed Area (ha)	CP	K	Ls	R	Erosion (ton/Ha/year)	Total Erosion (ton/year)	Average Slope	Manning's Roughness Coefficient	SDR	Potential Sediment (ton/year)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
1	Sengguruh 1	34,680.83	0.345	0.143	5.59	1,632.05	450.32	15,617,414.38	3.51	0.03	0.098	1,526,851.74
2	Sengguruh 2	25,287.34	0.541	0.209	2.17	1,632.05	400.69	10,132,428.30	0.80	0.03	0.106	1,069,922.43
3	Sengguruh 3	24,097.03	0.137	0.126	0.62	1,632.05	17.46	420,831.27	0.42	0.03	0.107	44,854.64
4	Sengguruh 4	13,467.69	0.707	0.276	3.64	1,632.05	1,159.47	15,615,357.19	1.92	0.03	0.123	1,921,698.13
5	Sengguruh 5	21,969.38	0.384	0.209	1.11	1,632.05	144.97	3,184,835.85	0.86	0.03	0.108	345,105.15
6	Sengguruh 6	24,237.51	0.340	0.143	5.04	1,632.05	400.44	9,705,609.55	3.59	0.03	0.106	1,033,344.06
7	Sengguruh 7	20,871.17	0.548	0.276	5.32	1,632.05	1,312.90	27,401,709.74	2.31	0.03	0.109	2,994,295.19
1	Sutami 1	26,338.69	0.397	0.243	3.13	1,618.07	488.39	12,863,678.97	0.77	0.03	0.105	1,347,055.63
2	Sutami 2	2,941.59	0.222	0.276	0.88	1,618.07	86.98	255,848.62	0.07	0.03	0.196	50,226.73
3	Sutami 3	7,053.73	0.613	0.309	2.34	1,618.07	717.36	5,060,084.49	0.18	0.03	0.142	717,444.43
TOTAL							5,178.98	100,257,798.35				11,050,798.14

The calculated erosion is 5,178.98 tons/ha/year, and sedimentation is 11,060,798.14 tons/year. In comparison, the SWAT model shows erosion at 5,280.45 tons/ha/year and sedimentation at 11,662,851.94 tons/year. This suggests that the results from the SWAT model and USLE analysis are quite similar, implying that the SWAT model offers fairly accurate outcomes.

4. Conclusion

The calibration using observed discharge data from 2022 and SWAT simulation discharge resulted in an NSE value of 0.778, which is considered "very good." In contrast, the validation with 2023 discharge data and SWAT simulation yielded an NSE value of 0.660, which is categorized as "good." These results suggest that the SWAT simulation accurately represents both calibration and validation processes, supporting the use of SWAT modeling in this study. The SWAT simulation indicates a total erosion rate of 5,280.45 tons/ha/year and a total sedimentation of 11,662,851.94 tons/year. When compared to the USLE method, which calculates an erosion rate of 5,178.98 tons/ha/year and sedimentation of 11,060,798.14 tons/year, the results are quite similar, confirming the accuracy of SWAT modeling. For future studies, it is recommended to assess the effectiveness of existing land conservation and reforestation practices, utilize SWAT for simulating different soil and water conservation scenarios to identify the most effective strategies, and combine SWAT modeling with remote sensing data (satellite imagery) for more precise mapping of erosion and sedimentation.

References

Arnold, J. G., & Fohrer, N. (2005). SWAT2000: current capabilities and research opportunities in applied watershed modelling. *Hydrological Processes: An International Journal*, *19*(3), 563–572.

Asdak, C. (2023). *Hidrologi dan pengelolaan daerah aliran sungai*. UGM PRESS.

Christanto, N., Setiawan, M. A., Nurkholis, A., Istiqomah, S., Sartohadi, J., & Hadi, M. P. (2018). Analisis laju sedimen DAS Serayu Hulu dengan menggunakan model SWAT. *Majalah Geografi Indonesia*, *32*(1), 50.

Daruati, D., & Arief, A. (2017). Integrasi Spasial Daya Serap Tanah Dan Lahan Kritis Untuk Penentuan Lokasi Prioritas Perbaikan DAS. *Limnotek: Perairan Darat Tropis Di Indonesia*, *24*(1).

Fitriyana, E. N. (2019). *ANALISIS BANGUNAN PENGENDALI SEDIMEN AKIBAT EROSI DAN SEDIMEN PADA DAS CIPUNAGARA MENGGUNAKAN MODEL SWAT*. Bandung.

Ines, G., Jalel, A., Manel, M., & Sihem, B. (2024). rological modelling using SWAT in a Complex Semi-Arid Watershed. *GSC Advanced Research and Reviews*, *Doi:10.30574/Gscarr.2024.21.2.0427*.

Irsyad, F., & Ekaputra, E. G. (2015). Analisis wilayah konservasi daerah aliran sungai (DAS) Kuranji dengan aplikasi SWAT. *Jurnal Teknologi Pertanian Andalas*, *19*(1), 39–45.

Marhendi, T. (2018). Analisa perubahan volume sedimentasi waduk Pangsar Soedirman menggunakan karakteristik curah hujan berbasis Universal Soil Loss Equation (USLE). *Jurnal Pengairan Undip*.

Perusahaan Umum Jasa Tirta I. (2023). *Laporan Akhir Kajian Kapasitas Tampungan Waduk Dalam*

doi: 10.14710/teknik.v46i2.67929

Rangka Pengelolaan Sedimentasi di Wilayah Sungai Brantas. Malang.

Riki, R., Ali, N., & Mona, A. W. (2017). *Integrasi Model SWAT dan SIG dalam Upaya Menekan Laju Erosi DAD Deli, Sumatera Utara*. Retrieved from https://jurnal.ugm.ac.id/mgi

Saputri, U. S., Saputra, M. A., Iskandar, I., Susanto, D. A., & Amdani, S. A. (2022). Aplikasi arc-swat pada analisis debit banjir rencana di daerah aliran sungai Cimandiri kabupaten Sukabumi. *Jurnal Teslink: Teknik Sipil Dan Lingkungan*, *4*(2), 107–123.

Soma, A. S. (2024). *Soil and Water Assessment Tool (SWAT) dalam Pengelolaan Daerah Aliran Sungai*. Penerbit NEM.

Sujarwo, M. W., Indarto, I., & Mandala, M. (2020). Pemodelan Erosi dan Sedimentasi di DAS Bajulmati: Aplikasi Soil dan Water Assesment Tool (SWAT). *Jurnal Ilmu Lingkungan*, *18*(2), 218–227.

Suroso, S. , A. M. R. , & R. M. C. (2012). Suroso, S., Anwar, M. R., & Rahmanto, M. C. (2012). Studi pengaruh sedimentasi kali Brantas terhadap kapasitas dan usia rencana waduk Sutami Malang. *Rekayasa Sipil, 1(1), 33-42.*

Vinay, D., Syed, A., Shilpa, K., & Shubham, S. (2024). 2. Comprehensive Review on SWAT for Sustainable Agriculture and Climatic Solutions. *Journal of Scientific Research and Reports, Doi: 10.9734/Jsrr/2024/V30i112604*.

doi: 10.14710/teknik.v46i2.67929