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Performance Evaluation of the HEC-HMS Model in Flood Discharge Simulation in the Upper Jeneberang Watershed

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Abstract: The Jeneberang Watershed is one of the river basins in South Sulawesi Province that is highly vulnerable to flood disasters due to land use change and extreme rainfall. This study aims to analyze the rainfall-runoff transformation in the upper Jeneberang Watershed using the HEC-HMS hydrological model through calibration and validation processes. The data used include daily rainfall data from five rainfall stations and daily inflow discharge data from the Bili-Bili Dam for the period 2017–2022. The HEC-HMS model was constructed using the SCS Curve Number method for water loss estimation, the SCS Unit Hydrograph for transformation, the Recession Method for baseflow, and the Lag Method for flow routing. Calibration was conducted for four flood events (2017, 2018, 2020, 2021) and validation for two independent events (2019, 2022). Model performance was evaluated using NSE, R^2, PBIAS, and RSR parameters. Calibration results showed an average NSE=0.76, R^2=0.84, PBIAS=−10.50%, and RSR=0.48, classified as Satisfactory to Very Good, while validation yielded NSE=0.63, R^2=0.73, PBIAS=−2.48%, and RSR=0.60, with overall performance classified as Satisfactory to Good and PBIAS specifically classified as Very Good. The consistency between calibration and validation indicates the model possesses adequate generalization capability and is declared suitable and reliable for flood discharge simulation in the upper Jeneberang Watershed.

Keywords: Calibration; HEC-HMS; Hydrological modeling; Rainfall-runoff transformation; Validation

Introduction

Indonesia, as a tropical country with two seasons, has high vulnerability to hydrometeorological disasters, particularly floods. Based on data from the National Disaster Management Agency (BNPB, 2019), 784 flood events were recorded throughout 2019, making floods one of the most frequent and destructive hydrometeorological disasters in Indonesia (Sari et al., 2025; Supiyati et al., 2024). This condition is further exacerbated by global climate change, which causes a significant increase in rainfall variability, thereby worsening flood risks across various regions (IPCC, 2021).

On 22 January 2019, extreme rainfall reaching 461 mm at Station Pos 1 triggered floods and landslides that affected six regencies in South Sulawesi, causing casualties and significant infrastructure damage (Arifin et al., 2023; Irawan et al., 2024).

One of the factors contributing to hydrological disasters in the Jeneberang Watershed is land use change that has occurred over the past two decades. The Jeneberang Watershed has undergone massive land use changes, including deforestation of 36.67 ha, forest degradation of 770.14 ha, and residential area expansion of 3,497.47 ha during the period 1999–2020 (Putera et al., 2020). This has resulted in approximately 83% of the total Jeneberang Watershed area currently consisting of non-forest land cover (Maulana et al., 2022), which directly increases surface runoff and reduces the watershed's infiltration capacity (Fajri et al., 2025; Ridwan et al., 2024; Wahyuni et al., 2024).

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In addition, the Jeneberang Watershed is a strategic watershed where several major water resource structures have been built to support water services, one of which is the Bili-Bili Dam. The dam serves as a multi-purpose reservoir providing raw water, agricultural irrigation, and hydroelectric power generation for the Gowa, Takalar, and Makassar regions (Putera et al., 2020).

Facing the complexity of flood problems, hydrological modeling has become a quantitative approach for accurately estimating flood discharge. The HEC-HMS (Hydrologic Modeling System) model developed by the US Army Corps of Engineers is one of the widely used hydrological models for rainfall-runoff transformation simulation at the watershed scale (U.S. Army Corps of Engineers, 2023). This model has been applied in various studies in Indonesia, including by Nurdianyoto et al. (2019) in the Sadar Sub-watershed, Mojokerto, Gunawan et al. (2025) in the Air Bengkulu Sub-Catchments, and Junianto et al. (2023) for flood risk spatial modeling, with results demonstrating HEC-HMS's ability to represent hydrological processes adequately (Hamdan et al., 2021).

This study aims to investigate flood events in the Jeneberang Watershed, focused on the upper portion. We perform rainfall-runoff transformation analysis at the study location using the HEC-HMS model. The model is then calibrated based on four flood events (2017, 2018, 2020, 2021) and validated on two independent flood events (2019 and 2022).

Method

Data Quality Testing

Rainfall data quality testing was conducted in two stages. First, consistency testing using the Double Mass Curve (DMC) method, by plotting the cumulative annual rainfall of each station against the cumulative average of reference stations. Data is declared consistent when the plot forms a straight line without significant slope changes, indicated by a coefficient of determination (R^2) value approaching 1.0 (Searcy et al., 1960; Zahrani et al., 2025). Second, trend absence testing using the Spearman Rank Correlation Test at 5% significance level (two-tailed test) with degrees of freedom dk = n−2 = 10, yielding a critical value tcritical = 2.228. It is acknowledged that the trend test was conducted on a 12-year annual rainfall series (2012–2023), which represents a relatively short period; however, this data period is constrained by the availability of concurrent rainfall and discharge records required for hydrological modeling. The null hypothesis is accepted when tcalculated < ttable, meaning the data contains no systematic trend and meets the stationarity requirements for further analysis (Limantara, 2010)(Li.

SCS (Soil Conservation Service) Method

The SCS method is used to estimate water loss and rainfall-to-runoff transformation. Surface runoff is calculated using the following equations (Soil Conservation Service, 1985):

$$P_e = \frac{(P-I_a)^2}{P-I_a+S} \quad (1)$$

$$I_a = 0.2 \times S \quad (2)$$

where Pe is cumulative effective rainfall (mm), P is cumulative rainfall depth (mm), Ia is initial abstraction (mm), and S is maximum storage capacity (mm). The relationship between S and watershed characteristics is expressed through the Curve Number (CN) value:

$$S = \frac{25400-254CN}{CN} \quad (3)$$

CN values range from 0 to 100, determined based on the combination of land use and Hydrologic Soil Group (HSG) classification. Composite CN for each sub-watershed is calculated as:

$$CN_{komposit} = \frac{\sum A_i \cdot CN_i}{\sum A_i} \quad (4)$$

where Ai is the area of sub-watershed i (km²) and CNi is the CN value of sub-watershed i.

Transformation of net rainfall to direct runoff is performed using the SCS Unit Hydrograph with the primary parameter of lag time (tlag) calculated through (Soil Conservation Service, 1985):

$$t_c = \frac{L^{0,8}\left(\frac{1000}{CN}-9\right)^{0,7}}{1900 \cdot Y^{0,5}} \quad (5)$$

$$t_{lag} = 0.6 \times t_c \quad (6)$$

where L is the hydraulic length of the sub-watershed (m), Y is the average slope of the sub-watershed (%), and tc is the time of concentration (hours).

HEC-HMS Modeling

The HEC-HMS (Hydrologic Modeling System) model version 4.10, developed by the US Army Corps of Engineers, is widely used for rainfall-runoff transformation simulation at the watershed scale (U.S. Army Corps of Engineers, 2023). In this study, the HEC-HMS model was constructed through four main components: basin model, meteorologic model, control specification, and time series data. The basin model represents hydrological elements consisting of 35 subbasins, 17 reaches, several junctions, and 1 sink as the outlet representing the Bili-Bili Dam control point. Each subbasin is configured with the SCS Curve Number method for water loss, SCS Unit Hydrograph for transformation, and The Recession Method for baseflow estimation uses two main parameters: Recession Constant (K) and Ratio to Peak, which are optimized during calibration (Sodikin et al., 2025). Flow routing on 17 river segments is performed using the Lag Method with lag time values calculated based on the length and slope of each river segment, ranging from 4.69 to 128.70 minutes.

The Lag Method was selected for flow routing based on the following considerations: the upper Jeneberang Watershed was discretized into 35 sub-watersheds with relatively small individual areas, resulting in short channel reaches between sub-watersheds; the short channel lengths reduce the significance of channel storage and attenuation effects on the overall hydrograph response; and the routing lag time for each reach was calculated analytically based on channel length and slope, ranging from 4.69 to 128.70 minutes, ensuring that temporal displacement of the hydrograph remains physically representative. Under these conditions, the Lag Method provides a computationally efficient and physically justifiable routing approach for the study watershed.

The meteorologic model uses daily rainfall data from five rainfall stations as input. Accordingly, the HEC-HMS model was configured at a daily time step, and model performance was evaluated against daily inflow discharge observations from the Bili-Bili Dam. The peak discharge values reported in this study represent daily maximum discharge, consistent with the daily resolution of both rainfall input and observed discharge data. The weight of each station for each subbasin is determined using the Thiessen Polygon method (Jawale et al., 2025; Pratiwi et al., 2023). The control specification is used to define the simulation time interval, adjusted to the recording period of rainfall and discharge data for each simulated event.

Calibration and Validation

Calibration was performed by comparing HEC-HMS model simulated discharge against observed inflow discharge of the Bili-Bili Dam for selected flood events. Selection of flood events was based on three criteria: monthly peak inflow discharge exceeding 200 m^3/s as an indicator of significant flood events, one representative event per year to ensure inter-annual hydrological variability representation, and simultaneous availability and completeness of rainfall and discharge data. Based on these criteria, four events were selected for calibration: February 2017, January 2018, December 2020, and March-April 2021, and two independent events for validation: January 2019 and May 2022.

The calibration process was conducted manually using the trial-and-error method by optimizing several parameters. The CN values were adjusted through conversion from normal moisture conditions (AMC II) to saturated conditions (AMC III) using the standard SCS equation, which effectively modifies the soil moisture storage capacity and directly influences the simulated runoff volume. In addition, the Recession Constant (K) and Ratio to Peak parameters of the baseflow component were also optimized. All other parameters, including initial abstraction, lag time, and routing, were set based on previously calculated analytical values and were not adjusted during calibration. This CN adjustment combined with baseflow parameter optimization provided sufficient model flexibility to achieve satisfactory performance across four flood events with varying characteristics.

Model performance evaluation was conducted using four statistical parameters following the guidelines of Moriasi et al. (2007): NSE, R^2, PBIAS, and RSR. These parameters have been widely adopted in hydrological model evaluation studies in Indonesian watersheds (Putri et al., 2025; Syaakiroh et al., 2024), formulated as follows:

$$NSE = 1 - \frac{\sum_{i=1}^{n}(Q_{obs,i} - Q_{sim,i})^2}{\sum_{i=1}^{n}(Q_{obs,i} - \bar{Q}_{obs})^2} \quad (7)$$

$$PBIAS = \frac{\sum_{i=1}^{n}(Q_{obs,i} - Q_{sim,i}) \times 100}{\sum_{i=1}^{n} Q_{obs,i}} \quad (8)$$

$$R^2 = \left[\frac{\sum_{i=1}^{n}(Q_{obs,i} - \bar{Q}_{obs})(Q_{sim,i} - \bar{Q}_{sim})}{\sqrt{\sum_{i=1}^{n}(Q_{obs,i} - \bar{Q}_{obs})^2} \cdot \sqrt{\sum_{i=1}^{n}(Q_{sim,i} - \bar{Q}_{sim})^2}}\right]^2 \quad (9)$$

$$RSR = \frac{\sqrt{\sum_{i=1}^{n}(Q_{obs,i} - Q_{sim,i})^2}}{\sqrt{\sum_{i=1}^{n}(Q_{obs,i} - \bar{Q}_{obs})^2}} \quad (10)$$

Model performance classification based on these four parameters is presented in Tables 1 and 2.

Table 1. Model Performance Classification Based on RSR and NSE Values

Classification	RSR	NSE
Very Good	0.00 ≤ RSR ≤ 0.50	0.75 ≤ NSE ≤ 1.00
Good	0.50 ≤ RSR ≤ 0.60	0.65 ≤ NSE ≤ 0.75
Satisfactory	0.60 ≤ RSR ≤ 0.70	0.50 ≤ NSE ≤ 0.65
Unsatisfactory	RSR > 0.70	NSE ≤ 0.50

Table 2. Model Performance Classification Based on PBIAS and R^2 Values

Classification	PBIAS	R2
Very Good	PBIAS < ± 10	R2 > 0.85
Good	±10 ≤ PBIAS < ± 15	0.75 ≤ R2 < 0.85
Satisfactory	± 15 ≤ PBIAS < ± 25	0.60 ≤ R2 < 0.75
Unsatisfactory	PBIAS > ± 25	R2 < 0.60

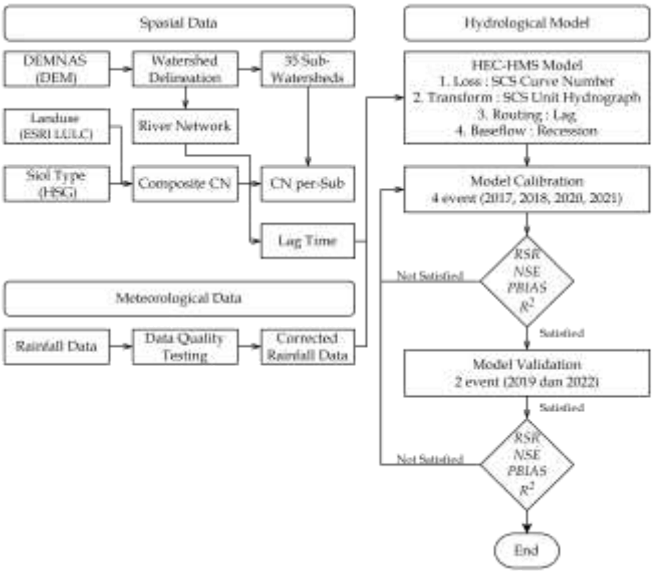

Figure 1. Research flowchart

Result and Discussion

Study Location

This study was conducted in the Jeneberang Watershed located in South Sulawesi Province, Indonesia, at coordinates 5°00'–5°30' South Latitude and 119°30'–120°00' East Longitude, with a total area of approximately 754.67 km². The Jeneberang River has a main channel length of approximately 90 km, flowing from the mountainous area in the upstream to the lowland downstream before discharging into the Makassar Strait. The HEC-HMS hydrological modeling was focused on the upstream area above the Bili-Bili Dam, covering an area of 609.23 km² or approximately 81% of the total Jeneberang Watershed area. The Bili-Bili Dam, located in the middle of the watershed, serves as the main control point (outlet) in the hydrological modeling. The study location map is presented in Figure 2.

Figure 2. Study location map of the upper jeneberang watershed

Data Quality Testing

Rainfall data quality testing was conducted in two stages: consistency testing using the Double Mass Curve (DMC) method and trend absence testing using the Spearman Rank Correlation Test at 5% significance level with degrees of freedom dk = n−2. The results of both tests are presented in Tables 3 and 4.

Table 3. Summary of Data Consistency Test Results

Station	R^2 (DMC)	DMC Conclusion
Bili-Bili	0.99	Consistent
Mangempang	0.98	Consistent
KD1	0.99	Consistent
Pos 1	0.99	Consistent
Panaikang	0.99	Consistent

Table 4. Summary of Trend Absence Test Results

Station	tcalculated	tcritical	Trend Conclusion
Bili-Bili	−0.73	2.23	No Trend
Mangempang	0.92	2.23	No Trend
KD1	−2.06	2.23	No Trend
Pos 1	−0.49	2.23	No Trend
Panaikang	−0.63	2.23	No Trend

All stations show DMC R^2 values approaching 1.0, indicating data consistency without significant slope changes. All Spearman tcalculated values are smaller than tcritical = 2.23, so the null hypothesis is accepted and the data is declared free from systematic trends and meets the stationarity requirements for further analysis.

HEC-HMS Model Parameters

Overlay analysis of the ESRI LULC 2019 land use map and soil type map produced HSG classification dominated by HSG D across most of the Jeneberang Watershed, followed by HSG C in the eastern upstream and HSG A in limited areas. The Composite CN values across 35 sub-watersheds range from 83.29 (S-8) to 94.77 (S-28) with an average of 91.14. The high CN values reflect saturated initial soil moisture conditions (AMC III) during flood events, consistent with the characteristics of the Jeneberang Watershed dominated by HSG D with low infiltration capacity (Rachmayanti et al., 2022). Conversion of CN values from normal conditions (AMC II) to saturated conditions (AMC III) was performed using the standard SCS equation as part of the calibration process. The percent impervious values across sub-watersheds range from 7.93% (S-5) to 41.88% (S-33) with an average of 18.75%. The HEC-HMS model parameter summary is presented in Table 5.

The SCS Unit Hydrograph lag time for each sub-watershed ranges from 2.34 minutes (S-20) to 42.78 minutes (S-18), reflecting significant morphometric variation among sub-watersheds. The Recession Constant (K) was optimized within the range 0.60–0.80, while the Ratio to Peak was set at 0.39 for all sub-watersheds based on calibration optimization results. The routing lag time for 17 river segments ranges from 4.69 minutes (R-16) to 128.70 minutes (R-14).

Table 5. Summary of HEC-HMS Model Parameters

Parameter	Method	Value Range
Composite CN (AMC III)	SCS CN	83.29 – 94.77
Percent Impervious	ESRI LULC 2019	7.93% – 41.88%
Lag Time SCS UH	Morphometry	2.34 – 42.78 min
Lag Time Routing	Channel length & slope	4.69 – 128.70 min
Recession Constant (K)	Trial and Error	0.60 – 0.80
Ratio to Peak	Trial and Error	0.387

Calibration Results

Model calibration was performed for four flood events: February 2017, January 2018, December 2020, and March–April 2021, by optimizing the Recession Constant (K) and Ratio to Peak parameters using trial and error. In addition to baseflow parameter optimization, calibration also included adjustment of the watershed's initial moisture condition from AMC II to AMC III for all sub-watersheds to represent saturated soil conditions during the selected flood events. Model performance evaluation results for the calibration period are presented in Tables 6 and 7.

Table 6. Observed and Simulated Peak Discharge for Calibration Period

Simulation Period	Observed Discharge (m^3/s)	Simulated Discharge (m^3/s)
Calibration 2017	733.00	351.70
Calibration 2018	210.80	159.90
Calibration 2020	442.80	305.08
Calibration 2021	547.00	344.50
Average	483.40	290.48

Table 7. HEC-HMS Model Performance Evaluation for Calibration Period

Simulation Period	RSR	NSE	PBIAS	R^2
Calibration 2017	0.60	0.67	-8.42	0.81
Calibration 2018	0.50	0.72	−11.87	0.78
Calibration 2020	0.40	0.84	−6.64	0.87
Calibration 2021	0.40	0.81	−15.07	0.91
Average	0.48	0.76	−10.50	0.84

Based on Table 7, the average calibration performance yielded NSE=0.76, R^2=0.84, PBIAS=−10.50%, and RSR=0.48, classified as Satisfactory to Very Good based on Moriasi et al. (2007). Comparison of simulated and observed hydrographs for the four calibration events is presented in Figures 3 through 6.

For the February 2017 event, a significant underestimation of peak discharge occurred (simulated: 351.70 m^3/s vs. observed: 733.00 m^3/s). This is related to the highly uneven rainfall distribution, where local convective mechanisms generated extreme rainfall intensities not fully captured by the Thiessen-based areal rainfall average (Ikhsan, 2021). Nevertheless, NSE=0.67 and R^2=0.81 fulfill the "Good" classification, while PBIAS=−8.42% indicates slight underestimation of flow volume but remains within the "Very Good" category.

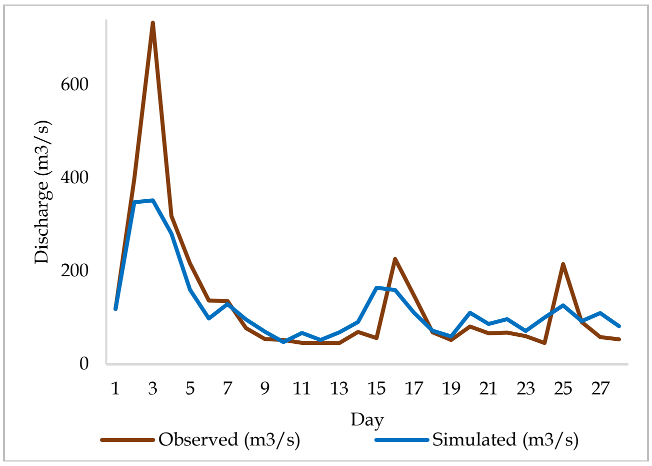

Figure 3. Comparison of simulated and observed hydrographs – calibration february 2017

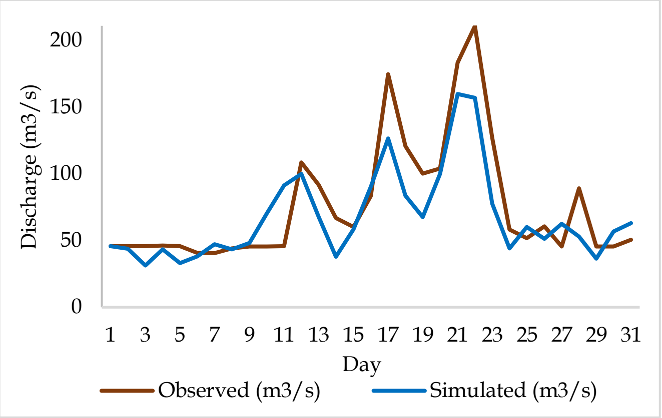

Figure 4. Comparison of simulated and observed hydrographs – calibration january 2018

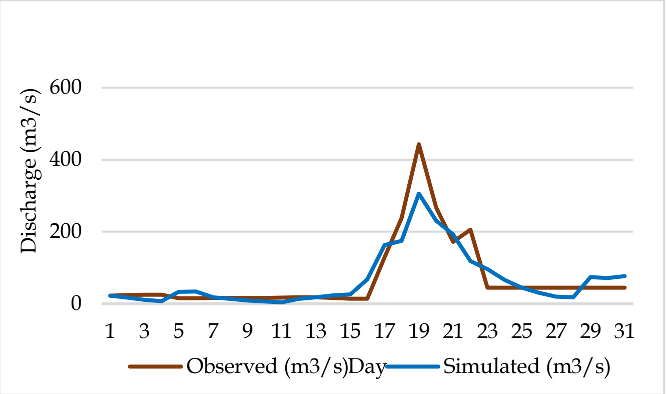

Figure 5. Comparison of simulated and observed hydrographs – calibration december 2020

The January 2018 calibration event shows good hydrograph shape agreement between simulation and observation with NSE=0.72 and R^2=0.78 ("Good" classification). PBIAS=−11.87% indicates low volume underestimation within the "Good" classification limit.

The December 2020 calibration event demonstrates the best performance with NSE=0.84 and R^2=0.87 ("Very Good" classification), along with RSR=0.40 and PBIAS=−6.64% classified as "Very Good", indicating the model's ability to accurately represent rainfall-runoff transformation for high-intensity flood events.

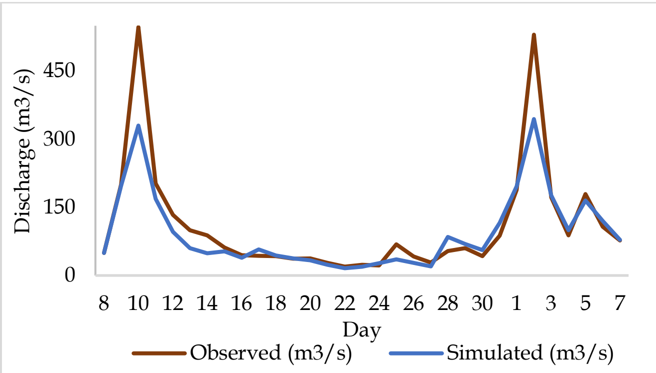

Figure 6. Comparison of simulated and observed hydrographs – calibration march-april 2021

The March–April 2021 calibration event has the highest R^2 value (0.91) with NSE=0.81 ("Very Good" classification), demonstrating the model's ability to represent multi-peak hydrographs occurring due to consecutive rainfall events. PBIAS=−15.07% falls within the "Satisfactory" classification, indicating greater flow volume underestimation in this event, possibly related to the two-month simulation period that complicates representation of the initial watershed moisture condition. Overall, the average calibration performance yielded NSE=0.76, R^2=0.84, PBIAS=−10.50%, and RSR=0.48, classified as Good based on Moriasi et al. (2007). The negative average PBIAS (−10.50%) indicates a underestimation but remains within acceptable limits. Although peak discharge underestimation occurred for all calibration events, three events (2018, 2020, 2021) showed good to very good agreement between simulated and observed hydrographs in terms of peak timing and overall hydrograph shape. These results indicate that the analytically-determined model parameters and calibration-optimized baseflow parameters are capable of representing the rainfall-runoff transformation process in the upper Jeneberang Watershed with adequate accuracy.

Validation Results

Model validation was conducted for two independent events: January 2019 and May 2022, without any parameter adjustment. Model performance evaluation results for the validation period are presented in Tables 8 and 9.

Table 8. Observed and Simulated Peak Discharge for Validation Period

Simulation Period	Observed Discharge (m^3/s)	Simulated Discharge (m^3/s)
Validation 2019	977.20	613.10
Validation 2022	202.00	190.60
Average	589.60	405.60

Table 9. HEC-HMS Model Performance Evaluation for Validation Period

Simulation Period	RSR	NSE	PBIAS	R^2
Validation 2019	0.60	0.64	-3.20	0.76
Validation 2022	0.60	0.62	-1.76	0.69
Average	0.60	0.63	-2.48	0.73

Based on Table 9, the average validation performance yielded NSE=0.63, R^2=0.73, PBIAS=−2.48%, and RSR=0.60, fulfilling the "Satisfactory" to "Good" classification based on Moriasi et al. (2007). Comparison of simulated and observed hydrographs for the two validation events is presented in Figures 7 and 8.

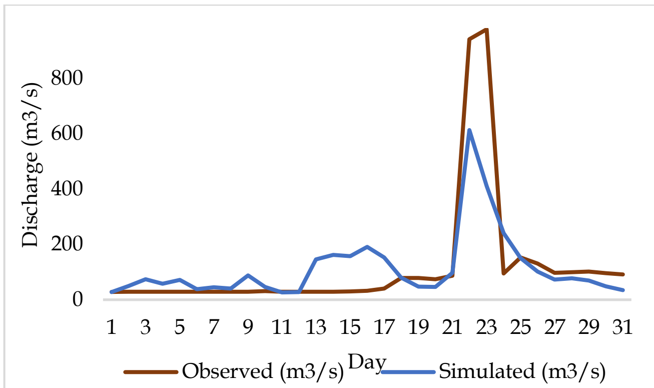

Figure 7. Comparison of simulated and observed hydrographs – validation january 2019

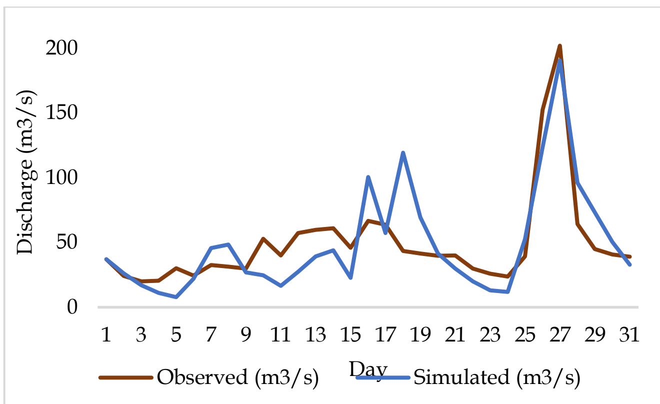

Figure 8. Comparison of simulated and observed hydrographs – validation may 2022

The May 2022 event demonstrates good performance with PBIAS=−1.76% and simulated peak discharge (190.6 m^3/s) closely approximating the observed value (202.0 m^3/s), indicating adequate model capability for moderate-intensity flood events. Peak discharge underestimation in the January 2019 event (simulated: 613.1 m^3/s vs. observed: 977.2 m^3/s) is closely related to the extreme characteristics of the 22 January 2019 flood event, where Station KD1 recorded 278 mm and Station Pos 1 reached 461 mm in a single day, indicating local convective mechanisms not fully captured by the Thiessen-based areal rainfall average (Maulana et al., 2022). In addition to spatial rainfall limitations, the severe underestimation during the 2019 event highlights the model's limitation when validated against an unprecedented extreme event that falls far outside the hydrological scale of the calibration periods (2017, 2018, 2020, 2021). The fixed model parameters, optimized under moderate-to-large flood conditions during calibration, were not sufficient to capture the full magnitude of this extraordinary event. Nevertheless, PBIAS=−3.20% for this event is classified as "Very Good", demonstrating good balance between simulated and observed flow volumes.

The HEC-HMS model performance in this study demonstrates better results compared to several similar studies in Indonesia. Ikhsan et al. (2021) reported an NSE value of 0.596 for HEC-HMS model calibration in the Kali Lamong Watershed using the SCS CN method, falling within the "Satisfactory" category. Meanwhile, Nurdianyoto et al. (2019) yielded NSE ranging from 0.60–0.70 for rainfall-runoff simulation in the Sadar Sub-watershed, and Amiruddin et al. (2024) reported similar performance in the Rawasari Watershed, Tarakan. Mujibadi et al. (2020) also reported NSE ranging from 0.60–0.75 for flood hydrograph prediction in the Rejoso Watershed, Pasuruan, due to land use change effects. Compared to these studies, the calibration performance of this study (average NSE=0.76) shows significant improvement (Ghaisani et al., 2024; Magarin et al., 2025), attributable to the use of multi-event calibration (4 events) ensuring inter-annual hydrological variability representation and the application of four more comprehensive evaluation parameters.

Jamal et al. (2025) developed a rainfall-runoff model for predicting inflow to Bili-Bili Dam in the same watershed but with a limited number of calibration events and without a systematic independent validation process. This study complements that deficiency through validation on two independent events (2019 and 2022) yielding NSE=0.63 and R^2=0.73, confirming the model's generalization capability beyond the calibration period. Aslam et al. (2020) also applied numerical modeling to the Jeneberang River but only on a 2D hydraulic model without integration of a calibrated hydrological model, so this study provides a validated hydrological model that can serve as an upstream boundary condition for HEC-RAS 2D hydraulic modeling in the downstream area of the Jeneberang Watershed.

Peker et al. (2024) emphasize that consistency between calibration and validation performance is an absolute prerequisite before a model is used for extreme event simulation. The NSE difference between calibration (0.76) and validation (0.63) of 0.13 remains reasonable considering the different characteristics of the events, and both values remain within acceptable classification ranges based on Moriasi et al. (2007), indicating the model has met those criteria and is suitable for further hydrological analysis in the Jeneberang Watershed.

Conclusion

This study analyzed the rainfall-runoff transformation in the upper Jeneberang Watershed using the HEC-HMS hydrological model version 4.10, constructed with the SCS Curve Number method for water loss estimation, SCS Unit Hydrograph for transformation, Recession Method for baseflow, and Lag Method for flow routing across 35 sub-watersheds and 17 river segments. Calibration on four flood events (February 2017, January 2018, December 2020, and March–April 2021) yielded average NSE=0.76, R^2=0.84, PBIAS=+10.50%, and RSR=0.48, classified as Satisfactory to Very Good, while validation on two independent events (January 2019 and May 2022) yielded NSE=0.63, R^2=0.73, PBIAS=+2.48%, and RSR=0.60, classified as Satisfactory to Good based on Moriasi et al. (2007). The acceptable performance across both periods indicates that the model possesses adequate generalization capability for independent flood events within a similar hydrological scale, and is therefore declared suitable and reliable for flood discharge simulation in the upper Jeneberang Watershed. Future research is recommended to incorporate sub-daily or hourly rainfall data to improve temporal resolution of flood hydrograph simulation, apply more physically-based routing methods such as Muskingum-Cunge on longer river segments, and utilize the validated model as an upstream boundary condition for HEC-RAS 2D hydraulic modeling to produce flood inundation maps in the downstream area of the Jeneberang Watershed, in support of disaster risk reduction aligned with SDG 11.

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Author Constribution

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