

Rainfall-Runoff Analysis Using HEC-HMS 4.11 Program in The Tukad Petanu Watershed Area, Gianyar Regency, Bali

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ABSTRACT

The Tukad Petanu Watershed is one of the main rivers in Gianyar Regency, Bali, playing a critical role in irrigating agricultural areas and supporting regional water needs. A significant challenge facing this watershed is a water deficit of $-0.65 \text{ m}^3/\text{s}$, driven by increasing water demand and growing conflicts over water allocation. To address this, rainfall-runoff transformation modelling was applied to better represent hydrological field conditions and support water resource planning. This study aims to determine the flow discharge characteristics and compare the differences between HEC-HMS simulation results and observational data. The rainfall-runoff simulation used observed discharge, rainfall, land-use maps, soil type maps, and Digital Elevation Model (DEM) data as model inputs, covering the 2022 analysis period. A composite Curve Number (CN) value of 81.31 was derived from land-use and soil type analysis. The modelling results produced a Root Mean Square Error (RMSE) value of 3.7, indicating a reasonable level of simulation accuracy. The peak simulated discharge occurred during the maximum rainfall event on October 17, 2022, with 87 mm of rainfall and a simulated peak discharge of $59.4 \text{ m}^3/\text{s}$. In contrast, the observed peak discharge occurred on November 8, 2022, with a value of $11 \text{ m}^3/\text{s}$. The discrepancy between simulated and observed peak discharges reflects the influence of weirs and water abstraction structures within the watershed that were not fully captured by the model. These findings indicate that HEC-HMS can represent the general runoff pattern of the Tukad Petanu Watershed, providing insights to enhance hydrological modelling accuracy for tropical watersheds and support sustainable water management strategies in Bali.

Keywords: HEC-HMS, Hydrological modelling, Rainfall-runoff, Tukad Petanu, Watershed management

ABSTRAK

DAS Tukad Petanu merupakan salah satu sungai utama di Kabupaten Gianyar, Bali, yang berperan penting dalam mengairi lahan pertanian dan mendukung kebutuhan air regional. Tantangan signifikan yang dihadapi DAS ini adalah defisit air sebesar $-0,65 \text{ m}^3/\text{s}$, yang disebabkan oleh meningkatnya permintaan air dan konflik alokasi yang semakin berkembang. Untuk mengatasi permasalahan tersebut, pemodelan transformasi hujan-aliran diterapkan guna merepresentasikan kondisi hidrologi lapangan dengan lebih baik dan mendukung perencanaan sumber daya air. Penelitian ini bertujuan untuk menentukan karakteristik debit aliran dan membandingkan perbedaan antara hasil simulasi HEC-HMS dengan data observasi. Simulasi hujan-aliran menggunakan input model berupa data debit observasi, curah hujan, peta tata guna lahan, peta jenis tanah, dan data Digital Elevation Model (DEM) yang mencakup periode tahun 2022. Nilai Curve Number (CN) komposit sebesar 81,31 diperoleh dari analisis tata guna lahan dan jenis tanah. Hasil pemodelan menghasilkan nilai Root Mean Square Error (RMSE) sebesar 3,7, yang mengindikasikan tingkat akurasi simulasi yang cukup memadai. Debit puncak simulasi terjadi saat peristiwa curah hujan maksimum pada 17 Oktober 2022, dengan curah hujan 87 mm dan debit puncak simulasi sebesar $59,4 \text{ m}^3/\text{s}$. Sebaliknya, debit puncak observasi terjadi pada 8 November 2022 dengan nilai $11 \text{ m}^3/\text{s}$. Perbedaan antara debit puncak simulasi dan observasi mencerminkan pengaruh bangunan air seperti bendung dan pengambilan air dalam DAS yang belum sepenuhnya

diperhitungkan oleh model. Temuan ini menunjukkan bahwa HEC-HMS dapat merepresentasikan pola limpasan umum DAS Tukad Petanu, memberikan wawasan untuk meningkatkan akurasi pemodelan hidrologi pada DAS tropis, serta mendukung strategi pengelolaan sumber daya air yang berkelanjutan di Bali.

Kata Kunci: HEC-HMS, Pemodelan hidrologi, Hujan-aliran, Tukad Petanu, Pengelolaan DAS

1. INTRODUCTION

Globally, watershed degradation has become a pressing environmental issue due to deforestation, land conversion, and climate variability, which threaten the achievement of Sustainable Development Goals (SDG 6: Clean Water and Sanitation) and SDG 13: Climate Action. These issues underscore the importance of effective watershed management to maintain ecosystem balance, reduce sedimentation, and improve water availability. In Indonesia, which contains more than 42,000 watersheds spanning approximately 190 million hectares and about 540 major rivers, maintaining hydrological balance poses significant challenges. One example is the Tukad Petanu watershed in Gianyar, Bali, which exemplifies these issues. It faces a notable water deficit of $-0.65 \text{ m}^3/\text{s}$ (Saptarahadi, 2020) and growing conflicts over water allocation despite its critical role in supporting irrigation, tourism, and religious activities (Aryastana, 2020).

Rainfall–runoff modelling is an effective approach to analyze watershed hydrological behavior and support water resource management. One of the widely used tools for this purpose is the Hydrologic Engineering Center – Hydrologic Modelling System (HEC-HMS). Although HEC-HMS has been extensively applied in various regions, its application and validation in tropical island watersheds such as Bali are still limited, creating a gap that needs to be addressed.

Therefore, this research focuses on the Tukad Petanu watershed with three main objectives: (1) to analyze flow discharge characteristics using rainfall–runoff modelling with daily rainfall data; (2) to evaluate the reliability of HEC-HMS in simulating rainfall–runoff processes in the study area; and (3) to compare simulated and observed discharge data to assess model accuracy in predicting peak discharge.

2. LITERATURE REVIEW

2.1 Watershed

A watershed is a land area that collects and channels precipitation toward a common outlet such as a river, lake, or ocean (Brooks et al., 2013; Moutaoikil et al., 2024; Shekar et al., 2023). It represents a hydrological unit where all surface water converges to a single point, controlled by topographic boundaries such as ridges and slopes. The characteristics of a watershed, including its shape, slope, and drainage network, influence the movement of water and sediment within the system (Moutaoikil et al., 2024). Watersheds play an essential role in maintaining water balance, as all activities occurring within the area directly affect downstream conditions. Land-use changes, deforestation, and human activities within a watershed can significantly alter runoff patterns, increase erosion, and degrade water quality (Tang & Adesina, 2022).

2.2 Hydrological process and runoff

Runoff is the portion of rainfall that flows over the land surface and eventually enters streams and rivers. It is a key component of the hydrological cycle and is influenced by several factors, including rainfall intensity, soil type, land cover, slope, and watershed area (Mohammed Salih & Omer, 2023; Gupta & Dixit, 2022). Infiltration capacity and surface storage determine how much rainfall becomes runoff. Areas with high impervious surfaces tend to produce greater runoff, increasing the risk of flooding. Conversely, vegetated areas promote infiltration and reduce surface flow (Kabeja et al., 2022; Jakir Hussain et al., 2024). Understanding runoff processes is crucial for predicting discharge and managing water resources effectively.

2.3 Rainfall analysis

Rainfall analysis is essential in hydrological studies to estimate the distribution and magnitude of precipitation over a watershed. One commonly used method is the Thiessen Polygon method, which calculates areal rainfall based on the influence area of each rainfall station (Triatmodjo, 2010). Frequency analysis is used to estimate rainfall for different return periods, which is important for hydrological design and flood prediction (Abiko, 2021; Alam et al., 2018). In addition, when hourly rainfall data are not available, rainfall distribution can be estimated using methods such as PSA 007, which approximates the percentage of total rainfall occurring in each hour. This approach allows for the development of rainfall hyetographs required in hydrological modelling.

2.4 HEC-HMS modelling

The Hydrologic Engineering Center – Hydrologic Modelling System (HEC-HMS) is a widely used tool for simulating rainfall–runoff processes in a watershed (U.S. Army Corps of Engineers, 2016). It integrates various components, including basin models, meteorological models, control specifications, and time-series data, to represent hydrological systems. In HEC-HMS, the Soil Conservation Service Curve Number (SCS-CN) method is commonly used to estimate runoff volume, while the SCS Unit Hydrograph method is applied to transform excess rainfall into direct runoff hydrographs (Mohammed Salih & Omer, 2023). Flow routing within river channels can be simulated using methods such as the Muskingum method. HEC-HMS has been widely applied in hydrological studies due to its flexibility and ability to model different watershed conditions. However, its performance depends on the accuracy of input data and parameter calibration, especially in complex environments such as tropical watersheds (Jawale & Thube, 2025).

3. METHODOLOGY

The study was conducted in the Tukad Petanu Watershed, located at coordinates 115°19'01.9" E and 8°22'11.6" S, with a total area of 94.49 km². The Tukad Petanu River flows through the Gianyar and Bangli Regencies. The upstream area lies in Banjar Bayunggede, Kecamatan Kintamani, while the downstream outlet is located at the border of Banjar Saba, Kecamatan Blahbatuh, and Banjar Sukawati, Kecamatan Sukawati. Rainfall data were collected from three stations: Pengotan, Tegallalang, and Kemenuh. The scope of the study assumes constant land use during the 2022 analysis period and does not account for sedimentation, evapotranspiration, or baseflow interactions.

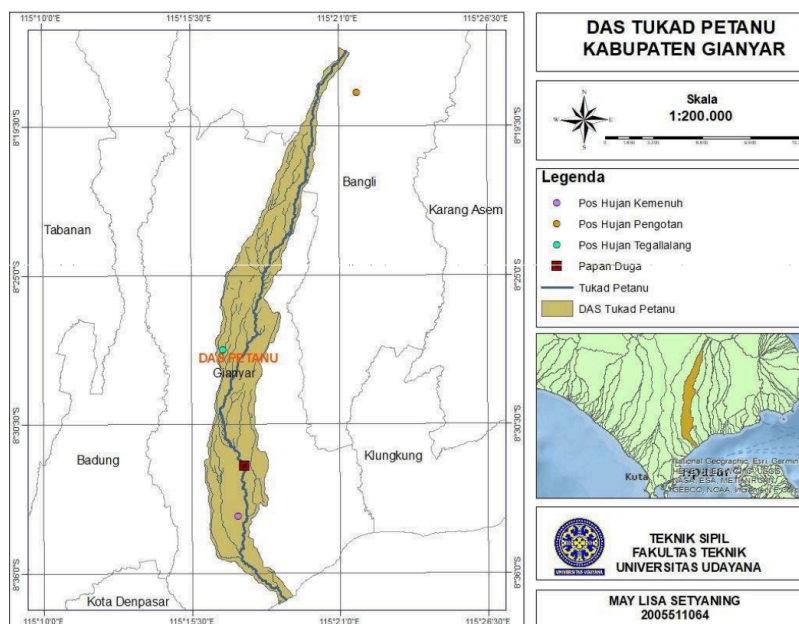


Figure 1. Research Study map

3.1 Data collection

This study involved a comprehensive literature review and the collection of key hydrological and spatial secondary data from institutional sources, including Balai Wilayah Sungai Bali Penida, Dinas Pekerjaan Umum, BPDAS Unda Anyar, and the Indonesia Geospatial Portal. The hydrological dataset, spanning from 2013 to 2022, comprised observed discharge records and daily rainfall measurements from the Pengotan, Tegallalang, and Kemenuh stations. For spatial analysis, the research utilized the 2022 land-use map, soil type classifications, Digital Elevation Model (DEM) data, and coordinate data for rainfall stations and dams within the Tukad Petanu watershed.

3.2 Data analysis

The data analysis involved several key methods. Thiessen Polygons were used for regional average rainfall calculation and Double Mass Curve for data consistency testing (Triatmodjo, 2010; Romdania & Herison, 2023; Achmad et al., 2020). Frequency analysis was performed on maximum annual rainfall and discharge data to identify the most suitable probability distribution, validated through Chi-Square and Smirnov-Kolmogorov tests (Giardini et al., 2020). Additionally, soil type and land use analysis determined the Hydrologic Soil Group (HSG) and calculated the Curve Number (CN) value for runoff calculations.

The core of the research utilized HEC-HMS modelling, incorporating Basin Models, a Meteorologic Model, Control Specification, and Time Series Data (Kabeja et al., 2022; Santillan et al., 2016). For hydrological processes, the SCS Curve Number (CN) method was applied for Runoff Volume, the SCS Unit Hydrograph method for Direct Runoff, and the Muskingum method for flow routing (Santillan et al., 2016; Jakir Hussain et al., 2024). Finally, model verification was conducted by comparing simulation results with observed data, calculating design discharge for various return periods, and evaluating performance using the Root Mean Square Error (RMSE), Percent Bias (PBIAS), and coefficient of determination (R^2) value (Ayele & Gebremariam, 2020; Jawale & Thube, 2025).

4. RESULT AND DISCUSSION

4.1 Geospatial analysis

The Tukad Petanu watershed, also known as DAS Tukad Petanu, was delineated using ArcGIS-ArcMap software with data provided by BWS Bali-Penida. This elongated watershed spans across two regencies, Bangli and Gianyar, covering an area of 94.49 km² with a river length of 46.79 km. It is equipped with three rainfall stations strategically located at Pengotan (upstream), Tegallalang (middle), and Kemenuh (downstream) to monitor precipitation. Additionally, a discharge measurement post is situated downstream to track water flow. The presence of nine weirs along the Tukad Petanu river suggests a potential influence on downstream discharge.

The soil type map was processed using ArcGIS-ArcMap, based on data from BPDAS Unda Anyar (2024). The Tukad Petanu watershed comprises several soil types, with Gleisol Eutrik dominating at 56.77% and Andosol Eutrik at 27.75%. These soil types are crucial for determining the Hydrologic Soil Group (HSG), which categorizes soils based on their infiltration rates.

Table 1. HSG distribution in Tukad Petanu watershed

HSG	Area (km ²)	Percentage (%)
A	0.88	0.88
B	27.57	29.18
C	66.09	69.94

Land use data for the Petanu watershed was processed using ArcGIS-ArcMap, based on 2022 data from the Department of Public Works, Spatial Planning, Housing, and Settlement Areas of Bali Province. The main land uses identified are plantations, fields, residential areas, rice fields, shrubs, and water bodies (rivers).

Table 2. Land use type area distribution in Tukad Petanu watershed

Land use types	Area (km ²)	Percentage (%)
Residential	29.695	31
Rice Fields	28.185	30
Plantations	27.019	7
Shrub/Bush	6.463	7
Fields	3.056	3
Highland Forest	0.060	0
Coastal Sand Spread	0.014	0

These geospatial characteristics are used to calculate key hydrological parameters required for the HEC-HMS model:

1. Composite Curve Number (CN): The composite CN value for Tukad Petanu watershed derived from land use and HSG data is **81.310**. This value is essential for estimating direct surface runoff from rainfall (Kabeja et al., 2022; Mehmood et al., 2021)
2. Composite Initial Abstraction (Ia): The composite initial abstraction value for the watershed is **7.444**. Initial abstraction represents the amount of precipitation retained in the watershed before runoff begins.
3. Composite Impervious Area: The composite impervious area of the watershed is **12.856%**. This parameter is based solely on land cover, as it is not influenced by HSG.

4.2 Hydrological Analysis

To ensure the reliability of the rainfall data, a consistency test was performed using the Double Mass Curve method for the three rainfall stations (Pengotan, Tegallalang, and Kemenuh). This method helps identify inconsistencies or changes in the rainfall measurement regime over time. The

data show inconsistency after 2019, so data in Pengotan Station after year 2019 needs to be corrected, and the correction factor is 1.354. The R^2 value of each station are as follow:

1. Pengotan Station = 0.9936
2. Tegallalang Station = 0.989
3. Kemenuh Station = 0.9975

These R^2 values, which are close to 1, indicate that the rainfall data from each station are consistent (Shekar et al., 2023). The corrected result of data consistency test in each station is shown in **Table 3**.

3. Corrected Result of Data Consistency Test in each station

Table 3. Corrected Result of Data Consistency Test in each station

No	Year	Pengotan Station (mm)	Tegallalang Station (mm)	Kemenuh Station (mm)
1	2014	85	87	136
2	2015	89	78	109
3	2016	99	77	114
4	2017	127	91	103
5	2018	183	83	186
6	2019	119	95	125
7	2020	131	144	130
8	2021	132	129	190
9	2022	197	99	104
10	2023	121	124	147

The regional average rainfall was calculated using the Thiessen polygon method (Mehmood et al., 2021). Based on the three rainfall recording station locations, the rainfall station's influence area can be depicted in ArcGIS-ArcMap software.

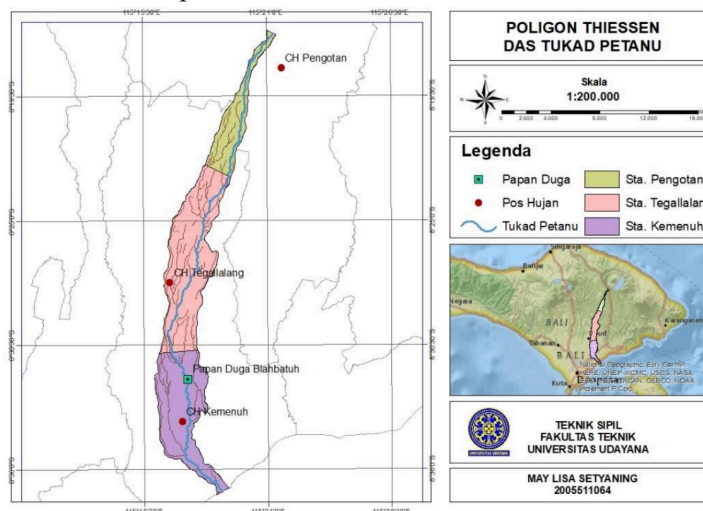


Figure 2. Thiessen Polygon of Tukad Petanu Watershed

The results of the area of influence of rainfall stations on the Tukad Petanu watershed based on ArcGIS-ArcMap processing can be seen in **Table 4**.

Table 4. The influence areas and Thiessen coefficients for each station

Station	Area (km ²)	Percentage (%)	Thiessen Coefficient
Pengotan	15.520	16.425	0.16
Tegallalang	45.180	47.815	0.48
Kemenuh	33.790	35.760	0.36

Calculating the average regional rainfall for subsequent years can be done using the same steps. A summary of the results of the regional average rainfall calculations is shown in **Table 5**.

Table 5. Result of Average Regional Rainfall

No	Year	Pengotan Station	Tegallalang Station	Kemenuh Station	Total rainfall of the region (mm)
	Coefficient	0.16	0.48	0.36	
1	2014	85	87	136	94.333
2	2015	89	78	109	87.025
3	2016	99	77	114	90.892
4	2017	127	91	103	105.797
5	2018	183	83	186	135.555
6	2019	119	95	125	108.496
7	2020	131	144	130	136.897
8	2021	132	129	190	140.335
9	2022	197	99	104	135.042
10	2023	121	124	147	126.395

Frequency analysis of hydrological data was conducted to determine the relationship between the magnitude and frequency of extreme events, calculating statistical parameters like standard deviation, skewness, and kurtosis coefficients for rainfall data (Abiko, 2021).

Table 6. Summary of Statistical Parameter Calculation

m	m/(N+1)	Year	Rainfall (mm)	Log [Rainfall (mm)]
1	0.091	2020	140.335	2.147
2	0.182	2019	136.897	2.136
3	0.273	2017	135.555	2.132
4	0.364	2021	135.042	2.130
5	0.455	2022	126.395	2.102
6	0.545	2018	108.496	2.035
7	0.636	2016	105.797	2.024
8	0.727	2013	94.333	1.975
9	0.818	2015	90.892	1.959
10	0.909	2014	87.025	1.940
Total Data		=	10	10
Average		=	116.077	2.058
Standard Deviation		=	21.033	0.081
Skewness Coefficient		=	-0.204	-0.317
Kurtosis Coefficient		=	2.201	2.320

Several distribution methods, including Normal, Gumbel, Log Normal, and Log Pearson Type III, were evaluated (Alam et al., 2018). Distribution methods were evaluated using goodness-of-fit (GOF) tests, showing how well the selected distribution fits to the given data (Mohamed et al.,

2016). While initial tests suggested Log Pearson Type III, further validation using Chi-Square and Smirnov-Kolmogorov tests, ultimately determined the Gumbel distribution as the most suitable, as it passed the Chi-Square test and exhibited the smallest delta in the Smirnov-Kolmogorov method. Frequency analysis of hydrological data was conducted to determine the relationship between the magnitude and frequency of extreme events, calculating statistical parameters like standard deviation, skewness, and kurtosis coefficients for rainfall data (Sharma & Kumar, 2016).

Table 7. Return Period Rainfall Gumbel Distribution

Tr (Tahun)	Ytr	KTr	RTr (mm)
100	4.600	4.322	206.99
50	3.902	3.587	191.528
25	3.199	2.847	175.949
10	2.250	1.848	154.949
5	1.500	1.058	138.329
2	0.367	-0.136	113.227

The hourly rainfall distribution analysis was conducted using the PSA 007 method, which estimates the percentage of total rainfall occurring during each hour of a storm event (Agustin et al., 2025). This approach is particularly useful when hourly rainfall records are unavailable, allowing the rainfall pattern to be adapted from previously established regional distributions. In this study, the runoff coefficient (C), which represents the proportion of rainfall that contributes to surface runoff, was calculated to be 0.276. This coefficient was subsequently applied to determine the net rainfall, while the detailed results of the hourly rainfall distribution for each return period derived from the PSA 007 method are presented in **Table 8**.

Table 8. Summary of Hourly Return Period Rainfall Distribution

Hour	Return Period (Tr; Year)					
	2	5	10	25	50	100
	Rainfall (mm)					
1	1.252	1.530	1.713	1.945	2.118	2.289
2	3.443	4.334	5.140	5.999	6.883	7.629
3	22.22	26.76	29.12	32.58	34.41	36.61
	2	6	6	7	3	9
4	1.878	2.549	3.427	4.215	5.294	6.103
5	1.252	1.530	1.713	1.945	2.118	2.289
6	1.252	1.530	1.713	1.945	2.118	2.289
Total	31.29	38.23	42.83	48.63	52.94	57.21
	9	8	2	7	3	8
Runoff Coef.	0.276	0.276	0.276	0.276	0.276	0.276

Return period discharge was also calculated. The frequency analysis of discharge data was performed using the same steps as the frequency analysis of rainfall data. The results of the hourly discharge distribution can be seen in the **Table 9**.

Table 9. Summary of Hourly Return Period Discharge Distribution

Hour	Return Period (Tr; Year)					
	2	5	10	25	50	100
	Discharge (m ³ /s)					
1	1.252	1.530	1.713	1.945	2.118	2.289
2	3.443	4.334	5.140	5.999	6.883	7.629
3	22.22	26.76	29.126	32.587	34.413	36.619
	2	6				
4	1.878	2.549	3.427	4.215	5.294	6.103

5	1.252	1.530	1.713	1.945	2.118	2.289
6	1.252	1.530	1.713	1.945	2.118	2.289
Total	31.29	38.23	42.832	48.637	52.943	57.218
	9	8				
Runoff Coef.	0.276	0.276	0.276	0.276	0.276	0.276

4.3 HEC HMS Modelling

Before running any HEC-HMS project, four essential components must be configured: the basin data component, meteorological data component, input data component, and control specification component. The basin model in HEC-HMS illustrates the elements within a watershed. In this study, the basin model includes subbasin, reach, diversion, and sink elements. The diversion element in the model is used to reroute a portion of the water flow, representing water usage for irrigation purposes. A recapitulation of the input data for the HEC-HMS model simulation is presented in the **Table 10**.

Table 10. HEC-HMS Simulation Input Parameter

No	Description	Parameter	Input Value	Unit
1	Area		94.49	km ²
2	Impervious	<i>loss</i>	12.86	%
3	Initial Abstraction	<i>loss</i>	7.44	mm
4	SCS Curve Number	<i>loss</i>	81.31	
5	SCS UH Lag	<i>transform</i>	10.96	minutes
6	Muskingum K1	<i>routing</i>	0.87	hours
7	Muskingum X1	<i>routing</i>	0.20	
8	Divertion	<i>divert</i>	4	m ³ /s
9	Muskingum K2	<i>routing</i>	2.56	hours
10	Muskingum X2	<i>routing</i>	0.20	

Meteorologic model simulates meteorological input data, such as rainfall. In this study, the meteorologic model input is categorized into two types: daily rainfall data and hourly rainfall data for return periods.

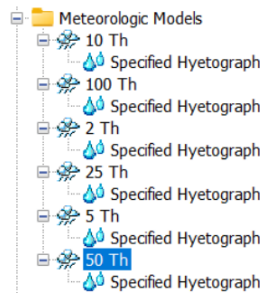


Figure 3. Meteorologic Model Input for Rainfall Return Period

Control Specification module is used to set the start and end times for model simulations and calibrations. The time interval defined in the Control Specification must match the time interval used in the Meteorologic Model input.

Time series data is used to input time-series information, specifically rainfall and discharge data in this study. The time interval depends on the rainfall period being transformed. This research models data on an annual, monthly, and return period basis. For the annual and monthly models, daily rainfall data is used as input, while hourly rainfall data is used for the return period transformation. The output of the HEC-HMS simulation is daily flow discharge. Through the model running process, a comparison between the model outflow and observed outflow can be determined. The graph comparing the model and observed outflow can be seen in **Figure 3**.

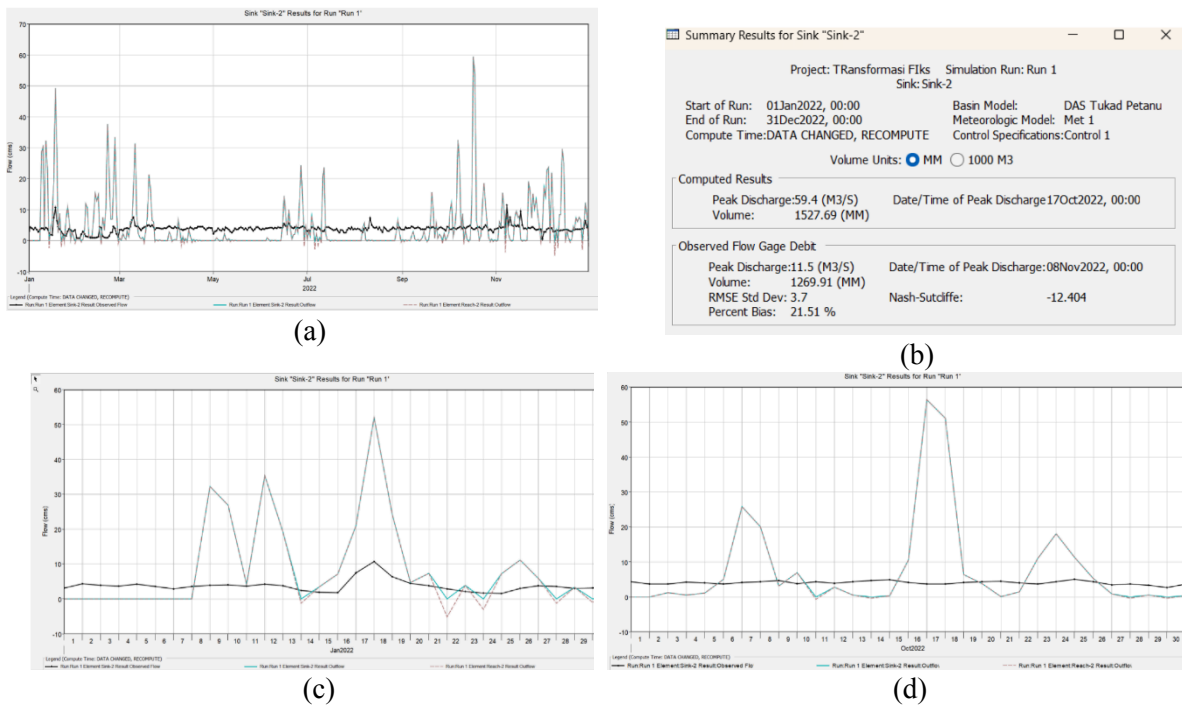


Figure 4. Comparison Chart of Simulated Discharge with Observed Discharge (a), Model Data Analysis Results (b), HEC-HMS Model Results Graph for January 2022 (c), HEC-HMS Model Results Graph for October 2022 (d).

From the three model experiments, it can be seen that the model graphs tend to have higher peaks compared to the observed discharge. This difference may be caused by several field factors that cannot be fully represented in the simulation. The river cross-section, which frequently changes along its course, can also cause differences between the simulated discharge results and the observed discharge.

In this research, the model's verification was conducted through three key approaches. Firstly, model outputs were compared with observed field data to ascertain the model's responsiveness to rainfall and discharge patterns. This involved generating comparative graphs of rainfall, simulated discharge, and observed discharge over a one-year period (**Figure 5.a** and **Figure 5.b**). Secondly, the model's ability to accurately calculate design discharge for various return periods was evaluated. Lastly, the model's performance was assessed quantitatively using Root Mean Square Error (RMSE) and Percent Bias (PBIAS) values.

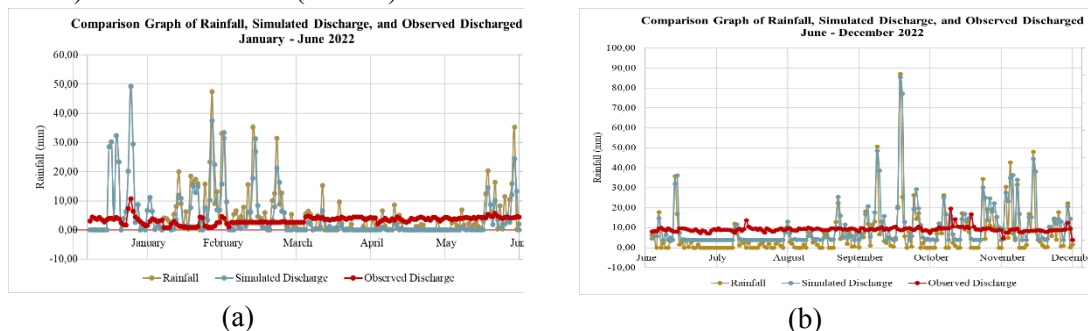


Figure 5. Comparison Graph of Rainfall, Simulated Discharge, and Observed Discharge in January-June 2022 (a) and June-December 2022 (b)

Based on the comparative graphs of rainfall, Simulated discharge, and observed discharge, it can be concluded that the model's outflow pattern generally follows the rainfall data trend. From **Figure 5.b**, the peak discharge from the model occurred on October 17, 2022. Therefore, model

verification needs to be carried out by comparing the rainfall, simulated discharge, and observed discharge values for October 2022, as presented in **Figure 6**.

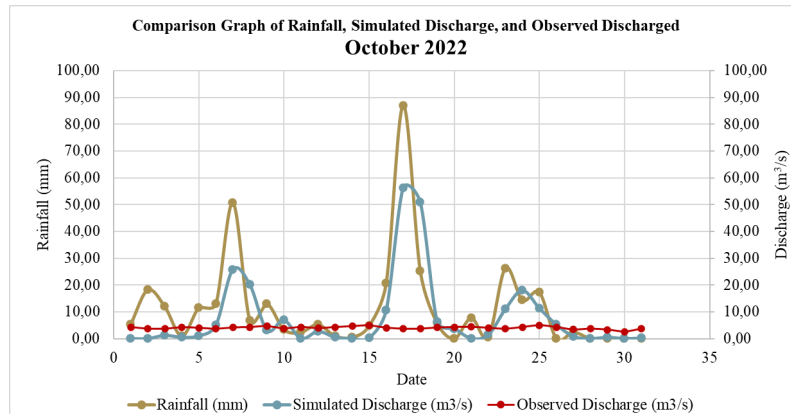


Figure 6. Comparison Graph of Rainfall, Simulated Discharge, and Observed Discharge for October 2022

Model verification for October 2022 confirmed that the HEC-HMS model accurately followed rainfall trends. When maximum rainfall occurred, the HEC-HMS model also produced a peak discharge. Model verification was further conducted by comparing the transformation of rainfall for various return periods with the calculated design discharge.

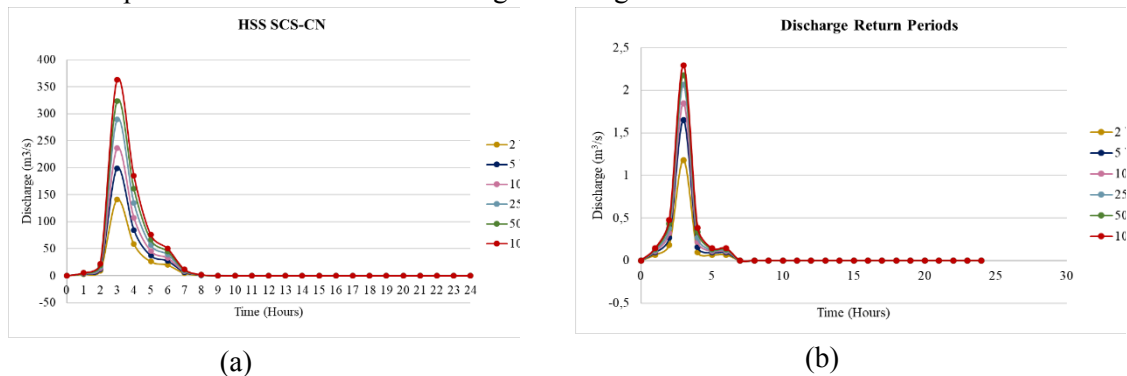


Figure 7. Simulated Hydrographs using the SCS-CN Method for Various Rainfall Return Periods (a), Design Discharge Return Periods Graph (b)

Model verification, using comparisons between model and observed data, shows that the model generally follows the same trend as the rainfall data. Within the HEC-HMS program, model verification considers the RMSE (Root Mean Square Error) value. The RMSE for the rainfall-runoff model is shown in **Figure 4.b**, where its value is 3.7. Differences between the simulated HEC-HMS discharge and observed discharge can arise from several factors. Observed discharge data might not accurately represent rainfall-runoff values because measurements are taken downstream. Additionally, given the morphology of Tukad Petanu, which consists of rock formations, water flow may be obstructed at certain locations.

5. CONCLUSION

Based on the analysis conducted in this study, the HEC-HMS simulation using daily rainfall data shows that the discharge characteristics of the Tukad Petanu Watershed respond significantly to rainfall events, with discharge trends closely following rainfall patterns. The simulated runoff volume was 1527.69 mm. The model's reliability, indicated by an RMSE value of 3.7, suggests that further improvement is needed, as values closer to zero indicate better accuracy. Although the model successfully predicted the peak discharge event on October 17, 2022, corresponding to the maximum rainfall event, significant differences were observed between simulated and observed discharge values. In particular, the HEC-HMS model tends to overestimate peak discharge ($Q_p =$

59.4 m³/s) compared to observed data ($Q_p = 11 \text{ m}^3/\text{s}$), and differences were also found in the timing of peak discharge.

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