

# Flood Discharge Modeling through Hydrological Parameter Calibration Using HEC-HMS in the Lower Air Bengkulu River

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## ABSTRACT

*The Air Bengkulu River experiences flooding at least twice a year due to increased discharge during the rainy season. This study aims to calibrate hydrological model parameters based on daily rainfall data for the flood event of 30 August 2022 using HEC-HMS modeling to obtain a best design for flood discharge. Calibration was conducted by simulating the rainfall occurred during the flood event to reproduce the observed discharge recorded at the gauging station, using the SCS-Curve Number (SCS-CN) loss method and the Snyder transform method in HEC-HMS 4.10. The parameters included the Peak Rate Factor (PRF) in the SCS loss scheme and the Ct and Cp coefficients in the Snyder method, while the CN and impervious values were determined based on land-use maps. The results indicated that both approaches produced relatively similar calibration outcomes; however, the Snyder method is better than the SCS-CN. The Snyder approach showed moderate performance with PBIAS = 0.34% (Very Good), RMSE = 0.7 (Satisfactory), and NSE = 0.509 (Good). It was, therefore, adopted for design flood discharge estimation with results  $Q_2 = 277.9 \text{ m}^3/\text{s}$ ,  $Q_5 = 458.5 \text{ m}^3/\text{s}$ ,  $Q_{10} = 585.9 \text{ m}^3/\text{s}$ ,  $Q_{25} = 752.6 \text{ m}^3/\text{s}$ , and  $Q_{50} = 879.4 \text{ m}^3/\text{s}$ . The observed discharge during the 30 August 2022 flood event ( $478.55 \text{ m}^3/\text{s}$ ) falls between the  $Q_5$  and  $Q_{10}$  return periods. Overall, the study demonstrates that parameter calibration plays a crucial role in improving hydrograph representation, although further evaluation using hourly data and multiple flood events is necessary to enhance model reliability.*

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## 1. INTRODUCTION

Flooding is a condition in which river discharge exceeds the channel capacity, resulting in overbank flow and inundation of areas that are normally dry. Floods are natural phenomena that cannot be entirely prevented; however, their impacts can be mitigated to reduce the associated losses and damages (Pusat Pengembangan Kompetensi Sumber Daya Air dan Permukiman, 2022). Bengkulu Province is located on the western side of the Bukit Barisan mountain range. Geographically, it is bordered by West Sumatra Province to the north, the Indian Ocean and Lampung Province to the south, the Indian Ocean to the west, and Jambi Province and South Sumatra Province to the east (Badan Pusat Statistik Provinsi Bengkulu, 2025).

The Air Bengkulu River, located within Central Bengkulu Regency and Bengkulu City, is part of a watershed that has not yet been managed in a well-planned and integrated manner (Nofirman, 2019). Floods in the Air Bengkulu River is primarily associated with the limited capacity of the main channel and its tributaries to convey incoming discharge. This capacity constraint may result from high flood discharges triggered by intense rainfall and watershed-related issues, as well as from channel cross-sectional reduction due to sediment deposition originating from upstream

areas. Sediment accumulation along the river course frequently leads to aggradation and, in some cases, blockage of the river mouth, thereby obstructing the flow of water into the sea (BWS Sumatera VII Bengkulu, 2020).

The Air Bengkulu River experiences flooding at least twice a year due to increased discharge (Q) during the rainy season. These flood events significantly affect local communities, causing economic losses through the inundation of agricultural and plantation areas, as well as disrupting transportation networks due to submerged roadways (Gunawan, 2017). The fluctuation of flood occurrences in the Air Bengkulu Watershed, based on positive–negative correlation analysis, is influenced by rainfall intensity and land cover characteristics. Residential areas, plantations, paddy fields, and mining areas show a positive correlation with flood events, indicating that an increase in these land uses tends to intensify flood discharge. In contrast, forest cover, shrubs, and swamp vegetation exhibit a negative correlation, meaning that greater coverage of these land types is associated with a reduction in runoff magnitude (Saraswati *et al.*, 2025).

Several recent studies have estimated the peak discharge of the Air Bengkulu River as a response to rainfall intensity within the Bengkulu Watershed. These studies generally applied statistical analysis of average daily rainfall data to derive peak discharge using synthetic unit hydrograph methods, such as the Nakayasu method (Amri *et al.*, 2018) or hydrological modeling software such as HEC-HMS. Therefore, a research gap exists in studies that calibrate rainfall–runoff analyses against observed flood discharge in the Bengkulu Watershed. Calibration is essential to obtain a model that realistically represents the hydrological response of the watershed. In order to simulate flow behaviour within the watershed system, the HEC-HMS model requires adjustment of its parameters through a calibration process (Tunas, 2005). This study aims to calibrate hydrological parameters using daily rainfall data against the flood event of August 30, 2022, through HEC-HMS modeling, in order to determine the most appropriate method for return period flood discharge analysis that best represents field conditions.

## 2. MATERIALS AND METHODS

### 2.1. Materials

This study utilized daily rainfall data obtained from the Bajak, Taba Mutung, Tanjung Jaya, and Batu Rata rainfall stations for the period 2008–2024 (17 years), as well as daily discharge data for 2022 collected from the Taba Terunjam gauging station. Supporting spatial data (Table 1) included the FABDEM Digital Elevation Model (DEM), the 2022 land use map, and soil type data derived from the FAO Harmonized World Soil Database, which were used as inputs for hydrological modeling of the Air Bengkulu Watershed.

Table 1. Data availability

| No. | Data Type       | Data Availability                                                            | Data Source                                                                            |
|-----|-----------------|------------------------------------------------------------------------------|----------------------------------------------------------------------------------------|
| 1.  | Daily rainfall  | Bajak, Taba Mutung, Tanjung Jaya dan Batu Rata rainfall stations (2008-2024) | River Basin Organization for Sumatera VII Bengkulu                                     |
| 2.  | Daily discharge | Daily discharge records, Taba Terunjam gauging station (2022)                | River Basin Organization for Sumatera VII Bengkulu                                     |
| 3.  | DEM Data        | FABDEM (Forest And Buildings removed Copernicus DEM)                         | University of Bristol: <a href="https://data.bris.ac.uk/">https://data.bris.ac.uk/</a> |
| 4.  | Land use map    | Peta Tata Guna Lahan Tahun 2022                                              | Ministry of Environment and Forestry, Indonesia                                        |
| 5.  | Soil type map   | FAO Harmonized World Soil Database (HWSD)                                    | <a href="https://gaez.fao.org/pages/hwsd">https://gaez.fao.org/pages/hwsd</a>          |

### 2.2. Study Area

The physical characteristics of the Air Bengkulu Watershed used in the hydrological analysis included watershed area of 498.79 km<sup>2</sup>, river length (61.29 km), length of the lower Air Bengkulu River (20.1 km), main channel length (191.03 km), and watershed slope (0.16125%). Bengkulu Watershed was divided into 8 sub watershed (S1 – S8).

The study area (Figure 1) covered the downstream reach of the Air Bengkulu River extending to the river mouth, with a length of 20.1 km, traversing Central Bengkulu Regency and Bengkulu City. The Taba Terunjam gauging station was used as the boundary condition for peak discharge calibration.

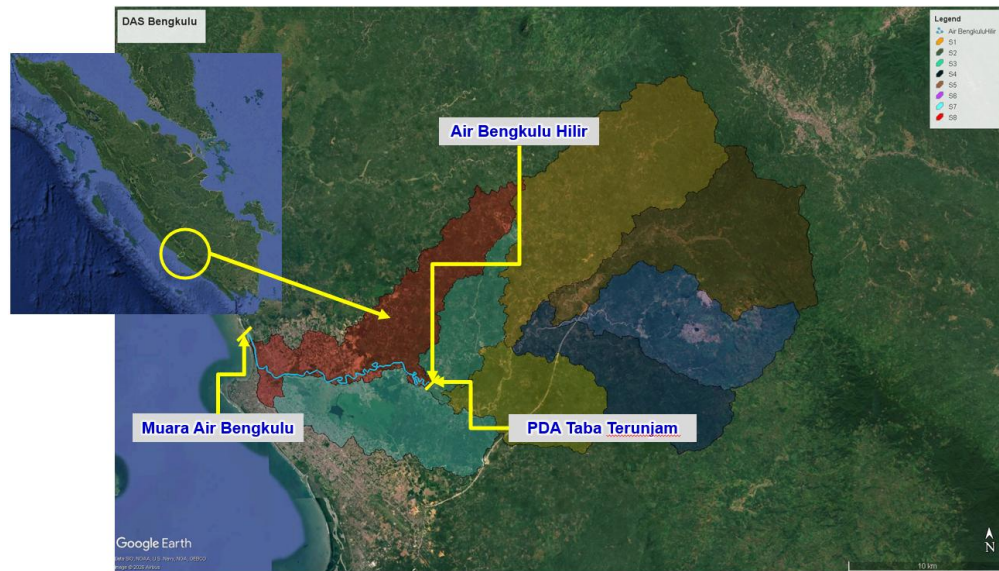


Figure 1. Study area

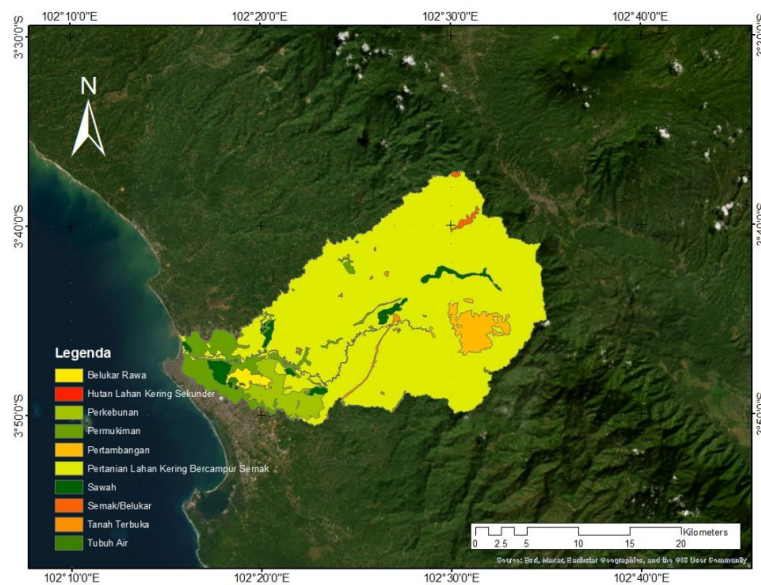


Figure 1. Land use map of the Bengkulu Watershed

Based on land use map analysis (Figure 2), the Bengkulu Watershed is predominantly characterized by mixed dryland agriculture covering 403.38 km<sup>2</sup> (80.87%), followed by residential areas occupying 33.83 km<sup>2</sup> (6.78%). Soil analysis indicates that the watershed consists of three main soil types: clay loam (covered 283.39 km<sup>2</sup> with Hydrologic Soil Group (HSG) D), loam (57.5 km<sup>2</sup>, HSG B), and sandy clay loam (157.9 km<sup>2</sup>, HSG C). Based on the analysis of land use (Table 2) and soil type data in the Bengkulu Watershed, the Curve Number (CN) and impervious values for each sub-watershed were presented in Table 3.

### 2.3. Research Method Flowchart

This study began with problem identification and a literature review, followed by data collection. The collected data were analyzed to determine watershed characteristics and hydrological parameters, which were subsequently used for flood discharge modeling of the August 30, 2022 event using HEC-HMS. The calibration process was conducted by

Table 2. Land use types of Bengkulu Watershed

| No. | Land Use                  | Area (km <sup>2</sup> ) | Percentage (%) |
|-----|---------------------------|-------------------------|----------------|
| 1.  | Secondary dryland forest  | 0.02                    | 0.005          |
| 2.  | Shrubland                 | 1.84                    | 0.37           |
| 3.  | Plantation                | 19.67                   | 3.94           |
| 4.  | Residential area          | 33.83                   | 6.78           |
| 5.  | Bare land                 | 2.53                    | 0.51           |
| 6.  | Water body                | 3.16                    | 0.63           |
| 7.  | Swamp shrub               | 4.67                    | 0.94           |
| 8.  | Mixed dryland agriculture | 403.38                  | 80.87          |
| 9.  | Paddy field               | 13.51                   | 2.71           |
| 10. | Mining area               | 16.17                   | 3.24           |

Table 3. Curve Number (CN) and Impervious Bengkulu Watershed

| Sub-Watershed | Area (km <sup>2</sup> ) | Channel Length <i>L</i> (km) | Watershed Slope <i>Y</i> (%) | Composite CN | Composite Impervious |
|---------------|-------------------------|------------------------------|------------------------------|--------------|----------------------|
| S1            | 107.94                  | 21.03                        | 21.03                        | 79.87        | 5.11                 |
| S2            | 84.16                   | 27.87                        | 27.87                        | 73.84        | 5.07                 |
| S3            | 60.41                   | 23.79                        | 23.79                        | 77.23        | 5.63                 |
| S4            | 50.69                   | 19.88                        | 19.88                        | 80.01        | 5.72                 |
| S5            | 44.38                   | 14.79                        | 14.79                        | 77.53        | 6.60                 |
| S6            | 30.19                   | 9.85                         | 9.85                         | 78.19        | 6.99                 |
| S7            | 66.84                   | 7.22                         | 7.22                         | 80.72        | 12.67                |
| S8            | 54.18                   | 3.80                         | 3.80                         | 85.43        | 21.56                |

comparing the SCS-CN and Snyder methods to identify the most representative approach. The selected method was then applied for return period flood discharge analysis. The research workflow was presented in Figure 3.

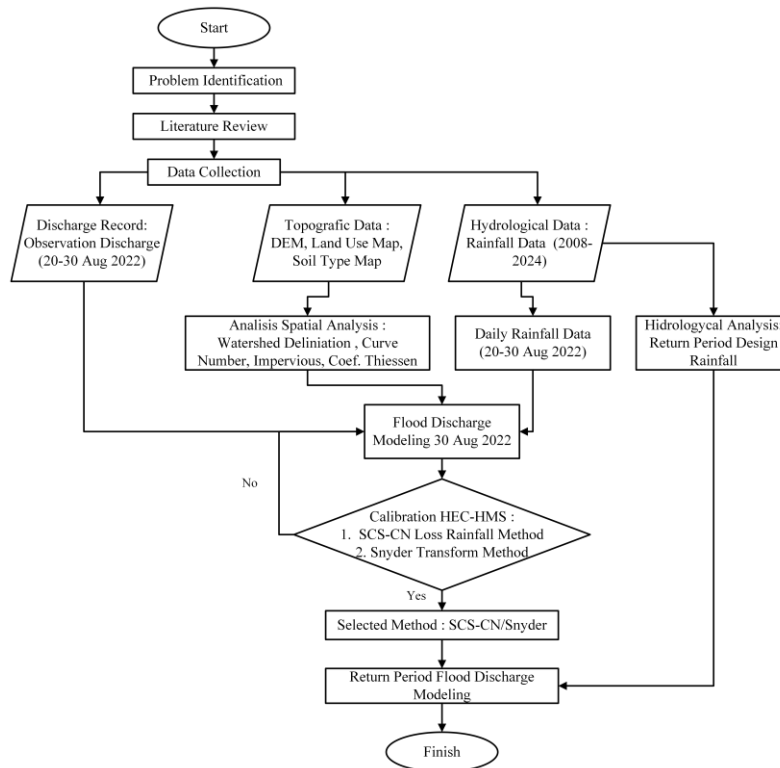


Figure 2. Research flowchart

## 2.4. Hydrological Analysis

In this study, the daily rainfall data were obtained from rainfall stations located within and around the Bengkulu Watershed. The initial step involved data quality control through an outlier test. An outlier refers to a data point within a series that significantly deviates from other observations, either excessively high or low. Therefore, the rainfall data series must first be examined to identify and assess potential outliers before further analysis (Balai Teknik Bendungan, 2022).

After data verification, the spatial distribution of rainfall was calculated using the Thiessen polygon method. The weighting coefficient for each rainfall station was determined based on the area of its respective Thiessen polygon and then multiplied by the corresponding daily rainfall values to obtain the annual maximum areal rainfall (annual maximum rainfall) for each year.

Frequency analysis was subsequently performed using the Gumbel distribution method. The Gumbel distribution is expressed by the following equation (Chow *et al.*, 1988):

$$x_T = \bar{x} + K_T s \quad (1)$$

$$K_T = -\frac{\sqrt{6}}{\pi} \left\{ 0.5772 + \ln \left[ \ln \left( \frac{T}{T-1} \right) \right] \right\} \quad (2)$$

with  $x_T$  is rainfall depth for a given return period,  $\bar{x}$  is mean value of variable  $x$ ,  $s$  is standard deviation,  $K_T$  is frequency factor corresponding to the exceedance probability. The statistical properties of the Gumbel distribution are expressed as follows:  $C_s = 1.139$  and  $C_k = 5.4002$  (Gumbel, 1941).

The results of the frequency analysis were subsequently subjected to a goodness-of-fit test to evaluate potential deviations between the observed data and the theoretical frequency distribution using the Kolmogorov–Smirnov test. The Kolmogorov–Smirnov test is expressed by the following equation:

$$D_n = \max |P(x) - P_o(x)| \quad (3)$$

with  $D_n$  is maximum vertical difference between the observed and theoretical cumulative distribution functions,  $P(x)$  is empirical probability of the sample data,  $P_o(x)$  is theoretical probability derived from the selected distribution.

The distribution is considered acceptable if the calculated value of  $D_n < D$  at the selected confidence level. If  $D_n < D$  based on the critical values of the Kolmogorov–Smirnov test as shown in the table below, the theoretical distribution can be accepted; otherwise, it is rejected (Massey, 1951).

## 2.5. Hydrological Parameter Calibration

Hydrological parameter calibration was performed by estimating flood discharge from rainfall data using either a trial-and-error approach or automatic calibration until a satisfactory agreement was achieved between the simulated and observed hydrographs. In hydrological modeling, data series are typically divided into two parts, where the first dataset is used for calibration and the second for verification. Model verification is essential to identify potential parameter bias resulting from the calibration process. Several considerations in data preparation for calibration and verification include:

1. Rainfall and discharge (or water level) data must represent the same hydrological event.
2. The rainfall data should adequately represent the entire watershed area.
3. The rainfall depth used for calibration should correspond to at least a 2-year return period event.

Since visual comparison between simulated results and observed data can be highly subjective, model performance evaluation requires the use of objective functions. Commonly used objective functions to quantify the differences between simulated and observed data include the Root Mean Square Error to Standard Deviation Ratio (RSR), the Nash–Sutcliffe Efficiency (NSE), and the Percent Bias (PBIAS). Performance of model evaluation was categorized into four rating, namely very good, good, satisfactory, and unsatisfactory. Table 4 provides range of RSR, NSE, and PBIAS for each performance class.

Table 4. Evaluation of model performance (Pérez-Sánchez *et al.*, 2017)

| Performance Rating | RMSE                              | NSE                           | PBIAS                               |
|--------------------|-----------------------------------|-------------------------------|-------------------------------------|
| Very Good          | $0.00 \leq \text{RMSE} \leq 0.50$ | $0.60 < \text{NSE} \leq 1.00$ | $\text{PBIAS} < \pm 10$             |
| Good               | $0.50 < \text{RMSE} \leq 0.60$    | $0.40 < \text{NSE} \leq 0.60$ | $\pm 10 \leq \text{PBIAS} < \pm 15$ |
| Satisfactory       | $0.60 < \text{RMSE} \leq 0.70$    | $0.20 < \text{NSE} \leq 0.40$ | $\pm 15 \leq \text{PBIAS} < \pm 25$ |
| Unsatisfactory     | $\text{RMSE} > 0.70$              | $\text{NSE} \leq 0.20$        | $\text{PBIAS} \geq \pm 25$          |

In this study, the Curve Number (CN) and impervious percentage were not calibrated, as they were determined based on land use map data provided by the Ministry of Environment and Forestry (KLHK) and were therefore treated as fixed parameters. The calibrated parameters included the Peak Rate Factor (PRF) in the SCS-CN method, as well as the  $C_t$  and  $C_p$  coefficients in the Snyder method. Calibration was performed using a trial-and-error approach until the simulated results closely matched the observed data.

## 2.6. SCS-CN Loss Method

The SCS Curve Number (SCS-CN) loss method was developed by Victor Mockus of the Soil Conservation Service (SCS), an agency under the United States Department of Agriculture (USDA). Victor Mockus also developed a dimensionless unit hydrograph based on observations of natural unit hydrograph characteristics derived from various watersheds of different sizes across the United States (Natakusumah *et al.*, 2011). The following equations were used in the SCS-CN rainfall loss analysis (USDA-NRCS, 2010) :

$$T_p = \frac{t_r}{2} + t_l \quad (4)$$

$$S = \frac{1000}{CN} - 10 \quad (5)$$

$$t_l = \frac{L^{0.8}(S + 2.54)^{0.7}}{1900 Y^{0.5}} \quad (6)$$

where  $T_p$  is time to peak of the hydrograph,  $t_r$  is rainfall duration,  $t_l$  is lag time,  $L$  is flow length,  $S$  is potential maximum retention, and  $Y$  is average watershed slope.

The SCS-CN rainfall loss method has been widely applied for flood discharge estimation, considering the influence of parameter variability in regions with dynamic climate conditions and land use characteristics (Sun & Liu, 2025). The CN value in the SCS Rainfall-Runoff Loss Method reflects the soil's infiltration capacity and the degree of imperviousness in a catchment area, which strongly depends on soil type, land use, and initial moisture conditions. (Cantik *et al.*, 2022).

## 2.7. Synthetic Unit Hydrograph Method (Snyder)

The Snyder Synthetic Unit Hydrograph (SUH) was developed by F.F. Snyder in 1983 based on studies in the Appalachian highlands of North America (Bedient *et al.*, 2013). The four main parameters in the Snyder SUH are lag time, peak discharge, base time, and the standard duration of effective rainfall (Gupta, 1989; Triatmojo, 2008). These parameters are expressed in the following equations:

$$t_p = CC_t(LL_c)^{0.3} \quad (7)$$

$$Q_p = \frac{C_p A}{t_p} \quad (8)$$

where  $t_p$  is time from the centroid of effective rainfall to the hydrograph peak (hours),  $C_t$  is watershed coefficient,  $L$  is length of the river from the observation point to the control point (km),  $L_c$  is length of the river from the watershed centroid to the control point (km),  $C$  is conversion constant (0.75 for SI units and 1.00 for the foot-pound system), and  $Q_p$  is peak discharge. Bedient & Huber (1992) reported that  $C_t$  typically ranges from 1.8 to 2.2. They also noted  $C_p$  ranges of 0.4 to 0.8, with higher  $C_p$  values corresponding to lower  $C_t$  values (Hydrologic Engineering Center, 1998).

## 2.8. Analysis using Software HEC-HMS

The HEC-HMS program, or Hydrologic Engineering Center's Hydrologic Modeling System, is a software capable of performing various hydrologic simulations. HEC-HMS can analyze losses or infiltration, unit hydrograph transformation, baseflow, and flood routing. According to the Manual for Flood Discharge Calculation of Dams Using HEC-HMS 4.0, HEC-HMS is designed to simulate the rainfall-runoff processes of a watershed system with the following components: Basin models, Meteorologic models, Control specification, Input data (time-series data manager, paired data manager, grid data manager) (Hydrologic Engineering Center, 1998).

## 3. RESULTS AND DISCUSSION

### 3.1. Hydrological Analysis

The rainfall data used in this study consist of daily precipitation records from 4 rainfall stations (PCH) within the Bengkulu watershed, namely Taba Mutung, Bajak, Tanjung Jaya, and Batu Raja, covering the period from 2008 to 2024 (17 years). The initial step in the hydrological analysis was to examine the rainfall data to ensure they were free from outliers (BSN, 2016). Results from the Outlier Test reveal that all data in 4 PCH are accepted. Table 5 provides covering areas and Thiessen coefficient values for the four PCH in Bengkulu Watershed.

Table 5. Coefficient of Thiessen for Bengkulu Watershed

| Station          | Influence Area (km <sup>2</sup> ) | Thiessen Coefficient |
|------------------|-----------------------------------|----------------------|
| PCH Taba Mutung  | 157.33                            | 0.32                 |
| PCH Bajak        | 215.759                           | 0.43                 |
| PCH Batu Raja    | 34.35                             | 0.07                 |
| PCH Tanjung Jaya | 91.35                             | 0.18                 |
| Total            | 498.79                            | 1.00                 |

Using the Thiessen Polygon method, the area-weighted contribution of each PCH station in the Bengkulu watershed was determined, resulting in the calculation of the Maximum Areal Rainfall. Based on the annual maximum rainfall data for the period 2008–2024, significant inter-annual fluctuations were observed. Figure 4 shows the annual maximum rainfall values tended to be relatively low in the early period (2011–2013), followed by an increase and occurrences of extreme rainfall in certain years, with the highest value recorded in 2016 at 164.41 mm. After 2015, maximum rainfall events with relatively high intensity occurred more frequently, indicating an increasing potential for extreme rainfall events in the study area. Subsequently, using the Annual Maximum Rainfall data, a rainfall frequency analysis was conducted employing the Gumbel method, as presented in Table 6.

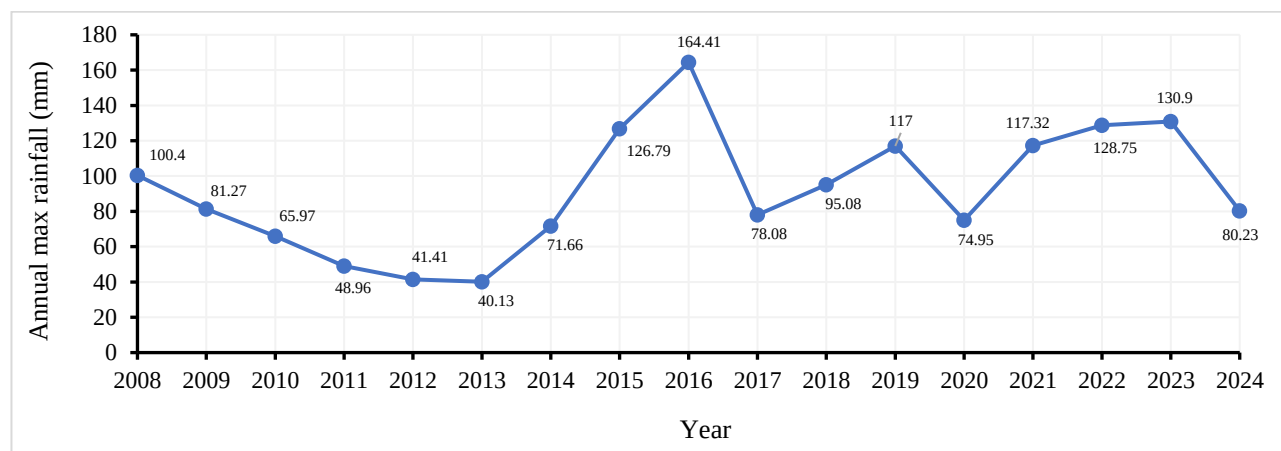


Figure 4. Annual maximum rainfall for Bengkulu Watershed based on data analysis

Table 6. Design of annual rainfall according to return period based on Gumbel Method

| Return Period | Design Rainfall (mm) |
|---------------|----------------------|
| 2             | 86.21                |
| 5             | 117.15               |
| 10            | 137.64               |
| 25            | 163.52               |
| 50            | 182.72               |

### 3.2. Calibration of Rainfall and Flood Discharge Parameters

The calibration was conducted by modeling the rainfall event that occurred during the flood event, which generated flood discharge corresponding to the recorded data at the PDA station, using the SCS-CN rainfall loss method and the Snyder unit hydrograph method in HEC-HMS 4.10. The HEC-HMS model offers the advantage of enabling calibration to obtain a hydrological model that closely represents actual field conditions (Amri *et al.*, 2018). The conditions applied in this calibration are as follows: (1) The daily rainfall data used correspond to the flood event on 30 August 2022 (20 August–30 August 2022), as presented in Table 7; (2) The observed flood discharge is based on the recorded data at PDA Taba Terunjam, August 2022 (20 August–30 August 2022); and (3) Land cover data for the year 2022.

Table 7. Daily rainfall (mm) and observed discharge during flood event of 2022 year

| Date | Month | Year | Daily rainfall (mm) |       |           |        | Flood Discharge (m <sup>3</sup> /s) |
|------|-------|------|---------------------|-------|-----------|--------|-------------------------------------|
|      |       |      | B. Raja             | Bajak | T. Mutung | T.Jaya |                                     |
| 20   | 8     | 2022 | 0                   | 7.4   | 41.9      | 239    | 16.89                               |
| 21   | 8     | 2022 | 8.5                 | 180.7 | 6.8       | 21     | 152.23                              |
| 22   | 8     | 2022 | 4                   | 47.2  | 0         | 0      | 63.64                               |
| 23   | 8     | 2022 | 9.5                 | 47.4  | 47.9      | 21.4   | 59.05                               |
| 24   | 8     | 2022 | 1.5                 | 20.5  | 1.7       | 0      | 82.86                               |
| 25   | 8     | 2022 | 52.5                | 0     | 21.3      | 0      | 50.02                               |
| 26   | 8     | 2022 | 0                   | 28.4  | 0         | 8.1    | 37.86                               |
| 27   | 8     | 2022 | 101.5               | 120.7 | 65.7      | 63.2   | 45.81                               |
| 28   | 8     | 2022 | 15                  | 22.1  | 14.9      | 0      | 209.67                              |
| 29   | 8     | 2022 | 191                 | 180.9 | 68.5      | 75.3   | 88.63                               |
| 30   | 8     | 2022 | 0                   | 0     | 0         | 0      | 478.55                              |

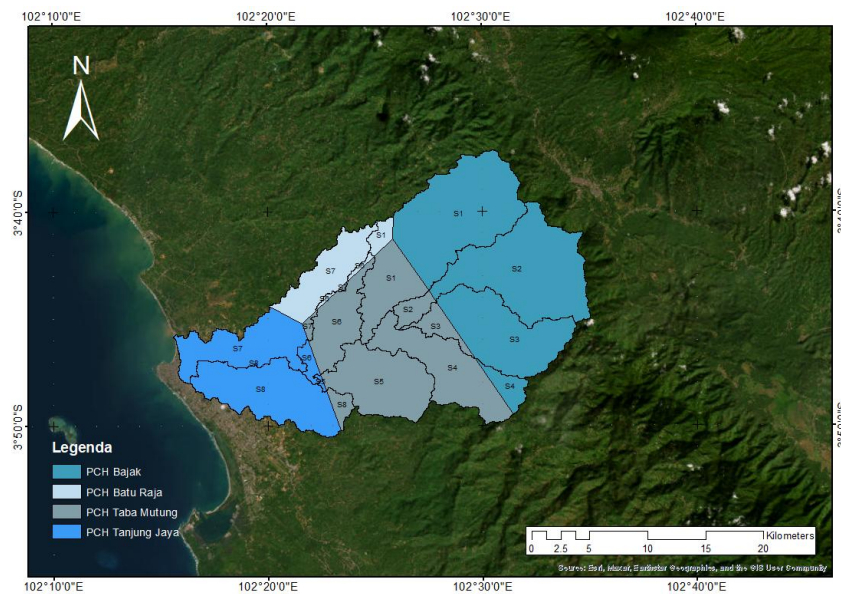


Figure 5. Overlay Thiessen coefficient influence of rainfall stations on sub-watersheds

Figure 5 shows overlay of Thiessen coefficient influence of rainfall stations on the 8 sub-watersheds. The calculation results of the ratio coefficients representing the influence of the 4 rainfall station (PCH) on each sub-watershed, as well as the parameters used in the development of the calibration model after trial-and-error adjustments, are presented in Tables 8 and 9.

Table 8. Coefficient ratio of 8 subwatershed within Bengkulu Watershed

| Subwatershed | Rainfall Stations | Cr   | Subwatershed | Rainfall Stations | Cr   |
|--------------|-------------------|------|--------------|-------------------|------|
| S1           | PCH Bajak         | 0.72 | S5           | PCH Taba Mutung   | 0.99 |
|              | PCH Batu Raja     | 0.04 |              | PCH Tanjung Jaya  | 0.01 |
|              | PCH Taba Mutung   | 0.24 | S6           | PCH Batu Raja     | 0.06 |
| S2           | PCH Bajak         | 0.92 |              | PCH Taba Mutung   | 0.82 |
|              | PCH Taba Mutung   | 0.08 |              | PCH Tanjung Jaya  | 0.13 |
| S3           | PCH Bajak         | 0.87 | S7           | PCH Batu Raja     | 0.42 |
|              | PCH Taba Mutung   | 0.13 |              | PCH Taba Mutung   | 0.03 |
| S4           | PCH Bajak         | 0.15 |              | PCH Tanjung Jaya  | 0.55 |
|              | PCH Taba Mutung   | 0.85 | S8           | PCH Taba Mutung   | 0.08 |
|              |                   |      |              | PCH Tanjung Jaya  | 0.92 |

Table 9. Transform parameters and loss input HEC-HMS

| Characteristics |                         | SCS CN-Transform |        |             |                | Snyder-Transform |      |      |           | Parameter Loss |                  |         |
|-----------------|-------------------------|------------------|--------|-------------|----------------|------------------|------|------|-----------|----------------|------------------|---------|
| Sub-W           | Area (km <sup>2</sup> ) | L (ft)           | S (in) | Slope Y (%) | Time Lag (min) | Lc (km)          | Ct   | Cp   | Tp (hour) | CN             | Initial Abs (mm) | Imp (%) |
| S1              | 107.94                  | 93871.30         | 2.52   | 21.03       | 157.99         | 17.22            | 2.00 | 0.7  | 9.64      | 79.87          | 12.80            | 5.11    |
| S2              | 84.16                   | 94326.48         | 3.54   | 27.87       | 164.71         | 19.37            | 1.80 | 0.7  | 9.00      | 73.84          | 18.00            | 5.07    |
| S3              | 60.41                   | 76017.82         | 2.95   | 23.79       | 135.96         | 11.26            | 1.80 | 0.7  | 7.17      | 77.23          | 14.98            | 5.63    |
| S4              | 50.69                   | 85210.21         | 2.50   | 19.88       | 149.73         | 13.88            | 2.00 | 0.68 | 8.77      | 80.01          | 12.69            | 5.72    |
| S5              | 44.38                   | 50773.43         | 2.90   | 14.79       | 123.75         | 9.05             | 2.20 | 0.6  | 7.27      | 77.53          | 14.72            | 6.60    |
| S6              | 30.19                   | 53016.80         | 2.79   | 9.85        | 153.87         | 6.62             | 2.20 | 0.56 | 6.70      | 78.19          | 14.17            | 6.99    |
| S7              | 66.84                   | 114214.01        | 2.39   | 7.22        | 307.15         | 19.60            | 2.20 | 0.56 | 11.69     | 80.72          | 12.13            | 12.67   |
| S8              | 54.18                   | 59294.79         | 1.71   | 3.80        | 214.11         | 8.39             | 2.20 | 0.56 | 7.44      | 85.43          | 8.67             | 21.56   |

The Curve Number (CN) values used are consistent with the dominance of agricultural and plantation land cover in the Air Bengkulu Watershed, which generally exhibits lower infiltration capacity compared to forested areas, thereby producing greater surface runoff. The lag time values calculated using Equation (6) are also physically reasonable, considering that the relatively long river length and the gentle watershed slope contribute to a longer flow concentration time. The results of the calibrated flood discharge modeling using the SCS-CN rainfall loss method and the Snyder unit hydrograph method, along with the evaluation of model performance, are presented in Figure 6.

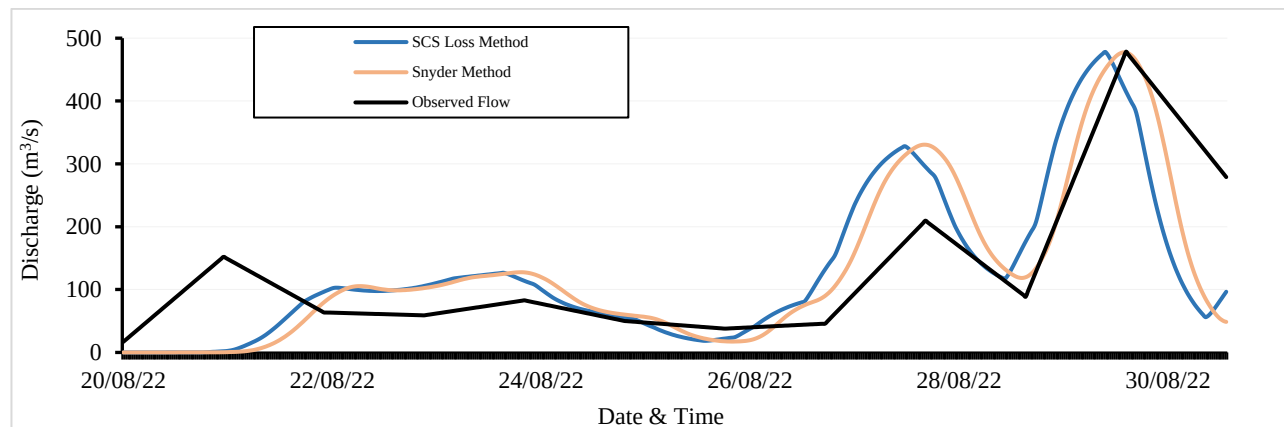


Figure 6. Model and observed discharge results using: (a) SCS-CN rainfall loss method, (b) Snyder method

Table 10. Recapitulation of statistical performance metrics for simulated and observed discharge

| No | Method | Q Peak (m <sup>3</sup> /s) | PBIAS | RMSE | NSE   |
|----|--------|----------------------------|-------|------|-------|
| 1  | SCS-CN | 478.3                      | 0.89% | 0.8  | 0.289 |
| 2  | Snyder | 477.5                      | 0.34% | 0.7  | 0.509 |

Based on the recapitulation of the hydrological modeling results presented in Table 10, it can be observed that both the SCS-CN rainfall loss method and the Snyder method are capable of simulating peak discharge (Q peak) values close to the observed discharge recorded at the PDA station. However, when evaluated using objective functions to quantify the differences between simulated and observed data—namely PBIAS, RMSE, and NSE—the Snyder method demonstrates better performance than the SCS-CN rainfall loss method.

The comparison results indicate that the Snyder method produces a hydrograph that more closely approximates the observed discharge, particularly in representing both the magnitude and timing of the peak discharge. The differences are evident in the hydrograph shape and the time shift of the peak. The Snyder parameters are more sensitive to variations in watershed characteristics, allowing for a more flexible calibration process.

An NSE value of 0.509 obtained for the Snyder method indicates moderate model performance, meaning that the overall hydrograph pattern has been reasonably represented, although discrepancies remain during the rising and recession limbs of the discharge. This moderate performance level is likely influenced by the use of daily data and the calibration being based on a single flood event.

Based on the statistical evaluation described above, the Snyder method is selected as the reference method, as it provides results that are closest to field observations. Therefore, for the analysis of flood discharge corresponding to specific return periods, the Snyder method will be applied.

### 3.3. Return Period Flood Discharge

In accordance with the watershed characteristics analysis, the Bengkulu Watershed has an area of 498.79 km<sup>2</sup> and is classified as a medium-sized watershed. Therefore, based on the guidelines of the Balai Teknik Bendungan, the rainfall distribution method applied was PSA-007, using a 6-hour rainfall distribution pattern.

Using the HEC-HMS model, flood discharges for the 2, 5, 10, 25, and 50-year return periods were simulated employing the Snyder method. In the HEC-HMS modeling, the hydrological parameters obtained from the calibration process were adopted. Consequently, the Snyder Synthetic Unit Hydrographs (SUH) for each return period are presented in Figure 7 with discharge debit based on return period is inzettet.

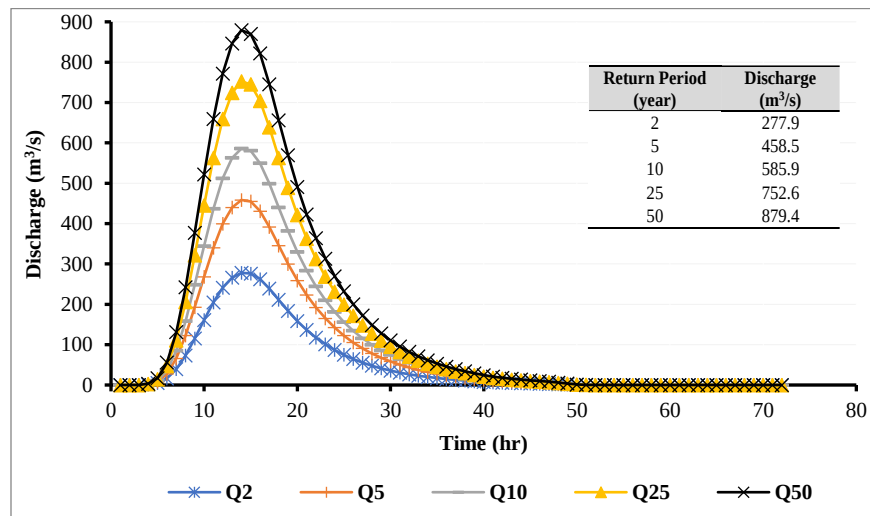


Figure 3. Snyder Synthetic Unit Hydrograph (SUH) of flood discharge at Air Bengkulu Lower (Taba Terunjam Water Level Station)

This study has several limitations. The calibration was performed based on a single flood event; therefore, the model's capability to represent other events has not been comprehensively validated. The use of daily-resolution data also limits the accuracy in capturing hydrograph dynamics. Furthermore, no independent verification has been conducted to assess the long-term reliability of the model.

#### 4. CONCLUSIONS AND RECOMMENDATIONS

The results indicate that, based on the recapitulation of hydrological parameter calibration using the HEC-HMS model with the SCS-CN rainfall loss method and the Snyder unit hydrograph transform scheme, both methods produced relatively comparable results. However, the Snyder transform scheme yielded better objective function values than the SCS-CN rainfall loss method. It can therefore be concluded that, in this study, the Snyder unit hydrograph transform scheme more accurately represents field conditions, with statistical performance values of PBIAS = 0.34% (Very Good), RMSE = 0.7 (Satisfactory), and NSE = 0.509 (Good). Accordingly, the Snyder method was selected for the calculation of return period flood discharges.

The estimated return period flood discharges obtained using the Snyder unit hydrograph transform scheme are as follows: Q2 = 277.9 m<sup>3</sup>/s, Q5 = 458.5 m<sup>3</sup>/s, Q10 = 585.9 m<sup>3</sup>/s, Q25 = 752.6 m<sup>3</sup>/s, and Q50 = 879.4 m<sup>3</sup>/s. Based on these results, the flood event that occurred on 30 August 2022, with an observed discharge of 478.55 m<sup>3</sup>/s, falls within the range between the 5-year and 10-year return period discharges (Q5–Q10).

For future research, it is recommended to use rainfall and discharge data with hourly resolution in order to more accurately capture peak discharge dynamics. In addition, calibration and verification should be performed using multiple flood events to enhance model reliability. Further research development may include sensitivity analysis of the Curve Number (CN) values due to land cover changes within the watershed and the corresponding changes in flood discharge, thereby representing hydrological conditions from previous years up to the present.

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#### AUTHOR CONTRIBUTION STATEMENT

| Author               | C | M | So                  | Va | Fo | I                             | R | D | O                         | E | Vi | Su | P | Fu |
|----------------------|---|---|---------------------|----|----|-------------------------------|---|---|---------------------------|---|----|----|---|----|
| EWS                  | ✓ |   | ✓                   |    |    |                               |   |   | ✓                         |   | ✓  |    | ✓ | ✓  |
| HK                   |   | ✓ |                     | ✓  |    |                               |   |   |                           | ✓ |    | ✓  |   |    |
| IPH                  |   |   |                     |    | ✓  |                               |   |   |                           |   |    |    |   |    |
| FS                   |   |   |                     |    |    | ✓                             |   |   |                           |   |    |    |   |    |
| HB                   |   |   |                     |    |    |                               | ✓ | ✓ |                           |   |    |    |   |    |
| C: Conceptualization |   |   | Fo: Formal Analysis |    |    | O: Writing - Original Draft   |   |   | Fu: Funding Acquisition   |   |    |    |   |    |
| M: Methodology       |   |   | I: Investigation    |    |    | E: Writing - Review & Editing |   |   | P: Project Administration |   |    |    |   |    |
| So: Software         |   |   | D: Data Curation    |    |    | Vi: Visualization             |   |   |                           |   |    |    |   |    |
| Va: Validation       |   |   | R: Resources        |    |    | Su: Supervision               |   |   |                           |   |    |    |   |    |

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