

# Analysis of Flood Discharge of Wae Mese Watershed, in Labuan Bajo, using the Snyder Hydrograph Synthetic and Soil Conservation Service Curve Number Unit Hydrograph

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**Abstract.** The Wae Mese River is one of the major rivers in the Labuan Bajo area, West Manggarai Regency, and plays an important role in supporting local community activities and the regional hydrological system. Historical flood records indicate that the region experienced extreme rainfall events on March 7, 2019, and December 31, 2021, which caused inundation in several villages within the Wae Mese Watershed (DAS) and resulted in significant material losses. These events highlight the need for a more accurate hydrological analysis better to understand the watershed's response to extreme rainfall and to support future flood mitigation efforts. This study aims to analyze flood discharge in the Wae Mese River using the Soil Conservation Service Curve Number (SCS-CN) method to estimate effective rainfall based on land-use, soil type, and hydrologic soil-group characteristics. The estimated effective rainfall was then transformed into a flood hydrograph using the SCS Unit Hydrograph approach, and the rainfall-runoff processes were simulated using the Hydrologic Engineering Center-Hydrologic Modeling System (HEC-HMS). The results indicate that flood discharge characteristics, including peak discharge, time to peak, and runoff volume, are strongly influenced by watershed physical conditions and rainfall intensity. The findings provide important insight into the hydrological response of the Wae Mese Watershed to extreme rainfall events and are expected to serve as a valuable reference for flood control planning, watershed management, and hydrometeorological disaster mitigation in the study area.

**Keywords:** Wae Mese Watershed, Flood, GPM, SCS-CN, mitigation.

## 1. Introduction

Flooding is one of the most frequent hydrological disasters occurring in many regions, particularly in watersheds characterized by complex topography, intense rainfall, and dynamic land-use changes [1]. Flood events occur when excessive surface runoff exceeds the capacity of natural river channels or man-made drainage systems, leading to the inundation of surrounding areas [2]. Such events pose significant hazards, including damage to infrastructure, disruption of socio-economic activities, loss of agricultural land, and increased risks to human safety and public health [3].

In recent decades, the frequency and magnitude of flood events have increased due to a combination of factors, such as land-use change, deforestation, urban expansion, and the intensification of extreme rainfall events associated with climate variability [4][5]. These changes alter watershed hydrological responses by reducing infiltration capacity, increasing surface runoff, and accelerating flow concentration, particularly in small to medium-sized watersheds with rapid response times.

This condition is also evident in the Wae Mese Watershed (DAS Wae Mese), located in West Manggarai Regency, Indonesia. The watershed plays a crucial role in supporting local communities, agricultural activities, and regional infrastructure, yet it is increasingly vulnerable to flooding due to geomorphological features and changing land-use patterns. In 2019, a major flood caused significant infrastructure damage, disrupted community activities, and led to substantial economic losses. Despite the severity of this event, hydrological studies in the Wae Mese Watershed remain limited, especially studies that quantitatively assess flood discharge generation under extreme rainfall conditions [4].

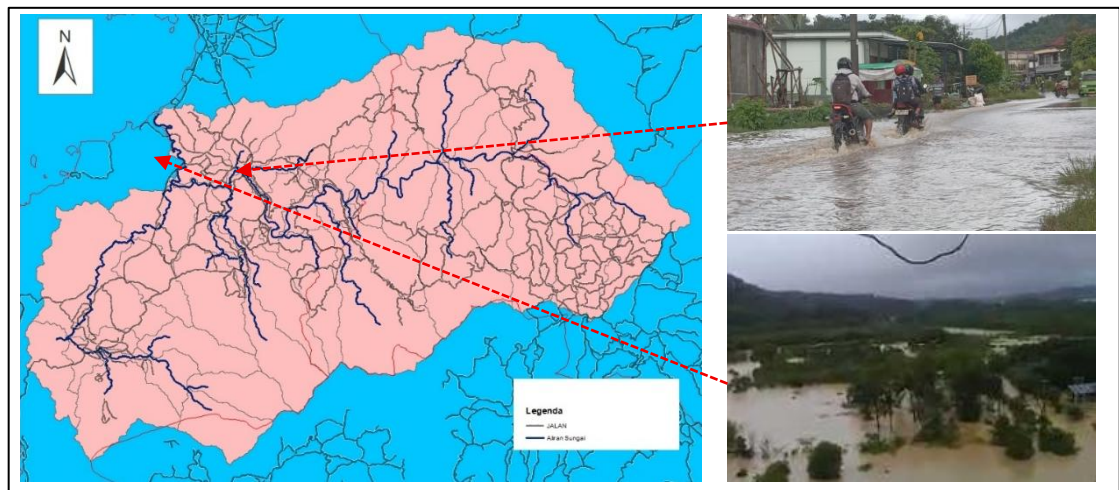
Reliable flood discharge estimation is essential for hydraulic structure design, flood risk mitigation, and sustainable water resources management. However, many watersheds in developing regions, including Wae Mese, are characterized by limited or incomplete discharge observation data. This data scarcity introduces significant uncertainty in flood analysis and often constrains the application of physically based hydrological models [6]. Consequently, there is a need for robust yet practical approaches that can effectively estimate flood discharge using limited available data.

One of the most widely applied methods in data-scarce watersheds is the Soil Conservation Service Curve Number (SCS-CN) method, which estimates effective rainfall based on land use, soil hydrologic groups, and antecedent moisture conditions. The effective rainfall is subsequently transformed into a flood hydrograph using the SCS Unit Hydrograph,

allowing flood discharge simulation with relatively simple input requirements [7]. While the SCS-CN method has been extensively applied worldwide, its performance is highly dependent on watershed characteristics and the quality of input data, particularly in tropical regions with high rainfall variability [8]

The scientific novelty of this study lies in the systematic application of the SCS-CN method to evaluate flood discharge in a data-scarce tropical watershed by integrating corrected satellite rainfall data [9] and detailed land-use information to represent spatial hydrological variability. Unlike many previous studies that apply the SCS-CN method in a purely deterministic manner, this study emphasizes a focused analysis of watershed response during an extreme flood event, highlighting the sensitivity of flood discharge to land-use characteristics and runoff parameters. Furthermore, the study provides a localized hydrological interpretation of flood generation mechanisms in the Wae Mese Watershed, which remains underrepresented in the existing literature.

By analyzing the 2019 flood event using this approach, the study contributes new insights into flood discharge estimation in ungauged or poorly gauged tropical watersheds. The findings are expected to support flood-control infrastructure planning, improve flood risk assessment, and provide a methodological reference for similar watersheds facing data limitations and increasing flood hazards.



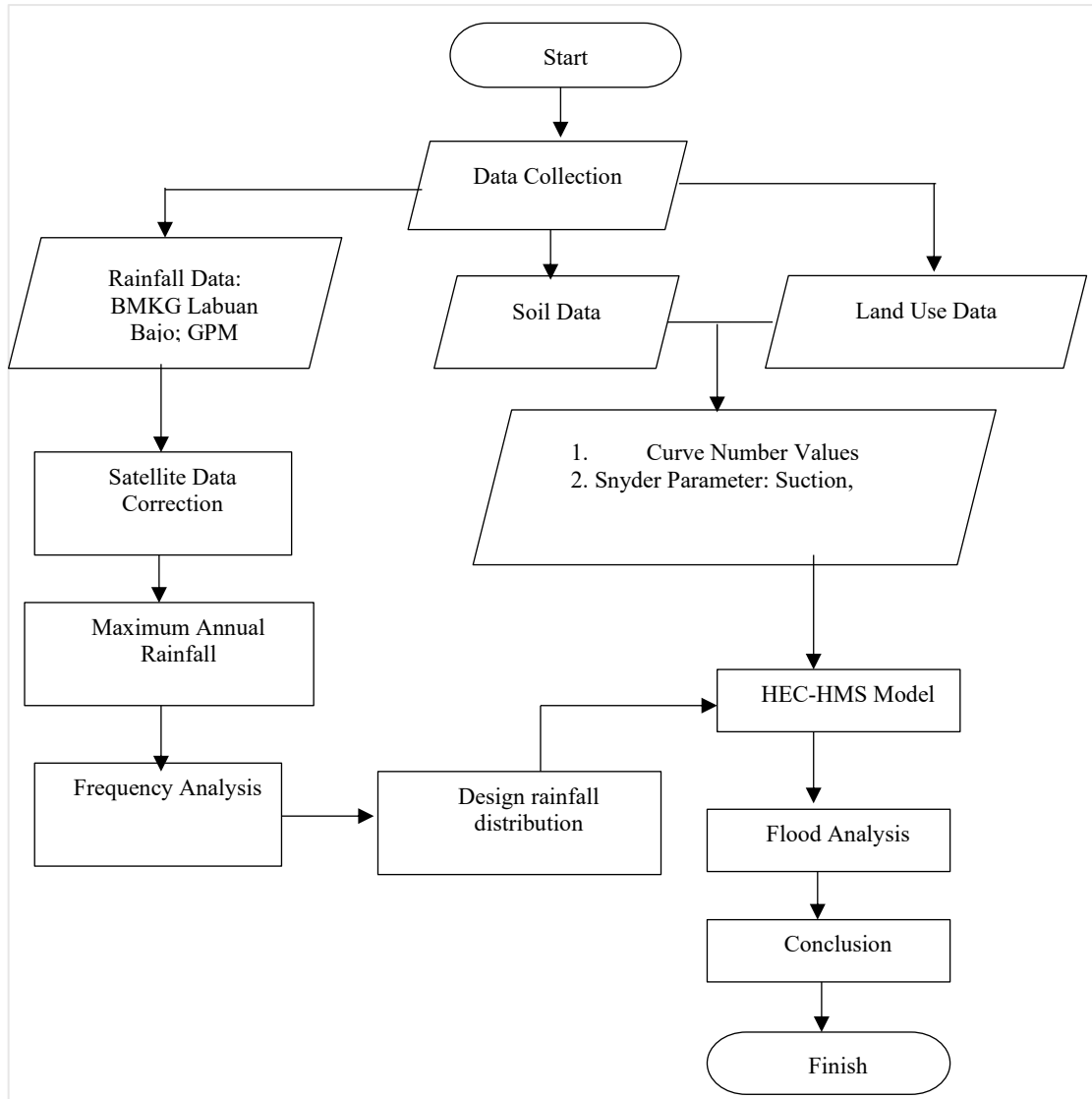
**Figure 1.** Wae Mese Watershed and 2019 flood events

## **2. Methods**

This study was conducted by collecting annual maximum rainfall data, topographic maps, land-use/land-cover (LULC) data, soil characteristics, and watershed morphometric parameters of the Wae Mese Watershed. Rainfall data were processed to develop an annual maximum rainfall series, which was then analyzed using several probability distribution models, including Gumbel, Log-Normal, and Log Pearson Type III distributions, to estimate design rainfall for various return periods [10]. The most appropriate distribution was selected based on goodness-of-fit tests, such as the Chi-Square and Kolmogorov–Smirnov tests. The selected design rainfall values were subsequently transformed into rainfall intensity using the Intensity–Duration–Frequency (IDF) curve corresponding to the watershed’s time of concentration.

Flood discharge analysis was carried out using a rainfall–runoff modeling approach implemented in the Hydrologic Engineering Center–Hydrologic Modeling System (HEC-HMS). The effective rainfall was estimated using the Soil Conservation Service Curve Number (SCS-CN) method, which accounts for the influence of land use, soil hydrologic group, and antecedent moisture conditions on runoff generation [11]. Curve Number (CN) values were assigned based on the interpretation of LULC maps and soil data within the watershed [12]. The estimated effective rainfall was then transformed into a flood hydrograph using the SCS Unit Hydrograph method within the HEC-HMS framework. The resulting hydrograph provides key flood characteristics, including peak discharge, time to peak, and runoff volume, which are used to evaluate the watershed’s flood response and potential flood occurrence under different rainfall scenarios [13].

Due to the absence of observed river discharge measurements at the study location, model calibration and validation against measured flow data could not be performed. Instead, parameter adjustment was limited to the assignment of Curve Number values based on established references and standard guidelines corresponding to the existing land-use/land-cover conditions in the Wae Mese Watershed. This approach is commonly adopted in ungauged or poorly gauged watersheds and allows for a reasonable estimation of flood discharge under data-scarce conditions, while acknowledging inherent uncertainties [14]. For clarity, the overall research procedure is summarized in a flowchart, as illustrated in Figure 2, which outlines the main stages of data collection, rainfall analysis, runoff estimation, hydrological modeling using HEC-HMS, and flood hydrograph analysis.



**Figure 2.** Research Procedure

## 2.1 Data Analysis

### 2.2 Rainfall Frequency Analysis

Rainfall frequency analysis is a crucial step in hydrology to estimate the probability of occurrence of extreme rainfall events and to support flood risk assessment. This analysis uses statistical probability distributions to describe the variability and recurrence of rainfall over time. In these case, the rainfall frequency analysis

1. The Gumbel distribution, also known as the Extreme Value Type I distribution, is widely used to model annual maximum rainfall or flood events. Its cumulative distribution function (CDF) is expressed as:

$$F(x) = \exp \left[ -\exp \left( \frac{x - \mu}{\beta} \right) \right]$$

Where  $x$  is rainfall amount,  $\mu$  is the location parameter, and  $\beta$  is the scale parameter. This distribution is suitable for extreme values because it emphasizes the tail of the distribution, representing rare, high-magnitude rainfall events. The return period  $T$  (years) is calculated using:

$$T = \frac{1}{1 - F(x)}$$

2. Normal Distribution

The Normal (Gaussian) distribution is often used for long-term average rainfall or moderately extreme events. Its probability density function (PDF) is defined as:

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} \exp \left[ -\frac{(x - \mu)^2}{2\sigma^2} \right]$$

where  $\mu$  is the mean and  $\sigma$  is the standard deviation. Although commonly used, the Normal distribution may underestimate extreme rainfall due to its symmetry, which does not reflect the skewness typical in hydrological data.

3. The Log-Pearson Type III (LP-III) distribution is one of the most widely used methods for flood and rainfall frequency analysis, particularly in the United States. In this method, the logarithms of rainfall data are assumed to follow a Pearson Type III distribution. The frequency factor  $K$  is determined based on the skewness coefficient ( $G$ ) of the log-transformed data. The log Pearson II equation is:

$$\log x_T = \bar{x} + K \times S_x$$

where:

$\log x_T$  : logarithm of rainfall for return period  $T$

$\bar{x}$  : mean of log-transformed rainfall

- $sx$  : standard deviation of log-transformed rainfall
- $k$  : frequency factor dependent on T and skewness G

This distribution is effective for skewed hydrological data and is commonly recommended in flood frequency guidelines.

4. In the Log-Normal distribution, rainfall values are assumed to follow a Normal distribution after logarithmic transformation. The probability density function for the log-transformed variable

### 2.3 SCS Curve Number (SCS-CN) Method

The SCS Curve Number method, developed by the U.S. Soil Conservation Service (now the Natural Resources Conservation Service, NRCS), is widely used to estimate direct runoff from rainfall events [15]. This method applies a rainfall–runoff relationship based on land use, soil type, hydrologic soil group, and antecedent moisture condition. The Curve Number (CN) value represents the runoff potential of a watershed, where higher CN values indicate lower infiltration capacity and greater surface runoff potential. Once the effective rainfall is determined, it can be transformed into a flood hydrograph using the SCS dimensionless unit hydrograph, which provides a standardized hydrograph shape that can be scaled according to watershed characteristics. The SCS-CN method is widely applied due to its simplicity, adaptability, and the availability of standardized CN tables for various land-use and soil conditions [15] [16].

HEC-HMS was selected because it allows the integration of rainfall data, watershed characteristics, and runoff transformation methods within a single modeling framework. Within the HEC-HMS environment, the SCS Curve Number method was implemented as the loss model to estimate rainfall losses, while the SCS Unit Hydrograph was used as the transform method to generate direct runoff hydrographs. Key watershed parameters, including Curve Number (CN), initial abstraction, basin area, and lag time, were defined based on land-use maps, soil data, and watershed morphometric characteristics.

1. Potential maximum soil moisture retention after runoff begins is calculated as:

$$S = 25400 / CN - 254$$

where:

- S : potential maximum retention (mm)
- CN : Curve Number (dimensionless)

2. Initial Abstraction (Ia)

Initial abstraction accounts for losses such as interception, infiltration, and surface storage before runoff begins. It is commonly assumed as:

$$I_a = 0,2S$$

### 3. Direct Runoff (Q)

The direct runoff depth is calculated using the following equations

$$Q = \frac{(P - 0,2S)^2}{P + 0,8S}$$

where:

Q : direct rainfall depth (mm)

P : total rainfall depth (mm)

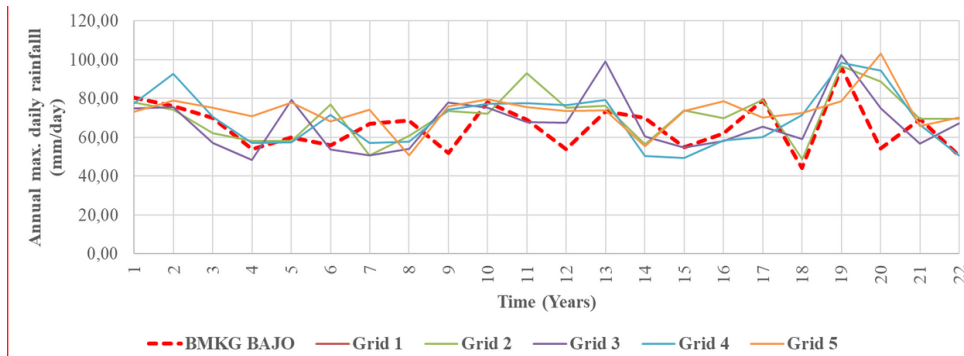
## 3 Analysis and Result

### 3.1 Rainfall Frequency

Rainfall frequency analysis was carried out using annual maximum rainfall data obtained from BMKG Labuan Bajo rain gauge observations and Global Precipitation Measurement (GPM) satellite data for the period 2001–2025. The use of both ground-based and satellite-derived rainfall data was intended to improve data reliability and spatial coverage, particularly in areas with limited rain gauge availability.

Prior to analysis, both rainfall datasets were compiled and subjected to consistency and quality control checks. To evaluate the reliability of the GPM satellite rainfall data, a satellite rainfall performance assessment was conducted by comparing satellite-derived rainfall with observed rain gauge data. Statistical indicators such as correlation coefficient, bias, and error magnitude were used to assess the agreement between satellite and ground-based rainfall records. Based on this evaluation, the satellite rainfall data were corrected using an appropriate adjustment factor to reduce systematic bias and improve its representativeness for local rainfall conditions.

After the data evaluation and correction process, the annual maximum rainfall series was derived from the adjusted rainfall data and used as the basis for rainfall frequency analysis. Design rainfall values for selected return periods were then estimated from the annual maximum series. The results of the rainfall frequency analysis are presented graphically, as shown in Figure 3, and subsequently used as input for hydrological modeling and flood discharge estimation in the study area.



**Figure 3.** Annual maximum rainfall data (years)

Based on the rainfall data presented in the table above, rainfall frequency analysis was conducted using several probability distributions, including the Gumbel, Normal, Log-Normal, and Log-Pearson Type III distributions. The suitability of each distribution was evaluated using goodness-of-fit tests, namely the Chi-Square test and the Kolmogorov–Smirnov (D) test.

The results of the goodness-of-fit analysis indicate that the Log-Pearson Type III distribution produced the smallest error values in both the Chi-Square and Kolmogorov–Smirnov tests. Therefore, the Log-Pearson Type III distribution was selected as the most appropriate distribution for estimating design rainfall at the study location and was subsequently used in the design rainfall analysis.

Table 1. Return Period Analysis

Return Period (years)	Grid 1	Grid 2	Grid 3	Grid 4	Grid 5	Area Rainfall (mm)
2	70,2	71,2	61,6	65,2	67,5	67,7
5	78,6	79,8	71,1	71,9	77,3	75,8
10	89,2	89,3	84	81,5	86,8	86
25	101,9	99,3	102,2	93,4	97,2	98,1

### 3.2 Duration and Distribution Rainfall Design

Duration analysis was carried out by collecting data on temporal extreme rainfall events derived from rainfall records. Based on the data examination, two types of consecutive rainfall events were identified, with durations of 9 hours and 12 hours. For the 9-hour rainfall events, two events were recorded with rainfall depths exceeding 90 mm. Meanwhile, for the 12-hour rainfall events, there were 11 events with total rainfall depths greater than 85 mm. Based on these events, a suitable rainfall distribution for the Wae Mese Watershed will be determined. The temporal rainfall event curve from GPM data is presented in Figure 4 below.

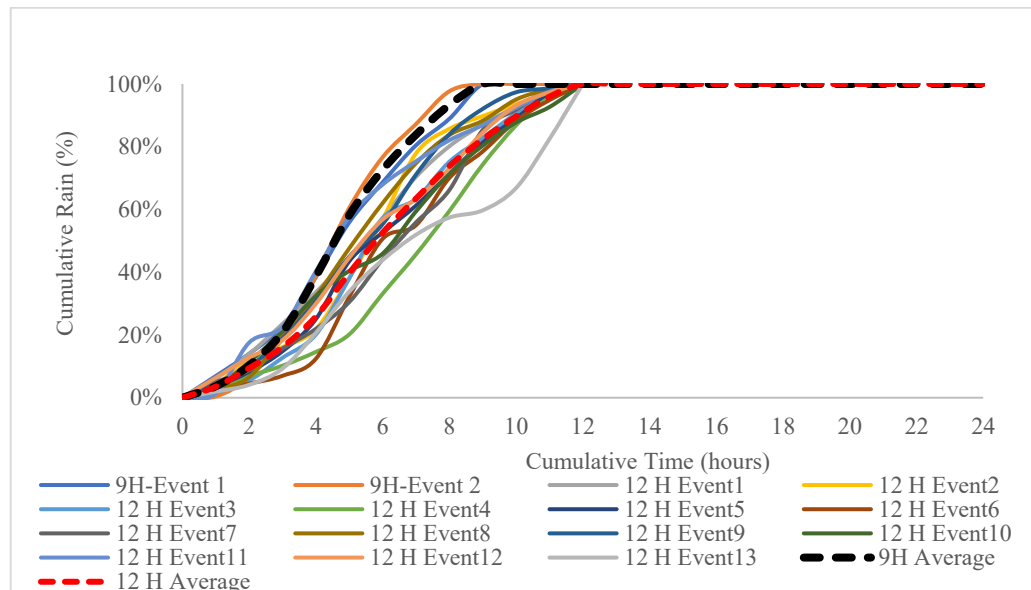
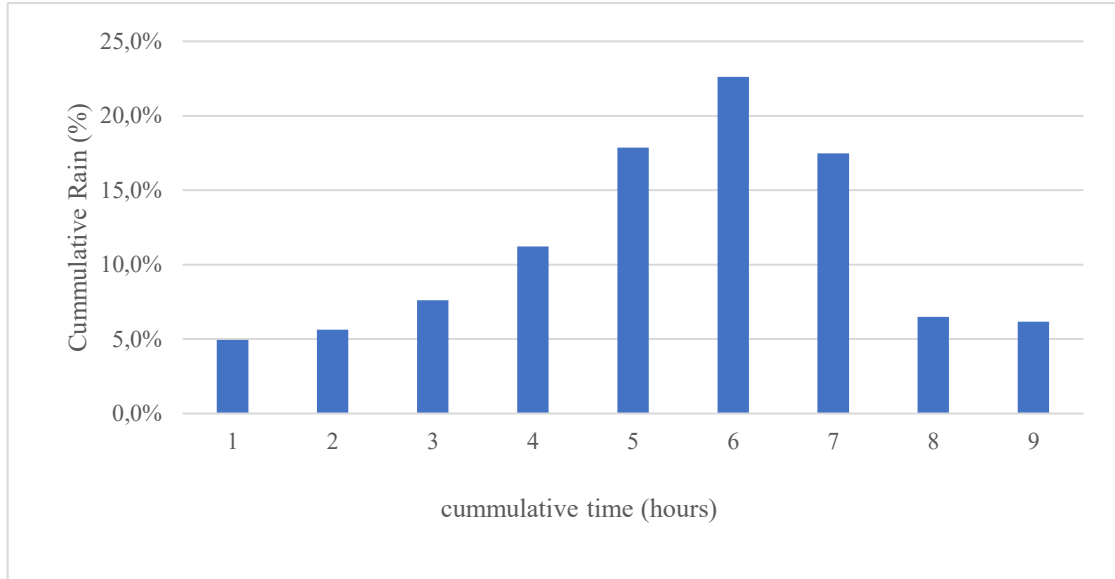
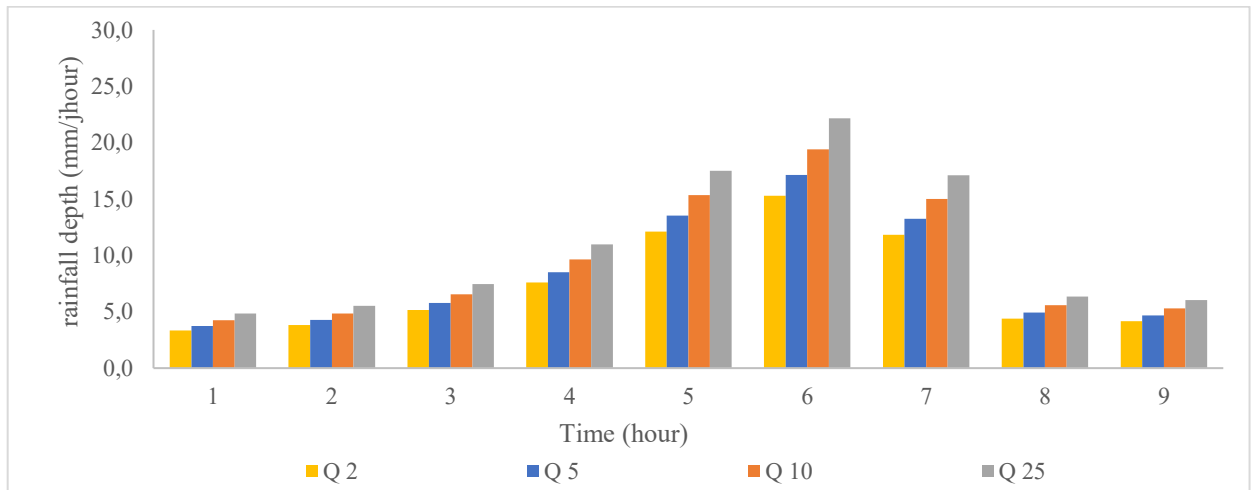


Figure 4. Temporal extreme rainfall events

Based on the rainfall duration curve, the temporal rainfall distribution in the Wae Mese Watershed was determined using hourly rainfall percentages derived from the previously analyzed design rainfall. The analysis indicates that extreme rainfall events predominantly occur with durations of 9 and 12 hours. The 9-hour distribution shows a higher peak rainfall (22.6%) compared to the 12-hour distribution (13%). Therefore, to represent extreme rainfall conditions in flood modeling, a 9-hour rainfall duration was selected. The rainfall intensity graphs are presented in Figures 5 and 6.



**Figure 5.** Temporal extreme rainfall distribution percentage

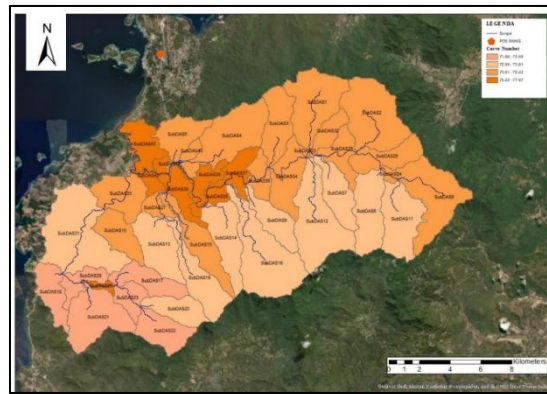


**Figure 6.** Rainfall distribution in Wae Mese Watershed

### 3.3 Hydrograph Analysis

The SCS Unit Hydrograph method was applied by incorporating watershed characteristics such as land use, soil type, and hydrologic soil group, which were represented through the

Curve Number (CN) value. Effective rainfall was estimated using the SCS-CN approach and subsequently transformed into a flood hydrograph based on the watershed time of concentration. The hydrological analysis and runoff simulation were conducted using the Hydrologic Engineering Center–Hydrologic Modeling System (HEC-HMS), which provides an integrated framework for rainfall–runoff modeling. Within the HEC-HMS environment, the SCS Curve Number method was employed as the loss model, the SCS Unit Hydrograph was used as the transform method, and appropriate basin parameters, including lag time, initial abstraction, and basin area, were defined based on watershed characteristics. The SCS Unit Hydrograph method was used by incorporating watershed characteristics such as land use, soil type, and hydrologic soil group, which were represented through the Curve Number (CN) value.



**Figure 7.** Wae Mese Sub Basins

Table 2. Curve Number Values

Land Use/Land Cover (LULC)	Soil Type	
	C	D
Forest/Woodland	73	74
Open Land	79	81
Grassland	71	74
Residential/Built-up Area	74	77
River and Wetland	100	100
Irrigation	73	78

Flood discharge modeling in the Wae Mese Watershed, Labuan Bajo, was conducted using the HEC-HMS hydrological modeling system, based on hydrological parameters derived from two rainfall–runoff events that had been previously analyzed. Using the available rainfall intensity data, the modeling covered various flood discharge return periods. Flood

discharge modeling for different return periods was carried out by considering the average characteristics of specific flood events, based on rainfall intensity or runoff volume. In this study, flood discharges corresponding to return periods ranging from 2 to 25 years were applied. The resulting flood discharge values represent the flood behavior of the Wae Mese Watershed and provide important input for flood mitigation and hydraulic structure planning.

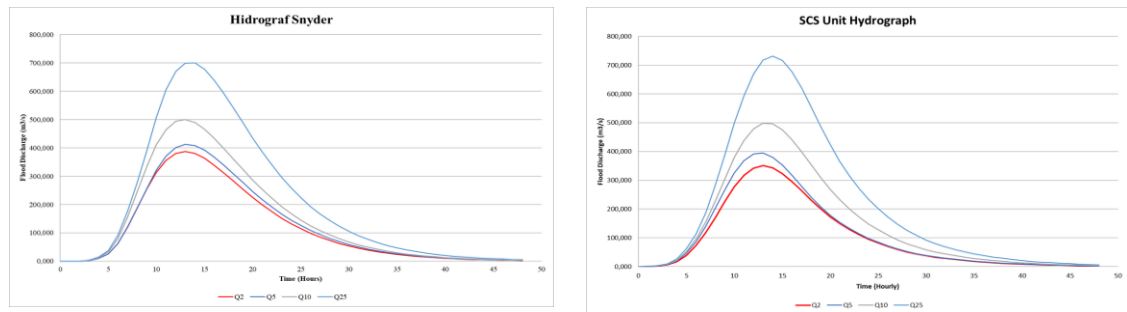


Figure 8. Comparison of scs-cn and snyder flood discharge ( $m^3/s$ )

### 3.4 Conclusion

Based on the flood hydrograph analysis of the Wae Mese Watershed using the Soil Conservation Service (SCS) methods, it can be concluded that the hydrological response of the watershed is characterized by increasing peak discharge with higher rainfall return periods. This finding confirms the direct relationship between extreme rainfall intensity and runoff generation within the watershed.

The flood hydrographs generated using the SCS Curve Number (SCS-CN) approaches indicate that land use, soil characteristics, and infiltration capacity play a significant role in controlling runoff processes. The results show that higher return periods produce greater peak discharges and larger runoff volumes, reflecting the watershed's sensitivity to extreme rainfall events.

Overall, the Wae Mese Watershed exhibits a moderate to high runoff potential during extreme rainfall conditions. The SCS-based approach provides reliable results and can be effectively applied as a basis for flood discharge estimation, watershed management planning, and flood mitigation strategies in the study area.

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