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Comparative Analysis of Observed and Empirical Rainfall Distribution for Flood Hydrograph Modeling

Risdiana Cholifatul Afifah[1,2*], Sri Sangkawati, Suripin, Dyah Ari Wulandari

[1]Faculty of Engineering, Universitas Diponegoro Semarang, Jl. Prof. Soedarto No.13, Tembalang, Semarang City, Central Java 50275, Indonesia

[2]Facutly of Engineering, Universitas PGRI Semarang, Jl. Sidodadi Timur No.24, Karangtempel, Semarang City, Central Java 50232, Indonesia

*risdiana.afifah@gmail.com

Abstract. Flood disasters in Indonesia are persistent challenges during the rainy season, primarily due to intense rainfall and inadequate flood control. This study evaluates hourly rainfall to characterize hydrology and predict flood discharge more accurately, benefiting water infrastructure planning. The research used modified Mononobe methods, observational data, and rainfall-runoff modeling, including HEC-HMS simulations with the SCS-CN unit hydrograph. Observed rainfall simulated a flood discharge of 779.7 m^3/s, while empirical rainfall yielded 3623 m^3/s, showing a 79.12% deviation. Comparing flood hydrographs, recorded rainfall data closely matched previous studies ($R^2 = 0.94$), unlike empirical rainfall ($R^2 = 0.88$). The study concludes that observed rainfall is highly effective for estimating flood runoff, accurately representing local characteristics. This method significantly aids planning and design of water resource infrastructure like dams, weirs, and bridges at the study site.

Keywords: Empirical Rainfall, Flood Modeling, HEC-HMS, Observed Rainfall, SCS-CN, Rainfall-Runoff.

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1. Introduction

Indonesia frequently experiences disasters, which can be categorized into two main types: geological and hydrometeorological. The hydrometeorological flood disasters in Indonesia are significantly influenced by meteorological factors, particularly rainfall intensity. Additionally, hydrological aspects come into play, determined by the capacity of river systems—including their inlets and outlets—to accommodate runoff, as well as factors such as land cover, soil moisture, and the availability of underground water [1]. To effectively address flooding, it is essential to construct water resource infrastructure as part of the physical efforts in flood disaster mitigation. The planning and construction of this infrastructure must involve careful calculations of design flood discharge, which rely on rainfall data tailored to the specific characteristics of the area under review [2,3]. Taliwang District City, located in West Sumbawa Regency, West Nusa Tenggara Province, is classified as a dry region, often facing a water deficit of more than six months [4]. However, it experiences annual flooding during periods of extreme rainfall. This flooding is primarily due to the accumulation of water flow from upstream areas. Taliwang City sits at the downstream position of the Brang Rea Basin, where the upstream topography is hilly and tends to funnel towards the valley below, particularly in Taliwang District City. This terrain causes high discharge levels from upstream, inundating the majority of the urban areas within the city. This scenario presents a compelling opportunity for studying flood discharge in alignment with the real conditions of the region.

In hydrology and related fields, the discharge value due to a particular extreme rainfall event can indeed be obtained from various combinations of rainfall duration and rainfall recurrence period. This concept is important to understand the possibility and magnitude of extreme events such as floods [5]. Identification of flood discharge that is in accordance with real conditions can be traced by the rainfall runoff model analysis method. The distribution of rainfall distribution at each hour affects the shape and time of the flood hydrograph, so that a good distribution of rainfall time that is in accordance with the characteristics of the area will have a significant impact on the flood hydrograph [3,4]. This method should be supported by good rainfall observation data and stored in a sufficiently long data series to obtain more accurate calculation results [8] .

Ideally, rainfall distribution should be determined through field observations using automatic rain gauges. In regions where automatic rainfall records are unavailable, several theoretical rainfall distribution models have been proposed to approximate actual distributions [9] . However, sub-daily rainfall records remain limited in many areas and often consist of short time series series [10] . In practice, particularly in Indonesia, rainfall distribution patterns from other regions are sometimes adopted, which may result in simulated hydrographs that deviate from actual conditions. Therefore, it is necessary to develop a site-specific rainfall time distribution pattern for the study area (2) .

The main issue to date is that the calculation of flood runoff flowing into Taliwang City has relied on an empirical rainfall distribution approach, in which daily rainfall data are disaggregated into hourly rainfall using the Mononobe method, as applied in the Bintang Bano Dam and Tiu Suntuk Dam projects [12] . This empirical method assumes a fixed rainfall duration of 24 hours due to the lack of sub-daily rainfall records [13] . However, in reality, rainfall events in Taliwang City do not consistently span 24 hours, as indicated by hourly rainfall data recorded by the Automatic Rainfall Recorder (ARR) in Taliwang. Variations in rainfall distribution directly affect the resulting flow rate and peak discharge [14] . This is reinforced by the statement [12,13]that there is a large deviation caused by the comparison of flood discharge with empirical rainfall input and observations in the Java Island region (western Indonesia). Therefore, this study aims to develop an hourly rainfall distribution pattern based on direct observations from the ARR Taliwang to improve the accuracy of flood runoff estimations for eastern Indonesia, particularly for Taliwang City.

Based on these considerations, the primary objective of this study is to evaluate whether the rainfall distribution pattern derived from the empirical method can adequately represent the actual design flood discharge in the study area when compared to the distribution pattern obtained from observed rainfall data. The Mononobe method generates an hourly rainfall distribution by disaggregating return period rainfall values through analytical procedures [3] , whereas the recorded (measured) rainfall method determines the rainfall duration directly from field observations. The hypothesis of this study posits that the rainfall distribution based on direct observations will provide a more accurate estimation of flood discharge

2. **Methods**

Administratively, Taliwang District is one of the small cities located in West Sumbawa Regency, West Nusa Tenggara Province. Taliwang City is hydrologically located downstream of the Brang Rea Basin which is annually affected by flooding from the upstream which tends to have many tributaries that contribute to discharge overflow, especially when there is extreme rain. In the Brang Rea Basin there are 2 (two) newly operating dams, namely the Bintang Bano Dam which has been operating since 2021, and the Tiu Suntuk Dam which will operate at the end of 2023. Both of these dams function as flood discharge reducers from the upstream area of the Brang Rea River. Several tributaries of the Brang Rea River downstream of the two dams are quite dominant with a total *catchment area* of 59% of *the overall* Brang Rea River water management system. Meanwhile, the percentage of the Bintang Bano Dam *catchment area* is only 24%, and the percentage of the Tiu Suntuk Dam *catchment area* is 17% [17] . Based on these conditions, the study location is depicted in Figure 1.

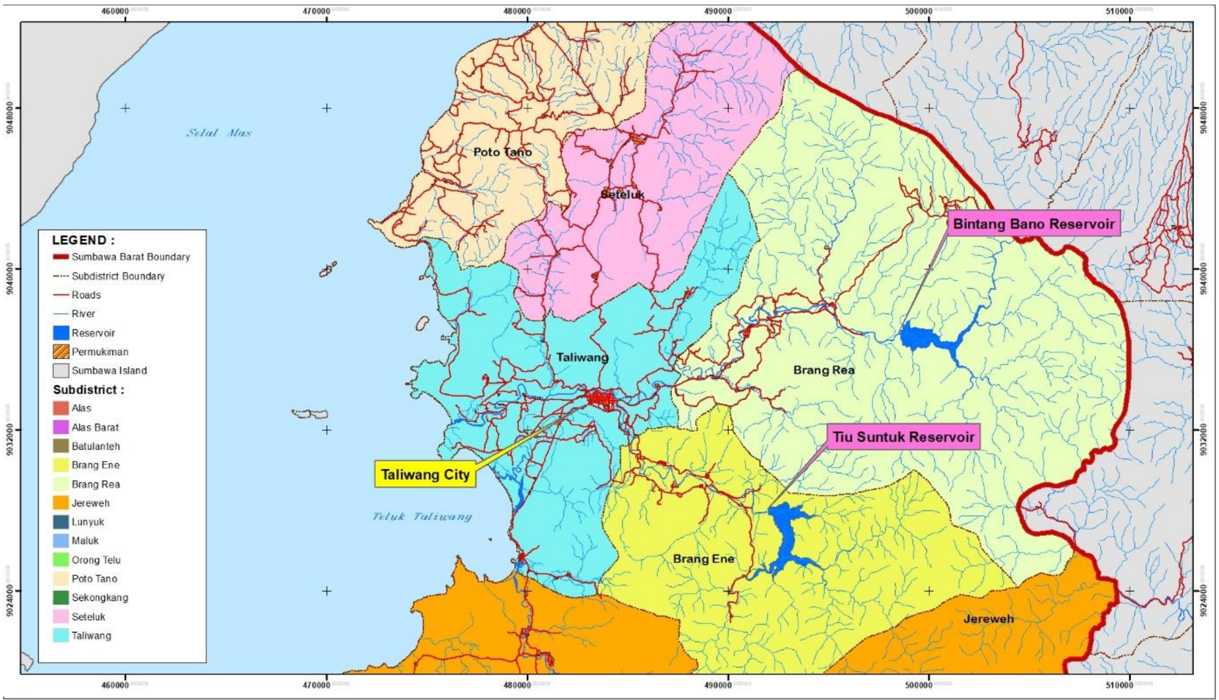

Figure 1. Administrative Location of Taliwang City.

2.1. Research Method

The research methodology is presented in a flowchart to visually describe the analysis procedures in a more systematic manner. All data utilized in this study are secondary data. The hydrological data comprise daily rainfall data and hourly rainfall data. The spatial data include land use, soil type, basin characteristics, Digital Elevation Model (DEM), and reservoir operation data. Flood discharge simulations are conducted twice, each using daily and hourly rainfall input data, respectively. The HEC-HMS modeling software is employed as a tool to support the flood discharge simulations. The resulting flood hydrographs are then compared with the hydrographs obtained from previous studies to validate any potential discrepancies in flood discharge generated by the two types of rainfall data. The research flowchart is shown in Figure 2.

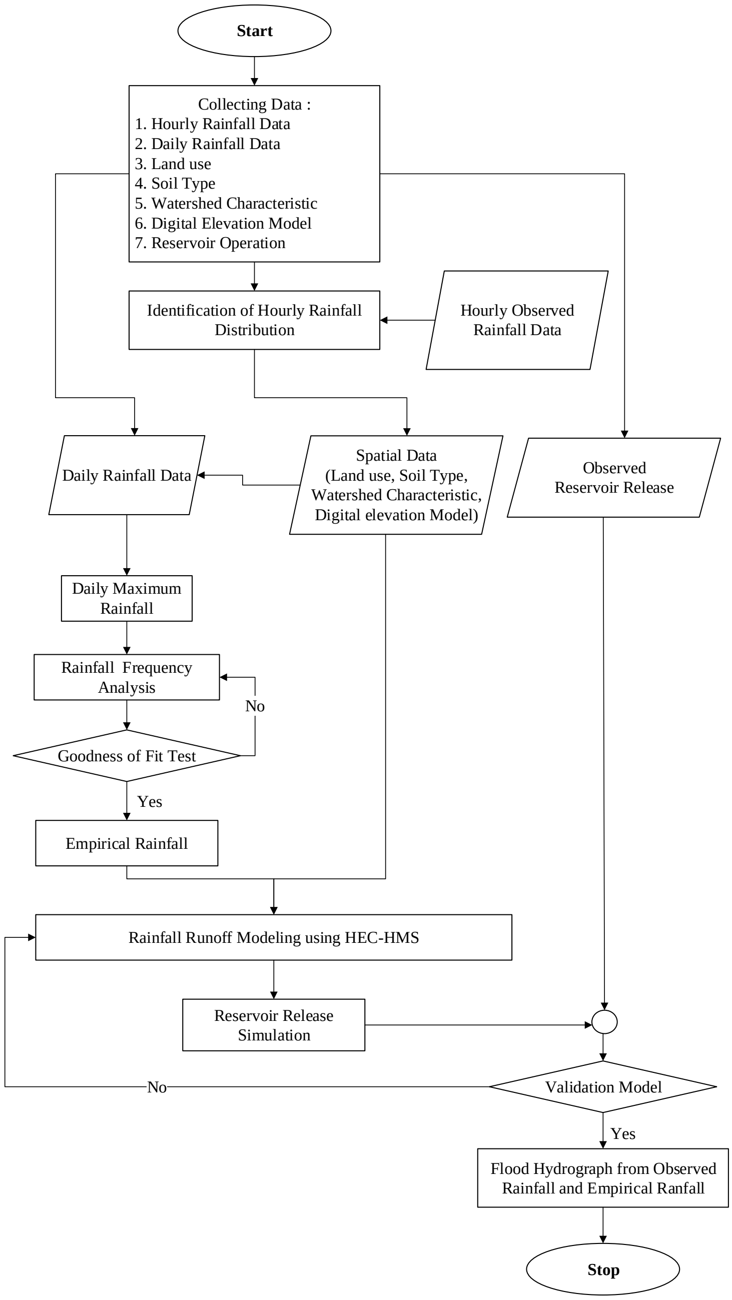

Figure 2. Research Flowchart.

2.2. Rainfall Data

Important basic data used in this study are daily rainfall and hourly rainfall. Maximum daily rainfall is an important input for analyzing design rainfall based on return period. Maximum daily rainfall is obtained from rainfall observations at Taliwang Rain Post, Seteluk Rain Post, Jereweh Rain Post, and Utan Rhea Rain Post. Where Brang Rea Basin is influenced by rainfall from each of these rainfall posts by 6.23% from Utan Rhea Rain Post, 51.92% from Seteluk Rain Post, 34.57% from Taliwang Rain Post, and 7.28% from Taliwang Rain Post. The percentage, which can also be called the Thiessen coefficient, is generated based on analysis using the Thiessen method. The percentage of rainfall influence is as presented in Figure 3.

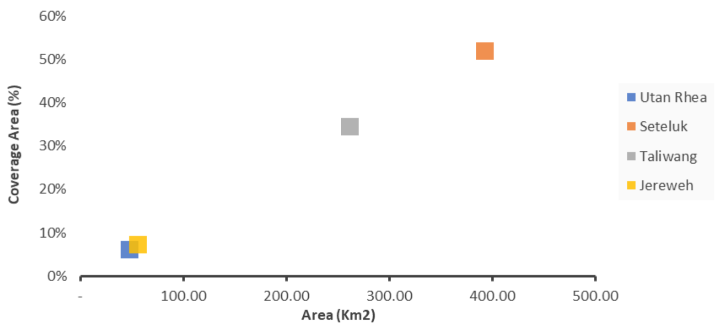

Figure 3. The Effect of Rain on Each Daily Rain Recording Post.

Considering the influence of rainfall from each rain gauge, the maximum daily rainfall data are transformed into areal rainfall by multiplying by the respective Thiessen polygon coefficients to determine the areal rainfall values, as shown in Table 1. Table 1 shows that the maximum daily rainfall at the study site tends to be relatively low, ranging from 35 mm to 108 mm. This is consistent with the typical rainfall conditions in eastern Indonesia, which generally receive lower rainfall compared to the western regions of the country.

Table 1. Maximum Daily Rainfall in the Brang Rea Basin Area

Year	Maximum Daily Rainfall in Brang Rea Basin Area (mm)
2010	90.00
2011	42.00
2012	42.00
2013	45.00
2014	35.00
2015	108.00
2016	95.00
2017	37.20
2018	38.12
2019	64.73
2020	47.20

Design rainfall is obtained from rainfall areas analyzed for rainfall frequency with several types of Normal, Log Normal, Gumbel, and Log Pearson III distributions. The AProb model is used as a tool to generate design rainfall [18] . The range of rainfall data series over a period of 11 (eleven) years with a confidence level of 90%, obtained a data average of 58.8, and a standard deviation of rainfall data of 26.6. The results obtained are that the selected distribution is Log Pearson III, with a maximum data difference of 0.165, which is smaller than other distribution distributions. As seen in Figure 4, the Log Pearson III Probability graph is displayed.

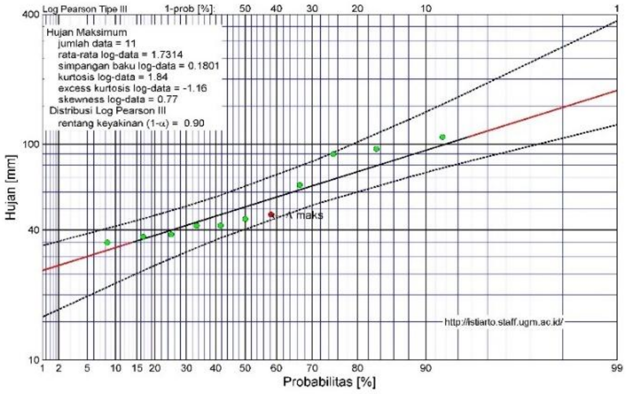

Figure 4. Frequency Distribution Statistics of Rain.

In this study, the analysis is limited to a 25-year rainfall recurrence period in accordance with the provisions of the authorized agency for the Brang Rea River, namely BBWS Nusa Tenggara 1. From the analysis using Aprob, it is known that at a 25-year return period, the design rainfall in each Basin is shown in Table 2. Where the design rainfall in the Bintang Bano Reservoir Basin is 118 m, in the Tiu Suntuk Reservoir Basin 92 mm, in the Brang Klongkeng Basin 109 mm, in the Brang Seloto Basin 103 mm, in the Brang Beru Basin 111 mm, and in the Brang Ene Basin 56 mm. This design rainfall will be input into the rainfall runoff model with the help of the HEC-HMS program, which will be analyzed in 2 conditions, namely with recorded hourly rainfall and empirically using the Modified Mononobe approach.

Table 2. Design Rainfall of Brang Rea Basin

Basin	Design Rainfall (mm)
Bintang Bano Reservoir	118.0
Tiu Suntuk Reservoir	92.0
Brang Klongkeng	109.0
Brang Seloto	103.0
Brang Beru	111.0
Brang Ene	56.0

Empirical methods often used to estimate hourly rainfall distribution. This method functions to convert daily rainfall data into hourly rainfall distribution. The Modified Mononobe method is based on an empirical equation that relates rainfall intensity to a certain duration and return period. [3] compared the measured rainfall distribution pattern with empirical methods, including Modified Mononobe, in calculating the design flood discharge which showed that the Modified Mononobe method has good agreement with measured rainfall data, making it a reliable tool in hydrological analysis when hourly rainfall data is not available. However, it is important to note that the effectiveness of the Modified Mononobe method can vary depending on the characteristics of rainfall in a particular area.

According to [19] , the Modified Mononobe method is only suitable for 2-hour and 6-hour rainfall tested in the Alang Sub-DAS. Meanwhile, according to [20] in [19] , the Modified Mononobe method can be used for rainfall durations of more than 2 hours. The difference between Mononobe and Modified Mononobe lies in the constant, where Modified Mononobe uses the constant m = 0.83 to obtain more accurate design flood discharge results. The following is equation (1) to obtain hourly rainfall with the Modified Mononobe approach.

$$I_T^t = \frac{R_{T.24}}{t_c}\left(\frac{t_c}{t}\right)^m \tag{1}$$

Where I_T^t is the intensity of rain with duration t; $R_{T.24}$ is the daily rainfall intensity at return period T; t is the duration of rain; t_c is the concentration time; and m for the mononobe constant.

Figure 4 shows the hourly rainfall intensity at a 25-year return period with an empirical rainfall pattern. where in the Bintang Bano Reservoir Basin the highest rainfall intensity is 104.9 mm and the lowest is 7.5 mm. in the Tiu Suntuk Reservoir Basin, the highest rainfall intensity is 81.8 mm, and the lowest is 5.8 mm. in the Brang Klongkeng Basin, the highest rainfall intensity is 96.9 mm and the lowest is 6.9 mm. Brang Seloto Basin with the highest rainfall intensity of 91.6 mm and the lowest at 6.5 mm. in the Brang Beru Basin with the highest rainfall intensity of 98.7 mm and the lowest is 7.1 mm. while in the Brang Ene Basin, the highest intensity is 49.8 mm and the lowest is 3.6. by looking at these results, the highest rainfall intensity is in the Bintang Bano Reservoir Basin and the lowest rainfall intensity is in the Brang Ene Basin with a high rainfall pattern in the first hour and decreasing sharply between the 2nd and 5th hours, then the decrease in rainfall depth becomes more gradual until the 24th hour.

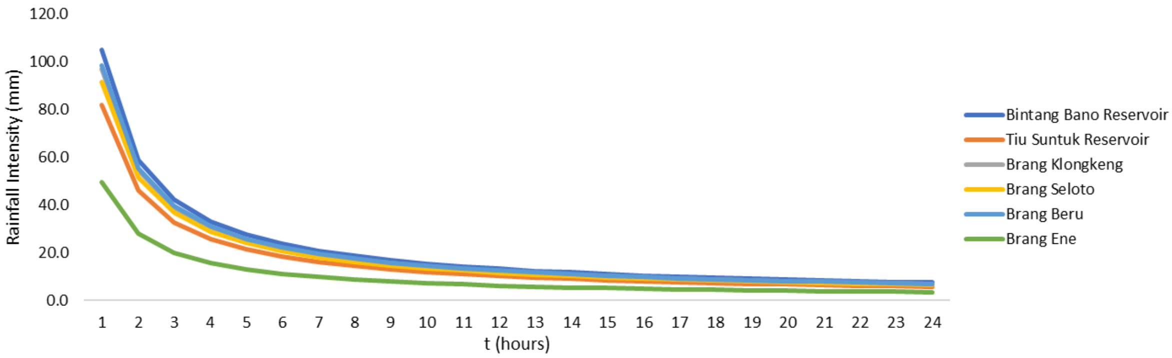

Figure 5. Frequency Distribution Statistics of Rain.

The recording of hourly rainfall is essential for flood analysis and simulation, as high-resolution temporal data enhance the accuracy of hydrological models and improve the reliability of flood predictions. For this study, hourly rainfall data covering the period from 2021 to 2023 were sourced from the Taliwang Automatic Rainfall Recorder, operated by Balai Daerah Sungai Nusa Tenggara 1.

Figure 5 shows the quantity of all rain events. From the analysis of rainfall data showed that during the 3 years of recording, there were 143 instances of two-hour rain events, 66 for three hours, 21 for four hours, 7 for five hours, 2 for six hours, 4 for seven hours, 1 for eleven hours, and 1 for thirteen hours. According to these data, the distribution of hourly rainfall varied greatly, but the two-hour period had the most rain incidents. The average rainfall depth (at the two-hour period) at the study site tended to be small, namely 5 mm for the first hour, and 3 mm for the second hour. With the maximum rainfall being 89.5 mm and the smallest being 0.5 mm.

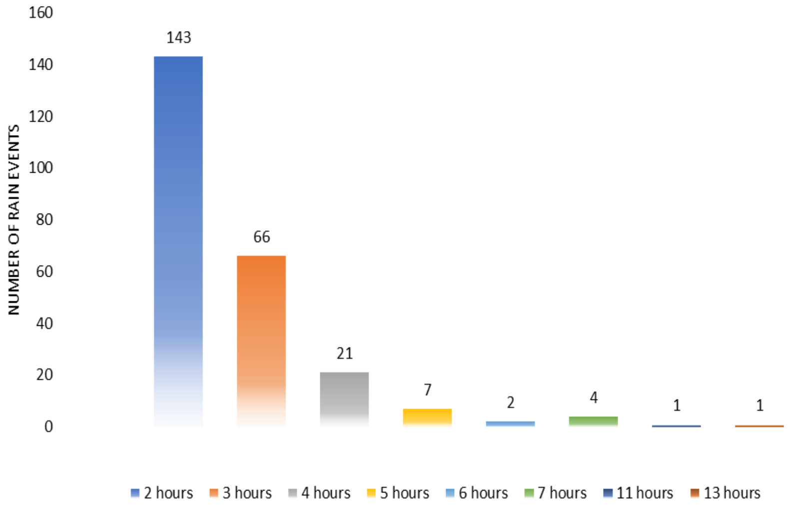

Figure 6. The Quantity of Hourly Rain Events.

The determined rainfall depth (the two-hour period) is converted to a percentage (%) in accordance with [49]. With a rainfall distribution percentage of 65% in the first hour and 35% in the second, it was found that the research area receives the most rainfall during the first two hours. This percentage is later used as the basis for the rainfall runoff analysis based on recorded rainfall. Figure 7 displays all the percentage distributions of rainfall in each rain incident.

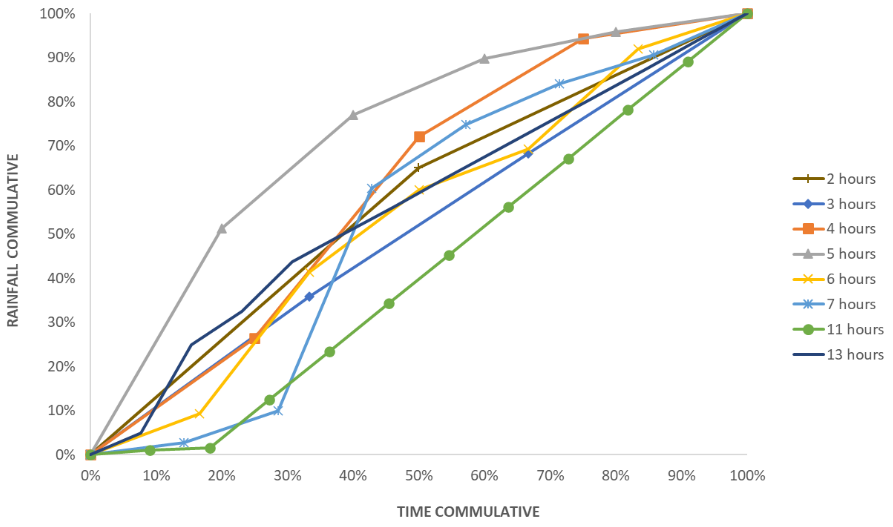

Figure 7. Hourly Rain Events Percentage

The percentage of rainfall distribution in the Taliwang ARR is then used to divide the 25-year design rainfall to obtain the hourly rainfall intensity, which is 2 hours in all Basins as input in the rainfall runoff simulation. Table 3 shows the magnitude of rainfall intensity at a 25-year return period based on the recorded rainfall pattern. The rainfall intensity in the first hour indicates greater rainfall than the rainfall in the second hour. This shows that in the study area, the rainfall that occurs experiences a high rising climb in minutes, and decreases after the first hour with a decreasing limb that tends to be slow.

Table 3. Rain Intensity Based on Rain Distribution Recording in Each Basin

Basin	Rain Intensity Hour T	
	1	**2**
	65%	**35%**
Bintang Bano Reservoir	76.8	41.2
Tiu Suntuk Reservoir	59.8	32.2
Brang Klongkeng	70.9	38.1
Brang Seloto	67.0	36.0
Brang Beru	72.2	38.8
Brang Ene	36.4	19.6

2.3. Basin Characteristic

Figure 7 shows the Topography of the Brang Rea Basin. The topography of the Brang Rea Basin in the upstream part is mostly hilly with elevations between +80 m to +1800 m above sea level, while in the downstream part it is mostly lowlands forming a basin with elevations ranging from +12.5 m to +75 m. This has the potential for flooding in the downstream area with a concave contour and fast flowing flow from the upstream.

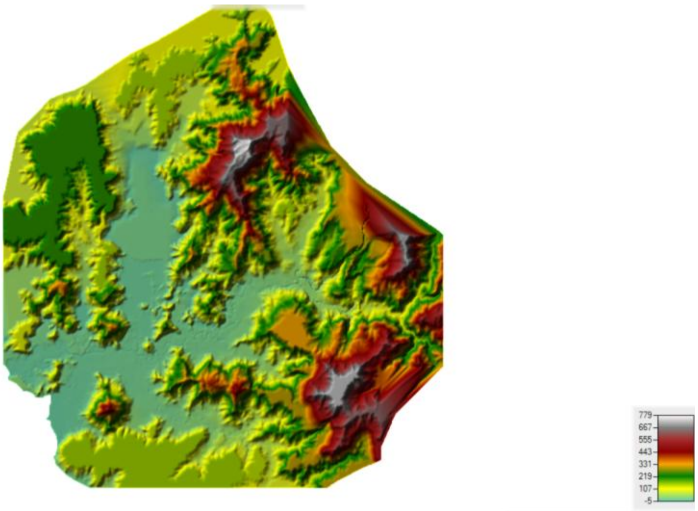

Figure 8. Topography of the Brang Rea Basin.

With the fairly steep contour conditions in the upstream section, this has an effect on the flood travel time or time concentration (tc) which is approximated by the Kirpich formula [21] in Equation 2. The length of the Brang Rea River is 21.55 km with a riverbed slope of 0.086 resulting in a tc of 2 hours, which means that the flood discharge from the main river upstream area (Brang Rea) can reach the Taliwang City area in ± 2 hours.

$$Tc = Ct0{,}01947\left(\frac{L^{0,77}}{S^{0,835}}\right) \quad (2)$$

Where Tc is time concentration; Ct is a coefficient for calibration; L is the length of the river; and S is the slope of the river bed.

In the analysis of rainfall runoff, topographic conditions must be supplemented with land cover data and soil types that will affect water from runoff that seeps into the soil. Curve Number (CN) is a number obtained from an empirical approach to calculate runoff based on land cover parameters and soil types [22] . Figure 8 shows the distribution of CN numbers in the Brang Rea Basin which shows that the majority of the Brang Rea area can still be a good water catchment area, with an average CN number between 70 and 80. The CN map was made by overlaying vector spatial data of land cover with soil types using the help of ArcGIS software. The CN number 80 occupies the largest percentage, namely 31%, according to [21] It can be identified that the area with the CN 80 number is mostly primary forest land cover and clay soil type so that the permeability tends to be low ranging from 0.5 - 2.3 . The second largest area is the CN 77 number with a percentage of 26%, the majority of land cover is shrubs and sandy clay soil types with permeability ranging from 4.3 - 6.9. The third largest CN number is 87 with a percentage of 17% with the majority of land cover being rice fields and sandy clay soil types with permeability ranging from 4.3 - 6.9. From the analysis of the CN numbers, it is known that the land cover in the Brang Rea Basin is still relatively good, namely dominated by forests. However, it has a type of soil that has the potential to drain high runoff and low permeability, namely clay soil, so the potential for flooding is quite large.

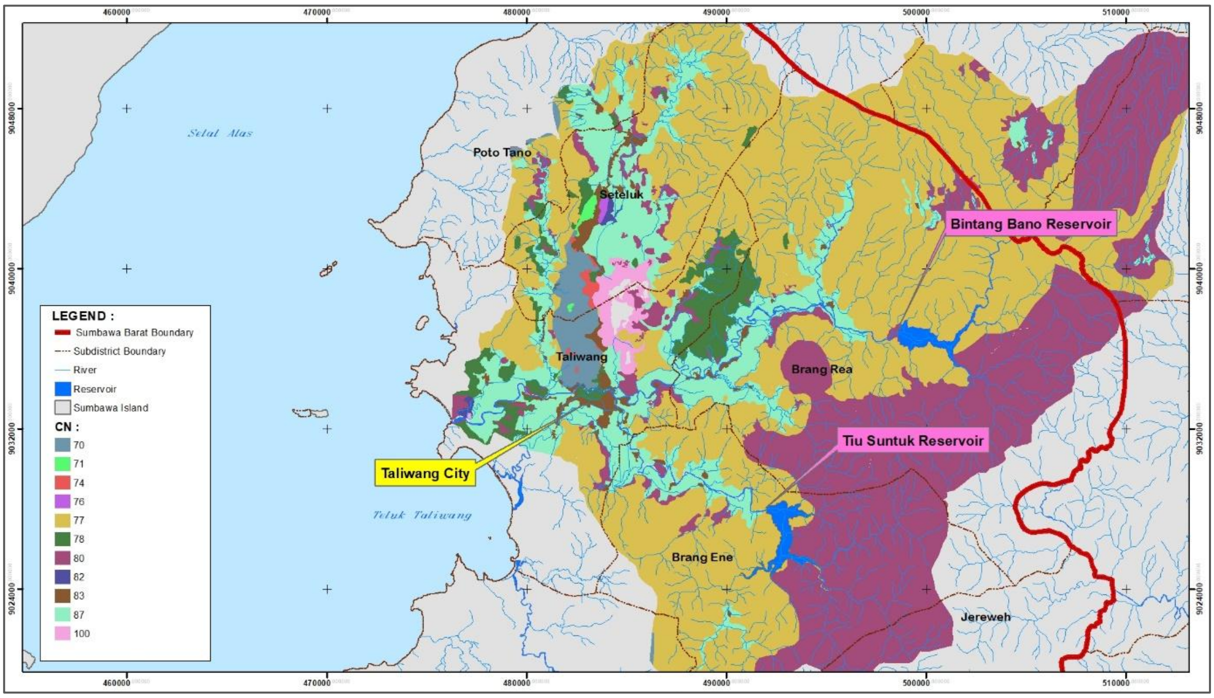

Figure 9. Curve Number Brang Rea Basin.

3. Results and Discussion

3.1. *Rainfall-Runoff Numerical Modelling*

There are many computer programs used to predict the magnitude of flood discharge in a Basin. This study uses the HEC-HMS modeling program. This program is used for hydrological analysis by simulating the process of rainfall into runoff in a Basin. This program was chosen because of several advantages, including accommodating *channel routing*, time travel discharge, differences in soil type and land use, and differences in rainfall in each Basin. The data needed include rainfall, Basin characteristics (land use, soil type, river geometry). Another element is the time lag *between* the center of gravity of effective rainfall and the peak of the hydrograph [24] . Figure 9 illustrates the Brang Rea Basin scheme in the HEC-HMS model network.

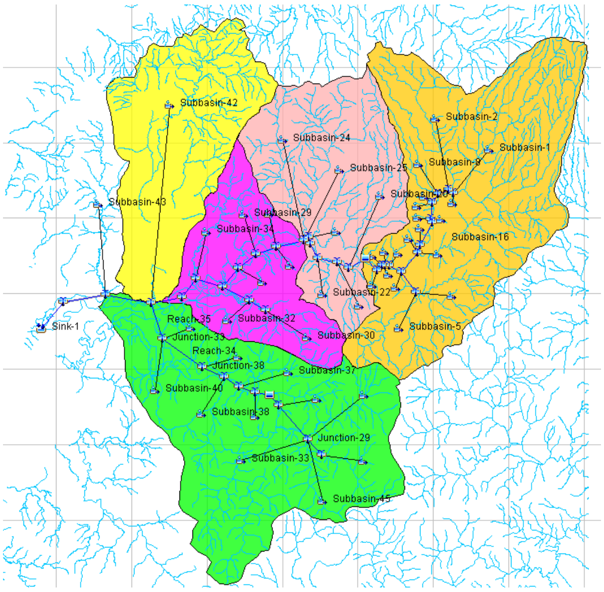

Figure 10. Brang Rea Basin Model Network on HEC-HMS.

This model has been well verified. The HEC-HMS model was verified by comparing the observation release with the analysis result release at one of the reservoirs, that is Waduk Bintang Bano on the 24-hour operation data series. Given that, at the study location there was no water level recording post in the river. For modeling the relationship between a dependent variable and one or more independent variables, the statistical technique known as linear regression is used [23]. The values of the independent variable determine the value of a dependent variable [23,24]. A good correlation between both variable was obtained (R2 = 0.97) as shown in Figure 10. A coefficient of determination (R^2) of 0.97 indicates that the simulated release closely matches the observed discharge, with a similarity of 97%.

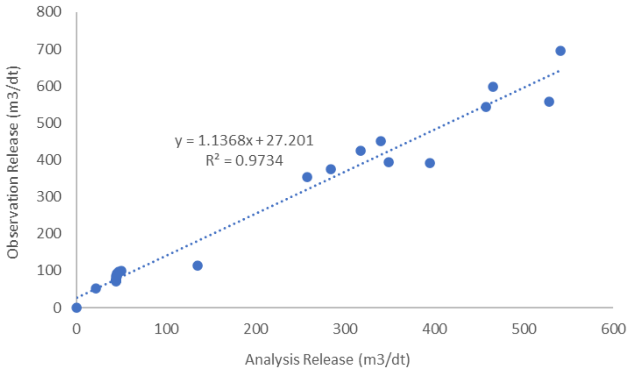

Figure 11. Verification of Observation Release with Analysis Result Release at Bintang Bano Reservoir.

To calculate runoff with the HEC-HMS model, a unit hydrograph with the SCS-CN (Soil Conservation Service Curve Number) method is used. The SCS-CN unit hydrograph method is an empirical method used to estimate the surface flow hydrograph due to effective rainfall in a Basin [25] . As previously identified, the CN value in the Brang Rea Basin ranges from 70-87. According to [26], a CN value of more than 70 can be an indication of a large flood discharge.

Flood runoff is simulated by taking into account the existence of 2 (two) reservoirs in the upstream part of the Basin, namely Bintang Bano Reservoir and Tiu Suntuk Reservoir. In the flood reduction function, the flood storage capacity of Bintang Bano Reservoir is 76.19 million m3 , while the capacity of Tiu Suntuk Reservoir is 55.9 million m3 [27] . Both reservoirs have gated spillways that can help reduce greater flooding. The height of the Bintang Bano Reservoir spillway gate is 12.25 m, and that of the Tiu Suntuk Reservoir is 4.5 m. Technical data for both reservoirs are shown in Figure 11.

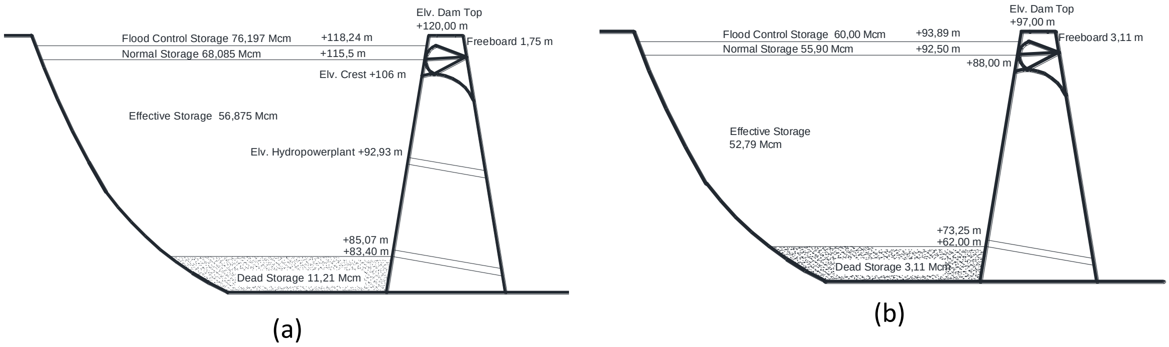

Figure 12. Technical Data at Bintang Bano Reservoir (a), and Tiu Suntuk Reservoir (b).

The spillway gates opening is simulated by considering the policy of releasing water from the reservoir must maintain the reservoir water level and minimize the condition of inundation downstream of the reservoir [28] . Therefore, the release of water must be done carefully, so that the optimal gate opening height is obtained. In its release function, Bintang Bano Reservoir can release water through the spillway with a total release of 1246.38 m ^{3}/s, while Tiu Suntuk Reservoir can release a total of 252.27 m ^{3}/s. However, in this study, the release is regulated by simulating the gate opening, so that the optimal gate opening height is 2.2 m in Bintang Bano Reservoir, and the gate opening height is 1.3 m in Tiu Suntuk Reservoir. The graph of the optimal gate opening in both reservoirs can be seen in Figure 12.

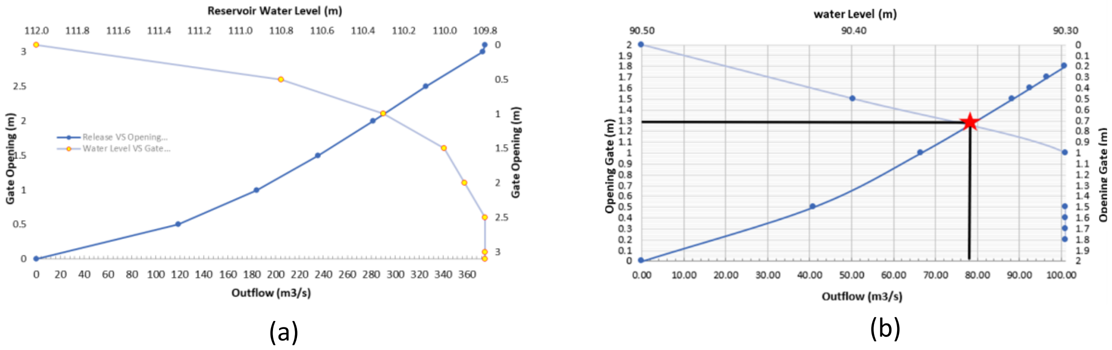

Figure 12. Opening Gate at Bintang Bano Reservoir (a), and Tiu Suntuk Reservoir (b).

The first rainfall runoff simulation was conducted with rainfall input based on recorded rainfall patterns. With the simulation with the operation of the spillway gates on both dams, the flood peak is 756.4 m^3/s. The second rainfall runoff simulation used empirical rainfall input with the modified mononobe method. The simulation results showed a flood discharge downstream of 3623 m^3/s. Both hydrographs were evaluated against the results of a previous study [15] which estimated the peak flood discharge for Taliwang City, specifically at the Brang Rea Hilir River, to be 779.7 m^3/s. The flood hydrograph graph with recorded rainfall intensity input and modified mononobe rainfall intensity is shown in Figure 13.

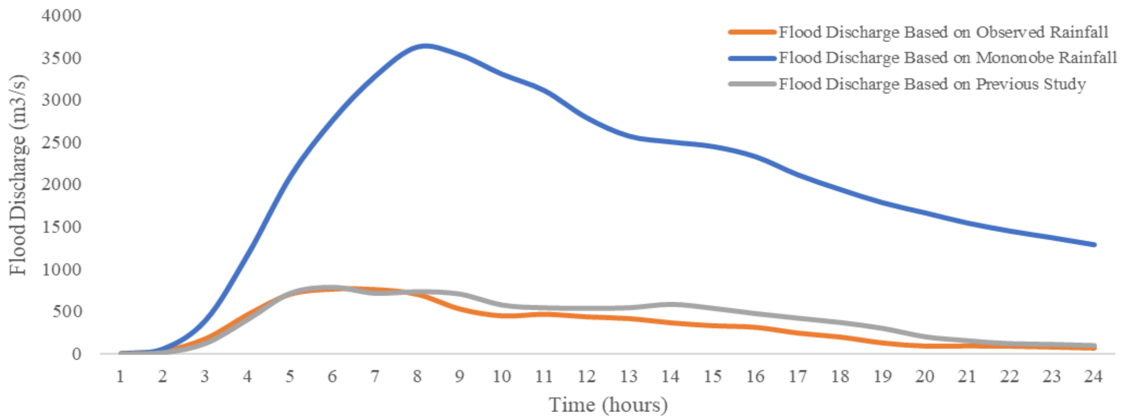

Figure 13. Flood Hydrograph on Both Rainfall Method.

As shown in Figure 13, the flood hydrograph based on the observed rainfall closely matches the hydrograph from the previous study, in contrast to the hydrograph generated using empirical rainfall data, which shows a significant discrepancy. the deviation between the peak flood discharge in the first and second simulations is 79.12% with a very large difference between the discharge derived from observed rainfall and empirical rainfall using the modified mononobe method. In addition, the statistical comparison of both rainfall methods with the previous study is quantified using the coefficient of determination (R^2), which is shown in Table 4.

Table 4. Coefficient of Determination Between Both Methods and the Previous Study

Flood Hydrograph	**R^2**
Revious Study-Observed Rainfall	0.94
Previous Study-Empirical Rainfall	0.88

Based on the coefficient of determination presented in Table 4, the flood hydrograph generated using the recorded rainfall data shows a very strong similarity with the previous study, with an R^2 value of 0.94. In contrast, the hydrograph produced using the empirical rainfall data demonstrates a weaker similarity with the previous study, with an R^2 value of 0.88.

This is reinforced by the results of research by [12,13]which also stated that the hourly rainfall distribution calculated using the empirical method tends to have a fairly high difference in the percentage of rainfall per hour with the results of the percentage of rainfall per hour based on observation data. To produce the right flood discharge at the study location, further analysis can be carried out to adjust the modified mononobe constant (m) in accordance with the characteristics of the Brang Rea Basin.

4. Conclusion

Based on the research results, it can be said that rainfall with empirical methods cannot always be applied to all Basins. Only Basins with certain characteristics can use empirical methods. Adjustments to the modified Mononobe constant (m) and longer rainfall data are made to better approximate the rainfall pattern specific to the characteristics of the study region. On the other hand, observational rainfall data is very good at estimating flood runoff, because the rainfall pattern represents the specific study location and the right rainfall depth. This can be the basis for BBWS Nusa Tenggara 1 as the authorized agency for the Brang Rea Basin to be able to increase the number of hourly recording rain posts so that in the future it can help facilitate the identification or prediction of floods in the study area. This recommendation is also good as one of the flood mitigation efforts from a non-structural perspective.

Acknowledgements

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