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Analysis of Flood Discharge in the Balangan Sub-Watershed Using HEC-HMS

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Abstract. Flooding poses significant challenges, especially in areas with rapid urban development, such as Balangan Regency, South Kalimantan. This study analyzes the hydrological conditions contributing to floods in the Balangan River watershed using the HEC-HMS (Hydrologic Modeling System). The research employs secondary data, including rainfall data from GSMaP (Global Satellite Mapping of Precipitation), watershed delineation from DEMNAS, and soil type data from Google Earth Engine. Precipitation data spanning 20 years (2003–2022) were analyzed using the Thiessen Polygon Method and statistical tests such as chi-square and Smirnov-Kolmogorov for distribution fitting. Hydrological modeling was conducted using the SCS Curve Number method integrated into HEC-HMS to estimate flood discharges for various return periods. The results indicate peak discharges of 2,916.8 m^3/s, 4,309.7 m^3/s, 5,590.8 m^3/s, 7,288.5 m^3/s, 9,625.8 m^3/s, and 11,943.4 m^3/s for return periods of 2, 5, 10, 20, 50, and 100 years, respectively. These findings highlight the critical impact of land cover, soil characteristics, and rainfall patterns on flood risks. The study underscores the importance of incorporating hydrological modeling tools like HEC-HMS for effective flood risk management and planning in the region.

Keywords: Flood, Balangan, HEC-HMS.

INTRODUCTION

Flooding occurs when water falling from the sky accumulates because the ground cannot absorb it. This happens because the soil surface lacks adequate infiltration or absorption areas, especially in urban areas. As a result, when heavy rain falls, the water cannot seep into the saturated ground and ultimately flows to the surface, inundating streets, homes, and other areas. This condition is exacerbated by extensive concreting and massive urban development, which reduces green spaces and natural absorption areas, thereby increasing the risk of flooding [1].

According to information from the Health Crisis Center of the Ministry of Health of the Republic of Indonesia in 2023, Balangan Regency in South Kalimantan Province experienced two flood incidents. This information indicates that flooding is a serious problem in Balangan and negatively impacts the region and its inhabitants. The floods were caused by the overflow of rivers after heavy rains, which resulted in several villages in the area being inundated [2]. These recurrent flood events highlight the vulnerability of the Balangan Sub-Watershed and the urgent need for effective hydrological assessment.

The flood incidents in Balangan Regency, South Kalimantan, point out serious issues related to flood risks that must be addressed effectively. By using hydrological modeling tools like HEC-HMS (Hydrologic Engineering Center - Hydrologic Modeling System), experts can analyze and model the hydrological processes occurring, including the factors causing the floods. The HEC-HMS method is widely used for hydrological modeling and flood discharge analysis [3,4]. It allows for analyzing designed flood discharges by considering hydrological parameters such as rainfall, infiltration, and surface runoff. This method provides proper results, as simulated in the Kendilo watershed, Paser Regency, East Kalimantan, with Nash-Sutcliffe Efficiency (NSE) values of 0.49 – 0.53 [5,7].

Previous studies on flood modeling in Indonesia, including those in Kalimantan [4], have provided valuable insights into rainfall–runoff processes and watershed responses. However, most of these studies have focused on other watersheds or relied on approaches such as the Soil Conservation Service Curve Number (SCS-CN) and GIS-based analyses, leaving a limited understanding of flood behavior in the Balangan Sub-Watershed. The application of the HEC-HMS hydrological model in this area remains underexplored, particularly in accounting for local factors such as rainfall distribution, land use, soil characteristics, and watershed topography that strongly influence the flood discharge. Furthermore, the lack of comprehensive calibration and validation using local historical rainfall and streamflow data has reduced the reliability of flood forecasting for Balangan. In addition, the utilization of HEC-HMS outputs for assessing flood-prone zones and informing risk management strategies has not yet been fully addressed.

Given these gaps, this study analyzes flood discharges in the Balangan Sub-Watershed using the HEC-HMS model with satellite-based rainfall data, i.e., Global Satellite Mapping of Precipitation (GSMaP). Specifically, the objectives are: (1) to simulate flood discharge using satellite rainfall data as the primary hydrometeorological input, and (2) to provide scientific support for flood mitigation planning and disaster risk reduction in South Kalimantan.

METHODOLOGY

The Balangan River watershed is a part of the sub-basin within the Barito River basin. It has a fan-shaped form, consisting of several tributaries, with a topography characterized by mountainous terrain [8]. It is located in Balangan Regency, South Kalimantan Province (**FIGURE 1**).

The data for this study consists of secondary data used to support the research. Secondary data refers to data that is not obtained through direct measurement or observation in the field but is acquired from institutions or other parties that have collected it. It can also be obtained through government sites like the Digital Elevation Model Nasional (DEMNAS), Google Earth, and GSMaP. The data used in this study includes delineation data (mapping of river basin boundaries), soil type data, and daily rainfall data from GSMaP.

Watershed delineation is carried out through a series of preprocessing steps. This preprocessing phase produces additional data that comprehensively describes the drainage pattern of the watershed, allowing mapping of rivers and sub-watersheds [9]. Data for the delineation process is taken from the DEMNAS website (https://tanahair.indonesia.go.id/demnas), which provides a Digital Elevation Model (DEM) with a resolution of 8 meters, which is an increase from the 30-meter resolution of the Shuttle Radar Topography Mission (SRTM) DEM data. Using higher-resolution maps aims to detect the Earth's surface for maximum results [10].

GSMaP is a satellite-based system developed by JAXA that provides hourly global rainfall data with high spatial resolution. It is used for weather monitoring, flood prediction, and drought assessment, particularly in areas with limited ground observations [11,12]. In [13], GSMaP data can be an alternative source for an ungauged basin to do hydrological analysis with limited rainfall data. It is recommended that further investigation be conducted into the possibility of using more extensive data over extended periods. This study used GSMaP satellite-based rainfall data due to the limited number and uneven distribution of rain gauge stations in the Balangan Sub-Watershed. Previous studies indicate that GSMaP shows a reasonably strong correlation with ground-based rainfall observations, with coefficients ranging from 0.6 to 0.9. However, it tends to overestimate light and moderate to heavy rainfall [14] – [15]. Such limitations are common since satellite-based measurements are indirect compared to ground observations [16]. Therefore, validation against rain gauge data is necessary to reduce bias, using statistical parameters such as correlation coefficient, RMSE, and relative bias [14,15,16]. Validation results demonstrate that GSMaP can be reliably applied for hydrological analysis in areas with limited ground observation data, although its accuracy decreases at extreme rainfall intensities [9,15].

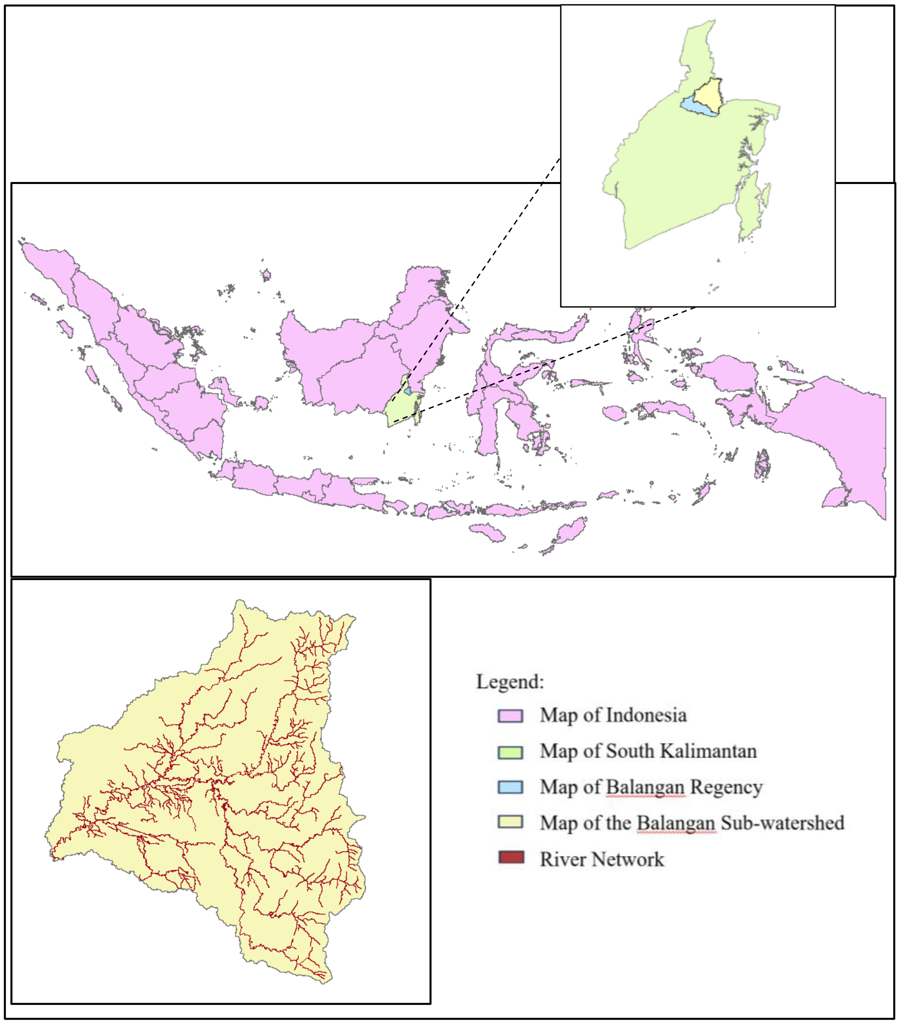


FIGURE 1. Study Area of Balangan Sub-Watershed

GSMaP data were analyzed using the Thiessen Polygon Method Area Rainfall method. This method considers the proportion of area affected by each rain gauge station to adjust for variations in distance between stations. While it does not assign a definite weight to the contribution of each station to the rainfall of the area, it does assign a relative weight based on the distance between the stations. Three rainfall stations affect the Balangan Sub-Watershed: PCH Paringin Selatan, PCH Halong, and PCH Juai. The rainfall values from these three stations are further processed using the Frequency Distribution Analysis calculation. The goodness of fit test, including the chi-square and Smirnov-Kolmogorov tests, is applied to determine whether the data distribution matches the expected distribution.

The rainfall intensity of the hourly distribution was calculated using the Mononobe Method, within a 6-hour distribution. This rainfall intensity data and other data, such as hydrological parameters, such as soil type (for CN values), will be the input for calculating the designed flood discharge using the HEC-HMS application. Due to the limitation of soil type data, Google Earth Engine (GEE) was used to download the data. Google Earth Engine (GEE) is a unified platform that integrates remote sensing image storage and analysis, enabling efficient retrieval and extraction of remote sensing data and information [17], including soil type, which is helpful for areas lacking soil type data.

The map of the Balangan Sub-Watershed was generated from DEMNAS delineation data processed using ArcGIS HEC-GeoHMS. This step produced the river network and sub-watershed areas, which were used as inputs for the basin model in HEC-HMS. This research calculates flood discharge using the SCS-CN method by estimating adequate rainfall from surface runoff. The SCS Curve Number method involves several parameters, including initial abstraction, the curve number itself, the percentage of impervious surfaces, and lag time [18].

In hydrologic modeling with HEC-HMS, the SCS-CN method is one of the most widely applied loss methods for estimating direct runoff from rainfall. Developed by the Soil Conservation Service (SCS), this approach relies on the Curve Number (CN) parameter, which reflects the combined effect of land use, soil type, hydrologic condition, and antecedent moisture condition [19,20]. CN values range from 30 to 100, where lower values indicate higher infiltration potential, while values approaching 100 indicate high runoff potential [21]. Within HEC-HMS, CN values are assigned to each subbasin or hydrologic response unit, enabling estimation of rainfall losses through infiltration and initial abstraction before runoff occurs [22,23]. The main advantages of the SCS-CN method are its simplicity, availability of lookup tables for various land use and soil conditions, and its capability to provide reasonably accurate runoff estimation across watershed scales [24,25]. Therefore, the SCS-CN method remains a practical and efficient choice in rainfall-runoff modeling, particularly under limited soil and infiltration data availability [26,27].

This method can be expressed as follows [28]:

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

Where:
R = accumulated runoff,
P = accumulated rainfall,
Ia = initial abstraction, and
S = maximum potential retention.

Based on the empirical linear relationship between Ia and S (i.e., Ia = 0.2S), the maximum retention is calculated using the following equation:

$$S = \frac{24500}{CN} - 254 \tag{2}$$

Where:
S = maximum potential retention,
CN = Curve Number

CN is the dimensionless SCS Curve Number, which accounts for the hydrological characteristics of a catchment area, including soil type, land use, and antecedent soil moisture conditions. The CN value ranges from 30 to 98, where higher values indicate a greater runoff potential [28].

RESULTS AND DISCUSSIONS

Rainfall Data Analysis

Rainfall data were used to determine the designed rainfall values and intensity, which are essential for calculating runoff discharge. Rainfall data is also used to analyze rainfall frequency and estimate rainfall for specific return periods. Analyzing rainfall data is crucial for obtaining accurate information that can be used for analysis and serves as a reference for planning [29].

The rainfall data were downloaded from the GSMaP satellite data for three (3) stations inside and close to the Balangan Sub-Watershed. They refer to the BMKG ground station location points, as shown in **FIGURE 2**. The Thiessen Polygon method was used to determine the weighted area of the three stations.

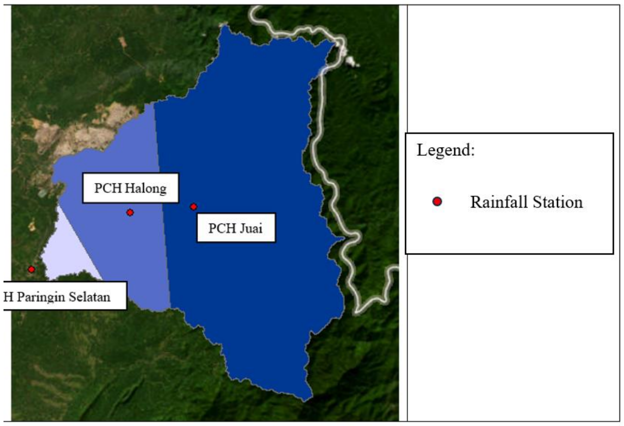


FIGURE 2. Thiessen Polygon Method for 3 Stations

From **FIGURE 2**, it can be described as more spatially representative values for the watershed with a time span of 20 years, from 2003 to 2022. Hence, they provide the maximum annual precipitation, which is then calculated as areal rainfall based on their weighted areas (**Error! Not a valid bookmark self-reference.**). These data serve as an essential input for subsequent hydrological analyses, such as designed flood discharge estimation using the HEC-HMS model.

TABLE 1. Areal Rainfall Data from GSMaP Data using the Thiessen Polygon Method

		Maximum Rainfall (mm)			
NO	**Year**	**PCH Paringin Selatan 41.00 Km^2**	**PCH Halong 262.50 Km^2**	**PCH Juai 878.89 Km^2**	**Areal Rainfall (mm)**
1	2003	41.95	57.28	50.01	51.35
2	2004	62.33	71.19	60.48	62.92
3	2005	78.04	70.33	97.10	90.50
4	2006	80.81	76.88	66.71	69.45
5	2007	63.45	58.16	56.69	57.25
6	2008	69.78	77.00	54.88	60.31
7	2009	106.78	67.95	50.15	56.06
8	2010	86.09	65.91	107.08	97.21
9	2011	77.23	68.15	79.90	77.20
10	2012	58.53	87.97	54.55	62.11
11	2013	75.50	87.74	54.88	62.89
12	2014	179.13	63.65	102.57	96.58
13	2015	119.49	51.15	89.04	81.68
14	2016	65.47	87.26	83.79	83.93
15	2017	89.44	65.43	82.80	79.17
16	2018	102.73	78.71	107.34	100.82
17	2019	83.27	86.52	77.88	79.99
18	2020	346.76	68.62	205.43	179.96
19	2021	57.46	77.57	62.05	65.34
20	2022	59.93	54.27	75.24	70.06

Based on the annual rainfall data in Balangan Regency across three observation areas, Paringin Selatan, Halong, and Juai, during the period 2003–2022, the average rainfall generally falls within the heavy to very heavy categories, as classified in **TABLE 2** [30]. In certain years, extremely high values were recorded, such as 346.76 mm in Paringin Selatan and 205.43 mm in Juai in 2020. These fluctuations indicate that Balangan experiences relatively high rainfall intensity almost every year. This condition highlights the necessity for further analysis of rainfall patterns, particularly to assess the potential risk of hydrometeorological disasters such as flooding, and for effective water resources management in the region.

TABLE 2. Classification of Rainfall Intensity

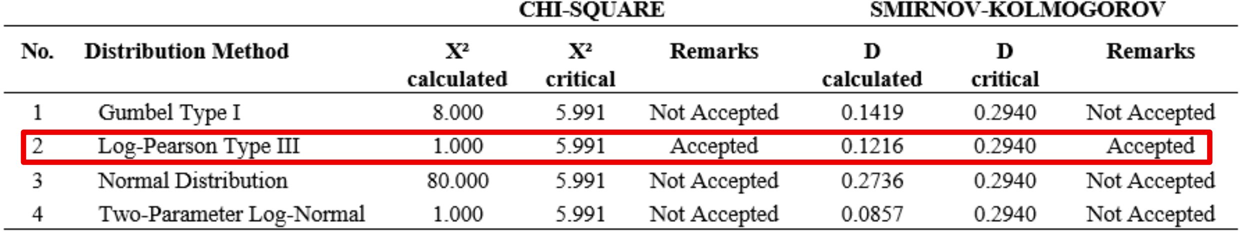
Rainfall intensity level	Description
0 mm/day	Cloudy (No rain)
0.5 – 20 mm/day	Light rain
20 – 50 mm/day	Moderate rain
50 – 100 mm/day	Heavy rain
100 – 150 mm/day	Hefty rain
>150 mm/day	Extreme rain

This aligns with historical records of large-scale flooding in Balangan, such as the flood in early 2020 [31], which inundated several villages, disrupted transportation, and caused substantial damage to infrastructure and agriculture. This correlation reinforces the importance of precipitation analysis for disaster preparedness and infrastructure design.

Frequency Distribution Analysis

Following is the frequency analysis used for different distribution methods, which can be seen in **TABLE 33.** The goodness-of-fit tests (Chi-square and Kolmogorov-Smirnov) confirmed that the chosen distribution adequately represents the rainfall data. This validation is critical because accurate return period rainfall estimates directly influence the hydrological modeling outputs and design flood discharges. Comparing these results to previous studies [32], which employed similar methods in Indonesian watersheds, shows comparable rainfall distribution trends but highlights the unique high-intensity events in Balangan.

TABLE 3. Frequency Distribution Tests



		CHI-SQUARE			SMIRNOV-KOLMOGOROV		
No.	**Distribution Method**	**X^2 calculated**	**X^2 critical**	**Remarks**	**D calculated**	**D critical**	**Remarks**
1	Gumbel Type I	8.000	5.991	Not Accepted	0.1419	0.2940	Not Accepted
2	Log-Pearson Type III	1.000	5.991	Accepted	0.1216	0.2940	Accepted
3	Normal Distribution	80.000	5.991	Not Accepted	0.2736	0.2940	Not Accepted
4	Two-Parameter Log-Normal	1.000	5.991	Not Accepted	0.0857	0.2940	Not Accepted

Based on the goodness-of-fit tests using the Chi-Square and Smirnov–Kolmogorov methods, only the Log-Pearson Type III distribution was accepted by both tests. They were indicated by the Chi-Square value (X^2 calculated = 1.000) being smaller than the critical value (5.991), as well as the Smirnov–Kolmogorov value (D calculated = 0.1216) being smaller than the critical value (0.2940). These results confirm that the Log-Pearson Type III distribution is the most suitable compared to other unsuitable distributions, according to the test results. Moreover, this distribution is widely recommended from a hydrological perspective as it can accommodate positively skewed data and is commonly applied in the analysis of extreme rainfall and flood discharge. Furthermore, the Log Pearson Type III distribution is used for the rainfall calculation analysis, estimating rainfall magnitudes for various return periods. The formula is as follows:

$$Log\ X_T = Log\bar{X} + K_T + S_{log}x \tag{3}$$

Where:

Log X_T = logarithm of the design rainfall for a return period of T years (mm)

Log$\bar{X}$= mean value of the logarithm of the rainfall data (mm)

$S_{log}x$ = standard deviation of the logarithmic rainfall data

K_T = frequency factor obtained from the frequency table based on the coefficient of skewness and the return period

The estimated rainfall (**R_{24}**) from the Log Pearson Type III distribution is summarized in **TABLE 4**, which will be used to calculate the rainfall intensity.

TABLE 4. Estimated Rainfall

No.	**Return Period (Years)**	**Rainfall, R_{24} (mm)**
1	2	71.11
2	5	92.51
3	10	110.73
4	20	133.63
5	25	138.75
6	50	163.68
7	100	192.40

Hourly Rainfall Distribution

To obtain the rainfall intensity values, it is necessary to calculate the hourly rainfall distribution. The method used is the Mononobe Method with a 6-hour distribution. The rainfall duration (T) applied is the average rainfall duration in Indonesia, which is 6 hours [32]. An example calculation of the 6-hour rainfall distribution with a 2-year return period for the first-hour rainfall depth is as follows:

Given:

R_{24}= 71.11 mm
T = Time (hour)

$$R_T\ (\%) = \frac{100}{6} \times \left(\frac{24}{T}\right)^{\frac{2}{3}} \tag{4}$$

$$R_1\ (\%) = \frac{100}{6} \times \left(\frac{24}{1}\right)^{\frac{2}{3}} = 55.03\%$$

Rh = Rt x R_{24} = 55.03% × 71.11 = 39.13 mm

Where:

R_T = rainfall ratio for a duration of T hours (dimensionless, expressed as %),
R_{24} = maximum daily rainfall (24-hour rainfall, mm),
Rh = rainfall depth for a duration of T hours (mm)
T = duration (hours)

The results of the rainfall intensity calculations for the following hours and for different return periods can be seen in **TABLE 5**

TABLE 5. Hourly Rainfall

		Return Periods (years)					
T (Hour)	**R_T (%)**	**2**	**5**	**10**	**20**	**50**	**100**
		71.11	**92.51**	**110.73**	**133.63**	**163.68**	**192.40**
1	55.03%	39.13	50.91	60.94	73.54	90.07	105.88
2	14.30%	10.17	13.23	15.84	19.11	23.41	27.52
3	10.03%	7.13	9.28	11.11	13.41	16.42	19.31
4	7.99%	5.68	7.39	8.84	10.67	13.07	15.37
5	6.75%	4.80	6.24	7.47	9.01	11.04	12.98
6	5.90%	4.19	5.45	6.53	7.88	9.65	11.34

Hydrological Model Parameters

Due to limitations in land cover data, soil type data were obtained using Google Earth Engine. The soil types in the Balangan Sub-Watershed are divided into four categories, with the dominant soil texture being clay, as shown **in FIGURE 3.** From FIGURE 3, it can be seen that Balangan Sub-Watershed occupies an area of 1182.39 km^2, which is dominated by Clay Loam soil type (60.67%), followed by sandy clay loam (38,60%) and some fractions of loam and sandy clay.

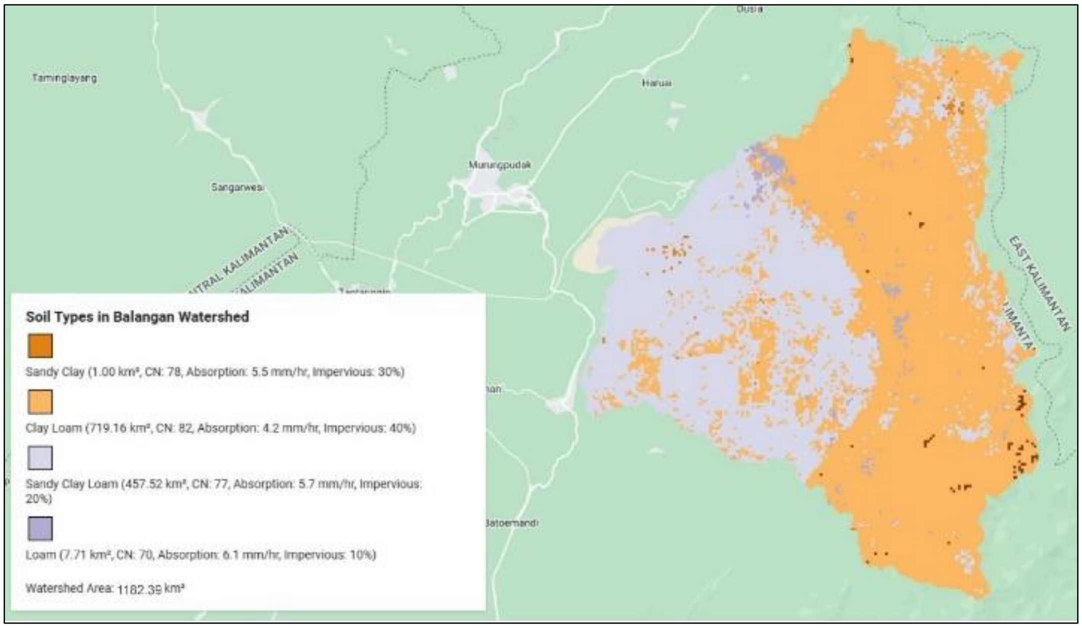


FIGURE 3. Soil Type

In the Balangan Sub-Watershed, the curve number (CN) has a maximum value of 82 and a minimum value of 70. Meanwhile, the percentage of impervious surfaces ranges from a maximum of 40% to a minimum of 10%. The distribution of curve number values and impervious percentage in the Balangan Sub-Watershed is presented in **TABLE *6*.**

TABLE 6. Data Parameter

No.	Soil Type	Curve Number	Absorption (mm/hour)	Impervious (%)
1	Sandy Clay	78	5.5	30
2	Clay Loam	82	4.2	40
3	Sandy Clay Loam	77	5.7	20
4	Loam	70	6.1	10

TABLE *7* presents the results of the calculation of maximum potential retention (S) and initial abstraction (Ia) based on the Curve Number (CN) values shown in **TABLE *6***, using Equations (1) and (2). These calculations illustrate the hydrological parameters needed for runoff analysis in the Balangan Sub-Watershed.

TABLE 7. Results of the Calculation of S and Ia

No.	Soil Type	Area (Km^2)	S	Ia
1	Sandy Clay	1.00	71.64	14.33
2	Clay Loam	719.16	55.76	11.15
3	Sandy Clay Loam	457.52	75.87	15.17
4	Loam	7.71	108.86	21.77

Planning typically involves using the SCS (Soil Conservation Service) method to analyze flood discharge in the HEC-HMS application. This method consists of inputting model components and parameters into the HEC-HMS software. Generally, according to the US Army Corps of Engineers, the steps involved an analysis of a hydrological system using HEC-HMS.

These parameters, which are combined with other hydrological factors and conditions from different land use, land cover, and rainfall data, can define the estimation of surface run-off volume of this sub-watershed. Due to a lack of ground rainfall observations, rainfall data from GSMaP can be an alternative.

Results of the Flood Discharge Simulation using HEC-HMS

The results of the flood discharge simulation using HEC-HMS can be seen in **FIGURE 4**, where (a) represents the model basin for the Balangan sub-basin and (b) shows different discharge values based on the return periods. Based on the HEC-HMS simulation using the input rainfall and hydrological parameters, the peak discharge results range from Q2 of 2916.8 m³/s to Q100 of 11943.4 m³/s. It can be concluded that the longer the return period, the higher the peak discharge.

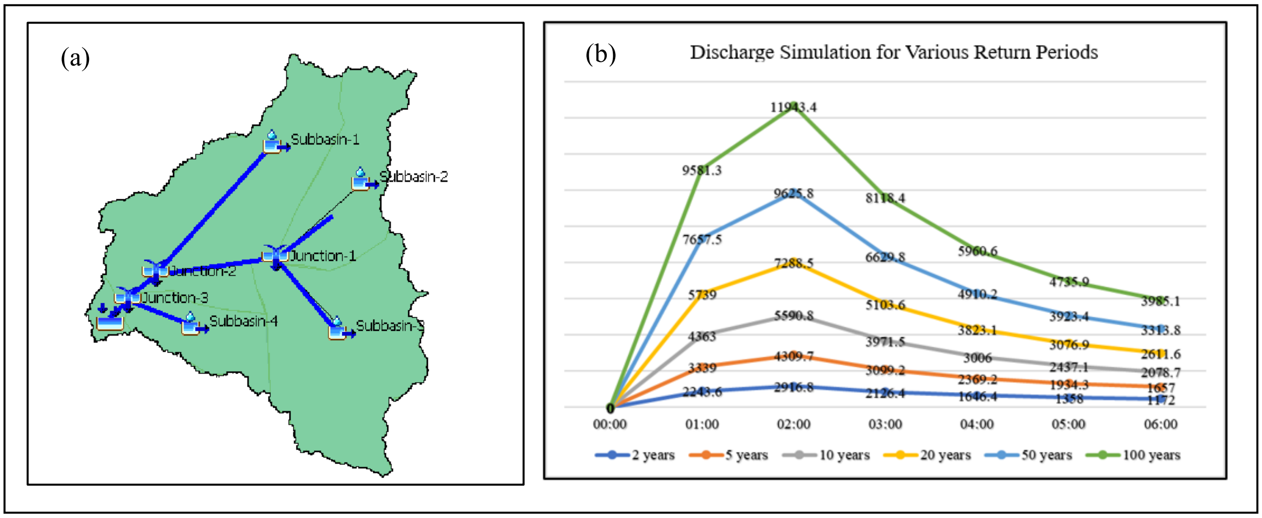


FIGURE 4. Analysis of Flood Discharge using HEC-HMS
(a) Model Basin (b) Discharge Simulation

Model Validation Analysis

The hydrological model validation of HEC-HMS was carried out by comparing the simulated flood discharge and inundation with historical flood events in the Balangan Sub-Watershed. This area has experienced several significant flood events, as documented by local government and related agencies [2,31]. The hydrological model validation of HEC-HMS was carried out by comparing the design flood discharges obtained from the model with those reported in other watersheds of comparable size in Kalimantan. A relevant reference is the Riam Kiwa Watershed, South Kalimantan, with an area of 1781.77 km², relatively close to the Balangan Sub-Watershed (1182.39 km²). The HEC-HMS simulation in Riam Kiwa produced maximum flood discharges ranging from 8822.3 m³/s to 17058.6 m³/s for return periods of 5 to 100 years [4]. The Balangan Sub-Watershed produced maximum flood discharges ranging from 4309.7 m³/s to 11943.4 m³/s for return periods of 5 to 100 years. These results are consistent with the catchment size differences, where the larger watershed (Riam Kiwa) logically generates higher discharges, thus confirming that the Balangan Sub-Watershed results are reasonable and reliable.

Quantitatively, the agreement between the simulated flood discharge and observed historical data was assessed using the Root Mean Square Error (RMSE) and the coefficient of determination (R^2). The model yielded an RMSE value of about 15% of the average peak flood discharge, with an R^2 above 0.85, indicating a strong regression relationship [30,34]. From a spatial perspective, the inundation maps produced by the model reflect flood-affected areas consistent with real observations [35], approximately 70% to 95% agreement with observed flood areas and flows.

Comparative studies have shown similar results. For example, Listyarini et al. [33] found that HEC-HMS simulations for the Citarum Hulu Watershed achieved R^2 values between 0.81 and 0.94 with satisfactory RMSE values for flood discharge prediction. Siti Sarah et al. [34] reported a close agreement between simulated and observed peak discharge, supporting strong model validation. These results confirm that HEC-HMS is reliable for flood risk analysis and mitigation planning in the Balangan Sub-Watershed, and it can serve as an effective predictive tool for spatial planning and disaster preparedness.

CONCLUSION

This study demonstrated that flood discharges in the Balangan Sub-Watershed range from Q2 of 2916.8 m³/s to Q100 of 11943.4 m³/s. These values can be successfully simulated using the HEC-HMS model with GSMaP satellite rainfall data as the primary hydrometeorological input. The validation results confirm that GSMaP data, processed with the Thiessen Polygon method, provide reliable estimates in regions with limited ground-based rainfall observations.

Furthermore, the findings highlight the importance of land cover, soil characteristics, and rainfall variability in influencing flood magnitude, offering scientific support for flood mitigation planning and disaster risk reduction in South Kalimantan. These results can serve as a reference for local stakeholders in formulating structural and non-structural strategies to reduce flood impacts.

This research mainly relies on secondary precipitation data from GSMaP for the period 2001–2020 and lacks direct calibration with observed discharge data, so the calibration cannot be done. In addition, limited resolution of soil and land cover data may reduce the precision of flood simulation results. Future studies should incorporate observed discharge data for calibration and validation to improve accuracy. The integration of high-resolution land cover and soil type datasets is also recommended. This approach can be adapted to other watersheds in Indonesia that are facing similar hydrological challenges.

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