

Analysis of Land Use Impacts on Flood Propagation and Inundation Area Using 2D HEC-RAS Modeling: A Case Study of the Babakan Watershed, Central Java

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Article History:

Received : 27 December 2025

Revised : 16 March 2026

Accepted : 17 March 2026

Keywords:

Babakan Watershed,
Flood propagation,
HEC-RAS 2D,
Land use,
Peak discharge.

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ABSTRACT

The Babakan Watershed is located in Brebes Regency, Central Java Province, and represents one of the river systems that experiences recurrent flooding events annually. These events indicate a high vulnerability of the area to changes in hydrological characteristics driven by land use dynamics. This study aims to evaluate the effects of land use change on the hydrological and hydraulic responses of the Babakan Watershed and their implications for flood potential and characteristics. The methodology applies the Soil Conservation Service–Curve Number (SCS–CN) Synthetic Unit Hydrograph approach based on land use data from 2015 and 2022, with the application of a 20-year return period design discharge calibrated against bankfull water level conditions of the Babakan River to ensure consistency with the actual channel capacity. The hydrological analysis results show that the 20-year return period peak discharge (Q_{20}) in 2022, at 274.63 m³/s, is lower than that in 2015, which reached 285.57 m³/s, indicating a reduced flood response associated with land use changes. Integration with hydraulic modeling reveals a decrease in Curve Number (CN), an increase in the percentage of impervious areas reflecting improved watershed infiltration capacity, as well as reductions in flood inundation extent and flow velocity. These findings confirm that integrated hydrological–hydraulic approach is effective for evaluating the impacts of land use change on flood propagation and risk in the Babakan Watershed, while also supporting improved preparedness and watershed management planning for future flood events.

1. INTRODUCTION

Central Java Province is a region that is highly vulnerable to flooding, particularly during the rainy season. The uneven distribution of rainfall is one of the main factors contributing to flooding in several areas (Pratama & Darmawan, 2025). Brebes Regency is located in the northern part of Central Java Province and administratively consists of 17 sub-districts, covering coastal areas, lowlands, and hilly regions in the southern part. In Brebes Regency, spatial planning is regulated through the Regional Spatial Plan (Regional Regulation No. 13 of 2019), which divides land use into protected and cultivation areas. However, increasing demand for land for settlements and economic activities has the potential to trigger land conversion that may affect the hydrological balance of watersheds if not properly controlled (Pemerintah Daerah Kab. Brebes, 2019).

The Babakan Watershed (DAS Babakan), located in Brebes Regency, Central Java Province, is one of the river systems that experiences recurrent flooding every year, especially during the rainy season. These flood events have significant impacts on settlements and infrastructure in downstream areas, such as Ketanggungan Sub-district and its

surroundings. Factors such as land use change, uncontrolled development, and climate change are the main drivers influencing the intensity and frequency of flooding in this area (Qoyyim *et al.*, 2021). The conditions are further exacerbated by limited drainage capacity and the reduction of water infiltration areas due to changes in land use (Juliandar, 2021).

Land is soil and its physical environmental factors such as slopes, hydrology, climate, and natural vegetation, all of which potentially influence land use (Susilawati *et al.*, 2019). Changes in land use, particularly the increase in impervious surfaces, significantly increase surface runoff volume and accelerate rainfall flow toward the main channel, ultimately raising flood risk in downstream areas (Muzakki *et al.*, 2024). This condition reflected in increasing Curve Number (CN) values and the percentage of impervious surfaces within the framework of the Soil Conservation Service (SCS) method, representing reduced infiltration capacity and increased runoff potential.

The Soil Conservation Service (SCS) method uses the Curve Number (CN) as the main parameter to represent the hydrological response of a watershed to rainfall, which reflects the combined influence of land use, hydrologic soil type (Hydrologic Soil Group), and initial soil moisture conditions. Higher CN values indicate lower infiltration capacity and greater surface runoff potential, which directly contributes to increased peak flood discharge (USDA-SCS, 1986; Mishra & Singh, 2003). In addition to CN, the percentage of impervious surface is an important parameter in the SCS method, particularly in urbanized watersheds. An increase in impervious area reduces infiltration and increases direct runoff, thereby shortening the time of concentration and increasing peak discharge (Shuster *et al.*, 2005; Zhang *et al.*, 2018). The integration of Curve Number and impervious parameters in SCS analysis serves as hydrological indicators representing the impact of land cover change on runoff and flood characteristics in the Babakan Watershed.

The Soil Conservation Service – Curve Number (SCS-CN) method has been widely applied in hydrological studies to evaluate the impact of land cover change on watershed hydrological responses, particularly surface runoff and flood discharge (Roger *et al.*, 2017; Kumar *et al.*, 2021). This study aims to identify the influence of land use in 2015 and 2022 and evaluate its impact on the hydrological and hydraulic response of the river using the Synthetic Unit Hydrograph (HSS) SCS Unit Hydrograph approach. The hydraulic response of the river was analyzed through two-dimension (2D) modeling to visualize the impacts caused by land use such as inundation areas, flow velocity in the Babakan watershed.

2. MATERIALS AND METHODS

The materials used for the hydrological analysis were daily rainfall data obtained from Rainfall Posts (PCH) located in and around the Babakan River Basin (DAS) with an observation period of 17 years (2008-2024). Of all available rainfall posts, 5 (five) posts were selected that had adequate data quality, continuity, and recording consistency, namely the Cisadap PCH, Ciseureuh PCH, Kubangwungu PCH, Ketanggungan PCH, and Kertasari PCH. Comparison with isohyet maps was carried out to validate the reasonableness of the planned rainfall values resulting from the frequency analysis to ensure consistency with regional rainfall distribution, thus making them suitable for use as input for hydrological and flood modeling. Regional topographic data was obtained from the National Digital Elevation Model (DEMNAS). Land use data for 2015 and 2022 were obtained from the Ministry of Environment and Forestry (KLHK), while soil type data was obtained from the Global Hydrologic Soil Group (HSG). All of this data was then used as the basis for the Babakan Watershed parameterization process. The parameterization results are used as input in hydrological modeling to generate the design flood discharge.

The design flood discharge calculation is determined using the Synthetic Unit Hydrograph (HSS) approach using the Soil Conservation Service Curve Number (SCS-CN) method. The design flood discharge calculation results are then calibrated against bankfull discharge, which represents flow conditions close to the channel's maximum capacity and typically occurs during flood events with a return period of 1–2 years (Mulvihill *et al.*, 2009). The calibrated discharge is then applied as a boundary condition in a two-dimensional flood hydraulic model using HEC-RAS to simulate flow patterns, velocity distribution, and flood inundation extent and depth in the Babakan Watershed.

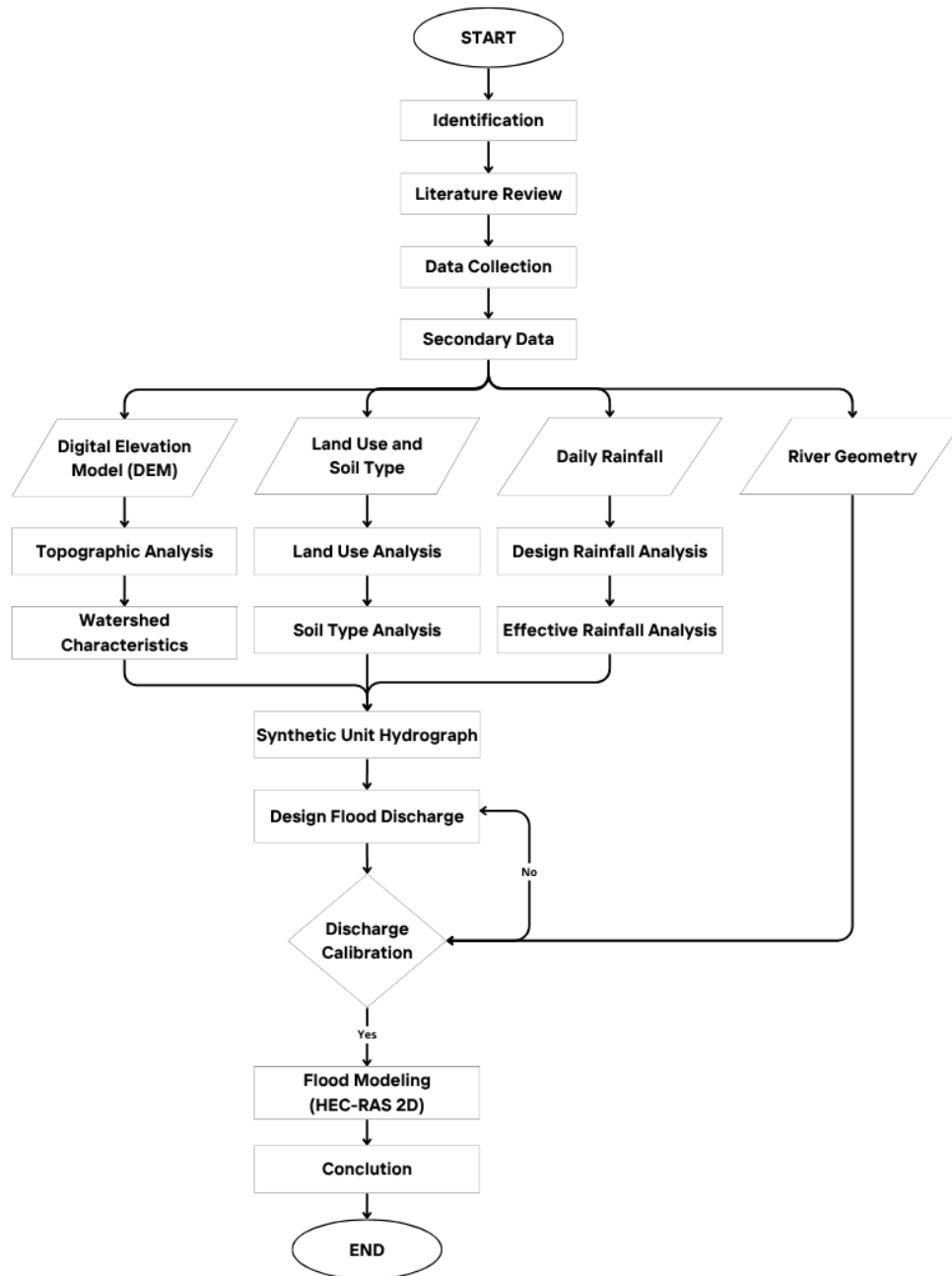


Figure 1. Research flowchart

2.1. Spatial Analysis

2.1.1. Babakan Watershed Delineation

This analysis was conducted using the National Digital Elevation Model (DEMNAS) data to represent the topographic conditions (elevation and slope) of the Babakan watershed area. Furthermore, the topographic model was used to delineate watershed boundaries to obtain the region's morphometric characteristics. The results of this analysis were then used as the basis for establishing spatial domains and geometric parameters in hydrological and hydraulic modeling, including the development of a two-dimensional flood model.

2.1.2. Land Use and Soil Type

Land use and soil type analysis was processed using ArcGIS software version 10.8 to produce land use maps for 2015 and 2022, as well as soil type maps. The integration of these two maps yielded data in the form of key hydrological parameters: Initial Abstraction, Curve Number (CN), and Impervious Surface Area (ISR).

2.2. Hydrological Analysis

Hydrological analysis was conducted using daily rainfall calculations for a 17-year period (2008-2024) obtained from the Cimanuk-Cisanggarung River Basin Center. Prior to further analysis, the rainfall data series were first evaluated for their feasibility through a series of statistical tests, including outlier tests, trend tests, stability tests for mean and standard deviation, and independence tests to ensure the quality and reliability of the data used (Balai Teknik Bendungan, 2022).

The determination of design rainfall was carried out through frequency analysis of the annual maximum rainfall series by applying several probability distributions, namely Normal, Log Normal, Log Pearson Type III, Pearson Type III, and Gumbel distributions. The selection of the most representative distribution was conducted using statistical suitability test, specifically the Chi-Square and Smirnov–Kolmogorov methods.

The distribution that satisfied the criteria of both tests was selected as the basis for determining design rainfall for various return periods, including the 100-year return period. The 100-year return period rainfall (R_{100}) was chosen as the basis for validation because rainfall with a large return period represents extreme rainfall events, which serve as a primary reference in the planning of flood control structures and flood risk analysis.

The use of R_{100} in the validation process with the isohyet map aims to ensure that the extreme rainfall values obtained from the analysis are consistent with regional rainfall characteristics and do not significantly deviate from them. Then to obtain regional rainfall, the Thiessen Polygon and Area Reduction Factor (ARF) methods were used. Hourly rainfall distribution using PSA 007 distribution method over a six hour period (Balai Teknik Bendungan, 2022). The effective rainfall calculation method uses an equation issued by The United States Soil Conservation Service (1972).

$$Pe = \frac{(P-0.2S)^2}{P+0.8S} \quad (1)$$

$$I_a = \lambda S \quad (2)$$

Correlation S value with CN value is presented in Equation (3):

$$S = \frac{25400}{CN} - 254 \quad (3)$$

with Pe is the cumulative excess rainfall (mm), P is the actual rainfall (mm), S is the maximum retention potential (mm), I_a is the rainfall abstraction (mm), λ is the coefficient with a value of 0–0.26, and CN is the Curve Number.

The distribution of abstraction over time was based on the equation of the Soil Conservation Service (1972) method as follows.

$$Fa = \frac{S(P-I_a)}{P-I_a+S}, P_a \geq I_a \quad (4)$$

$$Pe = P - (I_a + Fa) \quad (5)$$

The cumulative abstraction (Fa) represents the amount of rainfall lost through interception, depression storage, and infiltration processes before contributing to direct runoff. In the SCS-CN method, (Fa) is expressed as the difference between cumulative rainfall (P_a) and effective rainfall (Pe). The calculation of Fa is therefore required to quantify rainfall losses and to support the subsequent estimation of effective rainfall.

2.3. Analysis of Design Flood Discharge

The methods and procedures for calculating design flood discharge in channels or rivers are used for the planning of hydraulic structures. These methods consider data availability, technical requirements, and commonly applied approaches, especially for flows that are not affected by backwater conditions (Badan Standardisasi Nasional, 2016) In this study, the analysis of design flood discharge was carried out using an empirical approach with the assistance of

Microsoft Excel software. The calculation steps are as follows: (1) delineation of the Babakan Watershed using Sutamaja Bridge as the outlet point to obtain watershed morphometric characteristics; (2) analysis and determination of hydrological parameters, including Curve Number (CN), percentage of impervious surface, and initial abstraction (Ia), based on land cover conditions and soil type; (3) selection of design rainfall distribution based on rainfall frequency analysis for various return periods; (4) determination of effective rainfall and hourly rainfall distribution; and (5) development of a synthetic unit hydrograph using the Soil Conservation Service (SCS) Unit Hydrograph method to obtain the design peak flood discharge.

The SCS Synthetic Unit Hydrograph is a synthetic hydrograph expressed as the ratio between discharge (q) and peak discharge (q_p), and between time (t) and time of rise (T_p). The equations used in the SCS Unit Hydrograph method (Badan Standardisasi Nasional, 2016) are presented as follows.

$$q_p = \frac{CA}{T_p} \quad (6)$$

$$t_p = C_t(L \times L_c)^n \quad (7)$$

$$T_p = \frac{T_r}{2} + t_p \quad (8)$$

with q_p is the peak of the unit hydrograph (m^3/s), C is a constant (2.08), A is the watershed area (km^2), t_p is the time lag calculated using Snyder's equation, L is the main river length (km), L_c is the length to the centroid of the watershed (km), n is a constant (0.3), T_p is the time to peak (h), t_p is the time of rise (h), and T_r is the unit rainfall duration (1 h).

The modeling results produce a synthetic unit hydrograph with peak discharge values for the 1.25-year return period (Q1.25) and the 20-year return period (Q20) in the Babakan Watershed. The Q1.25 discharge is used as a reference for validation against the river bankfull discharge, while the Q20 discharge is applied as the design discharge in flood modeling in accordance with Minister of Public Works and Housing Regulation Number 28/2015.

Model calibration was carried out to improve the agreement between the simulation results and actual hydrological conditions. In this study, calibration used the 1.25-year return period discharge (Q1.25) as a reference, which was compared with the measured bankfull discharge at a river cross-section that has not been affected by river engineering works. This approach allows the model to represent the watershed's hydrological condition more accurately. The bankfull stage marks the point above which the river channel becomes connected with the floodplain (Keast & Ellison, 2022).

2.4. 2D Hydraulic Model Analysis

Two-dimensional hydraulic analysis was performed using HEC-RAS 6.3 by applying flow roughness parameters derived from land cover maps in 2015 and 2022. Both scenarios were modeled with the same boundary conditions to ensure that differences in simulation results could reflect the influence of land cover changes on flow patterns, velocity distribution, and flood inundation area and depth.

3. RESULTS AND DISCUSSION

3.1. Babakan Watershed Delineation

The Babakan watershed delineation was performed using HEC-HMS software version 4.12, with one control point (breakpoint) located downstream of the Babakan watershed, namely at the Krakahan estuary as the outlet. Based on the delineation results, the Babakan watershed area is known to be 125.01 km^2 with a main river length, namely the Babakan River, of 49,705 km. These results are visualized using ArcGIS version 10.8 and presented in Figure 2.

In addition to delineation on the overall watershed scale, a delineation focused on the research location was also conducted to confirm the position of the study area within the watershed system as a whole. This detailed delineation was carried out by determining the outlet point at the Sutamaja Bridge, which represents the downstream boundary of the study area in accordance with the research objectives. The delineation results in 5 (five) sub-watersheds as presented in Figure 3. The determination of these outlets is based on hydrological and hydraulic considerations, where the Sutamaja Bridge acts as a flow control point that receives accumulated runoff from all catchment areas in the upstream and middle parts of the Babakan Watershed.

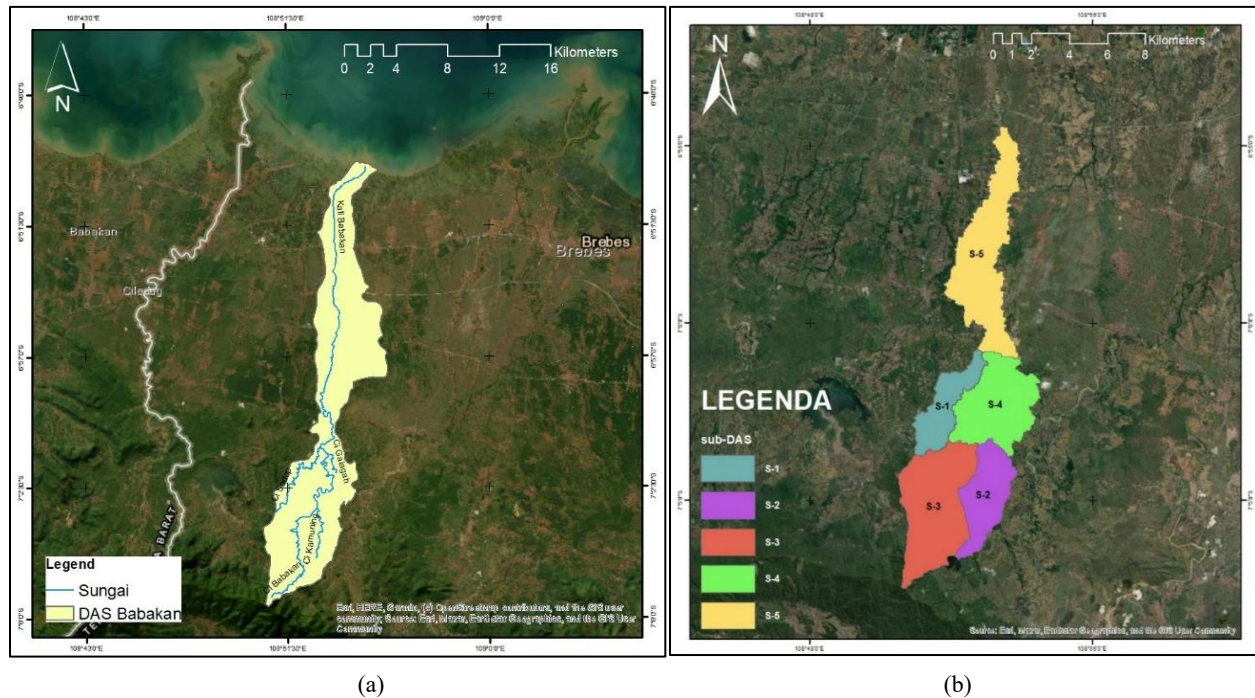


Figure 2. Delineation map for: (a) Babakan Watershed, and (b) Research location

The recapitulation of the area based on the formed watershed boundaries is then given the nomenclature S-1 to S-5. This data is used as the basis for calculating the Curve Number and Impervious values in hydrological analysis and hydraulic models. Based on Table 1, S-5 has the longest river length, at 16,532 km, which has a relatively longer propagation time compared to other sub-watersheds. This condition indicates that the length of the river channel influences the hydrological response of the watershed, where the longer the flow path, the greater the time of concentration and the time to peak discharge.

Table 1. Characteristics of the Babakan Watershed at the research location

No	Subbasin	Area (A) (km ²)	Main River Length (L) (km)	Main River Slope (S) (m/m)	Topographic Slope (m/m)
1	S-1	8.121	11.783	0.010	0.088
2	S-2	10.368	9.822	0.031	0.125
3	S-3	20.523	12.996	0.084	0.209
4	S-4	15.812	10.583	0.007	0.086
5	S-5	21.618	16.532	0.004	0.055
Total		76.442	61.717		

3.2. Topographic Conditions

The topographic analysis of the Babakan Watershed was carried out using elevation data (DEM), which were processed into an elevation map and a slope map. The slope classification refers to Minister of Environment and Forestry Regulation Number 10/2022, which divides land slope into several classes. The results of the elevation map analysis show that the Babakan Watershed has variations in elevation from upstream to downstream areas. The upstream area is dominated by relatively higher elevations, covering an area of 0.94 km², while the middle to downstream areas are located at lower elevations and function as flow accumulation zones. The summary of slope class distribution based on area percentage is presented in Table 2, while the topographic map of the Babakan Watershed is shown in Figure 3.

The slope map analysis indicates that the Babakan Watershed is dominated by the flat slope class (0–8%), covering an area of 86.025 km². This condition shows that the watershed has a relatively gentle topography, with a tendency for

Table 2. Slope of the Babakan Watershed

No	Class	Slope (%)	Area (Km ²)	Classification
1	I	0-8	86.025	Flat
2	II	8-15	19.491	Gentle
3	III	15-25	10.516	Moderately steep
4	IV	25-45	6.84	Steep
5	V	> 45	2.141	Very steep

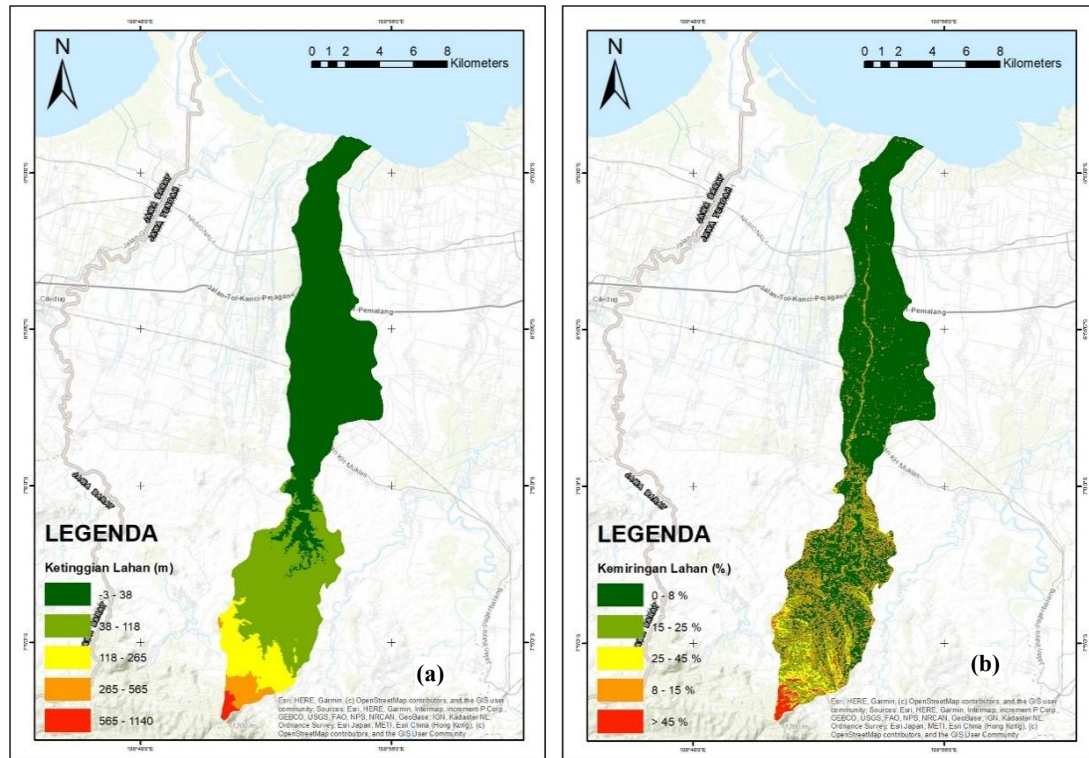


Figure 3. Babakan watershed topographic map: (a) land elevation, and (b) land slope

surface runoff to spread widely, especially in the middle to downstream sections. With the dominance of flat slopes, the watershed has a higher potential for runoff accumulation, longer inundation duration, and greater vulnerability to flooding in downstream areas.

3.3. Land Use and Soil Type Condition

Land use in the Babakan Watershed in 2015 and 2022 shows significant changes, especially a decrease in the area of dryland agriculture and mixed agricultural land with shrubs, as well as an increase in the area of paddy fields and residential areas. The dominant change in land use occurred in paddy fields. In 2015, the area of paddy fields increased significantly from 43.78 km² (35.03%) to 81.45 km² (65.15%) in 2022.

The land use changes between 2015 and 2022 may hydrologically increase the Curve Number (CN) value in the Babakan Watershed, mainly due to the expansion of residential areas and the shift in agricultural patterns from dryland farming to more extensive paddy field systems. This condition represents land conversion driven by population growth and increased development activities, which encourage the transformation of land into residential areas. Land use changes that occur intentionally due to population growth and increasing development are the main causes of land conversion into residential areas. This condition can increase surface runoff and reduce the infiltration capacity of water into the soil (Pratiwi & YUSDIANA, 2022). The results of the spatial land use analysis are presented in Figure 4, while Table 3 shows the quantitative recapitulation of land use changes during the eight-year observation period.

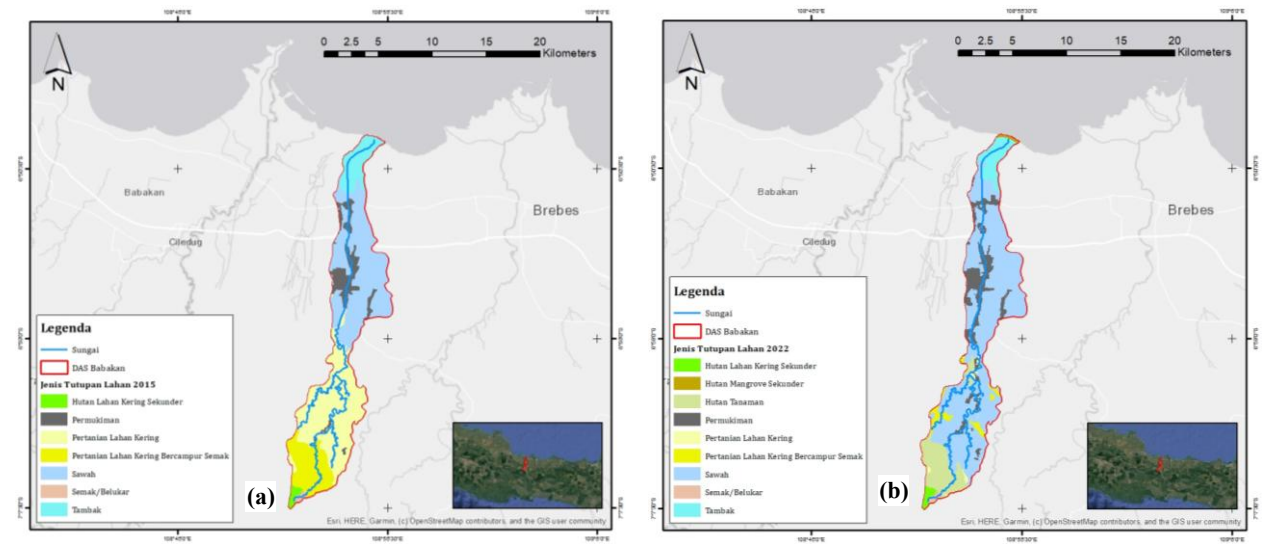


Figure 4. Land use maps of the Babakan Watershed in 2015 (a) and 2022 (b)

Table 3. Summary of land use conditions in the Babakan watershed

No	Land Use Type	2015		2022	
		Area (km ²)	Area (%)	Area (Km ²)	Area (%)
1	Secondary dryland forest	1.30	1.04	1.29	1.03
2	Secondary mangrove forest	0.00	0.00	0.43	0.34
3	Plantation forest	0.00	0.00	14.36	11.49
4	Settlement area	10.85	8.68	14.55	11.64
5	Dryland agriculture	42.79	34.23	1.83	1.47
6	Mixed dryland agriculture and shrubs	15.73	12.58	3.17	2.54
7	Paddy field	43.78	35.03	81.45	65.15
8	Shrubland	0.63	0.50	0.63	0.50
9	Fish pond	9.92	7.93	7.29	5.84
10	Bare land	0.00	0.00	0.00	0.00
Total		125.01	100	125.01	100

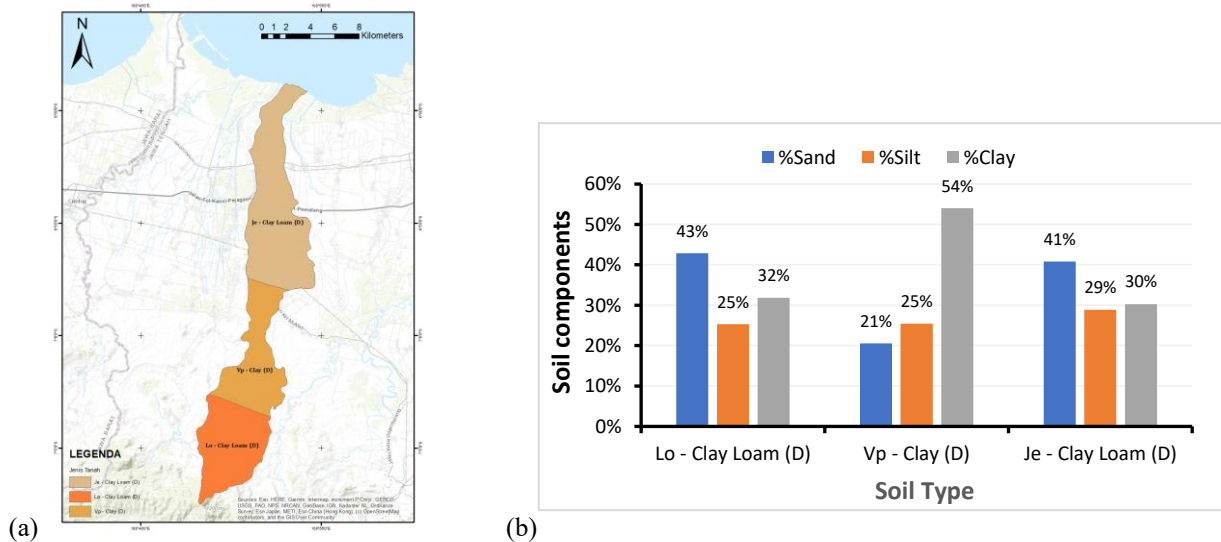


Figure 5. (a) Map of soil types in the Babakan Watershed, (b) Soil component fractions of soil types in the Babakan Watershed

The results of the soil type analysis show that the area is dominated by three soil mapping unit codes, namely Je, Lo, and VP, which are presented in Figure 5a. These codes are used as spatial identification of soil types, but they do not directly represent the infiltration and runoff behavior in the Babakan Watershed. Therefore, further analysis was conducted by integrating the Hydrologic Soil Group (HSG) parameter to determine the soil type in each area.

The integration results indicate that the Babakan Watershed is dominated by two main soil types, namely Clay Loam and Clay, which are generally classified into Hydrologic Soil Group (HSG) D. From the total area of the Babakan Watershed, the Clay Loam unit has the largest area, covering 34.95 km² (27.96%) and 57.32 km² (45.85%), with soil fraction compositions consisting of 41–43% sand, 25–29% silt, and 30–32% clay. Meanwhile, the Clay soil unit covers an area of 32.74 km² (26.19%), with a very dominant clay content of 54%, along with 21% sand and 25% silt. The three soil mapping units in the Babakan Watershed are presented in Figure 5b.

3.4. Hydrological Analysis

3.4.1. Polygon Thiessen

In the Babakan Watershed (DAS), several rainfall stations (PCH) were identified both inside and around the watershed area, which hydrologically may influence the rainfall characteristics of the region. The spatial distribution of these rainfall stations is presented in Figure 6a. However, after conducting a technical evaluation related to data quality and influence testing using the Thiessen method, five rainfall stations were selected in the study area, namely Cisadap, Ciseureuh, Kertasari, Ketanggungan, and Kubangwungu rainfall stations. These stations were considered to have adequate data quality with a recording period of 17 years (2008–2024), as presented in Figure 6b.

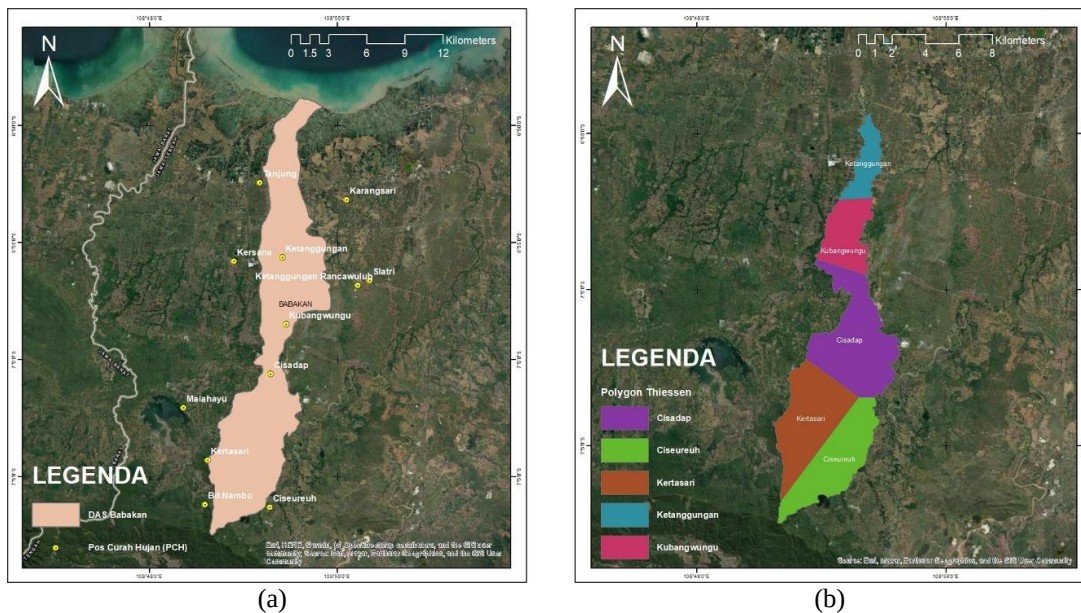


Figure 6. (a) Map of rainfall station distribution, and (b) Thiessen polygon map in the study area

Table 4. Coefficients Thiessen

Ground's Station	Area (Km ²)	Thiessen Coefficient
Cisadap	23.653	0.309
Ciseureuh	17.357	0.227
Kertasari	19.297	0.252
Ketanggungan	6.056	0.079
Kubangwungu	10.079	0.132
Total	76.441	1.000

The Thiessen Polygon analysis was used to determine the spatial distribution of daily rainfall based on the area of influence of each rainfall recording station (PCH). This method produces Thiessen coefficients through the weighting of the influence area of each rainfall station, which is calculated from the ratio between the Thiessen polygon area within the watershed boundary and the total watershed area. The Thiessen coefficients presented in Table 5 are used in the regional rainfall analysis.

3.4.2. Data Quality Test

Based on the guideline from the Dam Engineering Centre (Balai Teknik Bendungan, 2022), the annual maximum daily rainfall (HHMT) data from each rainfall station (PCH) were first evaluated using several tests, including the outlier test, trend test, stability test to mean and variance, and independency test. The result of HHMT graphs are presented in Figure 7, while the summary of the data quality test results is shown in Table 5.

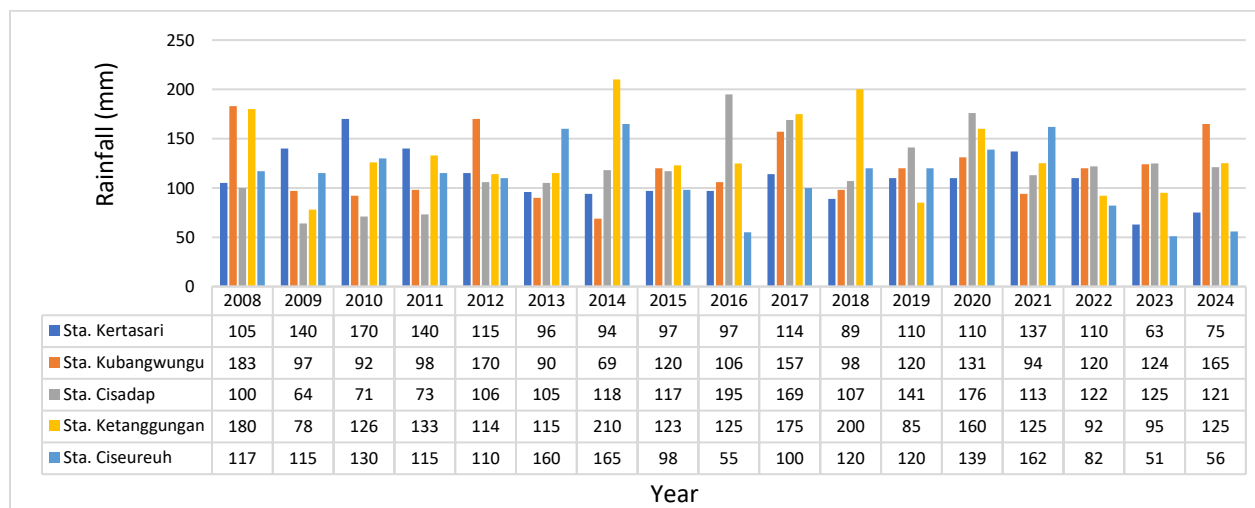


Figure 7. Chart of annual maximum daily rainfall (HHMT)

Table 5. Data consistency test

No	Consistency Test Type	Stations Name				
		Kertasari	Kubangwungu	Cisadap	Ketanggungan	Ciseureuh
1	Outlier (WR)	No Outlier	No Outlier	No Outlier	No Outlier	No Outlier
2	Outlier (G&B)	No Outlier	No Outlier	No Outlier	No Outlier	No Outlier
3	Trend Test	No Trend	No Trend	No Trend	No Trend	No Trend
4	Stability Test	Stable	Stable	Stable	Stable	Stable
5	Independence Test	Not Independent	Independent	Not Independent	Independent	Not Independent

The results of the independence test show that there are 3 (three) ground's station that have autocorrelation, so that the independence results are not fully met. This condition is commonly found in hydrological data, such as rainfall and streamflow, which naturally show temporal dependence due to the persistence of atmospheric and hydrological processes (Yue *et al.*, 2002; von Storch & Zwiers, 1999).

3.4.3. Frequency Analysis and Distribution Analysis

In this study, the estimated rainfall is carried out by applying several probability distribution models, namely the Normal, Log Normal, Pearson Type III, Log Pearson Type III, and Gumbel distributions. The recapitulation of the results of this frequency analysis aims to represent the statistical characteristics of rainfall events, which are presented in Table 6. The suitability test for rainfall distributions used the Chi-Square and Kolmogorov-Smirnov methods. The Chi-Square test requires the obtained X^2 value to be less than X_{α}^2 , using a table for a 5% degree of significance. The Kolmogorov-

Table 6. Result frequency analysis

No	Distribution	Condition	Calculation Result	Conclusion
1	Normal	$C_s \approx 0$	0.00	Qualify
		$C_k = 3$	-0.59	Not Qualify
2	Log Normal	$C_s = C_v^2 + 3C_v = 3$	3.00	Not Qualify
		$C_k = 5.383$	5.38	Not Qualify
3	Pearson III	In addition to other distribution requirements		
4	Log Pearson III	$C_s \neq 0$	0.72	Qualify
5	Gumbel	$C_s \leq 1.14$	0.61	Qualify
		$C_k \leq 5.4$	-0.09	Qualify

Smirnov test calculates the maximum vertical distance between observations and the theoretical value for each sample distribution. A distribution is considered to be suitable if $D_n < D_{critical}$ at the desired confidence level.

Based on the results of the frequency analysis and the distribution suitability test, the Gumbel distribution was selected as the most representative distribution in describing the statistical behavior of extreme rainfall in the Babakan Watershed. A summary of regional rainfall calculated using the Thiessen coefficient method is presented in Table 7.

Regional rainfall corrections to adjust for rainfall distribution are performed by applying the Area Reduction Factor (ARF). Based on SNI 2415:2016, for a watershed with an area of 30–3000 km², the ARF value can be calculated using the equation $1.152 - 0.123 \log(A)$ with a value of 0.92. The corrected ARF values are presented in Table 7, while a comparison of regional rainfall values for each return period is presented in Figure 8.

Table 7. Area reduction factor rainfall Babakan Watershed based on return period

No	Tr	P	Areal Rainfall (mm)	Rainfall $\times$ ARF (mm)
1	1.01	0.99	63.43	58.38
2	1.11	0.90	80.80	74.36
3	1.25	0.80	89.89	82.73
4	1.5	0.67	99.48	91.55
5	2	0.50	111.04	102.20
6	5	0.20	139.51	128.39
7	10	0.10	158.35	145.74
8	20	0.05	176.43	162.37
9	25	0.04	182.16	167.65
10	50	0.02	199.82	183.91
11	100	0.01	217.36	200.05

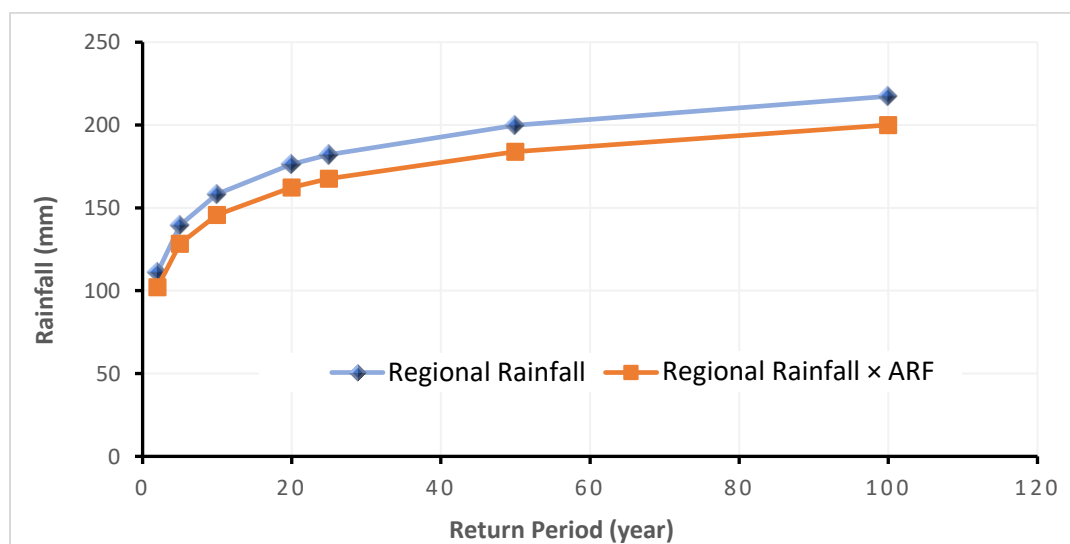


Figure 8. Comparison of rainfall in the region before and after correction with ARF values

The accuracy of the rainfall analysis results is validated through a data calibration process. The calibration of the planned rainfall is performed by comparing the calculated results with the 100-year return period Rainfall Isohyet Map published by the Dam Engineering Center. Data validation uses the Java Island Isohyet Map (R_{100}), which is regional in nature and is generally prepared for extreme rainfall events, and takes into account the location of the Babakan River in Brebes Regency, Central Java, as shown in Figure 9. It can be observed that the Babakan Watershed is located on the Isohyet R line with a rainfall range on the Isohyet R_{100} map of 200 – 225 mm, while in the analysis the R_{100} was obtained at 217.358 mm, which can be said that the data validation is appropriate.

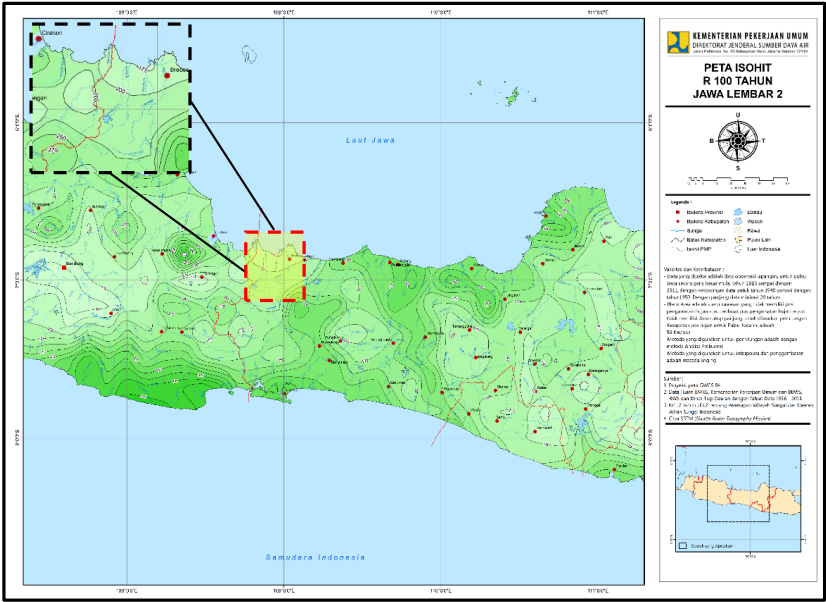


Figure 9. Rainfall isohyet map (R_{100}) of Brebes Regency, Central Java

3.4.4. Curve Number and Impervious

Curve Number (CN) and imperviousness represent differences in infiltration capacity and direct runoff in the Babakan watershed. Land use analysis (2015 and 2022) shows an increase in planted forest area of 13.90 km² with a CN value of 86.00 and imperviousness of 5.00 in 2022, as presented in Table 8.

Table 9 shows the changes in the composite Curve Number (CN) and composite impervious values in each sub-watershed between 2015 and 2022. The largest decrease in CN value occurred in Sub-watershed S-4, from 88.97 in 2015 to 82.12 in 2022 or a decrease of 6.86%. Overall, the total composite CN value decreased from 87.088 in 2015 to 83.170 in 2022, indicating an increase in the infiltration capacity of the watershed. However, on the other hand, the total composite impervious value increased from 6.630 to 8.098 or by 1.47%, thus potentially increasing surface runoff and accelerating the hydrological response of the watershed to rainfall. This data is used as an input parameter in the effective rainfall analysis to determine the amount of direct runoff.

Table 8. Comparison of CN and impervious values in land use in 2015 and 2022

Land Use Type	HSG	2015			2022		
		Area (km ²)	CN	Impervious	Area (km ²)	CN	Impervious
Secondary Dryland Forest	D	1.29	86.00	5.00	1.28	86.00	5.00
Secondary Mangrove Forest	D	-	-	-	13.90	86.00	5.00
Plantation Forest	D	4.98	87.00	30.00	9.47	87.00	30.00
Settlement Area	D	43.82	89.00	5.00	1.90	89.00	5.00
Dryland Agriculture	D	15.44	86.00	5.00	3.33	86.00	5.00
Mixed Dryland Agriculture and Shrubs	D	10.28	81.00	5.00	45.93	81.00	5.00
Paddy Field	D	0.63	83.00	5.00	0.63	83.00	5.00

Each sub-watershed has a distribution of land use with each area producing composite CN and composite impervious values.

Table 9. Composite CN and composite impervious values

Sub-watershed	Area (km ²)	2015		2022		Δ CN	Δ Impervious
		Composite CN	Composite Impervious	Composite CN	Composite Impervious		
S-1	8.12	88.97	5.00	82.33	5.00	-6.65%	0.00%
S-2	10.37	88.36	5.46	82.24	5.92	-6.12%	0.46%
S-3	20.52	86.66	5.34	84.49	5.52	-2.17%	0.18%
S-4	15.81	88.97	5.36	82.12	6.91	-6.86%	1.55%
S-5	21.62	84.80	9.96	83.45	13.62	-1.35%	3.66%
Total	76.441	87.088	6.630	83.170	8.098	-3.92%	1.47%

Table 7. Ratio of effective rainfall to land use

Effective Rainfall (T=20 years)			
Land Use	R (mm)	Ir (mm)	Re (mm)
2015	162.37	18.91	143.46
2022	162.37	24.35	138.03

Table 10 presents the effective rainfall analysis for a 20-year return period under different land-use conditions. Although the design rainfall (R) remained constant at 162.37 mm, the initial abstraction (Ir) increased from 18.91 mm in 2015 to 24.35 mm in 2022. Consequently, the effective rainfall (Re) decreased from 143.46 mm to 138.03 mm. These results indicate that changes in watershed characteristics associated with land-use conditions affected the rainfall abstraction capacity, thereby influencing the amount of rainfall available to generate direct runoff.

Effective rainfall analysis was conducted using the PSA-007 hourly rainfall distribution method by distributing daily design rainfall into hourly rainfall. Based on area, the Babakan watershed is classified as a small-to-medium watershed with an area of 1–100 km², so the rainfall duration was determined to be 6 hours, and the results of the effective rainfall analysis with return periods of 1.25 and 20 years based on land use are presented in Table 11.

Table 8. Effective rainfall distribution on land use

Hour-	PSA - 007	T (R24)	Land Use 2015		Land Use 2022	
			1.25	20	1.25	20
0	0	0	0.00	0.00	0.00	0.00
1	0.05	1	0.00	4.06	0.00	4.06
2	0.11	2	0.75	11.96	0.16	10.77
3	0.58	3	30.80	86.26	25.19	82.68
4	0.15	4	10.55	23.70	9.62	23.28
5	0.06	5	4.34	9.53	4.01	9.39
6	0.05	6	3.66	7.96	3.40	7.85

3.5. Analysis of Design Flood Discharge

The design flood discharge analysis with a 20-year return period (Q_{20}) and a 1.25-year bankfull calibration ($Q_{1.25}$) was conducted using the HSS SCS-CN Method. Within the SCS-CN method framework, a lower CN value represents relatively more permeable land cover and soil properties, allowing some rainfall to infiltrate into the soil before becoming direct runoff. This condition has implications for a decrease in runoff volume and potential peak flood discharge at the study outlet based on changes in land use, as presented in Table 12, while the characteristics of the SCS-CN flood hydrograph are shown in Figure 10.

Table 9. Maximum discharge value for land use using the SCS-CN method

HSS	Land Use	Maximum Discharge (m ³ /s)	
		$Q_{1.25}$	Q_{20}
SCS-CN	2015	99.98	285.57
SCS-CN	2022	84.38	274.63

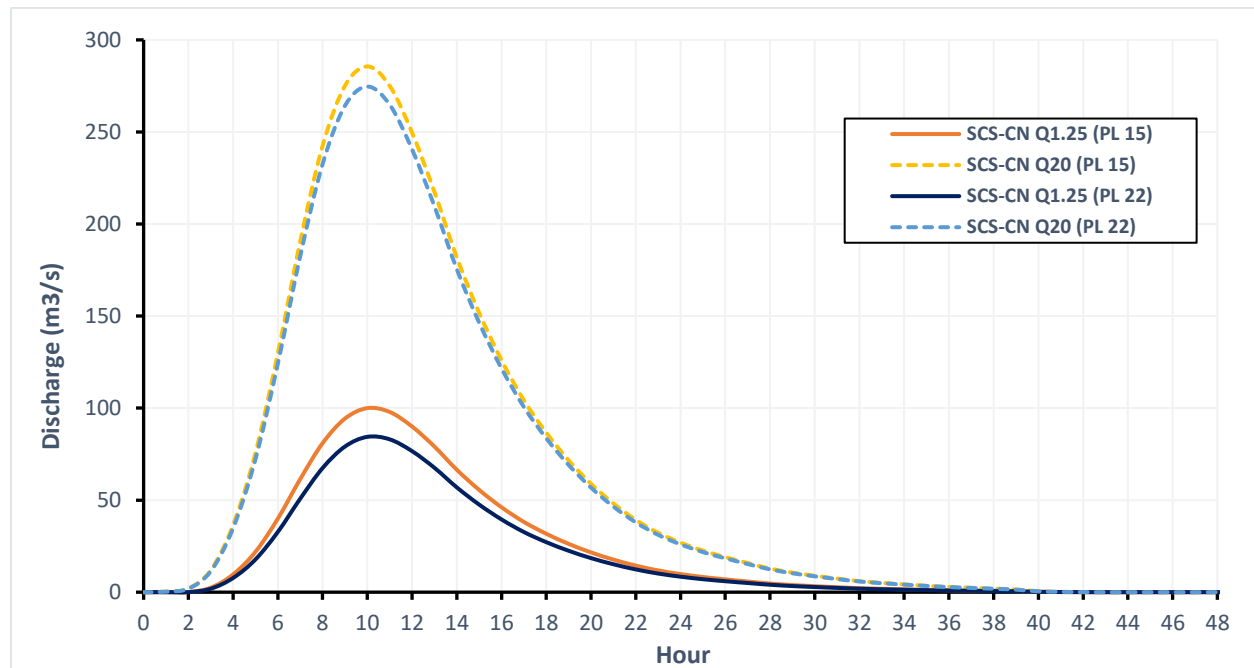


Figure 10. HSS SCS-CN characteristics based on land use

In Figure 10, the modeling results show that the peak discharge (Q20) for flood analysis in 2022 of 274.63 m³/s tends to be lower than in 2015 of 285.57 m³/s, this is in line with the decrease in the CN value which affects the amount of effective rainfall and surface runoff. The SCS-CN method is able to integrate land cover parameters, soil type, and initial moisture conditions in calculating surface runoff estimates spatially (Kumar *et al.*, 2021) and has high accuracy in representing the design discharge due to changes in land cover. (Wahyuni & Sachro, 2024). The hydrograph resulting from this modeling is then used as unsteady-flow input in hydraulic modeling for flood propagation analysis.

3.6. Hydraulic Model Analysis

Hydraulic model analysis was conducted to evaluate river channel capacity and flood propagation characteristics in the study area. Discharge calibration used a bankfull approach through 1D HEC-RAS modeling with bankfull discharge input (Q_{1.25}).

The results of the bankfull discharge calibration in Figures 11 and 12 show that the bankfull water level in the longitudinal section of the Babakan River ranges from 2.0–3.5 m above the riverbed. In the cross sections at STA. 3586 and STA. 3611, which represent natural river conditions, the water levels are 3.04 m and 3.11 m. These values indicate that the flow is still within the river channel capacity without causing overflow. Therefore, the bankfull discharge Q_{1.25} is considered representative for dominant flow conditions and is used for hydraulic model calibration.

Flood propagation analysis was carried out using a 2D HEC-RAS model with discharge input from hydrological modeling (Figure 13). The upstream boundary condition used a Q20 flood hydrograph with peak discharges of 285.57 m³/s for 2015 land use and 274.63 m³/s for 2022 land use. The downstream boundary condition used normal depth with a riverbed slope of 0.0004, while the upstream slope was 0.001.

The model results show that the 2015 land use condition produced a wider inundation area compared to 2022. The inundation area in 2015 reached 258.92 ha, while in 2022 it was 230.24 ha, a decrease of about 11.08% (Table 13). This reduction is related to land use changes that increase infiltration and runoff retention, which reduces surface runoff to the river. As a result, the peak flood discharge and inundation area decrease. The maximum flow velocity in both conditions is similar, but slightly higher in 2015 (around 0.2 m/s), which contributes to a wider flood spread compared to 2022.

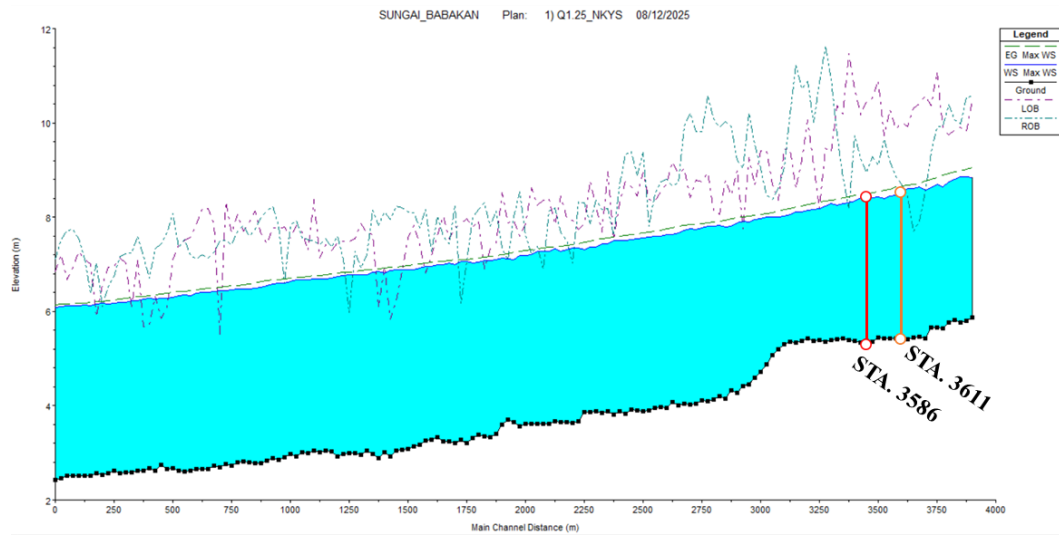


Figure 3. Long section bankfull debit calibration ($Q_{1.25}$)

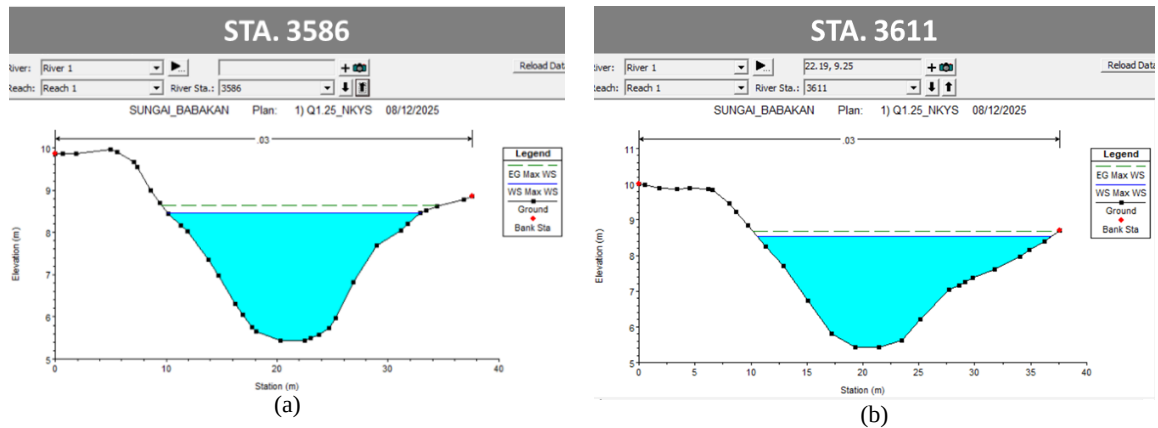


Figure 4. Cross section feature: (a) STA. 3586, and (b) STA. 3611

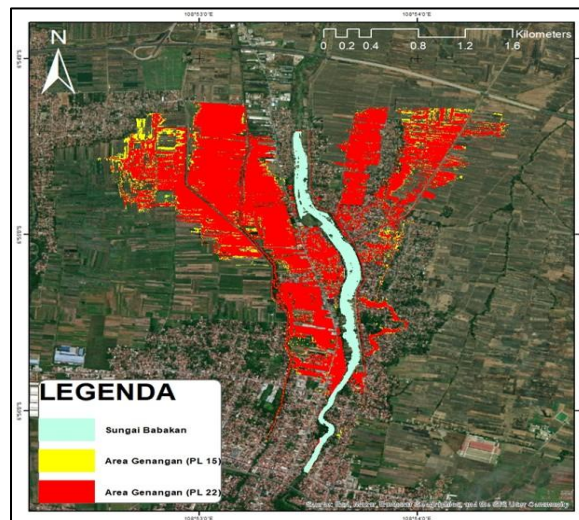


Figure 5. Inundation area based on land use

Table 10. Recapitulation of the relationship between discharge, inundation area, and velocity based on land use

Land Use	Discharge Q_{20} (m^3/s)	Inundation Area		Velocity (m/s)
		hectare	km ²	
2015	285.57	258.92	2.589	0 - 7.8
2022	274.63	230.24	2.302	0 - 7.6

Overall, the hydraulic modeling results show that land use conditions significantly affect discharge, flow velocity, and flood inundation area. This finding indicates that land use changes should be an important consideration in flood control planning in the Babakan Watershed.

4. CONCLUSIONS

This study analysis the effect of land use changes on the hydrological response of the Babakan Watershed using the SCS–CN Synthetic Unit Hydrograph approach integrated with the hydraulic conditions of the Babakan River. Modeling results show that land use changes during the 2015–2022 period caused a decrease in the Curve Number (CN) value and an increase in the percentage of impervious areas. This condition represents an increase in the watershed's infiltration capacity, which leads to a reduction in runoff volume. From a hydraulic perspective, the simulation results show a decrease in flood inundation area and a reduction in flow velocity. These findings indicate a decrease in the potential peak discharge and flood risk in the Babakan Watershed. Based on these results, more applicable watershed management recommendations are needed, including through land use conservation efforts that can increase infiltration and water retention capacity.

AUTHOR CONTRIBUTION STATEMENT

Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
AYW	✓	✓		✓		✓	✓	✓	✓	✓			✓	✓
MF											✓	✓		
VF			✓		✓									
APN			✓		✓									
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								

ACKNOWLEDGMENTS

The authors would like to express their gratitude to the Master's Program in Water Resources Management, Institut Teknologi Bandung, the Human Resources Development Agency (BPSDM) of the Ministry of Public Works, and the Cimanuk–Cisanggarung River Basin Authority (BBWS Cimanuk–Cisanggarung) for their support in the preparation of this journal.

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