

Assessing the Impact of Land Cover Change on Peak Discharge Using HEC-HMS: Case Study of the Batang Timpeh Watershed, Indonesia

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ABSTRACT

Recent deforestation driven by illegal logging, forest fires, and land conversion for oil palm plantations has significantly altered land cover conditions; however, its quantitative impact on peak discharge in the downstream Batang Timpeh Watershed remains poorly understood. This study aims to assess the impact of land cover change on peak discharge using the HEC-HMS model with the SCS-CN method, calibrated against the bankfull discharge of the Batang Timpeh River. Land cover data from 2015, 2019, and 2022 were analyzed using ArcGIS and integrated into hydrological simulations for a 20-year return period (Q₂₀). The results indicate that peak discharge increased from 469.60 m³/s in 2015 to 478.30 m³/s in 2022, representing a 1.85% increase. This increase is associated with higher Curve Number (CN) values and the expansion of impervious areas, indicating reduced infiltration capacity and a more rapid runoff response. These findings demonstrate that land cover change has significantly contributed to the intensification of peak discharge and increased flood potential in the downstream area, providing a quantitative basis for improving land use planning and developing more effective flood risk mitigation strategies in the Batang Timpeh Watershed, particularly in Dharmasraya Regency.

1. INTRODUCTION

Flooding is one of the most frequent hydrometeorological disasters, particularly in tropical regions, where increasing rainfall intensity and land use changes significantly influence watershed hydrological responses (Rahayu et al., 2009; Soulis, 2018). In Indonesia, flood events have become more frequent and severe, especially in areas experiencing rapid land cover transformation (Irwansyah et al., 2023; Wang et al., 2011).

Land cover change, particularly deforestation and the expansion of agricultural and plantation areas, plays a critical role in altering watershed characteristics by increasing impervious surfaces, reducing infiltration capacity, and accelerating surface runoff (Kumar et al., 2021; Rogger et al., 2016). These changes have been widely recognized as key drivers of increased flood discharge and hydrological instability.

In Dharmasraya Regency, flooding occurs almost every year, mainly due to the overflow of the Batang Timpeh River, which is unable to accommodate runoff from its upstream watershed. The Batang Timpeh Watershed has experienced significant land cover changes, where forested areas have been converted into oil palm plantations and other land uses. This transformation is driven by deforestation caused by illegal logging, forest fires, and land conversion for economic activities, contributing to increased runoff and flood potential in the downstream area (Adityarahman et al., 2024; Mufrodi & Sriyana, 2024).

Despite these conditions, the quantitative impact of land cover change on peak discharge in the Batang Timpeh Watershed has not been specifically evaluated, particularly using hydrological modeling approaches that integrate spatial land cover data. Most existing studies focus on general flood causes without providing a detailed assessment of how land cover dynamics influence peak discharge.

Therefore, this study aims to analyze land cover changes in 2015, 2019, and 2022 and assess their impact on peak discharge in the Batang Timpeh Watershed. The analysis is conducted using the HEC-HMS hydrological model with the SCS-CN method, supported by spatial analysis in ArcGIS, to simulate runoff response under a 20-year return period scenario (Gunawan *et al.*, 2025; Kumar *et al.*, 2021; Rogger *et al.*, 2016; Theresya *et al.*, 2026).

2. MATERIAL AND METHODS

2.1. Study Area and Data

The study was conducted in the Batang Timpeh Watershed, located in Dharmasraya Regency, Indonesia. Rainfall data were obtained from four rainfall stations, namely Komplek PU Sedasi, Padang Sidondang, Lubuk Ramo, and Koto Baru Piruko, covering a 13-year period (2012–2024). Figure 1 shows a flowchart of the overall research steps.

Topographic data were derived from the National Digital Elevation Model (DEMNAS), while land cover data for 2015, 2019, and 2022 were obtained from the Ministry of Environment and Forestry (KLHK). Soil data were sourced from the Global Hydrologic Soil Group dataset. These datasets were used to parameterize the hydrological model.

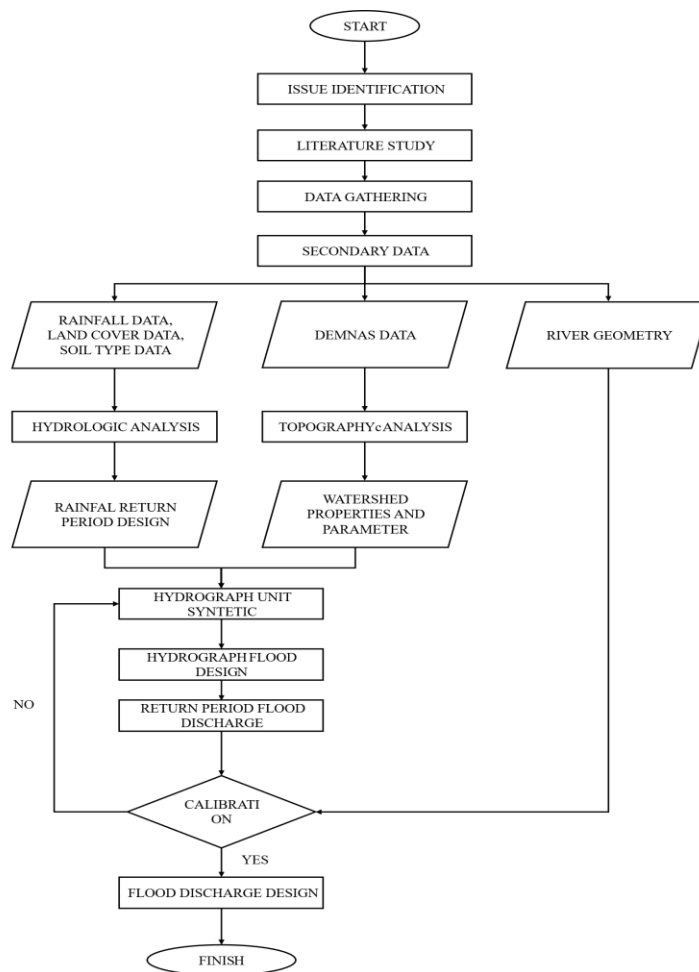


Figure 1. Research Flowchart

2.2. Land Cover Analysis

Land cover data were processed using ArcGIS 10.8 to generate land cover maps for 2015, 2019, and 2022. Spatial overlay and temporal analysis were applied to identify land cover changes and conversion trends (ESRI, 2020). The processed land cover data were used to determine hydrological parameters, including Curve Number (CN), impervious area, and initial abstraction (I_a). The weighted CN and initial abstraction (I_a) values were calculated using:

$$CN = \left(\frac{\sum A_i CN_i}{A_i} \right) \tag{1}$$

$$I_a: 0.2 S \tag{2}$$

$$S = \frac{25400}{CN} - 254 \tag{3}$$

where A_i is the area of each land cover type, CN_i is the corresponding Curve Number value, and S is watershed storage potential equal to maximum retention (mm). These equations are based on the SCS-CN method developed by the Soil Conservation Service (Chow *et al.*, 1998; USDA-NRCS, 2021).

2.3. Hydrological Analysis

To ensure data reliability, the rainfall datasets were subjected to comprehensive quality control tests, including consistency, outlier, trend, stability, and independence tests (Triatmodjo, 2008; Kim *et al.*, 2025). Design rainfall was determined using Normal, Log-Normal, Log-Pearson Type III, and Gumbel distributions.

The goodness-of-fit was evaluated using the Chi-Square and Kolmogorov–Smirnov tests (Chow *et al.*, 1998). Areal rainfall was estimated using the Thiessen Polygon method and adjusted with the Area Reduction Factor (ARF) suitable for large area (Pietersen & Gericke, 2019). Temporal rainfall distribution was applied using the PSA 007 method (SKBD, 2017). Figure 2 details the hydrological analysis steps performed for flood discharge design.

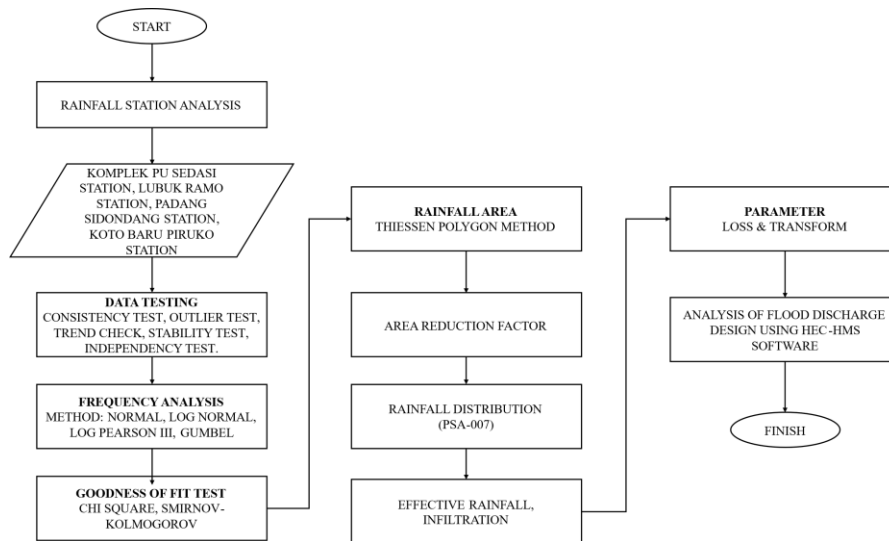


Figure 2. Hydrologic analysis flowchart

2.4. Hydrological Modeling (HEC-HMS)

Hydrological modeling was performed using HEC-HMS version 4.13 with the SCS-CN method for loss calculation and the SCS Unit Hydrograph for runoff transformation ((Hartawan *et al.*, 2025; Kumar *et al.*, 2021; Yu & Zhang, 2023). The SCS-CN (Soil Conservation Service Curve Number) is common model for rainfall estimation and the SCS-Unit Hydrograph model is popular tool for flood studies (Niyazi *et al.*, 2022). The modeling procedure included: (1) watershed delineation using DEMNAS data, (2) parameterization of CN, impervious area, and initial abstraction

based on land cover conditions, (3) development of the meteorological model using design rainfall, and (4) simulation of runoff hydrographs. The model outputs include discharge hydrographs and peak discharge values for return periods of 2 years (Q2) and 20 years (Q20). The Q20 discharge was used as the design flood based on PUPR Regulation No. 28 of 2015 (Menteri PUPR, 2015).

2.5. Calibration and Validation

Model calibration was conducted by comparing simulated discharge for a 2-year return period (Q2) with the estimated bankfull discharge of the Batang Timpeh River, derived from river geometry data at a representative cross-section that has not been affected by engineering modifications (Chow *et al.*, 1998). Due to the unavailability of observed discharge data, formal validation could not be performed. However, model outputs were evaluated through consistency checks with watershed characteristics and comparison with typical hydrological responses reported in similar studies (Kumar *et al.*, 2021). This approach provides a reasonable basis for assessing model reliability in data-scarce conditions.

3. RESULTS AND DISCUSSION

3.1. Watershed Characteristics

The delineation of the Batang Timpeh Watershed was performed using HEC-HMS version 4.13, with the outlet defined at the confluence of the Batang Timpeh River and the Batanghari River. The delineation results indicate that the watershed has a total area of 236.36 km² and is divided into nine sub-watersheds, labeled Dta-1 to Dta-9. Spatial visualization of the watershed and sub-watershed boundaries was generated using ArcGIS 10.8, as shown in Figure 3. These spatial data were used as the basis for integrating hydrological parameters and land cover information in the HEC-HMS model. The characteristics of each sub-watershed are presented in Table 1.

Topographic analysis of the Batang Timpeh Watershed was conducted using ArcGIS 10.8 based on slope classification following the Regulation of the Minister of Environment and Forestry No. 10 of 2022. The results indicate that the watershed is dominated by flat area (slope 0–8%) covering 27.6% of the area, followed by sloping (8–15%) at 19.2%, slightly steep (15–25%) at 16.6%, steep (25–45%) at 20.3%, and very steep slopes (>45%) at 16.1%. The spatial distribution of slope shows that flat areas are primarily located in the central part of the watershed, while

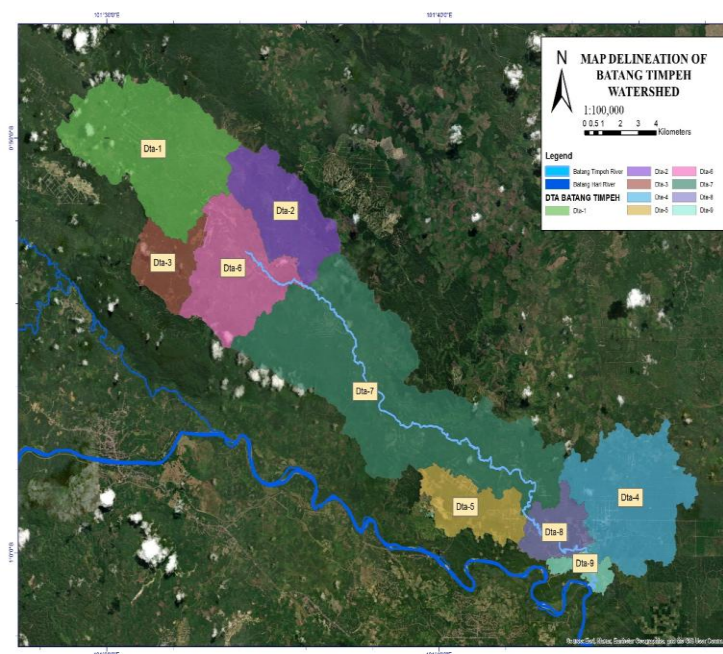


Figure 3. Map Delineation of Batang Timpeh Watershed

Table 1. Physical characteristic of Batang Timpeh Watershed

No	Sub-Watershed	Area (A)	Main River Length (L)	Main River Slope(S)	Watershed Slope
		(km ²)	(km)	(m/m)	(m/m)
1	Dta-1	42.251	14.799	0.007	0.244
2	Dta-2	20.205	9.812	0.011	0.286
3	Dta-3	10.322	8.762	0.042	0.351
4	Dta-4	32.824	10.856	0.002	0.133
5	Dta-5	12.624	8.397	0.002	0.179
6	Dta-6	25.007	11.407	0.012	0.236
7	Dta-7	80.771	29.218	0.001	0.244
8	Dta-8	8.699	6.887	0.002	0.162
9	Dta-9	3.656	6.495	0.002	0.138
Total		236.359	106.64		

steeper slopes are concentrated toward the outer boundaries, forming the watershed perimeter (Figure 4). This topographic configuration influences runoff concentration and flow response within the watershed. Slope characteristics were further used to estimate the time coefficient (Ct) in the Snyder Unit Hydrograph for each sub-watershed, representing the response time of the watershed to rainfall. The calculated Ct values are presented in Table 2. Soil analysis indicates that the watershed consists of two dominant soil textures, namely sandy clay loam (Hydrologic Soil Group C) and clay (Hydrologic Soil Group D). The analysis shows that clay soils dominate the study area, as illustrated in Figure 5. These soil characteristics indicate low infiltration capacity and a high potential for surface runoff, which significantly influence hydrological response in the SCS-CN method.

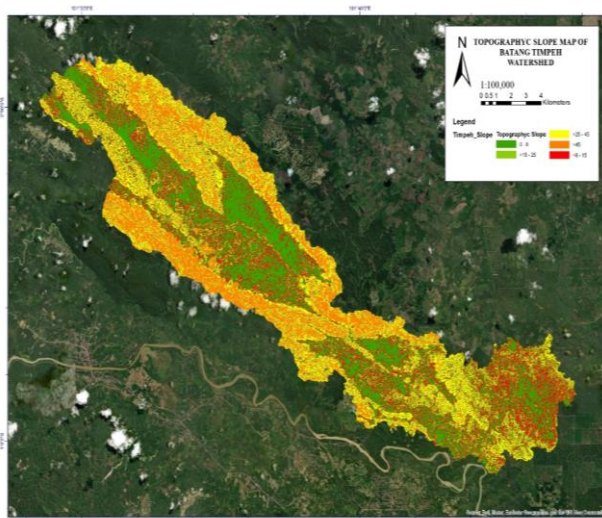


Figure 4. Topographic slope of Batang Timpeh Watershed

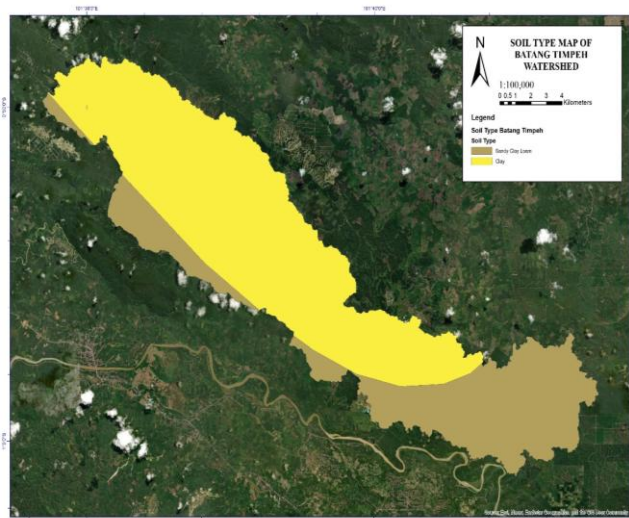


Figure 5. Soil type map of Batang Timpeh Watershed

3.2. Land Cover Change

Land cover of Batang Timpeh Watershed in 2015, 2019, and 2022 dominated by plantations and secondary dryland forest. In 2015 besides plantations, Batang Timpeh Watershed dominated by secondary dryland forest and bushland which clearly can be seen changes in 2019. Secondly, dryland forest has decreased area 3% and bushland decreased by 2.67% which is in line with the increase in plantations land by 9.76%. In 2022, there was a change in bushland with 6.69% amount which in line with the increase of plantations, secondary dryland forest, transmigration and addition of housing area. All the land cover presented in Table 3 and Figure 6 While map of land cover change shows in Figure 7.

Table 2. Topographic slope of 9 sub-watersheds (Dta-1 to Dta-9) within the Batang Timpeh Watershed

DTA	Slope	Slope Class	Area (km ²)	Percentage (%)	Time Coefficient (Ct)	Ct per DTA
Dta-1	0 - 8	Flat	10.600	25.09	2.2	2.01
	>8 - 15	Slope	6.490	15.36	2.1	
	>15 - 25	Slightly Steep	6.793	16.08	2	
	>25 - 45	Steep	10.973	25.97	1.9	
	>45	Very Steep	7.395	17.50	1.8	
	Total		42.251	100.00		
Dta-2	0 - 8	Flat	4.500	22.27	2.2	1.95
	>8 - 15	Slope	2.141	10.60	2.1	
	>15 - 25	Slightly Steep	2.473	12.24	2	
	>25 - 45	Steep	6.060	29.99	1.9	
	>45	Very Steep	5.031	24.90	1.8	
	Total		20.205	100.00		
Dta-3	0 - 8	Flat	1.256	12.16	2.2	1.89
	>8 - 15	Slope	1.230	11.92	2.1	
	>15 - 25	Slightly Steep	1.400	13.56	2	
	>25 - 45	Steep	2.800	27.13	1.9	
	>45	Very Steep	3.637	35.23	1.8	
	Total		10.322	100.00		
Dta-4	0 - 8	Flat	10.501	31.99	2.2	2.11
	>8 - 15	Slope	10.932	33.30	2.1	
	>15 - 25	Slightly Steep	8.120	24.74	2	
	>25 - 45	Steep	3.168	9.65	1.9	
	>45	Very Steep	0.103	0.31	1.8	
	Total		32.824	100.00		
Dta-5	0 - 8	Flat	3.645	28.87	2.2	2.05
	>8 - 15	Slope	2.796	22.15	2.1	
	>15 - 25	Slightly Steep	2.765	21.90	2	
	>25 - 45	Steep	2.686	21.28	1.9	
	>45	Very Steep	0.732	5.80	1.8	
	Total		12.624	100.00		
Dta-6	0 - 8	Flat	7.628	30.50	2.2	2.03
	>8 - 15	Slope	4.828	19.31	2.1	
	>15 - 25	Slightly Steep	3.732	14.92	2	
	>25 - 45	Steep	4.138	16.55	1.9	
	>45	Very Steep	4.681	18.72	1.8	
	Total		25.007	100.00		
Dta-7	0 - 8	Flat	23.204	28.73	2.2	2.01
	>8 - 15	Slope	13.905	17.22	2.1	
	>15 - 25	Slightly Steep	11.271	13.95	2	
	>25 - 45	Steep	16.199	20.06	1.9	
	>45	Very Steep	16.192	20.05	1.8	
	Total		80.771	100.00		
Dta-8	0 - 8	Flat	2.637	30.31	2.2	2.06
	>8 - 15	Slope	1.997	22.96	2.1	
	>15 - 25	Slightly Steep	2.043	23.48	2	
	>25 - 45	Steep	1.813	20.84	1.9	
	>45	Very Steep	0.210	2.41	1.8	
	Total		8.699	100.00		
Dta-9	0 - 8	Flat	1.255	34.31	2.2	2.08
	>8 - 15	Slope	0.995	27.22	2.1	
	>15 - 25	Slightly Steep	0.861	23.56	2	
	>25 - 45	Steep	0.423	11.57	1.9	
	>45	Very Steep	0.122	3.34	1.8	
	Total		3.656	100.00		

Table 3. Land cover recapitulation of Batang Timpeh Watershed

Land Cover Recapitulation	Area 2022		Area 2019		Area 2015	
	km ²	%	km ²	%	km ²	%
Secondary Dryland Forest	29.10	12.31	27.33	11.56	34.43	14.57
Plantation	167.95	71.06	158.97	67.26	135.90	57.50
Dryland Agriculture	5.36	2.27	5.69	2.41	5.66	2.39
Dry Land Agriculture with Mixed Bushes	16.88	7.14	13.38	5.66	5.70	2.41
Rice Fields	0.00	0.00	0.70	0.30	0.70	0.30
Bushland	6.33	2.68	22.13	9.36	28.44	12.03
Open Space	1.55	0.66	2.09	0.89	21.74	9.20
Transmigration	4.11	1.74	1.59	0.67	1.59	0.67
Housing	5.08	2.15	4.47	1.89	2.19	0.93
Batang Timpeh Watershed	236.36	100	236.36	100	236.36	100

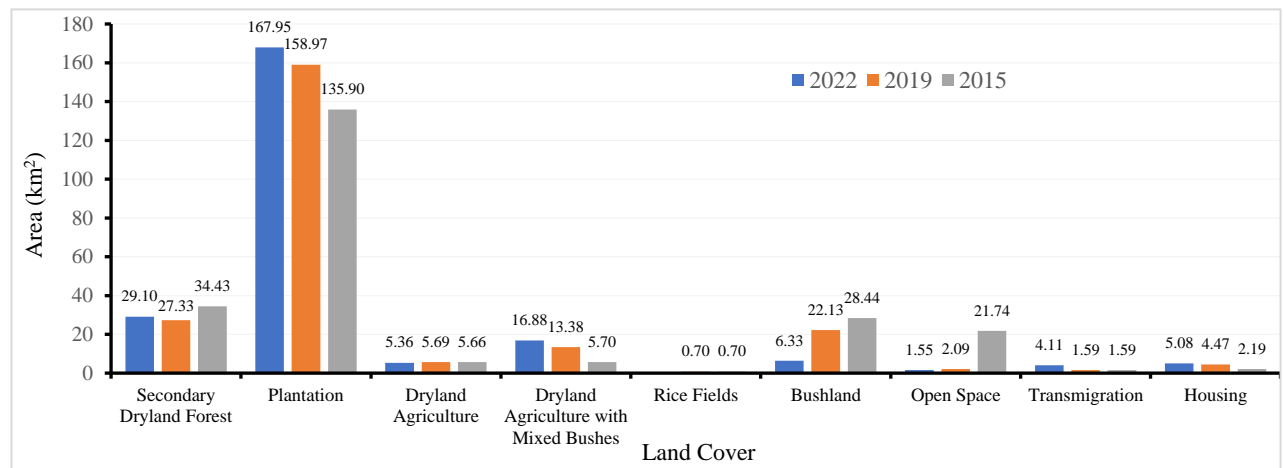


Figure 6. Land cover area comparison for Batang Timpeh Watershed in 2022, 2019, 2015.

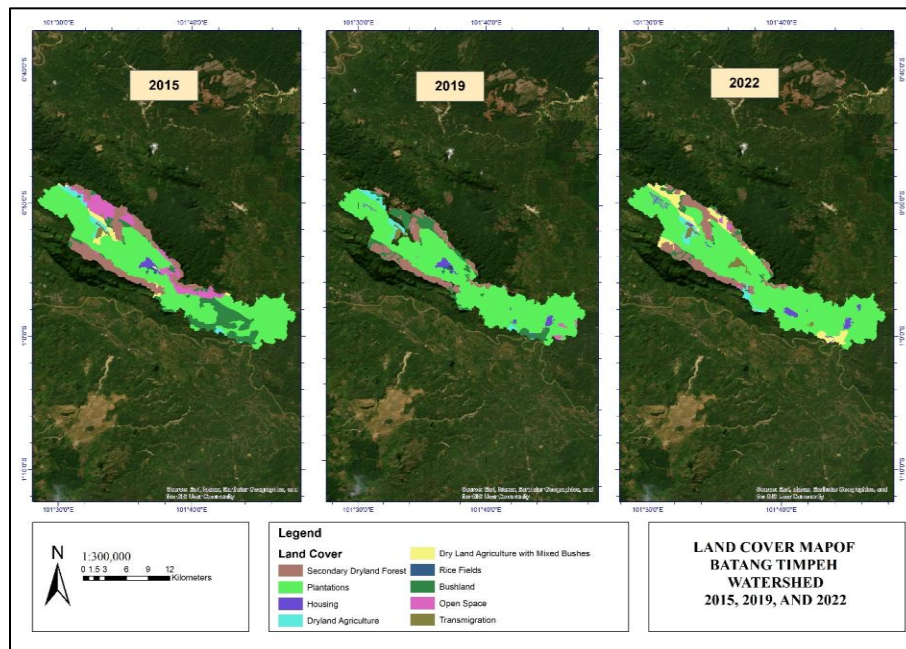


Figure 7. Land cover map of Batang Timpeh Watershed in 2015, 2019, and 2022

Based on analysis results, land cover changes at Batang Timpeh Watershed show dynamic changes in 2015, 2019, and 2022 as shown in Figure 6. Plantations have significantly increase from 57.5% (2015) to 71.06% (2022), for 8 years has increase by 13.56% (32.05 km²). Housing land shows upward tren from 0.93% (2015) to 2.15% (2022) which increases by 1.22%, in line with trasmigration from 0.67% (2015) to 1.74% (2022). Then, secondary dryland forest decrease area from 14.57% (2015) to 12.31% (2022). Land cover changes are simultaneously increasing CN value which have impact to surface discharge, especially in urban and industry area (Rizaldi *et al.*, 2022).

3.3. Hydrological Analysis

3.3.1. Calibration and Consistency Test of Rainfall Data

Rainfall data used on this test are annual maximum rainfall from 4 Rainfall Station: Komplek PU Sedasi Station, Lubuk Ramo Station, Padang Sidondang Station, and Koto Baru Piruko Station with data availability period 2012-2024. Rainfall Station distribution at Batang Timpeh Watershed shown in Figure 8.

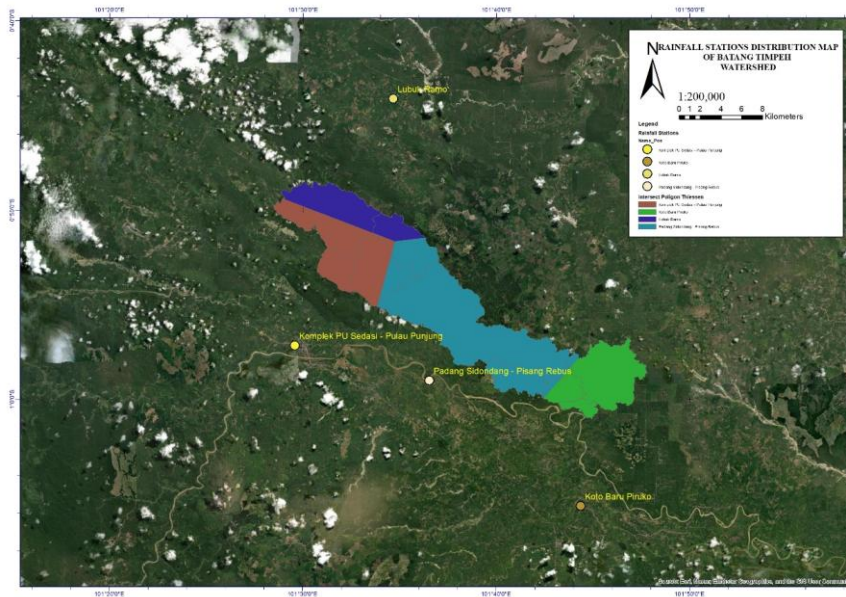


Figure 8. Distribution Map of Batang Timpeh Watershed Rainfall Station

From the collected data, rain data was test including consistency test, outlier test, tren test, stability test, and independency test. Consistency test of rainfall satation on Batang Timpeh Watershed shows that statistic value Q/\sqrt{n} and R/\sqrt{n} at Batang Timpeh Watershed Rainfall Station are in the allowable critical boundary. Consistency test recapitulation of Batang Timpeh Watershed Rainfall Station presented in Table 1. Consistency test rainfall station within the Batang Timpeh Watershed.

Parameter	Komplek PU Sedasi	Lubuk Ramo	Padang Sidondang	Koto Baru Piruko
n	13	13	13	13
Dy	23.11	74.86	18.13	29.24
Sk** max	1.45	2.81	2.05	2.07
Sk** min	-1.53	-1.06	-1.70	-1.59
Q	1.45	2.81	2.05	2.07
R	2.99	3.88	3.75	3.66
Q/\sqrt{n}	0.40	0.78	0.57	0.57
R/\sqrt{n}	0.83	1.08	1.04	1.01
	Meets Consistency	Meets Consistency	Meets Consistency	Meets Consistency

Table 1. Consistency test rainfall station within the Batang Timpeh Watershed.

Parameter	Komplek PU Sedasi	Lubuk Ramo	Padang Sidondang	Koto Baru Piruko
n	13	13	13	13
Dy	23.11	74.86	18.13	29.24
Sk** max	1.45	2.81	2.05	2.07
Sk** min	-1.53	-1.06	-1.70	-1.59
Q	1.45	2.81	2.05	2.07
R	2.99	3.88	3.75	3.66
Q/\sqrt{n}	0.40	0.78	0.57	0.57
R/\sqrt{n}	0.83	1.08	1.04	1.01
	Meets Consistency	Meets Consistency	Meets Consistency	Meets Consistency

Then, outlier test was used to see data distribution of Batang Timpeh Watershed to outlier boundary which use Water Resources Council method. Based on Figure 9 distribution data at Batang Timpeh Watershed Rainfall Station are in outlier boundary range so can be concluded there are No. outlier data or the recorded rainfall data does not exceed the upper limit of the outlier or less than the lower limit of the outlier.

LEGEND:

- : RAINFALL DATA PLOT
- (orange) : UPPER LIMIT OUTLIER
- (grey) : LOWER LIMIT OUTLIER

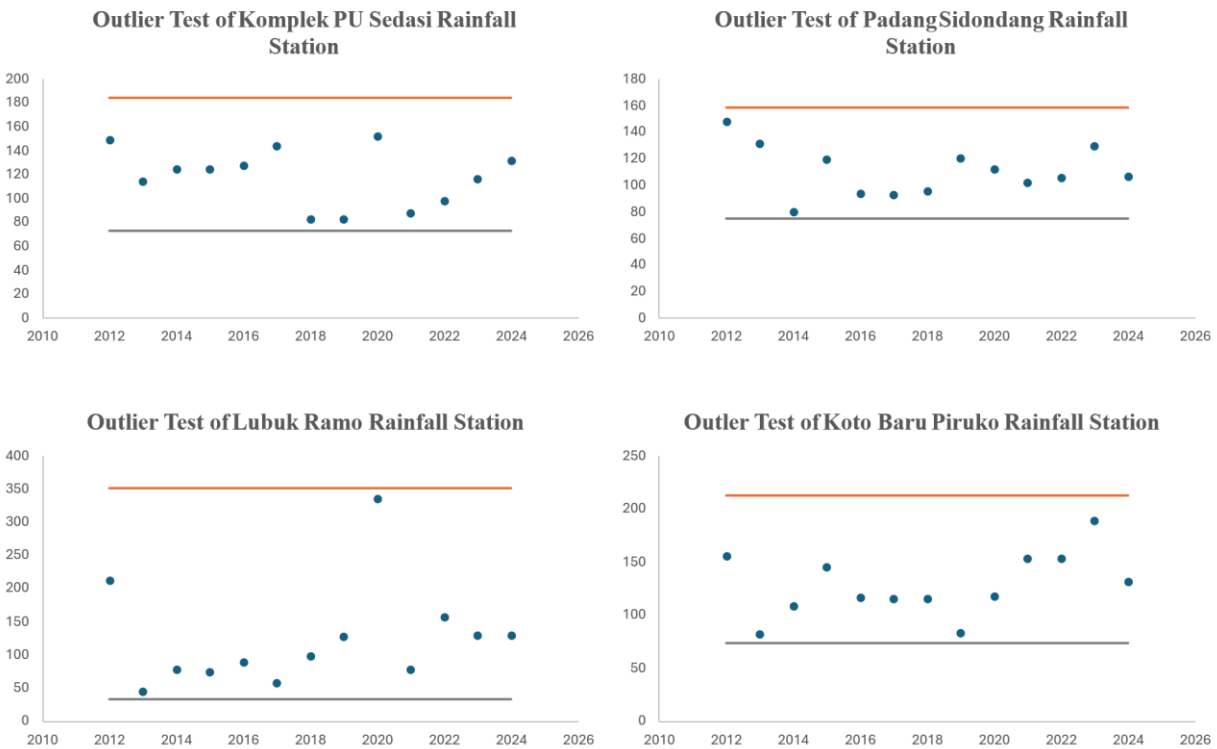


Figure 9. Outlier Test of Batang Timpeh Watershed Rainfall Station

Table 5. Trend check for rainfall stations within Batang Timpeh Watershed

Trend Check	Rainfall Station			
	Komplek PU Sedasi	Lubuk Ramo	Padang Sidondang	Koto Baru Piruko
Total	276	512	334	497
Number of data (n)	13	13	13	13

RSP	0.241758	-0.40659	0.082418	-0.36538
<i>t</i> -calculated	0.826333	-1.47603	0.274281	-1.30186
<i>t</i> -critical (20; 2.5%)	-2.18	-2.18	-2.18	-2.18
<i>t</i> -critical (20; 97.5%)	2.18	2.18	2.18	2.18
Conclustion <i>t</i> -critical (20; 5%) < <i>t</i> -calculated < <i>t</i> -critical (20; 95%)	No Trend	No Trend	No Trend	No Trend

Trend check was tested for rainfall data for assesment of Batang Timpeh Watershed Rainfall Station. Based on Table 5, the *t* value from all of the Batang Timpeh Watershed Rainfall is in specified *t* criticall so based on trend check, there are no trend data on Batang Timpeh Watershed Rainfall Station. The stability test of Batang Timpeh Watershed Rainfall Data presented in Table 6, stability check conducted with 13 data divided into 2 group data.

Table 6. Stability test of rainfall stations within Batang Timpeh Watershed

Year	Rainfall (mm) (X)			
	Komplek PU Sedasi	Lubuk Ramo	Padang Sidondang	Koto Baru Piruko
Group 1				
2012	149	213	148	156
2013	115	45	132	82
2014	125	78	80	109
2015	125	74	120	145
2016	128	90	94	117.2
2017	144	58	93	116
2018	83	99	96	116
<i>n</i> ₁	7	7	7	7
\bar{x}_1	124	94	109	120.17
<i>s</i> ₁	20.0	51.5	22.87	22.44
<i>s</i> ₁ ²	400.7	2652.1	523.14	503.66
Group 2				
2019	83	128.5	121	83
2020	152	335	112	118
2021	88	77.6	102	154
2022	98	158	106	153
2023	117	130.6	130	189
2024	132	130.5	107	132
<i>n</i> ₂	6	6	6	6
\bar{x}_2	112	160.03	113	138.17
<i>s</i> ₂	24.6	81.80	9.66	33.02
<i>s</i> ₂ ²	606.2	6690.94	93.33	1090.47
Varian Stability				
<i>v</i> ₁	7	7	7	7
<i>v</i> ₂	6	6	6	6
0.025	0.195	0.195	0.195	0.195
0.975	5.70	5.7	5.7	5.7
F _t	0.66	0.3964	5.6051	0.4619
Conclusion	Stable	Stable	Stable	Stable
Mean Stability				
V	13	13	13	13
0.025	-2.18	-2.18	-2.18	-2.18
0.975	2.2	2.18	2.18	2.18
tt	0.28	0.37953	0.2045336	0.27462
Conclusion	Stable	Stable	Stable	Stable

Therefore, the independence test was used for Batang Timpeh Watershed Rainfall Station. Based on Table 7, the values are in range of lower limit and upper limit, so the data series of Batang Timpeh Watershed are independent.

After conducting a correlation test of rainfall data, it can be concluded that rainfall data from 4 rainfall stations meets the test criteria. The recapitulation test of Batang Timpeh Watershed presented in Table 8.

Table 7. Independency test of rainfall stations within Batang Timpeh Watershed

Independency Test	Komplek PU Sedasi	Lubuk Ramo	Padang Sidondang	Koto Baru Piruko
Total	-1078.38	6945.08	-5751.58	72852.99
Average	118	124	111	128
<i>n</i>	13	13	13	13
r1	-0.16	-0.08	0.16	0.34
Lower Limit	-0.63	-0.63	-0.63	-0.63
Upper Limit	0.46	0.46	0.46	0.46
Decision	Data series are independent	Data series are independent	Data series are independent	Data series are independent

Table 8. Recapitulation test results of rainfall data from four station within Batang Timpeh Watershed

Station	Test				
	Consistency	Outlier	Trend	Stability	Independency
Komplek PU Sedasi	√	√	√	√	√
Lubuk Ramo	√	√	√	√	√
Padang Sidondang	√	√	√	√	√
Koto Baru Piruko	√	√	√	√	√

3.3.2. Rainfall Design

Frequency analysis was used for calculation of rainfall design with Q1.5, Q2, Q5, Q10, Q20, Q25, Q50, Q100, Q200, Q500 and Q1000 return period with Normal, Log Normal, Log Pearson III, and Gumbel Distribution Method as shown in Table 9 for four rainfall stations (Komplek PU Sedasi, Lubuk Ramo, Padang Sidondang, and Koto Baru Piruko). Frequency analysis was applied on annual maximum rainfall data. Goodness of fit test use Chi-Square Test and Smirnov-Kolmogorov Test. Based on analysis results and compared to Weibull Graphyc from Hydrogonomon Software 4.0.3 Version, can be concluded that Gumble Distribution is closest to statistical criteria. So, for this research, Gumble Method are selected for hydrological analysis on Batang Timpeh Watershed.

3.3.3. Curve Number (CN) and Impervious

Infiltration and effective rainfall calculation on HEC-HMS Simulation for each sub-watershed (Dta-1 to Dta-9) influenced by land cover parameter, soil texture classification & hydrologic soil group (HSG), and impervious area. Combination of HSG and land cover determine CN value that is used for calculate the magnitude of direct runoff. Soil group of Batang Timpeh Watershed area Group C and Group D. This grouping shows different values on soil infiltration on Batang Timpeh Watershed area. Land cover changes in 2015, 2019, and 2022 impacted the increase of CN and impervious. Significant changes happen to sub-watershed Dta-8 from 2015 to 2019, with difference increase are 4.35% so it increases runoff volume and accelerate flood response. Highest CN in 2022 have founded on sub-watershed Dta-1 (CN: 80.39), shows that this area has biggest potential surface runoff, this is because in 2022 the Dta-1 sub-watershed dominated by plantation 71.06%. Based on land cover analysis, calculated Curve Number (CN) and Impervious, lag time (T_L) and time of concentration (T_C) was calculated as the following (USDA-NRCS, 1986):

$$T_L = 0.6 T_c \tag{4}$$

$$T_c = \frac{L^{0.8}(S+2.54)^{0.7}}{1410Y^{0.5}} \tag{5}$$

where L is flow length (m), S maximum retention, and Y average of sub-watershed slope.

Analysis results show that their area changes in Batang Timpeh Sub-Watershed Characteristic between 2015, 2019, and 2022 which is characterized by change of land cover composition, especially the increase of plantations area. These changes have impact on Watershed Hydrologic response which is reflected by the increase of curve number

composite from 76.96 in 2015 to 77.61 in 2019 and 78.53 in 2022. Overall, CN increased by 2% during the 2015-2022 period. Initial abstraction (I_a) shows an inverse relationship with CN, where the increase of CN affect decrease of I_a , so surface runoff forms faster and have potential to increase flood discharge. Results of CN, T_L , I_a , and impervious percentage for each sub-watershed shows in Table 10 for year 2015, 2019, and 2022.

3.4. Model Results (Discharge)

Flood discharge design with 20-year return period (Q_{20}) use Unit Hydrograph Soil Conservation Services – Curve Number with hydrological input hourly rainfall distribution in any analyzed return period, and watershed parameters, such as curve number (CN) in J-4 (Batang Timpeh River Inlet). This inlet is located at Batang Timpeh Sta RS.512 T.12b which is upstream part with no affected by river engineering, as shown in Figure 10. For discharge design calibration of HEC-HMS results, discharge results with 2-year return period are compared with bankfull discharge at river upstream which not yet affected by river engineering. Bankfull discharge calculation (Figure 11) use trial and error method by HEC-RAS 1D modelling, so the bankfull discharge are 73.83 m³/s.

Table 9. Rainfall design of four rainfall stations within Batang Timpeh Watershed

Tr (year)	Komplek PU Sedasi Station. (mm)				Lubuk Ramo Station. (mm)				Padang Sidondang Station. (mm)				Koto Baru Piruko Station. (mm)			
	Normal	Log Normal	Log P III*	Gumbel	Normal	Log Normal	Log P III*	Gumbel	Normal	Log Normal	Log P III*	Gumbel	Normal	Log Normal	Log P III*	Gumbel
1.5	108.10	105.86	107.59	105.79	91.09	85.23	82.36	83.61	102.78	101.72	101.70	100.96	115.46	112.71	113.97	112.54
2	118.38	116.00	118.14	114.43	124.41	107.53	102.71	111.60	110.85	109.38	109.36	107.74	128.48	125.09	126.71	123.47
5	138.63	138.87	139.29	135.70	189.97	169.90	166.67	180.49	126.73	126.19	126.19	124.43	154.09	153.55	153.97	150.38
10	149.22	152.58	150.36	149.78	224.28	215.85	220.70	226.11	135.03	135.99	136.01	135.48	167.48	170.93	169.31	168.20
20	157.96	164.92	159.40	163.29	252.60	263.01	282.44	269.86	141.89	144.66	144.70	146.08	178.55	186.76	182.48	185.29
25	160.51	168.70	162.01	167.58	260.85	278.59	304.26	283.74	143.89	147.28	147.34	149.44	181.77	191.64	186.39	190.71
50	167.80	180.00	169.38	180.78	284.46	328.49	379.00	326.49	149.61	155.07	155.16	159.79	190.99	206.32	197.79	207.41
100	174.36	190.81	175.89	193.88	305.70	380.97	465.71	368.93	154.76	162.42	162.55	170.07	199.29	220.49	208.26	223.99
200	180.36	201.26	181.72	206.94	325.14	436.30	566.37	411.22	159.46	169.45	169.62	180.31	206.88	234.31	218.00	240.50
500	187.63	214.71	188.59	224.16	348.69	514.22	724.67	467.00	165.17	178.38	178.61	193.82	216.08	252.21	230.00	262.29
1000	192.73	224.67	193.28	237.18	365.21	577.04	866.81	509.16	169.17	184.92	185.21	204.04	222.53	265.58	238.51	278.76
Kolmogorof-Smirnov Test																
D _{max}	0.045	0.101	0.045	0.044	0.109	0.101	0.045	0.071	0.044	0.101	0.045	0.045	0.046	0.101	0.045	0.042
D _{kritis}	0.349	0.349	0.349	0.349	0.349	0.349	0.349	0.349	0.349	0.349	0.349	0.349	0.349	0.349	0.349	0.349
Notes	Accepted	Accepted	Accepted	Accepted	Accepted	Accepted	Accepted	Accepted	Accepted	Accepted	Accepted	Accepted	Accepted	Accepted	Accepted	Accepted
Chi-Square Test																
χ^2_b	0.46	1.23	0.46	2.00	0.46	2.77	2.00	2.00	0.46	1.23	0.46	2.00	0.46	1.23	1.23	2.00
χ^2_c	5.99	5.99	5.99	5.99	5.99	5.99	5.99	5.99	5.99	5.99	5.99	5.99	5.99	5.99	5.99	5.99
Notes	Accepted	Accepted	Accepted	Accepted	Accepted	Accepted	Accepted	Accepted	Accepted	Accepted	Accepted	Accepted	Accepted	Accepted	Accepted	Accepted
Statistical Parameter Terms																
1	Normal	Cs ≈ 0	0.05	Not Accepted	Normal	Cs ≈ 0	0.05	Not Accepted	Normal	Cs ≈ 0	0.05	Not Accepted	Normal	Cs ≈ 0	0.05	Not Accepted
		Ck = 3	-0.67	Not Accepted		Ck = 3	-0.67	Not Accepted		Ck = 3	-0.67	Not Accepted				
2	Log Normal	Cs = 3	0.38	Not Accepted	Log Normal	Cs = 3	0.87	Not Accepted	Log Normal	Cs = 3	0.32	Not Accepted	Log Normal	Cs = 3	0.42	Not Accepted
		Ck = 5.383	-0.58	Not Accepted		Ck = 5.383	0.25	Not Accepted		Ck = 5.383	-0.65	Not Accepted		Ck = 5.383	-0.53	Not Accepted
3	Log P III*	Cs ≠ 0	0.10	Accepted	Log P III*	Cs ≠ 0	0.58	Accepted	Log P III*	Cs ≠ 0	0.03	Accepted	Log P III*	Cs ≠ 0	0.14	Accepted
4	Gumbel	Cs ≤ 1.1396	0.57	Accepted	Gumbel	Cs ≤ 1.1396	0.57	Accepted	Gumbel	Cs ≤ 1.1396	0.57	Accepted	Gumbel	Cs ≤ 1.1396	0.57	Accepted
		Ck ≤ 5.4002	-0.20	Accepted		Ck ≤ 5.4002	-0.20	Accepted		Ck ≤ 5.4002	-0.20	Accepted		Ck ≤ 5.4002	-0.20	Accepted

Note: Log P III = Log Pearson III

Table 10. Parameter of CN, Ia, and Imp for Batang Timpeh Watershed in 2015, 2019, and 2022

No	Sub-W	Area (km ²)	CN	C1	Ct	L (km)	L _c (km)	T _L (h)	T _L (min)	PC	S	Ia (mm)	Imp. (%)
Year 2015													
1	Dta-1	42.25	79.87	0.75	2.01	14.80	9.9	6.73	403.64	0.69	64.0	12.80	5.00
2	Dta-2	20.21	78.41	0.75	1.95	9.81	6.5	5.11	306.54	0.69	69.9	13.99	5.00
3	Dta-3	10.32	74.36	0.75	1.89	8.76	5.8	4.61	276.36	0.69	87.6	17.52	5.00
4	Dta-4	32.82	77.74	0.75	2.11	10.86	7.2	5.86	351.45	0.69	72.7	14.54	5.00
5	Dta-5	12.62	77.63	0.75	2.05	8.40	5.6	4.88	292.55	0.69	73.2	14.64	5.00
6	Dta-6	25.01	78.83	0.75	2.03	11.41	7.6	5.80	347.87	0.69	68.2	13.65	5.00
7	Dta-7	80.77	79.03	0.75	2.01	29.22	19.5	10.13	607.96	0.63	67.4	13.48	5.68
8	Dta-8	8.70	73.52	0.75	2.06	6.89	4.6	4.35	260.97	0.69	91.5	18.29	5.00
9	Dta-9	3.66	73.20	0.75	2.08	6.50	4.3	4.25	254.99	0.69	93.0	18.59	5.00
Year 2019													
1	Dta-1	42.25	80.20	0.75	2.01	14.80	9.9	6.73	403.64	0.69	62.7	12.54	5.21
2	Dta-2	20.21	78.40	0.75	1.95	9.81	6.5	5.11	306.54	0.69	70.0	13.99	5.00
3	Dta-3	10.32	74.36	0.75	1.89	8.76	5.8	4.61	276.36	0.69	87.6	17.52	5.00
4	Dta-4	32.82	78.00	0.75	2.11	10.86	7.2	5.86	351.45	0.69	71.6	14.33	6.00
5	Dta-5	12.62	78.39	0.75	2.05	8.40	5.6	4.88	292.55	0.69	70.0	14.01	5.64
6	Dta-6	25.01	78.82	0.75	2.03	11.41	7.6	5.80	347.87	0.69	68.3	13.65	5.00
7	Dta-7	80.77	79.97	0.75	2.01	29.22	19.5	10.13	607.96	0.63	63.6	12.72	5.70
8	Dta-8	8.70	76.72	0.75	2.06	6.89	4.6	4.35	260.97	0.69	77.1	15.41	5.35
9	Dta-9	3.66	73.60	0.75	2.08	6.50	4.3	4.25	254.99	0.69	91.1	18.23	5.59
Year 2022													
1	Dta-1	42.25	80.39	0.75	2.01	14.80	9.9	6.73	403.64	0.69	62.0	12.39	5.74
2	Dta-2	20.21	77.03	0.75	1.95	9.81	6.5	5.11	306.54	0.69	75.7	15.15	5.00
3	Dta-3	10.32	75.22	0.75	1.89	8.76	5.8	4.61	276.36	0.69	83.7	16.74	5.00
4	Dta-4	32.82	78.57	0.75	2.11	10.86	7.2	5.86	351.45	0.69	69.3	13.86	6.28
5	Dta-5	12.62	79.13	0.75	2.05	8.40	5.6	4.88	292.55	0.69	67.0	13.40	6.80
6	Dta-6	25.01	79.13	0.75	2.03	11.41	7.6	5.80	347.87	0.69	67.0	13.40	5.37
7	Dta-7	80.77	80.10	0.75	2.01	29.22	19.5	10.13	607.96	0.63	63.1	12.62	5.19
8	Dta-8	8.70	77.81	0.75	2.06	6.89	4.6	4.35	260.97	0.69	72.4	14.49	5.35
9	Dta-9	3.66	77.27	0.75	2.08	6.50	4.3	4.25	254.99	0.69	74.7	14.94	5.89

Note: Sub-W = Sub-watershed; CN = Curve Number; Ct = Time coefficient; L = River length; L_c = Watershed weight point; T_L = Time lag; PC = Peaking coefficient; S = Potential maximum retention; Ia = Initial abstraction; Imp = Impervious.

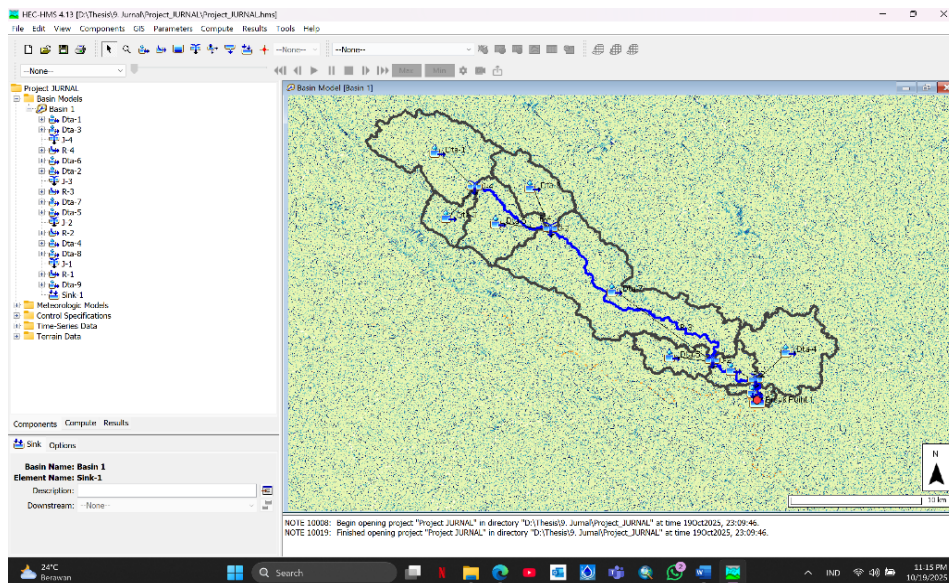


Figure 10. Inlet point J-4 of Batang Timpeh Watershed

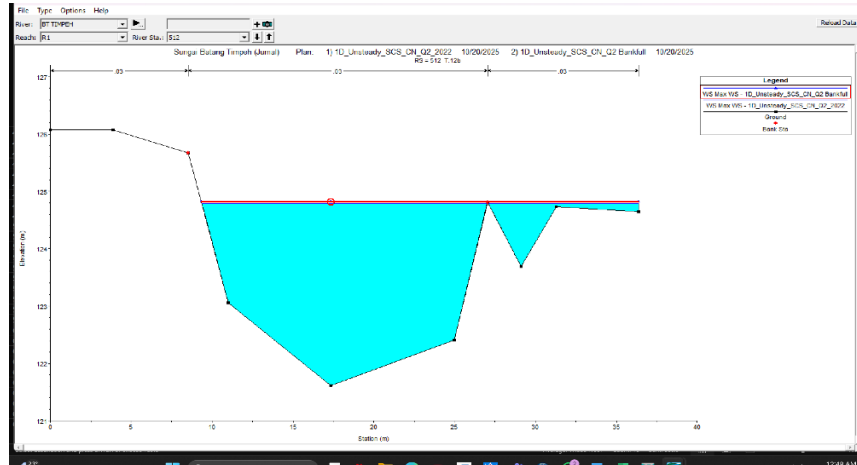


Figure 11. Calibration location for QBankfull RS.512 T.12b

Profile Output Table - Standard Table 1

HEC-RAS River: BT TIMPEH Reach: R1 Profile: Max

Reach	River Sta	Profile	Plan	Q Total (m3/s)
R.1	512	Max WS	1D_Unsteady_SCS_CN_Q2_2022	71.35
R.1	512	Max WS	1D_Unsteady_SCS_CN_Q2 Bankfull	73.83

Figure 12. QBankfull profile and Q₂ SCS-CN for land cover 2022

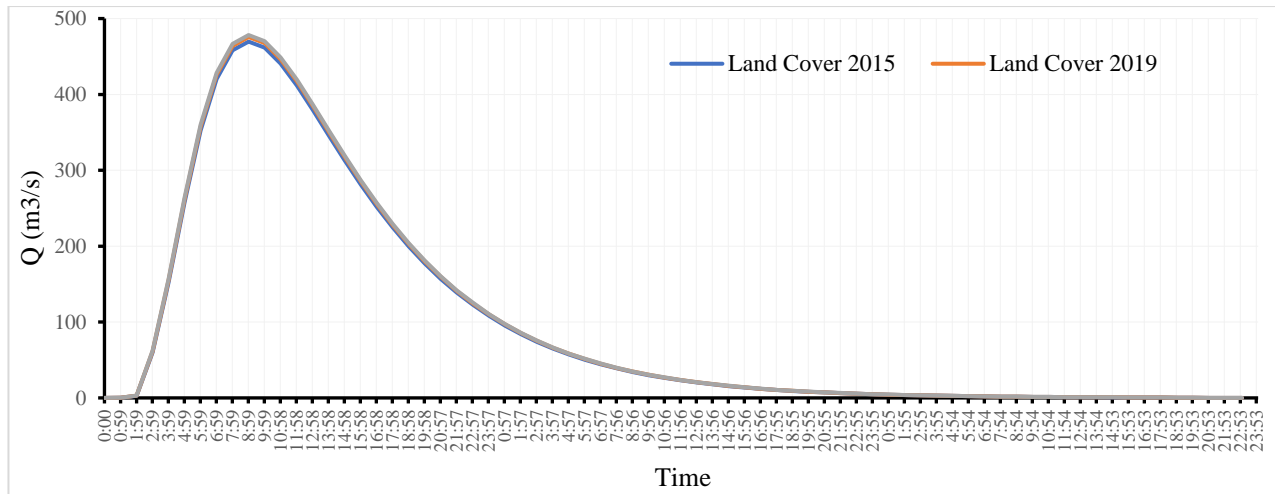


Figure 13. Q₂₀ flood discharge (Sink-1) due to land cover changes in 2015, 2019, and 2022

Based on flood discharge design analysis for land cover 2022 condition, SCS-CN method produce Q₂ flood discharge 71.35 m³/s (Figure 12). This value closest to bankfull discharge of Batang Timpeh River, so SCS-CN can be used for Q₂₀ flood discharge calculations. Flood discharge results with Q₂₀ return year period at downstream outlet of Batang Timpeh River (Sink-1) use SCS Syntetic Unit Hydrograph for land cover conditions 2015, 2019, and 2022 are detailed in Figure 13 with summary presented in Table 11.

Table 11. Recapitulation results of Q₂₀ flood analysis for Batang Timpeh Watershed

Land Cover Year	Peak Discharge (m ³ /s)	Average CN	Initial Abstraction (Ia) (mm)
2015	469.60	76.96	15.28
2019	475.70	77.61	14.71
2022	478.30	78.29	14.11

3.5. Discussion (Interpretation)

SCS-CN method capable to integrate land cover parameter, soil type, and initial abstraction in estimating spatial surface runoff (Keogh *et al.*, 2009; Kumar *et al.*, 2021) and have high accuration in representate discharge design due to land cover changes (Wahyuni & Sachro, 2024). HEC-HMS simulation with SCS-CN Unit Hydrograph shows that land cover changes in 2015, 2019, and 2022 affect to increase of peak discharge and decrease of time lag that enters the Batang Timpeh River. Based on Table 11, peak discharge increase from 469.60 m³/s (2015) to 478.30 m³/s (2022) with increase value by 8.70 m³/s. This is in line with the increase of CN from 76.95 (2015) to 78.29 (2022) with increase value by 1.34 and decreased Ia from 15.27 mm (2015) to 14.10 mm (2022) with decreased value by 1.17 mm, indicate that runoff has much faster and bigger.

This condition indicates that land cover changes between 2015 to 2022 cause increase in Batang Timpeh Hydrologic Respone which shows by increase of Curve Number Value, decrease of Initial Abstraction (Ia), and increase of peak flood discharge, which in the end increase risk of flood around Batang Timpeh River. This condition indicates the formation of faster surface runoff and bigger volumes, so increase flood events potential around Batang Timpeh River. Based on this research results, land cover management is an important factor in controlling the watershed hydrologic response, especially in areas with significantly land cover changes. Land cover management is expected to contribute to suppressing the increase of surface runoff and peak flood discharge. This research results in line with findings (Rizaldi *et al.*, 2022) which show that increase of CN value due to land cover changes contribute to the increase of peak flood discharge.

4. CONCLUSIONS

This study demonstrates that land cover change has significantly influenced the hydrological response of the Batang Timpeh Watershed. The expansion of plantation and built-up areas between 2015 and 2022 resulted in increased Curve Number (CN) values and reduced initial abstraction (Ia), indicating a decline in infiltration capacity. Consequently, the simulated peak discharge for the 20-year return period (Q₂₀) increased from 469.60 m³/s in 2015 to 478.30 m³/s in 2022, representing a 1.85% increase. Although the magnitude of change is relatively moderate, it indicates a consistent trend toward faster runoff generation and a higher flood potential, particularly in the downstream area. These findings emphasize the critical role of land use management in controlling watershed hydrological response and reducing flood risk. Limiting uncontrolled land conversion and maintaining infiltration capacity are essential to mitigate future flood hazards in the Batang Timpeh Watershed. However, this study is limited by the absence of observed discharge data for model validation. Future research should incorporate field-based hydrological measurements and consider the combined effects of land cover change and rainfall variability to improve model reliability.

AUTHOR CONTRIBUTION STATEMENT

Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
DI	✓	✓			✓				✓	✓				✓
IS										✓		✓		
INYM					✓					✓		✓		
RNN									✓	✓				
YPS					✓					✓				
C: Conceptualization	Fo: Formal Analysis			O: Writing - Original Draft				Fu: Funding Acquisition						
M: Methodology	I: Investigation			E: Writing - Review & Editing				P: Project Administration						
So: Software	D: Data Curation			Vi: Visualization										
Va: Validation	R: Resources			Su: Supervision										

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