G-Tech : Jurnal Teknologi Terapan
Vol. 9, No. 3, July 2025, p. 1645-1656
E-ISSN: 2623-064X | P-ISSN: 2580-8737

G-Tech Jurnal Teknologi Terapan

Land Use Dynamics and Their Impact on Surface Runoff in the Upper Brantas Watershed

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Article Information

Article History

Received : June 22, 2025
Revised : July 05, 2025
Published : July 26, 2025

***Keywords*:**

Land Use;
Surface Runoff;
Upper Brantas Watershed;
SCS-CN;
Flood.

ABSTRACT

The Upper Brantas Watershed (DAS Brantas Hulu) in Batu City plays a vital role in the hydrological system of East Java. However, it is currently classified as critical due to extensive land use changes. Over the past five years, the increasing frequency of floods including 18 events in a single month in 2023 indicates severe environmental degradation. This study aims to analyze land use changes in 2012, 2016, 2020, and 2024; and examine the correlation between these changes and the increase in surface runoff discharge. The methodology involves spatial analysis of land use change using ArcGIS 10.8 and calculation of surface runoff discharge using the SCS-CN hydrograph method. Curve Number (CN) values were determined based on land cover characteristics and soil types, while rainfall data were processed through frequency analysis, consistency testing, and probability distribution fitting. The results indicate a significant reduction in natural infiltration areas, such as primary forest (−3.3%) and secondary forest (−5.6%), along with an increase in impervious surfaces, including settlements (+30.9%) and industrial areas (+63.2%). These changes contributed to higher CN values and increased surface runoff, thereby elevating flood risks in the Upper Brantas Watershed. The findings emphasize the urgent need to control land conversion as part of sustainable spatial planning and disaster mitigation strategies.

INTRODUCTION

The Upper Brantas Watershed (DAS Brantas Hulu), located in Batu City, East Java, serves as the headwaters of the Brantas River and plays a critical role in supporting water security and flood control in downstream areas. However, the ecosystem condition of this watershed has become increasingly critical due to extensive land cover changes over the past decade (Kementerian Lingkungan Hidup dan Kehutanan, 2021). In 2023, more than 18 flood and landslide incidents were recorded within a single month in this region (AnataraNews, 2023). This phenomenon has been exacerbated by the rapid conversion of forest and agricultural lands into residential and built-up areas, which reduces infiltration capacity and increases surface runoff.

Data from the Central Statistics Agency indicate that between 2014 and 2022, Batu City experienced a 7.416% decrease in vegetated land and a 77.46% increase in built-up areas (Badan Pusat Statistik, 2022). The average annual population growth rate of 4.95%, along with the rapid development of tourism and residential zones, has further accelerated the degradation of water catchment areas (Katadata, 2025). These intensive human activities are spread throughout the watershed area, covering several surrounding districts and sub-districts.

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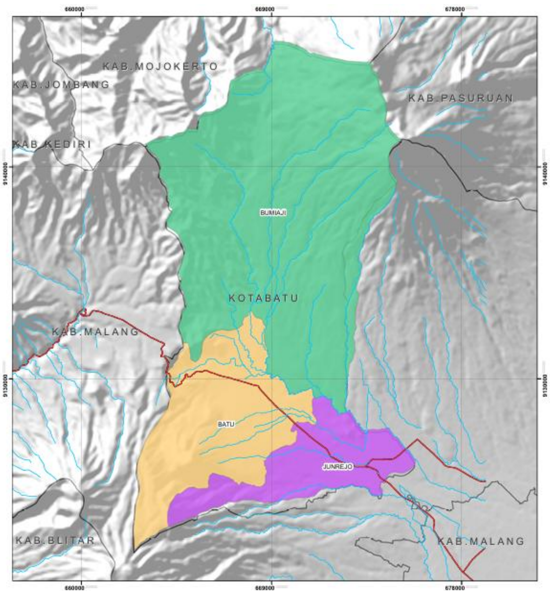
Massive land use change is the dominant factor causing the degradation of the hydrological conditions of the Upper Brantas Watershed. According to Batu City BPS data, during the 2014-2022 period, there was a decrease in forest, agricultural, and plantation areas by 7.416%, while industrial and residential areas increased by 77.46%. The conversion of vegetative land into built-up areas directly reduces water absorption capacity and increases the volume of surface runoff. High rainfall intensity on soil that cannot absorb water optimally causes most of the rainfall to turn into surface runoff that triggers flooding (Awaluddin et al., 2024). The increased impervious area due to urbanization also contributes to an increase in the volume and velocity of surface runoff, exacerbated by weather anomalies (Napitupulu et al., 2025)

Previous studies have examined the relationship between land use changes and surface runoff (Krisnayanti et al., 2021; Sentosa et al., 2021), However, few have explored long-term runoff responses in the Upper Brantas Watershed using an integrated spatial-temporal approach that combines land use mapping and rainfall-based hydrological modeling. To address this gap, the present study analyzes land use changes in 2012, 2016, 2020, and 2024 and examines their correlation with the increase in surface runoff discharge. The analysis employs spatial techniques using ArcGIS 10.8 and hydrological modeling through the SCS-CN method, integrating land cover classification, soil type data, and rainfall probability distribution to estimate runoff volume over time.

RESEARCH METHODS

Study Location

This research was conducted in the Upper Brantas Watershed (DAS Brantas Hulu), which includes the upstream area of the Brantas River, Batu City, East Java. Geographically, the Upper Brantas Watershed is located at 115° 17′ 0″ to 118° 19′ 0″ East Longitude and 7° 55′ 30″ to 7° 57′ 30″ South Latitude, with a total area of 19,415.22 hectares. The study was carried out over the period from 2012 to 2024, focusing on the analysis of land use changes over the last 12 years with 4-year intervals. This interval was selected to capture consistent temporal patterns and planning cycles. The 2024 land use data were extracted from the most recent high-resolution satellite imagery available on Google Earth Pro and interpreted using the same classification criteria as previous years, ensuring consistency and comparability across the time series.



Source: (Indraswari, 2022)
Figure 1. Administrative Map of Batu City

Research Stages

This study employs a quantitative approach by integrating spatial and hydrological methods to analyze the impact of land use changes on surface runoff in the Upper Brantas Watershed. All data used in this research are secondary data. Land use data were obtained from satellite imagery available on the Google Earth platform and processed using ArcGIS 10.8 software. Land cover classification refers to the Indonesian National Standard (SNI 7645:2010), and land use maps were generated for the years 2012, 2016, 2020, and 2024 to assess spatial and temporal patterns of change. Rainfall data, specifically daily maximum rainfall for each respective year, were obtained from Dinas Pekerjaan Umum Sumber Daya Air Provinsi Jawa Timur to support the hydrological analysis.

The estimation of surface runoff was conducted using the Soil Conservation Service–Curve Number (SCS-CN) method, which incorporates land cover characteristics and hydrologic soil groups (HSG). This method calculates effective runoff based on precipitation, water retention capacity, and initial abstraction, with the latter assumed to be 20% of the maximum retention. Curve Number (CN) values were assigned based on the combination of land use types and hydrological soil groups, allowing for the computation of annual runoff volumes. The results were then compared across the four observation years to identify trends in runoff variation as a response to land use change, particularly the conversion of vegetated land into impervious built-up areas. This integrated analysis provides a quantitative basis for understanding the hydrological implications of land development within the study area.

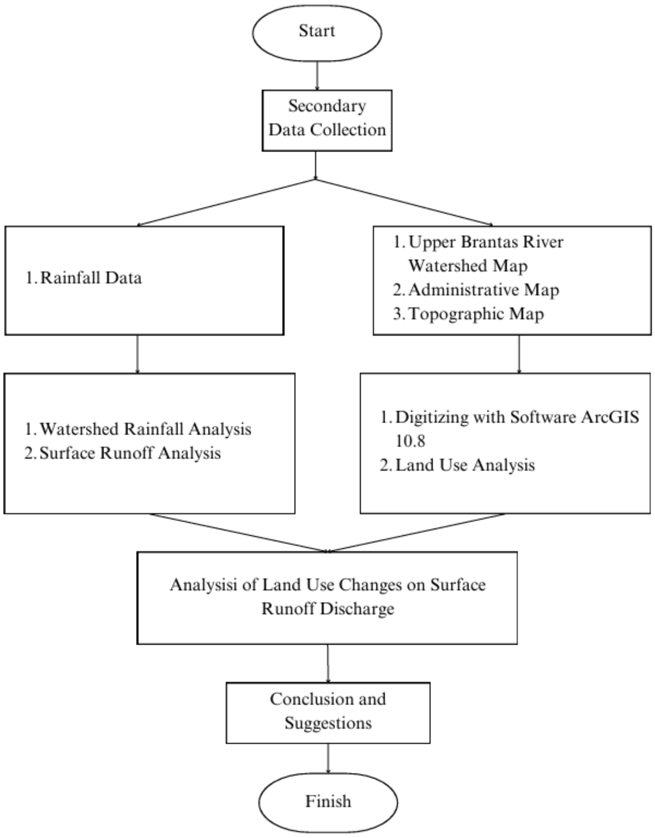


Figure 2. Administrative Map of Batu City

Land Use Classification

This study classified land use based on satellite image interpretation from Google Earth. Land use data were analyzed using ArcGIS 10.8 software to produce land use maps for the years

2012, 2016, 2020, and 2024. Land use grouping and classification referred to the Indonesian national standard, namely SNI 7645:2010 concerning land cover classification. A similar approach was successfully applied in the Citeureup Watershed using supervised classification and Google Earth imagery, where SNI 7645:2010 enabled accurate identification of land cover changes and was effective in capturing the dynamics of built-up expansion and agricultural land reduction (Jauhari et al., 2024)

Table 1. Land Cover Classes

No	Land Cover Class	Description
1.	Agricultural areas	Areas for cultivation of food crops and horticulture.
2.	Shrubs	Dry land with heterogeneous natural vegetation and sparse to dense density.
3.	Primary Forest	Natural forests that have not been disturbed by human activities have a layered canopy structure and high biodiversity.
4.	Secondary Forest	Regenerated forest after human or natural disturbance, with a simpler structure and dominance of pioneer species.
5.	Built-up land	Areas that have been replaced by artificial land.
6.	Settlement	Neighborhood of residence or dwelling.
7.	Undeveloped Land	Land results from human intervention without development, as in built-up land.
8.	Industrial building	Area for factories or industrial areas.
10.	Road network	Vehicle transportation infrastructure network.
11.	Lake/Reservoir	Permanent waters formed by nature (lake) or human engineering (reservoir) to hold water for an extended period.
12.	River	A natural, seasonal, or year-round watercourse.

Source: SNI 7645:2010

Table 1 presents the classification of land cover types used in this study, which is based on the Indonesian National Standard SNI 7645:2010. The table includes 12 distinct land cover classes, ranging from agricultural areas and forest types to built-up land and water bodies. Each class is defined according to its physical characteristics and land function. This classification serves as the foundation for analyzing land use changes over time and their influence on hydrological processes within the watershed.

Surface Runoff

Surface runoff calculation was carried out using the Soil Conservation Service Curve Number (SCS-CN) method. This method estimates effective runoff (Q) based on precipitation (P), water retention capacity (S), and initial abstraction (Ia), which is assumed to be 20% of S. The equations used are:

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

with the value of S calculated through:

$$S = \frac{25400}{CN} - 254 \quad (2)$$

Daily maximum rainfall data were obtained from the Department of Public Works for Water Resources, East Java Province, as input for runoff calculation in each year. The runoff calculation results were analyzed to assess the impact of land use change on the increase of surface runoff in the Upper Brantas Watershed during the 2012–2024 period. Soil types were classified into Hydrologic Soil Groups (HSG) based on their texture and permeability. This classification follows the USDA (2004) standard, which categorizes soils into groups A, B, C, and D depending on infiltration capacity. Similar classification approaches have been implemented in Indonesian watersheds, such as in the Pataruman catchment, where soil mapping and pedotransfer functions revealed dominance of group D soils, indicating low permeability and high runoff potential (Ramadan et al., 2020).

Table 2. Curve Number Values

Surface Description	Average Impervious Area Percentage	Curve Number (CN) – For Soil Group			
Surface Type & Hydrological Condition		**A**	**B**	**C**	**D**
URBANIZED AREA **Vacant land (fields, parks, golf courses, etc.)**					
Degraded land (50% dry grass)		68	79	86	89
Moderate land (more than 75% grass cover)		49	69	79	84
Fertile land (more than 75% grass cover)		39	61	74	80
IMPERVIOUS AREA					
- Parking lots, rooftops, roads (excluding ROW)		98	98	98	98
-Highways, intersections, and channels (excluding ROW)		98	98	98	98
Open ditches (including ROW)		83	89	92	93
Gravel surfaces (including ROW)		76	85	89	91
URBAN AREA					
Commercial centers	85	89	92	94	95
Industrial areas	75	81	88	91	93
RESIDENTIAL AREAS WITH AVERAGE LOT SIZES					
500 m2 or major city	65	77	85	90	92
1000 m2	38	61	75	83	87
1350 m2	30	57	72	81	86
2000 m2	25	54	70	80	85
4000 m2	20	51	68	79	84
8000 m2	12	65	65	77	82
Developing urban areas (for non-vegetated impervious areas)		86	86	91	94

Source: Natural Resources Conservation Servise (U.S. Departement of Agriculture) (Group, 2004)

Table 2 summarizes the Curve Number (CN) values used in the SCS-CN method for various land surface types and hydrologic soil groups (A–D). These values serve as key parameters in estimating surface runoff, reflecting the infiltration capacity of each land cover category combined with specific soil characteristics.

RESULTS AND DISCUSSION

Results of Land Use Interpretation and Classification

The interpretation of satellite imagery for the years 2012, 2016, 2020, and 2024 identified a total of eleven land use types in the Upper Brantas Watershed. These types include primary and secondary forests, rice fields, settlements, built-up land, industrial areas, and bodies of water. Spatial analysis using ArcGIS, as visualized in Figures 3 to 6, enabled the mapping of land use changes over time. Table 3 summarizes the quantitative area of each land cover class per year.

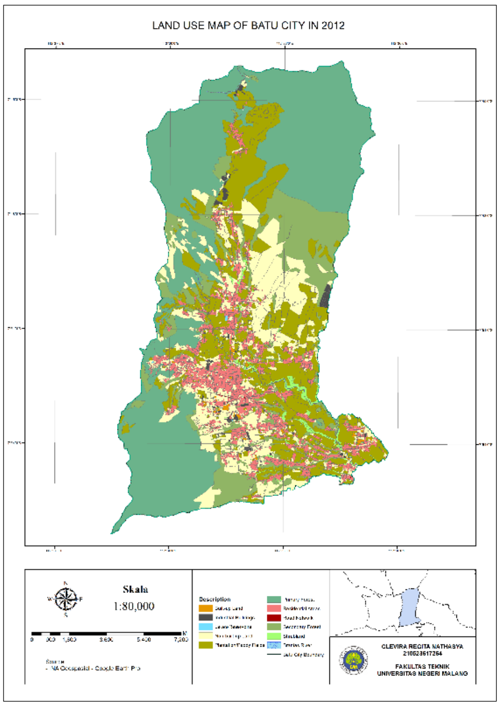


Figure 3. Land Use Map of Batu City in 2012

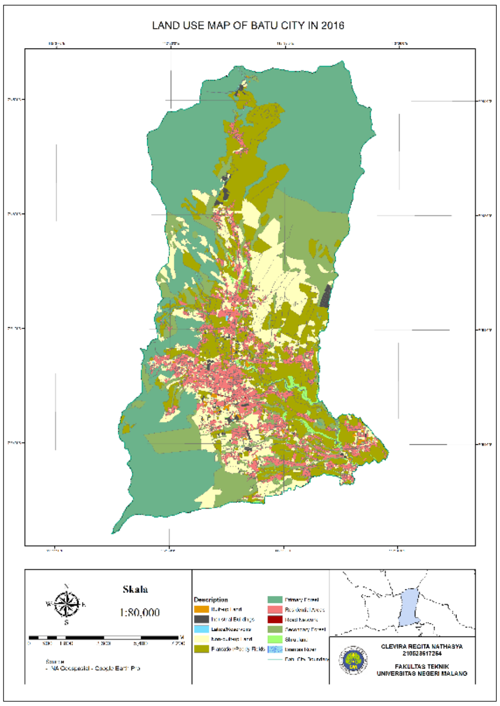


Figure 4. Land Use Map of Batu City in 2016

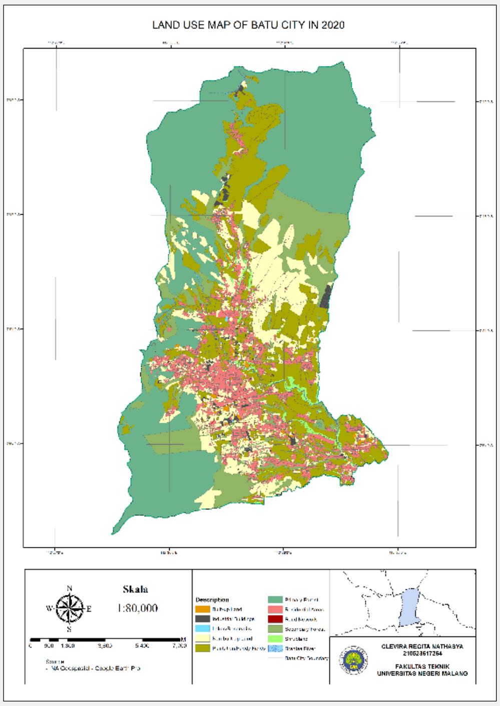


Figure 5. Land Use Map of Batu City in 2020

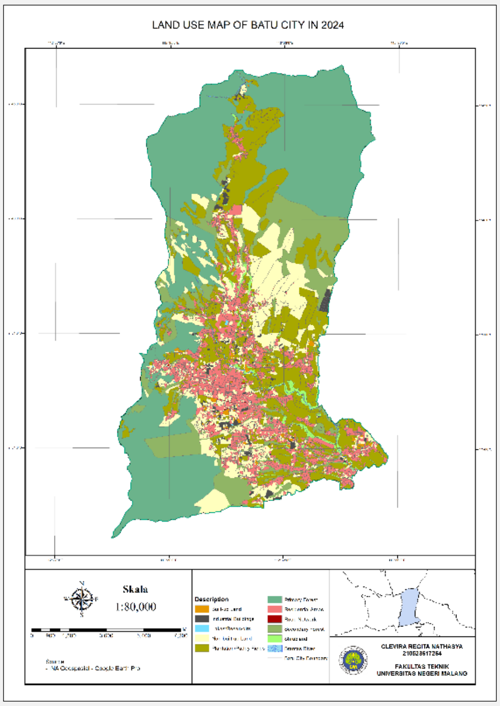


Figure 6. Land Use Map of Batu City in 2024

The analysis revealed a clear trend of land cover conversion over the 12-year period. Primary and secondary forest areas decreased by 3.3% and 5.6%, respectively, while built-up land, settlements, and industrial buildings increased significantly by 71.8%, 30.9%, and 63.2%. These findings highlight a notable shift from infiltration-supporting vegetative surfaces to impervious surfaces that accelerate surface runoff. Such a land cover transition corresponds with findings by Sujarwo et al., (2022), who reported similar patterns in the Upper Brantas Watershed between 2001 and 2015. Additionally, Nuariman & Harisuseno (2023) emphasized that land use mapping using GIS significantly improves hydrological analysis by predicting future runoff behavior under various land development scenarios.

Table 3. Data Luasan on Land Use Area in Batu City

Land Use Type	Area (ha)			
	2012	2016	2020	2024
Industrial Buildings	131.18	146.60	179.31	214.05
Lake/Reservoir/River	5.28	5.67	6.24	7.84
Primary Forest	7783.54	7533.17	7533.17	7528.51
Secondary Forest	2504.75	2700.60	2466.78	2363.72
Road Network	145.41	143.73	136.75	129.01
Built-up Land	56.12	69.15	88.12	96.49
Undeveloped Land	2998.93	2887.82	2882.94	2777.12
Plantation / Rice Fields	4002.61	3979.99	4014.75	4000.60
Settlement	1557.85	1706.58	1851.58	2039.22
Shrubs	188.03	200.40	214.07	217.15
Brantas River	41.52	41.52	41.52	41.52
Total	19415.22	19415.22	19415.22	19415.22

The Upper Brantas Watershed has undergone significant land use changes between 2012 and 2024. Areas previously dominated by natural vegetation cover have shown a declining trend, particularly in the categories of primary forest and secondary forest, which decreased by 3.3% and 5.6%, respectively. In contrast, impervious land types such as residential areas, industrial buildings, and built-up lands have experienced substantial increases of 30.9%, 63.2%, and 71.8%, respectively.

These changes indicate a land conversion trend from water infiltration zones to built-up areas, which tend to hinder the infiltration process. The main driving factors include the growth of development activities and urbanization within the watershed. Although other land types such as lakes, shrubs, and agricultural land have remained relatively stable or changed at smaller scales, the major expansion of impervious areas has critical implications for the watershed's hydrological function.

This trend is consistent with the findings of Kartikawati et al., (2016), who observed similar patterns in previous periods. The digital maps generated from satellite imagery interpretation and analyzed using ArcGIS further illustrate the spatial distribution changes in land use and are attached to support the visual analysis results.

Rainfall Frequency Analysis Results

Maximum daily rainfall data from four stations across the watershed (2012–2024) were analyzed using four probability distributions: Gumbel, Normal, Log-Normal, and Log-Pearson Type III. The Log-Pearson Type III distribution provided the best fit, as confirmed by Chi-square and Smirnov–Kolmogorov tests (Table 6). This finding aligns with Zainal & Zufrimar (2021) , who highlighted the reliability of Log-Pearson Type III for extreme rainfall modeling in tropical regions. The use of this distribution ensures accurate estimation of rainfall magnitude for various return periods, which is essential for runoff simulation and flood risk assessment.

Table 4. Data Curah Hujan

Year	Maximum CH			
	Sta. Ngaglik (A)	**Sta. Ngujung (B)**	**Sta. Pendem (C)**	**Sta. Temas (D)**
2012	58	91	81	51
2013	110	108	125	58
2014	68	91	80	71
2015	74	80	65	57
2016	55	60	84	66
2017	55	56	67	65
2018	35	85	61	71
2019	76.5	65	65	59
2020	58	89.5	67	75
2021	54	76	67	76
2022	49	70	87	87
2023	37	63	78	60
2024	62	91	69	59

Table 4 presents the annual maximum daily rainfall data recorded from four rainfall stations across the Upper Brantas Watershed during the period 2012–2024. This data serves as the input for frequency analysis and hydrological modeling.

Table 5. Hasil Analisis Frekuensi Curah Hujan

No	Type Distribution	Requirements	Result			Description
1	Gumbel	$Cs \leq 1.1396$	1.14	Cs	1.431	Non-compliant
		$Ck \leq 5.4002$	5.4	Ck	5.605	Non-compliant
2	Normal	$Cs \approx 0$	0	Cs	1.431	Non-compliant
		$Ck \approx 3{,}0$	3	Ck	5.605	Non-compliant
3	Log Normal	$Cs \approx 3\ Cv + Cv^3$	2	Cs	0.001	Non-compliant
		$Ck \approx Cv8 + 6Cv6 + 15\ Cv4 + 16Cv2 + 3$	4	Ck	3.000	Non-compliant
4	Log Pearson Type III	$Cs \neq 0$	0	Cs	-0.009	Compliant

Table 5 summarizes the results of rainfall frequency analysis using several probability distributions. The compliance of each distribution was evaluated based on skewness, kurtosis, and critical statistical values.

Table 6. Plan Rainfall Conclusion

Distribution Conformity Test			
Chi-Square Test	X^2 Count	5.846	Representative
	X^2 Critical	5.991	
Smirnov-Kolmogorov Test	X^2 Count	0.145	Representative
	X^2 Critical	0.368	

Suitability tests were conducted using the Chi-Square and Smirnov–Kolmogorov methods to evaluate the conformity of the selected rainfall distribution model. The results indicated that the calculated Chi-Square value (5.846) and K–S value (0.146) were both lower than their respective critical thresholds (5.991 and 0.368), demonstrating that the Log-Pearson Type III distribution is statistically valid for use in hydrological modeling. The choice of this distribution is further supported by its effectiveness in representing positively skewed rainfall data, which is characteristic of tropical regions. This finding is consistent with the results obtained in the Sub-DAS Badung, where the Log-Pearson Type III distribution provided the best fit for extreme rainfall estimation across various return periods, as confirmed by both the Chi-Square and K–S goodness-of-fit tests (Prawira et al., 2025).

Surface Runoff Discharge Result

Table 7. Table of Runoff Discharge

Year	Return Period	Plan Rainfall (mm)	CN Composite	S	Ia	Runoff (Q) (mm)	Runoff Discharge (m^3/dtk)
2012	2	221.127	65.215	135.4825	27.0965	114.25	36.816
	5	266.857				153.19	49.364
	10	294.482				177.47	57.185
	25	327.145				206.71	66.609
	50	350.183				227.63	73.350
	100	372.281				247.89	79.878
2016	2	221.127	69.470	111.627	22.325	127.31	41.024
	5	266.857				167.89	54.099
	10	294.482				193.00	62.189
	25	327.145				223.11	71.894
	50	350.183				244.58	78.812
	100	372.281				265.32	85.495
2020	2	221.127	71.459	101.448	20.290	133.44	42.997
	5	266.857				174.69	56.291
	10	294.482				200.14	64.492
	25	327.145				230.61	74.311
	50	350.183				252.30	81.300
	100	372.281				273.24	88.046
2024	2	221.127	73.534	91.417	18.283	139.83	45.056
	5	266.857				181.74	58.561
	10	294.482				207.51	66.867
	25	327.145				238.32	76.795
	50	350.183				260.22	83.852
	100	372.281				281.34	90.657

Runoff discharge was calculated using the SCS-CN method. As shown in Table 7, the Composite Curve Number (CN) increased from 65.215 in 2012 to 73.534 in 2024, indicating a reduction in infiltration capacity due to increased impervious land cover. This rise in CN indicates a reduced infiltration capacity, which directly correlates with the expansion of impervious surfaces. Similar trends have been observed in other watersheds, such as the Winongo Watershed, where the CN increased due to land use change from vegetation to urban areas (Pradipta et al., 2018)

Consequently, runoff volumes also increased significantly. As seen in Figure 7, the simulated runoff discharge for the 5-year return period rose from 49.364 m^3/s in 2012 to 58.561 m^3/s in 2024.

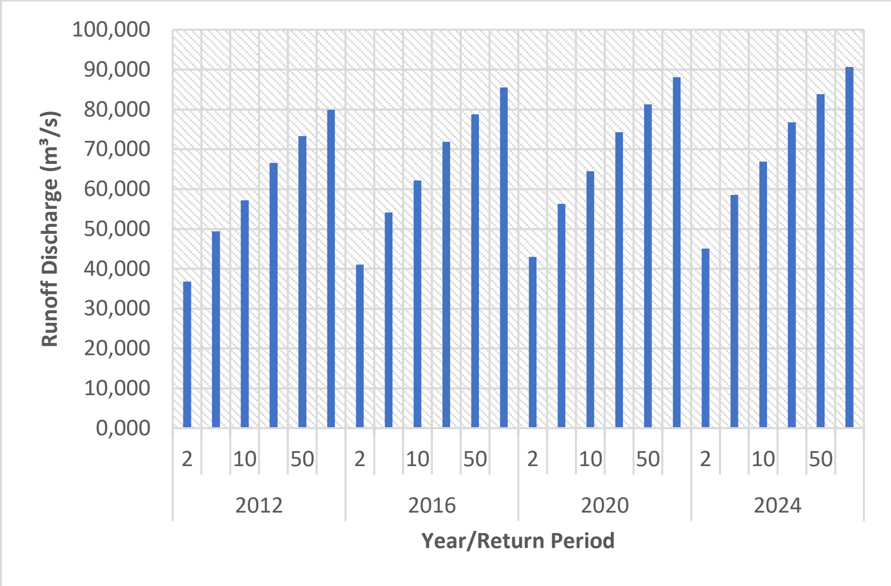


Figure 7. Graph of Runoff Discharge Values

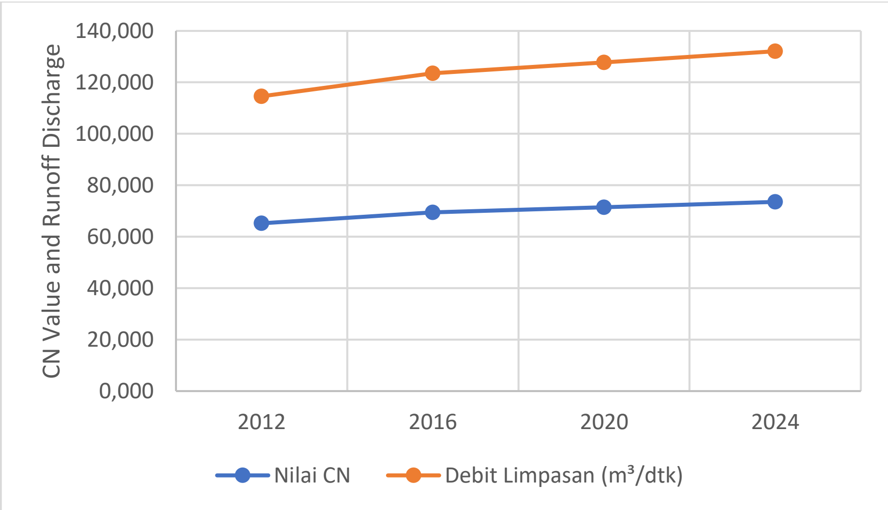


Figure 8. Graph of CN Value Changes and Runoff Discharge with 5-Year Return Period

The gradual increase in both CN values and runoff discharge, as illustrated in Figure 8, reflects a hydrological shift from a system capable of rainfall infiltration to one dominated by rapid surface runoff. This condition, primarily caused by land conversion to impervious surfaces, intensifies flood potential, soil erosion, and deteriorates water quality. These results support the findings of Soemadiredja & Asyiawati (2022), who demonstrated that urban expansion directly correlates with increased runoff generation. Such evidence highlights the need for integrating green infrastructure and sustainable spatial planning into watershed development policies.

CONCLUSION

The analysis of land use changes in the Upper Brantas Watershed from 2012 to 2024 indicates a substantial decline in natural infiltration zones alongside a significant expansion of impervious surfaces. Over this period, primary and secondary forest areas decreased by 3.3% and 5.6%, while industrial and residential land increased by 63.2% and 30.9%, respectively. This shift in land cover has led to a notable increase in surface runoff. Rainfall simulation using the SCS-CN method for a 5-year return period shows that runoff discharge rose by 18.6% during the study period. The conversion of vegetated land into built-up areas has reduced the watershed's infiltration capacity, intensified surface runoff, and elevated the potential for flooding. These findings highlight the critical importance of incorporating sustainable land use planning and green infrastructure into watershed management to mitigate adverse hydrological impacts in urbanizing regions.

ACKNOWLEDGEMENTS

The author gratefully acknowledges the support from the Institute for Research and Community Service (LPPM) through the 2025 Research and Community Service (PPM) program, which provided funding for both research and publication. Sincere appreciation is also extended to all team members whose contributions and assistance were invaluable throughout the research process and the completion of this publication.

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