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GIS-Based USLE Assessment of Land Use Change Impacts on Erosion and Streamflow in the Ciujung Watershed

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Abstract: *This study investigates the impact of land use change on streamflow discharge and soil erosion in the Ciujung Watershed, Indonesia. The research aims to evaluate hydrological responses and erosion dynamics associated with changes in land cover between 2016 and 2021. Rainfall and discharge analyses were conducted using the Thiessen Polygon method and statistical regression analysis, while erosion was estimated using the Geographic Information System (GIS)-based Universal Soil Loss Equation (USLE). Land use changes were identified through Landsat image interpretation. The results indicate that increased rainfall and substantial land use conversion have altered watershed conditions. Forest, shrubland, swamp, and paddy field areas decreased, while plantation, dryland farming, and settlement areas expanded significantly. These changes were associated with increases in annual flow volume, average discharge, runoff coefficient, erosion rate, and sediment yield, indicating a decline in watershed performance. Regression analysis revealed a strong positive relationship between rainfall and river discharge variables. The GIS-based USLE analysis showed a substantial increase in erosion and sediment production during the study period. The findings demonstrate that land use change, combined with increasing rainfall, has accelerated watershed degradation and heightened erosion risks in the Ciujung Watershed. Sustainable land management and conservation measures are therefore essential to mitigate future environmental impacts and maintain watershed functions.*

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INTRODUCTION

Watersheds play a fundamental role in regulating hydrological processes, maintaining water availability, controlling sediment transport, and supporting ecosystem sustainability (Edison et al., 2025). However, rapid population growth, urban expansion, agricultural intensification, and infrastructure development have accelerated land use changes in many watersheds worldwide (Mawardin & Arta Aryan, 2024). The conversion of forests and natural vegetation into agricultural land, settlements, and other built-up areas alters watershed hydrological responses by reducing infiltration capacity, increasing surface runoff, and accelerating soil erosion. These changes frequently result in declining water quality, increased sedimentation, higher flood risks during wet seasons, and reduced baseflow during dry periods (Yanti et al., 2023). Consequently, understanding the relationship between land use dynamics and watershed hydrological performance has become a major concern in watershed management and environmental planning (Naitkakin et al., 2021).

Numerous international studies have demonstrated that land use change significantly influences streamflow characteristics and erosion processes (Priatna et al., 2025). Research in China, Brazil, and several Southeast Asian countries has reported that reductions in forest cover are associated with increased runoff coefficients, higher peak discharges, and accelerated sediment production (Azwar et

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al., 2024). Recent studies have increasingly integrated Geographic Information Systems (GIS), remote sensing technologies, and the Universal Soil Loss Equation (USLE) model to quantify the environmental impacts of land use change at the watershed scale. These approaches provide effective tools for assessing spatial variations in erosion risk and hydrological responses under changing land cover conditions. Despite these advances, most previous studies have focused either on hydrological responses or erosion assessments separately, while integrated analyses combining land use change, streamflow dynamics, and erosion estimation remain relatively limited, particularly in tropical watersheds of Indonesia (Antara, 2021).

The Ciujung Watershed in Banten Province is one of the strategic watersheds supporting domestic water supply, agricultural production, and industrial activities. In recent decades, the watershed has experienced substantial land use transformation characterized by decreasing forest cover and expanding agricultural and built-up areas. These changes have raised concerns regarding watershed degradation, reflected in increasing flood frequency, sediment accumulation in river channels, and declining hydrological performance. Although several reports have documented environmental problems in the Ciujung Watershed, comprehensive quantitative studies that simultaneously evaluate land use change, streamflow response, and erosion dynamics remain scarce. This limitation creates a knowledge gap regarding the extent to which land cover transformation contributes to watershed degradation and hydrological instability in the region (Perdana & Susanti, 2017).

Therefore, this study aims to analyze the impacts of land use change on streamflow discharge and soil erosion in the Ciujung Watershed using an integrated GIS-based approach. Land use changes were identified through Landsat imagery analysis, hydrological responses were evaluated using rainfall and discharge data, and erosion rates were estimated using the Universal Soil Loss Equation (USLE) model. The novelty of this research lies in the integration of spatial land use analysis, hydrological assessment, and erosion modeling within a single watershed evaluation framework. Scientifically, the study contributes to a better understanding of the interactions between land cover dynamics and watershed processes in tropical environments. Practically, the findings provide evidence-based information to support sustainable land management, erosion control strategies, and watershed conservation planning in Banten Province.

RESEARCH METHOD

Research Location

The research was conducted in the Ciujung River Basin (DAS) in Banten Province. Administratively, the Ciujung River Basin is located in Lebak Regency, Pandeglang Regency, Serang City, and Serang Regency.

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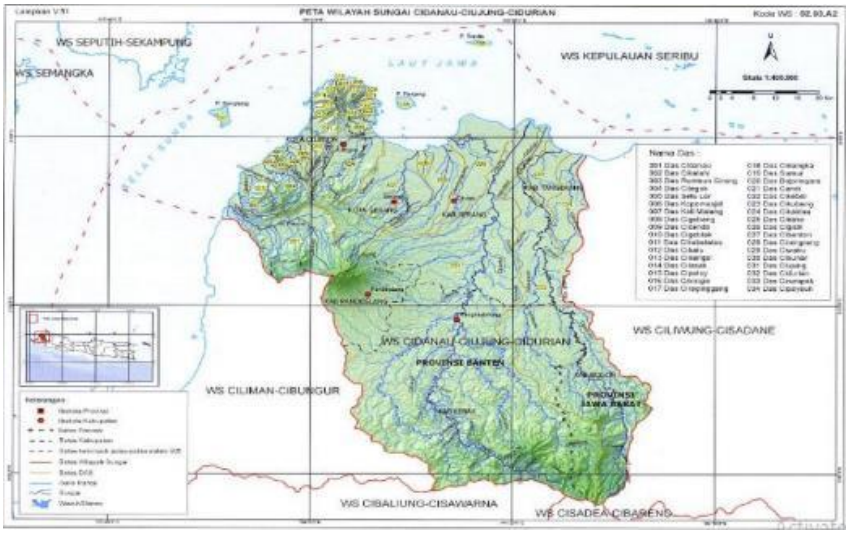

Figure 1. Map of the Cidanau-Ciujung-Cidurian River Basin

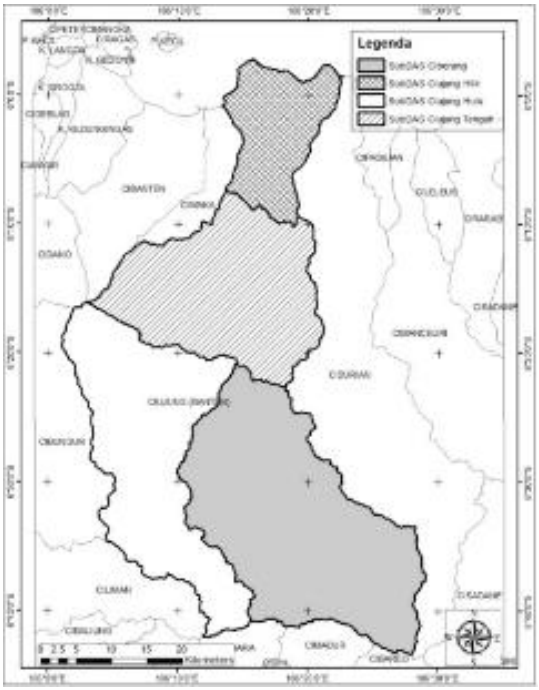

Figure 2. Ciujung Watershed Research Location

Research Data

In general, the methodology used in conducting this research is:

1. Data Collection Method

   Secondary data collection consisted of 10 years of daily rainfall data (2012–2021) affecting the Ciujung Watershed, 10 years of daily river flow data from the Ciujung Watershed (2012–2021) from the Cidanau-Ciujung-Cidurian River Basin Center, topographic maps using Digital Elevation Model (DEM) data obtained from the USGS, soil type maps obtained from the Food and Agriculture Organization (FAO) MapSoil, and land use maps obtained from interpretation of Landsat imagery from 2016 and 2021.

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2. Data Analysis Method

Using the data obtained, analysis can be conducted based on the type and nature of activities. Data analysis was conducted taking into account technical requirements to achieve the specified accuracy corrections. In the study "The Impact of Land Use Change on Flow Discharge and Land Erosion in the Ciujung Watershed," data analysis refers to applicable regulations and previous research. The results of the data analysis are presented in tables, figures, graphs, and maps.

Research Equipment

In conducting the study on the Effects of Land Use Change on Streamflow and Land Erosion in the Ciujung Watershed, the equipment used was a computer/laptop with an Intel Core i5 processor, 4 GB of RAM, a 64-bit operating system, and software applications such as ArcGIS and Excel for analysis.

RESULTS AND DISCUSSION

River Flow Discharge and Volume

River flow discharge and volume in the Ciujung River Watershed (DAS) are two hydrological parameters that are crucial for understanding the dynamics of water resources in the region. River flow discharge is defined as the rate of water flowing through a river cross-section per unit time, generally expressed in cubic meters per second (m^3/s). Meanwhile, river flow volume is the total amount of water flowing over a specific time period, obtained by integrating discharge with time.

In this study, the Ciujung River flow discharge and volume data used were data from 10 years, from 2012 to 2021, collected in the downstream part of the Ciujung River Watershed, specifically at the Pamarayan location, with measurements taken over a specific period. The results of the data processing for river flow discharge and volume in Pamarayan can be seen in Tables 1 and 2 below.

Table 1. Results of processing average monthly discharge data

	Year					Period		Year				Period
Month	**2012**	**2013**	**2014**	**2015**	**2016**	**I**	**2017**	**2018**	**2019**	**2020**	**2021**	**II**
Jan	247,35	408,90	223,83	177,84	60,63	**223,71**	174,28	165,89	198,15	88,09	115,27	**148,34**
Feb	93,88	112,15	175,30	131,74	132,97	**129,21**	290,95	163,06	161,03	109,43	160,83	**177,06**
Mar	71,82	55,44	94,78	55,18	154,83	**86,41**	90,58	97,63	98,37	122,18	58,72	**93,50**
Apr	73,66	111,95	84,73	128,22	194,87	**118,68**	107,02	130,91	114,89	103,75	162,15	**123,74**
May	47,93	91,33	101,69	107,83	84,70	**86,70**	88,22	136,78	140,08	168,22	81,06	**122,87**
Jun	16,46	42,62	40,75	53,34	53,36	**41,31**	114,08	48,82	37,56	130,00	105,59	**87,21**
Jul	11,81	114,61	44,23	11,77	90,44	**54,57**	44,67	12,62	12,07	64,67	31,88	**33,18**
Aug	6,28	62,74	70,53	11,91	39,49	**38,19**	26,44	3,25	22,10	49,96	80,52	**36,45**
Sep	6,40	52,91	13,15	4,03	67,44	**28,78**	26,38	13,35	3,62	69,75	166,10	**55,84**
Oct	19,79	40,96	27,07	11,76	110,96	**42,11**	66,01	17,34	10,90	78,11	58,00	**46,07**
Nov	146,44	88,68	90,56	46,21	127,27	**99,83**	62,89	76,90	12,92	89,10	119,45	**72,25**
Dec	117,54	117,93	49,48	106,94	181,87	**114,75**	97,89	90,00	52,49	266,40	121,17	**125,59**
Average	**71,61**	**108,35**	**84,68**	**70,56**	**108,23**	**88,69**	**99,12**	**79,71**	**72,02**	**111,64**	**105,06**	**93,51**

Based on Table 1, which presents the results of processing monthly discharge data in Pamarayan, the average monthly discharge in the 2017–2021 period was higher than in the 2012–2016 period, with values of 93.51 m^3/s and 88.69 m^3/s, respectively. The highest average monthly discharge in the

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2012–2016 period occurred in January at 408.90 m³/s, while in the 2017–2021 period it occurred in February at 290.95 m³/s. Meanwhile, the lowest average monthly discharge in the 2012–2016 period occurred in September at 4.03 m³/s, and in the 2017–2021 period it occurred in August at 3.25 m³/s.

Table 2. Results of Processing Monthly Flow Volume Data

	Year					Period	year					Period
Month	**2012**	**2013**	**2014**	**2015**	**2016**	**I**	**2017**	**2018**	**2019**	**2020**	**2021**	**II**
Jan	247,50	1095,20	599,51	476,33	162,38	**599,19**	466,80	444,32	530,72	235,95	308,73	**397,30**
Feb	235,22	271,31	424,09	318,71	321,67	**314,20**	703,86	394,48	389,57	274,18	389,08	**430,23**
Mar	192,35	148,49	253,87	147,79	414,71	**231,44**	242,61	261,50	263,48	327,24	157,28	**250,42**
Apr	190,92	290,17	219,62	332,35	505,09	**307,63**	277,39	339,32	297,80	268,91	420,30	**320,75**
May	128,39	244,62	272,37	288,80	226,86	**232,21**	236,29	366,34	375,18	450,56	217,11	**329,10**
Jun	42,66	110,46	105,63	138,25	138,31	**107,06**	295,68	126,53	97,35	336,95	273,68	**226,04**
Jul	31,62	306,98	118,47	31,52	242,24	**146,17**	119,63	33,79	32,32	173,22	85,38	**88,87**
Aug	16,83	168,04	188,90	31,91	105,77	**102,29**	70,81	8,72	59,19	133,81	215,67	**97,64**
Sep	16,58	137,13	34,09	10,45	174,79	**74,61**	68,39	34,61	9,40	180,78	430,54	**144,74**
Oct	53,00	109,71	72,49	31,50	297,20	**112,78**	176,79	46,45	29,19	209,21	155,36	**123,40**
Nov	379,58	229,86	234,73	119,77	329,87	**258,76**	163,01	199,33	33,50	230,94	309,60	**187,28**
Dec	314,83	315,86	132,53	286,43	487,13	**307,36**	262,18	241,06	140,60	713,52	324,54	**336,38**
Annual Vol.	**2264,47**	**3427,83**	**2656,31**	**2213,80**	**3406,02**	**2793,68**	**3083,45**	**2496,45**	**2258,30**	**3535,26**	**3287,26**	**2932,14**

Based on Table 2, which presents the results of processing monthly discharge data in Pamarayan, it is known that the average monthly discharge in the 2017–2021 period was higher than the 2012–2016 period, with values of 244.35 million m3 and 232.81 million m3, respectively. The highest average monthly discharge in the 2012–2016 period occurred in January at 1,095.20 million m3, while in the 2017–2021 period it occurred in February at 703.86 million m3. Meanwhile, the lowest average monthly discharge in the 2012–2016 period occurred in September at 16.58 million m3, and in the 2017–2021 period it occurred in August at 8.72 million m3. There was an increase in the average annual flow volume, reaching 2,793.68 and 2,932.14 million m3 per year between 2012 and 2016 and 2017 and 2021, respectively.

Peak Flow Discharge

Peak discharge is the maximum flow value that occurs in response to rainfall events, particularly high-intensity rainfall, and is influenced by watershed characteristics such as area, slope, soil type, and land use (Budianto et al., 2024). Conversely, minimum discharge is the lowest flow value, generally occurring during dry periods, when the primary contribution to flow comes from baseflow due to groundwater discharge. The results of the processing are shown in Table 3 below.

Table 3. Results of Peak Discharge Data Processing

	Year					Period	Year					Period
Month	**2012**	**2013**	**2014**	**2015**	**2016**	**I**	**2017**	**2018**	**2019**	**2020**	**2021**	**II**
Jan	1950,00	2600,00	1008,00	822,00	277,76	**2600,00**	1042,00	712,00	712,00	294,13	675,00	**1042,00**
Feb	289,23	259,10	609,13	369,67	470,00	**609,13**	749,00	810,00	724,44	355,00	527,00	**810,00**
Mar	251,42	327,10	204,67	214,67	441,29	**441,29**	275,19	286,72	189,95	283,49	125,72	**286,72**

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Apr	192,18	483,20	276,54	588,00	965,00	**965,00**	353,65	434,26	502,49	220,18	834,00	**834,00**
May	382,32	392,30	248,39	438,57	197,03	**438,57**	203,87	532,33	543,00	765,00	200,17	**765,00**
Jun	190,05	149,10	132,50	330,55	129,59	**330,55**	712,00	203,87	161,87	355,00	353,12	**712,00**
Jul	37,95	614,20	164,03	16,19	459,27	**614,20**	160,03	25,93	26,36	339,00	127,16	**339,00**
Aug	13,98	395,58	330,55	77,08	130,57	**395,58**	160,03	13,31	115,85	272,00	712,00	**712,00**
Sep	12,59	190,81	75,56	8,09	260,05	**260,05**	233,03	129,11	14,32	273,08	1008,00	**1008,00**
Oct	127,88	191,24	190,47	131,44	618,76	**618,76**	232,34	114,00	114,00	228,17	728,00	**728,00**
Nov	810,00	264,69	258,56	190,85	691,00	**810,00**	295,84	161,88	62,00	273,08	449,00	**449,00**
Dec	357,73	376,00	233,41	544,00	449,00	**544,00**	341,62	407,00	188,00	1332,00	580,00	**1332,00**
Debit Max	**1950,00**	**2600,00**	**1008,00**	**822,00**	**965,00**	**2600,00**	**1042,00**	**810,00**	**724,44**	**1332,00**	**1008,00**	**1332,00**

Source: BBWS C3 Data

Based on Table 3 above, the highest peak discharge in the 2012–2016 period occurred on January 10, 2013, at 2,600 m3/s. Meanwhile, the highest peak river flow in the 2017–2021 period occurred on December 8, 2020, at 1,332 m3/s. In general, the average monthly peak discharge in the 2017–2021 period was higher than in the 2012–2016 period, as shown in Table 4.

Table 4. Regional rainfall, river flow discharge, flow volume, and peak discharge in the 2012–2016 and 2017–2021 periods

	Rainfall (mm)		**Debit (m^3/s)**		**Flow Volume (million m3)**		**Peak Discharge (m^3/s)**	
Month	I	II	I	II	I	II	I	II
Jan	405,52	276,10	223,71	148,34	599,19	397,30	1331,55	687,03
Feb	274,90	319,88	129,21	177,06	314,20	430,23	399,43	633,09
Mar	174,73	198,24	86,41	93,50	231,44	250,42	287,83	232,21
Apr	197,54	221,43	118,68	123,74	307,63	320,75	500,98	468,92
May	162,00	193,97	86,70	122,87	232,21	329,10	331,72	448,87
Jun	90,58	153,45	41,31	87,21	107,06	226,04	186,36	357,17
Jul	124,86	69,09	54,57	33,18	146,17	88,87	258,33	135,70
Aug	59,82	85,22	38,19	36,45	102,29	97,64	189,55	254,64
Sep	75,95	128,07	28,78	55,84	74,61	144,74	109,42	331,51
Oct	139,55	145,44	42,11	46,07	112,78	123,40	251,96	283,30
Nov	236,77	173,26	99,83	72,25	258,76	187,28	431,02	248,36
Dec	226,14	243,40	114,75	125,59	307,36	336,38	392,03	569,72
Total	2168,36	2207,54	1064,25	1122,10	2793,68	2932,14	-	-

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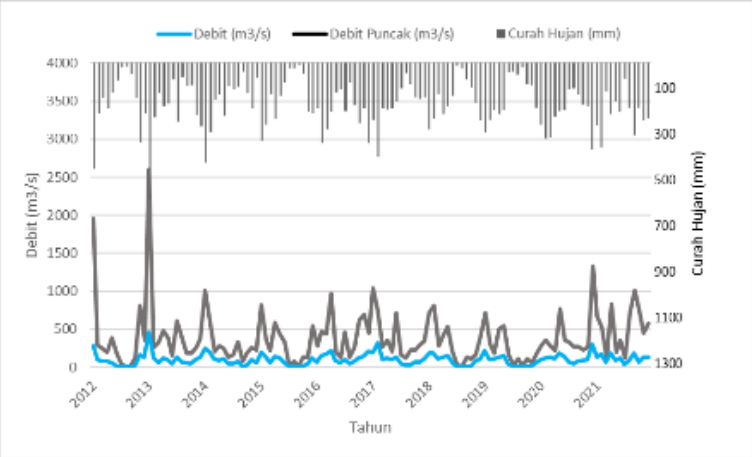

Figure 3. Relationship between discharge (m3/s), peak discharge (m3/s), and rainfall (mm); source: BBWS C3 (processed, 2025)

Linear Regression Analysis

Linear regression analysis is a statistical method used to examine the quantitative relationship between independent and dependent variables. In the context of hydrology, rainfall is often positioned as the independent variable, while discharge or peak discharge is the dependent variable (Saraswati et al., 2025). Through linear regression, it is possible to identify the extent to which changes in rainfall influence variations in river flow. This relationship is expressed in the form of a mathematical model that describes data trends, allowing researchers to assess the strength of the relationship, the direction of the influence (positive or negative), and the statistical significance of the variables being analyzed. Thus, linear regression analysis is an important tool in understanding the hydrological response of a watershed to rainfall variations (Dhoke et al., 2020).

The results of the linear regression analysis of the relationship between discharge and peak discharge as fixed variables and regional rainfall as independent variables for the 2012–2016 (Period I) and 2017–2021 (Period II) periods can be seen in Table 5 below.

Table 5. Linear regression equation of rainfall with discharge and peak discharge

Period	Dependent Variable	Independent Variable	R^2	P-value	Linear Regression Equation
2012 – 2016	Discharge	Regional Rainfall	0,9401	0,00	y = 0,5491x – 10,542
	Peak Discharge	Regional Rainfall	0,7987	0,00	y = 2,9239x – 139,15
2017 - 2021	Discharge	Regional Rainfall	0,9267	0,00	y = 0,6029x – 17,403
	Peak Discharge	Regional Rainfall	0,7698	0,00	y = 2,0535x +9,7776

Description: R2 = coefficient of determination; p = probability of error; y = river flow rate and peak discharge (m3/second); x = rainfall (mm); source: BBWS C3, 2025)

Based on the results of the linear regression analysis (Table 5), regional rainfall has a very significant effect on both flow rate and peak discharge in the Ciujung Watershed. The coefficient of determination (R^2) between rainfall and flow rate in the 2012–2016 and 2017–2021 periods was 0.9401 and 0.9267, respectively. Meanwhile, the relationship between rainfall and peak discharge during the same period showed R^2 values of 0.7987 and 0.7698. The significance values for both relationships indicate a probability of error of less than 0.01.

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The results of this analysis indicate that rainfall has a positive correlation with both flow rate and peak discharge. Thus, increases in regional rainfall tend to be followed by increases in flow rate and peak discharge. This indicates that river discharge variability in the Ciujung Watershed is significantly influenced by changes in rainfall, making rainfall a strong predictor in hydrological analysis.

Ciujung Watershed Condition

The surface runoff coefficient is a hydrological parameter that indicates the ratio between the amount of rainwater that becomes surface runoff and the total rainfall falling in a watershed (Harfia & Prijono, 2022). This coefficient ranges from 0 to 1, with values closer to 0 indicating that most rainwater infiltrates the soil (infiltration), while values closer to 1 indicate a predominance of surface runoff. The surface runoff coefficient is influenced by various factors, such as soil type, slope gradient, land cover, permeability, and land use within the watershed.

In watershed condition analysis, the surface runoff coefficient serves as an important indicator for assessing an area's ability to absorb water and control runoff. High coefficient values generally indicate watershed degradation, such as reduced vegetation or increased built-up areas, potentially increasing the risk of flooding and erosion (Mochammad Fikri Raihan Firdausy et al., 2024). Conversely, low values indicate a watershed that is still in good condition with high water absorption capacity. The results of the surface runoff coefficient analysis for the Ciujung Watershed for the periods 2012–2016 and 2017–2021 can be seen in Table 6 below.

Table 6. Surface runoff coefficient for the periods 2012–2016 and 2017–2021

Month	Period 2012 - 2016			Period 2017 - 2021		
	CH (mm)	RO (mm)	C	CH (mm)	RO (mm)	C
Jan	406	279	0,69	276	185	0,67
Feb	275	147	0,54	320	185	0,58
Mar	175	108	0,62	198	116	0,59
Apr	198	143	0,72	221	148	0,67
May	162	108	0,67	194	123	0,64
Jun	91	50	0,55	153	95	0,62
Jul	125	68	0,54	69	41	0,60
Aug	60	38	0,63	85	39	0,46
Sep	76	35	0,46	128	67	0,53
Oct	140	52	0,38	145	57	0,39
Nov	237	120	0,51	173	87	0,50
Dec	226	143	0,63	243	157	0,64
Average	181	106	0,58	184	112	0,59

Source: BBWS Ciujung - Cidanau - Cidurian (processed, 2025)

The highest monthly runoff coefficients in the 2012-2016 and 2017-2021 periods occurred in January, at 0.69 and 0.67, respectively. The lowest monthly runoff coefficients in the 2012-2016 and 2017-2021 periods occurred in October, at 0.38 and 0.39 (Table 6).

Overall, there was an increase in the annual runoff coefficient, from 0.58 in 2012-2016 to 0.59 in 2017-2021. This indicates a decline in the quality of the Ciujung Watershed. The maximum to minimum denit ratio (Qid) can be used as an indicator of watershed health. The Qid values for the 2012–2016 period were generally poor and moderate, ranging from 89 to 1,477. Meanwhile, the Qid

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values for the 2017–2021 period were generally poor, ranging from 354 to 730. The results of the ratio calculations can be seen in Table 7 below.

Table 7. Maximum and minimum discharge ratios for the 2012–2021 period

Debit (m^3/s)	Year									
	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Qmax	1.950	2.600	1.008	822	965	1.042	810	712	1.332	1.008
Qmin	2	2	10	2	11	2	1	2	4	2
Qmax/Qmin	1.275	1.477	98	514	89	534	730	385	354	494
Category	**J**	**J**	**S**	**J**	**S**	**J**	**J**	**J**	**J**	**J**

Description: B: Good; S: Moderate; J: Poor; source: BBWS C3 (processed, 2025)

Land Erosion

Land erosion is the process of dislodging and transporting soil particles by agents such as rainwater and surface runoff, which can lead to decreased soil fertility and environmental degradation (Yusril et al., 2022). At the watershed (DAS) scale, erosion is influenced by rainfall, soil properties, slope gradient, vegetation cover, and land management practices. High erosion intensity is generally associated with low land cover and high rainfall kinetic energy, thus increasing the potential for surface runoff. Therefore, land erosion is an important indicator in assessing the hydrological conditions and level of damage in a watershed, including the Ciujung Watershed.

Land erosion analysis in the Ciujung Watershed can be conducted using the Universal Soil Loss Equation (USLE) method, which estimates average annual soil loss based on the main factors causing erosion. This equation integrates rainfall erosivity (R), soil erodibility (K), slope length and steepness (LS), plant cover and management (C), and conservation measures (P).

Rainfall Erosivity Factor (R)

The rainfall erosivity factor (R) is a parameter in the Universal Soil Loss Equation model that describes the ability of rainfall to cause soil erosion. The R value reflects the kinetic energy of raindrops and the intensity of rainfall, which play a role in breaking down soil aggregates and triggering surface runoff. The higher the rainfall intensity and duration, the greater the erosivity value, thus increasing the potential for erosion. This factor is generally calculated based on long-term rainfall data, taking into account rainfall distribution patterns and intensity. In erosion analysis, the R factor serves as the primary indicator controlling the amount of rainfall energy that triggers the initial erosion process, making it crucial in assessing land vulnerability to degradation.

The rainfall erosivity factor (R) in the Ciujung Watershed area can be seen in Table 8 below.

Table 8. Rainfall Erosivity Factor (R) Values in the Ciujung Watershed

Years	Monthly Rainfall (mm)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2012	460,7	220,4	154,8	200,2	128,3	77,7	20,2	18,0	47,2	154,4	346,3	219,4
2013	593,7	235,8	131,9	189,4	178,3	74,0	254,6	64,0	101,5	97,4	225,5	274,9
2014	434,7	302,1	161,3	140,7	231,6	100,0	115,4	104,7	39,4	133,6	200,0	66,1
2015	339,8	267,7	136,5	245,1	142,0	86,9	23,8	23,9	8,3	49,6	211,5	219,8
2016	198,8	348,6	289,1	212,3	129,9	114,4	210,3	88,6	183,4	262,8	200,6	350,4
2017	246,5	409,7	197,4	203,4	198,8	166,0	112,9	43,7	94,7	151,2	156,4	150,9
2018	290,4	245,5	136,8	224,6	188,2	141,9	12,0	24,9	71,2	108,2	173,2	253,0
2019	302,6	247,1	205,0	223,6	204,7	40,7	36,3	51,0	19,6	92,2	96,6	195,3

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2020	269,0	329,4	325,8	233,4	210,2	204,2	114,0	112,7	139,9	181,5	187,2	376,6
2021	271,9	367,7	126,2	222,2	167,9	214,4	70,3	193,7	314,9	194,0	252,8	241,2
Rerata	**340,8**	**297,4**	**186,5**	**209,5**	**178,0**	**122,0**	**97,0**	**72,5**	**102,0**	**142,5**	**205,0**	**234,8**
Rain Erosivity	**268,3**	**222,9**	**118,2**	**138,4**	**110,9**	**66,4**	**48,6**	**32,7**	**52,0**	**82,0**	**134,4**	**161,6**

Source: 2025 Analysis Data

Calculation of Rainfall Erosivity Factor using the Lenvain method.

R = 2,21 x $P_y^{1,36}$ = 1.436,26

P_y = Monthly Rainfall (cm)

Soil Erodibility Factor (K)

The soil erodibility factor (K) is a parameter in the Universal Soil Loss Equation model that indicates the level of soil susceptibility to erosion by rain energy and surface runoff. The K value reflects the soil's ability to resist detachment and particle transport, which is strongly influenced by the soil's physical and chemical properties. Soils with weak structures, low organic matter content, and textures dominated by fine particles such as silt generally have high K values, making them more susceptible to erosion. Conversely, soils with stable structures, high organic matter content, and good permeability tend to have low K values. Therefore, the soil erodibility factor is an important indicator in evaluating land susceptibility to degradation (Kardhana et al., 2024).

The soil erodibility factor is calculated by considering the main soil properties: texture, structure, permeability, and organic matter content (Alhakim et al., 2025). Soil type data was obtained from the Food and Agriculture Organization (FAO) Soil Map, which was then processed using a geographic information system-based application to produce a soil type distribution map. Through this process, information on the area of each soil type in the Ciujung River Watershed (DAS) was obtained. The soil erodibility factor in the Ciujung Watershed (DAS) can be seen in Table 9.

Table 9. Soil Erodibility Factor (K) of the Ciujung Watershed

No	Soil Type	Surface Area A (Ha)	Surface Area (%)	K	% x K
1	Aluvial	27.894,39	12,98	0,300	0,03894
2	Andosol	1.630,56	0,76	0,200	0,00152
3	Latosol	76.666,01	35,69	0,175	0,06246
4	Planosol	4.135,32	1,92	0,275	0,00528
5	Podsolik	100.195,84	46,64	0,300	0,13992
6	Regosol	235,90	0,11	0,225	0,00025
7	Resina	4.082,52	1,90	0,225	0,00428
Total		**214.840,54**	**100**		**0,25265**

Source: 2025 Analysis Data

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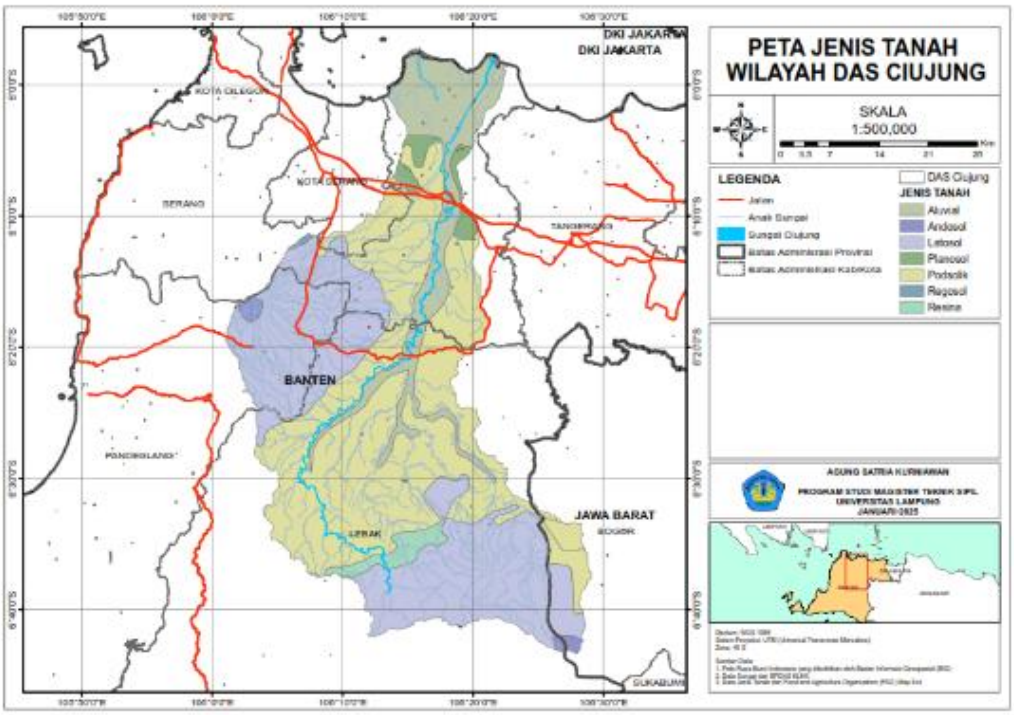

Figure 4. Soil Type Map of the Ciujung Watershed

Slope Length and Slope (LS) Factor

The slope length and slope (LS) factor is an important component in the Universal Soil Loss Equation model, describing the influence of topography on the extent of soil erosion. This factor integrates the effects of slope length (L), which is related to runoff accumulation, and slope gradient (S), which influences flow velocity and sediment transport energy. The longer and steeper the slope, the greater the potential for erosion because the volume and velocity of runoff increase. Therefore, the LS factor is a key indicator in assessing land vulnerability to erosion, especially in areas with significant topographic variation.

The calculation of the LS value in this study was carried out using slope length and slope index data obtained from the Digital Elevation Model (DEM) processing provided by the United States Geological Survey (USGS). The application of this LS factor plays a crucial role in the erosion estimation analysis. The results of the processing, in the form of a slope gradient map and the distribution of LS values in the Ciujung Watershed, are presented in Figure 5 and Table 10.

Table 10. LS Factor of Slope of Ciujung Watershed

Slope Gradient (%)	Area (Ha)	Area (%)	LS Value	% × LS
0–8	82,139.38	38.66	0.4	0.15464
8–15	49,795.08	23.43	1.4	0.32802
15–25	40,515.67	19.07	3.1	0.59117
25–45	30,344.98	14.28	6.8	0.97104
> 45	9,695.48	4.56	9.5	0.43320
Total	**212,490.59**	**100**		**2.47807**

Source: 2025 Analysis Data

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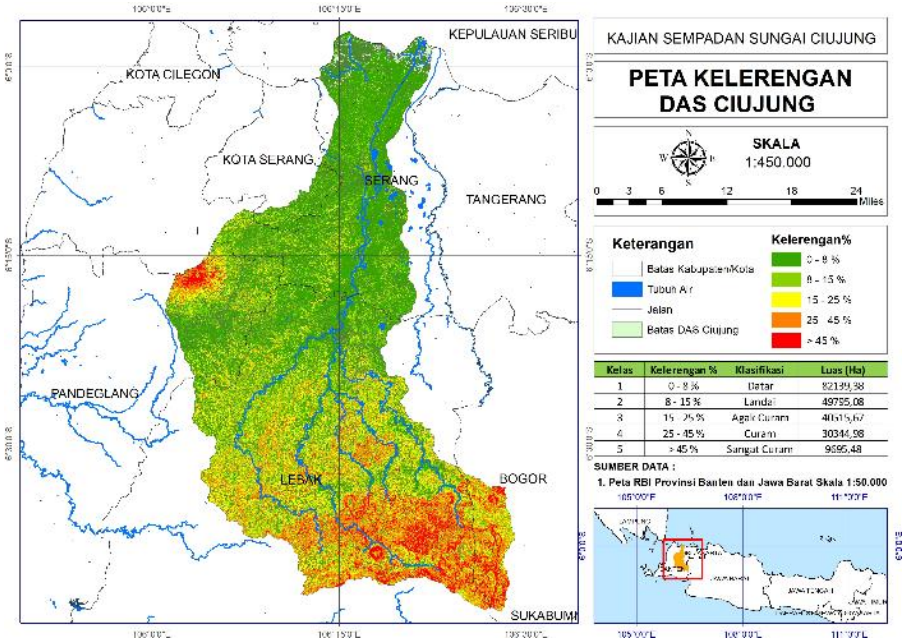

Figure 5. Slope Map of the Ciujung Watershed

Plant Management (C) and Plant Conservation (P) Factors

Plant management (C) and conservation (P) factors are important components of the Universal Soil Loss Equation model, reflecting the influence of human activities on soil erosion. The C factor indicates the ratio of soil loss on land with cover and specific management practices to land without cover (bare land). The C value is influenced by vegetation type, canopy density, planting system, and plant growth stage. Land with dense vegetation cover and good cultivation practices has a low C value, thus suppressing erosion. Meanwhile, the P factor represents the effectiveness of soil conservation measures, such as terracing, contour planting, and the construction of flow control channels. The P value ranges from 0 to 1, with lower values indicating greater conservation effectiveness in reducing erosion.

The determination of C and P values is generally done through an empirical tabular approach based on the type of land use and conservation practices implemented. The C value is obtained by identifying land cover (e.g., forests, plantations, rice fields, or open land) and comparing it with reference values in the literature. Meanwhile, the P value is determined based on topographic conditions and the type of conservation measures implemented on the land. In geographic information system-based analysis, these two factors are spatially mapped by combining land use data and conservation practice information. Factors considered include crop type, cropping pattern, vegetation density, tillage techniques, slope gradient, and the presence of conservation structures (Fatiawan et al., 2024). Thus, estimating the C and P values allows for a more comprehensive evaluation of the effectiveness of land management in controlling erosion rates (Agboola et al., 2020).

Sometimes, land use (C) and land management (P) factors are not separate, but are expressed as a single parameter known as the CP factor. Land cover maps are compiled using Landsat imagery data obtained from the United States Geological Survey (USGS). This data is then processed using a geographic information system-based application to determine the extent of each land cover type in

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the Ciujung Watershed (DAS). The values for the crop management and conservation (CP) factors are presented in Table 11.

Table 11. Plant Management and Conservation (CP) Factors of the Ciujung Watershed

Land Cover	2016		2021		CP	2016	2021
	Area (Ha)	Area (%)	Area (Ha)	Area (%)		% x CP	% x CP
Water Bodies	6.657,9	3,10	3.657,7	1,70	0,00	0	0
Lake	1.361,6	0,63	31,1	0,01	0,00	0	0
Forest	113.769,7	52,96	69.811,5	32,50	0,05	0,02648	0,01625
Plantation	11.148,0	5,19	48.456,0	22,55	0,07	0,003633	0,015785
Settlement	5.423,6	2,52	11.226,7	5,23	0,12	0,003024	0,006276
Paddy Field	48.689,3	22,66	45.054,0	20,97	0,01	0,002266	0,002097
Shrubland	382,4	0,18	25,2	0,01	0,01	0,000018	0,000001
Open Land	649,6	0,30	372,6	0,17	1,00	0,00300	0,00170
Dryland Farming	380,5	0,18	25.895,2	12,05	0,35	0,00063	0,042175
Cloud Cover	716,8	0,33	3.131,0	1,46	-	-	-
Swamp	25.656,7	11,94	7.174,7	3,34	0,00	0	0
Total	**214.836,1**	**100**	**214.835,7**	**100**		**0,039051**	**0,084284**

Source: 2025 Analysis Data

Based on data in 11 above, it can be seen that the crop management and conservation (CP) factor for the 2017–2021 period was 0.084, a 115.83% increase from 0.039 in the 2012–2016 period.

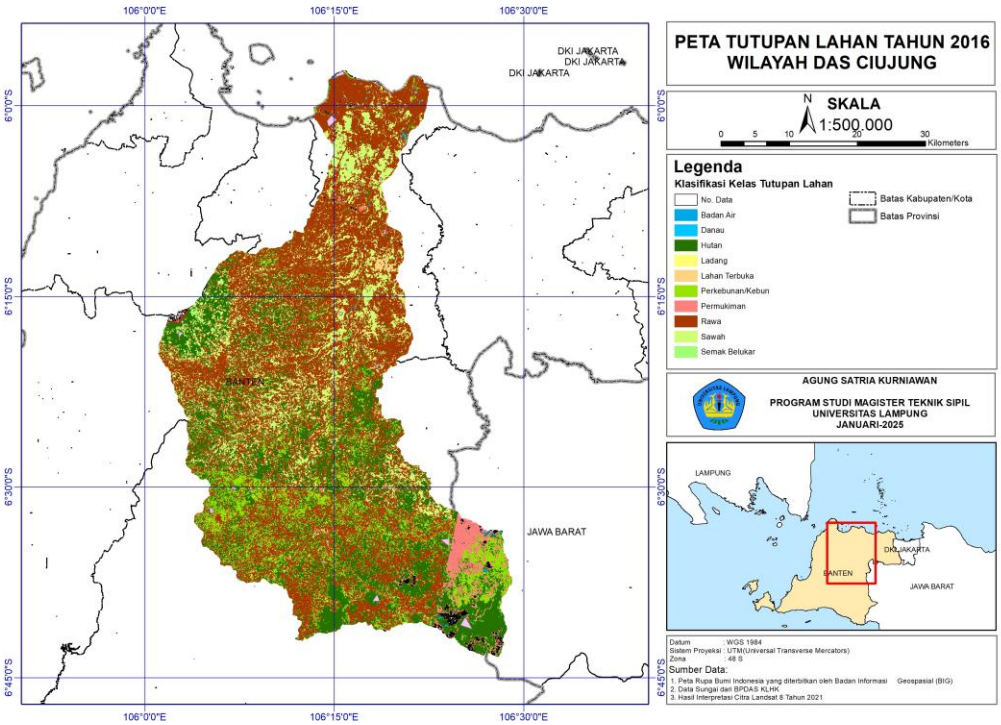

Figure 6. Land Cover Map of the Ciujung Watershed, 2016

Source: 2025 Analysis Data

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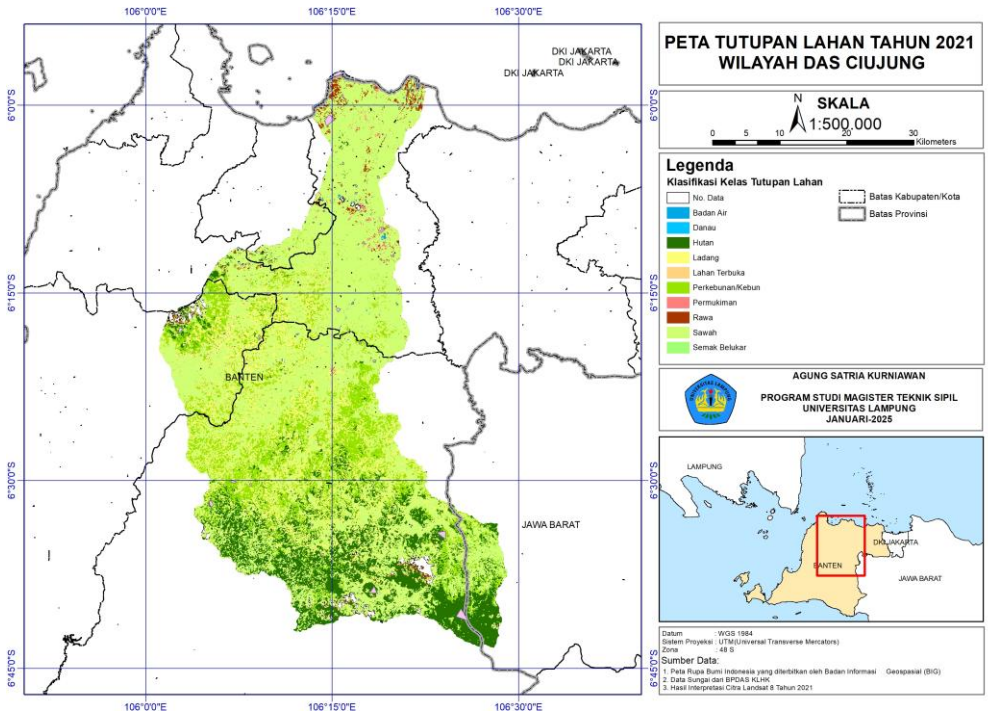

Figure 7. Land Cover Map of the Ciujung Watershed in 2021
Source: 2025 Analysis Data

Calculation of Estimated Total Erosion Using the Universal Soil Loss Equation (USLE) Method

Based on the previous factor calculations, the estimated erosion rate in the Ciujung Watershed (DAS) in 2016 and 2021 can be calculated using the Universal Soil Loss Equation (USLE) equation described previously.

E = R x K x Ls x C x P

E_{2016} = 1.436,26 x 0,25265 x2,47807 x 0,039051 = 35,1154 ton/Ha/year

E_{2021} = 1.436,26 x 0,25265 x2,47807 x 0,084284 = 75,7899 ton/Ha/year

Based on the calculations above, the erosion rate in 2016 was 35.1154 tons/ha/year, and in 2021 it was 75.7899 tons/ha/year. This represents an estimated 115.83% increase in land erosion over the five-year period compared to 2016 levels. Therefore, based on the erosion hazard class table, the erosion hazard level in the Ciujung River Watershed (DAS) has increased from Class II (Low) to Class III (Moderate).

From the erosion data above, the estimated sedimentation rate in the Ciujung Watershed can be analyzed using the following equation:

$$Y = E \times (SDR) \times A$$

Where:

Y = Sediment Yield (tons/yr)
E = Total Erosion (tons/ha/yr)
SDR = Sediment Delivery Ratio
A = Catchment Area (ha)
SDR = 0,41 x ($A^{-0,3}$)
SDR = *Sediment Delivery Ratio*
A = River Basin Area (km2)

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Before calculating the amount of sediment produced, the SDR value must first be calculated. Based on the equation above, the SDR value can be seen in Table 12, and the sediment value can be seen in Table 13 below.

Table 12. Calculation of Sediment Delivery Ratio (SDR) Value

Slope Gradient (%)	Area (Ha)	Area (km^2)	SDR
0 – 8	82.139,38	821,39	0,0548
8 – 15	49.795,08	497,95	0,0636
15 – 25	40.515,67	405,16	0,0677
25 – 45	30.344,98	303,45	0,0738
> 45	9.695,48	96,95	0,1039
Total			**0,3638**

Source: 2025 Analysis Data

From the SDR data above, the sediment (Y) values in the Ciujung River Basin (DAS) in 2016 and 2021 are as follows.

$Y_{2016} = E_{2016}$ x SDR x A

Y_{2016} = 35,1154 x 0,3638 x 214.836,1 = 2.744.527,42 ton/th

Y_{2021} = 75,7899 x 0,3638 x 214.835,7 = 5.923.528,47 ton/th

Land Use Change

Land use changes in the Ciujung River Basin (DAS) between 2016 and 2021 show a significant shift from vegetated land to cultivated land and intensive human use. Based on the results of Landsat image analysis in 2016 and 2021, there was a decrease in forest area by 38.6% from an area of 113,769.71 Ha to 69,811.50 Ha, there was also a decrease in the area of shrubs by 93.4% from an area of 382.43 Ha to 25.23 Ha, a decrease in the area of Open Land by 42.6% from an area of 649.58 Ha to 372.58 Ha, a decrease in the area of Swamps by 72.0% from an area of 25,656.66 Ha to 7,174.68 Ha, as well as a decrease in the area of rice fields by 7.5% from an area of 48,689.32 Ha to 45,053.96 Ha. On the other hand, there was a 334.7% and 6,705.2% increase in plantation and field areas, respectively, from 11,147.99 hectares to 48,456.03 hectares and from 380.52 hectares to 25,895.20 hectares, respectively. Furthermore, there was a 107.0% increase in residential areas, from 5,423.59 hectares to 11,226.69 hectares. The calculation of land use changes can be seen in Table 4.16.

Table 13. Changes in Land Use in the Ciujung Watershed, 2016–2021

Land Use	2012 Area (Ha)	2021 Area (Ha)	Change (Ha)	Change (%)
Water Bodies	6,657.9	3,657.7	-3,000.2	-45.1
Lake	1,361.6	31.1	-1,330.5	-97.7
Forest	113,769.7	69,811.5	-43,958.2	-38.6
Plantation	11,148.0	48,456.0	37,308.0	334.7
Settlement	5,423.6	11,226.7	5,803.1	107.0
Shrubland	382.4	25.2	-357.2	-93.4
Open Land	649.6	372.6	-277.0	-42.6
Dryland Farming	380.5	25,895.2	25,514.7	6,705.2
Cloud Cover	716.8	3,131.0	2,414.2	336.8
Swamp	25,656.7	7,174.7	-18,482.0	-72.0
Paddy Field	48,689.3	45,054.0	-3,635.4	-7.5

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Total	**214,836.1**	**214,835.7**

Source: USGS (processed, 2025)

Most forest land has been converted into plantations and fields. Meanwhile, some swamps, open areas, shrubs, and rice fields have been converted into residential areas and some into fields.

The Effect of Land Use Change on Streamflow and Land Erosion

The land cover coefficient (C) increased from 0.11 in the 2012-2016 period to 0.18 in the 2017-2021 period. This indicates that land cover in the Ciujung River Watershed (DAS) area is experiencing land degradation due to changes in land use caused by human activities. The average annual river flow rate from 2017-2021 was 1,122.10 m3/s, an increase of 5.44% compared to 1,064.25 m3/s from 2012-2016. The increase in river flow discharge was followed by an increase in the average annual flow volume from 2,793.68 million m3 in the 2012-2016 period to 2,932.14 million m3 in the 2012-2016 period.

Table 14. Changes in Land Use, Flow Discharge, and Land Erosion

Period	Land Cover Coefficient (C)	Discharge (m^3/s)	Flow Volume (million m^3)	Runoff Coefficient (C)	Total Erosion (E)	Sediment Yield (Y)
2012–2016	0.11	1,064.25	2,793.68	0.58	35.1154	2,744,527.42
2017–2021	0.18	1,122.10	2,932.14	0.59	75.7899	5,923,528.47

Source: 2025 Analysis Data

Forest land conversion is one factor that can influence increased river flow. Analysis of Landsat imagery from 2016 and 2021 revealed that forest land in the Ciujung Watershed has experienced a reduction in area between 2017 and 2021. Most of this forest land has been converted to fields and plantations. Degradation of watershed land cover increases runoff, which will increase as the area of buffer forest decreases (Puspitasari et al., 2023). The better maintained forest cover is, the lower the runoff will be. Conversely, the greater the conversion of forest land to other land uses, the higher the runoff will be. In the Ciujung Watershed, the runoff coefficient increased from 0.58 in 2012 to 2016, from 0.58 to 0.59 in 2017 to 2021. Furthermore, the decline in watershed quality, land degradation, and high flow and volume have resulted in potential land erosion and sedimentation potential in the Ciujung Watershed. Land erosion and sediment analysis using the Universal Soil Loss Equation (USLE) method revealed that the potential for land erosion from 2017 to 2021 was 75.7899 tons/ha/year, a 115.83% increase from 35.1154 tons/ha/year in 2012 to 2016. Similarly, the potential for sedimentation from 2012 to 2016 was 2,744,527.42 tons/year and from 2017 to 2021 was 5,923,528.47 tons/year.

In addition to increased rainfall due to climate change, the decline in the quality of the Ciujung River Watershed (DAS) due to changes in land use will impact surface runoff, resulting in increased discharge and flow volume, and potentially causing watershed degradation in the form of potential erosion and sedimentation in the watershed area (Imani et al., 2023).

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CONCLUSION

This study demonstrates that the Ciujung Watershed experienced significant hydrological and environmental changes between 2012–2016 and 2017–2021. Regional rainfall increased during the second period, accompanied by higher annual flow volume and average monthly discharge, although peak discharge declined. Linear regression analysis confirmed a strong and statistically significant positive relationship between rainfall, river discharge, and peak discharge, indicating that rainfall variability remains a major factor influencing the watershed's hydrological response.

The assessment of watershed condition revealed a gradual deterioration, as reflected by the increasing runoff coefficient and unfavorable discharge ratio (Qid) values. GIS-based USLE analysis further showed that estimated soil erosion more than doubled, increasing from 35.1154 to 75.7899 tons/ha/year, while annual sediment yield also increased substantially. Land use analysis revealed extensive conversion of natural vegetation, particularly forests, shrublands, and wetlands, into plantations, cultivated land, and residential areas, reflecting intensified human activities across the watershed.

Overall, the findings confirm that land use change, combined with increasing rainfall, has significantly altered the hydrological characteristics of the Ciujung Watershed, leading to greater runoff, increased erosion, and higher sediment production. These results highlight the urgent need for sustainable watershed management, including land conservation, reforestation, and integrated land-use planning, to mitigate further environmental degradation and maintain the long-term hydrological function of the watershed.

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