LIMNOTEK Perairan Darat Tropis di Indonesia
transforming into Journal Limnology and Water Resources
p-ISSN: 0854-8390 e-ISSN: 2549-8029
https://ejournal.brin.go.id/limnotek

The Effect of Land Cover Changes on Water Quality in the Cisadane River Basin, West Java, Indonesia

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Received: 28 November 2024; Accepted: 19 May 2025; Published: 20 June 2025

Abstract: The availability of water and clean water quality are increasingly affected by population growth. As the human population expands, the demand for goods and services rises, often leading to intensified in water use and pollution. This study examines the correlation between land cover changes and water quality in the Cisadane River Basin. Water quality data were collected as a time series from 2019 to 2022, focusing on eight parameters: TDS, TSS, BOD5, COD, DO, TP, NO3-N, and NH3-N. Water quality was classified using the Pollution Index (IP) method. Land cover changes were visually interpreted using ArcGIS at a 1:10,000 scale. Multiple linear regression analysis was used to assess the influence of land cover on river water quality. The results indicate that the overall water quality in the Cisadane River Basin falls under the 'slightly polluted' category, with noticeable influence from land cover changes. Between 2019 and 2022, built-up land increased by approximately 5.5%, contributing to elevated BOD_5 levels in several locations, such as Babakan and Genteng, indicating rising organic pollution from domestic waste and urban activities. Conversely, a decrease in vegetation cover by around 6.3% at various observation points correlated with decreased DO levels, especially in downstream areas such as Tanjung Burung and Vihara, potentially disrupting aquatic ecosystem balance. These findings suggest that vegetation cover plays an important role in maintaining water quality and ecological stability, while the expansion of built-up and agricultural areas tends to elevate pollutant loads in river water. Therefore, the results of this study can serve as a reference for policymakers in spatial planning of the Cisadane River Basin, especially in developing land conservation and waste management strategies to improve water quality and maintain the sustainability of water resources in the region.

Keywords: Cisadane River Basin, Land Cover Changes, Multiple Linear Regression Analysis, Pollution Index, Water Quality

DOI: https://doi.org/10.55981/limnotek.2025.8944

1. Introduction

The increasing demand for clean water continues to pose a challenge alongside population growth (Sasongko et al. 2014). Population growth not only escalates the need for water but also heightens the risk of water pollution due to waste from industrial and domestic activities. Improperly managed waste contains pollutants that flow into water bodies, thereby degrading water quality (Effendi et al., 2021; Syawal et al., 2016). Furthermore, population growth drives changes in land use, such as the conversion of natural vegetation into built-up or agricultural areas, which contribute to increased pollutant loads in water systems (Chu and Yu 2002; Kemp 2004).

p-ISSN 0854-8390 e-ISSN 2549-8029

In river basin areas, the impacts of land cover changes are significant. Studies by Effendi (2016, 2017) and Effendi et al. (2015, 2018) demonstrate that human activities altering land cover around river basins are closely associated with water pollution, as evidenced by the decline in various water quality indicators (Effendi, 2016, 2017; Effendi et al., 2015, 2018). The Cisadane River Basin, one of Indonesia's national priority river basins, has had significant land cover changes over the years due to economic activities and population growth (Dawud et al. 2016). The community's increasing demand for land for infrastructure and settlements has led to land degradation, ultimately reducing both the quantity and quality of water in the Cisadane River Basin. This, in turn, affects the watershed's capacity to meet community water needs and increases the pollution burden (Suwari et al, 2011, Yusuf et al., 2021).

Previous studies have established a relationship between land cover and water quality in the Cisadane river basin. Iqtashada and Febrita (2023) found that changes in land cover around the Cisadane River significantly affected water quality, particularly with increased Total Suspended Solids (TSS) and Nitrite levels in Bogor City (Iqtashada and Febrita 2023). Similarly, Nilda et al. (2015) reported that the conversion of vegetation into built-up areas directly impacted water quantity and exacerbated pollution, leading to a decline in water quality in the upstream regions of the Cisadane River Basin (Nilda et al. 2015). In contrast to previous studies by Iqtashada & Febrita (2023) and Nilda et al. (2015), this study includes a more comprehensive analysis of the entire Cisadane River Basin area, including upstream, middle, and downstream, thus providing a more holistic picture of the impact of land cover changes on water quality.

This study aims to conduct a more comprehensive analysis of the correlation between land cover and water quality in the Cisadane River Basin, covering the upstream, middle, and downstream areas. This study focuses on the effect of land cover variations on water quality in the Cisadane River Basin. Understanding the relationship between land cover change and water quality is essential to support environmental sustainability and effective water management policies, especially in areas under pressure from population growth and economic activity. This knowledge is not only relevant for water resource management, but also for broader environmental conservation and rehabilitation efforts. By understanding these dynamics, stakeholders can take more appropriate and informed actions to maintain water quality and ecosystem sustainability. This analysis uses a regression analysis approach, which effectively identifies relationship patterns between variables. This method is very useful in identifying patterns and trends in data and providing insight into how variations in land cover contribute to changes in water quality (Hamidi & Kamulyan, 2022; Wariunsora et al., 2024). This study is expected to provide a more comprehensive understanding of the effect of various land cover classes on water quality, and the results can be a basis for stakeholders in making more effective and sustainable Cisadane River Basin management policies.

2. Materials and Method

2.1 Time and Location of Study

The study was conducted in the Cisadane River Basin, located between 6°72′ to 6°76′ S and 106°58′ to 106°51′ E. Administratively, the Cisadane River Basin spans 518 villages across 44 sub-districts in five regencies/cities: Bogor Regency, Bogor City, Tangerang Regency, Tangerang City and South Tangerang City. The research took place from October 2023 to April 2024. The data used in this study included spatial and temporal water quality test results from the past four years and land cover data surrounding the Cisadane River Basin. The research location can be seen in Figure 1.

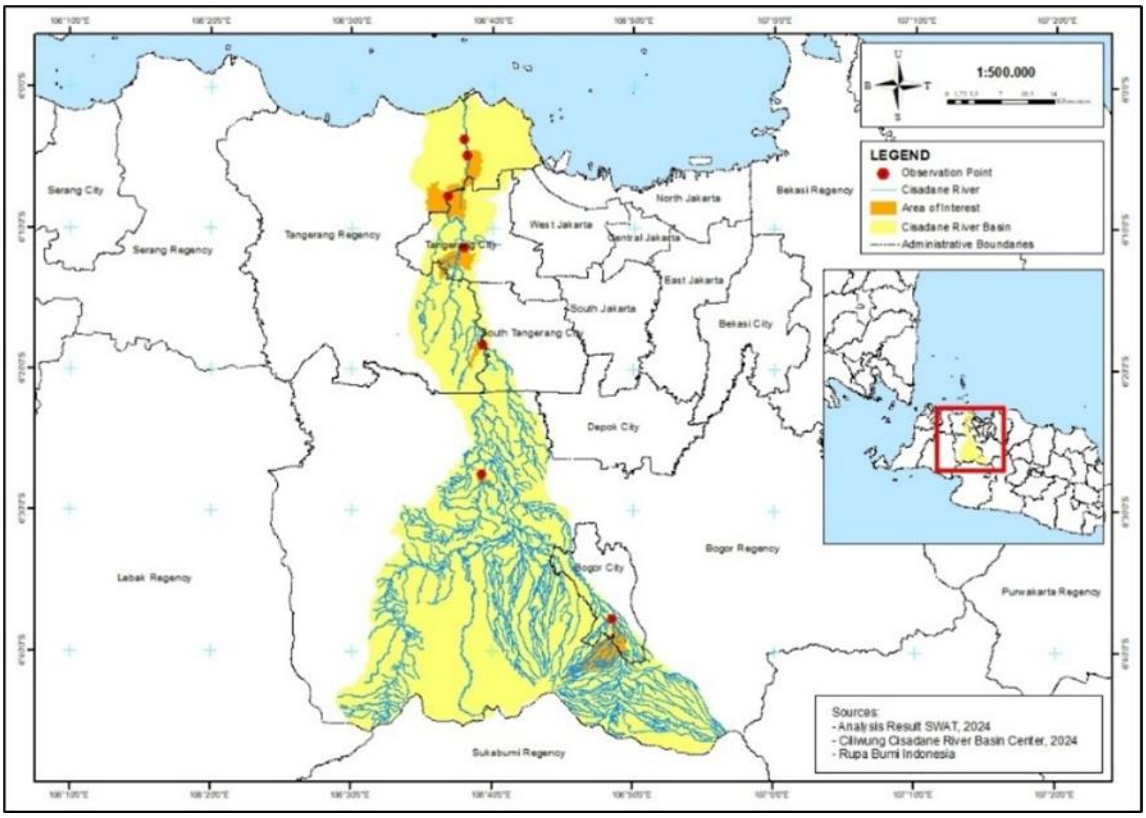


Figure 1. Study area map showing the Cisadane River Basin, Indonesia, including sampling points and watershed boundaries.

2.2 Water Quality

Water quality data were obtained Ciliwung Cisadane River Basin Center and Tangerang Regency Environmental and Sanitation Service. The data used in the study covered the period from 2019 to 2022 and included eight water quality parameters: Total Dissolved Solids (TDS), Total Suspended Solids (TSS), Biochemical Oxygen Demand (BOD5), Chemical Oxygen Demand (COD), Dissolved Oxygen (DO), Total Phosphate (TP), NO3-N, NH3-N. The study analyzed water quality at seven observation points along the Cisadane River, as can be seen in Table 1.

Table 1. List of observation points with corresponding sub-districts and regency/city in the Cisadane River Basin.

Observation Point*	**Sub-district**	**Regency/City**
Genteng	South Bogor	Bogor City
Batu Beulah	Ciseeng	Boger Regency
Serpong	Cisauk	Tangerang Regency
Babakan	Tangerang	Tangerang Regency
Kedaung	Neglasari	Tangerang Regency
Vihara	Teluk Naga	Tangerang Regency
Tanjung Burung	Teluk Naga	Tangerang Regency

*) sorted from upstream to downstream

The determination of the Pollution Index (PI) value is based on the Decree of the Minister of Environment No. 115 of 2003, which evaluates water quality conditions by measuring and/or testing specific parameters using established methods and comparing the results with water quality standards. The water quality standards referenced in this study align with Government Regulation of the Republic of Indonesia Number 22 of 2021, attachment VI for Class II River Water Quality Standards. Class II standards apply to water designated for recreational facilities, freshwater fish farms, livestock, irrigation, and similar uses. The Pollution Index calculation in this study was conducted at seven observation points using eight water quality parameters: TDS, TSS, BOD5, COD, DO, TP, NO3-N, and NH3-N. The Pollution Index value is determined using the following equation:

$$Pj = \sqrt{\frac{\left(\frac{Ci}{Lij}\right)_M^2 + \left(\frac{Ci}{Lij}\right)_R^2}{2}} \quad \text{...Eq 1}$$

Where Pj is the Pollution Index, Ci is the concentration of water quality parameter i, Lij is the concentration of water quality parameter i as specified in water quality standard j, M is the maximum value of the pollution index, R is the average value of the pollution index. Determination of water status based on the classification of pollution index values refers to the Decree of the Indonesia Minister of Environment No. 115 of 2003 concerning Guidelines for Determining Water Quality Status, as shown in Table 2.

Table 2. Methods Used for Water Quality Parameter Analysis in the Cisadane River by DLHK Tangerang Regency and BBWS Ciliwung Cisadane

Parameter (unit)	***DLHK Kab. Tangerang***	***BBWS Ciliwung Cisadane***
TDS (mg/L)	IKM.KHT-27 (Electrometry)	LAB/IK/KIM-ENV/61
TSS (mg/L)	IKM.KHT-41 (Spectrophotometry)	SNI 6989.3 : 2019
BOD_5 (mg/L)	SNI 6989.72:2009	APHA 5210 B 2012
COD (mg/L)	SNI 6989.2:2009	SNI 6989.2:2009
DO (mg/L)	SNI 06-6989.14-2004	LAB/IK/KIM-ENV/88
Total P (mg/L)	IKM.KHT-61 (Spectrophotometry)	SNI 06 - 6989.31 - : 2005
NO_3-N (mg/L)	IKM.KHT-22 (Spectrophotometry)	SNI 06- 6989.79 - : 2011
NH_3-N (mg/L)	SNI 06-6989.30-2005	SNI 06- 6989.30 - 2005

2.3 Multi-temporal Land Cover

The image data used for land cover classification were obtained from Maxar Technologies for 2019-2022. Maxar Technologies is one of the satellite used by Google. This data was obtained from https://earth.google.com/, and it is open to the public. Land Cover classification was performed using a visual interpretation method, with delineation of each land cover class conducted in ArcGIS software at a scale of 1:10,000. The visual interpretation analysis method has advantages, including being able to analyze images with high spatial resolution and having good knowledge of conditions in the field (Kosasih et al., 2019). The land cover types were categorized into five classes: water bodies, open land, built-up land, agricultural land and vegetation. The classification of each land cover type followed the SNI 7654:2010 Land Cover Classification standards. Before determining land cover, an Area of Interest (AOI) was defined to identify areas directly affecting water quality at the observation points. The AOI determination was conducted using ArcSWAT software, with input data including Digital Elevation Model (DEM) and the flow path of the Cisadane River. During the AOI delineation process, model outlet points were set at each water quality observation point. In this study, the AOI was restricted to areas with a direct impact on water quality measurement at the observation point, ensuring the selected region are those in direct contact with the research observation points.

2.4 Variable Selection

Before conducting the regression analysis, a classical assumption test was performed. Classical assumption testing is an essential step preceding linear regression analysis (Masiaga et al. 2022). The tests conducted included multicollinearity, heteroscedasticity, normality, and autocorrelation test. These tests aim to ensure the accuracy and reliability of the regression equation in estimating relationships (Alita et al. 2021; Nurcahya et al. 2024). These tests ensure the regression model meets the necessary assumptions for valid and reliable analysis.

2.5 Regression Analysis

The regression analysis in this study was conducted using SPSS 225 software. Each water quality parameter was a dependent variable, while land cover data were used as independent variables. The regression analysis involved eight dependent variables: TDS, TSS, BOD5, COD, DO, TP, NO3-N, NH3-N. The regression method applied was multiple linear regression analysis. The regression model equation used in this study is as follows:

$$Y = \alpha + \beta 0 + \beta 1X1 + \beta 2X2 + \beta 3X3 + \dots + \beta kXk + \varepsilon i \quad \text{...Eq 2}$$

where Y is water quality parameters (mg/l), α is constant or intercept of the regression model, β1 – β5 is the regression coefficient for each independent variable, X1 is water bodies, X2 is agricultural land, X3 is built-up land, X4 is open land, X5 is vegetation, and εi is error term representing unobserved factors.

3. Results and Discussion

3.1. Variable Selection

a. Multicollinearity Test

Based on the test results, all independent variables meet the multicollinearity criteria, with VIF values below 10 and tolerance values above 0.10. This indicates that there is no multicollinearity present in the data, confirming that the independent variables are sufficiently independent for further regression analysis (Ainiyah et al. 2016). The detailed results of the multicollinearity test are presented in Table 3.

Table 3. Multicollinearity Test Results

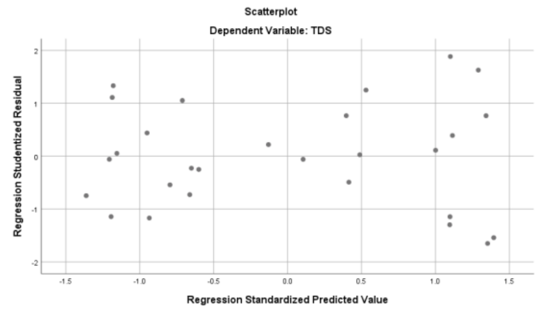
Model	Collinearity Statistics	
	Tolerance	VIF
Water bodies	0,181	5,515
Agricultural land	0,202	4,958
Built-up land	0,104	9,635
Open land	0,125	7,992
Vegetation	0,635	1,576

b. Heteroscedasticity Test

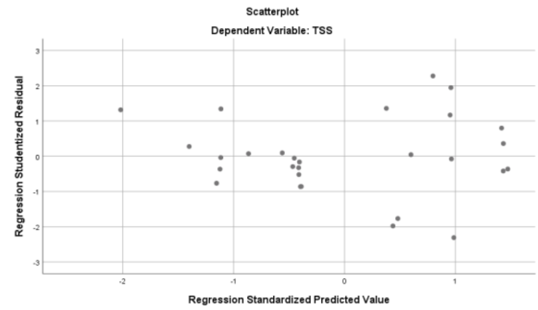
The heteroscedasticity test was conducted by analyzing the scatterplot for each variable. If the points on the scatterplot are randomly distributed and do not form a specific pattern, it can be concluded that there is no heteroscedasticity in the regression model, indicating the absence of residual variance similarity across observations (Purba et al. 2021). Based on the test results, the scatter plot shows no discernible pattern in the distribution of points. Therefore, it can be concluded that the data do not exhibit heteroscedasticity. The scatterplot results of the heteroscedasticity test are presented in the Figure 2.

c. Normality Test

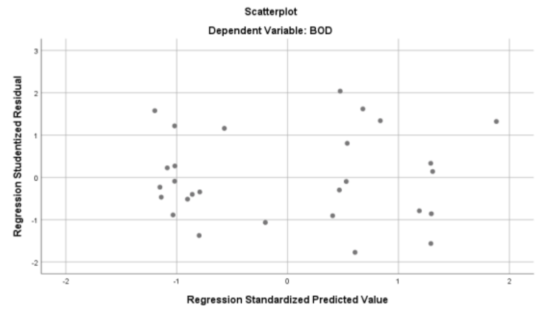
The normality test results in data processing indicate that the histogram of each variable forms a perfect bell curve. This suggests that the data for each variable are normally distributed. These findings align with previous research stating that a perfect bell-shaped histogram signifies normally distributed data (Purba et al. 2021). The histogram obtained from the normality test is presented in Figure 3.



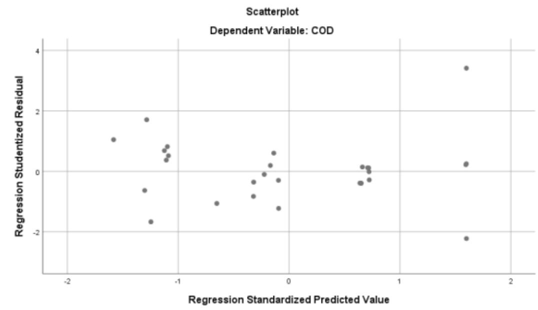
a. Scatterplot TDS



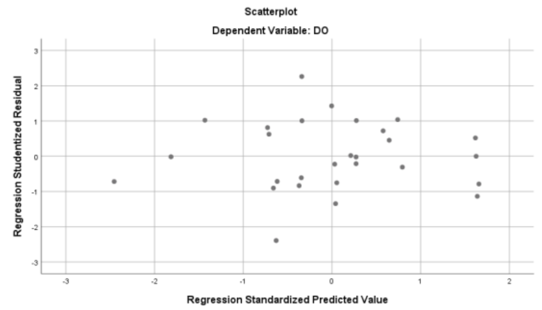
b. Scatterplot TSS



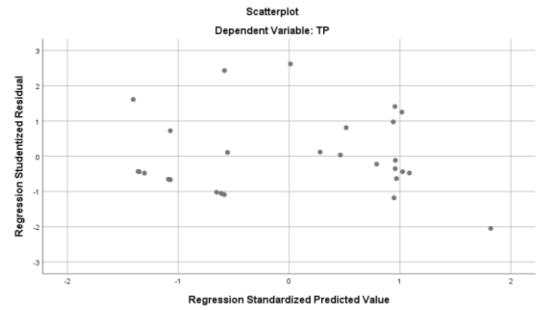
c. Scatterplot BOD



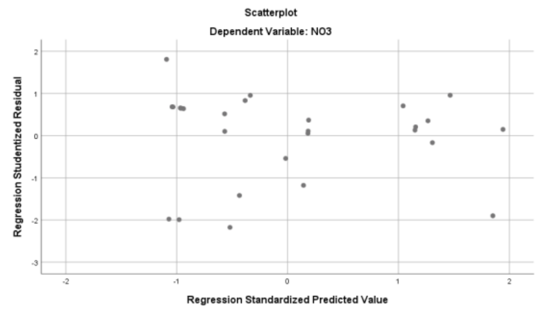
d. Scatterplot COD



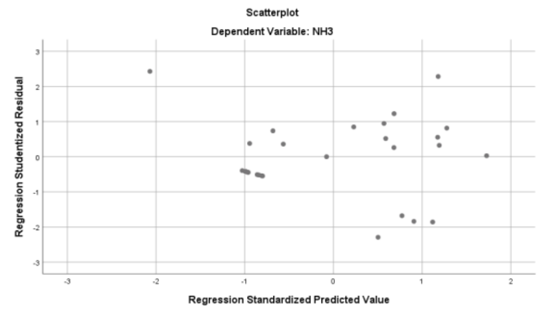
e. Scatterplot DO



f. Scatterplot TP

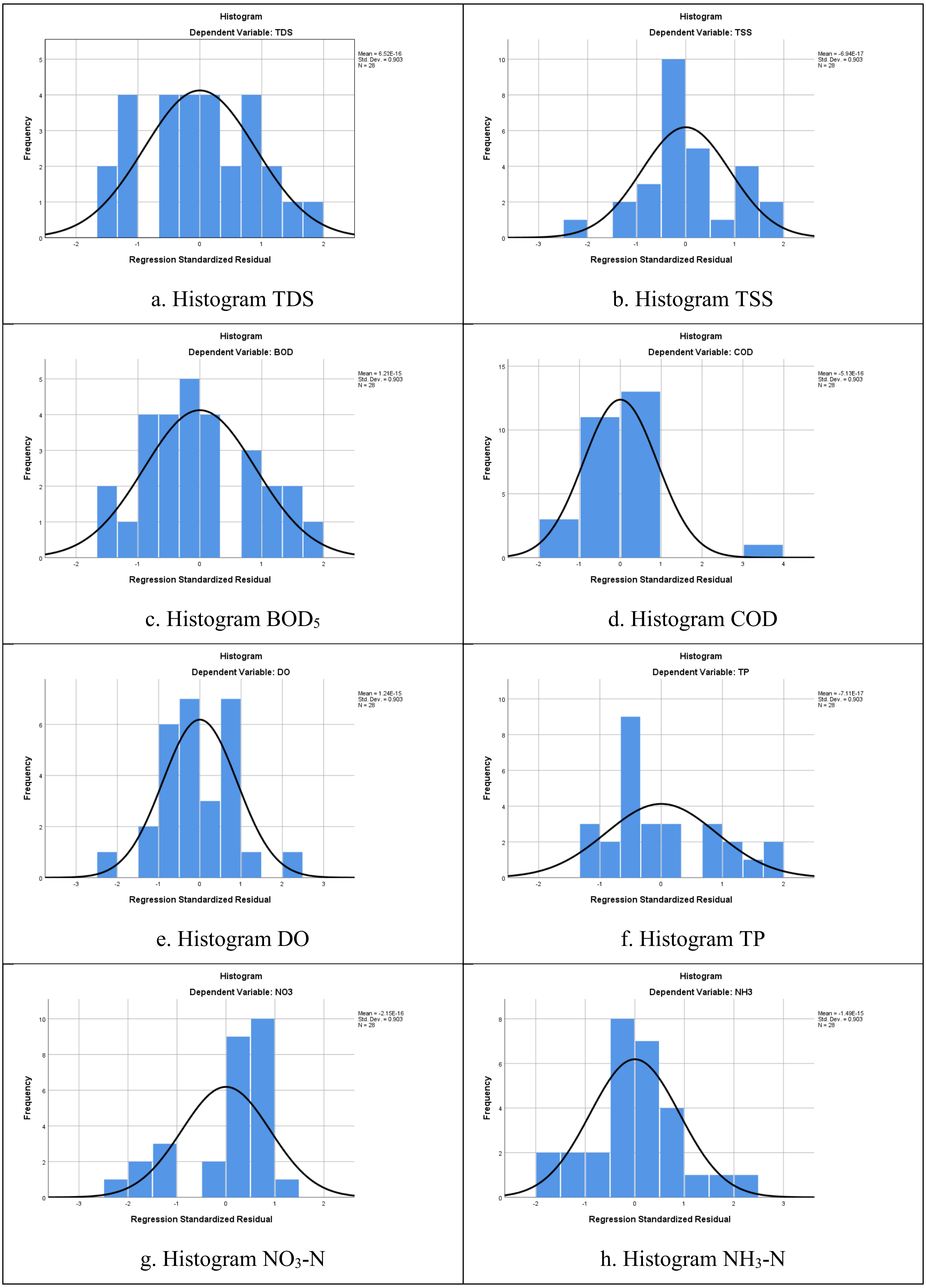


g. Scatterplot NO_3-N



h. Scatterplot NH_3-N

Figure 2. Heteroscedasticity Test Results



a. Histogram TDS
b. Histogram TSS
c. Histogram BOD_5
d. Histogram COD
e. Histogram DO
f. Histogram TP
g. Histogram NO_3-N
h. Histogram NH_3-N

Figure 3. Normality Test Results

d. Autocorrelation Test

The result of the autocorrelation test in data processing indicates that the Durbin-Watson (DW) value for each variable falls outside the range of the lower limit (dL) and upper limit (dU). This implies that there is no autocorrelation in the model. The dL and dU values used in the analysis refer to the Durbin-Watson Table (Junaidi 2010). These findings are consistent with previous research, which states that if the calculated DW value lies outside the dL and dU limits, the regression model is free from autocorrelation (Ainiyah et al. 2016). Details of the Durbin-Watson values are presented in Table 4.

Table 4. Autocorrelation Durbin-Watson Test Results

	TDS	**TSS**	**BOD_5**	**COD**	**DO**	**TP**	**NO_3-N**	**NH_3-N**
Durbin-Watson	2.060	2.029	2.171	2.025	1.856	2.131	2.072	1.884
dL	1.028	1.028	1.028	1.028	1.028	1.028	1.028	1.028
dU	1.850	1.850	1.850	1.850	1.850	1.850	1.850	1.850

3.2 Water Quality Status

In 2019, the overall water quality of the Cisadane River at various observation points was within acceptable limits for several parameters, except for BOD5 and DO, which mostly exceeded the quality standard limits. By 2020, the BOD5 levels showed improvement, as observed at the Kedaung and Vihara locations, which met the quality standards after exceeding the limits in 2019. However, the DO value at the Genteng location declined in 2020, failing to meet the standard it adhered to in 2019. The TP value at the Batu Beulah location also decreased in quality compared to 2019, exceeding the quality standard. In 2021, the TSS values generally declined in quality compared to 2020, with several locations surpassing the quality standard of 50 mg/l. At the same time, the COD levels at the Genteng location increased beyond the quality standard, reaching 27.32 mg/l. The NH3-N levels also rose, with several locations exceeding the quality standard limits. The BOD5 values at upstream locations, including Genteng, Batu Beulah, Serpong and Babakan, consistently exceeded the quality standard during this period. By 2022, the water quality of the Cisadane River showed overall improvement compared to 2021, as several locations met the quality standards. However, the TP values deteriorated further compared to 2021, particularly at Genteng, Batu Beulah, Serpong, and Babakan, where the values exceeded the quality standards.

Based on various parameters, the water quality in the Cisadane River Basin demonstrates variations across the years. TDS at all observation points, the TDS value consistently remains below the quality standard of 1000 mg/l, indicating that the concentration of dissolved solids has not reached levels that could significantly disrupt water quality (Vigiak et al. 2019). TSS mostly meets the standard of 50 mg/l, though spikes occurred at Genteng and Batu Beulah in 2021 and 2022. Elevated TSS levels can decrease water clarity, reducing light penetration necessary for photosynthetic organisms (Bilotta and Brazier 2008). BOD5 at many locations, particularly upstream areas such as Genteng, Batu Beulah, and Serpong, frequently exceed the standard of 3 mg/l. This suggests high concentrations of organic matter requiring oxygen for decomposition, which reduces dissolved oxygen availability and adversely affects aquatic ecosystems (Abdullahi et al. 2021). COD generally remains within the standard limit of 25 mg/l. However, locations such as Genteng experienced increased, indicating pollution from organic substances that elevate oxygen consumption and degrade water quality (Prilly and Harisuseno 2019). Dissolved oxygen levels vary significantly.

While upstream locations such as Batu Beulah and Serpong maintain values above the minimum 4 mg/l threshold supportive of aquatic life, downstream locations like Babakan and Kedaung show low DO values. These low levels can impair the growth and health of aquatic organisms (Susilowati et al. 2018; Samaras et al. 2023). Total Phosphate concentration at several points, including Batu Beulah and Serpong, occasionally exceed the safe limit of 0.2 mg/l. Elevated levels increase the risk of eutrophication, which can trigger algal blooms and deteriorate overall water quality (Akinnawo 2023). NO3-N and NH3-H are generally within safe limits. However, NH3-N concentrations spike at specific locations, such as Babakan and Genteng, during certain years. High NH3-N levels indicate domestic waste contamination, potentially causing oxidative stress and health issues for aquatic organisms (Li et al. 2023; Lin et al. 2023).

In more detail, the results of water quality tests in the Cisadane River in 2019-2022 obtained from the Ciliwung Cisadane River Basin Center and the Tangerang Regency Environmental and Sanitation Service can be seen in Table 5.

Table 5. Cisadane River Water Test Results 2019-2022

Station*	TDS (mg/l)	TSS (mg/l)	BOD_5 (mg/l)	COD (mg/l)	DO (mg/l)	Total P (mg/l)	NO_3-N (mg/l)	NH_3-N (mg/l)
BM II	1000	50	3	25	4	0,2	10	0,2
2019								
Genteng[1]	67	10	7	27	4,2	0,1	0,3	0,01
Batu Beulah[1]	70	12	7	17	4,1	0,1	0,5	0,01
Serpong[1]	81	40	7	22	4	0,1	1	0,01
Babakan[1]	83	15	10	21	3	0,08	0,5	0,01
Kedaung[2]	106	13	3,2	19	3,1	0,05	0,1	0,01
Vihara[2]	105	10	3,2	18	2,8	0,1	0,1	0,01
Tanjung Burung[2]	104	13	2,5	18	1,7	0,04	0,1	0,01
2020								
Genteng[1]	80,83	38	6,77	11,37	3,8	0,074	0,846	0,169
Batu Beulah[1]	70,1	35	7,13	12,8	5,9	0,241	1,37	0,038
Serpong[1]	80,61	38	5,59	11,8	5,3	0,041	1,29	0,127
Babakan[1]	88,7	19	5,35	8,3	3,8	0,1	1,56	0,183
Kedaung[2]	103	20	2,6	21	2,6	0,01	1	0,01
Vihara[2]	102	13	2,2	18	3	0,01	1	0,01
Tanjung Burung[2]	116	16	2,4	17	2,6	0,01	0,7	0,01
2021								
Genteng[1]	99,6	128	5,46	27,32	5,2	0,13	0,885	0,223
Batu Beulah[1]	92,9	70	4,32	15,21	4,9	0,096	1,52	0,144
Serpong[1]	88	60	4,63	16,26	3,8	0,414	1,21	0,212
Babakan[1]	105,7	17	3,74	11,53	2,7	0,088	2,56	0,322
Kedaung[2]	185	18	2,4	22	3,6	0,01	1	0,01
Vihara[2]	158	16	2,1	18	6,9	0,01	1	0,01
Tanjung Burung[2]	146	18	2,3	19	4	0,01	1	0,01
2022								
Genteng[1]	103,7	80	4,7	84	6	0,7	1,1	2
Batu Beulah[1]	104,9	110	2,9	12	5	0,6	1,8	0,08
Serpong[1]	108,1	77	3,4	19	4	0,6	1,5	0,1
Babakan[1]	130,5	23	3,7	19	2	0,4	1,8	0,3
Kedaung[2]	141	21	2	22	5,8	0,01	1	0,03
Vihara[2]	183	38	2,5	22	4,8	0,01	1	0,06
Tanjung Burung[2]	130	22	2	20	4,2	0,01	0,2	0,04

Locations such as Genteng experienced a significant increase in Pollution Index (PI) values, indicating a rise in pollution loads potentially caused by increased domestic or industrial activities. This may result from urbanization or intensified industrial activity around the river. Similarly, Anh et al. (2023) highlighted that residential and industrial land use, along with urbanization factors such as population growth and the expansion of impermeable surfaces, are primary contributors to river water pollution in urban areas. In contrast, locations like Vihara and Tanjung Burung showed a significant decrease in PI values, suggesting improved water quality linked to reduced pollution sources or enhanced environmental conditions. This improvement could be attributed to diminished local pollution activities or increased environmental carrying capacity to manage loads. Feng et al. (2023) emphasized that increased vegetation cover offers substantial benefits in reducing water pollution by absorbing nutrients and filtering pollutants (Feng et al. 2023). Other locations exhibited stability or fluctuations in PI values, reflecting the complex dynamics of water pollution influenced by various environmental factors and human activities. Overall, the Cisadane River's pollution index generally falls under the "slightly polluted" category. The detailed PI values and water quality status of the Cisadane River from 2019 to 2022 are presented in Table 6.

Table 6. Water Quality Status in the Cisadane River

Observation point	**2019**		**2020**		**2021**		**2022**	
	IP value	Status	IP value	Status	IP value	Status	IP value	Status
Genteng	2,07	S	2,05	S	2,28	S	4,49	S
Batu Beulah	2,06	S	2,08	S	1,36	S	2,50	S
Serpong	2,08	S	1,71	S	2,00	S	2,53	S
Babakan	2,65	S	1,68	S	2,11	S	2,58	S
Kedaung	1,75	S	2,10	S	1,28	S	0,64	G
Vihara	1,98	S	1,82	S	0,51	G	0,69	G
Tanjung Burung	2,59	S	2,10	S	0,76	G	0,63	G

where G is Good, S is Slightly Polluted, M is Moderately Polluted, H is Heavily Polluted.

3.3 Multi-temporal Land Cover Status

Watershed delineation in the SWAT model is a procedure that divides areas based on topography and river networks. The largest Area of Interest (AOI) is located in Genteng, covering an area of 2,267.85 hectares. This location is situated in the topography and steep slopes. In contrast, the smallest AOI is located in Tanjung Burung, covering an area of 63.81 hectares. Tanjung Burung is situated in the downstream part of the watershed, where the slope is relatively low. This observation aligns with previous studies, which reported that the upstream areas of the Cisadane River Basin reach altitudes of up to 3,000 meters above sea level with slopes of up to 40%. Meanwhile, the downstream areas are predominantly flat to gently undulating (Sudinda 2021). The AOI for each observation point is illustrated in Figure 2.

The Genteng location is predominantly covered by agricultural land and vegetation. From 2019 to 2022, agricultural land decreased significantly from 43.16% (978.89 ha) to 40.64% (921.67 ha), indicating substantial agricultural land conversion. Vegetation cover also declined, albeit slightly, from 30.47% (691.04 ha) to 30.24% (685.74 ha). The Batu Beulah location is similarly dominated by vegetation and agricultural land. During the same period, agricultural land significantly increased from 35.66% (52.14 ha) to 46.21% (67.56 ha), suggesting land conversion toward agriculture. Conversely, natural vegetation experienced a sharp decrease from 37.57% (54.93 ha) to 30.09% (43.99 ha), reflecting vegetation degradation in the area.

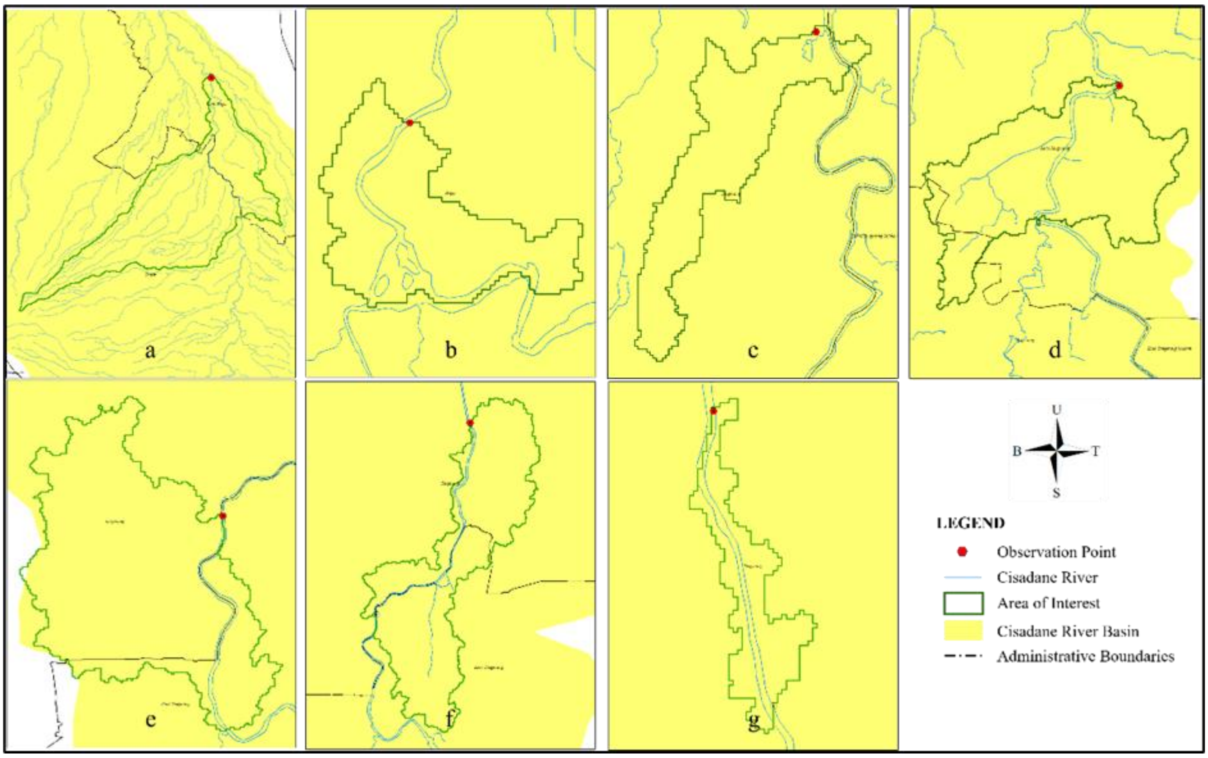


Figure 2. AOI of Each Observation Point (a. Genteng; b. Batu Beulah; c. Serpong; d. Babakan; e. Kedaung; f. Vihara; g. Tanjung Burung)

At the Serpong location, the dominant land covers are open land and built-up land. Built-up land increased from 32.74% (70.46 ha) to 34.99% (75.32 ha), signifying notable urban expansion. Meanwhile, open land, though still the largest land cover category, decreased slightly from 47.06% (101.29 ha) to 45.66% (98.27 ha), likely due to conversion for development purposes.

The Babakan location is primarily characterized by built-up land, which saw a significant rise from 70.79% (759.36 ha) in 2019 to 86.13% (923.93 ha) in 2022, indicating rapid urbanization. At the Kedaung location, agricultural land and built-up land are the dominant types of land cover. Agricultural land, the largest category, declined from 39.51% (428.31 ha) to 36.41% (394.69 ha), while built-up land increased gradually from 33.41% (362.11 ha) to 34.69% (376.00 ha), suggesting expanding urban development. The Vihara location was dominated by built-up land and agricultural land. Built-up land increased slightly from 39.41% (672.01 ha) to 40.04% (682.91 ha), reflecting growth in development. Agricultural land, however, decreased from 36.92% (629.66 ha) to 34.39% (586.47 ha), indicating a shift toward built-up land or other uses. Finally, the Tanjung Burung location was primarily dominated by built-up land cover, which rose from 36.38% (23.48 ha) in 2019 to 38.49% (24.84 ha) in 2021 but then decreased to 35.45% (22.88 ha) in 2022. This fluctuation indicates relative stability in the development of built-up areas over time.

The analysis of land cover changes from 2019 to 2022 shows a general trend of increasing built-up land in most locations, except for Tanjung Burung, which is likely influenced by government regulations restricting construction along riverbanks. Agricultural land has decreased in areas such as Kedaung and Vihara, while vegetation has significantly declined, particularly in Babakan. Conversely, open land has increased across nearly all locations, indicating extensive land-clearing activities. These changes suggest a shift in land use from agriculture and vegetation to open or built-up land, potentially disrupting natural ecosystems and altering land use dynamics in the future. These results are in accordance with a study conducted by Basu, R & Das, A (2024) which states that rapid urbanization causes the conversion of agricultural land and vegetation to built-up land, which has a negative impact on ecosystem services and environmental balance. Previous studies have also highlighted that rapid urbanization can exacerbate water quality issues, as observed in Nanjing, China, where urbanization has led to increased water pollution and reduced sustainability of water resources (Ma et al. 2022).

Table 7. Land Cover Classification in the Cisadane Watershed (2019–2022)

Classification	**2019**		**2020**		**2021**		**2022**	
	Ha	%	Ha	%	Ha	%	Ha	%
Genteng								
Water Bodies	28,429	1,25	28,429	1,25	28,429	1,25	28,429	1,25
Agricultural Land	978,891	43,16	941,879	41,53	929,443	40,98	921,672	40,64
Built-Up Land	212,170	9,36	219,410	9,67	227,907	10,05	231,522	10,21
Open Land	357,324	15,76	387,694	17,10	393,199	17,34	400,492	17,66
Vegetation	691,039	30,47	690,443	30,44	688,876	30,38	685,739	30,24
Total	2,267,854	100	2,267,854	100	2,267,854	100	2,267,854	100
Batu Beulah								
Water Bodies	14,958	10,23	15,115	10,34	16,374	11,20	16,480	11,27
Agricultural Land	52,139	35,66	60,188	41,17	61,902	42,34	67,558	46,21
Built-Up Land	9,048	6,19	11,315	7,74	11,094	7,59	16,364	11,19
Open Land	15,118	10,34	8,163	5,58	10,685	7,31	1,802	1,23
Vegetation	54,929	37,57	51,411	35,17	46,137	31,56	43,988	30,09
Total	146,192	100	146,192	100	146,192	100	146,192	100
Serpong								
Water Bodies	2,838	1,32	2,925	1,36	2,925	1,36	2,925	1,36
Agricultural Land	1,959	0,91	2,497	1,16	2,497	1,16	1,949	0,91
Built-Up Land	70,462	32,74	71,987	33,45	72,769	33,81	75,315	34,99
Open Land	101,292	47,06	100,888	46,88	100,180	46,55	98,273	45,66
Vegetation	38,667	17,97	36,921	17,16	36,848	17,12	36,756	17,08
Total	215,218	100	215,218	100	215,218	100	215,218	100
Babakan								
Water Bodies	37,053	3,45	37,084	3,46	37,263	3,47	31,361	2,92
Agricultural Land	1,184	0,11	0,992	0,09	1,347	0,13	0,972	0,09
Built-Up Land	759,359	70,79	886,657	82,66	905,972	84,46	923,931	86,13
Open Land	10,228	0,95	74,554	6,95	94,737	8,83	106,328	9,91
Vegetation	264,856	24,69	73,395	6,84	33,361	3,11	10,089	0,94
Total	1,072,681	100	1,072,681	100	1,072,681	100	1,072,681	100
Kedaung								
Water Bodies	25,357	2,34	25,357	2,34	25,357	2,34	25,283	2,33
Agricultural Land	428,306	39,51	419,111	38,66	411,992	38,01	394,692	36,41
Built-Up Land	362,110	33,41	364,884	33,66	369,784	34,11	375,997	34,69
Open Land	211,904	19,55	218,993	20,20	221,513	20,44	234,871	21,67
Vegetation	56,289	5,19	55,620	5,13	55,319	5,10	53,122	4,90
Total	1,083,965	100	1,083,965	100	1,083,965	100	1,083,965	100
Vihara								

Classification	2019		2020		2021		2022	
	Ha	%	Ha	%	Ha	%	Ha	%
Water Bodies	47,958	2,81	47,958	2,81	47,958	2,81	47,422	2,78
Agricultural Land	629,663	36,92	624,042	36,59	621,236	36,43	586,468	34,39
Built-Up Land	672,010	39,41	674,759	39,57	676,186	39,65	682,909	40,04
Open Land	301,719	17,69	301,804	17,70	302,515	17,74	329,780	19,34
Vegetation	54,008	3,17	56,795	3,33	57,462	3,37	58,779	3,45
Total	1705,358	100	1705,358	100	1705,358	100	1705,358	100
Tanjung Burung								
Water Bodies	12,121	18,78	12,121	18,78	12,121	18,78	12,121	18,78
Agricultural Land	10,901	16,89	10,918	16,92	10,496	16,27	9,807	15,20
Built-Up Land	23,477	36,38	24,284	37,63	24,837	38,49	22,877	35,45
Open Land	9,094	14,09	8,656	13,41	9,069	14,06	11,947	18,51
Vegetation	8,934	13,84	8,547	13,25	8,003	12,40	7,774	12,05
Total	**64,526**	**100**	**64,526**	**100**	**64,526**	**100**	**64,526**	**100**

The analysis of land cover changes from 2019 to 2022 shows a general trend of increasing built-up land in most locations, except for Tanjung Burung, which is likely influenced by government regulations restricting construction along riverbanks. Agricultural land has decreased in areas such as Kedaung and Vihara, while vegetation has significantly declined, particularly in Babakan. Conversely, open land has increased across nearly all locations, indicating extensive land-clearing activities. These changes suggest a shift in land use from agriculture and vegetation to open or built-up land, potentially disrupting natural ecosystems and altering land use dynamics in the future. These results are in accordance with a study conducted by Basu, R & Das, A (2024) which states that rapid urbanization causes the conversion of agricultural land and vegetation to built-up land, which has a negative impact on ecosystem services and environmental balance. Previous studies have also highlighted that rapid urbanization can exacerbate water quality issues, as observed in Nanjing, China, where urbanization has led to increased water pollution and reduced sustainability of water resources (Ma et al. 2022).

3.4 The Effect of Land Cover on Water Quality

The effect of land cover changes on water quality parameters in the Cisadane River Basin can be expressed in the equation below:

$$TDS = 4{,}762 - 0{,}071\,X1 + 0{,}076\,X2 + 0{,}143\,X3 - 0{,}055\,X4 - 0{,}167\,X5 \quad \text{...Eq 3}$$

Land cover variables: water bodies (X1), agricultural land (X2), built-up land (X3), open land (X4) and Vegetation (X5). The regression analysis revealed that water bodies, agricultural land, built-up land, open land, and vegetation significantly influence TDS concentrations. An increase in the area of water bodies, open land, and vegetation reduces TDS concentrations by 0.071, 0.055, and 0.167 units, respectively, indicating their role in mitigating dissolved solids. Conversely, agricultural land and built-up land increase TDS concentrations by 0.076 and 0.143 units. These findings align with Sinulingga et al. (2023), who identified a correlation between the prevalence of agricultural land and elevated TDS due to dissolved non-organic fertilizers entering water bodies (Sinulingga et al. 2023). Similarly, Widodo et al. (2019) highlighted the role of vegetation as a natural filter, effectively reducing TDS levels by absorbing harmful dissolved particles (Widodo et al. 2019).

$$TSS = 3{,}785 - 0{,}477\,X1 + 0{,}036\,X2 + 0{,}019\,X3 - 0{,}104\,X4 + 0{,}270\,X5 \quad \text{...Eq 4}$$

Land cover variables: water bodies (X1), agricultural land (X2), built-up land (X3), open land (X4) and vegetation (X5). The regression equation for Total Suspended Solids (TSS) indicates that water bodies, agricultural land, built-up land, open land, and vegetation significantly influence TSS concentrations. An increase in the area of water bodies and open land reduces TSS by 0.477 and 0.104 units, respectively, suggesting that these land covers help minimize suspended solid loads, possibly due to reduced sedimentation and runoff. Conversely, expansions in agricultural land, built-up land, and vegetation increase TSS by 0.036, 0.019 and 0.270 units, respectively. These findings align with Arkan Pratama and Chamid (2021) research, who highlighted that agricultural land contributes to higher TSS due to agricultural waste discharge into rivers (Arkan Pratama and Chamid 2021). This discrepancy underscores the importance of considering local river basin characteristics and human activities when analyzing TSS dynamics, as these factors significantly shape the relationship between land cover and suspended solids in rivers.

$$BOD5 = 0{,}629 + 0{,}159\ X1 - 0{,}175\ X2 - 0{,}207\ X3 + 0{,}096\ X4 + 0{,}377\ X5 \quad \text{...Eq 5}$$

Land cover variables: water bodies (X1), agricultural land (X2), built-up land (X3), open land (X4) and Vegetation (X5). The BOD5 regression equation indicates that water bodies, agricultural land, built-up land, open land and vegetation significantly influence BOD5 values. Expanding water bodies, open land and vegetation areas increase BOD5 by 0.159, 0.096, and 0.377 units, respectively, while agricultural land and built-up land reduce BOD5 by 0.175 and 0.207 units. These findings align with Locke (2024), who noted that runoff from built-up land, by reducing infiltration and accelerating surface flow, limits the decomposition time for organic matter, thereby lowering BOD5. Similarly, agricultural land, often associated with managed runoff, reduces BOD5 levels. However, while absorbing pollutants, vegetation may increase BOD5 when decomposed organic matter enters the water system, highlighting its dual impact on water quality (Locke 2024).

$$COD = 2{,}576 - 0{,}079\ X1 + 0{,}054\ X2 + 0\ {,}003\ X3 + 0{,}038\ X4 + 0{,}046\ X5 \quad \text{...Eq 6}$$

Land cover variables: water bodies (X1), agricultural land (X2), built-up land (X3), open land (X4) and Vegetation (X5). The regression equation for COD demonstrates that water bodies, agricultural land, built-up land, and vegetation significantly influence COD levels. An increase in water body area decreases COD by 0.079 units, while expansions in agricultural land, built-up land, open land and vegetation increase COD by 0.054, 0.003, 0.038 and 0.046 units, respectively. These findings align with Chapra et al. (2021), who observed that increased vegetation and open land could elevate COD levels due to organic matter contributions and runoff. Similarly, agricultural and built-up land were found to contribute to higher COD concentrations, driven by agricultural inputs and household activities that introduce organic pollutants into water systems (Chapra et al., 2021).

$$DO = 1{,}294 - 0{,}098\ X1 + 0{,}039\ X2 - 0{,}044\ X3 - 0{,}004\ X4 + 0{,}104\ X5 \quad \text{...Eq 7}$$

Land cover variables: water bodies (X1), agricultural land (X2), built-up land (X3), open land (X4) and Vegetation (X5). The regression equation for DO reveals that increasing the area of water bodies, built-up, and open land decreases DO concentrations by 0.098, 0.044, and 0.004 units, respectively. Conversely, agricultural land and vegetation increase DO levels by 0.039 and 0.014 units, respectively. Built-up land significantly impacts water quality, including DO levels, due to pollutant runoff that reduces oxygen availability. These findings are consistent with studies by Chapra et al. (2021) and Ullah et al. (2024), which highlight that vegetation-rich areas enhance DO through photosynthesis, while runoff from built-up and open land introduces pollutants, leading to lower DO concentrations (Chapra et al. 2021; Ullah et al. 2024).

$$TP = 3{,}442 + 0{,}066\ X1 - 0{,}364\ X2 - 0{,}370\ X3 + 0{,}120\ X4 + 0{,}778\ X5 \quad \text{...Eq 8}$$

Land cover variables: water bodies (X1), agricultural land (X2), built-up land (X3), open land (X4) and Vegetation (X5). The regression equation for TP shows that the independent variables water bodies, agricultural land, built-up, open land and vegetation significantly influence TP concentrations. An increase in the area of water bodies, open land and vegetation raises TP by 0.066, 0.120 and 0.778 units, respectively, while agricultural land and built-up land reduce TP by 0.364 and 0.370 units, respectively. These findings differ from those of Namugize et al. (2018), who reported that agricultural and built-up land generally increase TP levels due to runoff from fertilizers and phosphate sediments. The observed differences may result from agricultural practices and drainage systems that reduce direct runoff into water bodies in the study area. Additional factors such as climate, river basin characteristics, the intensity of human activities and management practices may also contribute to these discrepancies (Namugize et al. 2018).

$$\text{NO3-N} = -0{,}562 + 0{,}078\,X1 - 0{,}165\,X2 - 0{,}072\,X3 + 0{,}103\,X4 + 0{,}152\,X5 \quad \text{...Eq 9}$$

Land cover variables: water bodies (X1), agricultural land (X2), built-up land (X3), open land (X4) and Vegetation (X5). The regression equation for NO3-N shows that the independent variables water bodies, agricultural land, built-up land, open land, and vegetation significantly influence NO3-N concentrations. An increase in the area of water bodies, open land and vegetation raises NO3-N by 0.078, 0.103 and 0.152 units, respectively, while agricultural land and built-up land reduce NO3-N by 0.165 and 0.072 units, respectively. These findings differ from those of Bratek et al. (2020), who reported that agricultural and built-up land generally increase NO3-N concentrations due to runoff containing fertilizers and other anthropogenic pollutants (Bratek et al. 2020). The discrepancies in this study may be attributed to the NO3-N levels being below the detection limit and differences in the methodologies applied, thus impacting the equation obtained.

$$\text{NH3-N} = -5{,}303 + 1{,}012\,X1 - 0{,}582\,X2 - 0{,}885\,X3 + 0{,}869\,X4 + 0{,}506\,X5 \quad \text{...Eq 10}$$

Land cover variables: water bodies (X1), agricultural land (X2), built-up land (X3), open land (X4) and Vegetation (X5). The regression equation for NH3-N indicates that the independent variables water bodies, agricultural land, built-up, open land, and vegetation significantly influence NH3-N concentrations. An increase in the area of water bodies, open land, and vegetation raises NH3-N levels by 1.012, 0.869, and 0.506 units, respectively. Conversely, agricultural land and built-up land reduced NH3-N by 0.582 and 0.885 units. The role of land in raising NH3-N highlights its potential to lower water quality. However, Zhang et al. (2023) found contrasting results, showing that agricultural and built-up land typically increase NH3-N due to fertilizer runoff and organic matter contributions from urban activities. Additionally, vegetation has been shown to mitigate nitrogen pollutants through natural filtration processes (Zhang et al. 2023). These differences may arise from the unique characteristics of the Cisadane river basin and variation in measurement methods.

Regression analysis of water quality parameters reveals that land use variables exhibit varying effects on these parameters, with vegetation generally playing a positive role in maintaining water quality. A study by Kang and Kanniah (2022) in the Johor River Basin, Malaysia, showed that conversion of forests to plantations and settlements caused a decrease in forest cover of 45.82% in the last 30 years, which resulted in increased erosion and sedimentation, affecting water quality parameters such as turbidity (TSS) and organic load in waters. Similar results were also found in the Cisadane River Basin, where an increase in built-up land from 212,170 ha in 2019 to 231,522 ha in 2022 in several locations contributed to an increase in TSS values, such as in Genteng, which increased from 10 mg/l in 2019 to 80 mg/l in 2022. While in the Sungai Johor Watershed, pollution was more dominated by an increase in sediment due to erosion, in the Cisadane River Basin the impact of pollution was more visible in the form of an increase in organic matter and a decrease in DO at several points, such as in Tanjung Burung which had a low DO value in 2019 (1.7 mg/l) before increasing to 4.2 mg/l in 2022. This similarity shows that changes in land cover in both river basins contribute to a decrease in water quality, with the main difference in the type of dominant pollutant, which depends on the characteristics of land use in each region.

It aligns with the findings of Tchobanoglous et al. (2003), which highlight the critical role of vegetation and water bodies in pollutant reduction through natural filtration processes and runoff mitigation. On the other hand, agricultural and built-up land often negatively influence water quality, contributing to increased sediment loads, nutrients, and pollutants. These findings corroborate the research of Tong and Chen (2002), who emphasized the significant impact of urbanization and agricultural activities on water quality, particularly through elevated pollutant and nutrient loads.

4. Conclusion

The research highlights that land cover changes in the Cisadane River Basin from 2019-2022 significantly impacted river water quality. Increased built-up land and decreased vegetation contribute to decreased water quality, which is reflected in increased BOD_5 levels and decreased DO in several locations. This decrease in water quality indicates that changes in land cover affect the balance of aquatic ecosystems, especially through increased surface runoff and reduced vegetation function in filtering pollutants. The limitations of this study include the correlational approach, so it cannot explain the direct cause-and-effect relationship between changes in land cover and water quality. In addition, this study did not consider other external factors such as climate change and rainfall patterns, which can also affect water quality in the Cisadane River Basin.

Overall, water quality in the Cisadane River Basin can be categorized as lightly polluted, with higher pollution levels in areas dominated by built-up land. An increase in built-up land of ±5.5% in the 2019–2022 period contributed to the increase in BOD_5 levels. High BOD_5 concentrations indicate an increase in organic matter load originating from domestic waste and urban activities. Conversely, a decrease in vegetation cover of ±6.3% at several observation points correlated with a decrease in DO, especially in downstream areas such as Tanjung Burung and Vihara, which can disrupt the balance of the aquatic ecosystem. These results emphasize the need to implement conservation-based spatial planning policies, such as increasing green areas around the watershed and stricter domestic waste management, to prevent further water quality decline. For further research, it is recommended to develop a more comprehensive approach, such as the use of hydrological models to predict the impact of land cover changes on water quality in the long term. In addition, more detailed field studies with direct monitoring in various seasons can provide a deeper understanding of the factors contributing to water quality decline in the Cisadane River Basin.

Data availability statement

The data used in this study are secondary data in the form of Cisadane River water quality data and land cover data. Land cover data was obtained from Google Earth (https://earth.google.com/) which is open to the public. Cisadane River water quality data is provided by the Ciliwung Cisadane River Basin Center and the Tangerang Regency Environment and Sanitation Service. This data is available upon request and subject to the approval of the relevant institutions.

Funding Agencies

This research was conducted without any external funding. The authors confirm that no financial support was received from any funding agency for this study.

Conflict of interests

Every author has stated that there is no conflict of interest to the manuscript's writing or submission.

Acknowledgment

The authors would like to express their gratitude to Ciliwung Cisadane River Basin Center and Tangerang Regency Environmental and Sanitation Service for providing access to secondary data on water quality.

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