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Analysis of Water Resources Management Using The Dpsir Framework: Driver Pressure State Impact Response for River Water Pollution in Cilamaya Watershed

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Abstract: The availability of water in adequate quality is a crucial requirement for achieving various aspects of life, including human health, ecosystem, economy, social and environmental sustainability. This study analyzes the impact of land cover changes on water quality in the Cilamaya Watershed (DAS Cilamaya) using Qual2Kw and GIS modeling for the 2019-2023 period. The Cilamaya Watershed is closely related to the development of the north coast (Pantura Route), and the increasing number of development activities that have resulted in the increasingly concerning condition of the watershed. This condition is characterized by the presence of quite extensive critical land, and also river water pollution due to domestic waste from households, livestock, industry, and agriculture. Analysis of the effect of land cover on water quality show a positive correlation between the increase in settlement area and BOD concentration (r = 0.348–0.692) and TSS, particularly in segment 2 (r = 0.83944). Conversely, DO shows a negative correlation with settlements and plantations (r = -0.51 to -0.92), indicating that urbanization and plantation expansion negatively impact dissolved oxygen levels, while rice fields increase TSS with a correlation value (r = 0.2–0.593). The Driving Force – Pressure – State – Impact – Response (DPSIR) approach highlights the importance of managing green vegetation areas as a key measure in mitigating pollution and improving water quality in the Cilamaya Watershed, as well as in maintaining the overall balance of the ecosystem.

Keyword: : Cilamaya Watershed (DAS), River Water Quality, Pollution Load, Driving Force Pressure State Impact Response (DPSIR)

INTRODUCTION

Vegetation land cover, such as forests and green areas, plays an important role in maintaining river water quality. Vegetation acts as a natural buffer that reduces erosion, filters pollutants, and regulates water flow into rivers, which directly impacts water quality. However, over the past few decades, significant changes in vegetation cover due to various anthropogenic activities such as deforestation, urbanization, and land-use change have affected the ability of ecosystems to maintain water quality. Therefore, a comprehensive study of changes in vegetation cover over time is essential to understand its impact on river water quality as well as to regulate the balance of aquatic ecosystems amidst ongoing environmental changes. Recent studies have revealed that hundreds of river systems around the world have experienced serious pollution and degradation due to land-use change and human activities (Gilbert, 2019).

River ecosystems play an important role in providing fresh water, habitat for aquatic flora and fauna, nutrient transport, drainage, flood control, and maintaining regional ecological integrity. River protection also contributes to agricultural productivity and human health, in line with Sustainable Development Goal (SDG) 6: Clean Water and Sanitation (Florke et al., 2019). However, the decline in river water quality has become a global environmental issue caused by human activities and the lack of wastewater treatment facilities (Sun et al., 2019).

The DPSIR framework provides a comprehensive approach to analyzing the impacts of land use change on water quality, taking into account the drivers, pressures, states, impacts, and responses involved. Using this framework, a thorough identification of the factors influencing changes in water quality due to land use changes is conducted, along with the development of appropriate responses to sustain water resources.

METHOD

The flow diagram in Figure 1 illustrates the research method, which includes: (1) using GIS modeling to map changes in land cover and the distribution of river water quality pollution over the past five years in the Cilamaya Watershed. Land cover data for the Cilamaya Watershed is Landsat 8-Oli_TIRS image data which is classified using the revised method in ArcGIS software, based on the SNI 7645-2010 classification; (2) Qual2kw version 5.1 modeling, for the amount of pollution load in the Cilamaya Watershed; and (3) Analysis of the effect of land cover changes on water quality in the Cilamaya Watershed through correlation analysis.

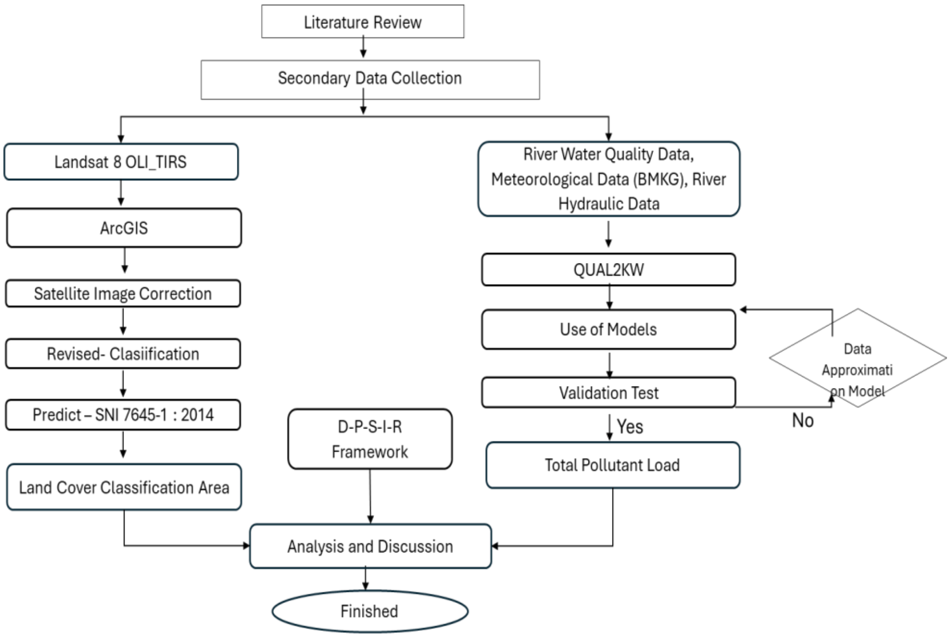


Figure 1. Research flow diagram

2.1 Study area

This study is conducted in the Cilamaya River Basin (DAS), located geographically between 107º 31’–107º 41’ E and 06º 12’–06º 44’ S. The Cilamaya Sub-DAS covers an area of approximately 33,591.29 hectares and drains into the Java Sea. The Cilamaya Watershed includes Purwakarta Regency, Subang Regency, and Karawang Regency.

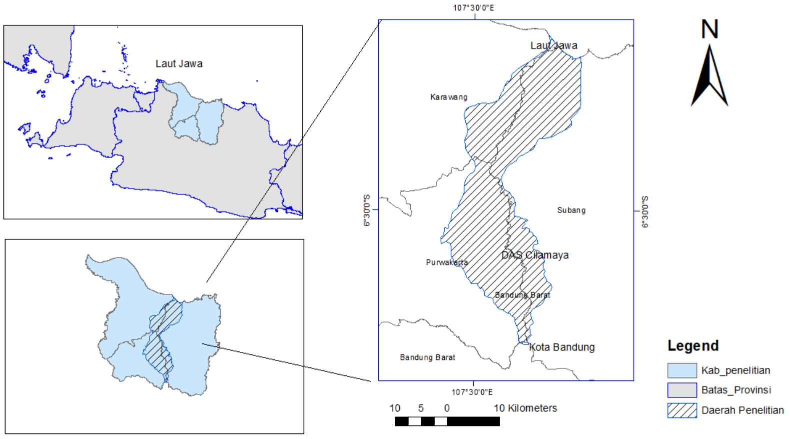


Figure 2. Study area

2.2 Research data

This study uses secondary data collected from several government agencies and relevant websites, including river water quality parameter data and hydraulic data from the West Java Provincial Environmental Service (DLH), meteorological data from the Meteorology, Climatology, and Geophysics Agency (BMKG), village potential data from the Central Statistics Agency and satellite imagery data from the USGS website.

Table 1. Water quality data of the Cilamaya River from 2019 to 2023 for the parameters Dissolve Oxygen (DO) (mg/L), CBOD (mg/L) and Total Suspended Solids (TSS) (mg/L)

Location	**2019**			**2020**			**2021**			**2022**			**2023**		
	DO	**BOD**	**TSS**	**DO**	**BOD**	**TSS**	**DO**	**BOD**	**TSS**	**DO**	**BOD**	**TSS**	**DO**	**BOD**	**TSS**
Wanayasa	5.4	2	14	8	0.43	11	7.3	1	19	7.9	1	5	7.8	1	2
Bendung Barugbug	3	3.5	820	2	3.45	48.3	5.7	4	94	5.4	2	110	1.3	9	27
Setelah BMP	3	3.9	480	2.7	2.73	49.22	3.6	21	95	4.9	3	106	0.4	19	36
Blanakan	4	4	1930	3.9	3.43	48.81	2.9	12	98	5.3	2	109	1.4	7	71

2.3 Water Quality Standards

Government Regulation No. 22 of 2021 on the Implementation of Environmental Protection and Management defines Water Quality Standards as the limits or levels of living organisms, substances, energies, or components that must be present or are tolerated in water, including pollutant elements.

Table 2. River water quality standards for TSS, pH, BOD and DO parameters

No	Parameter	Unit	Kelas I	Kelas II	Kelas III	Kelas IV
1	Padatan Tersuspensi Total (TSS)	mg/L	40	50	100	400
2	Kebutuhan oksigen biokimiawi (BOD)	mg/L	2	3	6	12
3	Oksigen terlarut (DO)	mg/L	6	4	3	1

Source: Appendix VI, PP No. 22 of 2021 concerning the Implementation of Environmental Protection and Management

2.4 Potential Pollution Load

The Water Environment Center of the Research and Development Center for Water Resources, Ministry of Public Works (2004), provides the following equation to calculate the potential pollution load from household sources.

$$PBP \ = \alpha \ x \ \Sigma Total \ population \ x \ Emission \ Factor \ x \ rek \qquad (1)$$

With :

PBP = Potential pollution load (kg/day)

α = Load transfer coefficient, determined based on the distance of the settlement to the river with the following criteria (Iskandar, 2010): Value α = 1, location with a distance between 0 to 100 meters from the river, Value α = 0.85 for locations that are between 100-500 meters from the river, Value α = 0.3 for locations that are more than 500 meters from the river,

Rek = city equivalent ratio, lifestyle affects the amount of pollutant load produced on each person. The equivalent ratio value for each city, namely city = 1, suburbs = 0.8125, and hinterland = 0.625.

Calculation of estimated pollutant load from farm waste, pollutant load from agricultural, plantation and forest waste (KLHK, 2017).

$$PBP\ farm = \Sigma\ Number\ of\ Livestock\ x\ Emission\ factor\ x\ Conversion\ factor\ x\ 20\% \tag{2}$$

$$PBP\ rice\ field = Area\ x\ Emission\ factor\ x\ Conversion\ factor\ x\ 10\% \tag{3}$$

$$PBP\ plantation = Area\ x\ Emission\ factor\ x\ Conversion\ factor\ \ x\ 1\% \tag{4}$$

$$PBP\ forest = Area\ x\ Emission\ factor\ x\ \ 1\% \tag{5}$$

Domestic emission factors for total suspended solids (TSS) are 38 grams per person per day, and the biochemical oxygen demand (BOD) is 40 grams per person per day. For livestock, the BOD emission factors are 292 grams per cattle per day, 34.1 grams per goat per day, 55.7 grams per sheep per day, 2.36 grams per chicken per day, and 0.88 grams per duck per day.

2.5 DPSIR Framework

In the DPSIR framework, human production activities (D) drive economic development and put pressure on water resources and the aquatic environment (P). Human activities also change the initial state of resources and the environment (S). Environmental changes affect the development of human life and society (I). In order to maintain a sustainable level of development, humans actively formulate policies and measures (R) to respond to the above-mentioned changes. The effects of these human responses will directly or indirectly affect the driving forces, pressures, states and influencing factors. The DPSIR framework includes the basic elements of economy, society and environment. The model is not only able to represent the threats of human activities to ecological security, but also can provide effective feedback on the impact of the environment on society.

RESULTS AND DISCUSSION

3.1 Land Cover Data Processing Results

Interpreting 8 OLI/TIRS images classifies them into seven categories: water bodies, forests, plantations, agriculture, settlements, ponds, and open land. To validate the accuracy of the land use classification results, we test the classification against known data. This accuracy assessment requires calculating the error rate to determine the mapping's percentage accuracy. We use the kappa index (Jaya, 2014) to compare the interpretation data with observation location data to measure mapping accuracy.

$$User's\ accuracy\ = \frac{x_{ii}}{x_{+i}} \tag{6}$$

$$Procedur's\ accuracy\ = \frac{x_{ii}}{x_{i+}} \tag{7}$$

$$Overall\ accuracy\ = \frac{\sum_{i=1}^{r} x_{ii}}{N} x100\% \tag{8}$$

$$Indeks\ Kappa\ = \frac{N\sum_{i=1}^{r} x_{ii}\ - \sum_{i=1}^{r} x_{i+}x_{+i}}{N^2 - \sum_{i=1}^{r} x_{i+}x_{+i}} \tag{9}$$

Table 3. Matrix of classification results for observation location data

Hasil Klasifikasi	Data lokasi pengamatan							Row Total	User's Accuracy
	(1)	(2)	(3)	(4)	(5)	(6)	(7)		
Hutan (1)	9	0	0	1	0	0	0	10	90%
Sawah (2)	0	8	0	0	0	1	1	10	80%
Pemukiman (3)	0	0	10	0	0	0	0	10	100%
Perkebunan (4)	1	0	0	9	0	0	0	10	90%
Tubuh Air (5)	0	0	0	0	10	0	0	10	100%
Lahan Terbuka (6)	0	1	0	1	0	10	0	12	83%
Tambak (7)	0	0	0	0	0	0	10	10	100%
total kolom	10	9	10	11	10	11	11	72	
Procedur's Accuracy	90.0%	88.9%	100.0%	81.8%	100.0%	90.9%	90.9%		

Source: calculation results (2024)

The results of the classification test with the Kappa index showed that the overall accuracy was 91.67% with a kappa index of 0.9. The United States Geological Survey (USGS) has set the level of accuracy of the results of remote sensing classification at least 85% (Mentari, 2013 in Sampurno and Thoriq, 2016), based on these provisions, the accuracy of the interpretation results in this study, both overall accuracy and the kappa index produced, can be concluded as valid and can be used for further analysis.

Table 4. Results of calculating the area of each land cover in the Cilamaya Watershed from 2019 to 2023

No	**Land Cover**	**Area_Ha**				
		2019	**2020**	**2021**	**2022**	**2023**
1	Forest	4614.79	4384.64	3621.90	2570.54	2307.26
2	Open Land	118.48	606.14	411.95	306.74	469.09
3	Settlements	7023.51	7583.85	7630.42	8563.64	8053.33
4	Plantations	20411.06	15755.86	12132.37	14618.36	14204.72
5	Rice Fields	33334.34	37171.26	41729.10	39469.30	40467.23
6	Fish Ponds	2394.15	2394.07	2393.30	2393.51	2394.02
7	Water bodies	69.82	69.82	69.82	69.82	69.82

Source: calculation results (2024)

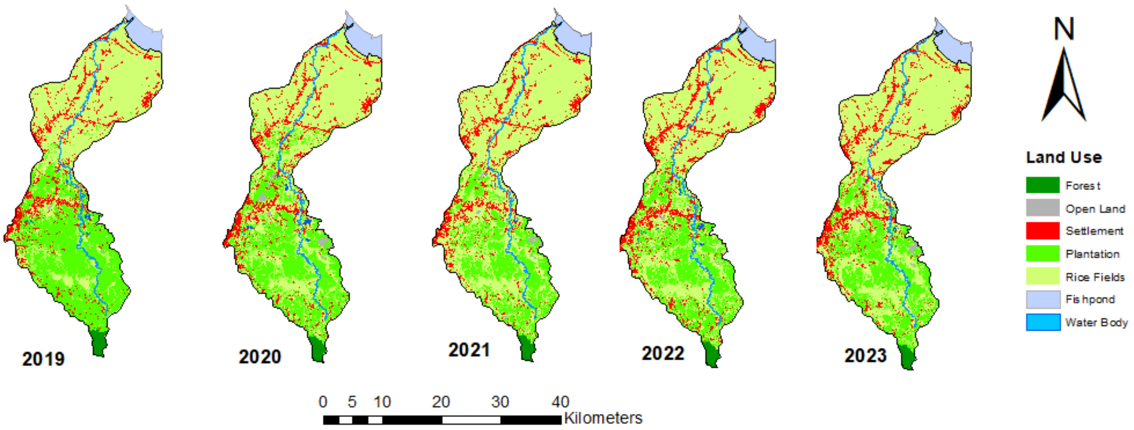


Figure 3. Map of land cover processing results in the Cilamaya Watershed from 2019 to 2023 using the supervised classification method

3.2 Results of Calculation of Potential Pollutant Load

The total estimation of BOD pollutant load in Cilamaya Watershed includes contributions from domestic, livestock, agriculture, and forest sources in each river segment. Segment 1 has the highest pollutant load dominated by contributions from the livestock and agriculture sectors, while segment 2 also shows significant pollutant load from livestock and domestic, and segment 3 shows significant contributions from livestock and agriculture.

Table 5. Estimation of the load of diffuse source pollutants in each segment of the Cilamaya River

No	**River Segment**	**BOD Pollutant Load from Uncertain Sources (Kg/day)**				**Total BOD (Kg/day)**
		Domestic	Livestock	Agriculture	Forest	
1	Segmen 1	15370.301	168788.09	378.1868	4.561234	184541.1
2	Segmen 2	11360.215	116487.41	141.5344	0.002746	127989.2
3	Segmen 3	9969.7934	103053.66	366.2496	0.026352	113389.7

Source: calculation results (2024)

3.3 Hasil Pemrosesan Data Kualitas Air

Pemodelan kualitas air sungai dilakukan menggunakan program Qual2kw. Langkah pertama adalah membagi segmen sungai dan menginput data yang mencakup kondisi sungai, kualitas dan debit air, data segmen, hidrolik, serta data pencemar dari sumber diffuse atau non point source. Pemodelan ini difokuskan pada sumber non point source karena keterbatasan data point source di lapangan, sehingga data point source tidak dapat dimasukkan dalam model. Data lain yang dibutuhkan untuk membentuk model ini adalah data hidrolik (debit, kedalaman dan kecepatan), model koefisien, serta data pendukung seperti suhu, kecepatan angin, persentasi tutupan awan dan bangunan menuju sungai.

Table 6. Research locations and data collection

No	**River**	**Code**	**Point (Km)**	**Coordinates**	
				Latitude	**Longitude**
1	Cilamaya River	Headwater	0	6º 40' 9.3" S	107º 35' 48.4" E
2	Cilamaya River	TS-4	50.03	6º 23' 55.5" S	107º 31' 44.0" E
3	Cilamaya River	TS-6	58.22	6º 21' 16.3" S	107º 33' 45.1" E
4	Cilamaya River	TS-7	77.92	6º 14' 58.3" S	107º 36' 3.6" E

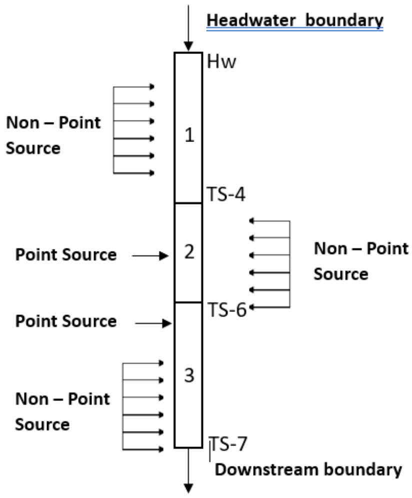


Figure 4. Illustration of river segmentation in the Cilamaya River

The data calibration process to ensure that the data inputted into the Qual2kw program produces output that closely reflects actual conditions and to verify the existing data, considering the differences in time and data variations. Calibration is carried out in two stages, hydraulic and water quality data calibration. The smaller the RMSE value, the more representative the model is of the river body conditions. Wahyu Teo Parmadi and Bangun Muljo Sukojo (2016) state that an RMSE value of ≤ 1 indicates better accuracy. The validation of modeling results is conducted using the following formula:.:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x}_i)^2}{N}} \qquad (10)$$

With :

Xi = Observation/measurement result values

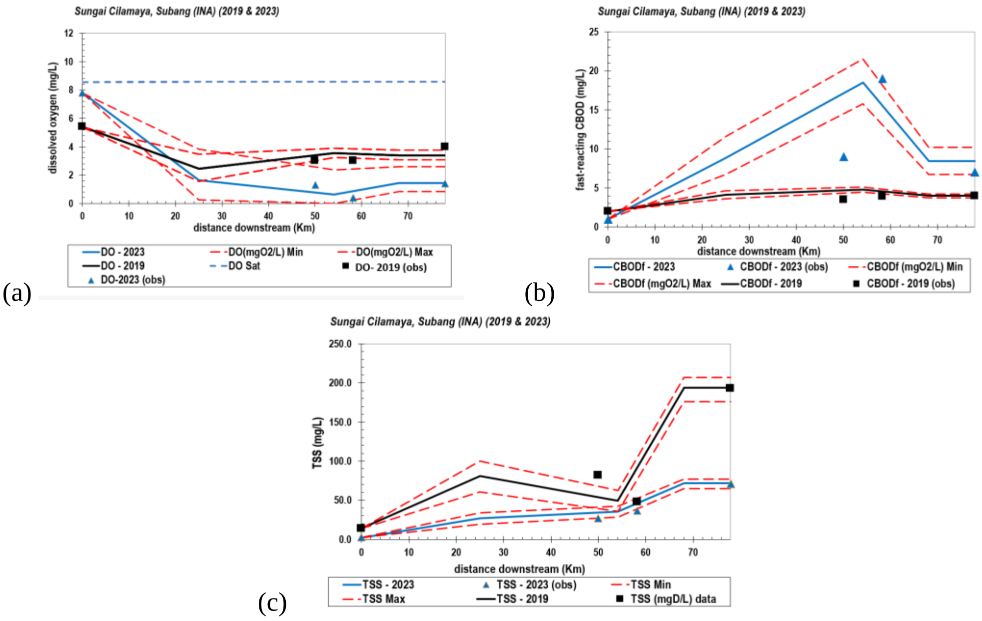
$\bar{x}_i$ = Modeling result value

N = Number of observations

Table 7. RMSE value of Qual2kw modeling of Cilamaya Watershed in 2023

	Validation	Temperature	pH	CBODf	DO	TSS
2019	RMSE	0.88	0.07	0.55	0.49	0.96
2020	RMSE	0.87	0.16	0.66	0.96	0.91
2021	RMSE	0.83	0.07	0.87	0.56	0.15
2022	RMSE	0.97	0.17	0.8	0.79	0.77
2023	RMSE	0.9	0.2	0.76	0.2	0.57

Water quality analysis in the three river segments reveals that land use strongly influences TSS, CBOD fast, and DO levels. In Segment 1, dominated by plantations and rice fields, TSS reaches 290 mg/L, and CBOD fast measures 160 mg/L, indicating significant soil erosion and high levels of organic pollution. In Segment 2, characterized by industrial settlements and rice fields, TSS drops sharply to 110 mg/L, and CBOD fast decreases to 87 mg/L, while DO increases to 3 mg/L, reflecting a slight improvement in water quality, although organic pollution remains present. In Segment 3, comprising rice fields and settlements, TSS rises again to 170 mg/L, CBOD fast drops significantly to 4 mg/L, and DO remains stable at 3 mg/L, indicating increased suspended matter but lower organic pollution. Figure 5 presents the model comparison curves for river discharge and water quality parameters.



(a) (b)

(c)

Figure 5. Results of comparative analysis of models with observation data for 2019 and 2023 for parameters (a) Dissolve Oxygen (DO) (mg/L), (b) Biochemical Oxygen Demand (BOD) (mg/L) and (c) Total Suspended Solids (TSS) (mg/L)

3.4 Correlation of Land Cover Data with Potential Diffuse Pollutant Load (Non Point Source)

Tests of Normality were conducted to determine the distribution of residual normality from each land cover category. Kolmogorov-Smirnov and Shapiro-Wilk tests were conducted to measure the deviation between the sample distribution and the normal distribution. Based on the results of the normality test, it was found that the value of p (Sig.) = 0.214 for forest residuals, p (Sig.) = 0.197 for settlement residuals, p (Sig.) = 0.257 for plantation residuals and p (Sig.) = 0.223 for rice field residuals this indicates that the null hypothesis is accepted, and the data may follow a normal distribution. So that the T-Test can be conducted to determine the significance of differences in land cover area from year to year.

One-Sample T-Test is used to test whether the average of one sample is significantly different from the expected average value or the average value of a certain population. Hypothesis Testing:

- Null Hypothesis (H_0): The average sample area of land cover is the same from year to year
- Alternative Hypothesis (H_1): The average sample area of land cover is not the same from year to year

From the results of the One-Sample T-Test, all land cover categories showed a p value <0.05. Where Sig. (2-tailed) = 0.001679 for changes in forest land, Sig. (2-tailed) = 7.15E-06 for changes in residential land, Sig. (2-tailed) = 0.0003627 for plantations and Sig. (2-tailed) = 1.298E-05 for changes in rice field area.

After performing a normality test using the Shapiro-Wilk method, the analysis confirmed that the land cover and diffuse pollutant load data followed a normal distribution. This normal data distribution is a strong basis for choosing Pearson Correlation as the right analysis method, because Pearson is designed to measure the strength and direction of the linear relationship between two continuous variables under normal conditions. Thus, the use of Pearson Correlation will provide more accurate and reliable results in describing the linear relationship between land cover and diffuse pollutant load, compared to other correlation methods that do not require the assumption of normal distribution.

The correlation between land cover data and potential diffuse pollutant loads helps identify how different land cover types contribute to pollution levels. Diffuse pollution comes from many sources spread across the landscape. This makes it hard to determine directly, so a broader analytical approach is necessary.

The diffuse pollutant load values for Dissolved Oxygen (DO) (mg/L), CBOD (mg/L), and Total Suspended Solids (TSS) (mg/L) were obtained from Qual2kw modeling and calibrated with an RMSE value <1. Table 13 presents the diffuse pollutant load values for each parameter.

Table 8. Correlation results of land cover data (forest, open land, settlements, rice fields and plantations) with potential diffuse pollutant load (non-point source) CBOD (mg/L)

DO		Forest	Open Land	Forest	Open Land	Forest
	Segment 1	0.287576	-0.215216	-0.51971056	0.228162986	-0.271879493
	Segment 2			0.060338694	0.792737507	-0.925052963
	Segment 3			-0.5390729	0.710877859	-0.594494707
CBOD		Forest	Open Land	Forest	Open Land	Forest
	Segment 1	-0.47546	0.358237	0.348031676	0.385255593	-0.32458107
	Segment 2			0.691723439	0.447977637	-0.465417736
	Segment 3			0.03432164	0.13978174	-0.641040078
TSS		Forest	Open Land	Forest	Open Land	Forest
	Segment 1	-0.218187	-0.425352	0.152424055	0.275619103	-0.218086294
	Segment 2			0.839440759	0.048612011	-0.304346517
	Segment 3			-0.49914098	0.59346173	-0.31667266

Based on the correlation analysis between water quality parameters BOD, TSS, and DO with various land uses in the three segments over the past five years, a positive correlation was found between the increase in settlement area and the rise in CBOD concentration, with correlation values ranging from 0.348 to 0.692, especially in Segment 2, which is dominated by residential and industrial areas. The CBOD correlation inversely relates to DO, showing a negative correlation between DO and residential and plantation areas in almost every segment of the Cilamaya Watershed, with values ranging from -0.51 to -0.92. This indicates that as the area of residential and plantation land increases, DO levels tend to decrease. This suggests that urbanization and plantation expansion negatively impact dissolved oxygen quality in the water.

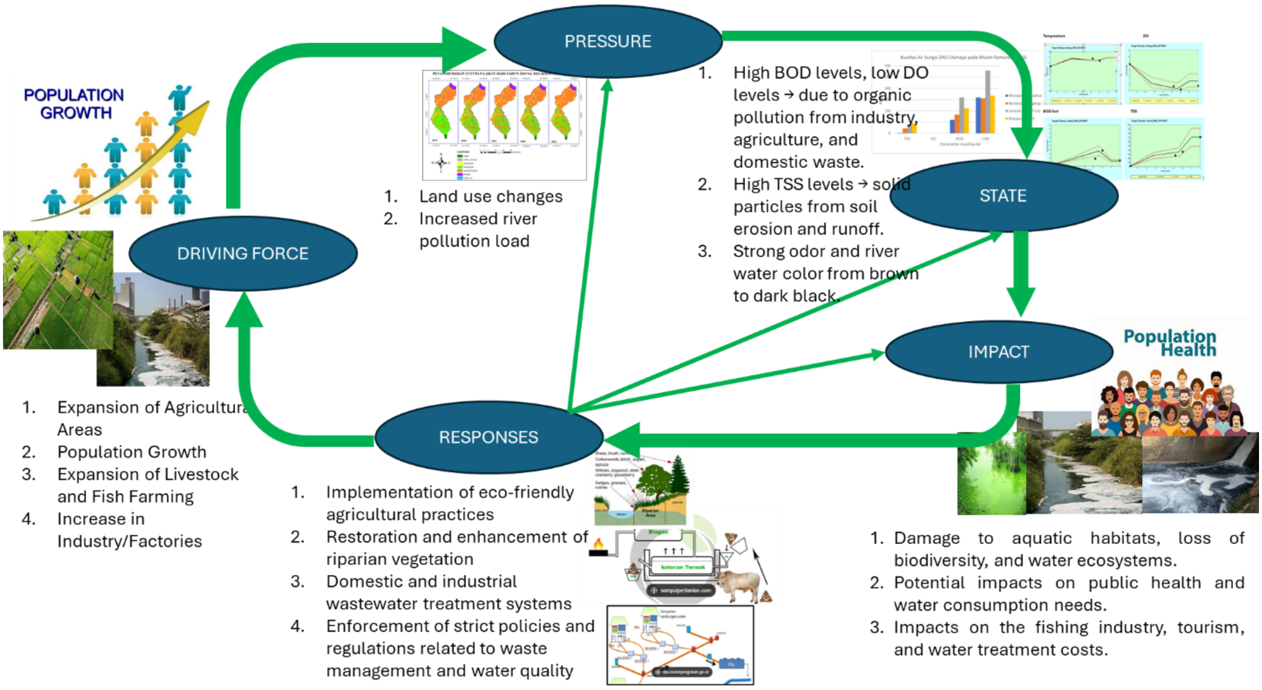
In contrast, TSS strongly correlates with the expansion of residential areas, particularly in Segment 2, with a correlation value of 0.83944, and a positive correlation is also observed in Segment 1. This indicates that the increase in residential land area significantly contributes to higher TSS levels in the water, suggesting that development and urbanization activities in this area likely increase the amount of sediment and suspended particles carried by surface runoff into the river.

3.4 DPSIR Analysis

DPSIR analysis of the influence of land cover in the Cilamaya watershed shows that human activities such as intensive agriculture, urbanization, livestock, and plantations are the main driving factors that change land use and affect water quality. The pressure from these activities increases the pollutant load such as BOD and TSS in the river, mainly due to organic waste and soil erosion. Urbanization also worsens the condition by increasing surface runoff that carries pollutants, reducing DO levels and further degrading water quality.

Table 9. Results of DPSIR analysis on the management of the Cilamaya Watershed for river water quality pollution load

Komponen DPSIR	Deskripsi
Driving Forces	- Expansion of paddy fields and use of chemical fertilizers and pesticides. - Urbanization and expansion of settlements.
Pressures	- Increased pollutant loads from residential, agricultural, and livestock activities, leading to higher BOD and TSS levels. - Decline in water quality due to runoff carrying pollutants. - Land cover changes causing increased TSS from soil erosion.
State	- High BOD levels indicate significant organic material from agriculture and domestic waste, both during rainy and dry seasons. - Low DO levels reflect decreased water quality due to organic pollution. - High TSS levels show solid particles from soil erosion and runoff.
Impacts	- Damage to aquatic habitats, reduced biodiversity, and impacts on water ecosystems. - Potential effects on human health and water consumption needs. - Effects on fisheries, tourism, and water treatment costs.
Responses	- Land cover management through the implementation of environmentally friendly agricultural practices and erosion control techniques. - Planting vegetation along riverbanks (riparian vegetation) to prevent soil erosion, reduce runoff, and absorb organic materials. - Domestic wastewater treatment systems for reuse in industry or irrigation, such as garden watering and industrial cooling. - Restoring wetlands to reduce runoff, filter pollutants, and provide habitat for biodiversity.- Restoring forests and protecting river catchment areas. - Implementing strict policies and regulations related to waste management and water quality.



1. Land use changes
2. Increased river pollution load

1. High BOD levels, low DO levels → due to organic pollution from industry, agriculture, and domestic waste.
2. High TSS levels → solid particles from soil erosion and runoff.
3. Strong odor and river water color from brown to dark black.

1. Expansion of Agricultur Areas
2. Population Growth
3. Expansion of Livestock and Fish Farming
4. Increase in Industry/Factories

1. Implementation of eco-friendly agricultural practices
2. Restoration and enhancement of riparian vegetation
3. Domestic and industrial wastewater treatment systems
4. Enforcement of strict policies and regulations related to waste management and water quality

1. Damage to aquatic habitats, loss of biodiversity, and water ecosystems.
2. Potential impacts on public health and water consumption needs.
3. Impacts on the fishing industry, tourism, and water treatment costs.

Figure 6. DPSIR framework in Cilamaya watershed

CONCLUSION

Water quality analysis using the QUAL2Kw model shows significant degradation in the Cilamaya Watershed. The results indicate that activities such as agriculture, plantations, and urbanization increase pollutant concentrations, reduce the river's capacity to support healthy aquatic life, and pose health risks to communities dependent on river water for their daily needs. Addressing these issues requires improved land cover management, including the adoption of environmentally sustainable agricultural practices and effective erosion control techniques. Furthermore, restoring the watershed, protecting the environment from detrimental activities, and enforcing stricter policies and regulations related to waste management and development are essential for enhancing water quality and maintaining the ecological balance of the Cilamaya Watershed.

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