Jurnal Presipitasi
Media Komunikasi dan Pengembangan Teknik Lingkungan
e-ISSN: 2550-0023

Vol 22, No 2, 2025, 485-496
Article available at [homepage presipitasi]

Regional Case Study

Analysis of Cikakembang River Water Quality Using the Pollution Index, STORET, and CCME-WQI Methods

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Abstract
River pollution is a significant environmental issue driven by urban growth and industrialization. The Cikakembang River, a tributary of the Citarum River in the Majalaya industrial area, receives wastewater from densely populated residential areas and textile manufacturing industries. Accurate assessment and monitoring of surface water quality are crucial to ensure its safe utilization. This study investigates the the Cikakembang River's water quality using the Pollution Index, STORET, and CCME-WQI methods, evaluating 14 water quality parameters across nine sampling locations during both wet and dry seasons to capture seasonal differences. The results reveal that the river fails to meet Class II water quality standards as outlined in Government Regulation No. 22 of 2021. While the Pollution Index classified contamination as mild to moderate, both STORET and CCME-WQI consistently indicated severe pollution across all sites and seasons. These findings suggest that STORET and CCME-WQI provide a more comprehensive assessment of pollution severity than the PI method, which may underestimate cumulative water quality degradation. This study highlights the urgent need for enhanced pollution control measures and stricter regulatory enforcement to mitigate further degradation of the Cikakembang River and improve its long-term sustainability.

Keywords: CCME-WQI; Cikakembang River; pollution index; STORET; surface water quality

1. Introduction

Water is a critical resource, vital for human survival and ecosystem sustainability. The rapid pace of urbanization and industrial development has significantly increased environmental challenges, particularly water pollution (Zhou et al., 2021). This pollution affects not only surface water bodies, such as rivers, but also poses serious risks to public health and the environment's overall integrity (Ilyas et al., 2019). Rivers are among the most impacted ecosystems, as they act as conduits for wastewater from urban, agricultural, and industrial sources.

Rivers possess a natural self-purification capacity, but this ability is influenced by the amount and type of pollutants entering the water from surrounding environments. When the pollution load exceeds the river's ability to process and degrade contaminants, water quality deteriorates significantly, causing adverse ecological impacts (Tanjung et al., 2022). Regular monitoring and evaluation of river water quality are essential for identifying pollution sources, mitigating negative effects, and ensuring sustainable water resource management (Pahlewi et al., 2020). Importantly, water quality monitoring should not only target heavily polluted rivers but also focus on rivers that remain relatively unpolluted to prevent future degradation through proactive management.

The Cikakembang River, a key tributary of the Citarum River in the Majalaya industrial zone, is a prime example of an impacted water body. The Citarum River, often referred to as one of the world's most polluted rivers, receives substantial volumes of untreated wastewater from textile factories and densely populated settlements (Blacksmith Institute, 2013; Fitriana et al., 2023). Similarly, the Cikakembang River has been found to fall short of meeting water quality standards outlined by the Indonesian Government (Kent et al., 2024). The worsening pollution levels underscore the urgent need for targeted interventions to prevent further environmental damage and health risks to local communities.

Various tools and techniques have been developed to assess and monitor water quality. Among the most widely used in Indonesia are the Pollution Index and Storage and Retrieval (STORET) methods, both of which are mandated by government regulations, including the Ministry of Environment and Forestry (MoEF) Decree No. 115 of 2003 and Government Regulation No. 22 of 2021 (MoEF, 2003; Government of Indonesia, 2021). These tools are invaluable for identifying pollution levels, pinpointing sources of contamination, and informing policy decisions. Studies have demonstrated the efficacy of these methods in various contexts. Hernaningsih (2020) employed both methods to analyze water quality in the Batang Toru River, highlighting their ability to provide comprehensive evaluations that inform local management strategies. Zahrah and Hidayah (2023) similarly demonstrated the application of the Pollution Index method in an industrial setting in East Java, showing its value for compliance monitoring and environmental regulation (Hernaningsih, 2021; Zahrah & Hidayah, 2023).

Beyond these methods, other frameworks have also been developed globally to address water quality challenges. The Overall Index Pollution (OIP) method, originating in India, and the Canadian Council of Ministers of the Environment Water Quality Index (CCME-WQI) approach are widely recognized for their effectiveness in evaluating water quality trends and compliance with environmental standards (Romdania et al., 2018; Lumb et al., 2011). In Indonesia, Damayanti et al. (2021) applied the CCME-WQI to assess the Cirarab River, noting its compatibility with the Indonesian Water Quality Index (WQI-INA) while acknowledging its reliance on additional parameters. This method's robustness makes it particularly suited for detailed evaluations, offering valuable insights for policymakers and environmental managers (Damayanti et al., 2021; Sari & Wijaya, 2019).

The Cikakembang River in Bandung Regency, Indonesia, has experienced significant water quality degradation due to rapid industrial development and domestic activities, particularly from the textile industry. This pollution has rendered the river unsuitable for daily needs, as highlighted in recent studies (Kent et al., 2024). While various water quality assessment methods have been applied individually in similar contexts, there is a lack of comparative studies evaluating the effectiveness of the Pollution Index, STORET, and CCME-WQI methods specifically within Indonesian river systems affected by industrial pollution. Addressing this gap is crucial for developing accurate water quality monitoring and management strategies. Given the escalating industrial pollution in the Majalaya region and its detrimental impact on local water sources, a comprehensive assessment using multiple methods is urgently needed to inform regulatory decisions and implement effective pollution control measures.

This study evaluates the water quality of the Cikakembang River in Bandung Regency, Indonesia, using the Pollution Index, STORET, and CCME-WQI methods. The integration of these approaches offers a robust framework for assessing pollution levels, ensuring regulatory compliance, and guiding sustainable water resource management. The Pollution Index quantifies pollutant concentrations relative to permissible limits, providing a straightforward assessment of individual contaminant levels. The STORET method evaluates deviations based on compliance with multiple standards, facilitating the identification of specific parameters that exceed regulatory thresholds. Meanwhile, the CCME-WQI method incorporates parameters such as scope and frequency to offer a comprehensive overview of water quality trends (Damayanti et al., 2021; Hu et al., 2022; Restrepo et al., 2023). Together, these tools provide an invaluable perspective on the health of the Cikakembang River, facilitating informed decisions to mitigate pollution and protect water resources.

By applying these methodologies in combination, this study provides novel insights into their comparative effectiveness under Indonesian environmental conditions, offering a unique approach to understanding pollution dynamics and supporting sustainable resource management. The primary objective of this research is to evaluate and compare the Pollution Index, STORET, and CCME-WQI methods in assessing the water quality of the Cikakembang River in Indonesia. Moreover, the study aligns with water quality standards outlined in Government Regulation No. 22 of 2021, highlighting its relevance for public and institutional decision-making. The results emphasize the need for enhanced water quality monitoring and underscore the importance of proactive measures to safeguard water resources for future generations.

2. Methods

2.1. Study Location

This study is a case study of the Cikakembang River, a 5.6 km tributary of the Citarum River within the Majalaya industrial area. The river is a tributary of the Citarum River, known for its high pollution levels. Sampling for water quality analysis was carried out during both the rainy and dry seasons to capture potential seasonal variations in water quality. Nine specific water quality monitoring points were selected based on their relevance to pollution sources and accessibility as seen in Figure 1. These locations are detailed in Table 1, providing geographical coordinates for precise identification.

In this study, a total of 14 water quality parameters were analyzed in compliance with the Standard Methods for the Examination of Water and Wastewater. Dissolved oxygen (DO) and pH were measured in the field using portable meters to ensure accuracy, while all other parameters were analyzed in the laboratory to maintain precision and reliability. The results from both wet and dry seasons were evaluated against the Class II Water Quality Standards outlined in Government Regulation No. 22 of 2021 on Environmental Protection and Management. These standards define the maximum allowable concentrations for various parameters to ensure water suitability for recreational use, freshwater aquaculture, livestock, irrigation, and similar purposes. Table 2 outlines the specific concentration limits defined by these standards, ensuring the water's suitability for such diverse purposes.

Figure 1. The sampling locations in the Cikakembang River

Table 1. Locations of water quality monitoring points

Sampling Points	Latitude Coordinates	Longitude Coordinates
T01	7° 3' 39.92" S	107° 44' 43.80" E
T02	7° 3' 21.06" S	107° 44' 49.20" E
T03	7° 3' 12.82" S	107° 44' 50.64" E
T04	7° 2' 59.75" S	107° 44' 46.32" E
T05	7° 2' 48.88" S	107° 44' 35.88" E
T06	7° 2' 45.85" S	107° 44' 20.40" E
T07	7° 1' 49.76" S	107° 43' 58.08" E
T08	7° 1' 47.57" S	107° 43' 55.92" E
T09	7° 1' 27.62" S	107° 43' 50.52" E

Table 2. Class II water quality standard

Parameter	Concentration (mg/L)	Details	Parameter	Concentration (mg/L)	Details
DO	4	Min Value	TP	0.2	Max Value
TDS	1	Max Value	NO_3-N	10	Max Value
pH	6-9	Max Value	NO_2-N	0.06	Max Value
BOD	3	Max Value	NH_3-N	0.2	Max Value
COD	25	Max Value	TN	15	Max Value
SO_4^{2-}	300	Max Value	F^-	1.5	Max Value
Cl	300	Max Value	H_2S	0.002	Max Value

Source: (Indonesian Government Regulation No. 22 of 2021)

2.2. Pollution Index Method

The Pollution Index method, developed by Nemerow and Sumitomo in 1970 at the University of Texas, USA, was designed as a tool to evaluate relative pollution levels by focusing on significant pollutant compounds for specific uses (Nemerow & Sumitomo, 1970). This approach is widely used for assessing water quality by comparing the concentrations of water quality parameters against their corresponding standard values. The Pollution Index method integrates two key metrics to provide a more comprehensive understanding of pollution: the maximum value of the ratio and the average value of the ratio of each parameter concentration relative to its standard. This dual-metric approach helps identify both peak pollution events and the overall pollution trend in the water body. The mathematical formula used for the Pollution Index is expressed in equation (1).

$$PI_j = \sqrt{\frac{(C_i/L_{ij})^2{}_M + (C_i/L_{ij})^2{}_A}{2}} \quad (1)$$

Where, PI_j: Pollution index for use j, C_i: Measured concentration of parameter I, L_{ij}: Standard value of parameter i for use j, M: Maximum value, A: Average value

The Pollution Index calculation enables the identification of pollution levels, offering insights into whether the water quality meets the required standards for its intended use. By incorporating both maximum and average values, this method ensures a balanced assessment, capturing critical pollution peaks while also representing the general pollution conditions across all samples (Su et al., 2022). Each water quality parameter is analyzed by determining the ratio of its measured concentration to its standard value. These ratios are then used to compute the two key metrics: the maximum ratio, which represents the highest observed concentration relative to permissible limits, and the average ratio, which provides the mean concentration compared to the standard across all samples. By combining these metrics, the Pollution Index offers a holistic view of pollution trends in the water body. Once calculated, the Pollution

Index values are used to classify water quality into four distinct categories based on severity, as illustrated in Table 3 (Sulthonuddin et al., 2020). These classifications, ranging from "Good" to "Heavily Polluted," serve as a guideline for understanding pollution levels and devising appropriate mitigation strategies. Such categorization is particularly beneficial for regulatory authorities and stakeholders to prioritize areas needing immediate intervention.

Table 3. Water quality parameter testing methods

Pollution Index Value	Water Quality Status
0.0 ≤ PI ≤ 1.0	Good
1.0 ≤ PI ≤ 5.0	Slightly Polluted
5.0 < PI ≤ 10	Moderately Polluted
PI > 10	Heavily Polluted

Source: (Sulthonuddin et al., 2020)

2.3. STORET Method

The STORET method is a widely acknowledged approach for evaluating water quality by systematically comparing water quality data against pre-established standard values. These standards are determined based on the intended use of the water, ensuring its suitability for purposes such as drinking, recreation, or supporting aquatic ecosystems (Marengke & Nurhayati, 2022). This method provides a structured framework for identifying deviations from acceptable quality levels, thereby serving as a valuable tool for water resource management. Within the STORET method, water quality is evaluated through a scoring system that considers the number of samples collected and the specific categories of tested parameters. Each parameter is assessed against its permissible limit, and points are deducted based on the extent of deviation. The greater the number of parameters exceeding the standard, the higher the overall deduction, indicating poorer water quality.

The scoring system employed in the STORET method is rooted in values established by the US Environmental Protection Agency (US-EPA), ensuring consistency and comparability across different regions and research studies. This method is particularly effective for both regulatory compliance and environmental impact assessments. Table 3 illustrates the detailed scoring structure, highlighting how points are assigned depending on whether the parameter exceeds maximum, minimum, or average allowable values. Furthermore, Table 4 outlines the classification of water quality based on the final score. This classification, ranging from "Excellent" to "Poor," enables a straightforward interpretation of results and helps prioritize areas requiring intervention. The STORET method's adaptability and comprehensiveness make it an essential tool for ensuring sustainable water management practices across diverse settings (Yolanda et al., 2019).

Table 3. Class II water quality standards

Number of Samples	Value	Parameter		
		Physical	Chemical	Biological
< 10	Maximum	-1	-2	-3
	Minimum	-1	-2	-3
	Average	-3	-6	-9
≥ 10	Maximum	-2	-4	-6
	Minimum	-2	-4	-6
	Average	-6	-12	-18

Table 4. Domestic wastewater quality standards

Class	Score	Water Quality Status
A: Excellent	0	Good
B: Good	-1 to -10	Slightly Polluted
C: Moderate	-11 to -30	Moderately Polluted
D: Poor	≥ -31	Heavily Polluted

2.4. CCME-WQI Method

The CCME-WQI method, developed by the Canadian Council of Ministers of the Environment, provides a comprehensive framework for assessing water quality by integrating three key factors: Scope (F1), Frequency (F2), and Amplitude (F3). This structure offers a standardized approach for evaluating water quality conditions and is widely recognized for its applicability in various contexts. (Lumb et al., 2006). Scope Factor (F1) measures the proportion of tested variables that fail to meet the acceptable standards, indicating how widespread the water quality issues are across the parameters. Frequency Factor (F2) quantifies how often the tested variables exceed the permissible limits, providing insights into the persistence of water quality issues. Amplitude Factor (F3) assesses the severity of deviations from the standard values, considering the magnitude of excursions (NSE) from acceptable ranges.

The water quality status derived by the CCME-WQI method is categorized based on an index value, as illustrated in Table 6. This classification provides a clear and standardized interpretation of water quality, ranging from "Excellent" to "Poor." The method's ability to simplify complex water quality data into meaningful categories has made it a widely utilized tool. It is applied in regions including Canada, Turkey, and India due to its capability to offer a comprehensive understanding of water quality status. By offering stakeholders actionable insights, this method supports informed decision-making for water conservation and effective resource management.

The equations used for the CCME-WQI calculations are detailed in Equations (2) through (6) (Panagopoulos et al., 2022). These calculations provide a quantitative basis for determining water quality status. By integrating these factors, the CCME-WQI method delivers a detailed and nuanced analysis of water quality. It helps identify the extent and severity of pollution, enabling the development of targeted strategies and policies to safeguard and enhance water resources.

$$CCME\_WQI = 100 - \sqrt{\frac{{F_1}^2+{F_1}^2+{F_1}^2}{1.732}} \tag{2}$$

$$F_1 = \left(\frac{number\ of\ failed\ variables}{total\ variables}\right) \times 100 \tag{3}$$

$$F_2 = \left(\frac{number\ of\ failed\ tests}{total\ test}\right) \times 100 \tag{4}$$

$$F_3 = \left(\frac{nse}{0{,}01 \times nse + 0{,}01}\right) \times 100 \tag{5}$$

$$nse = \frac{number\ of\ excursions}{number\ of\ tests} \tag{6}$$

Table 6. Water quality classifications according to the CCME-WQI Method

Value	Category	Description
95–100	Excellent	Water quality is exceptionally high, with negligible deviation from acceptable standards.
80–94	Good	Water quality shows minor issues but overall meets the required standards.
65–79	Fair	Water quality is adequate but may occasionally fail to meet acceptable criteria.
45–64	Marginal	Water quality is often below standard, requiring attention to prevent further

Value	Category	Description
		degradation.
0–44	Poor	Water quality is consistently inadequate, posing significant risks to aquatic life and other uses.

Source: (Kurniawan, 2018)

3. Results and Discussion

3.1. Water Quality Parameter Test Results

Based on the findings from the water quality parameter tests, it is evident that pollution levels in the Cikakembang River exhibit significant seasonal variation, with higher pollution levels observed during the dry season compared to the rainy season. This seasonal disparity is particularly evident in the dissolved oxygen (DO) parameter. Recorded values were generally higher during the rainy season, likely due to the increased flow and mixing caused by rainfall, which enhances oxygenation. Conversely, during the dry season, reduced flow limits the river's self-purification capacity, resulting in lower DO levels. Notably, at least four samples from the rainy season exceeded the minimum concentration standards required by Class II Water Quality Standards, whereas during the dry season, only one upstream sample met this standard.

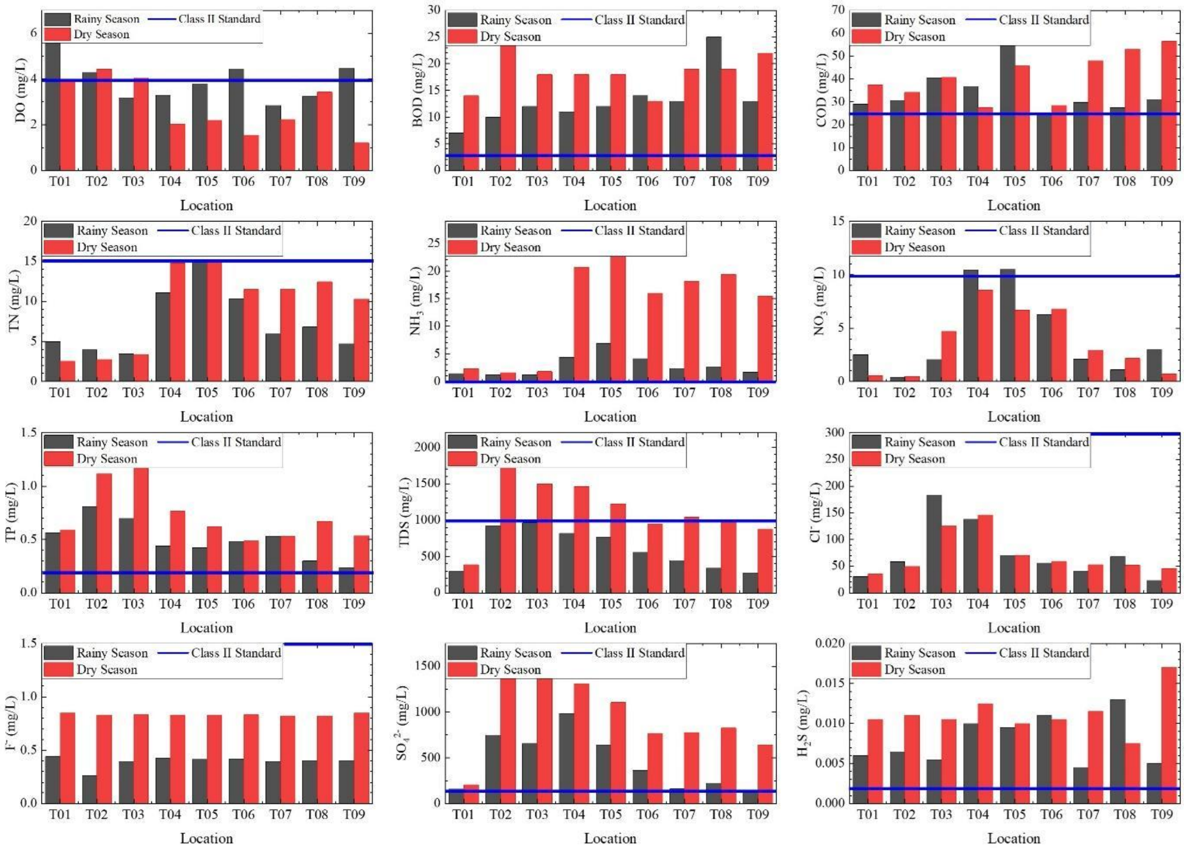

Figure 2. Water quality parameter test results for the Cikakembang River

The biochemical oxygen demand (BOD) and chemical oxygen demand (COD) parameters showed notable fluctuations during the dry season, with concentrations frequently exceeding acceptable limits. This variability is attributed to diminished river flow, which reduces the natural dilution of organic pollutants. As a result, the river becomes more vulnerable to contamination from organic matter and other pollutants that significantly increase oxygen demand. These findings highlight the river's reduced resilience to pollution during periods of low flow, emphasizing the need for targeted interventions to manage pollutant loads effectively. Other indicators, such as total nitrogen (TN), ammonia, and total phosphorus (TP), also demonstrated elevated concentrations during the dry season, particularly at locations influenced by domestic activities and waste disposal. These results suggest that nutrient inputs from anthropogenic sources contribute significantly to the river's overall pollution burden. Similarly, parameters such as total dissolved solids (TDS), sulfate, and fluoride showed increasing trends at multiple testing points, further indicating potential contamination from both natural and human-induced sources.

Conversely, parameters such as chlorine and fluoride generally remained within acceptable limits according to Class II Water Quality Standards across both seasons. This consistency suggests that the sources of these pollutants are either well-managed or less significant in this area. Such findings indicate that while certain pollutants pose substantial challenges, others are effectively controlled or inherently less problematic in the Cikakembang River system. Overall, these results provide a comprehensive understanding of the seasonal dynamics affecting water quality in the Cikakembang River. Variations between wet and dry seasons underscore the critical role of hydrological conditions in determining the river's capacity to manage and dilute pollutants. A more detailed visualization of the water quality parameter test results for the Cikakembang River is presented in Figure 2.

3.2. Analysis of Water Quality Status

The evaluation of water quality status in the Cikakembang River, assessed using three methods—Pollution Index, STORET, and CCME-WQI—offers a consistent depiction of significant pollution levels, particularly during the dry season. These methods collectively provide a comprehensive understanding of the spatial and seasonal variations in pollution intensity. Through the Pollution Index method, it was determined that locations T01 and T02 maintained a "Slightly Polluted" status during both the rainy and dry seasons. However, locations such as T04 to T09 experienced escalating pollution levels, with conditions worsening to "Moderately Polluted" during the dry season. This pattern indicates the impact of reduced river discharge, which diminishes the natural dilution of pollutants and leads to higher contamination levels downstream. A detailed depiction of the water quality status analysis using the Pollution Index is presented in Figure 3.

The analysis using the STORET method revealed that all locations were classified as "Heavily Polluted" across both seasons, with scores reaching as low as -102 at T05 during the dry season. The severity of these values suggests that multiple parameters exceeded acceptable thresholds simultaneously, triggering the high penalty deductions characteristic of the STORET scoring system. This underscores the significant pollution burden in the river, particularly in areas receiving higher industrial and domestic wastewater discharges. Further details of the analysis using the STORET method are provided in Figure 4.

Similarly, the results obtained through the CCME-WQI method aligned more closely with the STORET analysis, classifying all locations as 'Poor' in both seasons. Notably, locations such as T05 recorded exceptionally low WQI values in the dry season, reinforcing the observation that reduced water flow exacerbates pollution levels. This highlights the sensitivity of the CCME-WQI method in detecting cumulative water quality degradation over multiple parameters. A comprehensive summary of the analysis using the CCME-WQI method is illustrated in Figure 5.

The agreement among the results from the three methods underscores the severity of pollution levels in the Cikakembang River. However, the variation in classification severity suggests that each method evaluates pollution differently. The Pollution Index focuses on individual parameter exceedances, which may explain why it produced less severe classifications compared to STORET and CCME-WQI, both of which account for cumulative deviations across multiple water quality parameters. These variations, as summarized in Table 7, emphasize the importance of employing diverse assessment approaches to gain an accurate and holistic understanding of pollution dynamics.

Overall, the findings confirm the research objective of comparing the three assessment methods and demonstrate that STORET and CCME-WQI provide a more stringent classification of pollution severity than the Pollution Index. These results highlight the need for enhanced water resource management strategies, stricter pollution controls, and continuous monitoring, particularly in highly industrialized areas like Majalaya. This study provides a foundation for decision-makers to implement targeted interventions that mitigate pollution and safeguard the ecological and societal functions of the Cikakembang River.

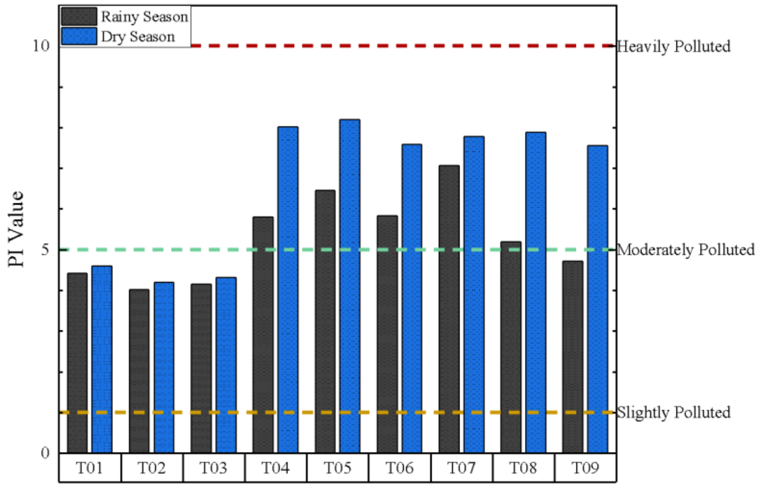

Figure 3. Water quality status of the Cikakembang River based on the Pollution Index Method

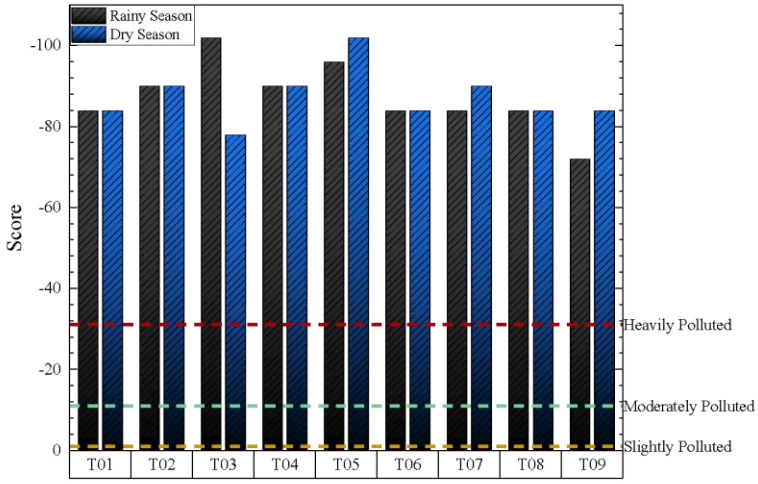

Figure 4. Water quality status of the Cikakembang River based on the STORET Method

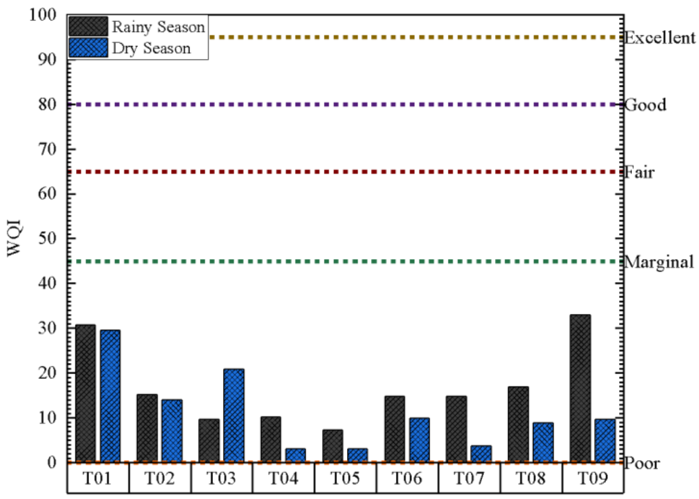

Figure 5. Water quality status of the Cikakembang River based on the CCME-WQI Method

Table 7. Water quality status of the Cikakembang River based on Pollution Index, STORET, and CCME-WQI Methods

No	Pollution Index Method		STORET Method		CCME-WQI Method	
	Pollution Index	WQ Status	Score	WQ Status	WQI	WQ Status
Rainy Season						
T01	4.4	Slightly Polluted	-84	Heavily Polluted	31	Poor
T02	4.0		-90		15	
T03	4.1		-102		10	
T04	5.8	Moderately Polluted	-90		10	
T05	6.4		-96		7	
T06	5.8		-84		15	
T07	7.1		-84		15	
T08	5.2		-84		17	
T09	4.7	Slightly Polluted	-72		33	
Dry Season						
T01	4.6	Slightly Polluted	-84	Heavily Polluted	30	Poor
T02	4.3		-90		14	
T03	4.4		-78		21	
T04	8.0	Moderately Polluted	-90		3	
T05	8.2		-102		3	
T06	7.6		-84		10	
T07	7.8		-90		4	
T08	7.9		-84		9	
T09	7.6		-84		10	

4. Conclusion

The evaluation of water quality parameters confirms that pollution levels in the Cikakembang River are significantly higher during the dry season, largely due to reduced river flow and increased contaminant concentration. By applying and comparing the Pollution Index, STORET, and CCME-WQI methods, this study provides a comprehensive assessment of pollution severity and classification differences across methods.

While the Pollution Index method categorized the river as "Slightly Polluted" to "Moderately Polluted", the STORET and CCME-WQI methods consistently classified it as "Heavily Polluted" or "Poor" across all sites and seasons. This discrepancy demonstrates the limitations of the Pollution Index method in fully capturing cumulative pollution impacts, whereas STORET and CCME-WQI provide a more stringent and multi-parameter evaluation.

The results confirm that industrial and residential wastewater discharge is a major contributor to the river’s declining water quality, especially in downstream areas where pollution levels worsen during the dry season. The findings directly support the need for stricter regulatory measures, improved wastewater treatment, and continuous monitoring using robust multi-parameter assessment tools like STORET and CCME-WQI.

The findings indicate that STORET and CCME-WQI provide a more comprehensive representation of pollution severity compared to the Pollution Index, which tends to underestimate cumulative water quality degradation. Given the industrial and residential pollution sources affecting the Cikakembang River, water quality management should prioritize assessment methods that consider multiple parameter exceedances rather than relying solely on single-parameter approaches. Strengthening pollution control measures and improving wastewater treatment infrastructure will be essential in mitigating the river's declining water quality, particularly during the dry season when pollution levels intensify.

The findings of this study indicate that weak wastewater treatment infrastructure and lack of strict law enforcement contribute significantly to the severe pollution levels observed in the Cikakembang River. Addressing these issues requires strengthening industrial wastewater treatment facilities (IPAL) and enforcing stricter regulations on industrial waste disposal to reduce pollutant loads. Without proper intervention, pollution levels will continue to escalate, further deteriorating water quality and increasing environmental and public health risks. Furthermore, continuous monitoring is essential to ensure that water quality is well-tracked, preserving the sustainability of the river. Future verification should involve long-term data collection and analysis to improve the accuracy of assessments.

Acknowledgements

The authors wish to express their gratitude to the Water Resources Laboratory and the Center for Water Resources Engineering within the Civil Engineering Department at Parahyangan Catholic University for their valuable support, data provision, and constructive feedback, which facilitated the successful completion of this research.

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