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Integration of Multi-Index Method and Qual2kw Evaluation Modeling of Quality Status and Pollutant Dispersion Pattern of Perian River in Kutai Kartanegara

Dwi Fitria Sari[1,*], Taufik Hamdani[1], Syelvialousiana Ningsih Kalauw[1], Rina Ermawati[1], Rudi Kartika[1], Slamet Hadi Raharjo[2]

[1]*Department of Chemistry, Faculty of Mathematics and Natural Sciences, Mulawarman University*
Barong Tongkok Street No. 04, Gunung Kelua, Samarinda City, East Kalimantan, 75123
[2]*Kutai Kartanegara Environmental Agency*
KH. Akhmad Dahlan Street, Sukarame Village, Kutai Kartanegara Regency, East Kalimantan, 75515, Indonesia
**e-mail correspondence: dwifitria51@gmail.com*

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ABSTRACT

This study is intended to assess water quality and determine the pollution status of the Perian River in its upstream (Perian Village) and downstream (Muara Aloh Village) sections in 2025. (COD) parameters. The findings reveal a marked deterioration in water quality from the upstream to the downstream segment of the river. Based on the CCME- WQI, both locations were categorized as "Poor," with scores of 61.95 (upstream) and 57.20 (downstream). The STORET method classifies the upstream status as "Moderately Polluted" (-23) and the downstream as "Heavily Polluted" (-42). Meanwhile, the PI method assigned a "Lightly Polluted" status to both locations. High concentrations of Nitrate (up to 42.57 mg/L) and Fecal Coliform (up to 12,976 counts/100ml) were the primary contributors to water quality degradation. The total actual COD pollution load was 25,344.52 kg/day, with the upstream area contributing a dominant share of 70.09%. Stringent conservation efforts and waste management along the river are required to prevent further degradation. This study also applied pollutant dispersion modeling using the Qual2Kw method.

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INTRODUCTION

Rivers are an important component of the domestic and industrial supply system, but changes in land use and anthropogenic activities often lead to declines in the quality of aquatic ecosystems [1]. The discharge of domestic and industrial waste into water bodies contributes to the growing pollution load borne by river systems [2]. Therefore, an accurate evaluation method is needed to determine water quality conditions quantitatively [3].

The Perian River in Muara Muntai District, Kutai Kartanegara Regency, is heavily used by the community for various purposes, including household activities, fishing, and transportation. The community's heavy reliance on this river has direct implications for water quality, particularly from domestic waste disposal and economic activities along its banks. This condition has the potential to degrade water quality and impact public health.

Water quality assessment is conducted by comparing measured water quality conditions with applicable water quality standards [4]. Several previous studies have shown that rivers in the Kutai Kartanegara region tend to experience moderate to severe levels of pollution. One such study was conducted by Mufti Cahyanto et al. (2019) [5]. The study of Water Quality and Water Quality Status of the Kahala River, Kenohan District, Kukar Regency, shows that the river's quality is categorized as moderately to heavily polluted based on STORET.

This study integrates three analytical techniques for determining water quality indices: STORET, Pollution Index, and CCME-WQI, to minimize bias from using a single method. Furthermore, Qual2Kw modeling is used to quantitatively simulate the dynamics of pollutant dispersion and transformation. This approach is expected to provide a more comprehensive picture of water quality conditions and pollutant distribution in the Perian River.

This study uses monitoring data from the Kutai Kartanegara Environmental Agency for 2025. The data are used to evaluate water quality at points 1 (upstream) and 2 (downstream) using the main parameters: BOD, COD, Nitrate, and Fecal Coliform. This study is expected to provide information on the status of water quality, the magnitude of the pollution load, and simulation results from the Qual2Kw model for the Perian River. The results of this analysis can serve as a basis for identifying pollution loads and for supporting water quality studies in environmental management.

RESEARCH METHODS

2.1 Location and Data Collection

The results of water quality measurements obtained from the Kutai Kartanegara Environmental Laboratory UPTD in 2025 were used as reference data for analysis, covering two observation points: the upstream area (Perian Village) and the downstream area (Muara Aloh Village), collected during the dry and rainy seasons. Parameters including TSS (suspended solids), pH (acid/base), DO (dissolved oxygen), BOD, COD, nitrate, total P (phosphate), and fecal coliform according to SNI standards.

Table 1. Coordinates of the Perian River Sampling Location, Kutai Kartanegara

Location	Coordinate
Point 1 (Upstream) Perian Village	0° 31'51.4° 116° 25'12.0"
Point 2 (Downstream) Muara Aloh Village	0° 28'14.8" 116° 21'30.2"

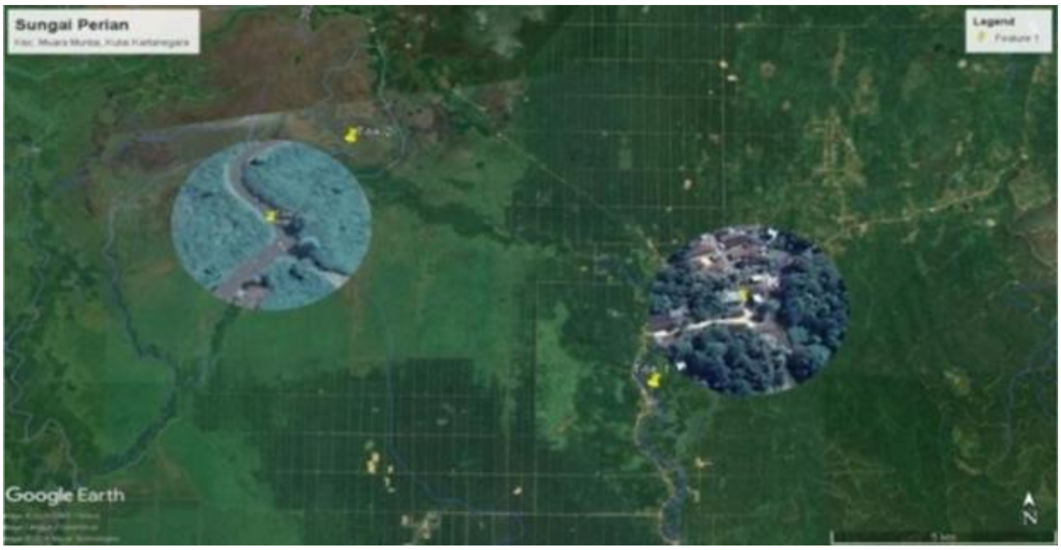

Figure 1. Perian River Sampling Map, Source: Google Earth 2026

Table 2: Results of Perian River Water Quality Analysis in 2025

Period 1. 26-27 February 2025

Parameter*	Unit	Quality Standards**	Location 1	Location 2	Test Method
TSS	mg/L	50	31.61	30	SNI 6989.3:2019
pH	(-)	6 – 9	9.45	7.91	SNI 6989.11:2019
BOD	mg/L	3	2.79	2.39	SNI 6989.72:2009
COD	mg/L	25	17.52	27	SNI 6989.2:2019
DO	mg/L	4>	4.96	12.13	SNI 06-6989.14-2004
Nitrate	mg/L	10	2.82	8.23	IKA 6.4-23-LL
Total phosphate	mg/L	0.2	0.02	0.02	SNI 6989.31:2021
Fecal Coliform	MPN/100mL	1000	12976	2548	SM 9223 B

Period 2. October 21, 2025

Parameter*	Unit	Quality Standards**	Location 1	Location 2	Test Method
TSS	mg/L	50	55	79	SNI 6989.3:2019
pH	(-)	6 – 9	7.25	8.06	SNI 6989.11:2019
BOD	mg/L	3	2.01	5.4	SNI 6989.72:2009
COD	mg/L	25	17.62	39.17	SNI 6989.2:2019
DO	mg/L	4>	6.76	7.38	SNI 06-6989.14-2004
Nitrate	mg/L	10	31.1	42.57	IKA 6.4-23-LL
Total phosphate	mg/L	0.2	0.01	0.05	SNI 6989.31:2021
Fecal Coliform	MPN/100mL	1000	60	448	SM 9223 B

2.2 Data Analysis

2.2.1 Water Quality Analysis

Water quality analysis is conducted to evaluate the suitability of parameters to applicable quality standards [6]. This analysis serves as a crucial instrument in identifying sources of pollution, mitigating environmental impacts, and providing a basis for policy-making on sustainable water resource management [7]. The methods used to determine these parameters are listed in Table 2 [8][9].

2.2.2 Water Quality Status

Determination of the status or quality of water is carried out to evaluate the condition of water quality, whether it is in a polluted or unpolluted state, from a certain water source at a certain time [10]. This study uses the STRORET method, Pollution Index (PI), and CCME_WQI. In addition, the pollution load is calculated based on the relationship among discharge, flow rate, and pollutant concentration [11].

a. **Storet Method**

According to MLH Decree No. 115 of 2003 on Guidelines for Determining Water Quality Status, Water quality status can be determined using the Storet method or the Pollution Index method [8]. The basis of the Storet method is a comparison of water quality data with quality standards adjusted to its intended use to determine water quality status. Water quality is classified into 4 classes and presented in Table 3.

Table 3. Classification of Water Quality Classes

No.	Class	Score	Water Quality Status
1	Class A	0	Meet Quality Standards
2	Class B	-1 to -10	Light Pollution
3	Class C	-11 to -30	Moderate Pollution
4	Class D	≥ -31	Heavy Pollution

b. Pollution Index Method

Assessment of water quality conditions in the environment uses a pollution index approach based on the Decree of the Minister of Environment No. 115 of 2003 on determining water quality status. The Pollution Index is used as an indicator to evaluate the level of contamination by comparing water quality parameter values against established quality standard limits [8]. Classification of water quality values that is:

Table 4. Classification of Water Quality PI Values

No.	PIj value	Water Quality
1	$0 \leq PI_j \leq 1.0$	Meet Quality Standards
2	$1.0 \leq PI_j \leq 5.0$	Light Pollution
3	$5.0 \leq PI_j \leq 10$	Moderate Pollution
4	$PI_j > 10$	Heavy Pollution

c. CCME-WQI method

The CCME-WQI (*Canadian Council of Ministers of the Environment Water Quality Index) method* is calculated based on three components, namely *scope* /F1 (scope of parameters that do not meet standard standards), quality, *frequency*/F2 (failure frequency), and *amplitude*/F3 (difference amplitude) [12]. Water categories according to the CCME-WQI method are:

Table 5. Water Quality Categories (*Source: Canadian Environment Quality Guidelines, 2001*)

No.	CCME-WQI Score	Water Quality
1	95 – 100	Very good
2	80 – 94	Good
3	65 – 79	Enough
4	45 – 64	Not enough
5	0 – 44	Bad

d. Determination of Pollution Load (BP)

According to the Decree of the Minister of Environment No. 110 of 2003 concerning Guidelines for Determining the Capacity of Water Pollution Loads in Water Sources, pollution load is defined as the quantity of pollutants contained in water bodies [8]. According to the 'US-EPA' (*Environmental Protection Agency*), the calculation of water *pollution load* is basically a function of pollutant concentration and flow rate, with the following equation:

$$BP = Q \times C \times 86.4$$

Description: BP is the pollutant load in kg per day; Q is the flow rate in m^3 / sec; C is the concentration (mg/L); and 86.4 is the kg/day conversion factor.

e. **Qual2Kw Modeling**

Water quality modeling was conducted using the QUAL2K software to simulate the distribution and transformation of pollutants along the river. Qual2Kw modeling version 5.1 is a modeling developed by the 'US-EPA' (*Environmental Protection Agency*) [8]. The modeling simulation steps are as follows:

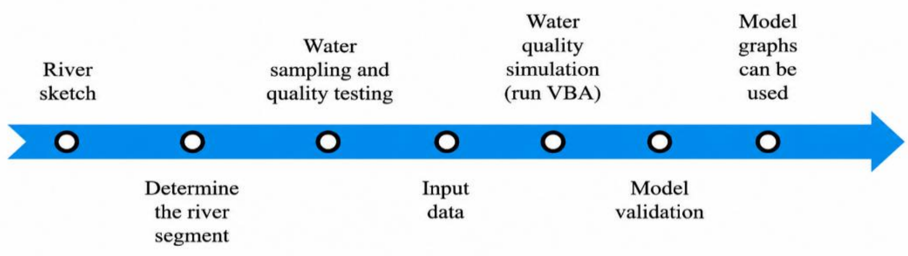

Figure 2. Flowchart of Qual2Kw modeling operations

Model validation is performed using the Root Mean Square Error (RMSE) to assess the agreement between observed data and simulation results [13].

RESULTS AND DISCUSSION

3.1 Water Quality Analysis and Determination of Pollution Status of the Perian River

Of the eight parameters tested over two periods at two observation points in 2025 in the Perian River and Muara Muntai, six parameters exceeded the quality standard thresholds as regulated by the Republic of Indonesia Government Regulation Number 22 of 2021, Appendix VI. These parameters were TSS, pH, BOD, COD, NO3, and Fecal Coliform [4].

Table 6. Results of Perian River Water Quality Parameter Tests

Parameter*	Unit	Quality Standards**	Period 1		Period 2	
			Location 1	Location 2	Location 1	Location 2
TSS	mg/L	50	31.61	30	55	79
pH	(-)	6 – 9	9.45	7.91	7.25	8.06
BOD	mg/L	3	2.79	2.39	2.01	5.4
COD	mg/L	25	17.52	27	17.62	39.17
DO	mg/L	4>	4.96	12.13	6.76	7.38
Nitrate	mg/L	10	2.82	8.23	31.1	42.57
Total phosphate	mg/L	0.2	0.02	0.02	0.01	0.05
Fecal Coliform	MPN/100mL	1000	12976	2548	60	448

3.1.1 TSS and pH parameters

TSS measures the amount of suspended solids in water that can affect turbidity and sunlight penetration. From the TSS test results for period 1 (dry season), the TSS values at the upstream (31.61 mg/L) and downstream (30 mg/L) sites were below the quality standard threshold of 50 mg/L. In the rainy season, the upstream exceeded the quality standard, reaching 55 mg/L, while the downstream exceeded it as well, at 79 mg/L. This increase indicates excessive input of suspended solids into the river, which may originate from rainfall-induced surface runoff or anthropogenic activities such as land clearing along the riverbanks. High TSS downstream indicates the accumulation of sediment particles along the river flow.

The pH parameter upstream of period 1 reached 9.45, significantly exceeding the maximum threshold. The extremely alkaline pH values upstream indicate alkaline contamination or intense phytoplankton photosynthetic activity during that period, which consumed CO_2 and increased the water's alkalinity. In period 2, the pH stabilized at 7.25.

3.1.2 Oxygen and Organic Load Characteristics: BOD and COD

In the upstream section, BOD (2.01-2.79 mg/L) and COD (17.52-17.62 mg/L) concentrations consistently met the established quality standards (BOD < 3 mg/L; COD < 25 mg/L). The COD parameter exceeded the quality standards in both periods, namely 27 mg/L and 39.17 mg/L in the second period. The BOD value downstream in the second period jumped to 5.4 mg/L, exceeding the 3 mg/L threshold.

There was an increase in BOD and COD values downstream, followed by a decrease in Dissolved Oxygen (DO) levels in the second period. This pattern indicates a buildup of organic pollutants in the downstream river. Furthermore, the relatively high COD-to-BOD ratio suggests that organic pollutants in the Lower Perian River originate not only from readily biodegradable domestic waste but also likely contain complex organic pollutants that are more difficult to degrade naturally.

3.1.3 Nitrate Concentration Parameters

In the upstream region, the dry-season nitrate concentration of 2.82 mg/L increased sharply to 31.1 mg/L in the rainy season, exceeding the quality standard (10 mg/L) by more than threefold. In the downstream area, similar conditions occurred, with a spike from 8.23 mg/L to 42.57 mg/L during the rainy season. High nitrate concentrations downstream correlated with organic load (COD) and microbiological contamination. This indicates a massive nutrient input, likely from agricultural fertilizer runoff or household waste accumulating along the river. The high nitrate values in the second period downstream were also influenced by lower water discharge, resulting in more concentrated nutrient concentrations.

3.1.4 Increased Microbiological Concentration of Fecal Coliform

The level of bacterial contamination in the upstream area of the river increased significantly during the dry season, reaching 12,976 MPN/100 mL, which is more than 12 times the permitted safe limit. The high concentration of indicator bacteria indicates fecal contamination, either from residents' domestic activities or from the livestock sector. directly discharged into river bodies without prior processing or treatment.

In the second period, this value decreased drastically to 60 MPN/100 mL. This sharp decrease indicates that microbiological pollution upstream is fluctuating or influenced by intermittent events (point-source pollution) that do not occur continuously. This decrease in the downstream is consistent with the downward trend observed in the upstream, although the value is still higher than the upstream value in the same period (448/60), indicating the accumulation of residual bacterial contamination in the downstream part of the river.

3.2 Analysis of Water Quality Status

Based on the analysis results of the Storet method, Pollution Index, and CCME-WQI, all methods indicate that the Perian River in 2025 is in a polluted or poor-quality condition for a body of water, but with different categories.

3.2.1 Accumulative Score-Based Severity Assessment (Storet)

The results of the data analysis using the Storet method generally show that the river quality is at moderate to severely polluted conditions. This decline in water quality is caused by the accumulation of TSS, BOD, COD, and nitrate, all of which consistently exceed standards.

3.2.2 Fluctuation in Quality Status Between Periods (Pollution Index)

The results of the water quality analysis of the Perian River, using the Pollution Index (PIj) method, show a significant decline in water quality from the upstream area (point 1) to the downstream area (point 2) throughout 2025. The difference in *Pij* values between upstream (3.699) and downstream (1.577) indicates that the pollution load in the upstream is more dominated by extreme fluctuations in one or two parameters (such as Fecal Coliform and Nitrate), while in the downstream, the pollution is more evenly distributed across various organic and nutrient parameters.

3.2.3 Integrated Quality System (CCME-WQI)

The CCME-WQI data analysis results indicate that the Perian River has experienced water quality degradation along its entire length. The decline in the score from 61.96 upstream to 57.20 downstream indicates an accumulation of organic pollutants and nutrient loads in the river's lower reaches.

Comparison of the analysis results of the three methods shows a complementary relationship (complementing each other) in assessing the ecological integrity of the Perian River, as shown in :

Table 7. Analysis of Determining the Water Quality Status of the Perian River in 2025

Location	Store		Pollution Index		CCME-WQI	
	Score	Status	PIj	Status	Score	Status
Point 1 (Upstream) Perian Village	-23	Moderate Pollution	3.69	Light Pollution	61.95	Not enough
Point 2 (Downstream) Muara Aloh Village	-42	Heavy Pollution	1.57	Light Pollution	57.20	Not enough

3.3 Pollution Load Evaluation

The results of the pollution load evaluation in the Perian River indicate that pollutant sources are more prevalent upstream than downstream. Cumulatively, the total pollution load along the river in 2025 reached 25,344.52 kg/day. The upstream load emphasizes that pollution control strategies must focus on reducing waste in the upstream region. If the upstream mass load is not reduced, these pollutants will continue to accumulate downstream, where the pollution load capacity is more limited.

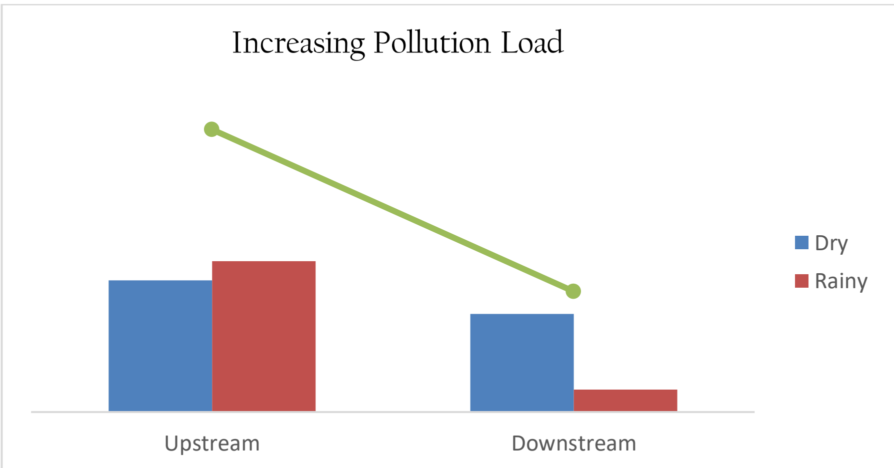

Figure 3 . Graph of the Increase in Perian River Pollution Load in 2025

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3.4 Qual2Kw Water Quality Modeling

Qual2Kw modeling is a program that simulates the migration, transformation, and dispersion patterns of various constituents in a water body, assuming perfectly mixed vertical and lateral flow and steady-state conditions [2]. The advantage of applying this model to a river system lies in its ability to represent non-uniform flow while remaining stable over a certain time scale, thus enabling the simulation of pollutant loads entering and leaving the system from various sources [13].

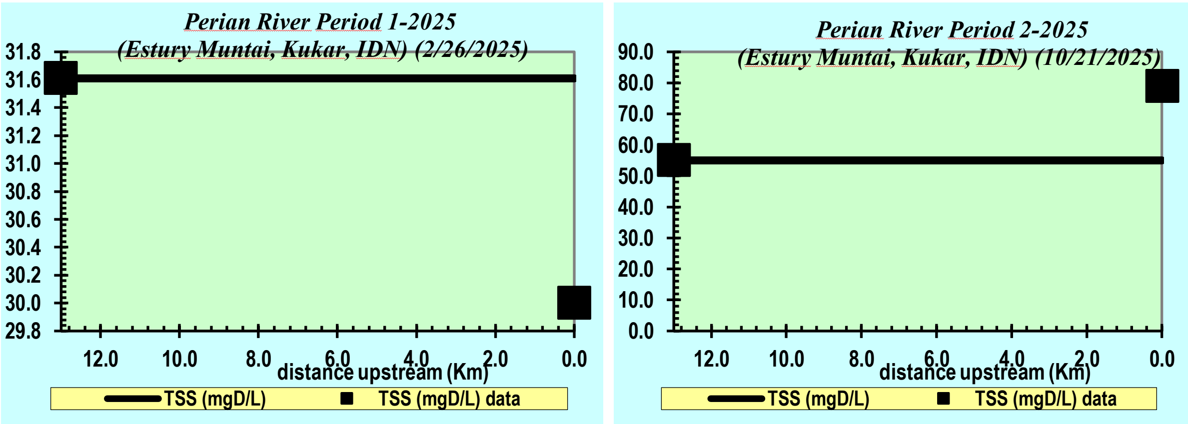

Figure 4. Dispersion Pattern of TSS Contamination in Period 1 and Period 2

The increase in TSS during the rainy season at these two points indicates the input of suspended solid material into the river body. The dispersion pattern shows that TSS increases at points with physical obstacles, such as waterfalls or low-flow areas, where particles tend to settle.

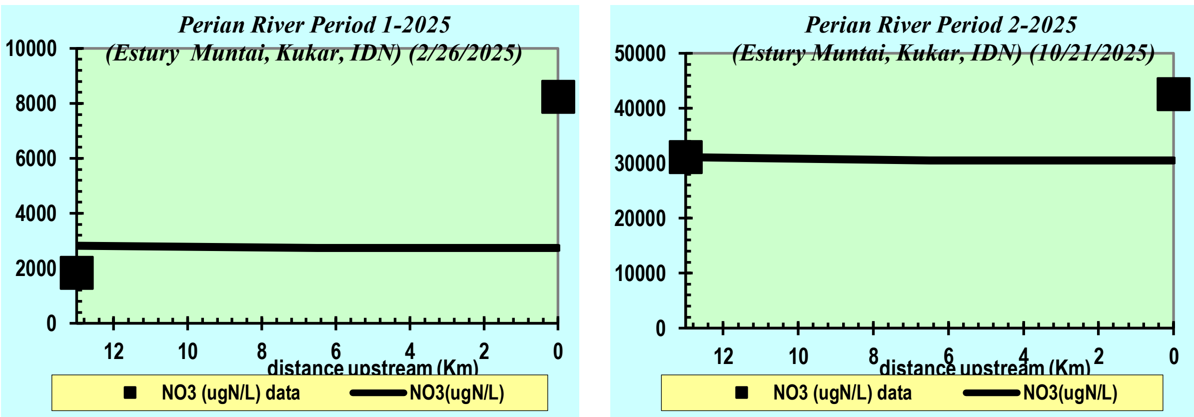

Figure 5. Dispersion Pattern of NO_3 Contamination in Period 1 and Period 2

NO_3 dispersion is higher downstream, indicating a massive nutrient input, such as fertilizer use on plantations along the river. The high NO+ levels during the dry season are influenced by lower discharge, which results in higher nutrient concentrations.

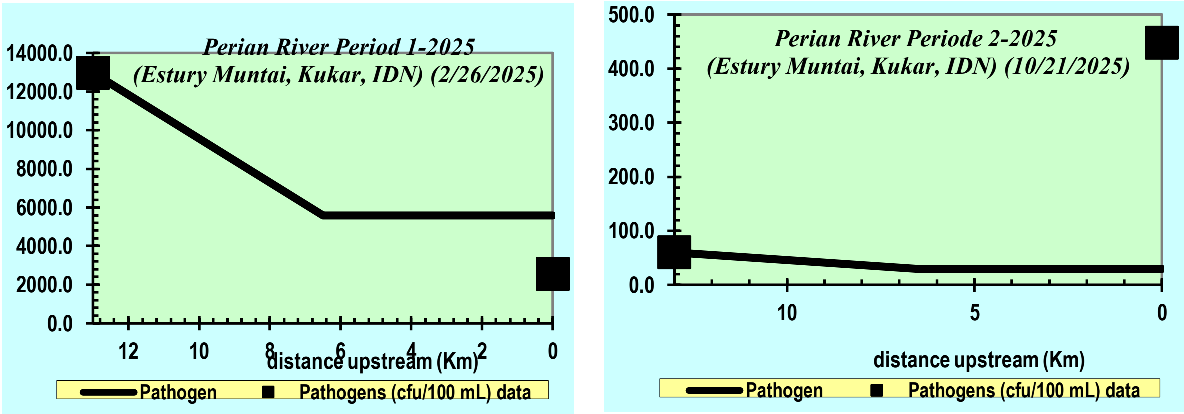

Figure 6. Dispersion Pattern of Fecal Coliform Contamination in Period 1 and Period 2

Fecal coliform dispersion patterns fluctuate: during the dry season, concentrations can increase sharply due to the minimal volume of diluting water, while during the rainy season, increases are driven by material carried by currents from the surrounding land into the river.

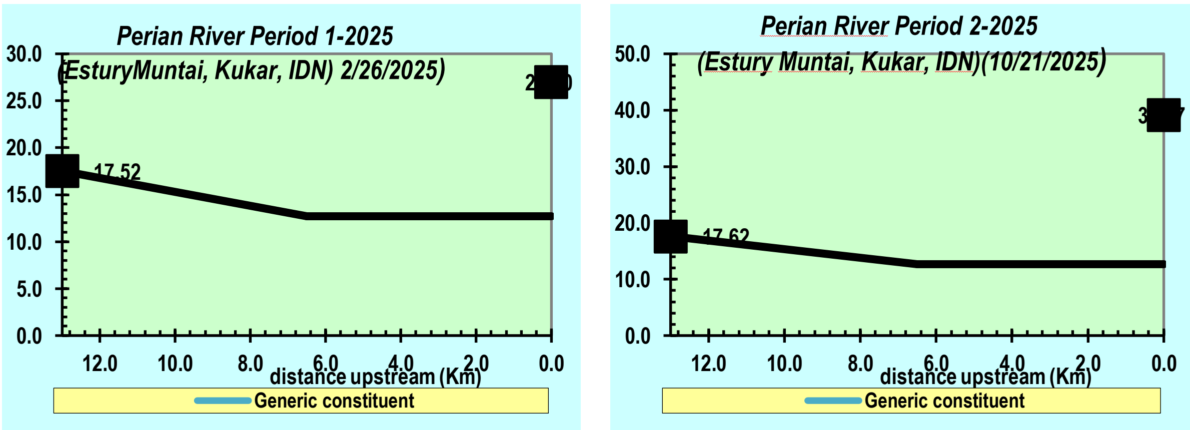

Figure 7. Dispersion Pattern of COD in Period 1 and Period 2

Under very low water-discharge conditions, the COD dispersion pattern can exhibit an exponential spike. This is known as the supersaturation phenomenon, in which organic pollutants become concentrated in one area due to slow flow rates and limited water volume, reducing natural dilution. Waste inputs from various fixed (point) and non-fixed (diffuse) sources along the flow significantly increase the organic load [14].

CONCLUSION

The results of the study indicate that the three methods used provide water conditions that do not meet Class II quality standards. Based on the STORET test, the water status is classified as moderately polluted upstream and heavily polluted downstream, with scores of -23 and -42, respectively. Meanwhile, the results of the Pollution Index (PI) test indicate that the status is lightly polluted in the upstream and downstream sections (3.69-1.75), and the CCME-WQI method consistently yields poor results. It can be concluded that the water quality of the Perian River has experienced significant degradation, with conditions worsening from upstream to downstream. Based on the multi-index evaluation, the downstream part of the river is in the most critical condition with a status of Heavy Pollution (STORET method) and a category of Less (CCME-WQI method). The main parameters that consistently exceeded the quality standards were TSS, nitrate, fecal coliform, and COD. Quantitatively, the upstream area was the largest contributor to the pollution load (accounting for 70.09% of the total COD load), but the most severe pollution impact was felt in the downstream area due to a drastic decrease in water discharge, which reduced the river's natural dilution capacity.

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