WATER QUALITY POLLUTION INDEX IN KRUENG PEUSANGAN RIVER BIREUEN REGENCY

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Abstract: A continuous assesment of river water quality is a crucial aspect of water resources management and environmental protection. This research aims to assess the water quality status in Krueng Peusangan River that crosses Bireuen, Bener Meriah and Aceh Tengah Regency, Aceh Province, using the pollution index (IP) method. The water quality data used in this research is secondary data from monitoring results at several sampling locations from upstream to downstream over 10 (ten) years period from 2016 to 2025. Key parameters analyzed include physical, chemical, and biological parameters, such as pH, temperature, Dissolved Oxygen (DO), Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), nitrate, nitrite, phosphate, and bacteriological (Total Coliform). The pollution index calculation results show fluctuations in water quality status from year to year. In 2016-2018 and 2020-2021, the river was categorized as moderately polluted with IP values ranging from 5.829 to 8.898. Meanwhile, in 2019 and the 2022-2025 period, water quality experienced significant improvement and remained stable in the lightly polluted category, with IP values decreasing and remaining in the range of 1.243 to 3.378. This trend change needs to be observed by considering the change in the number of parameters for the IP calculation from 21 parameters (2016-2021) to 9 parameters (2022-2025). This indicates that the use of a more comprehensive parameter set (21 parameters) can provide higher analytical resolution and be sensitive to fluctuations in various pollutants. Therefore, parameter simplification has the potential to affect the interpretation of long-term pollution trends.

Keywords: water quality; pollution index; environmental monitoring

Abstrak: Penilaian kualitas air sungai secara berkelanjutan merupakan aspek krusial dalam manajemen sumber daya air dan perlindungan lingkungan. Penelitian ini bertujuan untuk menentukan status kualitas air Sungai Krueng Peusangan yang melintasi Kabupaten Bireuen, Bener Meriah dan Aceh Tengah, Provinsi Aceh, dengan menggunakan metode Indeks Pencemaran (IP). Data kualitas air yang digunakan merupakan data sekunder hasil pemantauan pada beberapa titik sampling dari hulu hingga hilir selama periode 10 (sepuluh) tahun mulai tahun 2016 hingga 2025. Parameter kunci yang dianalisis meliputi parameter fisika, kimia, dan biologis, seperti pH, suhu, Dissolved Oxygen (DO), Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), nitrat, nitrit, fosfat, serta bakteriologis (Total Coliform). Hasil perhitungan Indeks Pencemaran menunjukkan fluktuasi status kualitas air dari tahun ke tahun. Pada tahun 2016, 2017, 2018, 2020, dan 2021, sungai berada dalam kategori tercemar sedang dengan nilai IP berkisar antara 5,829 hingga 8,898. Sementara itu, pada tahun 2019 dan periode 2022-2025, kualitas air mengalami perbaikan yang signifikan dan stabil masuk dalam kategori tercemar ringan, dengan nilai IP menurun dan bertahan di kisaran 1,243 hingga 3,378. Perubahan tren ini perlu dicermati dengan mempertimbangkan perubahan jumlah parameter untuk perhitungan IP dari 21 parameter (2016-2021) menjadi 9 parameter (2022-2025). Hal ini mengindikasikan bahwa penggunaan parameter yang lebih komprehensif yaitu 21 parameter, dapat memberikan resolusi analitik yang lebih tinggi dan sensitif terhadap fluktuasi berbagai polutan, sehingga penyederhanaan parameter berpotensi memengaruhi interpretasi tren pencemaran jangka panjang.

Kata Kunci: kualitas air; indeks pencemaran; pemantauan lingkungan

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Introduction

The Krueng Peusangan River is a river basin (DAS) which has a watershed area with total area of 2,007 km^2 and originates in Lake Lut Tawar, Aceh Tengah Regency. The Krueng Peusangan River Watershed has the total area of 238,550 ha, the river length is 142 km and the average slope is 0.008445 and has 107 river consing of 12 sub-basin, with total of irrigation area of 15,212.09 ha. This river has water potential that reaches 16,573,744,800 m^2/year which is utilized for hydroelectric power. Geographically, this river located at 04^o 30' 38" – 05^o 16' 34" north latitude and 96^o 27' 12" – 97^o 02' 40" east longitude.

The Krueng Peusangan watershed is highly vulnerable to flooding, particularly in Bireuen Regency, which is affected by low topography, land cover changes, and extreme rainfall pattern due to climate change (Aznita et al., 2025). The pollution index (PI) is an analytical method used to comprehensively evaluate water quality status by integrating various pollutant parameters. This method compares water quality parameters with quality standards, thus quantifying the level of pollution in a water body (Irfannur and Khairan, 2021; Santika, 2024; Novianti et al., 2022).

River water quality is a vital indicator of the health of aquatic ecosystems, which are affected by various anthropogenic activities (Novita et al., 2023; Supardiono et al., 2023; R. Ichwana et al., 2020). Water quality assessment can be conducted using the Pollution Index (PI) method, which provides a comprehensive overview of pollution levels by comparing water quality parameter concentrations with Class II quality standards (Peraturan Pemerintah Republik Indonesia Nomor 22, 2021; Rokhianah et al., 2023; Alfatihah et al., 2022).

River water quality status can be assessed using the Pollution Index (PI) approach. This method is effective for evaluating pollution levels based on physical, chemical, and biological parameters, thereby providing an overview of the aquatic environment (Aulia et al., 2024). River water pollution caused by anthropogenic activities such as domestic and industrial activities along the river can be quantified objectively using the Pollution Index (PI) (Artiningrum and Saeful, 2023).

Anthropogenic activity along the river stream such as domestic resident, agriculture, and industrial activities, have the potential to pollute water bodies through the entry of organic matter and suspended solids that can reduce river water quality (Bahagia et al., 2020; Rahmadi et al., 2023; Rachmawati et al., 2020). This activity is important for identifying water quality trends, detecting early deterioration in quality, and providing accurate baseline data for policy formulation and effective environmental recovery strategies (Frebhika Sri Puji Pangesti, 2020; Aprilia et al., 2022).

Considering the condition of the Krueng Peusangan River, which is under pressure due to anthropogenic activities, this study aims to analyze the water quality status of the Krueng Peusangan River using the Pollution Index method based on river water quality monitoring data from the Aceh Environment and Forestry Agency from 2016 to 2025. This method is applied to evaluate pollution levels based on key physical-chemical and biological parameters. The results of this analysis are expected to provide an overview of the water quality status of the Krueng Peusangan River as a scientific basis for formulating sustainable water quality management policies and pollution control efforts in the Krueng Peusangan river basin in Bireuen Regency.

Methods

Area of Study Description

The area of study take place in six monitoring location spread along the Krueng Peusangan River Basin (Figure 1). This study is using secondary data type, obtained from the recapitulation of water quality monitoring of the Krueng Peusangan River by the Aceh Environment and Forestry Public Agency in period time of 2016-2024. Meanwhile the data for 2025 comes from field observation.

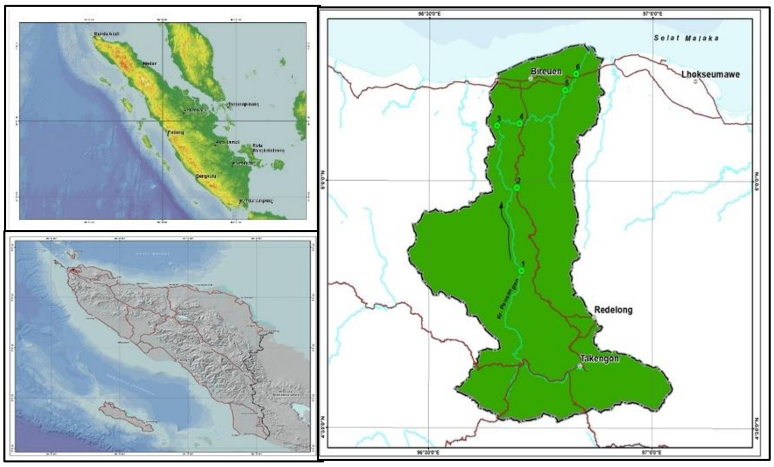

Figure 1. Krueng Peusangan River Basin Map

The Krueng Peusangan river basin has three main sub-basin (Figure 2). The integration of these three sub-basin is crucial to the performance of the Krueng Peusangan basin in supporting agricultural, mining, industrial, and residential activities along its flow to the coastal area.

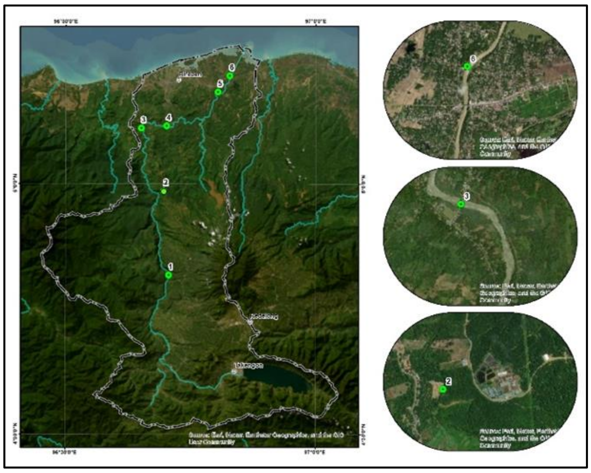

Figure 2. Research Location

Location of water quality monitoring of the Krueng Peusangan River in 2025 in Bireuen Regency, Aceh Province. The map shows that the river and its tributaries flow through areas with various land uses, including residential areas, agriculture, plantations, mining, industry, and livestock farming. The monitoring points are spread from upstream to downstream, making it possible to assess the impact of these various anthropogenic activities on water quality along the river.

Tools and Materials

The materials used in the Krueng Peusangan River water sampling activity included ice cubes, sample blanks, preservatives, and the river water samples themselves.

The equipment used for sampling and measuring in-situ parameters, which had undergone internal calibration, included a Thermo brand pH meter, a Consort

DO meter, a mercury thermometer, a Thermo conductometer, a Garmin eTrex 32x GPS, a Lion cool box, a Van Dorn horizontal water sampler, polyethylene bottles, and special glass bottles for BOD and fecal coliform analysis.

Procedure

The method of collecting river water samples uses the grab method, which involves collecting water samples at a specific time and location. Meanwhile, the composite method combines several samples taken from various locations or times to obtain a more comprehensive representation of river conditions (Zhang, 2007). The method of collecting water samples uses grab sampling in accordance with SNI 6989.57:2008. Samples were taken in the morning from several representative points (Fitria et al., 2025).

Water sampling activities on the Krueng Peusangan River were carried out in two monitoring stages, namely the dry season and the rainy season. Procedurally, each monitoring stage must go through three main stages. These stages consist of initial preparations, which include surveying the sampling locations upstream, midstream, and downstream using GPS to ensure accuracy and consistency of location, as well as preparing in-situ water quality measuring equipment. The second stage involves taking composite river water samples using water samplers and sterile sample bottles in accordance with SNI by certified sampling officers from the laboratory. Measuring in-situ parameters, recording measurement results, and recording environmental conditions around the sampling location. Measuring river discharge such as width, depth, and flow velocity using current meters, echo sounders, and meters at each sampling location. The third stage involves testing samples at the UPTD BPPPL DLHK Aceh laboratory by laboratory analysts using the Winkler, reflux, spectrophotometry, gravimetry, and MPN methods.

Pollution Index (IP) Formula

The IP is calculated based on the ratio between the concentration of water quality parameters (C_i) and the water quality standard value (L_{ij}) for a specific designation. If L_{ij} is the concentration of parameters in the Water Designation Standard (j) and Ci is the concentration of water analysis results at a location, then PIj is the Pollution Index for designation (j) as a function of the C_i/L_{ij} ratio.

$PI_j = (C_1/L_{1j}, C_2/L_{2j}, C_3/L_{3j},\ldots,C_i/L_{ij})$ ……………………………………….(1)

$PI_j = [(C_i/L_{ij})_R, (C_i/L_{ij})_M]$…………………………………………………..(2)

Showing that:

$(C_i/L_{ij})_R$ = Average C_i/L_{ij} value

$(C_i/L_{ij})_M$ = Maximum C_i/L_{ij} value

The pollution index is determined using the formula of $IP = \sqrt{\left[\left(C_i/L_{ij}\right)M^2 + \left(C_i/L_{ij}\right)R^2\right]/2}$, where C_i is the concentration of the measured parameter and L_{ij} is the standard value. The (C_i/L_{ij})M value is the maximum ratio and (C_i/L_{ij})R value is the average ratio of all parameters. Water quality status is

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classified based on the resulting IP value (Suriadikusumah et al., 2021); (Hardina et al., 2024); (Lihawa et al., 2024). The water quality category is determined by the pollution index (PIj) value result from the calculation (Table 1).

Table 1. Water Quality Category

IP Value	Water Quality	Description
$0 \leq PI_j \leq 1.0$	Good	Not polluted
$1.0 < PI_j \leq 5.0$	Low Pollution	Slightly less than from standard quality
$5.0 < PI_j \leq 10.0$	Moderate Pollution	Significant deviations from standard quality
$PI_j > 10$	Heavy Pollution	Serious deviations from standard quality

Source: (Keputusan Menteri Lingkungan Hidup Nomor 115, 2003)

The data analysis conducted includes a comparative analysis to compare the measurement data of parameters with Class II water quality standard from Peraturan Pemerintah Republik Indonesia Nomor 22 Tahun 2021 Lampiran VI, using IP method and scoring based on categories specified in Keputusan Menteri Lingkungan Hidup Nomor 115 Tahun 2003.

In this research case, C_i/L_{ij} calculation result are replaced with the following calculation:

$$(C_i/L_{ij})_{new} = \frac{C_{im}-C_i \quad (calculation\ result)}{C_{im}-L_{ij}} \text{ .... (3)}$$

The calculation of $(C_i/L_{ij})_{new}$ differentiated based on the following conditions:

If $C_i \leq$ Average L_{ij}:

$$(C_i/L_{ij})_{new} = \frac{[C_i-(L_{ij})_{average}]}{\{(L_{ij})_{minimum}-(L_{ij})_{average}\}} \text{ .... (4)}$$

When 2 (two) C_i/L_{ij} value are close to the reference value of 1,0 (e.g., 0,9 and 1,1) or have a large difference, such as 5,0 and 10,0, it becomes difficult to determine the level of water body damage. The solution is:

1. If it is < 1.0, use the measured C_i/L_{ij} value,
2. If it is > 1.0, use the following C_i/L_{ij} formula:

$$(C_i/L_{ij})_{new} = 1.0 + P.\log(C_i/L_{ij})_{measured}$$

Where P is a constant determined based on environmental observations or allocation requirements (P = 5).

Calculate the average value $(C_i/L_{ij})_R$ and maximum value $(C_i/L_{ij})_M$ of all parameters. Calculate PI_j using the following formula:

$$PI_j = \sqrt{\frac{(C_i/L_{ij})^2_M+(C_i/L_{ij})^2_R}{2}} \text{ .... (5)}$$

Results and Discussion

The Pollution Index (PI) is a scientific approach to quantitatively assess the water quality status of the Krueng Peusangan River. This study is generally conducted by taking water samples at several representative points along the river. The measured values of each parameter are compared with the river water quality standards based on Government Regulation No. 22 of 2021. The final result is an

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index score that classifies water quality into specific categories, ranging from meeting quality standards to heavily polluted. This information is important for stakeholders as a scientific basis for planning and implementing sustainable watershed management strategies.

The IP value during the dry season is in the “lightly polluted” category, and increases during the rainy season to “moderately polluted”(Table 2). This indicates that surface runoff and pollution load increase significantly during high rainfall (Pebiola et al., 2025). The difference between the dry season with an IP value in the “moderately polluted” category and the rainy season with a value in the “lightly polluted” category. This is due to the reduced water volume in the dry season, which increases pollutant concentrations (Istomi et al., 2025). Increased organic and bacteriological pollution downstream reflects the cumulative impact of domestic and industrial waste (Marselina et al., 2025).

Table 2. Pollution Index (IP) Recapitulation on Krueng Peusangan River

Year	IP Krueng Peusangan	Category
2016	5.829	Moderate
2017	7.864	Moderate
2018	8.025	Moderate
2019	3.378	Low
2020	8.898	Moderate
2021	7.270	Moderate
2022	1.920	Low
2023	1.444	Low
2024	1.243	Low
2025	1.316	Low

Sources: Aceh Environmental and Forestry Public Agency

Based on the graph and IP calculations, the water quality of the Krueng Peusangan River for the period 2016-2025 shows fluctuating dynamics (Figure 3). In 2016-2018, the water status was categorized as moderately polluted with an IP value of 5.829–8.025. A significant improvement occurred in 2019 with a status of slightly polluted (IP 3.378), but this was followed by an increase again in 2020 to the moderately polluted category (IP 8.898). A stable improvement trend has been observed from 2022 to 2025 with a slightly polluted status. This change in trend needs to be observed carefully, considering the change in the number of parameters for IP calculation from 21 parameters (2016-2021) to 9 parameters (2022-2025). As a comparison, IP calculations using 9 parameters consistently throughout 2016-2025 produced a more stable pattern. This indicates that the use of more comprehensive parameters, namely 21 parameters, can provide higher analytical resolution and sensitivity to fluctuations in various pollutants, so that simplifying the parameters has the potential to affect the interpretation of long-term pollution trends.

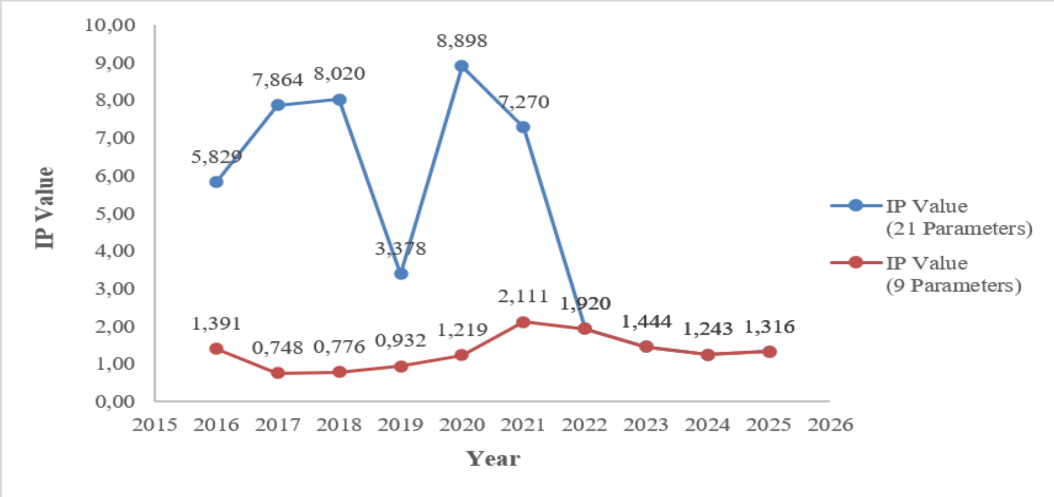


Figure 3. Pollution Index (IP) Krueng Peusangan River

The Pollution Index (PI) value for the entire river is 1.316, with variations between monitoring points (Table 3). The point with the highest PCI is located at the Iron Bridge on the Banda Aceh - Medan Road, Gampong Tingkeum Manyang (PCI = 1.496), while the lowest point is located upstream, namely the Iron Bridge at Ayun Kampung Meriah Jaya (PCI = 1.176). The IP values show an upward trend from upstream to downstream, indicating an accumulation of pollution load along the river flow. This condition requires regular monitoring to prevent further deterioration in quality.

Table 3. Pollution Index (IP) Calculation Result Year 2025

Location	Coordinate	IP/Point	Average IP	Category
Besi Ayun Bridge Kp. Meriah Jaya, Gajah Putih, Bener Meriah	N : 04° 49’ 01,03” E : 096° 42’ 25,03”	1.176	1,316	Low
Gp. Suka Tani, Juli, Bireuen	N : 04° 59’ 07,03” E : 096° 41’ 47,02”	1.293		
Besi Bridge Gp. Simpang Jaya, Juli, Bireuen	N : 05° 06’ 38,08” E : 096° 39’ 07,03”	1.291		
PDAM Intake Desa Beunyot, Juli, Bireuen	N : 05° 06’ 55,01” E : 096° 42’ 08,02”	1.249		
Besi Bridge Gp. Kubu, Peusangan, Bireuen	N : 05° 11’ 00,03” E : 096° 48’ 16,01”	1.392		
Besi Bridge Gp. Tingkeum Manyang, Kuta Blang, Bireuen	N : 05° 12’ 58,03” E : 096° 49’ 41,09”	1.496		

Test results show that the water quality of the Krueng Peusangan River deteriorates drastically from the dry season to the rainy season (Table 4). A sharp increase in several key parameters indicates the worsening condition of the river, with much higher levels of organic and nutrient pollution during the rainy season. This increase reinforces the suspicion of domestic or agricultural waste, which is rich in nutrients.

Table 4. Water Quality Monitoring Data Result Krueng Peusangan in 2025

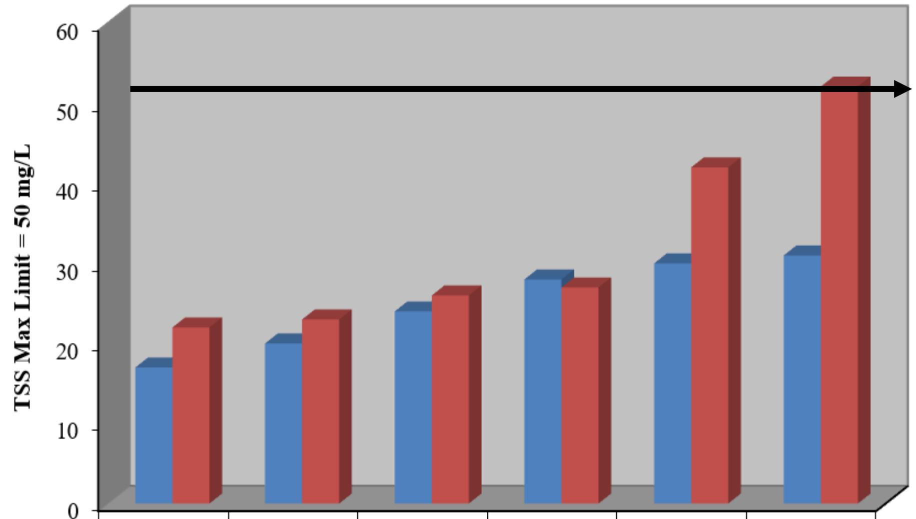
Location	Parameter												
	Temp. (°C)	pH	DHL (µs/cm)	TSS (mg/L)	DO (mg/L)	BOD (mg/L)	COD (mg/L)	Nitrate (mg/L)	Nitrite (mg/L)	NH_3-N (mg/L)	Chlorine(mg/L)	T-P (mg/L)	Fecal Coliform (MPN/100 ml)
Dry Season (25 Juni 2025)													
1	25.5	8.15	135	17	6.55	2.10	24.10	5.09	0.03	0.06	0.01	0.06	50
2	26.0	8.20	146	20	6.75	3.30	23.20	6.02	0.04	0.08	0.01	0.08	25
3	26.0	7.80	215	24	7.02	2.80	25.60	4.03	0.06	0.06	0.02	0.15	30
4	26.0	8.18	230	28	6.76	2.34	22.77	5.77	0.05	0.06	0.01	0.06	120
5	26.5	8.30	235	30	7.10	3.60	23.10	7.20	0.04	0.16	0.03	0.09	20
6	26.5	8.02	238	31	7.18	3.50	18.34	10.21	0.04	0.21	0.02	0.25	180
Rain Season (27 September 2025)													
1	25.0	8.20	130	22.0	6.82	2.27	18.78	2.48	0.030	0.06	0.01	0.35	200
2	25.0	7.60	142	23.0	6.70	2.82	20.0	1.10	0.030	0.06	0.01	0.36	150
3	26.0	7.55	210	26.0	7.20	2.40	24.20	3.20	0.040	0.08	0.01	0.38	180
4	28.0	7.82	222	27.0	7.82	2.17	20.11	1.14	0.030	0.06	0.01	0.39	650
5	26.5	7.2	230	42.0	7.50	3.20	28.00	4.20	0.036	0.21	0.04	0.35	600
6	29.0	7.18	235	52.1	7.18	3.06	21.44	10.2	0.070	0.22	0.02	0.38	1020
Max Limit	Dev 3	6.9		50	- 4	3	25	10	0.06	0.2	0.03	0.2	1000

Total Suspended Solids (TSS)

TSS is a solid that causes water turbidity, is insoluble, and cannot settle immediately (Figure 4). Suspended solids consist of particles that are smaller in size and weight than sediments. Suspended substances usually consist of organic and inorganic substances that float in water; physically, these substances cause water turbidity.

Excessive TSS blocks sunlight penetration, disrupts photosynthesis, and reduces dissolved oxygen, which has a negative impact on aquatic ecosystems (Nurbaya & Sari, 2023). Increased currents and activity downstream cause more suspended particles. Low TSS conditions are also influenced by the sampling time when community activity is not yet high (Izzah et al., 2024).

The highest TSS values during the rainy season are caused by high water discharge and increased turbidity, as well as sedimentation carried by rainwater into rivers, thereby increasing TSS values (Figure 4). Turbidity is caused, among other things, by mining activities around the Krueng Peusangan River.



	Location 1	Location 2	Location 3	Location 4	Location 5	Location 6
Phase I	17	20	24	28	30	31
Phase II	22	23	26	27	42	52

Figure 4. TSS Standard Quality Comparison

Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD)

BOD is the amount of oxygen required to oxidize organic substances by aerobic bacteria into inorganic substances, expressed as the amount of oxygen consumed by bacteria within a certain period of time and temperature. COD is the chemical oxygen demand for oxidation reactions of waste materials in water or the amount of oxygen required to oxidize organic substances in 1L of water sample. This COD value includes the oxygen demand for biochemical reactions. Thus, the COD value from the analysis will always have a higher numerical value than the BOD value.

BOD measures the oxygen required by microorganisms to break down organic matter in water. A high BOD value indicates organic pollution, such as from domestic waste. COD measures the oxygen required to oxidize organic and inorganic matter chemically. COD values are generally higher than BOD and indicate pollution from industrial and domestic waste. Both are inversely proportional to dissolved oxygen (DO) levels (Zaman et al., 2023).

The highest BOD values were found at location 1 and decreased along the river flow to location 6 (Figure 5). This decrease was caused by the dispersion and dilution of water. Although the values decreased, all BOD measurements exceeded the permissible threshold, indicating the presence of organic contamination in the river (Raymond Alex Ekemube et al., 2025). These high COD values (Figure 6) indicate high levels of organic matter in the water, which is dominated by domestic, industrial, and agricultural waste. High COD requires a lot of oxygen to break down organic matter, thereby potentially reducing dissolved oxygen (DO) levels and disrupting aquatic life due to the accumulation of pollutant loads from all inlets (Aristawidya et al., 2020).

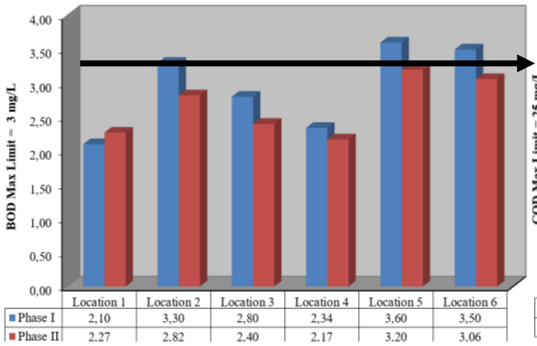


Figure 5. BOD Standard Quality Comp.

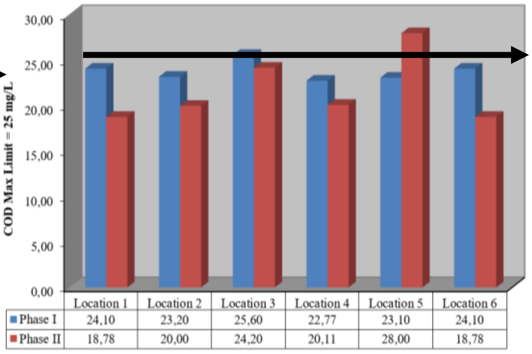


Figure 6. COD Standard Quality Comp.

High BOD values during the dry season are due to reduced river water volume, resulting in higher concentrations of organic waste, while high BOD values during the rainy season are caused by domestic waste runoff from local residents, waste from animal slaughterhouses flowing into rivers, and waste seepage from palm oil mills.

High COD values during the dry season are due to reduced water volume, which increases the concentration of chemical pollutants, while high COD values during the rainy season are caused by increased community activity along the river, such as domestic waste, palm oil mill waste, agricultural waste, plantation waste, and mining waste.

Nitrate (NO_3^-) dan Nitrit (NO_2^-)

Nitrification/denitrification Ammonia causes direct loading and decomposes oxidized organic nitrogen in a two-step process to form nitrite (NO_2^-) and nitrate (NO_3^-). This process requires oxygen, which can lead to oxygen depletion in the water. Under anaerobic conditions, nitrate can be reduced to nitrite, and nitrite is converted to free nitrogen through denitrification. The end result of the nitrification process is nitrate. Such problems often arise in agricultural areas as a source of nitrate (nonpoint source) originating from excessive use of fertilizers, resulting in nitrification from the source (point source).

Nitrate (NO_3^-) is the main form of nitrogen in water that comes from fertilizers, waste, and human activities. Excessive nitrate can trigger excessive algae growth. Nitrite (NO_2^-) is an intermediate form of nitrogen between ammonia and nitrate (Figure 7 and Figure 8). It is toxic because it can interfere with oxygen transport in the blood and is usually found in low concentrations in natural waters (Sitorus et al., 2023). High nitrate levels are caused by anthropogenic activities around river basins. Seasonal fluctuations also affect nitrate concentrations. As a primary nutrient, nitrates have the potential to trigger eutrophication if excessive, but based on pollution index values, nitrates are not a critical parameter causing pollution in this river (Prasetyo et al., 2025).

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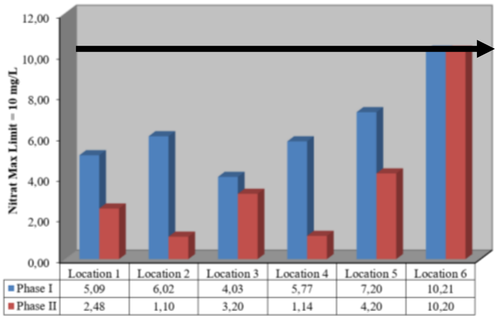


Figure 7. Nitrate Standard Quality Comp.

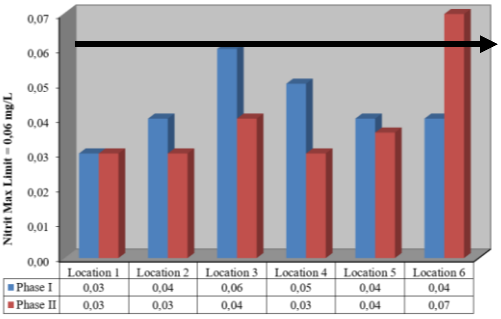


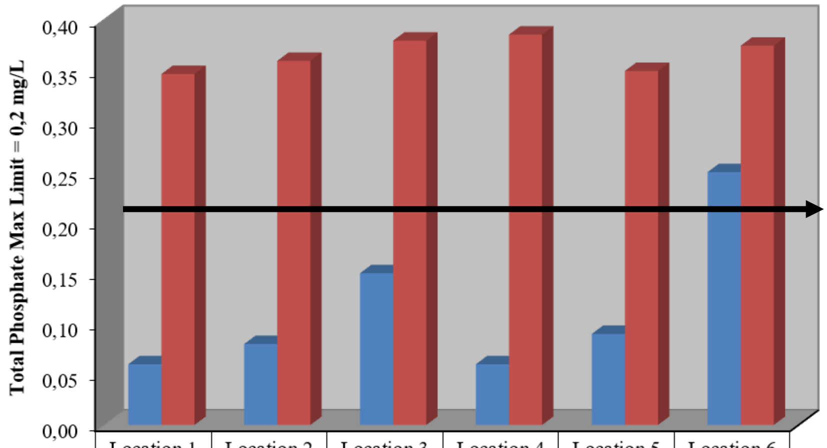
Figure 8. Nitrite Standard Quality Comp.

High nitrate levels during the dry season are due to water evaporation, which increases pollutant concentrations, while high nitrate levels during the rainy season originate from fertilizer runoff from agricultural land, community plantations, animal waste, and domestic waste around rivers that flow into the river. Meanwhile, high nitrite levels during the rainy season are due to surface water runoff carrying fertilizers from agricultural land, animal waste, and organic waste that undergoes incomplete bacterial decomposition.

Total Phosphate

Total phosphate is a key parameter that measures all forms of phosphorus in water (Figure 9). This compound acts as an important nutrient for the growth of algae and aquatic plants, but excess phosphate can cause eutrophication, which disrupts the balance of aquatic ecosystems. Phosphate is found in natural water or wastewater as orthophosphate, polyphosphate, and organic phosphate compounds. In wastewater, phosphate compounds can originate from residential, industrial, and agricultural waste. Polyphosphate can enter rivers through residential and industrial wastewater that uses detergents containing phosphate.

Phosphate (PO_4) is an important pollutant and a major nutrient in river water, generally originating from domestic waste and agricultural activities, which can contribute to a decline in water quality and is one of the factors that negatively affects the water quality index (Anwar et al., 2023; I. Ichwana et al., 2016). The main causes of phosphate are the entry of organic materials such as fertilizer residues from agriculture, detergents, garbage, and domestic waste from residential activities. Excess phosphate can trigger eutrophication or excessive water fertilization, which is characterized by algae blooms and disrupts the balance of the aquatic ecosystem (Aulia et al., 2024).



	Location 1	Location 2	Location 3	Location 4	Location 5	Location 6
Phase I	0,06	0,08	0,15	0,06	0,09	0,25
Phase II	0,35	0,36	0,38	0,39	0,35	0,38

Figure 9. Total Phospate Standard Quality Comparison

High total phosphate levels during the dry season are caused by reduced water volume and intensive decomposition of organic matter in the water, while high total phosphate levels during the rainy season are caused by surface water runoff carrying phosphate fertilizers from agricultural land, plantations, soil erosion, and domestic and industrial waste along the Krueng Peusangan river basin.

Conclusion

Based on the results of the Pollution Index (PI) analysis of water quality data for the Krueng Peusangan River, Bireuen Regency, for the period 2016–2025, it can be concluded that water quality status shows fluctuating dynamics with a significant improvement trend in the final years of observation. During the period 2016–2018 and in 2020, the water quality status was categorized as moderately polluted with a PCI value ranging from 5.829 to 8.898. Meanwhile, the 2019 and 2022–2025 periods showed an improvement in water quality with a slightly polluted status, as indicated by a decrease in the IP value to 1.243–3.378. It should be noted that in the 2022–2025 period, there was a change in the number of IP calculation parameters from 21 to 9 parameters, which directly changed the status to slightly polluted. Sensitivity analysis by applying 9 parameters consistently for the entire period (2016–2025) resulted in a slightly polluted status with varying values from upstream to downstream. The increase TSS, BOD, COD, nitrate, and phosphate parameters is strongly suspected to originate from anthropogenic activities along the river basin, such as domestic waste, agriculture, oil palm plantations, livestock farming, and mining. Seasonal differences also affect water quality, with the rainy season tending to increase pollution loads due to surface runoff and sedimentation.The decline in the Pollution Index (PI) in recent years, which is technically influenced by a reduction in the number of parameters used in the calculation, cannot yet be used as a valid indicator of the effectiveness of the pollution control measures that have been implemented. Therefore, this study recommends the need for consistency in monitoring parameters to ensure data validity and accuracy in interpreting long-term trends. These policy recommendations should include improving environmental monitoring strategies, targeted restoration programs in watersheds, and strengthening efforts to reduce pollution loads from both point sources and non-point sources.

Conflict of Interest

The individual contributions of the authors are as follows: Cut Hasriani and Ichwana Ramli: Conceptualization; Cut Hasriani and Suhendrayatna: Methodology, Software Saiful , Syaubari, Cut Hasriani : Writing- Original draft preparation. Ichwana ramli and Suhendayatna: Visualization, Investigation. Cut Hasriani, Ichwana Ramli and Suhendrayatna: Writing- Reviewing and Editing.

Regarding the use of technology, the authors confirm that no generative Artificial Intelligence (AI) tools were utilized for data analysis, substantive content generation, or the drawing of scientific conclusions. AI assistance was limited solely to improving the grammatical clarity and linguistic flow of the manuscript during editing and correction stage.

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