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The pollution status of Banten Bay waters based on physical and chemical parameters using CCME index

Ameliani Wardania Putri[1], *Sulistiono* Sulistiono[1*], *Ali* Mashar[1], and *Aliati* Iswantari[1]

[1]Aquatic Resources Management Department, Faculty of Fisheries and Marine Science, IPB University, Bogor, Indonesia, 16680

Abstract. Banten Bay are located in northern part of Cilegon City, Banten Province. The water quality of Banten Bay is influenced by both environmental and anthropogenic factors, which if not properly managed can lead to pollution. This study aimed to assess the pollution status of Banten Bay waters using the Canadian Council of Ministers of the Environment (CCME) Water Quality Index, both temporally and spatially. The observed parameters were temperature, turbidity, TSS, pH, dissolved oxygen, ammonia, nitrate, nitrite, and total phosphate. The results indicate that most parameters are within the seawater quality standards for marine life, with the CCME index classifying the pollution status as fairly good. However, nutrient enrichment from land-based activities and sediment input from river discharge have been identified as key factors influencing water quality. Potential pollution sources include domestic wastewater, agricultural runoff, and industrial effluents, which, if unmanaged, can deteriorate the water quality. This study highlights the need for sustainable waste management practices to maintain the ecological health of the bay.

1 Introduction

The Banten Bay, northern part of Cilegon City, Banten Province. Banten Bay has an area of 150 km^2 and relatively shallow water depth of approximately 7 m [1]. Various activities such as urban areas, fish farming, shrimp farming, sea transportation, recreation, and industry have been developed [2]. These activities (anthropogenic) can produce a variety of both liquid and solid waste discharges into the marine environment, causing a decrease in water quality and possible water pollution [3], due to appropriate environmental management [4]. Water pollution describes a decrease in water quality as a result of input from organisms, components, and materials which act as pollutant and results in water defunction [5].

Water quality is an indicator used to assess the extent of management measures [6]. The assessment includes several physical parameters (transparency, turbidity, temperature, total suspended solid, and total dissolved solid), chemical parameters (pH, salinity, dissolved oxygen, biochemical oxygen demand, chemical oxygen demand, ammonia, nitrate, nitrite, and total phosphate), and biological parameters (total coliform and plankton) [7]. Other

* Corresponding author: onosulistiono@gmail.com

factors affecting water quality include ocean currents, rainfall, and anthropogenic activities[8].

The pollution status of Banten Bay has been determined mostly in coastal areas such as the waters of Bojonegara Beach [9], Cengkok Beach [10], Kronjo coast of Tangerang Regency [11], water from Tanjung Pasir Coast [12], and water of Karangantu Coast [13]. Research related to the status of water pollution in the middle of the sea in the waters of Banten Bay in determining the status of water pollution has not been carried out. This study aimed to investigate the pollution status of Banten Bay based on physical and chemical parameters using the CCME WQI method temporally and spatially.

2 Materials and methods

2.1 Time and location

The research was carried out for seven months from July 2022 to January 2023 in the waters of Banten Bay, Banten Province. Observations and sampling of water samples were carried out at six locations representing the area starting from the outermost line of Karangantu Beach, Banten Province, to the waters of Panjang Island, Banten Province. Pollution status monitoring was conducted on different dates and months based on the season. A map of the research locations for the Banten Bay waters is presented in Figure 1.

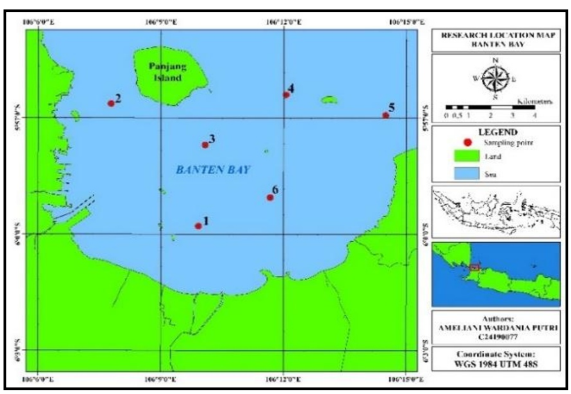

Fig. 1. Map of research locations in the waters of Banten Bay, Banten Province.

2.2 Data Collection

No ethics approval required in collecting data, since water quality data was collected directly from water in the field using purposive sampling to determine the location points for sampling. The parameters observed in situ were dissolved oxygen, pH and temperature were measured in situ. The samples were collected from each location using a vertical water sampler. The water sample was placed in a sample plastic bottle (250 ml in size) without preservatives and a sample plastic bottle (100 ml in size) with sulfuric acid (H_2SO_4) preservative was taken. Both types of plastic bottles are marked by its sampling point code and then put into a coolbox. Then, the water samples are taken to laboratory. In the meantime, water samples were put into a refrigerator so that the water content in the sample plastic bottle does not change before the analysis is done.

Unpreserved samples 250 ml were used to measure turbidity, Total Suspended Solid (TSS), nitrite, and total phosphate parameters, while 100 ml H_2SO_4 preserved samples were used to measure ammonia and nitrate parameters in the laboratory for ex situ observation using the APHA standard [14]. The samples were analyzed at the Macro Biology Laboratory, Department of Aquatic Resources Management and Environmental Laboratory, Department of Aquaculture, Faculty of Fisheries and Marine Sciences, Bogor Agricultural University.

Secondary data collection was carried out using a licensing procedure from IPB University to Meteorology, Climatology and Geophysics Agency (BMKG). The data collected was rainfall data and ocean currents from July 2022 to January 2023 from six research locations based on the Meteorology, Climatology and Geophysics Agency (BMKG) at Serang Station, Banten Province. The water quality parameters are listed in Table 1.

Table 1. Water quality parameters along with measuring instruments and analytic methods used.

Parameter	Units	Measuring instruments	Analytic methods
Physics			
Turbidity	NTU	Turbidity meter	Nephelometric method
Temperature	°C	Thermometer	Visual
Total Suspended Solid	mg/L	Balance sheet	Gravimetry
Chemical			
pH	-	pH meter	Electrometric method
Dissolved Oxygen	mg/L	DO meter	Visual
Ammonia (NH_3)	mg/L	Spectrophotometry	Phenate method
Total Phospate	mg/L	Spectrophotometry	Ascorbic acid method
Nitrate (NO_3)	mg/L	Spectrophotometry	Cadmium reduction method
Nitrite (NO_2)	mg/L	Spectrophotometry	Sulfanilamide method

2.3 Data Analysis

The data obtained were compared descriptively to those of seawater quality standards for Indonesia's marine biota using PPRI No.22 of 2021 in Appendix VIII [15]. The Canadian Council of Ministers of the Environment Water Quality Index (WQI) was used to determine the status of pollution in Banten Bay waters. This method was used to compare the water quality between the physical and chemical parameters of the waters and their pollution status in the research results. The pollution status of the Banten Bay waters was assessed using the CCME WQI method according to [16]. Data were processed using Microsoft Excel.

The Canadian Council of Minister of the Environment Water Quality Index (CCME WQI) method is one of the most effective methods for determining water quality status. It was created by the British Columbia Ministry of Environment, Lands and Parks and then developed through the Alberta Environment. In the CCME method, the determination of the types of parameters, quality standards, and time periods depends on the actual conditions that occur in each water area. This method evaluates the dynamics of changes in water quality at certain locations based on time-series data and can compare the overall water quality index at each location using water quality standards and the same variables [17].

The CCME WQI calculation consists of several formulas and variables that determine the status of water pollution in an area. These formulas and variables use values F1, F2, and F3. The value of each of these calculations has a different function, as explained below.

1. F1 (*Scope*) functions shows the percentage of parameters that do not meet quality standards (a parameter does not meet standards if at least in one test it does not reach the quality standard).

$$F_1 = \left(\frac{\textit{Number of failed parameters}}{\textit{Total number of parameters}}\right) \times 100 \quad (1)$$

2. F2 (*Frequency*) functions shows the percentage of parameters that do not meet quality standard in every tests (failed test).

$$F_2 = \left(\frac{\text{Number o failed tests}}{\text{Total number of tests}}\right) \times 100 \qquad (2)$$

3. F3 (*Amplitude*) functions show degree of difference of the test value to the quality standards. It only calculates parameters of each tests that do not comply with the standard. Results can be acquired by these steps:
   a) For parameters indicating increasing pollution during elevated value (value exceeds quality standard), establish excursion by this formula:

$$\text{Excursion} = \left(\frac{\text{Deviant test values}}{\text{Quality standards}}\right) - 1 \qquad (3)$$

   b) For parameters indicating increasing pollution during reduced value (value below quality standard, for example DO parameter), establish excursion by this formula:

$$\text{Excursion} = \left(\frac{\text{Quality standards}}{\text{Deviant test values}}\right) - 1 \qquad (4)$$

   c) Establish normalization of deviations value from the test results for each parameter that do not comply with the standard (non sampling error or nse) by this formula:

$$\text{nse} = \left(\frac{\sum_{i=1}^{n} \text{Excursion}_i}{\text{Number of test values}}\right) \qquad (5)$$

Determine the degree of difference of the test value to the quality standards to specify the inappropriateness of the water to the quality standards. This can be done as follows:

$$F_3 = \left(\frac{nse}{0{,}01nse + 0{,}01}\right) \qquad (6)$$

The level of water pollution can be calculated as the accumulated values of F1, F2, and F3, which were previously calculated using the following formula:

$$\text{CCME WQI} = 100 - \left(\frac{\sqrt{F1^2 + F2^2 + F3^2}}{1{,}732}\right) \qquad (7)$$

The water criteria used in the CCME WQI method consist of five class classifications. Each class had a certain range of values to determine the status of water pollution as presented in Table 2.

Table 2. Criteria for waters based on the CCME WQI.

CCME WQI Score	Water Criteria
95-100	Excellent
80-94	Good
60-79	Fair
45-59	Marginal
0-44	Poor

Source : Canadian Council of Minister of the Environment (CCME) (2001)

3 Results and discussion

3.1 Water Quality in Banten Bay

The results of the water quality parameter tests that have been analyzed both physically and chemically in the temporal waters are presented in Table 3.

Table 3. Minimum, maximum, average, and standard deviation values of physical and chemical parameters of water quality in Banten Bay during July 2022 – January 2023.

Parameters	Units	Quality standard	Month						
			Jul-22	Aug	Sep	Oct	Nov	Dec	Jan-23
Physics									
Turbidity	NTU	5	3,71-8,06*	4,48-9,17*	4,58-9,17*	4,89-7,16*	4,73-8,34*	4,24-9,03*	3,85-9,53*
			5,68±1,81	6,44±1,92	6,46±1,89	5,91±1,01	6,24±1,46	6,34±2,05	6,33±2,33
Temperature	°C	28-30	27,8-29*	29,3-30,8*	29-30	29,4-31*	28-30	27-28,8*	26,7-28,2*
			28,62±0,42	30,3±0,55	29,5±0,55	30,05±0,66	28,83±0,98	28,29±0,68	27,4±0,55
TSS	mg/L	20	5,5-10	7,8-13,4	9,1-10,3	9,2-12,4	8,1-11,3	9,5-12,9	8,2-13,8
			8,17±1,94	10,64±2,2	9,73±0,46	10,6±1,3	9,62±1,06	10,62±1,3	11,03±1,9
Chemical									
pH	-	7-8,5	7-7	7,51-7,84	7-7,57	7-7	7-7,32	7-7	7,11-7,19
			7±0	7,65±0,11	7,33±0,22	7±0	7,09±0,14	7±0	7,15±0,03
Dissolved Oxygen	mg/L	> 5	7,05-7,3	6,35-7,95	4,5-5,4*	5,6-8	7-8	6,9-7,8	7,6-9,1
			7,15±0,12	7,13±0,66	5,03±0,33	7,11±0,89	7,5±0,55	7,4±0,33	8,3±0,57
Ammonia (NH_3)	mg/L	0,3	0,24-0,43*	0,22-0,36*	0,12-0,2	0,07-0,1	0,03-0,09	0,03-0,12	0,02-0,06
			0,32±0,08	0,3±0,05	0,16±0,03	0,09±0,01	0,05±0,02	0,08±0,03	0,04±0,02
Total Phospate	mg/L	-	0,015-0,02	0,01-0,025	0,002-0,01	0,001-0,008	0-0,006	0,009-0,02	0,004-0,02
			0,02±0,003	0,02±0,01	0,01±0,002	0,004±0,003	0,002±0,002	0,02±0,004	0,01±0,005
Nitrate (NO_3)	mg/L	0,06	0,03-0,05	0,03-0,07*	0,01-0,06	0,02-0,05	0,02-0,05	0,012-0,05	0,021-0,04
			0,04±0,006	0,04±0,01	0,04±0,017	0,035±0,013	0,033±0,011	0,03±0,015	0,03±0,007
Nitrite (NO_2)	mg/L	-	0,03-0,08	0,03-0,12	0,05-0,25	0,03-0,2	0-0,15	0,013-0,05	0-0,1
			0,05±0,02	0,09±0,04	0,14±0,08	0,12±0,07	0,07±0,06	0,03±0,01	0,03±0,04

* Parameter values are not in accordance with the quality standard

Most of the physical and chemical parameters per month are not within the range of the quality standards, such as turbidity, temperature, ammonia, nitrate, and dissolved oxygen. The values vary: turbidity and TSS parameters were at the highest mostly during the rainy season (October 2022 – January 2023), while other parameters mostly during the dry season (July-September 2022). The highest average of overall water quality parameters values was found in the temperature parameter (by 30.3°C) during August 2022, while the lowest value was found in the total phosphate parameter (by 0.002 mg/L) during November 2022.

The minimum, maximum, average and standard deviation of physical and chemical parameters and their quality standards for marine biota is spatially presented in Table 4.

Table 4. Minimum, maximum, average, and standard deviation values of physical and chemical parameters of water quality in Banten Bay at each observation location.

Parameters	Units	Quality standard	Station					
			1	2	3	4	5	6
Physics								
Turbidity	NTU	5	7,16-9,17*	6,11-7,17*	3,96-4,98	3,71-4,89	4,83-5,31*	6,12-9,53*
			8,4±0,84	6,88±0,38	4,56±0,35	4,42±0,49	5,09±0,2	7,83±1,07
Temperature	°C	28-30	26,7-31*	27,6-30,1*	27,7-30,7*	26,9-30,3*	28-30,6*	27,3-30,8*
			28,82±1,67	29,2±0,96	28,97±1,1	28,79±1,11	29,04±0,94	29,17±1,24
TSS	mg/L	20	6,5-13,4	7,5-10,3	9-12,6	5,5-11,3	9,47-11,7	8,1-13,8
			10,21±2,15	9,12±0,97	10,61±1,38	9,19±1,98	10,3±0,79	10,91±2,09
Chemical								
pH	-	7-8,5	7-7,51	7-7,84	7-7,62	7-7,63	7-7,64	7-7,63
			7,16±0,19	7,17±0,31	7,19±0,27	7,16±0,25	7,2±0,29	7,16±0,25
Dissolved Oxygen	mg/L	> 5	5,2-7,95	5,4-9,1	4,5-8,1*	5,1-7,8	5,2-8,5	4,8-8,7*
			7,11±0,91	7,11±1,11	7,06±1,27	6,55±0,93	7,34±1,07	7,36±1,23
Ammonia (NH_3)	mg/L	0,3	0,03-0,31*	0,03-0,28	0,03-0,43*	0,02-0,36*	0,06-0,29	0,03-0,38*
			0,13±0,11	0,14±0,1	0,18±0,16	0,15±0,13	0,14±0,09	0,15±0,14
Total Phospate	mg/L	-	0-0,025	0,001-0,019	0,001-0,019	0,003-0,022	0-0,018	0,003-0,022
			0,012±0,009	0,009±0,007	0,011±0,007	0,012±0,006	0,008±0,007	0,013±0,009
Nitrate (NO_3)	mg/L	0,06	0,03-0,07*	0,014-0,05	0,02-0,04	0,01-0,05	0,031-0,05	0,02-0,05
			0,05±0,01	0,03±0,01	0,03±0,01	0,03±0,01	0,04±0,01	0,03±0,01
Nitrite (NO_2)	mg/L	-	0,05-0,25	0,005-0,12	0,01-0,17	0-0,21	0-0,05	0-0,1
			0,14±0,07	0,07±0,04	0,09±0,06	0,09±0,08	0,02±0,02	0,05±0,04

* Parameter values are not in accordance with the quality standard

The analysis of water quality parameter reveals spatial variations across the six sampling stations. Turbidity is notably higher at Stations 1 and 6, exceeding the quality standard of 5 NTU. This suggests increased sedimentation activity in these areas, likely influenced by river inflows or anthropogenic factors. Water temperature remains relatively consistent across all stations, ranging from 26.7°C to 31°C, which falls within the acceptable range of 28-30°C. Total Suspended Solids (TSS) fluctuate between stations, with the highest concentrations observed at Station 5 and 6. Dissolved Oxygen (DO) levels show a decline at certain stations, particularly Station 3 and 5, where values fall below the minimum standard of 5 mg/L. This indicates a potential risk of hypoxic conditions, which could negatively impacts aquatic life. pH levels remain stable across all stations, ranging from 7 to 7.84, within the acceptable range. Nitrate (NO_3) and nitrite (NO_2) concentrations are within permissible limits across all stations, although minor variations are observed. In contrast, ammonia (NH_3) levels are elevated at certain stations, suggesting potential contamination from domestic or industrial sources. Overall, water quality appears to deteriorate in some stations, particularly in terms of DO and turbidity, while better conditions are found at stations farther from pollution sources or river inflows. These spatial variations highlight the influence of environmental factors such as depth, anthropogenic activities, and nutrient inputs on water quality in the study area.

3.2 Water Pollution Status

The status of water pollution from July 2022 to January 2023 can be determined using the Canadian Council of Minister of the Environment Water Quality Index (CCME WQI) method. Analysis using the CCME method in Banten Bay waters from July 2022 to January 2023 showed varying criteria. The results of the overall analysis using the monthly CCME method are shown in Figure 2.

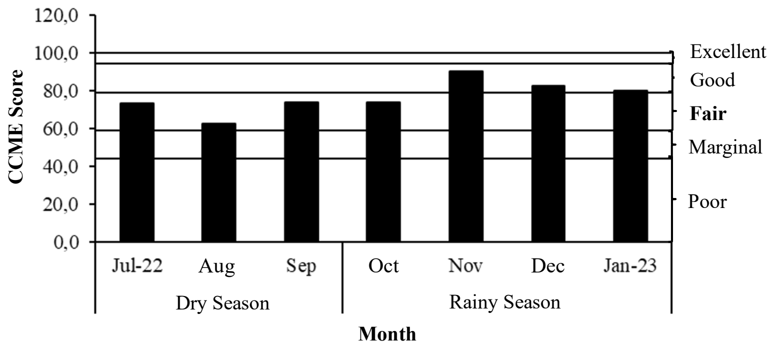

Fig. 2. Banten Bay water pollution status per month.

The highest pollution level in Banten Bay waters was in August 2022 during the dry season at 62.34 categorized as fairly good, while the lowest was in November 2022 during the rainy season at 89.88 classified as good status. During the rainy season, water pollution tend to be good due to the flushing of pollution loads in the sea because of the currents and tides that form are quite strong in this season. The results of the overall analysis of the CCME method from July 2022 to January 2023 show that the condition status of the Banten Bay waters is in the criteria of sufficiently good, although there is tendency to more adequate status during rainy season.

The overall results of the analysis of the pollution status data in Banten Bay waters using the CCME method for each observation location (Stations 1 – 6) are presented in Figure 3.

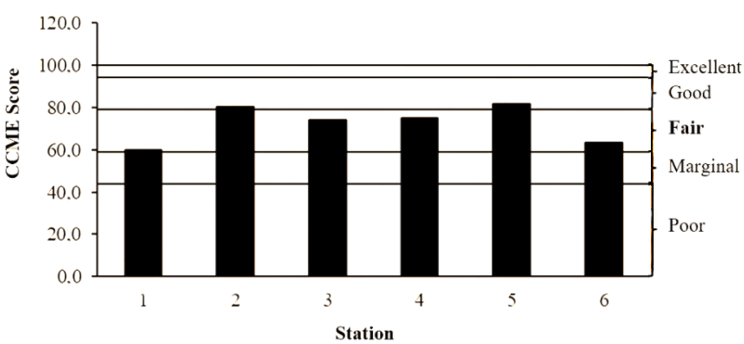

Fig. 3. Banten Bay water pollution status per station.

Spatial analysis shows that the highest pollution level occurred at Station 1 with a score of 59.95, categorized as fairly good status, while the lowest occurred at Station 5 with a score of 81.56, categorized as good status. Station 1 and 6 fall in the fairly good category because those locations are close to the estuaries of the Karangantu and Kemayungan-Linduk rivers, where pollution load from the river easily accumulates in these areas. Meanwhile, station 2-5 is in the middle of the sea, hence smaller pollution load since it was thinned by the distribution of currents and ocean waves from the Banten Bay to the high seas of Northern Java. The results of the overall analysis of the CCME method at Stations 1 – 6 show that the condition status of Banten Bay waters is sufficiently good.

3.3 Discussion

All analyzed data are acquired directly on the sampling location and thus available within the paper. Based on temporal and spatial analysis, the overall water quality of Banten Bay is sufficiently good. Some of the parameters such as turbidity, temperature, ammonia, dissolved oxygen, and nitrate are not within quality standards. According to Juniardi *et al*. [18], in 2019 the conditions of Banten Bay waters, which were analyzed using the CCME method, showed that these waters were still in the fair good category, because several water quality parameters studied were still in accordance with the quality standards (safe category). This is also supported by research from Wardani *et al*. [19] which shows the same results as research on the pollution status of Banten Bay waters from July 2022 to January 2023, where the pollution status of Banten Bay waters is in the fair good category. The input of nutrients, organic matter, and heavy metals in Banten Bay waters is still relatively low compared to Jakarta Bay and its surroundings; therefore, the pollution status of the waters in the bay is still in the fair good category [20].

Research using the CCME WQI method shows that there is consistency in the results of the water pollution status from time to time at each station. This is supported by research from Eljaiek-Urzola *et al*. [21] in the Caribbean Sea and El-Nemr *et al*. [22] in the waters of Red Sea Coast, Egypt which states the pollution status results are quite the same and fluctuate slightly every year. According to previous research from Akhtar *et al*. [23], the CCME method is quite effective and specific for determining the status of water pollution in an area.

Pollution level differs between months and locations. During the dry season (July-September 2022), higher levels of pollution was detected since higher amounts of industry, agricultural, and domestic runoff were dumped into sea. However, a slower pace of agitation and rinsing occurred during the season since low sea current (0,04-0,28 m/2) prompted the pollution burden to settle at the location. Whereas during the rainy season (October 2022-January 2023), a faster pace of agitation and rinsing occurred with sea current of 0,28-0,37 m/s which caused the pollution burden to be easily diluted so as to reduce pollution level to low category [24]. Spatially, station 1 and 6 fall into fairly good category, which are higher in terms of pollution compared to other stations since its location is adjacent to the estuaries of Karangantu and Kemayungan-Linduk rivers which results in higher accumulation of pollution burden by industry, agricultural, and also domestic organic and inorganic waste carried by river runoff at the stations.

Overall, pollution level at Banten Bay waters is influenced the most by turbidity. Turbidity values that exceed the quality standard can be caused by high rainfall, large amount of organic matter, substrate runoff from rivers and land into the water column, high sedimentation rates, wind direction and speed, as well as patterns of currents and tides. Increasing turbidity levels in waters can also cause a decrease in the concentration of dissolved oxygen [25]. During the rainy season, turbidity and TSS values tended to increase compared to those observed during the dry season [26].

However, ammonia and nitrate may also have its effects to increased water pollution. Levels of ammonia (NH_3) that do not reach quality standards are caused by influx of several sources of ammonia, such as the breakdown of organic nitrogen (urea and protein), decomposing inorganic nitrogen in waters, and the decomposition of organic matter by microbes and fungi from plants and biota or dead aquatic animals [27]. Nitrate (NO_3) levels that do not reach quality standards are caused by several factors, namely temperature and dissolved oxygen. Higher temperatures cause lower levels of nitrate in waters [28]. Nitrates also play an important role in marine biogeochemical cycles, and their presence must still be controlled according to quality standard thresholds [29]. Dissolved oxygen levels lower than the quality standard can be caused by increasing concentrations of ammonia and turbidity levels in the oceans, as well as the process of decomposing organic matter in the region [30].

It is clear that several water quality parameters do not comply with quality standards. This could be caused by several factors, such as abrasion, dynamics of sediment transport, conversion of mangrove land into ponds, development of industrial areas, increase in beach construction by years, and illegal sand mining by local residents and private parties surrounding the bay [24]. Pollution in water bodies can occur because of the input of waste and other foreign substances into water bodies, causing changes in water quality [31]. The greatest influence of water pollution in Banten Bay is from anthropogenic factors related to domestic and industrial activities. Allowing this to continue, and it can cause an increase of pollution status in Banten Bay which is dangerous for the survival of humans and aquatic biota around the aquatic ecosystem. Biota contaminated from these waters can poison the human body if consumed continuously [32].

Therefore, there is a need for recommendations to sustainable management of Banten Bay waters based on their pollution status. Recommendations for the management of Banten Bay waters can be carried out in various ways, including having an appropriate wastewater treatment installation system for anthropogenic activities around Banten Bay waters to control the input of waste into these waters. This effort aims to reduce the levels of ammonia, nitrate, nitrite, and total phosphate, which are not in accordance with the quality standards, and can improve the status of pollution in Banten Bay waters. In addition, it is necessary to coordinate, monitor, and evaluate activities between related stakeholders so that the management of Banten Bay waters can be carried out optimally and create a sustainable Banten Bay waters ecosystem [33].

Monitoring and managing the input of garbage and waste originating from the waters of Banten Bay is necessary to maintain the quality of the waters in good condition, especially for the parameters of temperature, dissolved oxygen, and pH, which are often used in the survival of marine biota [34]. The management of these areas can also be carried out by conducting reviews and making appropriate policies related to development efforts around coastal areas (especially settlements and industries) so that the levels of turbidity, TSS, and other organic pollution loads that accumulate in the area can always be controlled so that they are always in good condition (according to quality standards) to create a sustainable Banten Bay aquatic ecosystem [35].

4 Conclusion

The water quality status of Banten Bay, as determined by average concentration, was generally suitable for marine biota. However, temporal and spatial analysis revealed instances where specific parameters fell into categories unsuitable for marine life. The pollution status of Banten Bay waters assessed using the CCME method shows that the water conditions are fairly good or in lightly polluted category. Overall, the primary parameters identified to contributing the pollution status of Banten Bay is turbidity. It is caused by various activities surrounding the bay such as industrial, agricultural, and domestic activities that can contribute to increased sedimentation and pollutant loads influenced by river inflows. Seasonal variations and local oceanographic dynamics, such as currents and tides, also affect the distribution of pollution in this area. Pollution control in Banten Bay requires continuos water quality monitoring, strict regulations on industrial and domestic waste disposal, as well as conservation and coastal ecosystem rehabilitation strategies. Collaboration between the government, local communities, and the industrial sector is essential to ensure sustainable water management and maintain the ecological balance of Banten Bay.

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