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SEAWATER QUALITY ANALYSIS IN THE JETTY FOR THE FUEL TERMINAL OPERATIONAL

Analisis Kualitas Air Laut di Sekitar Jetty Penimbunan Bahan Bakar Minyak

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ABSTRACT

Coastal areas are dynamic ecosystems that hold strategic value both ecologically and economically. The presence of infrastructure, such as jetties, has the potential to cause a decline in seawater quality in coastal regions. This study aims to determine the seawater quality and the Pollution Index based on physical, chemical, and microbiological parameters over a two-year period around a jetty used for fuel termina operations. The research was conducted in the sea water of Ulakan Village, Manggis District, Bali Province. The research method involved in-situ measurements of several parameters and the collection of seawater samples for laboratory analysis. The laboratory test results were then used to determine the seawater quality status using the Pollution Index (PI), based on the quality standards for marine life. The results showed that the seawater quality around the jetty for fuel storage operations exhibited significant dynamics in physical, chemical, and microbiological parameters throughout the period from 2024 to early 2025. Parameters that did not meet the established quality standards were water clarity in July 2024, as well as Copper (Cu) at locations AL2 and AL3 in January 2025. The Pollution Index analysis concluded that while all locations were initially in 'Good' condition in January 2024 with a value of 0.62, a degradation in quality occurred, moving into the 'Slightly Polluted' category in July 2024 with values ranging from 1.02 to 1.03. By January 2025, only location AL1 showed recovery in quality with an index of 0.59, demonstrating a better environmental recovery capacity in that area. Meanwhile, AL2 and AL3 experienced an increase in the index to 2.15 and 1.98, respectively, remaining in the 'Slightly Polluted' category.

Keywords: Fuel Terminal, Jetty, Pollution Index, Sea Water Quality

ABSTRAK

Wilayah pesisir merupakan ekosistem dinamis yang memiliki nilai strategis baik secara ekologis maupun ekonomi. Keberadaan infrastruktur seperti dermaga khusus (jetty) dapat berpotensi menyebabkan penurunan kualitas air laut di daerah pesisir. Penelitian ini bertujuan untuk mengetahui kualitas air laut dan Indeks Pencemaran berdasarkan dari parameter fisik, kimia dan mikrobiologi pada 2 tahun di sekitar operasional jetty pada kegiatan operasional penimbunan bahan bakar minyak. Penelitian ini dilaksanakan di perairan Desa Ulakan, Kecamatan Manggis, Provinsi Bali. Metode penelitian yaitu mengukur secara insitu terhadap beberapa parameter dan mengambil sampel air laut dan dianalisis di laboratorium. Hasil uji laboratorium kemudian ditentukan status mutu air lautnya menggunakan Indeks Pencemaran (IP) berdasarkan ambang baku mutu untuk kehidupan biota laut. Hasil penelitian yang diperoleh adalah kualitas air laut di sekitar Jetty untuk operasional penimbunan bahan bakar minyak menunjukkan dinamika signifikan pada parameter fisik, kimia, dan mikrobiologi sepanjang periode 2024 hingga awal 2025. Parameter yang tidak memenuhi baku mutu yang ditetapkan adalah kecerahan pada Juli 2024, serta Tembaga (Cu) di AL2 dan Al3 pada Januari 2025. Analisis Indeks Pencemaran menyimpulkan bahwa meskipun seluruh lokasi awalnya pada Januari 2024 pada kondisi baik yaitu 0,62, terjadi degradasi kualitas menjadi kategori "Tercemar Ringan" pada Juli 2024 dengan nilai 1,02-1,03. Pada Januari 2025, hanya lokasi AL1 menunjukkan pemulihan kualitas menjadi indeks 0,59, yang memperlihatkan daya pulih lingkungan yang lebih baik di area tersebut. AL2 dan AL3 mengalami kenaikan indeks menjadi 2,15 dan 1,98 sehingga masih "Tercemar Ringan".

Kata Kunci: Fuel Terminal, Indeks Pencemaran, Jetty, Kualitas Air Laut

INTRODUCTION

Coastal areas are dynamic ecosystems with strategic value both ecologically and economically. Ecologically, coastal areas provide habitat for marine life, while economically, they serve as locations for various human activities and infrastructure development. However, their close connection to land makes coastal waters highly vulnerable to anthropogenic pressures, which can trigger water quality degradation.

The presence of infrastructure such as dedicated jetties for the loading and unloading of vital commodities like fuel oil (BBM) is a crucial pillar in the national energy distribution chain. However, the intensity of operations around jetties can exert persistent anthropogenic pressure on the health of the surrounding aquatic environment.

Jetty operations are accompanied by various forms of pollution. Marine pollution analysis is crucial and complex due to the diversity of pollution types, sources, impacts, and characteristics. This pollution can negatively impact both natural ecosystems and populations (Nitonye & Uyi, 2018). The impact of declining seawater quality can extend to sensitive ecosystems in these locations, such as coral reefs. High sedimentation and water pollution lead to a decrease in coral cover and disrupt the balance of the marine ecosystem around jetties. This indicates that the pollution load from human activities is directly correlated with the degradation of marine biodiversity.

Physical and chemical parameters are key indicators in determining the health of a body of water. Fluctuations in physical parameters such as temperature, turbidity, and Total Suspended Solids (TSS), as well as chemical parameters such as pH, Dissolved Oxygen (DO), and oil and grease content, can reflect the level of environmental disturbance. The Pollution Index (PI) can be used to provide a comprehensive overview of environmental status. The Pollution Index method, stipulated in national regulations, allows researchers to classify water quality status into categories of meeting quality standards, lightly, moderately, or heavily polluted.

This study aims to determine seawater quality and the Pollution Index based on physical, chemical, and microbiological parameters around a jetty operation during fuel oil storage operations. This study took samples from Ulakan Village, Manggis District, Bali Province.

RESEARCH METHODS

The research was conducted in January 2025 at one of Indonesia's fuel terminals, located in the waters of Ulakan Village, Manggis District, Bali Province. The seawater sampling locations are shown in the following image.

Figure 1. Sampling Location Map

The sampling location is at the coordinate point:
Sea water 1 (AL1) = S:08°30'47,31" E:115°30'48,48"
Sea water 2 (AL2) = S:08°30'54,14" E:115°30'44,13"
Sea water 3 (AL3) = S:08°30'45,40" E:115°30'39,57"

The research materials used were sample bottles, HNO_3, HCl, distilled water, stationery, and seawater samples from three locations. The equipment used included a pH meter, thermometer, measuring pipette, camera, ice box, and GPS (Global Positioning System).

Seawater samples were collected using 500 ml polyethylene containers from a water column with a depth of 30–50 cm. This depth was chosen to obtain an accurate representation of the vertical homogeneity of pollutant dispersion while also avoiding data anomalies due to surface effects. The samples were then acidified by adding a few drops of HNO_3 until the pH reached <2. This preservation step is crucial for maintaining the stability of the metal phase by preventing oxidation, precipitation, and adsorption of materials on the container walls. All samples were then stored in an ice box to maintain temperature stability during transport to the laboratory.

The data obtained consisted of laboratory test results and direct field measurements (in situ) for each water quality parameter, which were then subjected to descriptive data analysis. This process is carried out by comparing each parameter value with the seawater quality standards based on Government Regulation of the Republic of Indonesia Number 22 of 2021 concerning the Implementation of Environmental Protection and Management, Appendix VII, water quality standards for marine biota, specifically for marine life.

Furthermore, laboratory test results then determine the seawater quality status based on the quality standard threshold for marine life. The Pollution Index (IP) is determined using the formula:

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

Lij : concentration of water quality parameters specified in the designated quality standards (j)
Pij : pollution index for its intended use (j)
Ci : concentration of water quality parameters in the field
(Ci/Lij)M : maximum Ci/Lij value
(Ci/Lij)R : average Ci/Lij values

The level of pollution is obtained by linking it using the pollution index criteria based on the Decree of the Minister of State for the Environment Number 115 of 2003 concerning the Determination of Water Quality Status, namely:
0≤PIj≤1,0 : Meets quality standards (good condition)
1,0<PIj<5,0 : Lightly contaminated
5,0<PIj≤10 : Moderately contaminated
PIj>10 : Heavily polluted

Table 1. Analysis methods for each seawater quality parameter

No	Parameter	Analysis Type	Specification of Analysis Tools/Methods
1	Brightness	Insitu	IKM-EI-SML-11 (Visual Check)
2	Total Suspended Solids (TSS)	Laboratory	SM APHA 2540 D, 2017
3	Temperature	Insitu	Thermometer digital
4	pH	Insitu	pH meter
5	Total Ammonia (NH_3-N)	Laboratory	SNI 19-6964.3-2003
6	Sulfide	Laboratory	SNI 19-6964.4-2003
7	Hydrocarbon Petrolium Total	Laboratory	IKM-EI-SML-40 (FTIR)
8	Total Phenol Compounds	Laboratory	APHA 5530 C-2017
9	Surfactants	Laboratory	APHA 5540 C-2017
10	Oils and Fats	Laboratory	IKM-EI-SML-40 (*FTIR*)
11	Mercury (Hg)	Laboratory	SNI 19-6964.2-2003
12	Kadmium (Cd)	Laboratory	APHA 3113 B-2017
13	Copper (Cu)	Laboratory	APHA 3113 B-2017
14	Lead (Pb)	Laboratory	APHA 3113 B-2017
15	Seng (Zn)	Laboratory	APHA 3111 B-2017
16	Total Coliform	Laboratory	IKM-EI-SML-30 (*Membrane Filter*)

RESULT

Marine waters, which serve as habitats for biota and support various human activities, must meet quality standards, both physically, chemically, and biologically. If the concentration of water quality parameters exceeds the established maximum threshold, the waters are categorized as polluted. The following is a summary of laboratory test results and field measurements compared with secondary data from 2024, presented in a table.

Table 2. Seawater Quality Test Results in the Study Area, Seawater Location 1

No	Parameter	Unit	AL1			Quality standards *
			2024		2025	
			January	**July**	**January**	
1	Brightness	M	7	3	7	Coral > 5
2	Total Suspended Solids (TSS)	mg/L	<7,1	10	15	Coral 20
3	Temperature	˚C	29,7	32,3	31,9	Alami, Coral 28-30
4	pH	-	7,86	7,61	7,44	7-8.5
5	Total Ammonia (NH_3-N)	mg/L	<0,075	0,05	<0,05	0,3
6	Sulfida	mg/L	<0,018	0,0002	0,0003	0,01
7	Hydrocarbon Petrolium Total	mg/L	<0,28	0,013	<0,013	0,02
8	Total Phenol Compounds	mg/L	<0,002	<0,002	<0,002	0,002
9	Surfactants	mg/L	<0,09	0,26	<0,1	1
10	Oils and Fats	mg/L	<0,28	<0,28	<0,28	1
11	Mercury (Hg)	mg/L	0,0006	0,00011	0,00055	0,001
12	Cadmium (Cd)	mg/L	<0,00018	<0,0005	<0,0005	0,001
13	Copper (Cu)	mg/L	<0,001	<0,001	<0,001	0,008
14	Timbal (Pb)	mg/L	<0,0015	<0,003	<0,003	0,008
15	Seng (Zn)	mg/L	<0,02	<0,0015	<0,015	0,05
16	Total Coliform	Jml/100 mL	50	170	250	1000

Table 3. Results of Seawater Quality Tests in the study area of Seawater location 2

No	Parameter	Unit	AL2			Quality standards *
			2024		2025	
			January	July	January	
1	Brightness	M	7	3	7	Coral > 5;
2	Total Suspended Solids (TSS)	mg/L	<7,1	12	17	Coral 20;
3	Temperature	˚C	29,6	32,6	31,8	Alami, Coral 28-30;
4	pH	-	7,87	7,66	7,5	7-8.5
5	Total Ammonia (NH_3-N)	mg/L	<0,075	<0,05	<0,05	0,3

No	Parameter	Unit	AL2			Quality standards *
			2024		2025	
			January	July	January	
6	Sulfida	mg/L	<0,018	0,0002	0,0003	0,01
7	Hydrocarbon Petrolium Total	mg/L	<0,28	0,013	<0,013	0,02
8	Total Phenol Compounds	mg/L	<0,002	<0,002	<0,002	0,002
9	Surfactants	mg/L	0,22	0,21	<0,1	1
10	Oils and Fats	mg/L	<0,28	<0,28	<0,28	1
11	Mercury (Hg)	mg/L	0,0006	0,0001	0,00026	0,001
12	Cadmium (Cd)	mg/L	0,00028	<0,0005	<0,0005	0,001
13	Copper (Cu)	mg/L	<0,001	<0,001	0,02	0,008
14	Timbal (Pb)	mg/L	<0,0015	<0,003	<0,003	0,008
15	Seng (Zn)	mg/L	<0,02	<0,0015	<0,015	0,05
16	Total Coliform	Jml/100 mL	190	200	130	1000

Table 4. Results of Seawater Quality Tests in the study area of Seawater location 3

No	Parameter	Unit	AL3			Quality standards *
			2024		2025	
			January	July	January	
1	Brightness	M	7	3	7	Coral > 5;
2	Total Suspended Solids (TSS)	mg/L	<7,1	10	14	Coral 20;
3	Temperature	˚C	29,6	32,9	31,9	Alami, Coral 28-30;
4	pH	-	7,81	7,69	7,49	7-8.5
5	Total Ammonia (NH_3-N)	mg/L	<0,075	<0,05	<0,05	0,3
6	Sulfida	mg/L	<0,018	0,0002	0,0002	0,01
7	Hydrocarbon Petrolium Total	mg/L	<0,28	0,013	<0,013	0,02
8	Total Phenol Compounds	mg/L	<0,002	<0,002	<0,002	0,002
9	Surfactants	mg/L	<0,09	0,42	<0,1	1
10	Oils and Fats	mg/L	<0,28	<0,28	0,39	1
11	Mercury (Hg)	mg/L	0,00059	0,0008	0,00014	0,001
12	Cadmium (Cd)	mg/L	0,0006	<0,0005	<0,0005	0,001
13	Copper (Cu)	mg/L	<0,001	<0,001	0,018	0,008
14	Timbal (Pb)	mg/L	<0,0015	<0,003	<0,003	0,008
15	Seng (Zn)	mg/L	<0,02	<0,0015	<0,015	0,05
16	Total Coliform	Jml/100 mL	30	40	910	1000

DISCUSSION

Physical Parameters

Water clarity is an indicator of the ability of sunlight to penetrate the water column to a specific depth. This parameter is significantly influenced by the concentration of suspended material, dissolved substances, and water color characteristics, which affect light transmission (Ijabah, 2016).

Based on measurement data, there have been significant fluctuations in water clarity at the locations over the past year. Water clarity is a vital indicator of the health of aquatic ecosystems, especially in the presence of nearby coral reefs. All three locations showed similar levels of water clarity at each measurement time. In January 2025, all three locations met the water clarity standard of over 5 meters, but this decreased to 3 meters in July 2025. High water clarity values are influenced by clear weather conditions, which allow optimal sunlight penetration into the water column. Conversely, low water clarity is caused by high concentrations of suspended solids, which act as physical barriers to sunlight transmission (Sari et al., 2024). Jetty activities, such as fuel tanker maneuvers, can trigger the resuspension of seabed sediments, reducing the intensity of sunlight entering the water column.

The TSS parameter for each measurement at each point still meets the quality standard of below 20 mg/L. The increase in TSS in the jetty area is closely related to loading and unloading activities and sediment runoff from the onshore fuel storage area, carried by rainwater into the sea. Total Suspended Solids (TSS) are particulate matter that float and are insoluble in water. Increased TSS levels will decrease water clarity. Ecologically, high levels of suspended solids limit sunlight penetration, inhibiting primary productivity (phytoplankton photosynthesis), thereby reducing dissolved oxygen levels and directly disrupting aquatic organisms (Haposan Purba et al., 2018).

Seawater temperatures fluctuated between 29.6°C and 32.9°C, with the highest temperature occurring in July 2024. This temperature variation is generally influenced by seasonal factors and sunlight intensity. Test results indicate that the temperature remains within the natural range and meets the quality standards for coral reefs.

Chemical Parameters

The pH values at the three monitoring locations showed a stable trend with a slight decrease, from 7.81 to 7.87 in January 2024 to 7.44-7.5 in January 2025. Current test results remain within the standard range of 6.5-8.5, indicating that the water's chemical conditions are still ideal for biota.

Several measured chemical parameters showed low values, even below the detection limits of laboratory test equipment. Total ammonia levels at all sampling points were very low, ranging from <0.05 to 0.075 mg/L, well below the threshold of 0.3 mg/L. High levels of ammonia in the sea often originate from residential waste and the waste products of living organisms in the form of urine. Ammonia compounds can also form naturally through two mechanisms: as metabolic residues of marine animals and as the end result of the decomposition of organic matter assisted by bacteria (Hamuna et al., 2018). In addition to ammonia, sulfide concentrations were also recorded at very stable low values, below the quality standard, ranging from <0.018 to 0.0003 mg/L at all three locations.

As a fuel storage area, the TPH parameter is a crucial indicator. Test results showed values <0.28 mg/L, except in July 2024, when it was recorded at 0.013 mg/L. TPH is a key parameter for detecting oil contamination. The presence of TPH in the jetty area typically originates from small spills during fuel transfers or ship engine leaks. Test results for phenol compounds at all points and periods showed values below the detection limit of <0.002 mg/L. Phenolic compound contamination in aquatic ecosystems is triggered by a combination of anthropogenic factors such as industrial, domestic, and agricultural activities, as well as natural processes. Phenols can form from the degradation of organic material native to the water or enter through waste disposal and land runoff. A crucial characteristic of this chemical is its ability to transform into new, potentially more toxic derivatives due to dynamic interactions with physical-chemical elements and microbial activity in the water column (Anku et al., 2017).

Detergent or surfactant parameters showed a significant increase at all three locations in July 2024, particularly in AL3, at 0.42 mg/L, compared to <0.09 mg/L in January 2024. However, they then decreased again in January 2025, to <0.1 mg/L. The most common source of surfactants is soap. The use of surfactants in large volumes for various purposes, such as the textile industry, household needs, and vehicle maintenance, has triggered an increase in the concentration of these compounds in domestic and industrial wastewater. As a result, the surfactant pollutant load released into aquatic ecosystems has become increasingly significant (Sur, 2015).

Measured oil and grease levels remained below the 5 mg/L standard, with the highest value recorded at AL3 in January 2025 at 0.39 mg/L. Oil and grease pollution can damage sensitive marine ecosystems, resulting in biodiversity loss, habitat degradation, and ecological imbalance. Oil and grease are significant marine pollutants that have the potential to harm marine ecosystems due to their low solubility and slow microbial decomposition. Oil spills from ships, illegal dumping of waste oil, leaks from offshore oil and gas installations, and other factors can contribute to this type of pollution (Francis et al., 2024).

Dissolved Metal Parameters

Mercury, the heavy metal, showed low fluctuations, with the lowest value being 0.0001 mg/L in July 2024 at the AL2 site and the highest being 0.0008 mg/L in July 2024 at the AL3 site. However, all measured values remained below the 0.003 mg/L standard. Cadmium concentrations were also recorded as very low, reaching a peak of 0.0006 mg/L at the AL3 site in January 2024.

Copper (Cu) levels in January 2024 were below the detection limit of <0.001 mg/L, but increased in January 2025 to 0.02 mg/L at AL2 and 0.018 mg/L at AL3. Although essential for marine organisms, copper can be toxic if concentrations exceed certain thresholds. The use of anti-fouling paint on ships is a major source of copper contamination in coastal waters. Locations with low water dilution rates, such as bays, tend to experience greater pollution stress than open waters. Global studies, including those in San Diego and San Francisco, have confirmed a close link between maritime activity and elevated copper levels in aquatic environments (Biggs & D'Anna, 2012). Despite the increase, this value of 0.018 mg/L still meets the established quality standard (0.05 mg/L), so the seawater quality around the location is still categorized as safe and free from copper contamination.

Lead (Pb) parameters showed stable and very low values, ranging from <0.0015 to <0.003 mg/L, well below the 0.05 mg/L standard. Similarly, zinc (Zn) levels at all three locations remained well below the 0.1 mg/L threshold.

All measured dissolved metal parameters showed values far from the established quality standard, even below the detection limit of the test equipment, so the study sites remained free of dissolved metals.

Microbiological Parameters

The microbiological parameter Total Coliform also showed fluctuations, with the highest value reaching 910 J/100 mL in AL3 in January 2025, approaching the threshold of 1000 J/100 mL. Total Coliform is an indicator of domestic waste or sewage contamination. This increase could be caused by worker activities in the jetty area or the discharge of sanitary waste from docked vessels without adequate treatment, particularly in the early part of 2025.

Pollution Index

Water quality status in the waters was determined using the Pollution Index method. The results of the Pollution Index analysis at each station in 2024 and 2025 are presented in the following table and figure.

Table 5. Pollution Index at three sampling locations at different times

location	Times	IP	Kategori
AL1	January 2024	0,62	meet quality standards
	July 2024	1,02	lightly contaminated
	January 2025	0,59	meet quality standards
AL2	January 2024	0,62	meet quality standards
	July 2024	1,02	lightly contaminated
	January 2025	2,15	lightly contaminated
AL3	January 2024	0,62	meet quality standards
	July 2024	1,03	lightly contaminated
	January 2025	1,98	lightly contaminated

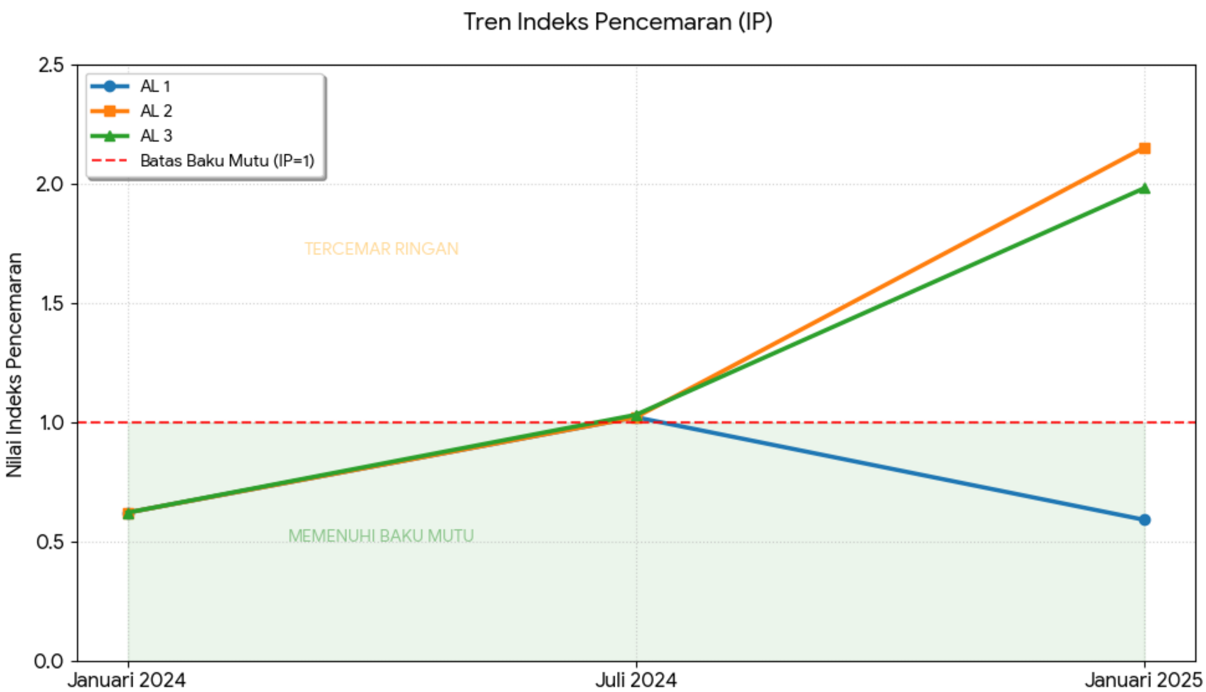

Figure 2. Pollution Index around the jetty location

In January 2024, AL 1 was in good condition with a score of 0.62 (Meets Quality Standards). Then, the quality declined in July 2024 to 1.02 (Lightly Polluted), but recovered significantly in January 2025 to 0.59. This indicates that AL 1 has good environmental carrying capacity and is capable of recovering from seasonal pollution loads.

AL 2 was also analyzed with the same value as AL 1 (0.62). This location also declined to the Lightly Polluted category in July 2024 (1.02) and deteriorated significantly in January 2025 with an index of 2.15. This increase in the index indicates a consistent accumulation of pollutants. This is because AL 2 is directly impacted by jetty activities. As the point closest to loading and unloading activities, AL 3 exhibits a worrying pattern. After being at 0.62 in early 2024, the index jumped to 1.03 (July 2024) and settled in the Lightly Polluted category at 1.98 in January 2025. Although slightly lower than the AL 2 in the last period, this figure approaching 2.0 indicates that Jetty activities directly exert anthropogenic pressure on seawater quality.

CONCLUSION

The results of the analysis of seawater quality around the Jetty for fuel oil storage operations show significant dynamics in physical, chemical, and microbiological parameters throughout the period of 2024 to early 2025. There are 2 parameters whose values are above the quality standards for marine biota, namely the clarity at three locations in July 2024 which is 3 meters while for the quality standard for coral marine biota, the clarity is above 5 meters. The second parameter is Copper (Cu) at point AL2 of 0.02 mg/L and AL3 of 0.018 mg/L in January 2025, while the Cu quality standard for marine biota is 0.08 mg/L. Physically, fluctuations in brightness and an upward trend in TSS values indicate the influence of dock activities and seasonal factors, while chemical parameters such as copper (Cu) and oil-grease at the AL3 location showed an increase in January 2025. From a microbiological perspective, there was a drastic increase in the Total Coliform parameter at the AL3 location which reached 910 Jml/100mL, reflecting an increase in anthropogenic pressure from ship operational activities or sanitation of the jetty area. Pollution Index analysis concluded that although all locations initially met the quality standard of 0.62 in January 2024, there was a degradation in quality to the "Lightly Polluted" category at the AL2 location at 2.15 and AL3 at 1.98 in January 2025. In contrast, the AL1 location showed quality recovery with an index of 0.59, which indicates better environmental recovery in the area.

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