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Analysis of Eutrophication Levels in the Coastal Waters of Parepare City

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ABSTRACT

Marine eutrophication is the increasing concentrations of nutrients, especially nitrogen and phosphorus, in marine ecosystems due to anthropogenic activities such as domestic, agricultural, and industrial waste disposal. This nutrient accumulation triggers excessive phytoplankton growth (algal bloom), which can cause the death of marine biota, disrupt the food chain, and decrease fisheries' productivity. This research aimed to analyze the level of eutrophication in the coastal waters of Parepare City. The eutrophication level was examined at four stations using the trophic index (TRIX) to achieve the research objectives. The results showed that some water quality parameters exceeded environmental standards, such as ammonia, nitrate, and nitrite, thus contributing to increased eutrophication. Based on the trophic index calculation, the level of eutrophication at the four stations was categorized in mesotrophic status ranging from $2 \leq$ TRIX < 4. Station IV recorded the highest trophic index value of 3.00, which is located around the Cempae Fish Landing Base and Suppa Power Plant, an area with a high intensity of human activities. These waters reflect a moderate level of primary productivity.

INTRODUCTION

Eutrophication is a process that can degrade the environmental quality of coastal waters and disrupt the ecological balance within them. One of the leading causes of this phenomenon is the excessive accumulation of nutrients, particularly phosphorus (P) and nitrogen (N), which accelerates the uncontrolled growth of phytoplankton. These nutrients generally originate from various anthropogenic activities, including the discharge of industrial and domestic effluents (such as household detergents), the use of chemical fertilizers in agricultural practices, as well as organic waste from the livestock sector, aquaculture (floating net cages), and unutilized feed residues. These persistent nutrient inputs contribute to excessive primary productivity, increasing the risk of hypoxia, habitat destruction, and biodiversity loss in coastal ecosystems **(Lan *et al.*, 2024)**. The input of organic matter from various types of wastes into water bodies can cause significant ecological disturbances, especially if the concentration exceeds the assimilative capacity of the water body. Under certain conditions, a high accumulation of organic matter is one of the primary triggers for eutrophication, a process characterized by increased phytoplankton biomass and excessive proliferation of aquatic plants (algal bloom) **(Anderson *et al.*, 2021)**.

Phytoplankton is a significant component in the trophic structure of coastal aquatic ecosystems due to its ability to photosynthesize through chlorophyll pigments, particularly chlorophyll-α. This photosynthetic activity produces energy from organic compounds, the leading indicators of primary productivity in aquatic environments. The level of primary productivity of phytoplankton is highly dependent on environmental factors, especially the availability of nutrients such as nitrogen and phosphorus. In coastal areas, chlorophyll-α concentrations are generally higher due to high nutrient inputs from river flows, surface runoff, or anthropogenic activities from land. In contrast, in open ocean (pelagic) waters, chlorophyll-α concentrations tend to be lower due to limited nutrient supply, limiting phytoplankton growth and overall primary productivity **(Trivedi *et al.*, 2022)**.

Water quality status indicates a water source's polluted or good condition at a certain point by comparing it with the established water quality standard or water class. The level of eutrophication, in this case, trophic status, is the state of water quality of a water body based on nutrient and phytoplankton biomass content or productivity. A water body's trophic status can be determined based on water quality data and trophic status criteria (MENLH Regulation No. 110 Year 2003). Trophic status classification of waters is generally divided into three main categories: eutrophic, mesotrophic, and oligotrophic. Eutrophic waters are characterized by high concentrations of nutrients, especially nitrogen and phosphorus, which support the growth of primary productivity, such as phytoplankton and aquatic plants. Mesotrophic indicates conditions with moderate nutrient levels, while oligotrophic describes waters with low nutrient content. Oligotrophic waters typically have high clarity, large depths, and little aquatic vegetation and algal biomass. In addition, there is also a dystrophic category that refers to waters that are degraded in quality, often characterized by high organic matter content and low biological productivity **(Werther *et al.*, 2021)**. The trophic status of a water body is determined by the distribution and concentration of chlorophyll-α, as well as the availability of key nutrients such as nitrogen and phosphorus. Chlorophyll-α acts as a commonly used biological indicator to assess the fertility of waters, as it reflects the phytoplankton biomass that develops due to the availability of these nutrients **(Reyes-Velarde *et al.*, 2023)**.

The trophic index (TRIX), as described by **Vollenweider *et al.* (1998)**, is an analytical tool that combines four main variables: chlorophyll-α, dissolved oxygen saturation (DO saturation), inorganic nitrogen, and orthophosphate. TRIX values are expressed on a scale of 0 to 10, where higher values indicate more significant levels of eutrophication. This method allows the incorporation of multiple parameters to provide a more comprehensive picture of the fertility of coastal waters.

The waste problem on Parepare City, South Sulawesi's coast, has been a serious concern recently. The accumulation of rubbish in coastal areas damages environmental aesthetics. It threatens marine ecosystems and contributes to the increase of nutrients that can affect the level of eutrophication in the area **(Indriani *et al.*, 2023)**. Based on this background, this study aimed to evaluate the level of eutrophication of coastal waters and provide helpful information for sustainable water management.

MATERIALS AND METHODS

Place of research and frame

This research was conducted from January to March 2025 in the coastal waters of Parepare City, South Sulawesi. Laboratory analyses were performed at the Chemical Oceanography Laboratory of the Department of Marine Science, Faculty of Marine Science and Fisheries, Hasanuddin University.

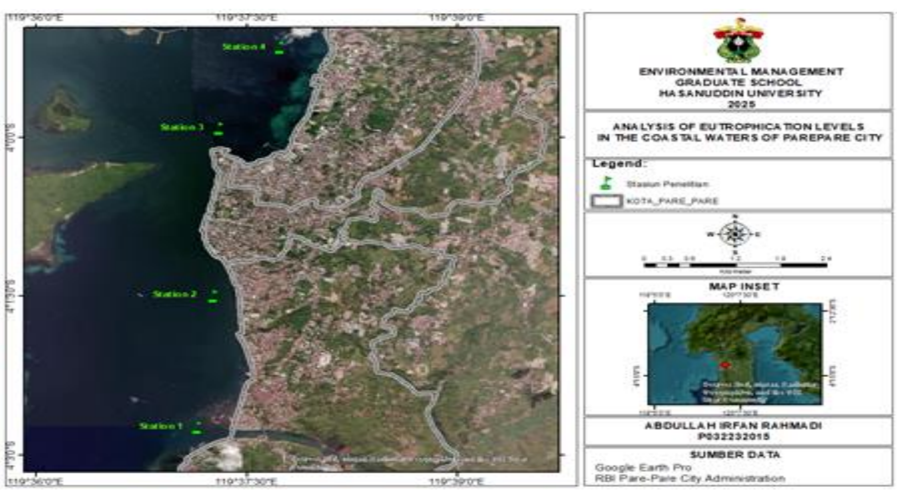

Fig. 1. Map of research location and sampling stations

The station points that are the focus of this research are as follows:

Station 1: Located at 3°58'35.5' N and 119°37'30.9' East. Adjacent to the Karajae River estuary and Ainun Habibie Teaching Hospital

Station 2: 4°00'04.2' N-S and 119°37'32.5' E. Adjacent to residential areas and Mattirotasi Park

Station 3: 4°01'51.5' N-S and 119°37'19.4' E. Adjacent to Cappa Ujung Parepare Ship Port and Parepare Fuel Terminal Platform

Station 4: 4°02'48.8' N-S and 119°37'13.8' E. Adjacent to Cempae Fish Landing Base and Suppa Power Plant

Measurement of environmental parameters

Measurements of environmental parameters were carried out *in situ* (Field Observation) and in the laboratory. Laboratory measurements were conducted at the Chemical Oceanography Laboratory of the Department of Marine Science, Faculty of Marine Science and Fisheries, Hasanuddin University. Environmental parameters measured during the study can be seen in Table (1).

Table 1. Environmental parameters determined during the study

No.	Data Component	Unit	Collection Technique
1.	**Water Quality**		
	Turbidity of Waters	NTU	Field Observation
	Temperature	ºC	Field Observation
	Salinity	$^0/_{00}$	Field Observation
	pH	-	Field Observation
	DO (Dissolved Oxygen)	mg/L	Field Observation
	Ammonia	mg/L	Field Observation - Laboratory
	Nitrate	mg/L	Field Observation - Laboratory
	Nitrite	mg/L	Field Observation - Laboratory
	Orthophosphate	mg/L	Field Observation - Laboratory
	Chlorophyll-α	mg/m^3	Field Observation - Laboratory

Determination of trophic status

The trophic index (TRIX) method can determine the eutrophication assessment of coastal waters. This index is considered more effective than other methods because it covers many tophic conditions ranging from oligotrophic to eutrophic. The trophic index (TRIX) method has also been adopted as a rule by law in Italy to describe the trophic condition of coastal waters in the country **(Fiori *et al.*, 2016)**.

Giovanardi and Vollenweider (2004) concluded that determining the trophic status of water results from the analysis of water quality parameters, which are then used to identify the level of water fertility based on the trophic index (TRIX). This trophic status score is the trophic index (TRIX) average value of the four water quality parameters (chlorophyll-α, DO saturation, total phosphate, and total nitrogen). The TRIX index value limits are presented as follows:

Table 2. TRIX index classification

TRIX Value	Trophic Status	Eutrophication Level	Water Conditions
$0 < TRIX < 2$	Oligotrophic	Low	• Low water productivity • Absence of watercolor anomalies • High water brightness • Saturated bottom oxygen concentration
$2 \leq TRIX < 4$	Mesotrophic	Medium	• Medium water productivity • Water sometimes turbid • Occasional watercolor anomalies • Occasional hypoxic events in bottom waters
$4 \leq TRIX < 6$	Eutrophic	High	• High water productivity • Low water brightness • Frequent water color anomalies • Occasional anoxic events in bottom waters • Benthic organisms under stress
$6 \leq TRIX < 10$	Hypertrophic	Very High	• Very high water productivity • Very high water turbidity • Water color anomalies are widespread and sustained • Hypoxic and anoxic events are widespread and sustained • High mortality rate of benthic organisms • High biodiversity community change occurs

The calculation of the trophic index (TRIX) from **Giovanardi and Vollenweider (2004)** is as follows:

TRIX = [log10 (PO_4 x Tn x Chl-α x DO Saturasi) + a] / b

Description:

PO_4 = Total Phosphate (mg/L)
Tn = Total Nitrogen (mg/L)
Chla-α = Chlorophyll concentration- α
DO Saturation = Oxygen saturation percentage
Variables = a =1,5 and b = 1,2 is the scale coefficient

RESULTS

Environmental parameter analysis

The research results at four stations provide an overview of the concentration of each environmental parameter in the coastal waters of Parepare City. These results will be described to indicate the quality conditions of a water body. Data on the value of environmental parameters in this study are presented in Table (3).

Table 3. Mean value and standard deviation at each station

Station	Temperature	pH	Salinity	DO (Dissolved Oxygen)	Turbidity	Nitrate	Nitrite	Ammonia	Phosphate	Chlorophyll
Station I	29.8 ± 2.40	7.95 ± 0.17	17 ± 0.58	4.25 ± 0.05	6.90 ± 0.44	0.238 ± 0.002	0.009 ± 0.001	0.471 ± 0.008	0.044 ± 0.001	3.781 ± 0.076
Station II	30.7 ± 0.29	8.39 ± 0.01	28 ± 0.58	4.38 ± 0.19	0.58 ± 0.01	0.124 ± 0.001	0.003 ± 0.001	0.549 ± 0.007	0.039 ± 0.002	2.087 ± 0.038
Station III	30.8 ± 0.29	8.64 ± 0.02	25 ± 0.58	4.90 ± 0.10	1.45 ± 0.17	0.138 ± 0.001	0.003 ± 0.002	0.547 ± 0.006	0.028 ± 0.002	1.249 ± 0.049
Station IV	31.0 ± 0.50	8.65 ± 0.03	26 ± 0.58	5.63 ± 0.21	2.46 ± 0.33	0.192 ± 0.002	0.023 ± 0.001	0.660 ± 0.003	0.091 ± 0.002	1.301 ± 0.056
Quality Standard	28 – 30	7 – 8.5	33 – 34	≥ 5	5	0.06	0.25	0.3	0.015	<15

Based on this data, several concentrations of environmental parameters exceed the quality standards set by the Government of the Republic of Indonesia based on Government Regulation No. 22 of 2021. The high concentration of ecological parameters indicates that the increase in concentration comes from various sources such as community waste, port activities, fish auctions, and industry. Fig. (2) shows the environmental parameter data at each station.

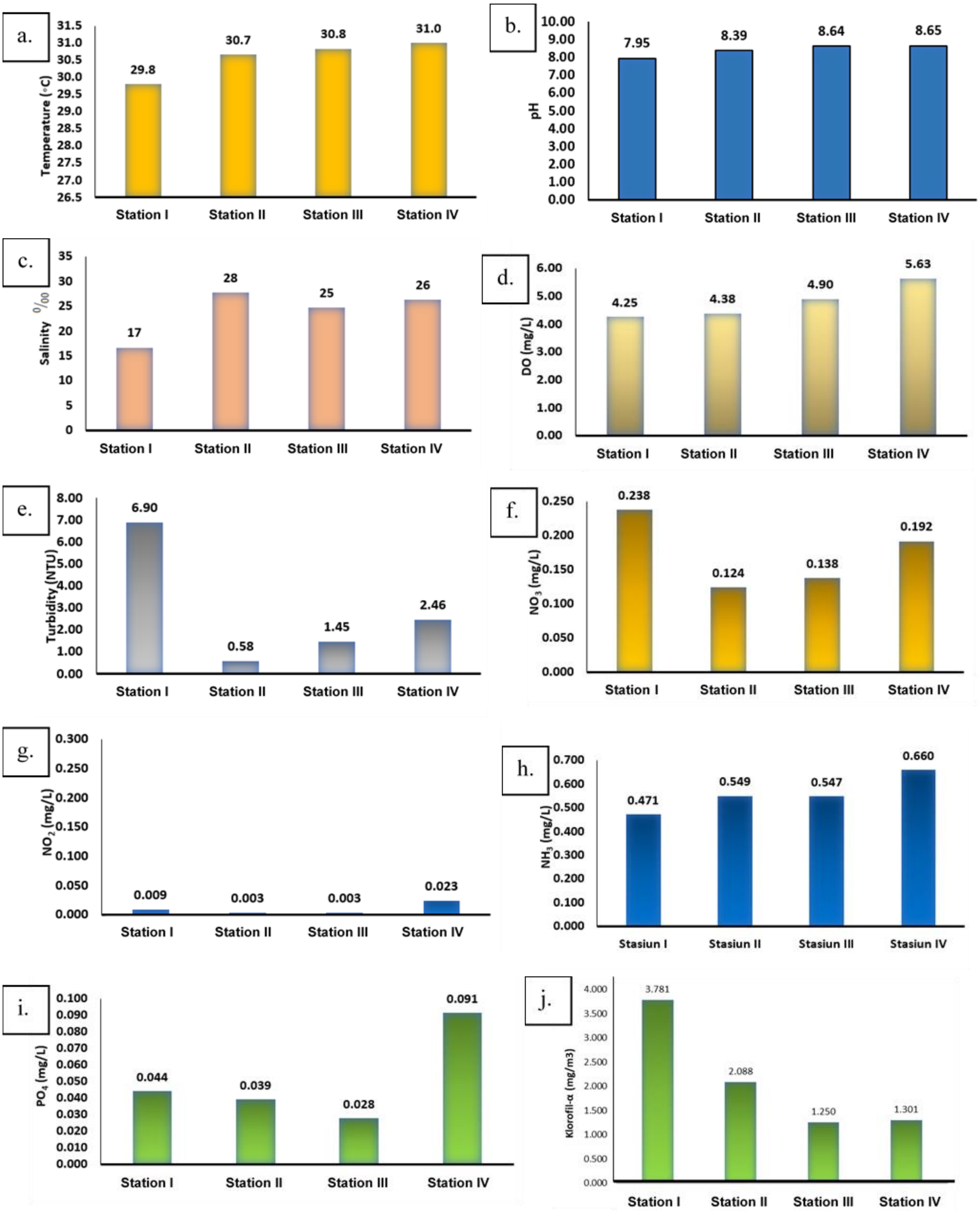
a.
Temperature (◦C)
29.8
30.7
30.8
31.0
Station I
Station II
Station III
Station IV
b.
pH
7.95
8.39
8.64
8.65
Station I
Station II
Station III
Station IV
c.
Salinity 0/00
17
28
25
26
Station I
Station II
Station III
Station IV
d.
DO (mg/L)
4.25
4.38
4.90
5.63
Station I
Station II
Station III
Station IV
e.
Turbidity (NTU)
6.90
0.58
1.45
2.46
Station I
Station II
Station III
Station IV
f.
NO3 (mg/L)
0.238
0.124
0.138
0.192
Station I
Station II
Station III
Station IV
g.
NO2 (mg/L)
0.009
0.003
0.003
0.023
Station I
Station II
Station III
Station IV
h.
NH3 (mg/L)
0.471
0.549
0.547
0.660
Stasiun I
Stasiun II
Stasiun III
Stasiun IV
i.
PO4 (mg/L)
0.044
0.039
0.028
0.091
Station I
Station II
Station III
Station IV
j.
Klorofil-α (mg/m3)
3.781
2.088
1.250
1.301
Station I
Station II
Station III
Station IV

Fig. 2. Environmental parameters: **(a)** Temperature, **(b)** pH, **(c)** Salinity, **(d)** DO, **(e)** Turbidity, **(f)** Nitrate, **(g)** Nitrite, **(h)** Ammonia, **(i)** Phosphate, **(j)** Chlorophyll-α

Trophic status

The study results at four stations in the coastal waters of Parepare City showed that the trophic index (TRIX) values at each station were relatively uniform, ranging from 2.89 to 3.00. Station I, located near the river mouth, recorded the lowest TRIX value of 2.89. Meanwhile, Station IV showed the highest TRIX value of 3.00 and was situated in an area with high anthropogenic activities, namely around the Cempae Fish Landing Base (PPI). The TRIX values at each station are shown in Fig. (3).

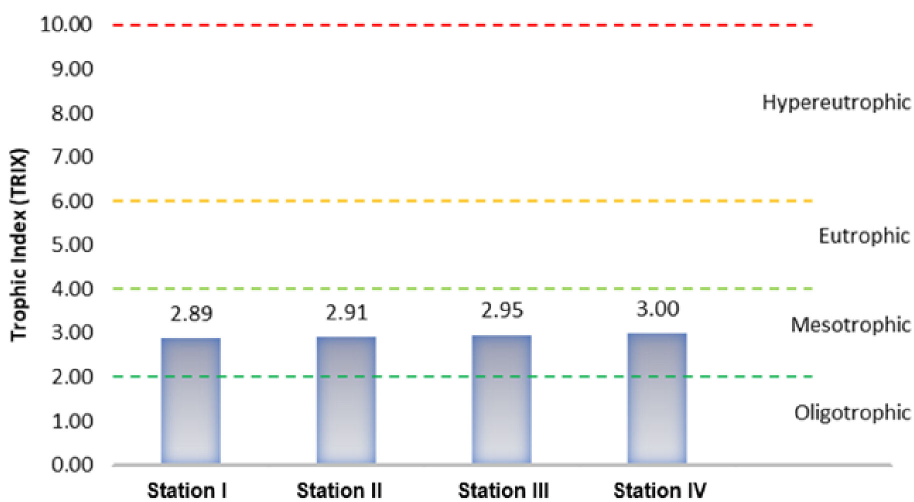

Fig. 3. Tropic index at each station

DISCUSSION

The temperature at Station 1 is 29.8ºC, the lowest among all stations and representing the entry and exit points of river water flow. This is considered a relatively low temperature. At Stations 2 and 3, the temperatures are similar, both recorded at 30.7ºC. The highest temperature is observed at Station 4, measuring 31.0ºC. This station is located near the Suppa PLTD, which may contribute to the temperature increase in the area.

Based on these results, three stations exceed the seawater temperature quality standard threshold. According to Government Regulation Number 22 of 2021 concerning the Implementation of Environmental Protection and Management, a temperature change of up to 2ºC from the natural baseline is permitted. This is in line with the results of research by **Uwem *et al.* (2013)**, which states that varying water temperatures can be influenced by several internal factors, including atmospheric conditions, weather, wind, and solar intensity entering the water area. Industrial activities can also affect changes in sea temperature through waste discharged into the sea.

The pH value at each station is not significantly different. The value at station 1 is 7.95, station 2 has a value of 8.39, station 3 has a value of 8.64, and station 4 has a value of 8.65. There is one station with a value below 8.0, namely station 1, where station 1 is close to the estuary, allowing changes to occur due to the mixing of fresh water from the river and sea. The farther the station is from the river mouth, the more the pH value will increase; this is reinforced by the research of **Asare *et al.* (2021)**, which states that, in general, the pH of seawater will be more alkaline than the pH of river water. In seawater, the central cation is Na^+, and the primary anion is Cl^-, while in freshwater, the main cations are Ca^{2+} and Mg^{2+}, and the primary anion is HCO_3^-.

In general, the salinity value in the study is not much different; it's just that there is one station with a value that is very different from the other stations. Station 1 has the lowest salinity value of 17o/oo due to the conditions in that location adjacent to the Karajae River estuary. Station 2, station 3, and station 4 have salinity that is not too different from the value at Station 2 of 28 o/oo, station 3 of 25o/oo, and Station 4 of 26o/oo. This shows that the increase in salinity value is in line with the distance of the station from the mouth of the river. In addition, the dilution factor due to high rainfall resulted in the salinity value of the four stations below the threshold of seawater quality standards. Salinity values are also often associated with rainfall; the higher the rainfall, the lower the salinity value in the area, and vice versa **(Jalil *et al.,* 2020)**.

The DO concentration in the coastal area of Parepare City shows only at station 4, which has a value above >5, namely 5.63mg/ L. This makes the location suitable for aquaculture sites; several fish cages at the station indicate that the dissolved oxygen conditions suit marine biota's life. At station 1, which has the lowest DO value at 4.25mg/ L, the location is below the appropriate threshold for the life of marine biota. Likewise, station 2 has a value of 4.39mg/ L. Station 4 has a value of 4.90mg/ L. The DO content at several research stations is below the seawater quality standards set by the Government of the Republic of Indonesia based on Government Regulation No. 22 of 2021, which is> 5mg/ L, which means that there is a decrease in water quality due to the input of organic waste. The conditions in this study are also in line with research conducted by **Chapra *et al.* (2021)**, which states that one of the causes of a decrease in dissolved oxygen content in a water area is the increase in organic waste so that the oxygen needed by bacteria to break down organic substances into inorganic substances is increasing.

The magnitude of the turbidity value is inversely proportional to the salinity value due to the influence of freshwater flow from the river, which carries suspended materials. Station 1 has the highest turbidity value of 6.90 NTU, while station 2 has the lowest turbidity value of 0.58 NTU. This is influenced by the location at station 1, which is adjacent to the Karajae River mouth, which is inversely proportional to station 2, so there is an influence of freshwater drainage that carries suspended materials. Meanwhile, station 3 has a value of 1.45 NTU and is close to the harbor. The value at station 4 is 2.46 NTU, a not-too-significant increase caused by anthropogenic activities and PLTD Suppa.

This is supported by research conducted by **Zhu *et al.* (2021)**, which states that high rainfall results in a lot of substrates in the form of household waste, garbage, and mud from land entering marine waters through rivers so that the highest value is in coastal waters adjacent to the river mouth. Vice versa, which leads to the high seas, the turbidity level of the water is getting lower.

The four stations in the coastal area of Parepare City exhibit high concentrations of nutrients. According to the data, the highest nitrate concentration was recorded at Station 1, with a value of 0.238mg/ L. This station is located near the river mouth, where upstream water likely transports nitrate-rich material into the coastal zone. Station 2 recorded the lowest nitrate concentration at 0.124mg/ L, being located farther from the river mouth. Station 3 showed a value of 0.138mg/ L and is situated near a fuel terminal platform, which may contribute to nitrate levels. Station 4, located near PPI Cempae and PLTD Suppa, had a nitrate concentration of 0.192mg/ L. The elevated nitrate concentrations at these stations pose potential risks to marine life.

According to **Nippatlapalli *et al.* (2022)**, nitrate levels increase due to the discharge of organic waste, including household wastewater (e.g., detergents, food scraps, and human metabolic waste). **Chen *et al.* (2022)** also reported that estuaries tend to have elevated nitrate levels due to accumulation of nitrate-rich water from upstream.

In contrast, nitrite concentrations in this study were relatively low, ranging from 0.003 to 0.023mg/ L. This is expected, as nitrite is an intermediate product in the nitrification and denitrification processes, converting ammonia into nitrate and eventually nitrogen gas. As noted by **de Melo Filho *et al.* (2020)** and **Ayiti and Babalola (2022)**, nitrite levels are generally lower than other inorganic nitrogen compounds due to this transitional nature.

Ammonia concentrations were relatively high, with Station 4 recording the highest value at 0.660mg/ L. This station is located near several potential pollution sources, including PPI Cempae and PLTD Suppa. Station 1, at the mouth of the Karajae River, had the lowest ammonia concentration at 0.471mg/ L. Stations 2 and 3 showed similar values—0.549 and 0.547mg/ L, respectively—likely due to anthropogenic activities at the Nusantara Port (Station 2) and the Pertamina Fuel Terminal (Station 3). **Hamuna *et al.* (2018)** suggest that ammonia levels in coastal waters often rise due to domestic waste, including garbage, urine, and feces.

According to Government Regulation Number 22 of 2021 on Environmental Protection and Management, the acceptable orthophosphate concentration for marine biota is 0.015 mg/L. Station 4 showed the highest orthophosphate concentration at 0.091 mg/L, likely due to its proximity to intensive anthropogenic activities. Station 3 had the lowest value at 0.028mg/ L, while stations 2 and 1 recorded 0.039 and 0.044mg/ L, respectively. **Mabagala and Mng'ong'o (2022)** explained that elevated orthophosphate levels may result from weathering, decomposition of organic matter, and input of terrestrial waste, including domestic and industrial discharge. This is further supported by a 2020 study indicating that port activities such as loading/unloading and vessel movement contribute significantly to nutrient inputs.

Chlorophyll-a concentrations, used as a proxy for phytoplankton biomass, were at their highest at Station 1 (3.781mg/ m³), which is near the river mouth—likely a key nutrient source. Station 2, close to the archipelago harbor, recorded 2.088mg/ m³; Station 3, near the fuel terminal platform, had 1.250mg/ m³; and Station 4, adjacent to PPI Cempae and PLTD Suppa, had 1.301mg/ m³. These findings align with those of **Amorim *et al.* (2024)**, who observed high chlorophyll-a concentrations near the Elbe River mouth in the German Bight, driven by temperature and water column dynamics.

Trophic index values at all stations ranged from 2.89 to 3.00, indicating mesotrophic conditions—moderate nutrient levels and productivity. This trophic status supports moderate phytoplankton growth and signals a risk of eutrophication if nutrient inputs increase. **Böttjer-Wilson *et al.* (2021)** found that eutrophication promotes algal growth, often due to nutrient input from domestic sources.

Primary productivity, often assessed through chlorophyll-a and phytoplankton abundance, is a vital indicator of aquatic fertility. **Tambaru *et al.* (2024)** emphasized phytoplankton's role in aquatic trophic dynamics and noted their dependence on nutrient availability. Environmental parameters such as temperature, turbidity, salinity, and concentrations of nitrate and phosphate greatly influence phytoplankton community structure and abundance.

Mesotrophic waters, such as those observed in this study, fall between oligotrophic (low productivity) and eutrophic (high productivity) conditions. They typically contain moderate nutrient levels that sustain phytoplankton growth without triggering harmful algal blooms. **Yang *et al.* (2023)** noted chlorophyll-a concentrations in mesotrophic waters ranging from 0.5 to 2.0mg/ m³ in the Yellow Sea and western Pacific, with nano-sized phytoplankton (2–20µm) dominating due to their adaptability to moderate nutrients.

Amorim *et al.* (2024) reported seasonal increases in chlorophyll-a in mesotrophic areas of the German Bight, without evidence of severe eutrophication. This variation was linked to sea surface temperature and mixed layer depth, which affect phytoplankton dynamics and light availability.

The phytoplankton community structure offers a clear reflection of trophic status and water quality. Dominant taxa in mesotrophic waters include nano- and micro-phytoplankton, particularly diatoms (e.g., *Chaetoceros*, *Thalassiosira*, *Skeletonema*) and dinoflagellates (e.g., *Ceratium*, *Peridinium*). **Yang *et al.* (2023)** observed similar community patterns in mesotrophic zones of the Yellow Sea. **Radia (2024)**, studying the waters around Umming Island, also reported *Chaetoceros* as the dominant genus, consistent with findings from this region.

Numerous studies have emphasized the importance of integrating physicochemical parameters with phytoplankton community analysis to track ecological changes. **Amorim *et al.* (2024)** demonstrated that shifts in temperature, salinity, turbidity, and nutrient levels can significantly alter phytoplankton composition in tropical and subtropical marine ecosystems.

Understanding mesotrophic dynamics is essential for sustainable water resource management. Mesotrophic waters are ecologically balanced and support critical services such as water purification, biodiversity, and recreation. Monitoring these ecosystems is crucial to prevent degradation and ensure long-term ecological health.

CONCLUSION

The results of research on the level of eutrophication in the coastal waters of Parepare City show that the environmental parameters in the region have exceeded the threshold of environmental quality standards set by the Government of the Republic of Indonesia, thus requiring further attention. The trophic status at the four observation stations is classified as mesotrophic, with moderate eutrophication. The waters in the area reflect a moderate level of primary productivity. The highest value was recorded at Station IV, 3.00, around the Cempae Fish Landing Base (PPI) and Suppa Power Plant.

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