Spatial Variability of Nutrients and Chlorophyll-A as Contributing Factors of Trophic Condition in Kendari Bay, Southeast Sulawesi

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Abstract

Estuaries and coastal waters are heavily influenced by anthropogenic activities and environmental factors, which can lead to ecosystem degradation, increased nutrients, and the risk of eutrophication. Kendari Bay, with its complex hydrodynamic conditions and various human activities in the vicinity, requires an analysis of the distribution of nutrients and chlorophyll-a (chl-a) to estimate the potential for eutrophication and its impact on aquatic ecosystems. This research was conducted in March-May 2023 at six stations in Kendari Bay. The distribution of nutrients in Kendari Bay revealed a varied pattern, with DIN concentrations higher in the "neck area" or narrow parts of the bay, phosphates more concentrated in the inner part due to slow water flow, and silica more abundant in estuaries because it comes from weathering rocks carried by river flows. Chl-a concentration tended to correspond DIN pattern, suggesting that phytoplankton growth was more influenced by nitrogen nutrients than phosphorus nutrients, as supported by an N:P ratio of less than 16. Overall, Kendari Bay was classified as mesotrophic with a relatively uniform trophic level due to morphological and hydrodynamic characteristics that narrow towards the sea and a low flushing rate. A comprehensive approach to managing human activities from upstream to downstream must be performed effectively to protect the bay area from eutrophication and environmental decline due to excessive nutrient runoff from land-based activities.

Keywords: estuary, nitrogen, phosphorus, phytoplankton, water quality

INTRODUCTION

Nutrient pollution is a form of environmental degradation resulting from development in coastal watersheds (Oelsner & Stets, 2019). Population growth and human activities can disrupt the biogeochemical cycle through increased nutrient inputs to the environment leading to excess nutrients, especially nitrogen (N) and phosphorus (P) (Quandra & Brovini, 2023). Although N and P are essential elements for sustaining life (Chen *et al*., 2013; He *et al*., 2023), high levels can cause ecological disturbances, affecting ecosystem functions and services (Quandra & Brovini, 2023). Agricultural fertilizers, waste, animal manure, atmospheric inputs, and coastal aquaculture contribute to escalated nutrient concentrations in coastal waters (Davidson *et al*., 2014). Chlorophyll-a (chl-a) in phytoplankton can be an indicator of changes in phytoplankton abundance and the extent of aquatic nutrient pollution (He *et al*., 2023).

These challenges are further compounded by the complex and dynamic nature of estuarine and coastal ecosystems, which are influenced by the interaction of physical, chemical, and biological factors occurring between freshwater and seawater (Armid *et al*., 2014). Along with the

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development of science and technology of human life, the input of pollutants from the mainland increasingly has an impact on coastal waters. Chen *et al*., (2013) reported that increased pressure of anthropogenic activities and external nutrient load are the main causes of water degradation and eutrophication. At chronic levels, eutrophication results in algal bloom decreased dissolved oxygen and water quality, and mass death of fish and other organisms (Gemilang *et al*., 2019; He *et al*., 2023; Pérez-Ruzafa *et al*., 2019).

Kendari Bay exemplifies these issues, as it lies in the center of Kendari City and serves as the estuary for four major rivers, with the Wanggu River being the largest. Around Kendari Bay, there has been a revitalization of sedimentation products that enter Kendari Bay. The revitalization is used as a tourist area for the local community. In addition to tourism activities, there are also fish landings, i.e. the Kendari Samudera Fisheries Port (PPS), brackish water cultivation, post-fish processing, agriculture, and crossing ports (Asriyana & Irawati, 2019). These activities have the potential to affect the presence of nutrients in the waters of the gulf.

Complicating matters further, the bay's morphology, with a wide in the interior and narrows towards the sea making the change of water mass in the bay low. Based on its hydrodynamic characteristics, Kendari Bay is classified as a shallow and complex semi-enclosed bay, caused by the influx of water masses from the Wanggu River and the flow of seawater masses (Imalpen *et al*., 2024). Looking at these factors, an analysis of the distribution of nutrients and chl-a in Kendari Bay is essential to estimate the potential for eutrophication in this bay. Therefoe, this research specifically aims to analyze the spatial distribution of nutrients and chl-a concentration in Kendari Bay, in order to estimate the trophic status of the waters. The findings will provide essential data to support sustainable management and protection efforts in this vulnerable coastal ecosystem.

MATERIALS AND METHODS

This research was carried out in Kendari Bay, Southeast Sulawesi, Indonesia in March – May 2023. Sample analysis was conducted at the Productivity and Environment Laboratory of Halu Oleo University. Sampling was carried out at six stations determined based on the location gradient from the river mouth to the offshore part (Figure 1). Station 1: Wanggu River mouth; Station 2: Estuary; Station 3: the inner part of the bay; Station 4: port and “neck area” (constricted waterway sections connecting broader areas); Station 5: the outer bay; Station 6: the offshore section. Kendari Bay is a coastal water located in Kendari City, with a coastline length of ±35.85 km and an area of ±10.84 km^2 (Putra *et al*., 2017). The largest river that discharges into Kendari Bay is the Wanggu River which is located in the west of the bay.

The data collected included nitrates (NO_3-N), nitrites (NO_2-N), ammonia (NH_3-N), phosphates (PO_4-P), silica (SiO_2-Si), dissolved oxygen (DO), chl-a, temperature, pH, and salinity. In this study, dissolved inorganic nitrogen (DIN) consisted of nitrates, nitrites, and ammonia. Data collection was carried out three times with a span between data collection of 2 weeks. DO, pH, and salinity were measured using a DO meter, pH meter, and refractometer, respectively. Surface water samples were taken to then analyze the nitrate, nitrite, ammonia, phosphate, silica, and chl-a content based on APHA (2012) in the laboratory. Sample collection and preservation were carried out based on SNI-062412-1991 (BSN, 1991). The samples taken for nitrate, nitrite, ammonia, phosphate, and silica analysis were 100 mL each, while for chlorophyll analysis 500 mL.

Spatial data analysis of nutrient and chl-a distribution was carried out using ArcGIS and Surfer software. The methods used were Inverse Distance Weighted (IDW) and color relief. The advantage of using IDW is that the interpolation results can be determined by limiting the points used in the study (Pramono, 2008).

Analysis of the trophic level of the waters was carried out using the trophic index (TRIX) method which was calculated using the following formula (Vollenweider *et al*., 1998),

$$TRIX = \frac{k}{n}\sum_{i}^{n}\frac{(Log\ M - Log\ L)}{(Log\ U - Log\ L)_i},$$

Note: k= scaling factor (10); n= number of parameters (4); U= upper limit; L= lower limit; M= the average value of the parameter. The scaling factor is a measure of trophic level between 0-10 which indicates that the greater the index value, the higher the level of eutrophication in these waters (Table 1). The parameters used in the calculation of TRIX were chl-a, DIN, phosphate, and $DO_{saturation}$. $DO_{saturation}$ is the comparison of the measured DO value with the theoretical DO at the temperature at the time of measurement, multiplied by one hundred percent.

Principal Component Analysis (PCA) was conducted to descriptively describe the relationship between parameters, especially chl-a, and nutrients in Kendari Bay. The analysis was carried out using Minitab 17 software. In addition, a one-way analysis of variance (ANOVA) was also conducted to see the significance of differences in chl-a and nutrient concentrations spatially (a=0.5).

Table 1. Trophic Index (TRIX) Classification (Vollenweider *et al*., 1998)

TRIX Scale	Water Quality Status	Eutrophication Level
0.0 – 4.0	Oligotrophic	Low
4.1 – 5.0	Mesotrophic	Moderate
5.1 – 6.0	Eutrophic	High
6.1–10.0	Hypertrophic	Very High

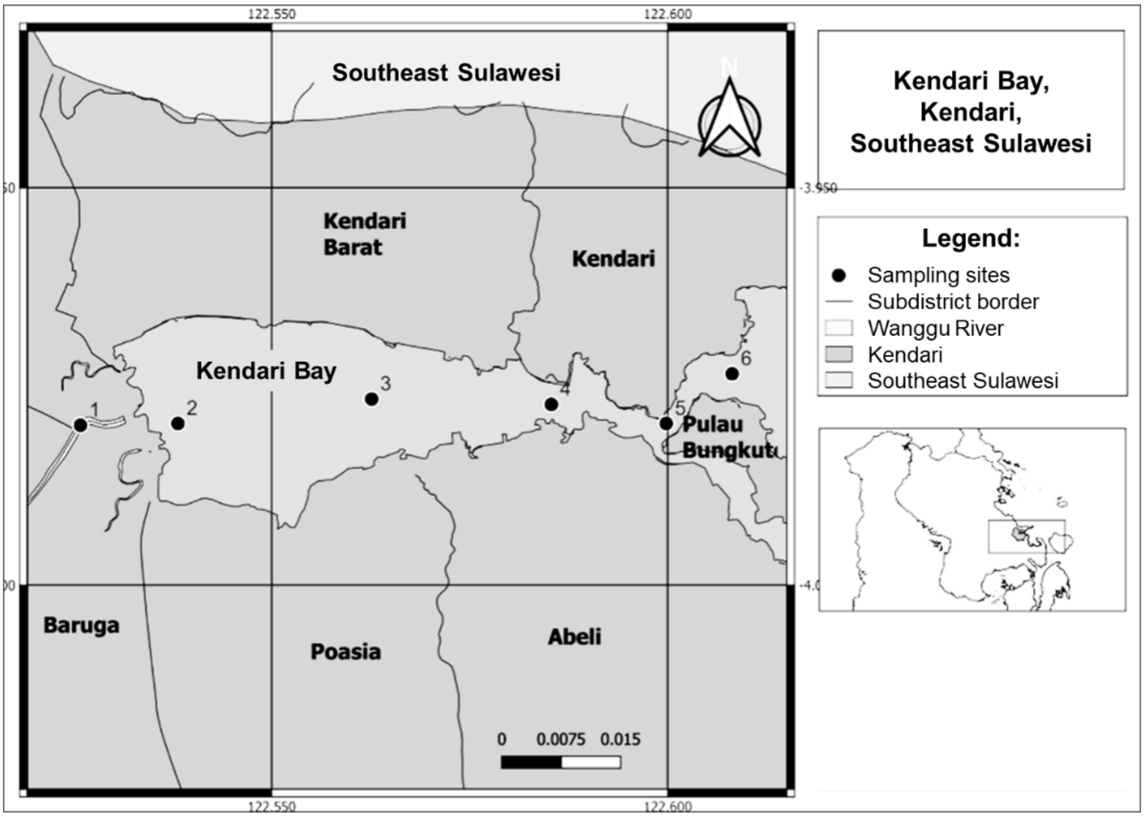

Figure 1. Kendari Bay sampling stations

RESULTS AND DISCUSSION

This study revealed that the distribution patterns of DIN, phosphate, and silica nutrients in Kendari Bay differed from each other Figure 2. The average concentration of DIN in Kendari Bay ranged from 0.2027 – 0.3867 mg/L. DIN managed to be concentrated in the port area or "neck area" (station 4, constricted waterway sections connecting broader areas), while lower concentrations were in the estuary area and the outer part of the bay (stations 2 and 6 respectively) (Figure 2A). The presence of mangroves in the estuary area of rivers or estuaries can reduce the concentration of nutrients in the waters. As stated by Adame & Lovelock (2011), mangrove forests can import dissolved nutrients from the land by absorbing them directly from the water and indirectly by absorbing them from the sediments deposited. The DIN in Kendari Bay was generally dominated by nitrate species with a proportion of more than 50%, except at station 4 (port area) which was dominated by ammonia (Figure 3). While the proportion of nitrite to DIN was less than 10% at all stations.

The mean phosphate ranged from 0.0420 – 0.0690 mg/L. The highest phosphate concentration was at station 3, while the lowest was at station 6. Phosphates were likely to be more intense in the inner part of the bay to the mouth of the river and low in the offshore part (Figure 2B). The slow current in the inner part of the bay has implications for the accumulation of phosphate in the bay, causing phosphate to tend to be higher in the inner part of the bay. The current speed in the bay is quite sluggish ranging from 0.0001 m/second to 0.6393 m/second (Ondara & Husrin, 2017).

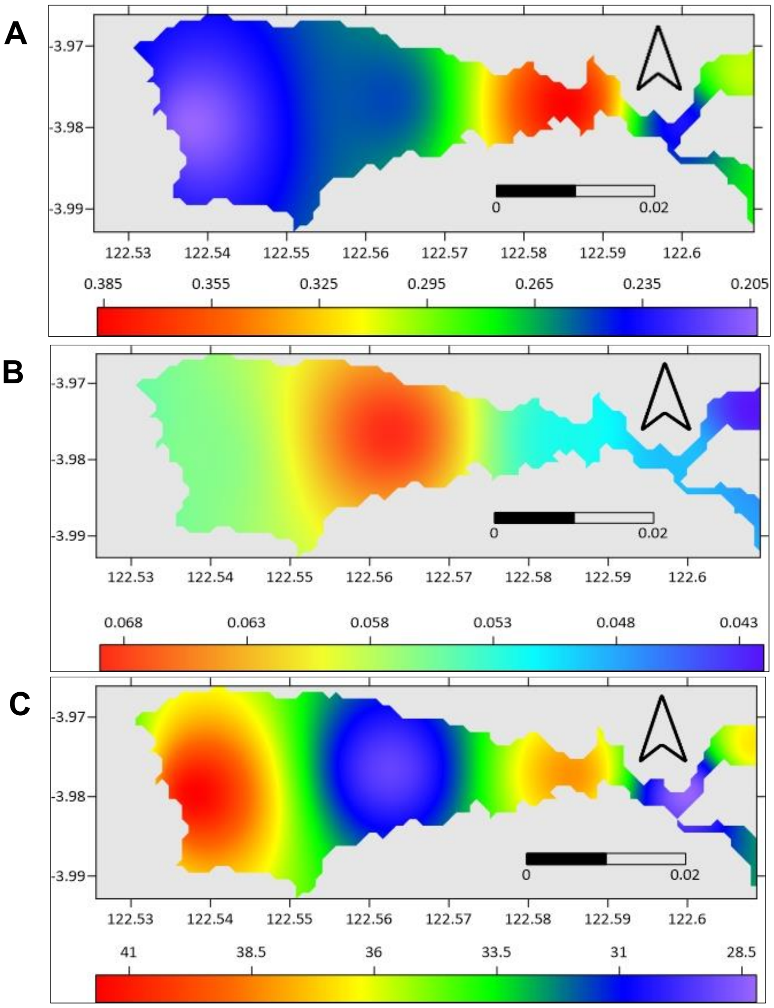

Figure 2. Distribution patterns of nutrients Dissolved Inorganic Nitrogen (DIN) (A), phosphate (B), and silicates in Kendari Bay (C) (mg/L)

The mean silicate concentration in Kendari Bay ranged from 28.18–41.69 mg/L. The highest silicate concentration was at station 2, while the lowest was at station 5. The silicate distribution was relatively higher in the river estuary, while the inner part of the bay was lower (Figure 2C). This is because silica in coastal waters derives from the weathering of rocks carried by river flows to the ocean (Ladwig *et al*., 2016; Liu *et al*., 2009), so the concentration was greater in the area. However, the results of the one-way ANOVA reveal that neither DIN, phosphate, nor silicate concentrations had significant differences spatially (p-value > 0.05).

The composition of nutrients in the waters affects the composition of phytoplankton in the waters. The optimal ratio between nitrogen and phosphorus in the waters is 16:1 referred to as the Redfield ratio (Redfield *et al*., 1963). Higher ratios indicate that phytoplankton growth tends to be limited by phosphorus, while lower ratios indicate limitation by nitrogen (Damar *et al*., 2012). Figure 4 reveals that the ratio of N:P was less than 16 which indicated phytoplankton growth was more limited by nitrogen than phosphorus.

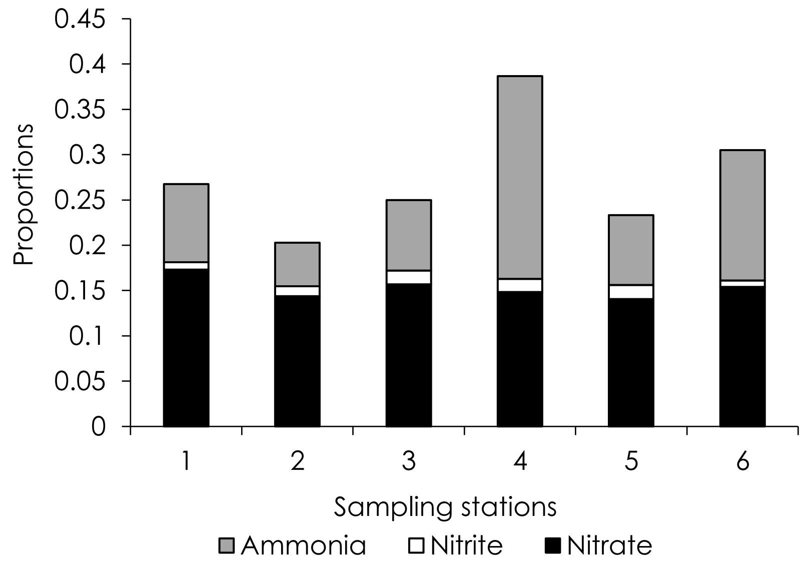

Figure 3. Proportion of nitrates, nitrites, and ammonia to DIN in Kendari Bay

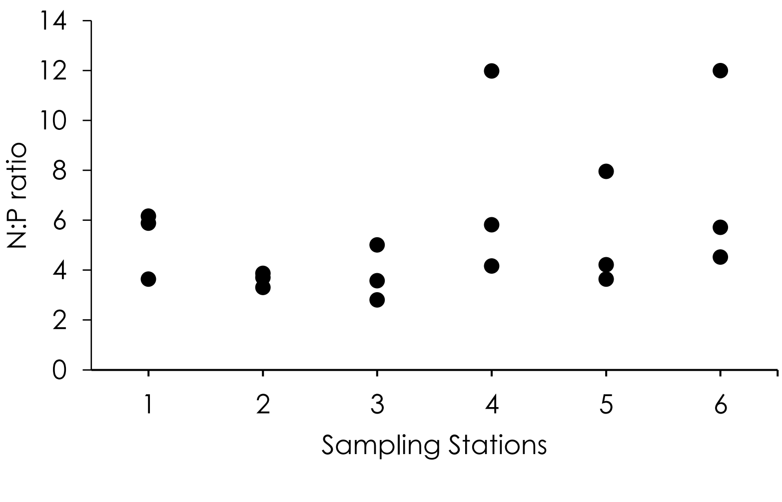

Figure 4. N:P ratio on each observation in Kendari Bay

The distribution of chl-a in Kendari Bay is presented in Figure 5. The mean concentration range of chl-a at the location was 0.68–6.24 mg/m^3. The concentration of chl-a tended to be higher and was spread in the "neck area" (station 4), while the low concentration was in the offshore area (station 6). The high concentration of chl-a in the "neck area" corresponded to the high concentration of DIN at the site. High concentrations of nutrients usually correspond to high concentrations of chl-a. Despite these results, statistically, the concentration of chl-a did not vary significantly between stations (one-way ANOVA, p-value > 0.05). Nevertheless, this pattern varied from the findings of Irawati (2014), whose research at the same location indicated that chl-a was concentrated in the estuary or mouth of the Wanggu River.

The relationship between chl-a and nutrients was examined through Principal Component Analysis (PCA). As much as 40.6% of the total variation could be explained by PC1 and 28.2% of the total variation could be explained by PC2. PC1 and PC2 explained 68.8% of the overall variation (Figure 6). The results exhibit that chl-a was positively correlated with nitrites and DO, and negatively correlated with nitrates. On the other hand, Chl-a was weakly correlated with phosphate, silicate, and ammonia.

Chl-a, nitrites, and phosphates tended to characterize station 5, while ammonia and silicates tended to characterize station 2. Meanwhile, stations 1 (Wanggu River estuary) and 6 (offshore) stand alone on the left and bottom of the diagram, while the other stations are on the right side of the diagram. This suggests that stations 1 and 6 had relatively different nutrient characteristics from other stations. Station 1 at the mouth of the Wanggu River was still heavily affected by freshwater input, while Station 6 on the outside of the bay was heavily affected by seawater dilution.

Generally, the development of chl-a follows the nutrient pattern (Damar *et al*., 2020). In this study, although the concentration did not vary significantly (one-way ANOVA p-value > 0.05), chl-a tended to follow the DIN pattern, which was high in the port area or "neck area" (station 4, constricted waterway sections connecting broader areas). The PCA results confirm that chl-a was characterized by DIN components, in particular nitrite and nitrate (Figure 6), though chl-a and nitrate were negatively correlated suggesting the utilization of nitrate by phytoplankton (Sridhar *et al*., 2006). This indicated that the presence of phytoplankton was more controlled by nitrogen nutrients than phosphorus nutrients supported by N:P ratios with a value of less than 16 (Figure 4). As stated by Damar *et al*., (2012), a ratio lower than 16 indicates a limitation by nitrogen for phytoplankton. This result is different from that in Jakarta Bay where the growth of phytoplankton in most areas was limited by phosphorus (Rahayu *et al*., 2019; Sidabutar *et al*., 2016).

Other water quality parameters measured including DO, pH, salinity, and temperature are presented in Figure 7. The concentration of DO ranged from 4.4–5.9 mg/L. The lowest DO concentration was at station 1 located on the Wanggu River, while the highest DO concentration was at station 4 which is the port or "neck area". Based on the one-way ANOVA, the DO value at the study site varied significantly (p-value 0.0182). The distribution pattern of oxygen concentration was consistent with chl-a, which was relatively high in the "neck area". Chl-a in phytoplankton is an important indicator for monitoring changes in phytoplankton abundance and also an important indicator of eutrophication (He *et al*., 2023). Phytoplankton, as primary producers, perform photosynthesis, which generates oxygen and leads to a high concentration of dissolved oxygen in the water.

The average pH range was 6.66–7.00. The highest pH was at station 6, located offshore of the bay, and the lowest pH was at station 1, located at the mouth of the Wanggu River. The pH at the study site was not statistically significant (p-value > 0.05). The salinity at the research site ranged from 10.7 – 33.7 ppt. The lowest salinity was at station 1 (mouth of the Wanggu River), while the highest was at station 6 (offshore). The salinity varied significantly (p-value 0.0245). The temperature at the six stations ranged from 28 - 30°C and was not significantly different (p-value > 0.05).

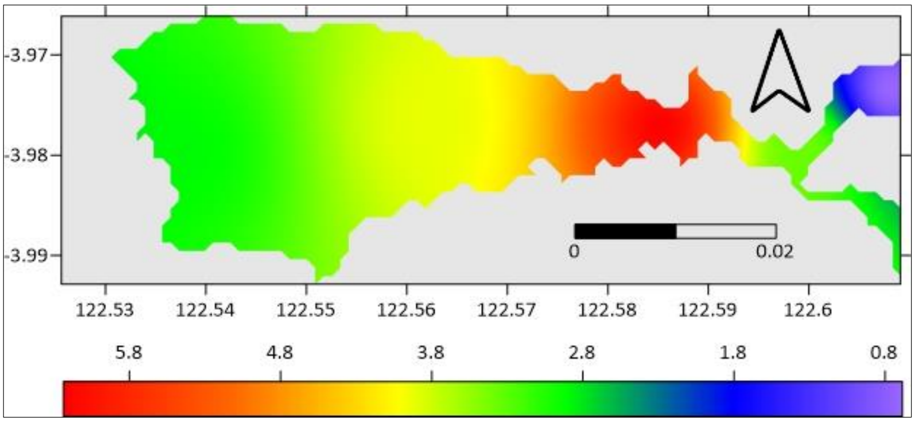

Figure 5. Distribution pattern of chlorophyll-a in Kendari Bay (mg/m³)

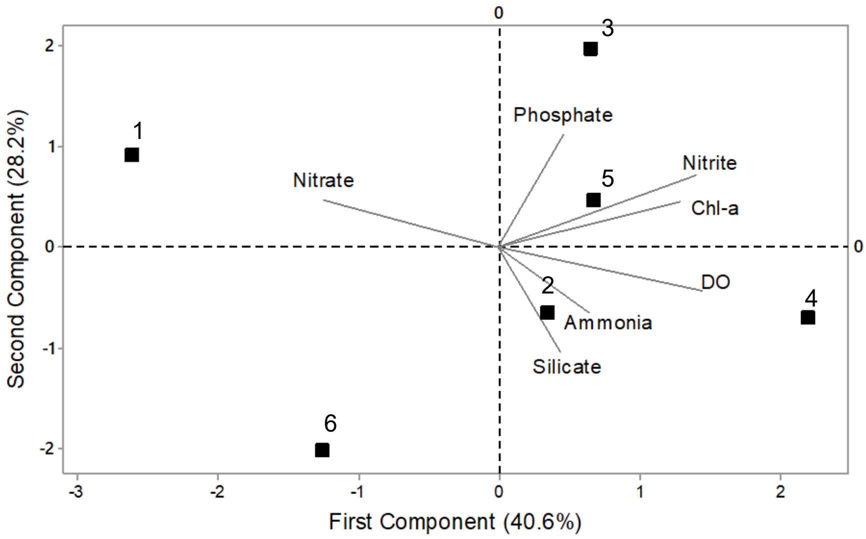

Figure 6. The Principal Component Analysis (PCA) results of chlorophyll-a (chl-a) and nutrients in Kendari Bay

Nonetheless, the results of ANOVA's one-way analysis of water quality parameters reveal that only DO and salinity were spatially significantly different (p-values of 0.0182 and 0.0245, respectively). While other parameters, such as DIN, phosphate, silicate, temperature, and pH were not significant (p-value > 0.05). This had implications for a uniform concentration of chl-a (one-way ANOVA, p-value > 0.05). This is influenced by the shallow (0-30 m) and semi-closed condition of Kendari Bay where the area of the western part of the bay is wider than the eastern part which is getting narrower (Imalpen *et al*., 2024), implying the flushing rate or residence time in this bay is relatively long. In keeping with Defne & Ganju (2014); Wang *et al*. (2007), flushing rates in the bay are influenced by several factors such as the volume of the bay, the presence of narrow openings that limit water exchange, and connectivity to larger bodies of water such as the sea. The flushing rate is the estimated time a body of water stays in a system. A longer flushing rate suggests that the solute or suspension is in the system for a longer time (Defne & Ganju, 2015; Wang *et al*., 2007). This factor allows water exchange or mixing to occur for longer which causes the water quality characteristics in the bay to not differ significantly spatially.

Kendari Bay was classified as mesotrophic or moderate trophic levels with a TRIX value range of 4.30-4.69 (Table 2). Although all stations were classified as mesotrophic, station 4 (the port/"neck area") had a relatively higher index value than the other stations. This is related to higher concentrations of chl-a, DIN, and DO in this area. The unique characteristics of Kendari Bay, as described prior, narrow towards the sea, shallow, and relatively slow flushing rates lead to uniform trophic characteristics throughout the section. This result is different from previous research in the same location (Irawati, 2014). According to the findings of Irawati (2014), Kendari Bay is classified as eutrophic to hypertrophic waters with a value range of 5,644-7,113.

The source of nutrients in Kendari Bay comes mostly from organic waste from human activities. The total population of Kendari City in 2023 was 351,085 people (BPS Kendari City, 2024). The people of Kendari City usually carry out activities around the bay. Activities carried out around Kendari Bay are fish landing activities at the Kendari Samudera Fisheries Port, crossing activities, tourism, and

Table 2. TRIX index calculation in Kendari Bay

Stations	TRIX Index	Water Quality Status	Eutrophication Level
1	4.30	Mesotrophic	Moderate
2	4.47	Mesotrophic	Moderate
3	4.46	Mesotrophic	Moderate
4	4.69	Mesotrophic	Moderate
5	4.59	Mesotrophic	Moderate
6	4.33	Mesotrophic	Moderate

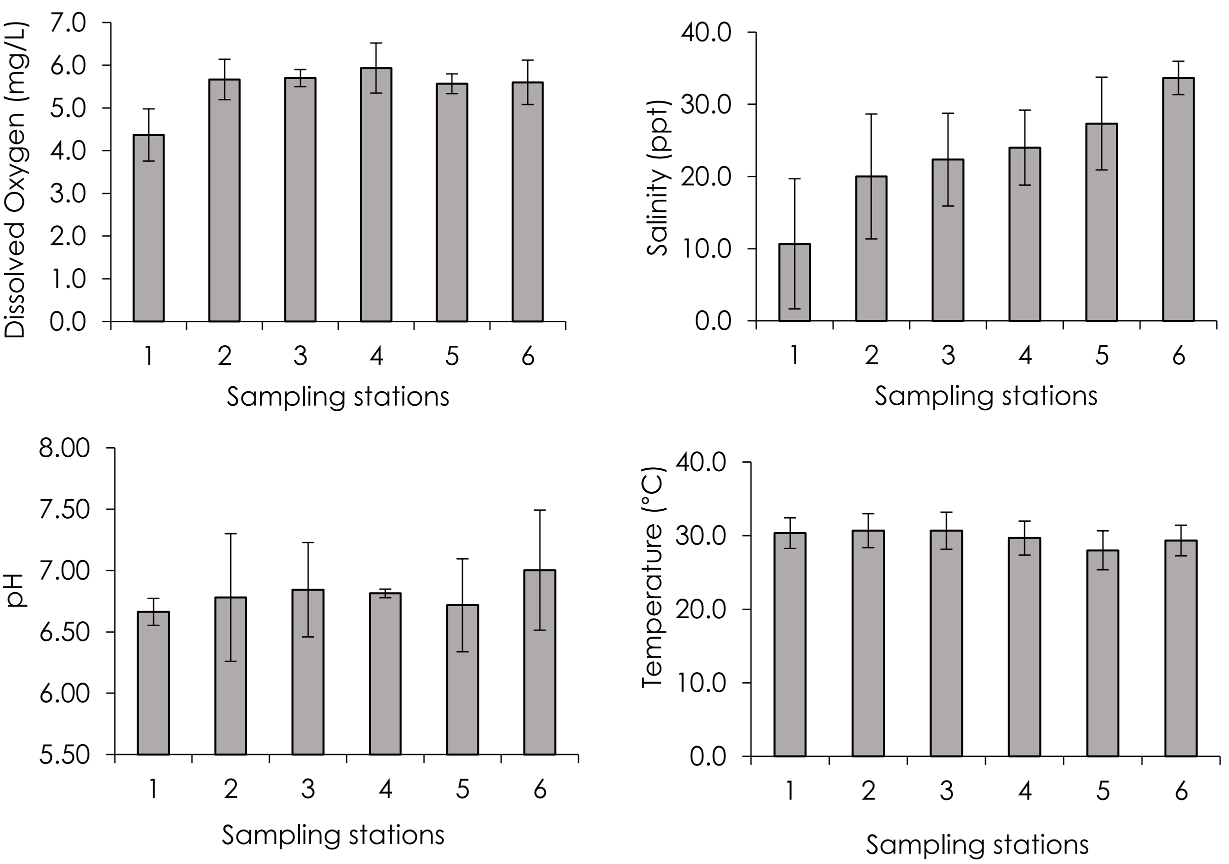

Figure 7. Mean values of dissolved oxygen (DO), pH, salinity, and temperature at the observation station

buying and selling activities at the Lapulu Market. In addition, nutrients that enter the waters of Kendari Bay also originate from land that is drained through rivers. Activities around Kendari Bay can affect the concentration of nutrients in the waters of the bay either directly or indirectly. Integrated management of human activities from upstream to downstream areas needs to be executed to prevent eutrophication and environmental degradation in the bay area, which can occur due to excess nutrient runoff from activities on land. This condition can reduce the quality of aquatic ecosystems and have a direct impact on the quality of life of people who depend on resources in the bay.

CONCLUSION

The nutrient distributions of DIN, phosphate, and silica show different patterns from each other. DIN concentrations are generally higher in the "neck area", while estuarine areas tend to be lower. Meanwhile, phosphates are more concentrated in the central part of the bay. On the other hand, silica has a higher concentration in estuarine areas. Chl-a tends to adhere to DIN, which suggests that phytoplankton growth is more constrained by nitrogen nutrients than phosphorus nutrients, as supported by an N:P ratio of less than 16. The trophic level of Kendari Bay is classified as mesotrophic throughout the observation site. The unique characteristics of Kendari Bay, which narrows towards the sea, relatively shallow depths, and relatively slow flushing rates, lead to relatively uniform trophic level throughout its territory. Hydrodynamics, geographic features, riverine inputs, and nutrient limitations are the main factors shaping nutrient and chl-a patterns in Kendari Bay. Effective management of human activities throughout upstream and downstream areas is necessary to protect the bay area from eutrophication and environmental harm.

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