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ECOLOGICAL PRESSURES IN PUSONG HARBOUR: INTEGRATED ASSESSMENT OF WATER QUALITY, NUTRIENT ENRICHMENT, AND POLLUTION INDEX

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ABSTRACT

Pusong Harbor in Lhokseumawe City doubles as a center for fisheries activities as well as a habitat for marine biota, making it vulnerable to pollution pressure from anthropogenic activities. This study aims to assess water quality through the analysis of physico-chemical parameters, nutrient content (nitrate and phosphate), pollution index, and spatial variation patterns using a multivariate approach. Measurements were taken at three stations representing the locations of boat moorings, settlements, and fish farms. The measurement results showed that basic parameters such as salinity (32-33‰), pH (7.5-8.0), dissolved oxygen (5.8-6.3 mg/L), and BOD (1.6-3.6 mg/L) were still within the quality standard range, but the brightness level was low (0.8-0.9 m) and the phosphate concentration was very high (7.2-10.1 mg/L), exceeding the quality standard by hundreds of times. The pollution index based on the harbor quality standard showed a Slightly polluted (PI = 1.09-1.11), but based on the marine biota quality standard it was classified as "heavily polluted" (PI = 10.3-10.9). PCA analysis identified phosphate and BOD as the dominant factors differentiating water quality, while temperature, salinity and DO were more reflective of natural conditions. Cluster analysis showed that stations 1 and 3 were similar, while station 2 differed significantly due to local pressures. This finding confirms the serious ecological pressures in the harbor area, especially due to excessive nutrient loads, and calls for pollutant control strategies and continuous monitoring to maintain the sustainability of coastal ecosystems. The study highlights the urgent need to address nutrient-driven pollution in Pusong Harbor, where phosphate concentrations exceed marine biota standards by hundreds of times despite most basic water parameters remaining within acceptable limits. This excessive nutrient load poses a serious threat of eutrophication, habitat degradation, and loss of biodiversity in a harbor that supports both fisheries activities and critical marine life. By integrating physico-chemical measurements, nutrient analysis, and multivariate statistics, the research identifies phosphate and BOD as key pollution drivers and reveals spatial variation linked to human activities. These findings provide evidence-based guidance for local management and policy, calling for targeted pollutant control and continuous monitoring to protect coastal ecosystems. The multivariate framework also offers a replicable approach for similar small-harbor environments across Southeast Asia.

***Keywords**: water quality, pollution index, PCA, cluster, nutrients, Pusong Harbour*

INTRODUCTION

Port pollution is a significant environmental concern, primarily arising from both air and water pollutants associated with maritime activities (Astou *et al.,* 2024). Ports contribute to pollution through emissions from vessels, cargo-handling equipment, and other operational activities, which release greenhouse gases and other pollutants into the atmosphere(Barberi *et al.,* 2021). Additionally, water pollution is caused by oil spills, ballast water discharge, fish farming activities, fishery household activities and waste disposal (Santosa, 2013). Polluted waters can experience metabolic disorders of the food chain, so that humans in a certain time can consume biota will experience health problems and accumulate in the body (Jiang & Kirsten, 2025). Areas exposed to pollutants usually

have a pungent odor, and the color of the water turns cloudy (Oktaviani *et al.,* 2023). Pusong waters in Lhokseumawe City, Aceh, have been utilized as a place for boat berthing, fishermen's settlements, as well as utilization as a fish farming area using floating jarring cages. Nitrate and phosphate play a major role in eutrophication events. Eutrophication, caused by excess nitrogen and phosphorus, leads to algal blooms, hypoxia and ecosystem disruption, impacting fisheries and local communities (Akinnawo, 2023). These nutrients mainly enter aquatic systems through agricultural runoff, sewage and aquaculture activities, posing challenges for water quality management. Nitrate and phosphorus originating from agricultural runoff causing difficult-to-control water pollution (Ngatia *et al.,* 2019), fish farming (Lazzari & Baldisserotto, 2015), and urban sewage and industrial effluents impacting water quality near fishermen's homes and boatyards (Weis, 2024).

In addition to eutrophication, nitrate and phosphate can cause other problems such as algae blooms, and can further disrupt the economy and ecology. Excessive nitrates and phosphates stimulate the growth of algae, which upon decay, deplete oxygen levels, causing hypoxic conditions detrimental to aquatic life(Ngatia *et al.,* 2019). Some algal species produce toxins, which cause health risks to humans and marine life, and can contaminate fish and shellfish, posing a risk to consumers (Weis, 2024). Eutrophication affects fisheries, tourism and local economies by altering food chains and causing fish kills (Ngatia *et al.,* 2019). It is feared that polluted aquaculture waters could have an effect on the fish farmed in the area (Martinez-Porchas, 2012). However, naturally the concentration of nitrate in seawater is only a few mg/L and is one of the compounds that function in stimulating the growth of marine biomass (Harvey, 1926), so that it directly controls the development of primary production so that it is closely related to the fertility of a water body (Ngabito, 2018). This study aims to assess the condition of seawater quality in Pusong Harbor based on physico-chemical parameters, nutrients (nitrate and phosphate), and pollution indices that refer to water quality standards. In addition, this study also aimed to analyze the relationship between water quality indicators using Pearson correlation, identify dominant factors that influence variations in water quality through Principal Component Analysis (PCA), and group water quality characteristics between stations with cluster analysis to understand the spatial pattern of pollution in the port area.

This research is important because Pusong Harbor in Lhokseumawe City is a coastal area with dual functions, namely as a center of fisheries activities, a location for fishermen's settlements, and a dense fish farming area. The complexity of these activities has the potential to increase pollutant pressure, especially from nutrient and organic matter inputs that can trigger eutrophication, reduce dissolved oxygen, and disrupt the sustainability of coastal ecosystems. Information on the actual condition of water quality in this area is still very limited, even though economically and ecologically the area has a strategic role for the community and the coastal environment. Therefore, the results of this study are expected to provide a comprehensive picture of the status of water quality while identifying key parameters that must be controlled, so that it can become a scientific basis in the formulation of pollution mitigation strategies and efforts to maintain a balance between port utilization and the sustainability of the marine ecosystem.

MATERIALS AND METHODS

Time and Place

The research was conducted in June 2023 at the Pusong Fish Landing Base (PPI), Banda Sakti District, Lhokseumawe City, Aceh Province. Lhokseumawe City based on its geographical situation is a large coastal area and has a very strategic role so that it can support national development. Lhokseumawe City is also the center of economic growth supported by several public facilities, such as coastal beaches that are used as marine tourism sites, public ports, and there are capture fisheries activities centered on the Pusong Fish Landing Base (PPI) (**Figure 1**).



Figure 1. Research Location

Procedures

Tools used in this study include: 100 mL sample bottle, 10 L bucket, GPS, stationery, Multi Tester, Secchi Disk, and analytical scales. The materials used in this study were sulfuric acid (H_2SO_4), sodium nitrate ($NaN0_3$), distilled water, and measuring flasks. The research location was determined using a purposive sampling method by determining the research location based on locations that are considered to have the potential as areas that accommodate excess pollutant loads and have a negative impact on biota that will be utilized by humans, so that the selection of areas based on the characteristics of the area can be seen in **Table 1.**

Table 1. Coordinates and characteristics of the study site

No.	Observation Station	Coordinate	Area Characteristics
1	Station 1	5°10'05.1"N - 97°08'08.4"E	The place where the ship docks
2	Station 2	5°10'00.2"N - 97°08'52.5"E	Residential areas
3	Station 3	5°10'00.6"N - 97°09'01.0"E	Fish farming

Seawater sampling is done with 3 repetitions at each station which aims to make the data obtained more accurate. Water sampling is carried out in the morning, with a distance of 10 meters perpendicular to the direction of the sea. The method used in sampling is purposive sampling method (Puspitasari *et al.,* 2020).

Seawater samples are taken using a sterile 100 mL sample bottle by inserting the bottle to a depth of 15 cm from the surface of the water, and closed with the position of the bottle still in the water column (Mijaya *et al.,* 2019). The sample bottle is then stored in cold conditions in a cool box, before it will be analyzed in the laboratory. Measurements of several water quality parameters such as salinity, temperature, pH, and dissolved oxygen (DO) were also taken at the seawater sampling locations at each station. Brightness measurement using secchi disk. With further analysis as follows:

$$K = \frac{(D1 + D2)}{2} \qquad (1)$$

Where, K is Secchi disk brightness; D1 is Depth of water when the Secchi disk starts to become invisible; D2 is Depth of water when the Secchi disk starts to be visible

Temperature measurements using a thermometer in units of °C. salinity is carried out directly at each observation station using a calibrated hand refractometer. Measurement of pH is done directly at each observation station using a calibrated pH meter. Dissolved oxygen measurements were made directly by inserting the tip of the pen on the DO meter into the water. The DO value indicated on the device is then recorded and at each observation station using a calibrated DO meter in mg/L units. BOD analysis was conducted based on (Ayuni & Bimantara, 2023).

The principle of BOD measurement is basically quite simple, namely measuring the initial dissolved oxygen content (DO1) of the sample immediately after sampling, then measuring the dissolved oxygen content in samples that have been incubated for 5 days in dark conditions and a fixed temperature (20°C) which is often referred to as DO5. The difference between DO1 and DO5 (DO1 - DO5) is the BOD value expressed in milligrams of oxygen per liter (mg/L). BOD measurement is done with a DO meter.

Nitrate analysis was conducted based on the nitrate-nitrogen measurement technique with the Brucine method (Mariyam, 2016), with a spectrophotometer method (SNI 06-2480-1991) at a wavelength of 420 nm. The nitrate measurement procedure was carried out by making a standard series solution first with a concentration of 0 mL; 0.2 mL; 0.4 mL; 0.6 mL; 0.8 mL; and 1.0 mL. The next stage the sample water was put into a 50 mL beaker glass. The standard series and samples were then added with 0.5 mL of brucine sulfate reagent and 5 mL of concentrated H_2SO_4, then the solution was allowed to cool for 30 minutes. The cooled solution was then measured for absorbance using a spectrophotometer at a wavelength (λ) of 420 nm with distilled water as a blank, then the measurement results were recorded.

Determination of total phosphate content was carried out using the ascorbic acid spectrophotometer method (SNI 06-69899.31-2005). The total phosphate measurement procedure was carried out by making a standard series first. In the range of levels 0.0 mg P/L to 1.0 mg P/L. The principle of this method is based on the formation of a blue phospholybdate complex compound. The complex is then reduced with ascorbic acid to form a blue color molybdenum complex. The intensity of the color produced is proportional to the phosphorus concentration. The blue color is

measured with a spectrophotometer at a wavelength of 700 nm-880 nm.

Data Analysis

Correlation of physico-chemical indicators in Pusong Harbour

The analysis of water quality in Pusong Harbor was conducted using a multivariate statistical approach to determine the relationship between physico-chemical indicators and their interrelationship patterns between stations. First, Pearson correlation analysis was conducted to determine the closeness of the linear relationship between variables. Correlation was calculated using the equation (Zar, 1999):

$$r_{xy} = \frac{\sum(X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum(X_i - \bar{X})^2 . \sum(Y_i - \bar{Y})^2 .}} \quad \text{..... (2)}$$

Where, r_{xy} is Pearson correlation coefficient between variables X and Y; $\bar{X}$ dan $\bar{Y}$ is the mean value of each variable, and Xi, Yi are the i-th observation values. The coefficient ranges from -1 to +1, with values close to +1 indicating a strong positive correlation, while close to -1 indicates a strong negative correlation.

Water Pollution Index (IP) in Pusong Harbour

Sampling that has been done at each station, the parameter values are obtained. The next step is to calculate using the Pollution Index (IP) method in order to determine the quality status at each station. The pollution index is a way of determining the level of pollution in a body of water based on water quality parameters. Determination of pollution status is determined by using the pollution index using Numerow index (Sudirman *et al.* 2013), Nemerow's pollution index calculated by the following formula:

$$\mathrm{PI_j} = \sqrt{\frac{\left(\frac{Ci}{Lij}\right)_M^2 + \left(\frac{Ci}{Lij}\right)_R^2}{2}} \quad \text{..... (3)}$$

Where, L_i is Concentration of water quality parameters in the water designation quality standard (j); C_i is Concentration of water quality parameter from the survey; Plj is Pollution index for designation (j); $(C_i/L_{ij})_M$ is Maximum Ci/Lij value; $(C_i/L_{ij})_R$ is Average Ci/Lij Value

The relationship between the level of pollution and the pollution index criteria based on the Decree of the Minister of Environment Number 115 of 2003 concerning Determination of Water Quality Status as follows:

$0 \le PI_j \le 1$	:	Good condition
$1 < PI_j < 5_i$	:	Slightly polluted
$5 < PI_j \le 10$	:	Moderately polluted
$PI_j > 10$	:	Heavily polluted

Multivariate Patterns of Water Quality Variation in Pusong Harbor

Principal Component Analysis (PCA) was conducted to reduce the dimensionality of the data and identify the dominant variables that influence variations in water quality. PCA is based on the eigenvalue decomposition of the covariance or correlation matrix. PCA was selected to address the multivariate and highly inter-correlated nature of coastal water-quality data. Water samples typically contain numerous physico-chemical and nutrient parameters, many of which are strongly correlated, such as nitrate with biochemical oxygen demand or phosphate with salinity gradients. PCA reduces this complexity by transforming the original variables into a smaller set of independent principal components, allowing the identification of dominant pollution drivers while separating natural environmental variation (e.g., temperature and salinity) from anthropogenic signals. This dimensionality-reduction approach enhances the reliability of pollution-index interpretation by revealing which variables most influence spatial and temporal differences in water quality. The covariance matrix C is calculated by:

$$C = \frac{1}{n-1}(X - \bar{X})(X - \bar{X})^T \quad \text{..... (4)}$$

where X is the standardized data matrix, and nnn is the number of samples. The eigenvalues (λ) and eigenvectors (e) are obtained from the characteristic equation (Hair *et al.,* 2010):

$$Ce = \lambda \mathrm{e} \quad \text{..... (5)}$$

Cluster of Physics-Chemical Indicators in Pusong Harbor Waters

Cluster analysis complements PCA by grouping sampling stations according to the similarity of their overall chemical profiles. This technique highlights spatial patterns of contamination, distinguishing sites that share comparable pollution characteristics and detecting hot spots or outliers that may require targeted management actions. When used alongside a pollution index such as the Nemerow Index, cluster analysis verifies whether high index

values correspond to specific geographic zones and supports evidence-based zoning or mitigation strategies. Together, PCA and cluster analysis provide a robust multivariate framework for understanding the ecological gradients and anthropogenic pressures shaping coastal water-quality conditions. The principal component with the largest eigenvalue represents the most significant proportion of data diversity. To complete the analysis, a hierarchical clustering analysis was also conducted using the Euclidean distance measure. The distance between samples was calculated using the equation:

$$d_{ij} = \sqrt{\sum_{k=1}^{p} \left(x_{ik} - x_{jk}\right)^2} \quad \text{..... (6)}$$

where d_{ij} is the distance between samples i and j, x_{ik}, x_{jk} are the kth variable values in each sample (Kaufman & Rousseeuw, 1990). The clustering results were visualized in the form of a dendrogram to see the level of similarity between stations based on water quality parameters.

RESULT AND DISCUSSION

Water Quality Measurement in Pusong Harbour

The relationship between water quality variables (pH, salinity, temperature, dissolved oxygen DO and BOD) and nitrate and phosphate measurements is complex and influenced by various environmental factors. These variables interact to influence the concentration and distribution of nitrate and phosphate in the aquatic environment, which are important indicators of water quality and ecosystem health. pH can affect the solubility and availability of nutrients such as nitrate and phosphate. pH values found within the normal range, support ecosystem productivity (Jikumerasa *et al.,* 2015). Variations in pH can affect the chemical forms of nitrogen and phosphorus, impacting their uptake by aquatic organisms (Voutsa et. al., 2000). Salinity has an impact on nutrient distribution. Higher salinity is often correlated with lower nutrient concentrations. In the coastal region of Chattogram, salinity fluctuates seasonally, which affects nitrate and phosphate level (Rahman *et al.,* 2023). The salinity gradient from estuary to sea affects nutrient concentrations, with higher levels typically found in estuarine areas (Rustiah *et al.,* 2019). Temperature affects the metabolic rate of aquatic organisms and the solubility of gases, which affects nutrient cycling. Warmer temperatures can increase microbial activity, enhancing organic matter decomposition and nutrient release (Kermovant *et al.,* 2023). **Table 2** shows the results of water quality measurements as well as nitrate and phosphate at the observation stations.

Table 2. Water quality measurement results

Parameter	Kualitas air		
	Stasiun 1	Stasiun 2	Stasiun 3
Brightness (m)	0.93 ± 0.00	0.92 ± 0.00	0.82 ± 0.04
Temperature (°C)	30.83 ± 0.14	32.09 ± 0.20	31.61 ± 0.09
Salinity (‰)	32.71 ± 0.31	32.95 ± 0.03	32.85 ± 0.11
pH	7.55 ± 0.25	8.05 ± 0.45	7.73 ± 0.15
DO (mg/L)	5.80 ± 0.46	6.17 ± 0.35	6.27 ± 0.45
BOD (mg/L)	3.57 ± 1.34	1.60 ± 0.17	2.17 ± 0.15
Nitrate (mg/L)	0.03 ± 0.01	0.03 ± 0.01	0.02 ± 0.01
Phosphate (mg/L)	7.91 ± 2.41	10.05 ± 4.63	7.22 ± 0.64

Seasonal temperature variations are associated with changes in nutrient levels, with higher concentrations during the rainy season (Rahman *et al.,* 2023). DO levels are critical for the oxidation of nitrogen compounds. High BOD can lead to oxygen depletion, which affects nitrate and phosphate dynamics (Voutsa *et al.,* 2000). Adequate DO levels can support normal nutrient cycling and productivity (Patty *et al.,* 2015). Although these factors are interrelated, their influence on nitrate and phosphate levels can vary significantly depending on local environmental conditions and anthropogenic activities. Understanding these relationships is critical for effective water quality management and ecosystem conservation.

The results of water quality measurements at three stations show an unbalanced condition between physico-chemical parameters that are relatively favorable with nutrient parameters that far exceed the quality standards, so that ecologically it has the potential to suppress the sustainability of marine biota. Basic parameters such as salinity (32-33‰), pH (7.5-8.0), and dissolved oxygen (5.8-6.3 mg/L) are still within the range that can support the life of marine organisms in accordance with PP No. 22 of 2021, even DO has met the minimum requirement of >5 mg/L for aquatic biota. The relatively low BOD (1.6-3.6 mg/L) also indicates that the dissolved organic matter load is not too high, so it does not directly suppress DO. However, two main issues may arise: first, the brightness level was only 0.8-0.9 m, far below the quality standard of >6 m brightness to support phytoplankton photosynthesis and coral growth, indicating high turbidity due to suspended sediments or land runoff. Second, nutrient concentrations, especially nitrate (0.02-0.03 mg/L) and phosphate (7.2-10.1 mg/L), were recorded far above the quality standards for marine life (nitrate max. 0.008 mg/L; phosphate max. 0.015 mg/L), with differences

reaching tens to hundreds of times. This condition is very worrying because it can trigger eutrophication, algal bloom, a drastic decrease in dissolved oxygen at night, and lead to mass death of aquatic organisms and damage to coral reefs. Coupled with moderately high waters temperatures (30.8-32.1 °C), Slightly above the ideal range of 27-30 °C, the potential for thermal stress on marine biota is even greater, especially on corals that are prone to bleaching. Thus, although some parameters still meet the standard, the combination of low brightness, high temperature and excessive nutrient content clearly indicates that the waters in the study site are under serious ecological pressure and do not meet optimal conditions for the sustainability of marine biota ecosystems, so mitigation efforts such as controlling sediment runoff, managing sources of nutrient pollution, and periodic monitoring are needed to prevent further ecosystem degradation.

Correlation of Physico-Chemical Indicators in Pusong Harbour

Pearson correlation coefficient (r) is a statistical measure used to evaluate the strength and direction of linear relationships between two continuous variables, ranging from −1 (perfect negative correlation) to +1 (perfect positive correlation). The correlation heatmap presented in this study (**Figure 2**) illustrates the degree of association among key physicochemical indicators of water quality, including dissolved oxygen (DO), biochemical oxygen demand (BOD), nutrients (phosphate and nitrate), pH, salinity, temperature, and water brightness.

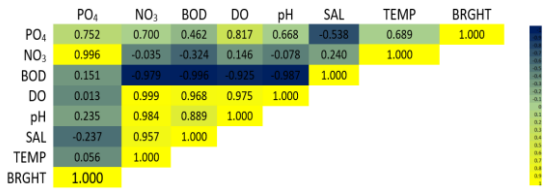


Figure 2. Pearson's correlation of physico-chemical indicators in Pusong Harbour

In aquatic environmental studies, correlation analysis provides valuable insights into the interdependence of water quality parameters, allowing researchers to identify potential redundancy among variables, infer underlying ecological processes, and support the interpretation of pollution dynamics.

The results reveal several ecologically meaningful patterns. A strong negative correlation between BOD and DO ($r \approx -0.9$) confirms the well-established relationship whereby higher organic loads increase oxygen consumption during microbial decomposition, thereby reducing oxygen availability in the water column. Similarly, DO demonstrates a strong positive correlation with pH, reflecting the role of photosynthetic activity in simultaneously elevating oxygen concentrations and shifting the carbonate equilibrium towards higher pH during daylight hours. Nutrients also exhibit notable associations: phosphate and nitrate are strongly and positively correlated, suggesting a common anthropogenic source such as domestic or agricultural runoff. Their positive association with BOD further indicates that nutrient enrichment may enhance primary production and subsequent organic matter decomposition. In addition, water brightness shows a positive correlation with both DO and pH, consistent with enhanced photosynthesis under clearer water conditions.

Nevertheless, some correlation coefficients approach values of ±1.000, which is unusual in natural ecosystems and may indicate potential data limitations such as small sample size, collinearity among variables, or measurement redundancy. Despite these caveats, the correlation matrix provides important diagnostic information. The clustering of high positive correlations among nutrients, BOD, and pH alongside the strong negative relationship with DO highlights a characteristic eutrophication signal, which is of significant concern for water quality management. These findings emphasize the importance of reducing external nutrient and organic matter inputs to mitigate oxygen depletion and preserve ecological balance.

Pollution Index at Pusong Harbor

The results of the pollution index analysis based on port quality standards (**Figure 3**) show that the three stations in Pusong Harbour are in the mild condition category, with pollution index values ranging from 1.09-1.11.

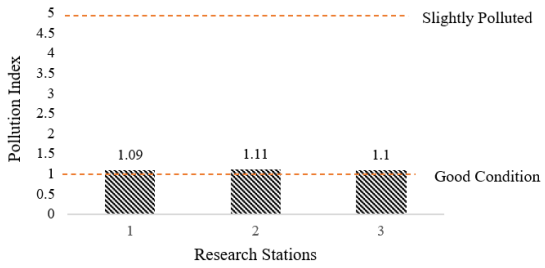


Figure 3. Pollution index in Pusong Harbor based on harbor quality standards

This value is Slightly above the threshold of 1.0, but still far from the Slightly polluted category. This condition indicates that from the perspective of port designation, the water quality at the three stations is relatively well maintained and has not shown significant symptoms of pollution. The relatively small variation in values between stations indicates that the distribution of environmental stress within the harbor area is fairly uniform.

In contrast, the pollution index based on the quality standard for marine biota designation (**Figure 4**) gives a different picture. The pollution index values at all stations are in the range of 10.33-10.85, which puts the waters in the Heavily pollution category. This shows that although the waters still meet the standards for port activities, but to support the sustainability of marine biota ecosystems, these conditions are already at an alarming level of pollution. Increased nutrient loads and organic matter are likely to be the main factors driving the high pollution index for ecological uses.

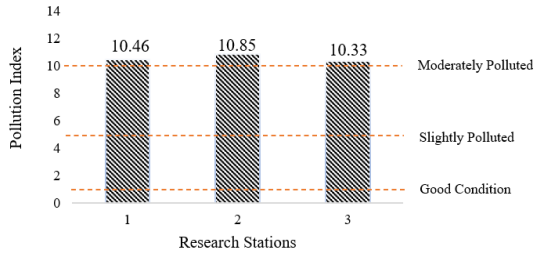


Figure 4. Index of seawater pollution in Pusong Harbor for marine biota.

The difference in assessment results based on the two quality standard references confirms that the function of waters as a port and as a habitat for marine biota has a different sensitivity to pollutant pressure. Waters that are still considered suitable for port activities are not necessarily ideal for the sustainability of marine organisms, especially sensitive biota such as coral reefs, reef fish, and plankton. This finding underscores the importance of applying double standards in coastal water quality management: one side to support utilization activities, and the other side to ensure the sustainability of marine ecosystems. Thus, the management strategy in Pusong Harbor needs to be directed towards stricter control of pollutant loads, especially related to nutrient and organic matter inputs, so that the dual function of waters as a port area as well as a habitat for marine biota can be maintained. the surrounding environment. Due to the large number of community activities in Pusong PPI, which resulted in high concentration values of some parameters such as phosphate. resulting in high concentration values of some parameters such as phosphate.

In designing effective management policies, policymakers must carefully compare pollution status based on both marine biota and harbor standards, especially in areas where high contamination coincides with intensive fish-farming activities. Such dual assessment is crucial because pollution from harbor use and aquaculture operations may directly affect marine organisms that enter the human food chain, posing ecological and public-health risks.

Multivariate Patterns of Water Quality Variation in Pusong Harbor

Principal component analysis (PCA) showed that the variation in water quality at the three stations was mainly influenced by the parameters, they are phosphate, BOD, and a group of physical-chemical variables consisting of temperature, salinity and DO. The phosphate vector has a large contribution to Component 1 in a positive direction, while BOD is more dominant in component 2 in the opposite direction. The temperature, salinity, and DO variables tend to cluster with consistent contributions in the lower quadrant of the biplot. Brightness, nitrate, and pH parameters have relatively short vector lengths so that their contribution to the two main components is not as large as the other parameters. The distribution pattern of the station points in the biplot shows that there are differences in conditions between stations, where some station samples tend to be associated with high phosphate and BOD values, while others are closer to the physical-chemical characteristics of the waters. The results of the PCA analysis (**Figure 5**) show that phosphate and BOD parameters are the main factors that differentiate the water quality conditions at the study site.

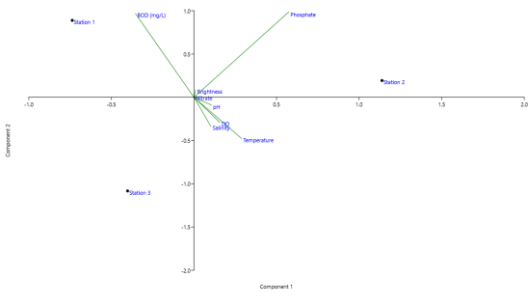


Figure 5. Principal Component Analysis (PCA) of Physics-Chemical Indicators in Pusong Harbor Waters

In contrast, temperature, salinity, and DO form a variable group that reflects the natural conditions of the waters, as these parameters are typically controlled by ocean circulation and water mass exchange. The strong contribution of phosphate and organic-related parameters indicates substantial nutrient inputs, commonly linked to terrestrial sources such as domestic waste, agriculture, and other coastal activities.Similarly, high BOD indicates an organic load that can reduce dissolved oxygen levels and ultimately affect the balance of the aquatic ecosystem. This suggests a clear distinction between the influence of natural factors and pressures due to anthropogenic activities. The distribution of station points in the PCA biplot showed that some station samples were more closely associated with high phosphate and BOD, while others were more closely associated with physical-chemical factors. This pattern indicates both spatial and temporal variations in water quality. Stations that tend to be associated with phosphate and BOD can be considered more susceptible to anthropogenic pressures, while stations close to temperature, salinity and DO variables reflect relatively more natural water conditions.

Spatial relationship pattern of water quality based on cluster analysis in Pusong Harbor.

The results of the hierarchical cluster analysis support the PCA pattern, where station 1 and station 3 form one relatively similar group, while station 2 is separate and only joins at a higher distance level. This indicates that the water quality of stations 1 and 3 have similar characteristics, while station 2 is more distinct than the other two stations. Cluster analysis (**Figure 6**) supports the PCA results by showing that station 1 and station 3 have similar water quality characteristics, while station 2 is quite different. This difference is likely influenced by local factors, such as proximity to the estuary, intensity of human activities around the water, or differences in current circulation patterns.

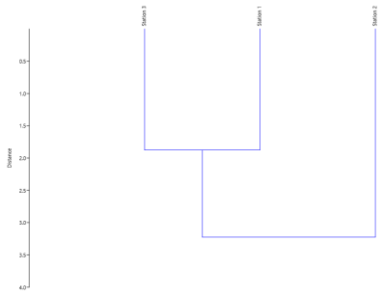


Figure 6. Hierarchical Clustering Physics-Chemical Indicators in Pusong Harbour Waters

This finding is important because it shows that even though the stations are in the same area, water quality conditions can vary significantly depending on external pressures and local oceanographic characteristics. Ecologically, the dominant influence of nutrient and organic loads at some stations needs attention, because it has the potential to trigger eutrophication, reduce water clarity, and impact the health of coral reef ecosystems. Therefore, continuous monitoring and control of pollutant sources are important in maintaining water quality to support the sustainability of coastal ecosystems. Station 2 represents a settlement area, so its ecological meaning is closely tied to nitrogen (nitrate) and phosphorus (phosphate) inputs from human habitation. Household wastewater and surface runoff typically contain detergents, food residues, and other organic material that release dissolved inorganic nitrogen and phosphorus directly into coastal waters. Elevated nitrate and phosphate concentrations stimulate phytoplankton growth, increasing the risk of eutrophication and harmful algal blooms. As algae die and decompose, the process further raises biochemical oxygen demand, potentially lowering dissolved oxygen and stressing fish and invertebrates. Because Pusong Harbor supports fisheries and aquaculture, excess nitrate and phosphate from the residential zone can degrade habitat quality and affect the safety and productivity of seafood resources, underscoring the need for effective domestic-waste management and continuous nutrient monitoring.

CONCLUSIONS AND SUGGESTION

This study shows that there is an imbalance between the basic parameters of water quality that are still in accordance with the quality standards and the excessive nutrient content in Pusong Harbor. The pollution index based on the harbor quality standard indicates a mildly polluted condition, but based on the marine biota quality standard, it has reached the heavily polluted category. Multivariate analysis confirmed that phosphate and BOD were the main factors influencing spatial variation in water quality, with station 2 showing the most distinct characteristics due to anthropogenic pressures. Ecologically, these conditions could potentially lead to eutrophication, reduced habitat quality and risk of ecosystem degradation. Therefore, port area management needs to focus on controlling nutrient-based pollutant sources especially phosphates and nitrates, reducing organic waste, and regularly monitoring water quality to support the

sustainability of Pusong Port's dual function as a fisheries center and marine biota habitat.

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