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Seasonal Changes in Water Quality in the Coastal Area of Xiangshan, China

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Abstract

The aim of this study was to investigate the seasonal variation of water quality in the coastal region of Xiangshan, China, and the main environmental factors affecting water quality. The study collected surface water samples from eight monitoring stations for water quality testing in summer, autumn and winter. Through principal component analysis (PCA) and correlation analysis, the study revealed the seasonal variation patterns of water temperature (WT), dissolved oxygen (DO), pH, electrical conductivity (EC), nutrients (N, P) and organic matter (TC and TOC). The results showed that DO was the highest in winter, pH was the highest in autumn, while EC decreased gradually with time. Seasonal variations of nutrient salts and organic matter were significant, with NH4+-N, NO-2-N and PO3-4-P being the highest in winter and NO-3-N in summer. In addition, PCA revealed correlations between physicochemical variables, where PC1 was mainly composed of PO3-4-P, NO-2-N, pH, NH4+-N, DO, and WT, while PC2 was mainly composed of NO-3-N, TN, TOC, EC, and WT. The results of the study provide a scientific basis for understanding how human activities and natural factors jointly affect coastal ecosystems and help to develop effective conservation measures.

Keywords: Principal component Analysis; Marine water quality; Seasonal variation; Filtration; Environmental factors

Abbreviations: PCA: Principal Component Analysis; WT: Water Temperature; DO: Dissolved Oxygen; EC: Electrical Conductivity; TN: Total Nitrogen; TOC: Total Organic Carbon; TC: Total Carbon; ANOVA: Analysis of Variance

Introduction

Water, the most vital resource for all forms of life, has been severely affected by human activities. In response to this situation, humankind has rapidly stepped up its efforts to combat this impact. Since the industrial revolution, natural and polluted water bodies have been intensively studied throughout the world [1-3]. Considerable data are now available on most types of pollutants and their effects on ecosystems as well as living organisms.

Coastal zones, as valuable and fragile ecosystems of the planet, are not only critical to biodiversity but also of irreplaceable value to human societies [4]. Fourteen of the world's 17 largest cities are located in coastal zones, making coastal areas one of the most significantly affected by human activities. Eutrophication, hypoxia and other human-induced environmental problems are becoming increasing challenges in many estuaries and coastal areas, from developed to developing countries [5]. Over the past decades, the impacts of natural factors and human activities have led to a significant deterioration of environmental indicators, posing a serious threat to marine biodiversity and the health of coastal ecosystems [6,7]. Waste discharges, overfishing and accidents (e.g. oil pollution) are the main environmental threats to coastal water quality [8,9].

Water quality is affected by biological, chemical and physical factors and can even be assessed by them. In a mature system, water temperature regulates the rate of all chemical reactions and affects fish growth, reproduction and immune function. Fish may die as a result of sudden temperature changes. The rates of biological and chemical processes depend on temperature. Aquatic organisms from bacteria to fish require different temperatures for optimal health. The rate of photosynthesis in aquatic plants, the metabolic rate of aquatic organisms, and the susceptibility of organisms to toxic wastes, parasites, and disease are all affected by temperature [10]. The pH is the most critical factor in determining the corrosiveness of water; the more corrosive the water, the lower the pH. Decreased rates of photosynthesis and assimilation of carbon dioxide and bicarbonate in the summer ultimately lead to higher pH, as both a decrease in oxygen and an increase in temperature occur in the summer. Seasonal variations in nutrient salts (N, P) and organic matter (C) are also significant.

Problems of data reduction and interpretation, characteristic variation in water quality parameters, and identification of indicator parameters can be addressed through the use of Principal Component Analysis (PCA), which are multivariate statistical techniques used to identify the significant components that explain much of the variation in a system. They are designed to reduce the number of variables to a small number of indicators (i.e., principal components) while attempting to maintain the relationships present in the original data. Detailed information on techniques for mastering PCA can be found elsewhere [11].

In the coastal area of Xiangshan, China, eight monitoring stations were set up in this study and surface water samples were collected for water quality testing in summer, autumn and winter. This testing aims to reveal the main environmental factors affecting water quality and to analyze the pattern of their changes with seasons. Through these data, we can better understand how human activities and natural factors jointly affect coastal ecosystems, and thus provide a scientific basis for formulating effective conservation measures to maintain the health and biodiversity of aquatic ecosystems.

Material and methods

Study area

A total of eight sampling sites were set up in a sea area (29°4′ N-29°5′ N, 121°58′ E-121°59′ E) in Hepu, Xiangshan (Figure 1), and surface water samples were collected in August 2023 (summer), October 2022 (autumn), and December 2022 (winter) at each of the eight sites. These stations are located away from living areas, eliminating anthropogenic interference and better reflecting the effects of seasonal variations. Surface (0.5m) water samples were collected using a 5L water sampler. Approximately 1 L of seawater was first filtered through a 100 µm nylon filter and then 500 ml was filtered through a 0.45 µm filter membrane and preserved in brown sampling bottles.

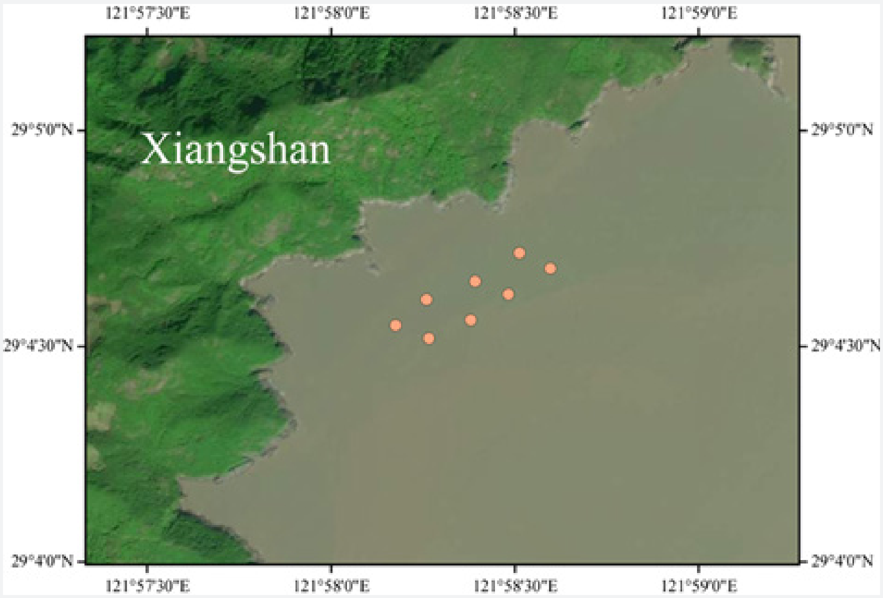

Figure 1: Relative Abundance of the Phyla annotated in the Metagenomes of Grass Carps.

Sample collection and processing

To prevent contamination between sites, water samplers and filtration systems were carefully cleaned with sterile water prior to water sample collection and filtration. Water temperature (WT), electrical conductivity (EC), dissolved oxygen (DO) and pH were measured on site. Total nitrogen (TN), phosphate (PO3-4-P), nitrate (NO-3-N), nitrite (NO-2-N) and ammonia (NH4+-N) were measured using standard methods (AQSIQ, 2007). Total carbon (TC) and total organic carbon (TOC) were determined using a Vario TOC Select analyzer from Elementar, Germany.

Data analysis

In this study, 11 physiochemical parameters obtained from eight monitoring sites located in the coastal zone were used for analysis. The data were pre-processed in Excel 2007 software, plotted using Prism 9.5 and analyzed by one-way analysis of variance (ANOVA) using SPSS 26 software. Spearman's correlation coefficient using R 4.1.0 was used to analyze the relationship between the postgraduate physio-chemical parameters. In addition, principal component and factor analyses explored the relationship between physiochemistry and pollutants.

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Results

Environmental variables across coastal zones

The results of environmental variables analysis showed that WT, DO, pH and EC exhibited significant changes between seasons ($P < 0.01$); DO was highest in winter at 11.185 mg/L±0.029 mg/L; while pH peaked in autumn at 8.280±0.022; EC decreased gradually over time, with a range of 38.8 ms/cm- 45.6 ms/cm; NH_4^+-N, NO-2-N and PO3-4-P were all highest in winter at 0.047 mg/L±0.007 mg/L, 0.060 mg/L±0.003 mg and 0.134 mg/L±0.005 mg/L, respectively, which were significantly higher than that in summer and autumn ($P < 0.001$), and were lowest in summer. NO-3-N was highest in summer at 0.772mg/L±0.035mg/L, which was significantly higher than that in autumn and winter ($P < 0.001$), and the concentrations of TC were autumn>winter>summer, and both were significantly different ($P < 0.001$); TN and TOC were lowest in summer at 1.317mg/L±0.633mg/L and 2.376mg/L±0.268mg /L and were not significantly different in autumn and winter.

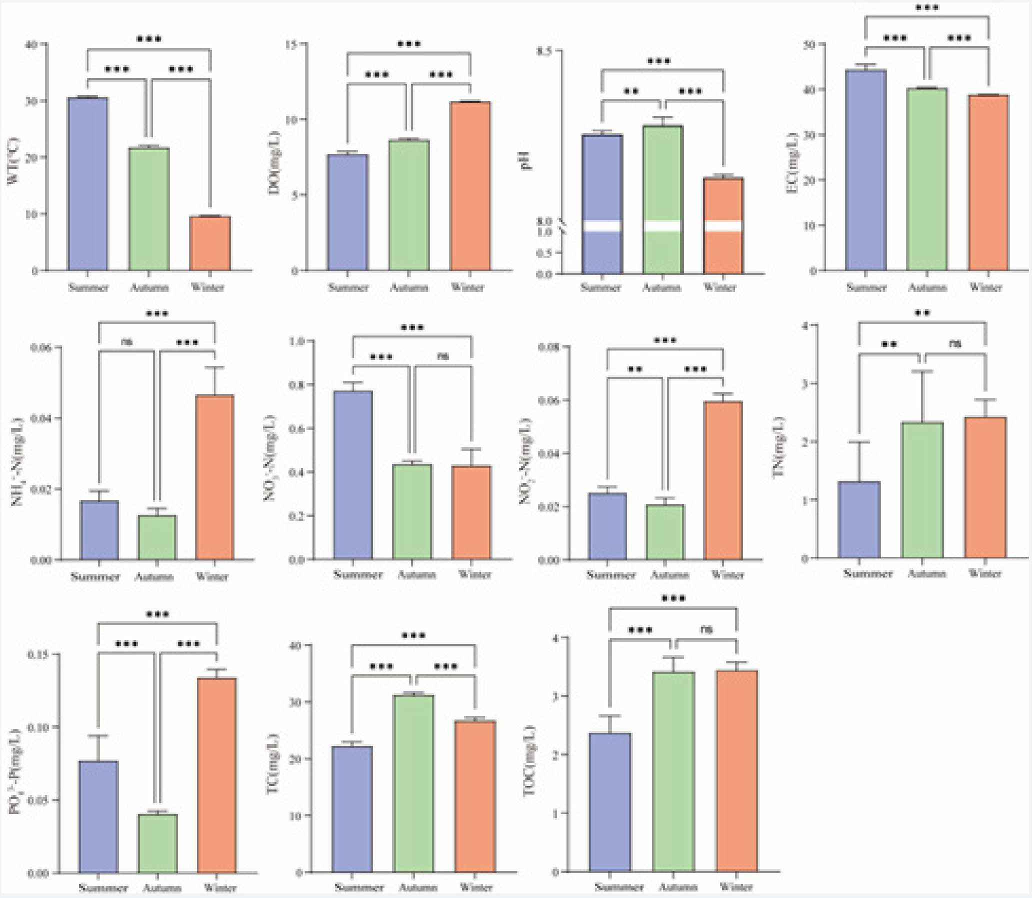

Figure 2: analysis of differences in water quality between seasons. *P < 0.05; **P < 0.01; ***P < 0.001.

Correlation analysis of environmental factors

Based on the Spearman correlation analysis of physio-chemical parameters in the water body (Figure 2), WT showed significant positive correlations with pH, EC, and NO-3-N ($P < 0.001$), while exhibiting significant negative correlations with DO, NO-2-N, NH_4^+-N, PO3-4-P, TN, TC, and TOC ($P < 0.05$). DO showed significant negative correlations with pH, EC, and NO-3-N ($P < 0.001$), while displaying significant positive correlations with NO-2-N, NH_4^+-N, PO3-4-P, TN, and TOC ($P < 0.05$). pH exhibited significant positive correlations with EC ($P < 0.01$), and significant negative correlations with NO-2-N, NH_4^+-N, and PO3-4-P ($P < 0.001$). EC demonstrated significant positive correlations with NO-3-N ($P < 0.001$), and significant negative correlations with NO-2-N, NH_4^+-N, TN, TC, and TOC ($P < 0.01$). NO-3-N showed significant negative correlations with TN, TC, and TOC ($P < 0.01$). NO-2-N exhibited significant positive correlations with NH_4^+-N and PO3-4-P ($P < 0.001$). NH_4^+-N showed significant positive correlations with PO3-4-P ($P < 0.001$). TN displayed significant positive

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correlations with TC and TOC (P < 0.01). TC showed significant positive correlations with TOC (P < 0.001). However, there was no significant correlation between NO-2-N, NH_4^+-N, PO3-4-P and TN, TC and TOC (Figure 3).

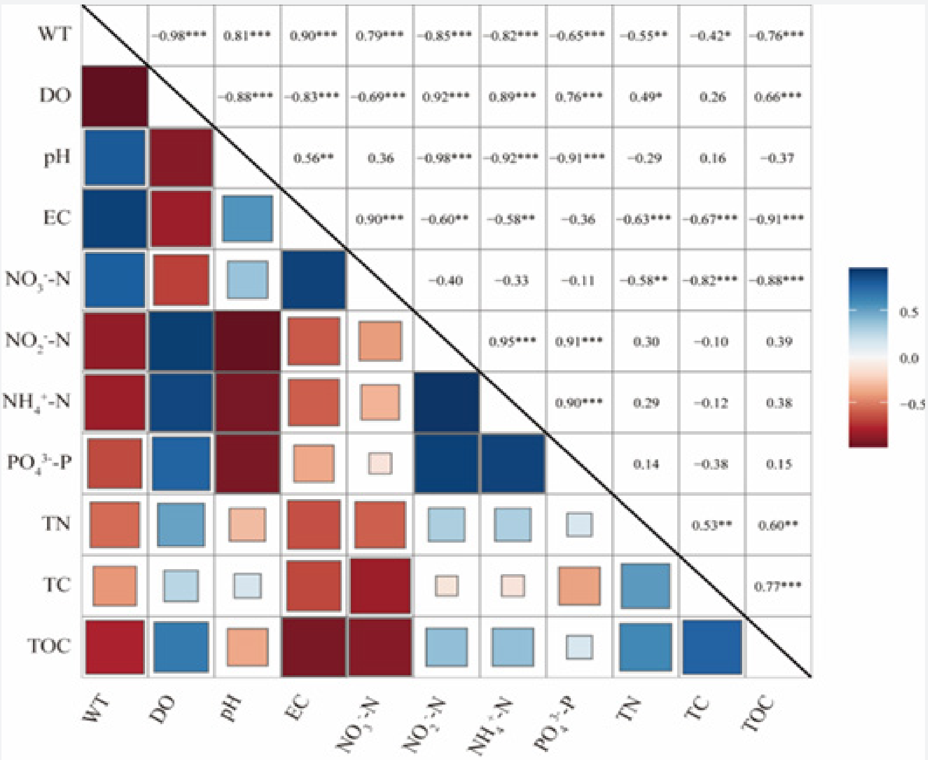

Figure 3: Correlation analysis of various parameters of water body physio chemistry. *P < 0.05; **P < 0.01; ***P < 0.001.

Principal component and factor analysis

The KMO indicator for these data suggests that the appropriateness of sampling is greater than 0.5. In this study KMO = 0.836, which indicates that the variables are adequate and can be used in the analysis. Bartlett's test of sphericity showed that the water quality data achieved a sphericity assumption of P < 0.05, allowing for principal component analysis. Principal component analysis (PCA) describes the variation of physicochemical variables over the three seasons (summer, autumn and winter). The first two principal components, PC1 and PC2, explained 48.89% and 42.41% of the total variance, respectively, and together they explained 91.30% of the variation in the total variance (Figure 5). The PCA/FA (Principal Component Analysis/Factor Analysis) identified correlations among the physicochemical variables, and the results of the PCA/FA are presented by means of the component suspension diagrams (Figure 4). After the third eigenvalue, a significant change in the slope of the eigenvalues was observed. Based on the criterion of eigenvalues greater than 1, two principal components were extracted (Table 1). Principal component I PC1 was mainly composed of PO3-4-P, NO-2-N, pH, NH_4^+-N, DO and WT, while principal component II PC2 was mainly composed of NO-3-N, TN, TOC, EC, WT and TC.

Table1: Rotated component values for physio chemical variables.

Variable	Factor1	Factor2
PO3-4-P	0.973	-0.085
NO-2-N	0.97	0.2
pH	-0.965	-0.159
NH_4^+-N	0.954	0.175
DO	0.833	0.536
WT	-0.733	-0.669
NO-3-N	-0.205	-0.935
TC	-0.306	0.931
TOC	0.223	0.919
EC	-0.445	-0.868
TN	0.179	0.697
Eigenvalue	5.378	4.666
%Variance	48.887	42.414
Cumulative%	48.887	91.301

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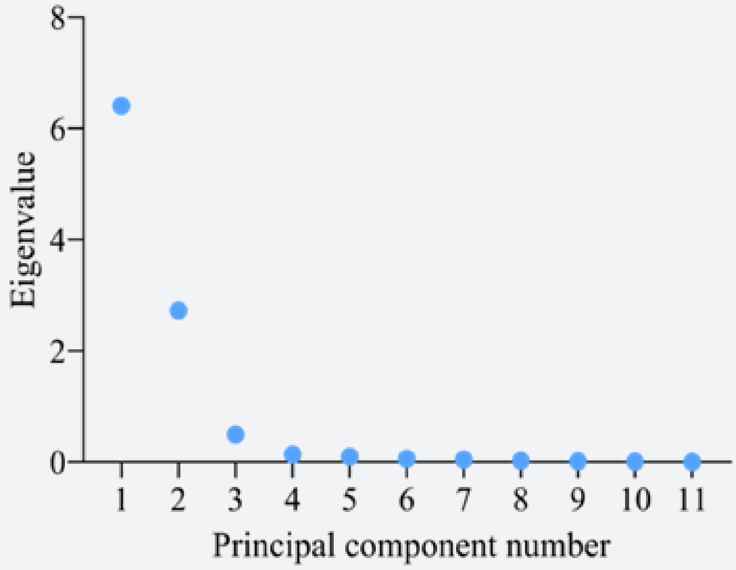

Figure 4: Scree plot of principal component eigenv.

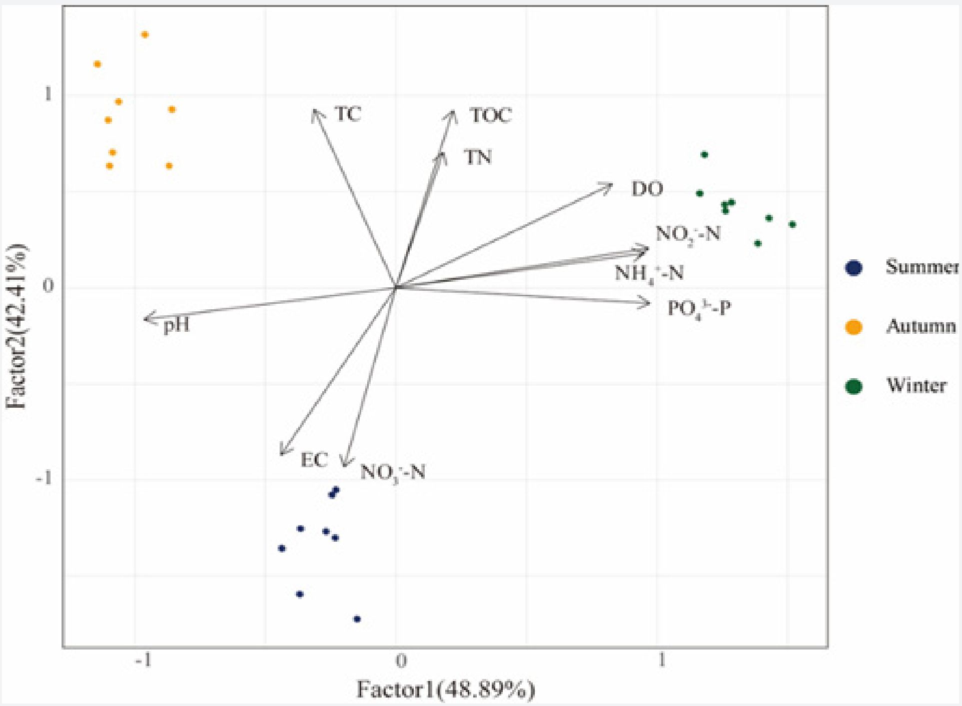

Figure 5: Components loading for PC1 and PC2 after rotation.

Discussion

In this study, a comprehensive seasonal analysis of water quality in the coastal region of Xiangshan, China, was conducted, focusing on conventional indicators (WT, DO, pH, and EC), nutrient concentrations (NH_4^+-N, NO-3-N, NO-2-N, PO3-4-P, and TN), and concentrations of organic matter (TC and TOC), all of which exhibited significant seasonal fluctuations. In particular, DO, an important parameter reflecting the life-supporting capacity of a water body, peaks in winter and falls to a minimum in summer, a

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phenomenon that may be related to the acceleration of microbial metabolic activity and consumption of more dissolved oxygen by high temperatures in summer [12]. pH is an important parameter of water because many properties, processes and reactions depend on it. Elevated pH in autumn may be related to the buffering effect of seawater, while anthropogenic nutrient inputs may also be an influencing factor [13]. The decrease in electrical conductivity (EC) may be related to temperature changes and seasonal variations in dissolved substances. In terms of nutrient salt concentrations, NH_4^+-N, NO-2-N and PO3-4-P were higher in winter, whereas NO-3-N was higher in summer, and TC and TOC were both higher in summer. In winter, the metabolic activity of aquatic organisms slows down due to lower temperatures, which may lead to a minimum reduction in nutrient consumption, while in summer, increased photosynthesis by phytoplankton and algae can consume nutrients in the surface layer [14].

Spearman's correlation analysis of physio-chemical parameters of the water column revealed the interrelationships between different water quality indicators. The analyses revealed significant correlations between WT and nutrient concentrations, including N, P and C. This may be related to seasonal variations in water temperature, which can affect microbial metabolic activity, and consequently nutrient cycling and availability [15]. EC was negatively correlated with a number of nutrients, including N and C. These results are in agreement with the findings of Desai et al [16] and Iwata [17] et al. In addition, NO-3-N was negatively correlated with TN, possibly due to the conversion of NO-3-N to other forms of nitrogen such as nitrogen gas or utilization by microorganisms, which reduces the concentration of TN [18]. NH_4^+-N was positively correlated with PO3-4-P. NH_4^+-N indicates pollution from household waste. Other nutrients may be associated with agricultural wastewater in surface runoff [19].

PCA can elucidate the alignment of data in detail by removing latent data. PCA aims to transform the original variables (parameters in this study) into new, uncorrelated variables (axes) called principal components (PCs), which are linear combinations of the initial variables. PCA/FA identifies relationships between physicochemical parameters. PC1 has positive loading for PO3-4-P, NO-2-N, NH_4^+-N and DO, but negatively loaded on pH and WT. PC2 positively loaded on TC and TOC, but negatively loaded on WT, NO-3-N, and EC. These components may reflect nutrient and organic pollution.

Conclusion

In this study, through water quality monitoring in the coastal area of Mount Object in different seasons, it was found that conventional indicators (WT, DO, pH, and EC), nutrient salt concentrations (NH_4^+-N, NO-3-N, NO-2-N, PO3-4-P, and TN), as well as concentrations of organic matter (TC and TOC) exhibited significant seasonal variations. Dissolved oxygen (DO) was highest in winter, possibly related to seasonal temperature changes, and pH was highest in autumn, possibly related to changes in the buffering capacity of seawater and anthropogenic nutrient supply. Seasonal variations in nutrient concentrations reflected the metabolic activities of aquatic organisms and the effects of human activities. Correlation analyses revealed the interrelationships among different water quality indicators, suggesting that temperature variations can affect the metabolic activities of microorganisms, which in turn affects nutrient cycling and availability. PCA further elucidated the relationships among physicochemical parameters, reflecting the characteristics of nutrients and organic pollution. The results of the study are important for the development of environmental protection measures in coastal areas, which can help to maintain the health and biodiversity of aquatic ecosystems.

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