Multivariate Assessment of Marine Water Quality Impacts on Phytoplankton Diversity in Thoothukudi Coast

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ABSTRACT

The current study is to examine the physicochemical attributes of seawater and assess microbial diversity obtained from the Thoothukudi coast. Physicochemical parameters were assessed following the APHA protocol and their corresponding values were documented. Differences in physicochemical parameters of marine water were noted at each station, influencing unique conditions that shape the distribution patterns of microalgae. In the course of this study, a comprehensive identification of phytoplankton revealed a total of 36 species, including the Class Bacillariophyceae, Cyanophyceae, Chlorophyceae and Euglenaceae. Throughout the study period, the occurrence of most dominant species was observed from class Bacillariophyceae. The diversity index such as Dominance, Simpson index, Shannon index, Evenness and Margelef index showed rich diversity in station I compared to station II. Karl Pearson's correlation coefficient calculated between physico-chemical parameters and number of phytoplanktons. The results revealed that concentration of physicochemical parameters (Temperature, chloride and total phosphorous) increased, the growth of phytoplankton also increased in station II. Canonical Correspondence Analysis (CCA) between environmental variables and number of microalgae indicated the influence of physico-chemical parameters on phytoplankton distribution in marine water of Thoothukudi coast.

Keywords: Physicochemical parameter, seawater, phytoplanktons, diversity index and Canonical Correspondence Analysis

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1. INTRODUCTION

Coastal waters represent dynamic interfaces between terrestrial and marine ecosystems, characterised by significant biological and non-biological potential. These areas serve as hubs for various human activities such as fisheries, tourism and transportation, while simultaneously acting as reservoirs of biodiversity (Wijaya *et al.,* 2020). However, the quality of coastal waters is strongly influenced by inputs from terrestrial sources, such as river discharge and surface runoff, which carry organic matter and nutrients. These inputs not only alter the physical and chemical properties of the water but also affect the ecological balance, making coastal areas vulnerable to changes such as pollution and eutrophication (Asensio Montesinos *et al*., 2024; Marwa *et al.,* 2024; Zakiyah *et al*., 2024). Such changes impact the immediate aquatic environment and surrounding terrestrial ecosystems. The abundance, composition and distribution of microalgae in marine waters are controlled by factors such as physico-chemical parameters (dissolved nutrients, light, pH, turbulence, salinity and temperature), biological parameters (predators, mortalities) and the water cycle (Rekik *et al*., 2015; Martonen, 2017). These physico-chemical parameters are essential for the biological functions in the marine environment. Fluctuations of the levels of physico-chemical parameters in the aquatic environment are normally caused by anthropogenic activities (Okuku *et al*., 2011) as well as seasonal changes (Kitheka *et al*., 1996; Jumba and Mwashote, 2002). As a result of such fluctuations, there is need to understand the factors that may influence the abundance, composition, distribution and diversity of microalgae within the Gazi ecosystem. The environmental status of water quality can be determined by calculating the diversity index, evenness index and dominance index of microalgae (Arsad *et al.* 2019). Microalgae are sensitive to variations in water quality, making them important indicators of environmental health and productivity. These organisms respond rapidly to fluctuations in nutrient availability, light penetration and pollution levels. Thus, the dynamics of microalgae populations provide valuable insights into the short-term and long-term health of coastal ecosystems. They serve as early responders to anthropogenic pressures, offering insights into the ecological status of coastal waters (Li *et al*. 2021). Phytoplankton can be use as good bio-indicator of water quality including pollution, since they relect even the suitable changes taking place in their environment by changing their species composition, biomass, community structure and productivity. More over the abundance of phytoplankton can be taking as the best mean for quantitative assessment of potential fisheries of an area (Babu *et al*., 2013).

The present study aimed to identify the diversity and abundance of microalgae in the beaches of Vembar and Punnakkayal, Thoothukudi coast for a period of one year from June 2023 - May 2024 in varying habitats and to analyse environmental factors that affect the abundance of microalgae on these substrates. The result of this study might be useful to reveal the biodiversity and composition of microalgae based on their habitats and to understand the relationship between microalgae and environmental conditions.

2. MATERIALS AND METHOD

2.1 STUDY AREA

Thoothukudi, situated on the Coromandel Coast of the Bay of Bengal, is a port city, a municipal corporation, and an industrial hub in the state of Tamil Nadu, India. Thoothukudi serves as the capital and administrative center of Thoothukudi district, positioned approximately 590 kilometers southwest of Chennai, 190 kilometers northeast of Thiruvananthapuram, and 580 kilometers southeast of Bengaluru. Thoothukudi encompasses 21 islands located between the shores of Thoothukudi and Rameswaram in the Gulf of Mannar, acknowledged as the inaugural Marine Biosphere Reserve in India. The coastal area surrounding Thoothukudi is habitat to unique and uncommon marine flora and fauna. The current study focused on two selected coastal regions within Thoothukudi district, namely Vembar (latitudes 8.996223°, longitude 78.255771°) and Punnakkayal (latitude 8.637021°, longitude 78.122176°)

2.2 COLLECTION OF SAMPLES

Water samples were collected from Vembar as Station I and Punnakkayal as Station II. Using sterilized 2L plastic bottles, water samples were collected at a depth of 1m. Microalgae samples were obtained using a plankton net with a mesh size of 20 micrometers and promptly transferred to the laboratory after collection.

2.2.1 CHARACTERISATION OF PHYSICOCHEMICAL PARAMETERS

Standard protocols outlined by APHA (1999) were employed to determine various physicochemical parameters including pH, temperature, salinity, nitrite, nitrate, ammonia, chloride, phosphate, potassium and sodium. All values were recorded and the data were collected in triplicate for each parameter.

2.2.2 MORPHOLOGICAL IDENTIFICATION OF MICROALGAE

The microalgae samples were centrifuged and the resulting pellet was collected. Subsequently, a drop of the samples was placed on a trinocular light microscope and the microalgae within were examined under magnifications of 10x, 40x and 100x, each with 10 times magnification. Images were captured to aid in the identification of microalgae species, referencing standard manuals by Venkataraman (1939), Subrahmanyan (1946), Smith and Johnson (1977) and Al-Kandari *et al*. (2009).

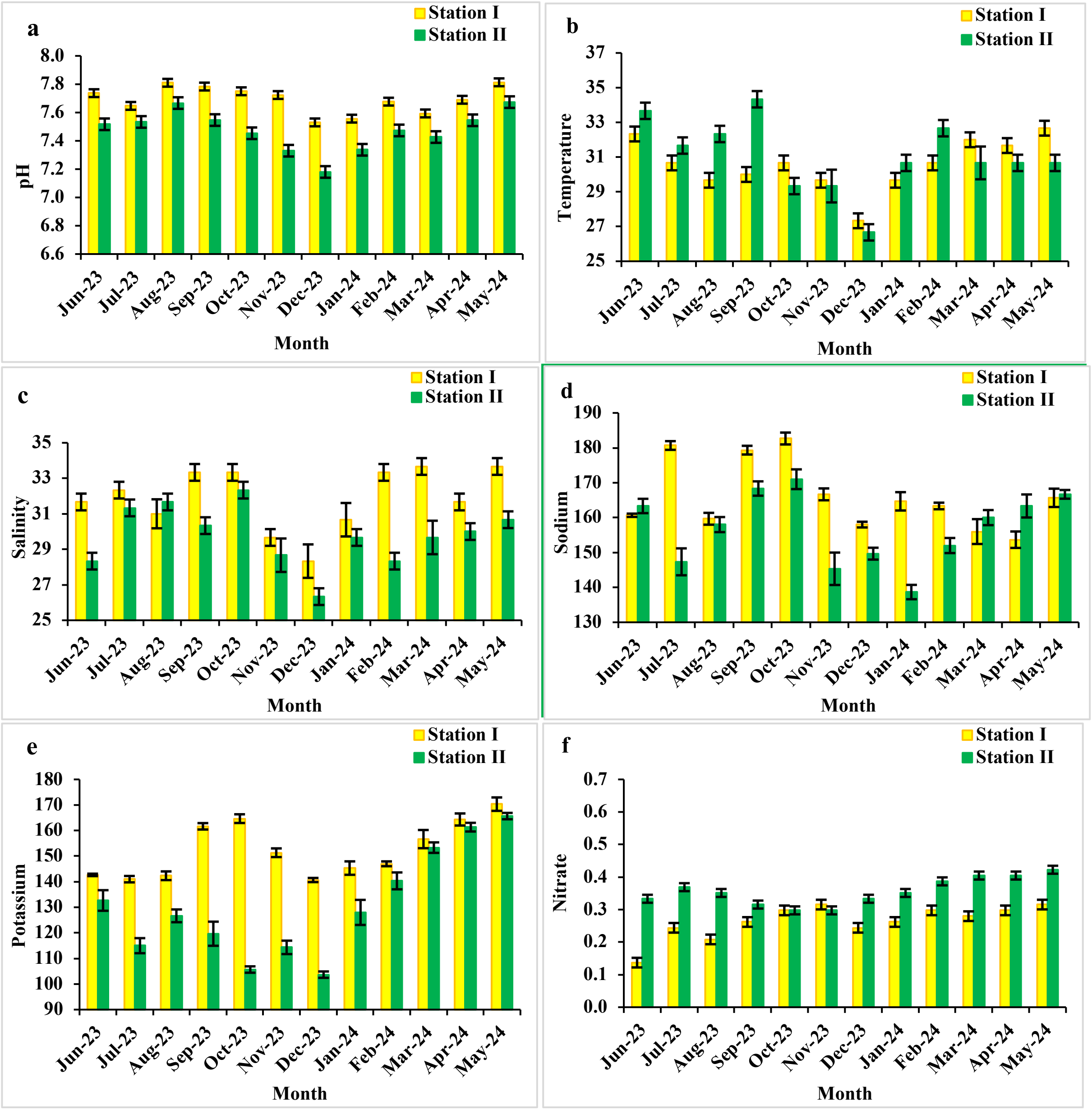
2.3 STATISTICAL ANALYSIS

Statistical tools Palaeontological Statistics (PAST), version 4.03 were used for univariate and multivariate data analysis. Basic descriptive statistics (mean and standard deviation) were performed in MS Excel, 2010. The relationships between physico-chemical parameters and marine microalgae were unveiled through Canonical Correspondence Analysis (CCA) using Palaeontological Statistics.

3. RESULT AND DISCUSSION

3.1 PHYSICOCHEMICAL PARAMATERS

The findings indicated that across the two stations, the average pH range exhibited variability, ranging from 7.18 to 7.81. Station II recorded the lowest average minimum pH at 7.18 in December, while Station I registered the highest average maximum pH at 7.81 in May (Figure 1a). Boyd and Lichtcoppler (1979) proposed an optimal pH range of 6.09 to 8.45 to support aquatic life, while Umavathi *et al.* (2007) suggested that a pH range between 5 and 8.5 is most conducive to plankton growth. The current results indicated that water samples from two locations exhibited a moderate alkalinity, which falling well within the permissible limit (pH 6.5 – 8.5) conducive to plankton growth. The surface water temperature is usually influenced by the intensity of solar radiation, evaporation, insulation and the low temperature during monsoon. This could be due to strong sea breeze and cloudy sky (Behrenfeld *et al*., 2006; Nassar *et al*., 2014). In the present study, Station II registered an average minimum water temperature of 26.67 °C in December and maximum water temperature of 34.33 °C in September while station I recorded the maximum water temperature of 32.33 in June and minimum of 27.33 December (Figure 1b). Archana and Babu (2013) recorded temperature fluctuations from 26.3 to 32.3°C at the seashore waters of Visakhapatnam.



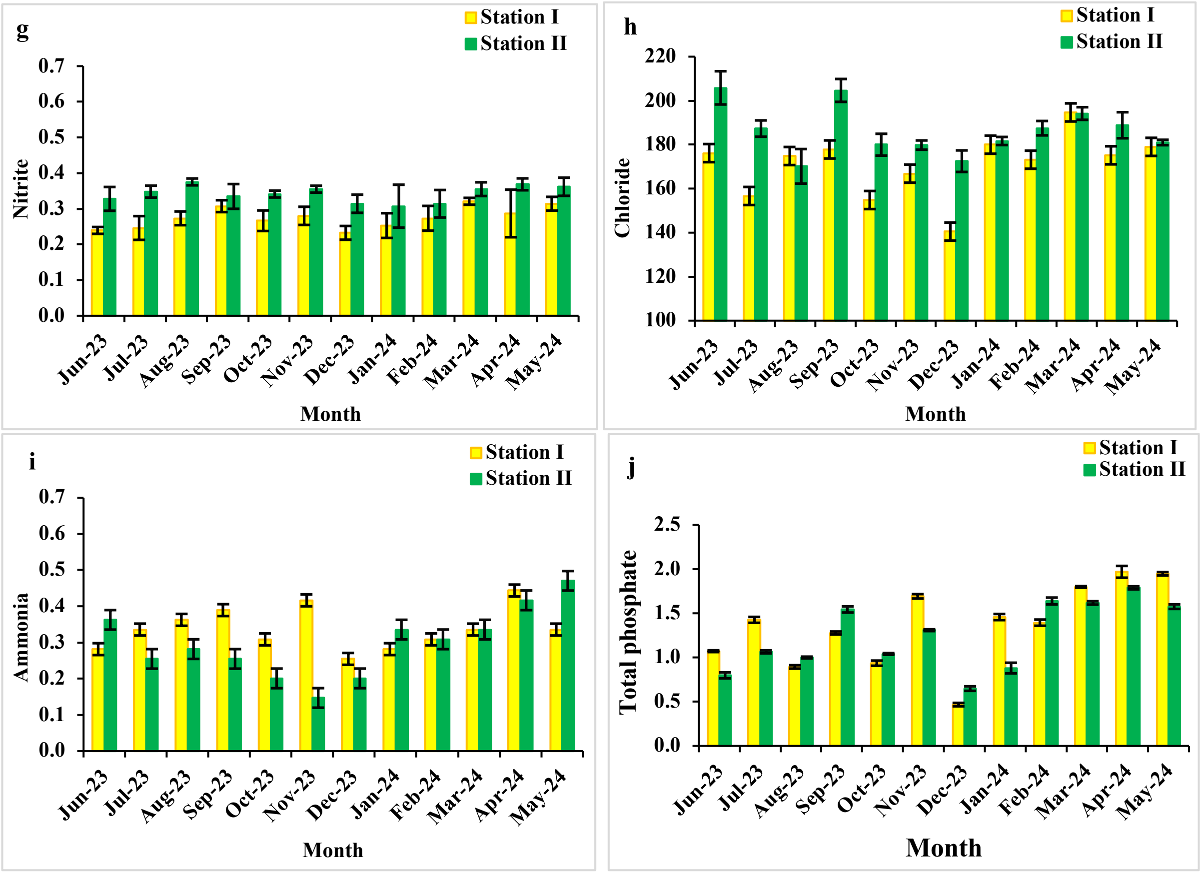


Fig. 1 Physicochemical parameters of the Thoothukudi coast a - pH, b - temperature, c - salinity, d - sodium, e - potassium, f - nitrate, g - nitrite, h - chloride, i -ammonia, j -total phosphate

Salinity plays a crucial role as an environmental factor affecting the growth of microalgae in marine algal cultures. It also significantly influences the distribution and abundance of phytoplankton species within aquatic ecosystems. Variations in salinity have been observed to prompt changes in cellular volume and osmotic adjustments in microalgae. Salinity serves as a fundamental water quality parameter monitored by freshwater and marine ecologists due to its significant impact on biota. In this study, salinity ranging between 26.33 and 33.67 ppt was recorded, as shown in Figure 1c. Station I recorded the average maximum salinity of 33.67 ppt in March and minimum salinity of 28.33 ppt, while Station II had maximum salinity of 32.33 ppt in October and the minimum salinity of 26.33 ppt. In the present study, the observed decline in salinity in December was attributed to heavy rainfall. This finding is corroborated by Chindah (2004).

The sodium and potassium in Station I and Station II ranged from 152 to180.67 mg/L and 103.67 to 170.33 mg/L respectively in surface seawater (Figure 1d and 1e). Weathering of rocks is very common in sea which results in addition of sodium and potassium in aquatic bodies (Sharma, 2014). Nitrate predominates as the primary form of nitrogen in marine water (Wang *et al.*, 2009). An increase in nitrogen content leads to increased microalgae growth. The nitrate in Station I and Station II ranged from 0.13 to 0.32 mg/L and 0.30 to 0.42 mg/L respectively in surface seawater (Figure 1f). The Station I and Station II observed lowest concentration of nitrate in June and October. Conversely, the peak concentration was observed in May for both stations. Nitrate plays a vital role as a nutrient for aquatic life and, when combined with other nutrients such as phosphate, it fosters algal bloom, thereby leading to eutrophication (Rai and Tripathi, 2006).

The nitrite concentration exhibited a range of 0.23 mg/L to 0.38 mg/L, with Station I recorded the average maximum nitrite of 0.32 mg/L in March and minimum nitrite of 0.23 mg/L in December, while Station II had maximum nitrite of 0.38 mg/L in August and the minimum nitrite of 0.30 mg/L in January (Figure 1g). The enrichment of nitrites and nitrates is likely influenced by various factors and it is noted that unpolluted waters typically maintain minimal levels of nitrates, as indicated by Jaji *et al.* (2007). The higher concentration nitrite could be due to the increased planktonic excretion, oxidation of ammonia and reduction of nitrate and by recycling of nitrogen and also due to bacterial decomposition of plankton detritus present in the environment (Govindasamy *et al.,* 2000).

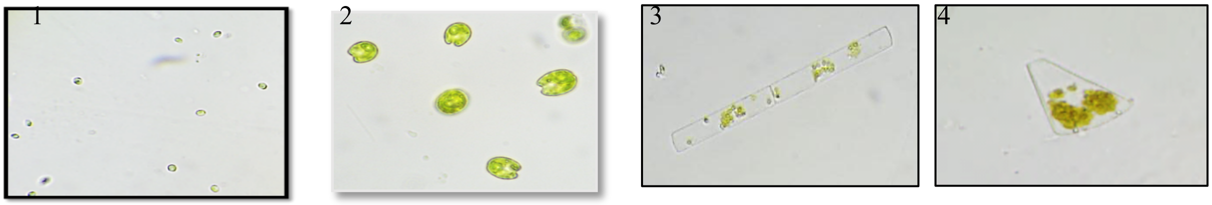
In the present study, chloride ranged from 140.5 mg/L to 205.8 mg/L (Figure 1h). In station I, maximum concentration of chloride was noticed in March (194.7 mg/L), and the minimum was in December (140.5 mg/L) while station II maximum concentration of chloride was noticed in June (205.8 mg/L), and the minimum was in August (170.2 mg/L). Sinha (1986) recorded high concentrations of chloride are indicators of a large amount of organic matter in the water, suggesting eutrophic conditions. Sarojini *et al*. (1997) pointed out that a high amount of chloride influences the level of dissolved oxygen in water. The major sources of chloride in natural waters are sediments (Mishra *et al.,* 2008). Higher chloride content is an indication of pollution, attributable to either organic wastes or industrial effluents (Ravindra *et al.,* 2003). Figure 1i showed that a higher concentration of ammonia (0.443 mg/L) was observed in station I during April, whereas a lower concentration (0.255 mg/L) was recorded during December while station II recorded higher concentration of 0.470 mg/L during May and lower concentration of 0.147 mg/L during November. The elevated concentrations may be attributed partially to the death and subsequent decomposition of phytoplankton, as well as to the excretion of ammonia by plankton, as suggested by Segar and Hariharan (1989).

Phosphorus is an essential nutrient and can play an important role as a limiting factor (Dugan, 1972). It is responsible for the growth of phytoplankton in aquatic ecosystems (Hutchison, 1975). The total phosphate ranged from 0.47 to 1.97 mg/L (Figure 1j). The concentration of phosphate in station I peaked at 1.97 mg/L and Station II at 1.79 mg/L during April, while the minimum of 0.47 mg/L and 0.65 mg/L in December.

3.2. DISTRIBUTION OF PHYTOPLANKTON

Throughout the study period, a total of 31 phytoplankton species were identified in station I and 27 species in Station II. Among these, 21 species belonged to diatoms (Bacillariophyceae), 2 species to green algae (Chlorophyceae), 1 species to Euglena (Euglenaceae) and 7 species to blue-green algae (Cyanophyceae), as illustrated in Figures 2 whereas in station II displayed the maximum abundance with 19 species belonged to diatoms (Bacillariophyceae), 2 species to Green algae (Chlorophyceae), 1 species to Euglena (Euglenaceae) and 5 species to blue-green algae (Cyanophyceae). The study area of Baldi stream is rich in calcareous rocks, which favour the growth of Bacillariophyceae. Pearsall (1924) and Pattrick (1977) suggested that calcium carbonates–bicarbonates promote the growth of Bacillariophyceae.

Fig. 2: PHOTOGRAPHS OF PHYTOPLANTON SPECIES FROM TWO STATIONS



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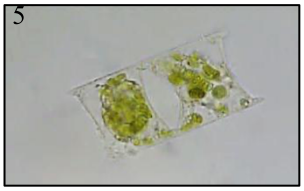
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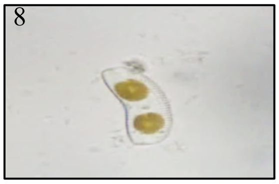
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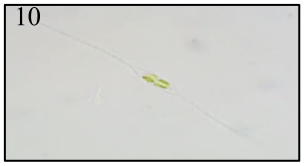
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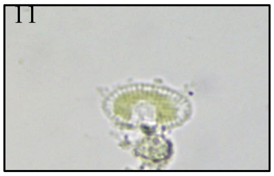
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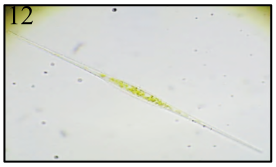
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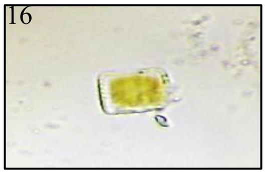
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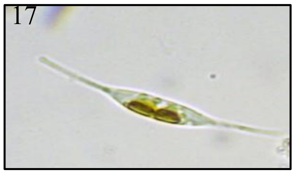
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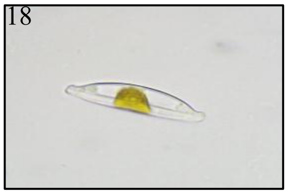
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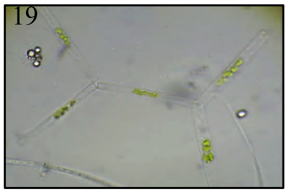
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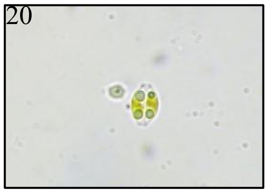
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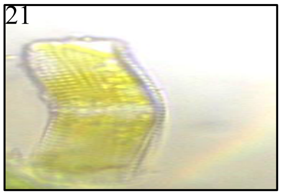
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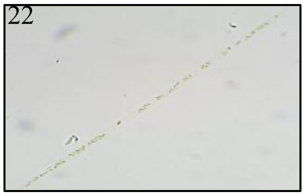
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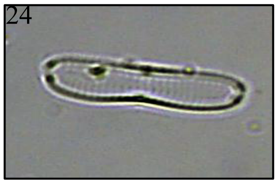
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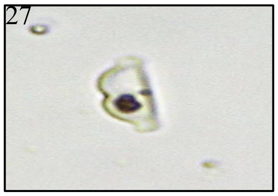
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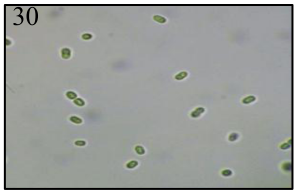
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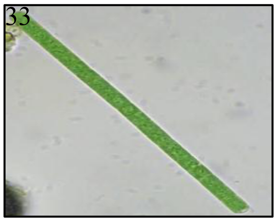
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Table 1: OCCURRENCE OF MICROALGAE IN TWO DIFFERENT STATIONS

S. No.	Class	Name of the taxa	Station I	Station II
1	Chlorophyceae	*Nannochloropsis spp.*	+	+
2		*Tetraselmis spp.*	+	+
3	Bacillariophyceae	*Leptoylindrus spp.*	-	+
4		*Licmophora spp.*	+	-
5		*Hemiaulus spp.*	-	+
6		*Diploneis spp.*	+	-
7		*Gyrosigma spp.*	+	+
8		*Nitzschia spp.*	+	+
9		*Nitzschia spp.*	+	+
10		*Nitzschia spp.*	+	+
11		*Cocconeis spp.*	+	-
12		*Closterium spp*	+	+
13		*Navicula spp.*	+	+
14		*Chaetoceros spp.*	-	+
15		*Diploneis spp.*	+	+
16		*Striatella spp.*	+	-
17		*Cylindrotheca spp.*	+	+
18		*Cymbella spp.*	+	+
19		*Asterionella spp.*	-	+
20		*Amphora ovalis*	+	+
21		*Achnanthes spp.*	+	+
22		*Rhizosolenia spp.*	-	+
23		*Navicula spp.*	+	+
24		*Amphiprora spp*	+	+
25		*Navicula spp.*	+	+
26		*Synedra spp.*	+	-
27		*Amphora spp.*	+	-
28		*Navicula spp.*	+	-
29	Euglenaceae	*Euglena spp.*	+	+
30	Cyanophyceae	*Synechococcus spp.*	+	+
31		*Plectonema spp.*	+	-
32		*Oscillatoria spp.*	+	+
33		*Oscillatoria spp.*	+	+
34		*Oscillatoria spp.*	+	+
35		*Phormidium spp.*	+	-
36		*Oscillatoria spp.*	-	+

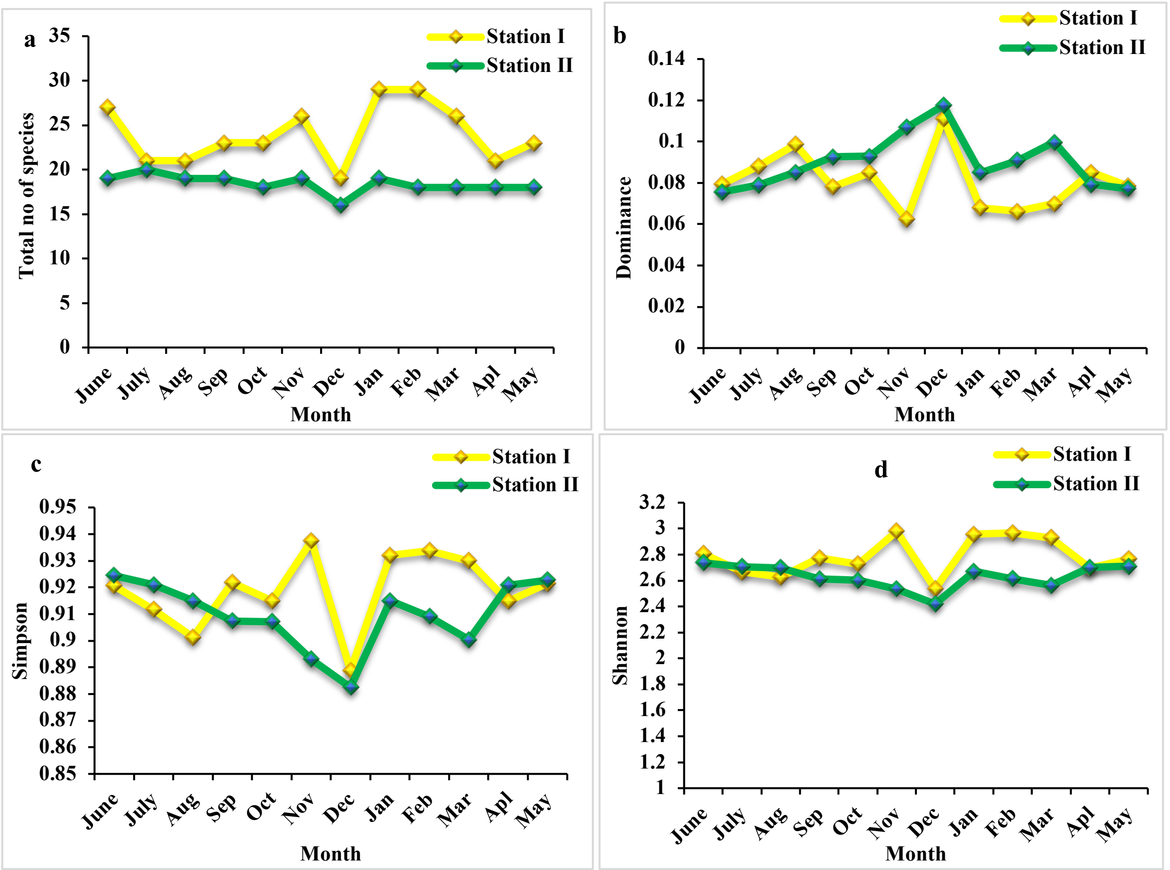
In this study, a variety of species, *Leptoylindrus, Hemiaulus*, *Chaetoceros, Asterionella Rhizosolenia* and *Oscillatoria* were exclusively found in station I. Likewise, species of *Licmophora., Cocconeis, Striatella, Synedra, Amphora, Navicula and Phormidium* were exclusively identified in station II. Other all species are commonly seen in both station I and station II. The variations in phytoplankton abundance and distribution could be attributed to differences in the availability of light and nutrients between the two stations.

3.3 DIVERSITY INDICES

Samples of phytoplankton from station I and Station II were collected between June 2023 and May 2024. Analysis of phytoplankton community structure and distribution was conducted utilising multiple indices including Dominance index, Simpson diversity index, Shannon diversity index, Pielou evenness index, and Margalef diversity index. The outcomes of these diversity indices are illustrated in Figure 2a to 2f.

To evaluate the diversity and ecological suitability of the chosen study location, the microalgal data underwent assessment using diversity indices. In the present study, the dominance (D) values representing species diversity ranged from 0.063 to 0.118, where 0 signifies infinite diversity and 1 denotes low diversity. Diversity indices analyses of microalgae from station I and station II showed the highest dominance index of 0.118 and 0.112, in the month of December, while the lowest dominance index of 0.076 and 0.062 in the month of June and November. In our study, the D values for all months of two stations were below 1, indicating rich diversity. The lower species diversity values recorded at few sites in this study might also be associated with the environment under stress. The lower the dominance, the higher is the species diversity. According to Whittaker (1965), the value of dominance index is always higher where the community is dominated by fewer numbers of the species.

According to the Simpson diversity index, a value of 0 suggests low diversity, while a value of 1 suggests higher diversity (Türkmen and Kazanu, 2010). Simpson diversity index ranged from 0.882 to 0.934 in all the stations. In our research, all months in station I and station II exhibited values closer to 1, indicating optimal diversity richness. The Shannon index values ranged between 2.419 to 2.978, where values below 1 indicate pollution and degradation of the water body (Halder *et al.,* 2019) and values exceeding this threshold indicate a healthy and stable ecosystem (Mandaville, 2002). It is a diversity index taking into account the number of individuals as well as the number of taxa. It varies from 0, for communities with only a single taxon, to higher values for community with many taxa, each with a few individuals (Hosmani, 2010). Balloch *et al.* (1976) also found that the Shannon's diversity index is a suitable indicator for the water quality assessment.



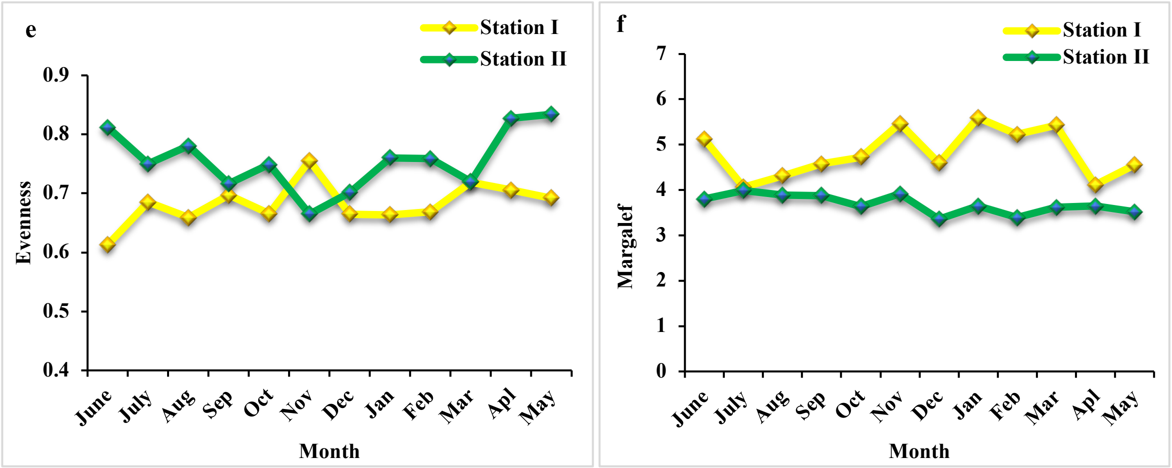


Figure 3: Microalgal diversity indices recorded at the Thoothukudi coast during June 2023 to May 2024. a - Total no. of species, b - Dominance index, c – Simpson, d – Shannon diversity index, e - evenness index, d and f - Margalef's index

In the present study, data from all months in station I and station II indicated a stable and healthy status. The species evenness index values range from 0 to 1, with a value closer to 1 suggesting an even distribution of species (Pielou, 1966). The Margalef diversity index facilitates the comparison of species variation among different months at the study site**.** Margalef indices ranged from 3.36 to 5.60. The station I and station II showed highest value of 3.99 and 5.60 during July and January, the least value of 3.36 and 4.07 during December and July.

3.4 CORRELATION

Karl Pearson's correlation coefficients were computed to assess the relationship between different physico-chemical parameters and number of microalgae. In station I, pH exhibited positive correlation with Bacillariophyceae ($r = 0.600$, $p < 0.05$) and Euglenaceae ($r = 0.355$, $p < 0.05$). Temperature showed positive correlation with Chlorophyceae ($r = 0.252$, $p < 0.05$) and Bacillariophyceae ($r = 0.639$, $p < 0.05$). Salinity exhibited positive correlations with Bacillariophyceae ($r= 0.578$, $p < 0.05$), Euglenaceae ($r = 0.297$, $p < 0.05$) and Cyanophyceae

Table 2.1: Pearson's correlation coefficient between physico-chemical parameters and microalgae in station I

	pH	**Temperature**	**Salinity**	**Nitrate**	**Ammonia**	**Sodium**	**Potassium**	**Chloride**	**Nitrite**	**T. Phosphate**	**Chlorophyceae**	**Bacillariophyceae**	**Euglenaceae**	**Cyanophyceae**
pH	1													
Temperature	0.667	1												
Salinity	0.676	0.295	1											
Nitrate	0.410	0.099	0.047	1										
Ammonia	0.421	0.245	-0.023	0.428	1									
Sodium	0.565	0.293	0.407	0.068	0.619	1								
Potassium	0.517	0.264	0.073	0.871	0.594	0.287	1							
Chloride	0.209	0.685	-0.070	0.032	0.513	0.367	0.240	1						
Nitrite	0.626	0.065	0.561	0.289	0.231	0.405	0.392	-0.154	1					
Total Phosphate	0.421	0.289	0.195	0.556	0.408	0.355	0.697	0.304	0.426	1				
Chlorophyceae	-0.137	0.252	-0.093	-0.231	-0.071	-0.248	-0.248	0.283	-0.053	0.291	1			
Bacillariophyceae	0.600	0.639	0.578	0.018	-0.035	-0.055	0.115	0.294	0.315	0.115	0.140	1		
Euglenaceae	0.355	-0.017	0.297	0.181	-0.244	-0.201	0.192	-0.560	0.349	0.255	0.000	0.320	1	
Cyanophyceae	-0.070	-0.112	0.080	0.146	0.498	0.306	0.099	0.376	-0.162	-0.117	-0.309	-0.101	-0.707	1

Correlation significant at $p < 0.05$.

Table 2.2: Pearson's correlation coefficient between physico-chemical parameters and microalgae in station II

	pH	**Temperature**	**Salinity**	**Nitrate**	**Ammonia**	**Sodium**	**Potassium**	**Chloride**	**Nitrite**	**T. Phosphate**	**Chlorophyceae**	**Bacillariophyceae**	**Euglenaceae**	**Cyanophyceae**
pH	1.000													
Temperature	0.419	1.000												
Salinity	0.426	0.733	1.000											
Nitrate	-0.010	0.024	0.242	1.000										
Ammonia	0.458	0.217	0.131	0.402	1.000									
Sodium	0.295	-0.066	0.352	0.142	-0.014	1.000								
Potassium	0.295	-0.066	0.352	0.142	-0.014	1.000	1.000							
Chloride	0.214	0.642	0.521	0.029	0.301	-0.330	-0.330	1.000						
Nitrite	0.396	0.488	0.621	0.553	0.565	-0.058	-0.058	0.683	1.000					
T. Phosphate	0.134	0.664	0.440	0.543	0.586	-0.154	-0.154	0.646	0.670	1.000				
Chlorophyceae	0.401	0.007	-0.186	-0.162	0.301	-0.175	-0.175	0.455	0.296	0.125	1.000			
Bacillariophyceae	-0.302	0.057	-0.060	-0.142	-0.425	-0.287	-0.287	0.357	-0.059	0.077	0.186	1.000		
Euglenaceae	-0.216	0.177	0.101	0.032	-0.290	-0.027	-0.027	0.255	-0.080	0.071	0.115	0.609	1.000	
Cyanophyceae	0.116	0.311	0.432	0.315	0.199	0.233	0.233	0.370	0.161	0.378	0.026	-0.008	0.535	1.000

Correlation significant at $p < 0.05$.

(r = 0.080, p < 0.05). Positive correlations were observed between Nitrate and various microalgae groups, including Bacillariophyceae (r = 0.018, p < 0.05), Euglenaceae (r = 0.181, p < 0.05) and Cyanophyceae (r = 0.146, p < 0.05). Additionally, Ammonia and Sodium displayed a positive correlation with Cyanophyceae (r = 0.498 and r = 0.306, p < 0.05).

Potassium exhibits a positive correlation with Bacillariophyceae (r = 0.115, p < 0.05), Euglenaceae (r = 0.192, p < 0.05) and Cyanophyceae (r = 0.099, p < 0.05). Chloride demonstrates positive correlations with Chlorophyceae (r = 0.283, p < 0.05), Bacillariophyceae (r = 0.294, p < 0.05) and Cyanophyceae (r = 0.376, p < 0.05). Nitrite displayed positive correlations with Bacillariophyceae (r= 0.315, p < 0.05) and Euglenaceae (r = 0.349, p < 0.05). Total phosphorus exhibits positive correlations with Chlorophyceae (r = 0.291, p < 0.05), Bacillariophyceae (r = 0.115, p < 0.05), and Cyanophyceae (r = 0.255, p < 0.05).

Conversely, Ammonia and Sodium showcase negative correlations with Chlorophyceae, Bacillariophyceae and Euglenaceae. pH and Nitrite exhibited negative correlation with Chlorophyceae and Cyanophyceae. Temperature showed negative correlation with Euglenaceae and Cyanophyceae. Salinity, Nitrate and Potassium exhibited negative correlation with Chlorophyceae. Chloride and Total Phosphate showed negative correlation with Euglenaceae and Cyanophyceae in table 2.1.

In station II, pH exhibited positive correlation with Chlorophyceae (r = 0.401, p < 0.05) and Cyanophyceae (r = 0.116, p < 0.05). Temperature showed positive correlation with Chlorophyceae (r = 0.007, p < 0.05), Bacillariophyceae (r = 0.057, p < 0.05), Euglenaceae (r = 0.177, p < 0.05) and Cyanophyceae (r = 0.311, p < 0.05) Growth of phytoplankton composition is governed by the temperature (Rajkumar *et al*., 2009; Sharma *et al.,* 2016).

Salinity exhibited positive correlations with Euglenaceae (r = 0.101, p < 0.05) and Cyanophyceae (r = 0.432, p < 0.05). Nitrate showed positive correlation with Euglenaceae (r = 0.032, p < 0.05) and Cyanophyceae (r = 0.315, p < 0.05). Additionally, Ammonia displayed a positive correlation with Chlorophyceae (r = 0.301, p < 0.05) and Cyanophyceae (r = 0.199, p < 0.05).

Sodium and Potassium exhibits a positive correlation with Bacillariophyceae (r = 0.455, p < 0.05). Chloride demonstrates positive correlations with Chlorophyceae (r = 0.283, p < 0.05), Bacillariophyceae (r = 0.357, p < 0.05), Euglenaceae (r = 0.255, p < 0.05) and Cyanophyceae (r = 0.370, p < 0.05). Nitrite displayed positive correlations with Chlorophyceae (r = 0.296, p < 0.05) and Cyanophyceae (r = 0.161, p < 0.05). Total phosphorus exhibits positive correlations with Chlorophyceae (r = 0.125, p < 0.05), Bacillariophyceae (r = 0.077, p < 0.05), Euglenaceae (r = 0.071, p < 0.05) and Cyanophyceae (r = 0.378, p < 0.05) in table 2.2.

Conversely, pH, Ammonia and Nitrite showcase negative correlations with Bacillariophyceae and Euglenaceae. Sodium and Potassium exhibited negative correlation with Chlorophyceae, Bacillariophyceae and Euglenaceae. Nitrate showed negative correlation with Chlorophyceae and Bacillariophyceae. The abundance and composition of phytoplankton communities are controlled by available nutrients and light (Altman and Paerl, 2012).

3.5 Canonical Correspondence Analysis

The Canonical Correspondence Analysis (CCA) method was employed to assess the associations between phytoplankton and physico-chemical parameters. The length of the arrows reflects the significance of variables and demonstrates positive or negative correlations with the axis (Abrantes *et al*., 2006).

Table 3. Canonical correspondence analysis biplot scores of physico-chemical parameters at two stations of Thoothukudi coast

	Station I		Station II	
	Axis 1	**Axis 2**	**Axis 1**	**Axis 2**
pH	-0.147	-0.179	0.354	-0.211
Temperature	0.277	-0.010	0.001	0.210

Salinity	0.335	0.178	0.283	-0.194
Nitrate	0.216	0.197	0.162	-0.265
Ammonia	-0.144	0.040	-0.266	-0.117
Sodium	0.211	0.200	-0.189	-0.252
Potassium	0.211	0.200	0.184	-0.279
Chloride	0.127	-0.383	-0.560	0.246
Nitrite	-0.066	-0.145	0.338	-0.097
Total Phosphate	0.148	0.033	0.246	0.260
Chlorophyceae	-0.184	-0.240	-0.028	0.211
Bacillariophyceae	-0.037	0.012	-0.015	-0.014
Euglenaceae	0.704	-0.332	0.346	-0.023
Cyanophyceae	0.132	0.076	-0.096	-0.060
Eigen values	0.017	0.008	0.014	0.006
Percentages of variance	57.180	25.840	65.700	28.340

Percentages of variance and Eigen values on axis 1 were observed to exceed those on axis 2 as shown in Table 3. Comparable results were noted by Liu *et al.* (2010). At the sampling station I, CCA has been drawn between 10 physico-chemical parameters and 4 phytoplankton classes (Fig. 4.1) Eigen value for axis 1 (0.017) explained 57.18% correlation and axis 2 (0.008) explained 25.840% correlation between physico-chemical parameters and phytoplankton classes. Salinity, nitrate, sodium, potassium and total phosphorus shows positive correlation with Cyanophyceae and least to Chlorophyceae (Figure 3.1).

The station II showed eigen value for axis 1 (0.002) explained 65.7% correlation and axis 2 (0.001) explained 28.34% correlation between physico-chemical parameters and phytoplankton classes. Microalgal species belonging to Euglenaceae and Chlorophyceae exhibited a partial positive correlation with pH, temperature and total phosphorus depicted in Figure 4.2.

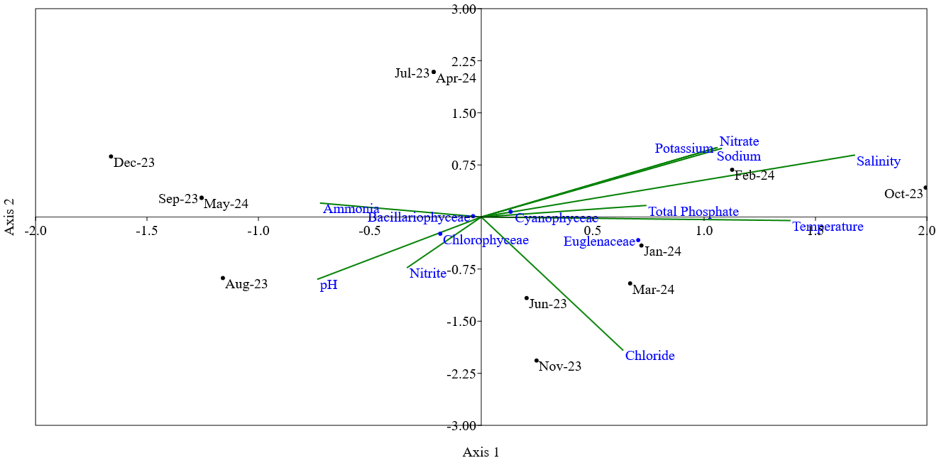


Fig 4.1. Canonical Correspondence Analysis to investigate the relationship between physicochemical parameters and microalgae group in station I

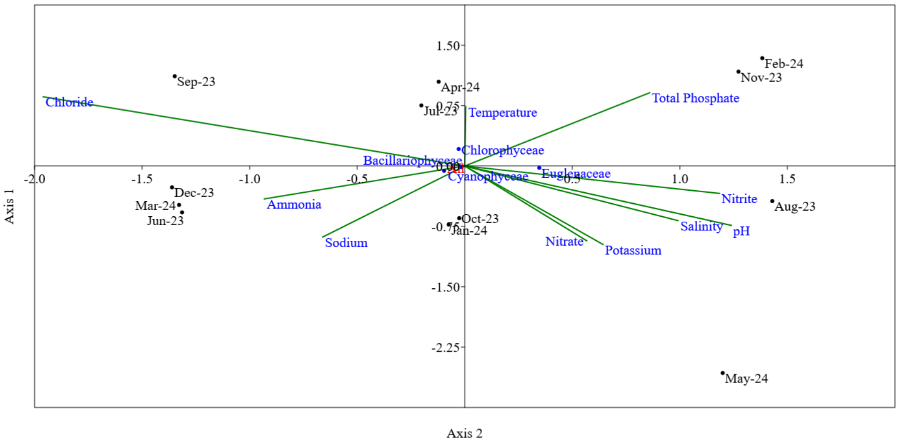


Fig 4.2. Canonical Correspondence Analysis to investigate the relationship between physicochemical parameters and microalgae group in station II

During the present study, CCA detected the cause and effect of relationships between environmental parameters, sites and species diversity and density. The CCA results of these experiments showed that some of the microalgal species were closely associated with certain physicochemical parameters. Further, some species could tolerate and thrive at certain levels of a few physicochemical parameters, while others showed sensitivity to the same parameters at these levels. Since the environmental requirements of different species differ, they respond differently to the variations in these factors.

4. CONCLUSION

The monthly variation of physico-chemical factors and phytoplankton community in the Thoothukudi coast were explored. The results offer valuable insights into phytoplankton composition and abundance, their interactions with environmental variables, and the overall ecological condition of the study area. The dataset generated can serve as an important reference for future investigations on coastal water quality. Moreover, sustained monitoring of additional parameters, including nutrient dynamics and hydrodynamic processes, is vital for the effective management and conservation of healthy coastal ecosystems. Proper maintenance of water bodies is essential for long-term ecological sustainability. In this context, the implementation of adequate sanitation practices and environmental awareness programs is crucial to protect water quality. Measures such as sewage diversion and the reduction of nutrient runoff from catchment areas through afforestation and other land-management strategies can substantially promote a clean, resilient and sustainable coastal environment.

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