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# Phytoplankton distribution in pre-monsoon and post-monsoon seasons and its relation with physicochemical parameters in coastal waters of Ratnagiri, West Coast of India

Prathamesh J. Ade<sup>1\*</sup>, Aniruddha D. Adsul<sup>1</sup>, Rajiv H. Rathod<sup>2</sup>, Sachin W. Belsare<sup>2</sup>, Sagar A. Joshi<sup>2</sup>, Pratiksha V. Nimbarte<sup>1</sup> and Mayuresh S. Nagawekar<sup>1</sup>

<sup>1</sup>College of Fisheries, Ratnagiri, Dr Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli-415629, Maharashtra, India.

<sup>2</sup>College of Fishery Science, Nagpur, Maharashtra Animal and Fishery Sciences University, Nagpur-440006, Maharashtra, India.

\*Correspondence e-mail: [praveshade7@gmail.com](mailto:praveshade7@gmail.com)  
ORCID: <https://orcid.org/0009-0007-2045-8253>

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Original Article

## Abstract

The present study evaluated phytoplankton assemblages and their interaction with physicochemical parameters along the coastal waters of Ratnagiri, Maharashtra, West Coast of India. Water temperature, pH, dissolved oxygen, alkalinity, nitrite, nitrate, ammonia, silicate, phosphate, and Chl-a were measured at four sampling stations. A total of 26 diatom species and 6 dinoflagellate species were recorded, with *Skeletonema costatum* and *Thalassionema frauenfeldii* having the highest abundances. Canonical Correspondence Analysis (CCA) identified alkalinity and silicate as the key factors driving phytoplankton dispersion and seasonal variations, whereas other nutrients had lesser effects. Diatoms regularly dominated over dinoflagellates throughout the pre- and post-monsoon seasons. Overall, alkalinity and silicate appeared as the key drivers of phytoplankton community structure, while diversity indices revealed probable anthropogenic influence at a few sampling locations.

**Keywords:** Phytoplankton, diversity index, CCA, Maharashtra

## Introduction

Coastal zones are among the most ecologically productive and economically valuable regions on Earth, encompassing habitats such as coral reefs, mangroves, estuaries, and

seagrass beds. These systems support a wide array of ecosystem services and human activities, including fisheries, aquaculture, tourism, and transportation, that are critical to coastal livelihoods and food security. However, the increasing intensity of anthropogenic activities, coupled with the impacts of climate change, has significantly reduced the resilience of coastal ecosystems, making them more vulnerable to environmental degradation (Bijlsma *et al.*, 1996). The ecological dynamics of coastal systems are influenced by both natural processes and human interventions. Factors such as water exchange with adjacent marine areas, coastline morphology, precipitation, and riverine input create unique hydrological and physicochemical conditions in each region (Ilyash *et al.*, 2015). These environmental gradients strongly influence the distribution, abundance, and succession of phytoplankton communities, key primary producers that form the base of the aquatic food web (Biswas *et al.*, 2015). Phytoplankton play a crucial role in supporting aquatic food chains by serving as a direct food source for zooplankton, shellfish, and finfish (Price, 2001). Owing to their sensitivity to environmental changes such as temperature, light, salinity, and nutrient availability, they are widely used as biological indicators of water quality and ecosystem health (Gharib *et al.*, 2011). Seasonal and spatial variability in these parameters often results in distinct phytoplankton community structures, making them effective tools for monitoring aquatic ecosystems.

In India, extensive research has been conducted on phytoplankton dynamics across various coastal and estuarine systems along the west coast, including the Cochin backwaters (Madhu *et al.*, 2007, 2010), the Mandovi-Zuari estuary (Patil and Anil, 2011, 2015) and Mumbai coastal waters (Ramaiah *et al.*, 1998; Jaiswar *et al.*, 2013). These studies have emphasised the influence of monsoon, eutrophication, and physicochemical parameters on phytoplankton assemblages. It is well documented that estuaries and nearshore coastal zones are biodiversity hotspots serving as nurseries for commercially important fish species (Kawabata *et al.*, 1993; Saravanakumar *et al.*, 2008), and the phytoplankton communities within these habitats are therefore vital to maintaining ecological balance and productivity. Despite this growing body of research along India's west coast, however, limited data are available on phytoplankton community dynamics specific to the Jiagad, Ratnagiri coastal area is a less-studied but ecologically important region. Thus, understanding the phytoplankton distribution and their relationship with environmental variables in this area is essential for assessing the ecological status and guiding sustainable coastal management. In light of these considerations, the present study aims to investigate the species composition and community structure of phytoplankton in the Jiagad coastal waters in relation to key water quality parameters in the post-monsoon and pre-monsoon seasons. The findings will provide insights into the spatial and temporal variations in phytoplankton assemblages and enhance our understanding of their role as bio-indicators in a changing coastal environment.

## Material and methods

The present study was carried out at four sampling stations (S1, S2, S3 and S4) twice a month along the Jaigad coastal area from October 2023 to May 2024 (in pre-monsoon and post-monsoon seasons, excluding the monsoon season) for a total time period of eight months (Fig. 1). Sampling was carried out at four designated stations where station S1 and S2 were fixed at a depth of 18 m, while station S3 and S4 were located further offshore at a depth of 36 m. During each sampling, water samples were collected at each station for analysis of sea surface temperature, water pH, dissolved oxygen, salinity, nitrate, nitrite, reactive silicate, inorganic phosphate and Chlorophyll-a. Sea surface temperature was measured with a mercury thermometer, water pH with a digital pH pen (Eco Tester pH 2) with an accuracy of  $\pm 0.01$  pH units, dissolved oxygen was estimated by Winker's method (Strickland and Parsons, 1972), water transparency was measured with a Secchi disk, salinity was estimated by using the argentometric method (Strickland and Parsons, 1972), and nutrients such as nitrite, nitrate, inorganic phosphate and silicate were estimated by the colorimetric method using standard procedures (Strickland and Parsons, 1972). A standard

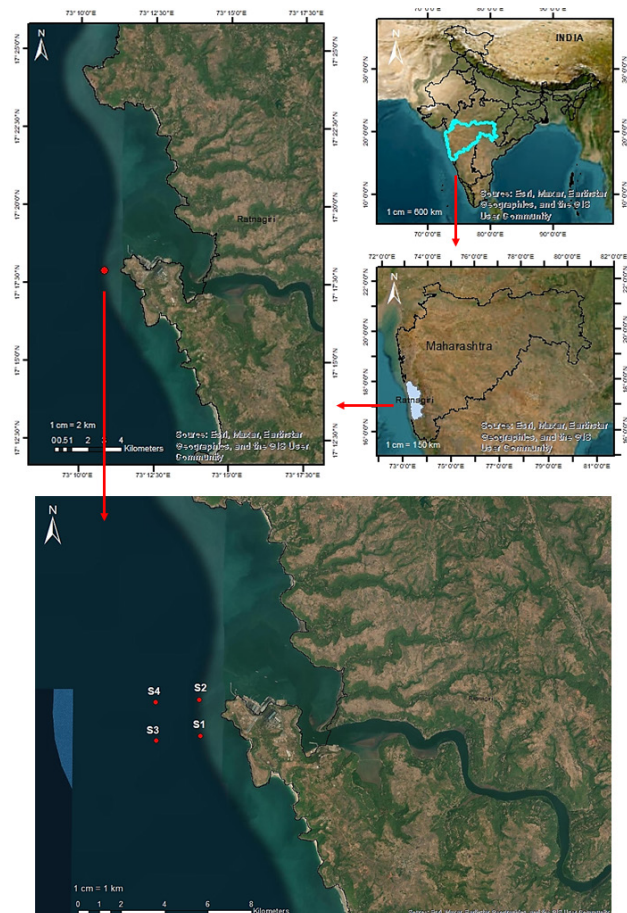


Fig. 1. Sampling stations along the coastal waters of Ratnagiri

plankton net of diameter 0.25 m ( $\emptyset$ : 60  $\mu$ m) was used for the plankton collection. For phytoplankton analysis, 50 L of the water sample was filtered through a plankton net with a 60  $\mu$ m mesh size, and the sample was concentrated to a final volume of 200 mL (Jagadeeshappa and Kumara, 2013). Lugol solution and 5% neutralized formalin solution were used to preserve plankton samples. 1 ml of the concentrated sample was placed on the Sedgwick Rafter Chamber for taxonomic identification, and enumeration was done using a binocular microscope (ZEISS PrimoStar Binocular Microscope, 40X magnification). Identification of phytoplankton was done using the conventional taxonomic keys (Desikachary, 1959; Newell and Newell, 1977). The number of phytoplankton cells present in all 1000 grids was counted, and phytoplankton density (cells  $L^{-1}$ ) was determined. Chlorophyll-a (Chl-a) concentration was analysed with the acetone extraction method Grasshoff *et al.*, 1999) for which water samples were collected at fixed stations in 250 ml plastic bottles and subsequently filtered through glass fibre filter paper with a pore size of 0.45  $\mu$ m. Clean plastic bottles containing inorganic dissolved nutrients, such as silicate ( $SiO_4$ ), ammonia ( $NH_4$ ), phosphate ( $PO_4$ ), nitrite ( $NO_2$ ), and nitrate ( $NO_3$ ), were gathered and stored in an icebox. In the laboratory, these water samples

were filtered through Millipore filter paper (0.45  $\mu\text{m}$ ) and examined by the spectrophotometric technique and analysed using the standard procedures prescribed by APHA (2023). Pearson's correlation matrix ( $r$ ), the Shannon-Wiener diversity index ( $H' \log_2$ ), Pielou evenness ( $J'$ ), and canonical correspondence analysis (CCA) were used to determine the diversity and environmental drivers of phytoplankton assemblages, while CCA was mostly used to explore the environmental variables influencing the phytoplankton community. Phytoplankton species diversity index ( $H'$ ) and evenness ( $J'$ ) were calculated using PAST (v.4.0) according to species diversity ( $H' = \sum (P_i \log_2 (P_i))$ ) (Shannon, 1963), and species evenness ( $J' = H' / \log_2 (S)$ ) (Pielou, 1975). Where  $P_i = n_i/n$  (proportion of the sample belonging to the  $i$ th species 'S' is the number of species). All the statistical analyses were performed using PAST (v 4.0) and OriginPro (v 9.8).

## Results

All the physicochemical parameter results are represented in Table 1. The maximum mean SST (29.38  $^{\circ}\text{C}$ ) was observed in the pre-monsoon season, while the minimum temperature (28.38  $^{\circ}\text{C}$ ) was recorded in the post-monsoon season. Water pH was recorded as the highest (8.21) in the pre-monsoon season, while the lowest pH (8.09) was recorded in the post-monsoon season. Dissolved oxygen ranged from 3.80 to 5.25  $\text{mg L}^{-1}$  in the entire sampling time. Salinity readings didn't vary significantly and varied between 32.18 psu and 33.25 psu. Nitrite concentration was measured at its lowest

(0.01  $\mu\text{mol L}^{-1}$ ) in the pre-monsoon season and 0.02  $\mu\text{mol L}^{-1}$  in the post-monsoon season. Nitrate values varied from 0.02 to 0.12  $\mu\text{mol L}^{-1}$ , with high amounts recorded in the post-monsoon season. The maximum inorganic phosphate (0.19  $\mu\text{mol L}^{-1}$ ) was recorded in the late pre-monsoon season, while the lowest (0.014  $\mu\text{mol L}^{-1}$ ) was recorded in the post-monsoon season. The silicate content ranged from 0.23  $\mu\text{mol L}^{-1}$  to 0.45  $\mu\text{mol L}^{-1}$  in the total sampling period, with the greatest concentration in the pre-monsoon season (Fig. 2).

All four sampling stations (S1, S2, S3 and S4) were chosen for performing canonical correspondence analysis (CCA) to determine the relation between physicochemical parameters and phytoplankton abundance (Fig. 3, Table 2). Physicochemical parameters such as DO, phosphate, pH, water temperature and Chl-a appear to have a strong influence on phytoplankton distribution. Species such as *Ditylum brightwellii*, *Ditylum sol*, *Guinardia striata* and *Skeletonema costatum* appear on the negative side of axis 1, indicating that these species prefer lower water temperature, salinity and nitrate and nitrite concentration. *Thalassionema nitzschioides* indicates a positive association with higher values of water temperature and salinity. Axis 2 is associated with physicochemical parameters such as silicate, Chl-a, pH, dissolved oxygen and phosphate, and species such as *Ceratium breve*, *planktoniella sol*, *Ornithocercus* sp. and *Leptocylindrus danicus* are found near the centre of the plot, suggesting more tolerance to physicochemical parameters, while other species such

Table 1. Water quality parameters along the Jaigad coastal waters in the pre-monsoon and post-monsoon seasons

Seasons and stations	Parameters										
	Water Temperature ( $^{\circ}\text{C}$ )	pH	Alkalinity ( $\text{mgL}^{-1}$ )	Salinity (psu)	DO ( $\text{mgL}^{-1}$ )	NO <sub>2</sub> ( $\mu\text{mol L}^{-1}$ )	NO <sub>3</sub> ( $\mu\text{mol L}^{-1}$ )	NH <sub>4</sub> ( $\mu\text{mol L}^{-1}$ )	PO <sub>4</sub> ( $\mu\text{mol L}^{-1}$ )	SiO <sub>4</sub> ( $\mu\text{mol L}^{-1}$ )	Chl-a ( $\mu\text{mol L}^{-1}$ )
Pre-monsoon											
S <sub>1</sub>	29.00 ( $\pm 1.68$ )	8.16 ( $\pm 0.05$ )	107 ( $\pm 2.58$ )	32.88 ( $\pm 0.63$ )	5.25 ( $\pm 1.15$ )	0.01	0.02 ( $\pm 0.02$ )	0.12 ( $\pm 0.01$ )	0.19 ( $\pm 0.10$ )	0.45 ( $\pm 0.18$ )	0.86 ( $\pm 0.18$ )
S <sub>2</sub>	29.00 ( $\pm 1.68$ )	8.21 ( $\pm 0.07$ )	109.50 ( $\pm 4.43$ )	33.00 ( $\pm 0.41$ )	5.10 ( $\pm 0.96$ )	0.01	0.05 ( $\pm 0.03$ )	0.12 ( $\pm 0.01$ )	0.18 ( $\pm 0.05$ )	0.41 ( $\pm 0.19$ )	0.74 ( $\pm 0.16$ )
S <sub>3</sub>	29.13 ( $\pm 1.25$ )	8.15 ( $\pm 0.07$ )	103.50 ( $\pm 1.91$ )	33.00 ( $\pm 0.41$ )	4.90 ( $\pm 1.09$ )	0.02	0.06 ( $\pm 0.01$ )	0.13 ( $\pm 0.02$ )	0.18 ( $\pm 0.07$ )	0.41 ( $\pm 0.16$ )	0.51 ( $\pm 0.12$ )
S <sub>4</sub>	29.38 ( $\pm 1.44$ )	8.14 ( $\pm 0.04$ )	101 ( $\pm 1.15$ )	33.25 ( $\pm 0.65$ )	4.50 ( $\pm 1.23$ )	0.01	0.08 ( $\pm 0.02$ )	0.12 ( $\pm 0.01$ )	0.14 ( $\pm 0.04$ )	0.33 ( $\pm 0.16$ )	0.45 ( $\pm 0.14$ )
Post-monsoon											
S <sub>1</sub>	28.38 ( $\pm 1.03$ )	8.12 ( $\pm 0.06$ )	106.50 ( $\pm 1.00$ )	32.00 ( $\pm 0.82$ )	4.35 ( $\pm 0.85$ )	0.01	0.10 ( $\pm 0.06$ )	0.014 ( $\pm 0.02$ )	0.16 ( $\pm 0.04$ )	0.38 ( $\pm 0.11$ )	0.71 ( $\pm 0.16$ )
S <sub>2</sub>	28.38 ( $\pm 1.03$ )	8.12 ( $\pm 0.06$ )	103 ( $\pm 4.76$ )	32.18 ( $\pm 0.96$ )	4.45 ( $\pm 1.15$ )	0.02 ( $\pm 0.01$ )	0.10 ( $\pm 0.02$ )	0.13 ( $\pm 0.02$ )	0.16 ( $\pm 0.03$ )	0.37 ( $\pm 0.09$ )	0.57 ( $\pm 0.14$ )
S <sub>3</sub>	28.50 ( $\pm 1.08$ )	8.11 ( $\pm 0.03$ )	103.50 ( $\pm 4.73$ )	32.50 ( $\pm 0.82$ )	4.20 ( $\pm 0.91$ )	0.02 ( $\pm 0.01$ )	0.12	0.13 ( $\pm 0.03$ )	0.15 ( $\pm 0.01$ )	0.28 ( $\pm 0.13$ )	0.62 ( $\pm 0.14$ )
S <sub>4</sub>	28.88 ( $\pm 1.11$ )	8.09 ( $\pm 0.07$ )	102.50 ( $\pm 2.52$ )	32.50 ( $\pm 0.82$ )	3.80 ( $\pm 0.37$ )	0.01	0.12 ( $\pm 0.01$ )	0.14 ( $\pm 0.05$ )	0.13	0.23 ( $\pm 0.07$ )	0.49 ( $\pm 0.14$ )

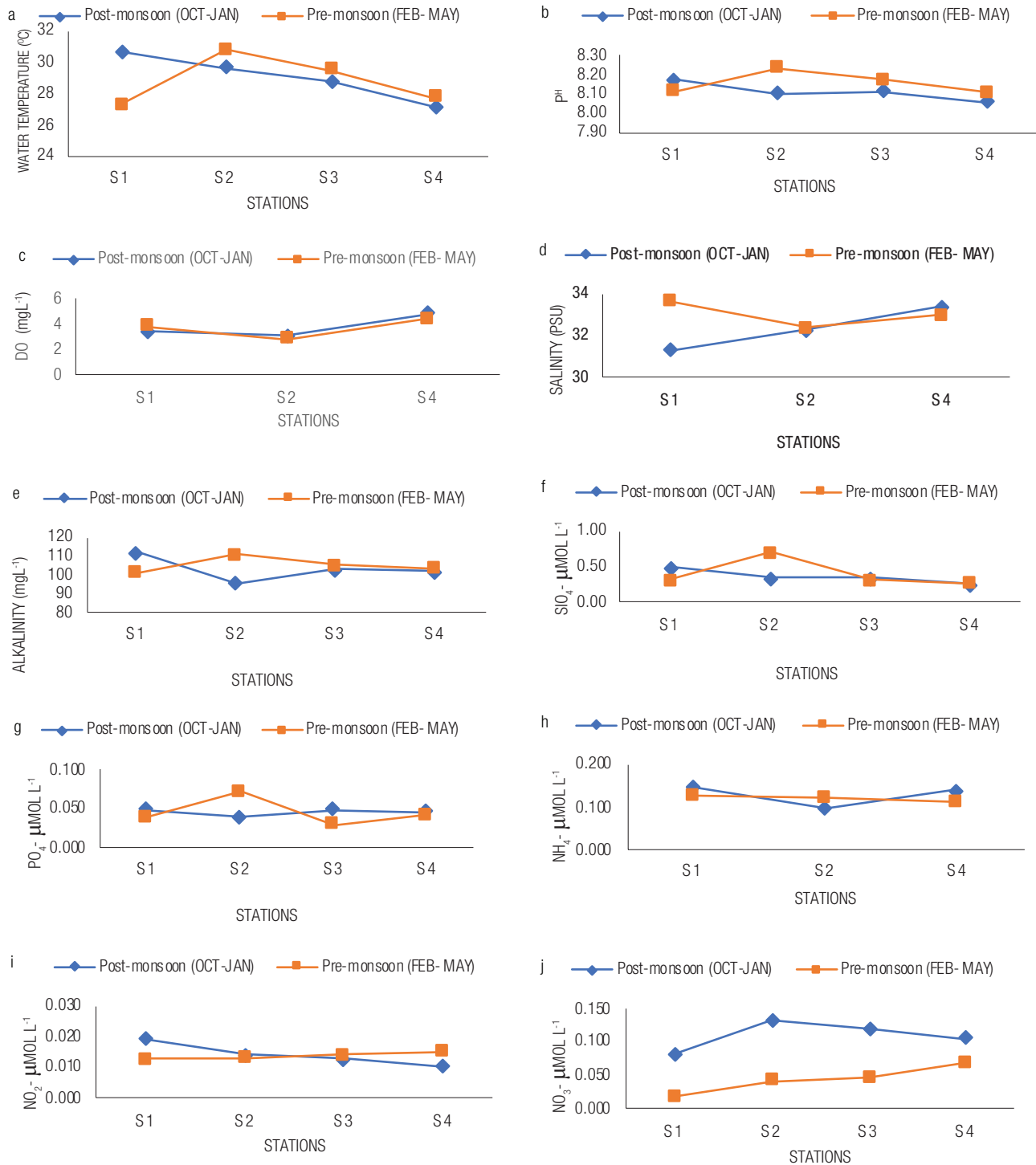


Fig. 2. Pre-monsoon and post-monsoon variations of different physico-chemical parameters. (a. Water temperature; b. pH; c. Dissolved oxygen; d. Salinity; e. Alkalinity; f. Silicate; g. Phosphate; h. Ammonia; i. Nitrite; j. Nitrate)

as *Coscinodiscus granii* and *Rhizosolenia gracillima* are more sensitive to silicate, Chl-a, pH and phosphate levels. The first two axes show a substantial amount of variation, showing 60.23% and 24.55% of the constrained inertia, respectively. Combining a total of 84.46% of the variation

in physicochemical parameters and phytoplankton species relationships. Axis 1 has the highest eigenvalue (0.00526), explaining 60% of total inertia, indicating that it is the most significant gradient affecting phytoplankton distribution. While the second and third axes explain relatively small

Table 2. The CCA results of environmental variables against the dominant phytoplankton species

Species/ stations	Axis 1	Axis 2	Axis 3
<i>Chaetoceros decipiens</i>	-0.11634	2.57777	0.261015
<i>Coscinodiscus granii</i>	-2.24032	-1.27947	-0.7623
<i>Ditylum brightwellii</i>	0.984511	-0.24217	-0.2737
<i>Ditylum sol</i>	1.10213	-0.62287	0.824253
<i>Planktoniella sol</i>	-0.83354	0.584619	-0.02951
<i>Rhizosolenia alata</i>	-0.40183	0.322128	3.94091
<i>Skeletonema costatum</i>	0.811658	-0.54702	-1.04535
<i>Thalassionema nitzschioides</i>	0.423653	0.399008	-0.38492
<i>Guinardia striata</i>	2.23895	-1.37719	1.55404
<i>Leptocylindrus danicus</i>	-1.46959	0.131105	1.8925
<i>Rhizosolenia gracillima</i>	-0.41502	-1.01937	1.38052
<i>Ceratium breve</i>	-0.1303	-0.16608	0.113719
<i>Ceratium furca</i>	-1.51888	-0.72743	-0.21536
<i>Ornithocercus</i> sp.	-1.16968	-0.12111	-1.24119
S <sub>1</sub>	-0.0449	-0.01177	0.049275
S <sub>2</sub>	-0.07286	0.032793	-0.03877
S <sub>3</sub>	0.047032	-0.0754	-0.02749
S <sub>4</sub>	0.115877	0.053312	0.00734
Water temperature	0.97062	0.285239	-0.00775
DO	-0.93853	-0.38203	0.036113
Alkalinity	-0.95311	-0.23822	0.193521
Salinity	0.896163	0.160348	-0.39287
Nitrate	0.865477	0.238153	-0.41986
Nitrite	0.577097	-0.71074	-0.38923
Phosphate	-0.88191	-0.48721	0.102367
Silicate	-0.94281	-0.24205	0.228349
Eigenvalue	0.005256	0.002143	0.001328
% of constr. in.	60.23	24.55	15.22
% of total inertia	60	24.46	15.16

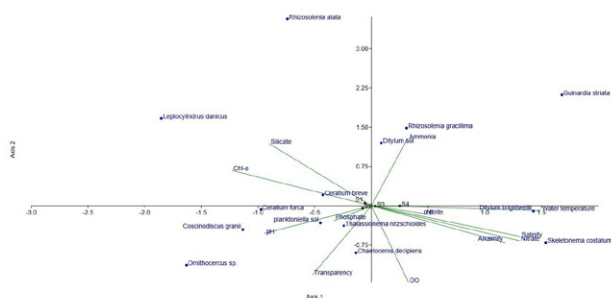


Fig. 3. The CCA bi-plot of dominant plankton species and water quality parameters

portions of variation, 24.55% and 15.22% of the constrained inertia, respectively. From October to May, the Jaigad coastal area's phytoplankton (cells L<sup>-1</sup>) qualitative and quantitative distribution showed clear seasonal changes (Table 3).

Pearson correlation was performed to correlate each phytoplankton species with physicochemical parameters; it was found that phytoplankton species such as *Coscinodiscus granii* (-0.986, P<0.05), *Skeletonema costatum* (-0.955, P<0.05), *Ceratium furca* (-0.961, P<0.05) and *Ornithocercus* sp. (-0.956, P<0.05) showed significant negative correlation with water temperature. Phytoplankton species such as *Ditylum brightwellii* (0.993, P<0.01), *Skeletonema costatum* (0.972, P<0.05), *Leptocylindrus danicus* (0.981, P<0.05), *Rhizosolenia gracillima* (0.998, P<0.01) and *Ceratium breve* (0.982, P<0.05) showed significant positive correlation with pH. Dissolved oxygen and alkalinity levels were positively correlated with *Coscinodiscus granii* (0.994, P<0.05) and *Skeletonema costatum* (0.994, P<0.05); moreover, *Ceratium breve* (0.952, P<0.05), *Ceratium furca* (0.990, P<0.05) and *Ornithocercus* sp. (0.963, P<0.05) also showed significant positive correlation with alkalinity. *Coscinodiscus granii* (0.990, P<0.01), *Skeletonema costatum* (0.996, P<0.01), *Ceratium breve* (0.958, P<0.05), *Ceratium furca* (0.989, P<0.05) and *Ornithocercus* sp. (0.957, P<0.05) also showed significant positive correlation with silicate (Fig. 5).

At the beginning of the post-monsoon season, *Asterionella japonica*, *Cyclotella striata*, *Rhizosolenia alata*, *Skeletonema costatum*, *Corethron criophilum* and *Hemiaulus sinensis* were not present among phytoplankton; nevertheless, they began to increase from January in the pre-monsoon season. In comparison to other phytoplankton species at all sampling stations, the most prevalent ones during the pre-monsoon season were *Rhizosolenia gracillima*, *Skeletonema costatum*, *Planktoniella sol*, and *Thalassionema frauenfeldii*. *Skeletonema costatum* and *Thalassionema frauenfeldii* exhibited variability, with the maximum abundances (92.01 and 102.45 cells L<sup>-1</sup>, respectively) occurring in May during the pre-monsoon season. *Biddulphia mobiliensis*, *Chaetoceros decipiens*, *Chaetoceros muelleri*, *Coscinodiscus granii*, *Ditylum brightwellii*, *Ditylum sol*, *Planktoniella sol*, *Pleurosigma* sp., *Thalassionema nitzschioides*, *Thalassionema frauenfeldii*, *Guinardia striata*, *Melosira* sp., and *Leptocylindrus danicus* were among the phytoplankton species that were observed during both pre-monsoon and post-monsoon seasons. *Ceratium breve* showed a downward trend among dinoflagellates, going from 7.80 cells L<sup>-1</sup> in October to 1.01 cells L<sup>-1</sup> in May. *C. furca* and *C. fucus* also showed a downward trend; at all stations during the same period, *C. fucus* decreased from 4.09 cells L<sup>-1</sup> to 0.82 cells L<sup>-1</sup>, and *C. furca* decreased from 6.48 cells L<sup>-1</sup> in October to 0.75 cells L<sup>-1</sup> in May. The abundance of *C. trichoceros* fluctuated, peaking in November (4.54 cells L<sup>-1</sup>)

Table 3. Phytoplankton species (cells L<sup>-1</sup>) encountered during the present investigation (+ = 0-100, ++ = 100-500, +++ = >500 and – = absent)

Species	Post-monsoon				Pre-monsoon			
	S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>	S <sub>4</sub>	S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>	S <sub>4</sub>
<b>Diatoms</b>								
<i>Asterionella japonica</i>	-	-	+	+	+	+	+	+
<i>Biddulphia mobilensis</i>	+	+	+	+	+	+	+	+
<i>Chaetoceros decipiens</i>	+	+	+	+	+	+	+	+
<i>Chaetoceros muelleri</i>	+	++	+	+	+	+	++	+
<i>Coscinodiscus granii</i>	+	++	+	+	+	+	+	+
<i>Cyclotella striata</i>	-	-	-	+	+	+	+	+
<i>Ditylum brightwellii</i>	+	+	++	++	+	+	+	+
<i>Ditylum sol</i>	+	+	+	++	++	+	+	+
<i>Navicula</i> sp.	+	-	-	+	+	+	+	+
<i>Planktoniella sol</i>	+	++	++	++	++	++	++	+
<i>Nitzschia</i> sp.	+	-	-	+	+	+	+	+
<i>Pleurosigma</i> sp.	-	+	+	+	+	+	+	+
<i>Rhizosolenia alata</i>	-	-	+	+	+	+	+	+
<i>Skeletonema costatum</i>	-	-	-	+	++	++	+	+++
<i>Thalassionema nitzschioides</i>	++	+	+	+	+	++	++	++
<i>Thalassionema frauenfeldii</i>	+	+	+	+	+	++	+	+++
<i>Guinardia striata</i>	+	++	+	+	+	+	+	+
<i>Leptocylindrus danicus</i>	+	+	+	+	+	+	++	+
<i>Melosira</i> sp.	+	+	+	+	+	+	+	+
<i>Rhizosolenia gracillima</i>	-	+	++	++	++	++	+	+
<i>Lauderia annulata</i>	-	+	+	+	+	+	+	+
<i>Hemiaulus sinensis</i>	-	-	-	+	+	+	+	+
<i>Rhizosolenia calcaravis</i>	-	-	+	+	+	+	+	+
<i>Eucampia zodiacus</i>	-	-	+	+	+	+	+	+
<i>Corethron criophilum</i>	-	-	-	+	+	+	+	+
<b>Dinoflagellates</b>								
<i>Ceratium breve</i>	++	++	++	+	+	+	+	+
<i>Ceratium furca</i>	++	++	+	+	+	+	+	+
<i>Ceratium fucus</i>	+	+	+	+	+	+	+	+
<i>Ceratium trichoceros</i>	+	+	+	+	+	+	+	+
<i>Perinidium oceanicum</i>	+	+	+	+	+	+	+	+
<i>Ornithocercus</i> sp.	+	++	++	+	+	+	+	+

and then gradually declining. A fluctuating trend was shown by *Perinidium oceanicum*, which peaked in March at 5.28 cells L<sup>-1</sup> and had the lowest abundance in January at 1.13 cells L<sup>-1</sup>. The Shannon-Weiner diversity index ( $H'$  at log<sub>2</sub>) ranged from 1.08 to 3.31, and evenness ( $J'$ ) ranged from 0.14 to 0.89 in the study region, with station S2 having the highest diversity index ( $H' = 3.31$ ) during the pre-monsoon period and station S2 having the lowest ( $H' = 1.08$ ) during the post-monsoon period. The dominance index ranged from 0.04 to 0.537, with the lowest and highest values occurring in January and May of the pre-monsoon season, respectively (Fig. 4).

## Discussion

It is well known that phytoplankton are effective indicators of ecological changes and are highly sensitive to a variety of environmental stressors (Paerl *et al.*, 2007). Previous studies on phytoplankton in Mediterranean Sea estuaries found that environmental factors like temperature, salinity, water transparency, and nutrients significantly impact seasonal variation in phytoplankton abundance and diversity (Cetinic *et al.*, 2006; Buric *et al.*, 2007; Barbosa *et al.*, 2010; Jasprica *et al.*, 2012). The temporal fluctuation in phytoplankton biomass in eutrophic estuaries is similarly linked to light availability (Cloern, 1987; Mallin *et al.*, 1999). It has also been suggested that light limitation, salinity fluctuations, and water circulation may limit phytoplankton development (McLusky and Elliott, 2004). Seasonal variations in physical, chemical, and biological processes determine phytoplankton succession and abundance (Thillai *et al.*, 2010) and phytoplankton species composition is primarily determined by nutrient fluxes and environmental variables (Achary *et al.*, 2014).

The coastal areas face various threats from both natural and anthropogenic activities, which influence the physicochemical parameters and the distribution and abundance of phytoplankton as well as the survival of aquatic creatures, which are greatly influenced by physicochemical parameters such as water salinity, temperature, dissolved oxygen, and nutrients (Godhe *et al.*, 2015). Environmental factors like air temperature and the intensity of solar radiation could lead to changes in water temperature (Reddy, 2001). In the present study, high water temperature values were seen in the pre-monsoon season and slightly lower temperature values in the post-monsoon season. A similar trend was observed by Sushanth and Rajshekhar (2012) along the west coast of India; Anantharaj *et al.* (2013) and Rajthilak *et al.* (2016) along the Tamil Nadu, southeast coast of India; Tekade *et al.* (2017) along the Ratnagiri, west coast of India and Hardikar *et al.* (2017) along the Malvan, west coast of India. The mean water pH in the present study didn't vary much, and it ranged from 8.09 to 8.21. Nutrients like inorganic phosphate were present

in high concentration ( $0.19 \mu\text{mol L}^{-1}$ ) in the pre-monsoon period and lower ( $0.13 \mu\text{mol L}^{-1}$ ) in the post-monsoon season. A similar trend was observed by Bhatkar *et al.* (2018) along the Malvan, west coast of India and Tekade *et al.* (2017) along the Ratnagiri, west coast of India.

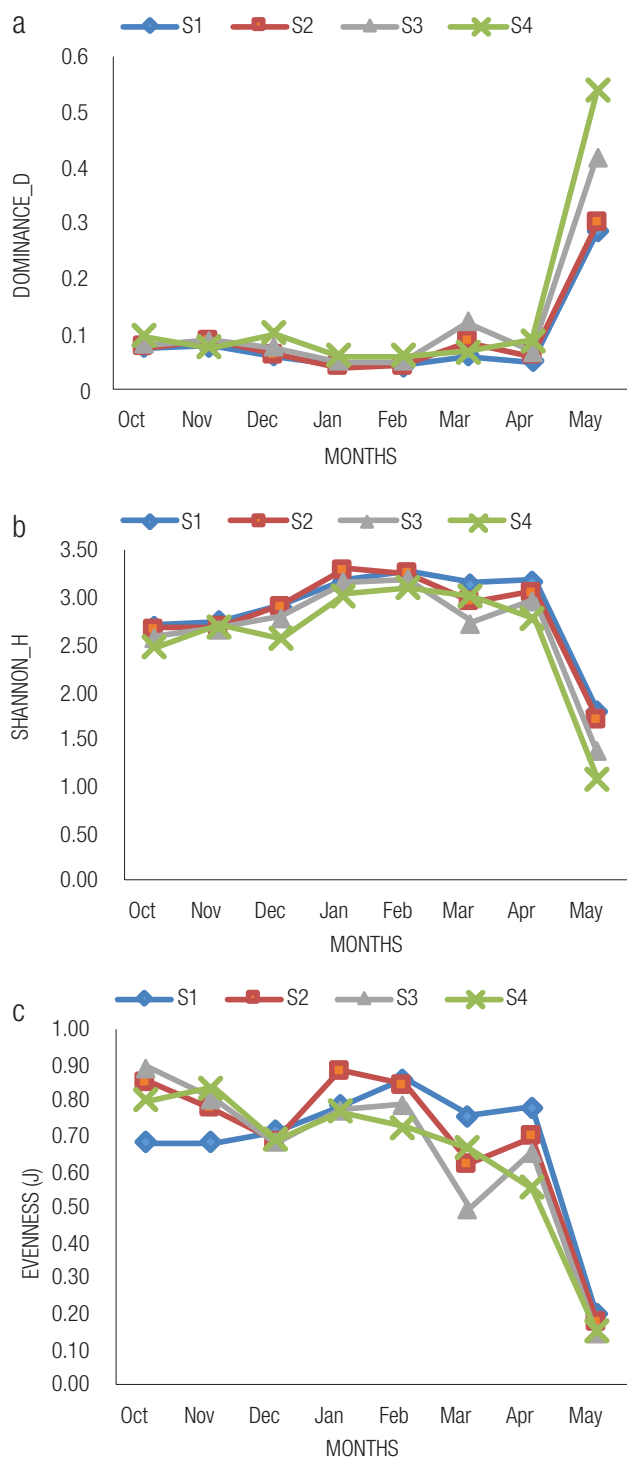


Fig. 4. Diversity indices, a) Dominance, b) Shannon Diversity, c.) Evenness

Silicate is one of the main nutrients that regulates the phytoplankton distribution in coastal waters. In the present study, the mean silicate concentration was recorded as maximum ( $0.45 \mu\text{mol L}^{-1}$ ) in the pre-monsoon season and the lower concentration ( $0.23 \mu\text{mol L}^{-1}$ ) in the post-monsoon season. Similarly high concentrations of silicate levels were observed by Sridhar *et al.* (2006) along the Palk Bay in the pre-monsoon period compared to the post-monsoon period. Sahu *et al.* (2012) and Anantharaj *et al.* (2013) also recorded a similar trend of silicate concentration along the southeast coast of India. In the present study, silicate showed a significant positive correlation with phytoplankton species such as *Coscinodiscus granii*, *Skeletonema costatum* and *Ornithocercus* sp.; similar findings were reported for these phytoplankton species by Conway *et al.* (1976); Taylor (1985); Egge and Aksnes (1992), Sun *et al.* (2007); Subhan *et al.* (2021) and Pradhan *et al.* (2023). In the present study, alkalinity was positively correlated with phytoplankton species such as *Ceratium breve*, *Ceratium furca*, *Skeletonema costatum* and *Coscinodiscus granii*. Taraldsvik and Mykkestad (2000) observed that *S. costatum* is tolerant to a wide range of pH (6.5 to 8.5), though its growth declines under highly alkaline conditions; similarly, a positive correlation of *Ceratium* spp. with alkalinity was reported by Pradhan *et al.* (2023). However, when interpreting these statistical results, it is imperative to distinguish between correlation and causation. While Pearson's correlation reveals strong predictive relationships, increases in silicate or alkalinity do not unilaterally drive the observed phytoplankton distribution. Instead, these distributions reflect a complex interplay of unmeasured variables, including trace metal availability, microzooplankton grazing pressure, and localised coastal hydrodynamics (George *et al.*, 2012; Xin *et al.*, 2024).

According to the CCA biplot of physico-chemical parameters and phytoplankton species composition, which mostly reacted to seasonal variations in environmental variables. High abundance of *S. costatum* ( $102.45 \text{ cells L}^{-1}$ ) and *Thalassionema frauenfeldii* ( $92.01 \text{ cells L}^{-1}$ ) was observed in the pre-monsoon season, which could be due to favourable pre-monsoonal conditions and a rich supply of silicate and phosphate availability. The Shannon-Wiener diversity index ( $H'$ ) is one of the most widely used indices for quantifying diversity. It can change with major ecological processes such as competition, predation, and succession, modifying the diversity through changes in evenness without any change in species richness (Stirling and Wilsey, 2001). This index can be used for monitoring the changes in ecosystems caused by pollution or eutrophication. According to Balloch *et al.* (1976), it is a good way to measure the quality of water. Using the Shannon-Wiener index, Hendley (1977) proposed a scale for measuring pollution in diatom communities: 0-1 for strong contamination, 1-2 for moderate pollution, 2-3 for marginal pollution, and 3-5 for incipient pollution. In the present study, the Shannon-Wiener index

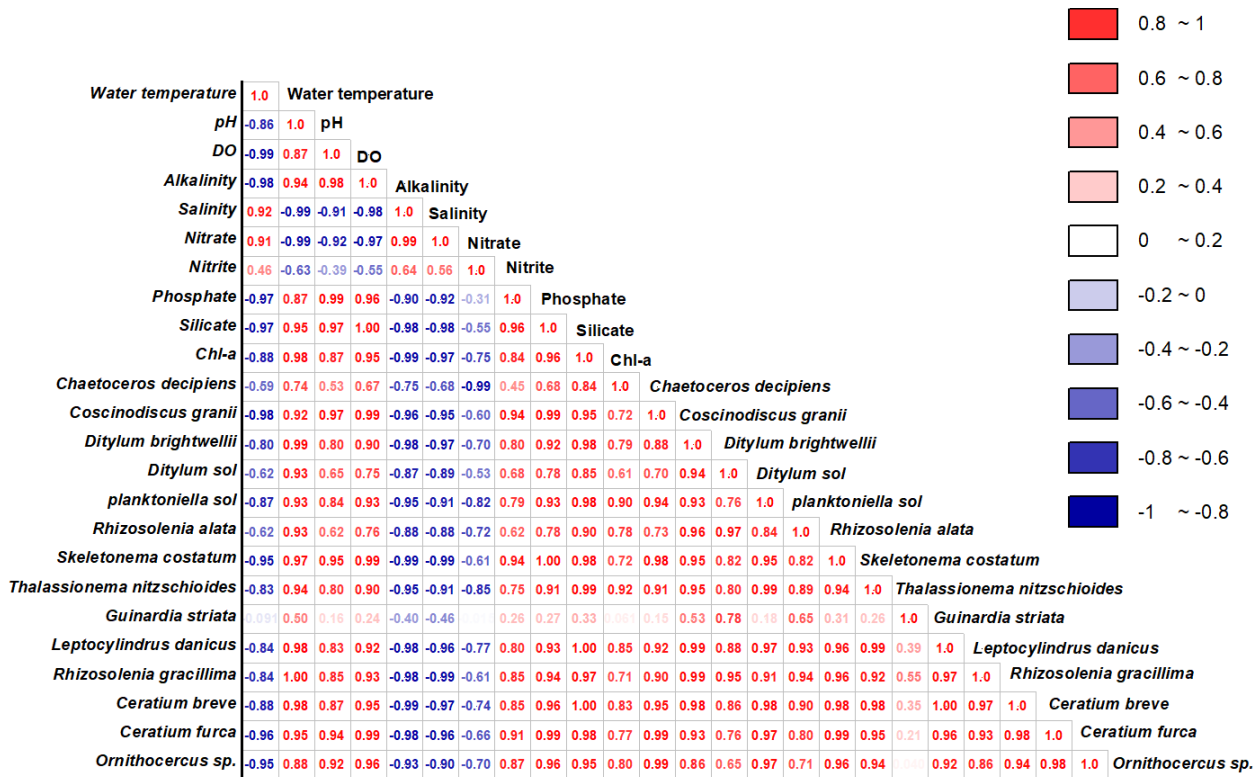


Fig. 5. Pearson's correlation analysis of dominant plankton species and physicochemical parameters

ranged from 1.08 to 3.31, where the maximum index was recorded at stations S1 and S2, while the lower index value was recorded at stations S3 and S4, which were farther from the coastal area. The nearshore enrichment along the Ratnagiri coast, driven by estuarine runoff and stratification, supports heterogeneous communities exploiting varied nutrient niches, mirroring patterns in tropical west coast Indian estuaries. In contrast, stations (S3–S4), which were at 36 m depth, exhibit homogenised assemblages characteristic of Arabian Sea dynamics, where monsoon-driven upwelling, shelf-slope fronts, and nutrient dilution promote diatom-dominated but less diverse blooms, consistent with regional oceanographic processes (Minu and Prabhakaran, 2025). These gradients align with west coast India trends, where pre-monsoon warming and land-derived nutrients favour coastal peaks, while post-monsoon mixing extends productivity offshore (Mhatre *et al.*, 2022; Naqvi *et al.*, 2010).

## Conclusion

The present study showed that phytoplankton community structure in the coastal waters of Jaigad, India's west coast, was mainly influenced by silicate and alkalinity, while dissolved oxygen, nitrate and nitrite had comparatively lesser effects. Diatoms dominated throughout the sampling period, with 26 diatom and 6 dinoflagellate species recorded. *Skeletonema*

*costatum* and *Thalassionema frauenfeldii* were the most abundant species. Canonical correspondence analysis confirmed the strong role of silicate and alkalinity in shaping phytoplankton distribution. Diversity indices also indicated possible anthropogenic influence at some stations, likely linked to harbour and port activities. Overall, the findings provide a useful baseline for monitoring phytoplankton dynamics and supporting sustainable coastal ecosystem management.

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## Author contributions

Conceptualisation: PJA, ADA; Methodology: PJA, ADA; Data Collection: PJA, MSS, PVN; Data Analysis: PJA, ADA; Writing Original Draft: PJA, PVN; Writing Review and Editing: PJA, PVN; Supervision: RHR, SWB, SAJ

## Data availability

The data are available and can be requested from the corresponding author.

## Conflicts of interest

The authors declare that they have no conflict of financial or non-financial interests that could have influenced the outcome or interpretation of the results.

## Ethical statement

No ethical approval is required as the study does not include activities that require ethical approval or involve protected organisms/ human subjects/ collection of samples/ protected environments.

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